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Microbiological and Physico-Chemical Analyses of Selected Bore-hole Waters in World Bank Housing Estate, Umuahia, Abia State, Nigeria

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Abstract: The microbiological and physico-chemical analyses were carried out for fifteen boreholes in World Bank Housing Estate, Umuahia. The microbiological analysis was carried out using the Most Probable Number Technique (Multiple-Tube Technique) for the detection of faecal coliform and subsequently organisms present in the samples of water were identified following the Standard Methods. The identified organisms include: *Escherichia coli*, *Staphylococcus sp.*, *Streptococcus sp.*, *Citrobacter sp.*, *Enterobacter sp.*, *Klebsiella pneumonia*, *Proteus*, *Pseudomonas*, *Serratia marcescene*, 63.6% being of the family Enterobacteriaceae. Two yeast genera were identified namely: *Saccharomyces* and *Kluyveromyces*. The Total Heterotrophic Plate Count (THPC) gave a range of 1.1×10^{4}-2.03×10^{5}CFU mL^{-1} with a mean of 5.2×10^{4}CFU mL^{-1} while the Total Coliform Plate Count (TCPC) gave a range of 1.1×10^{3}-8.5×10^{5}CFU mL^{-1} with a mean of 4.5×10^{3}CFU mL^{-1}. The Yeast Plate Count (YPC) ranged between 2.1×10^{1}-6.2×10^{1}CFU mL^{-1} and a mean of 4.6×10^{1}CFU mL^{-1}. The presumptive faecal coliform ranged between 0-180 coliforms 100 mL^{-1} giving a mean of 18.73 coliforms per 100 mL. *E. coli*/faecal coliforms were detected in 60% of the water samples. The aesthetic properties of the water samples were acceptable however the boreholes showed high values with ranges of 221-280, 52-77, 209-301 mg L^{-1}, 200-250 us cm^{-1} for sodium, nitrate, chloride and conductivity respectively in comparison with local and international standards. These results showed that there is need for treatment of these water boreholes by the borehole proprietors and also by simple treatment methods such as boiling and agitation by the consumers.

Key words: Bore-holes, contamination, microorganisms, water, microbiological, physico-chemical analysis

INTRODUCTION

Water is a common resource quite abundant in nature but unfortunately not readily available to man in the form desired. Water is fundamentally important to all plants, animals and man (Ajewole, 2005).

Water is essential for life and life evolved in water. It is significant due to its unique chemical and physical properties. Water is made up of two atoms of hydrogen and one of oxygen and because of the unique nature of the binding; water is a solvent for many minerals and can be referred to as a universal solvent. It can exist in three states as liquid, gas (at 100°C) and as solid (at freezing temperature of below-4% (Nelson, 2002, Mbagwu, 2003). Water is the matrix of life as all biological reactions occur in water and are the most versatile chemical formed within any metabolizing cell (Uriah and Izuagbe, 1990).

Since the beginning of recorded history, water has been recognized as a potential carrier of diseases. The connection between a freshwater supply and the health of an urban population was recognized by the time of the Roman Empire (27.B.C) (Prescott *et al*., 2002). The important use of water cannot be overemphasized water constitutes up to 70-80% by weight of a eukaryotic cell and profoundly influences all molecular interaction in biological systems (Nelson, 2002; Prescott *et al*., 2002).

The need for determining the suitability of water for drinking and bathing purposes has been recognized since 1855 when Snow and Budd related outbreaks of Typhoid Fever and cholera to water contaminated with faecal wastes (Moore, 1974). It is estimated that up to 80% of ill health in developing Countries are water and sanitation related (Cheesbrough, 2000). In the year 2000, the estimated global burden of disease associated with poor water supply equaled more than 2 billion cases of diseases with an annual death toll of 2.2 billion (WHO, 2004).

Recently, according to the United Nations (UN) more than 5 million people die annually first from diseases caused by unsafe drinking water and lack of sanitation. The major problems of safe drinking water are those of availability and quality (Ajewole, 2005). Only 61% of

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people in developing countries are estimated to have access to a good water supply, greater in rural than urban areas and 36% to sanitation facilities greater in urban than rural areas (WHO Health Report, 1998).

Generally, the sources of water can be grouped into three namely, rain, surface (which include river water, streams, sea water) and underground and ground water (including well water and borehole water) (Oyebode, 2005; Ajewole, 2005). The first key step in providing safe drinking water is the selection of the best available source of water. The most protected source of water will be the easiest and cheapest to transform into safe drinking water. Borehole is a ground water in which at least a depth of 150feet is drilled to source for drinking water. Borehole as a groundwater is pumped out with the aid of a submersible pumping machine of 1 H.P into an overhead tank (Olowo, 2005).

Groundwater occurs in the interstices (pores and crevices) of rock below the earth's surface. In many places, it is the vital source of water that sustains life and agriculture (Akinoso, 2005). It is generally accepted that groundwater contains less pathogenic organism compared to other sources of water. This is because groundwater from deep aquifers is protected from pathogen contamination by the covering soil layers. Rainwater and other water sources (surface water infiltration, irrigation, sewer leakages) that percolate through the soil can harbour pathogens but these are effectively removed by attachment to soil particles, die off and biological processes (example, predation) (Medema *et al*., 1999; Tsen, 1999).

The quality of groundwater is a function of natural process as well as anthropogenic activities. That is to say that ground water (e.g. borehole) is not completely protected from contamination, which could be either microbial or inorganic agent or even due to human activities and environmental conditions (Keswick, 1984).

Justification: Borehole water is the sole source of drinking water in the study area (World Bank Housing Estate, Umuahia), a part from periods of rainfall (rainy seasons). The potential for pathogens from human and animal waste present in the vicinity of the borehole to contaminate drinking water is very high. There has been report of borehole water contamination through many domestic wastewater and livestock manure especially if there is puncture in the layers of soil. These waste and sewage when deposited near the borehole may travel with percolating rainwater directly into the borehole or may travel along the well-wall or surrounding materials of the drill-hole (Medema, *et al*., 1999). The possibilities of such contaminations justify the purpose of this research. Also, borehole water available to the public may be contaminated in the storage tanks since the water does not undergo any form of treatment before consumption. This study carried out in 2006 was intended to identify the possible sources of contamination of borehole water in the study area and thus proper meaningful solutions to these. Furthermore, the microbial groundwater quality is affected by the forms of human activities and structural facilities which promote contamination of the sole source of drinking water in the study area have been set out to be identified in this research work. This research work is exceptionally important because borehole water is the only stable source of water in the study area supply owing to the absence of pipe-borne water.

MATERIALS AND METHODS

Environment of study: The water samples analyzed in this project were sourced from borehole located in World Bank Housing Estate, Umuahia. The estate is divided into roads and poles, having up stair lines and bungalow areas. The roads are alphabetically categorized. World Bank Housing Estate is in Umuahia, the capital City of Abia State. The major population of the Estate is made up of the higher and the middle classes of socio-economic category. Boreholes in the area include both private and public ones and serve as the 99% source of drinking water in the area. However only public borehole serving up to 150 individuals per day were analyzed.

Sample collection: The borehole water samples were collected using sterile 250 mL glass bottles that were sterilized using the hot air oven at 160°C for 1 h and were covered tightly until when used. The samples were aseptically collected and the plastic taps were sterilized using 99% ethanol soaked in cotton wool. The water was allowed to run to waste for 3-5 min before collection. The water samples were kept between a temperature of 4-10°C and transported to the laboratory less than 6 h of collection. All samples were analyzed within 24h of collection (Cheesbrough, 2000; Sloat and Ziel, 1991; WHO, 2004).

Media preparation: All the metallic and laboratory glass wares were sterilized by autoclaving at 121°C for 15 min. The media used were prepared the previous day by dissolving known quantities in corresponding volume of water according to the manufacturer's specification. The plates were prepared in duplicates and kept in the incubator to check for contamination while an uninnoculated plates was kept as control.

Enumeration of fungi and bacteria: A four-fold serial dilution was used for the analysis. For the heterotrophic plates count on nutrient agar, the fourth serial diluent (10^{-4}) was used; the third serial diluent (10^{-3}) was used for the total coliform count on MacConkey agar, while the first diluent (10^{-1}) was used for the total fungal count on Sabouraud and Dextrose Agar (Ogbulie *et al.*, 1998; Adams and Moss, 1995 and Sloat and Ziel, 1991).

Determination of bacterial and fungal flora of the water samples: The methods described by Fawole and Oso (1988) and Ogbulie *et al.* (1998) were used.

Identification and characteristics of isolates: The pure isolates were identified following a four-step analysis. The steps employed are cultural examination, microscopic examination, Biochemical reaction and carbohydrate utilization test (Ogbulie *et al.*, 1998).

Test for coliforms (multiple tube technique/most probable number.): The standard method of analysis for the test of presence of coliform in water samples was followed in three stages namely presumptive, confirmed and completed tests as prescribed by Ogbulie *et al.* (1998) and Cheesbrough (2000) for untreated water (alpha-technique).

Methods for the phsico-chemical analyses of water: The methods described by Dewis and Freitas (1990) were used in determining the Turbidity, Temperature, Total Suspended Solids (TSS) Total Hardness, Acidity and Mineral (Sodium, Calcium, Chloride, Nitrate and Sulphate) status of the water samples while the pH, Conductivity and Salinity of the water samples were determined by the methods described by Uzoukwu (2006).

RESULTS

A total of eleven bacterial and 2 yeast species were isolated from the fifteen selected borehole water samples analyzed in this work. Table 1 and 2 indicate the bacterial and yeast isolates respectively while the results of the Total Heterotrophic Plate Count (THPC) and Total Coliform Plate Counts (TCPC) are shown in Table 3.

Table 1: Identified bacterial isolates

			Biochemical tests								Carbohydrate utilization						
Isolates	Colonial morphology	Cell arrangement (Microscopy)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Proposed organism
1.	Smooth and circular, translucent on Nutrient agar	Short rods single and separate	-	+	+	-	+	-	-	-	AG	AG	AG	A^G	AG	AG	*Escherichia coli*
2.	Large swarming colonies, creamy colour on nutrient agar	Single short rods	-	+	+	-	+	-	-	+	AG	A^G	A	AG	AG	A	*Proteus sp.*
3.	Deep red pigment colonies rhizoid edges	Short rods	-	+	+	-	+	+	-	-	AG	A	AG	AG	AG	A	*Sertatia sp.* (mrcenscens)
4.	Smooth colonies shiny with grey tint in nutrient agar	Small scattered rods	-	+	+	+	+	-	-	+	AG	-	A	AG	A	A	*Pseudomonas aeruginosa*
5.	Raised small moistened colour with smooth edge	Straight long rods	+	-	+	+	+	-	-	-	A^G	A	-	A	-	-	*Bacillus sp.*
6.	White to cream, medium sized colonies; circular and foul smelling	Short rods	-	+	+	-	-	+	-	+	AG	A^G	AG	AG	AG	AG	*Citrobacter sp.*
7.	Large, smooth circular and cream colonies with outlined edge	Cocci in cluster	+	-	+	-	+	-	+	-	AG	A	AG	A	AG	AG	*Staphylococcus sp.*
8.	Small smooth colonies with convex elevation and opaque	Cocci in chains	+	-	-	+	+	-	+	-	A		AG	A	A	AG	*Streptococcus fecalis*
9.	Large circular smooth and slightly raised mucoid colonies, creamy	Short rods	-	-	+	-	+	-	-	++	AG	AG	AG	AG	A	AG	*Klebsiella pneumonia*
10.	Small to medium sized colourless colonies, circular and elevated	Coccobacilli (rod-like spheres)	-	-	+	-	-	+	-	-	AG	-	-	-	-	-	*Acinetobacter sp.*
11.	Smooth round colonies, creamy to white colour, dull and soft appearance	Short rods	-	+	+	-	+	+	-	-	AG	AG	AG	AG	AG	AG	*Enterobacter aerogenes*

1. Gram stain, 2. Motility, 3. Catalase, 4. Oxidase, 5. MR, 6. VP, 7. Coagulate, 8. Urease, 9. Sorbital, 10. Lactose, 11. Sacchams, 12. Manitol, 13. Celliobiose, 14. Glucose
Key: + = Positive, - = Negative, AG = Gas and Acid Production, G = Gas Production only, A = Acid Production only, A^G = Slight gas production; acid production ++ = Speedy/fast positive result,

Table 2: Identified yeast isolates

			Carbohydrate utilization						
Yeast	Morphological characteristics	Microscopic characteristics	Sorbitol	Manitol	Glucose	Lactose	Sachharose	Cellobiose	Proposed yeast
Yeast 1	Large creamy and umbonately raised colonies with smooth round edges	Budding yeast cells oval in shape	-	AG	G	AG	-	A^G	*Kluyveromyces sp.*
Yeast 2	Small white to creamy circular convex colonies with thick surface	Actively budding yeast	A	-	A	-	-	-	*Saccharomyces sp.*

Key: A = Acid production only, G = Gas production, AG = Gas with acid production, - = No fermentation, A^G = Acid production with little gas production

Table 3: Total viable bacteria count (CFU mL^{-1})

S/N	Code	Heterotrophic plant count	Total coliform plate count
1.	RDA	3.1×10^4	1.1×10^3
2.	CGBU	2.8×10^4	2.5×10^3
3.	RFD	2.6×10^4	4.0×10^3
4.	OLFRK	3.3×10^4	1.6×10^3
5.	TIMB	4.0×10^4	7.2×10^3
6.	P/S	3.0×10^4	2.0×10^3
7.	DOT	5.0×10^4	6.0×10^3
8.	HLTHRD	1.05×10^5	8.0×10^3
9.	ABTR	3.5×10^4	6.4×10^3
10.	LKWA	3.2×10^4	2.0×10^3
11.	RDO	1.1×10^4	8.5×10^3
12.	OPT	6.2×10^4	2.4×10^3
13.	NNKWA	2.03×10^4	4.7×10^3
14.	LYMN	4.3×10^4	4.9×10^3
15.	UMUH	5.3×10^4	6.7×10^3
	Range:	2.6×10^4-2.03×10^5	1.1×10^3-8.5×10^3
	Mean:	52.20×10^4	45.33×10^3

Table 4: Total viable yeast count

S/N	Code	Yeast count (CFU mL^{-1})
1.	RDA	3.6×10^1
2.	CGBU	5.9×10^1
3.	RFD	5.0×10^1
4.	OLFRK	4.0×10^1
5.	TIMB	5.0×10^1
6.	P/S	3.9×10^1
7.	DOT	6.0×10^1
8.	HLTHRD	5.9×10^1
9.	ABTR	3.0×10^1
10.	LKWA	3.2×10^1
11.	RDO	6.1×10^1
12.	OPT	2.1×10^1
13.	NNKWA	6.2×10^1
14.	LYMN	5.8×10^1
15.	UMUH	3.1×10^1
	Range	2.1×10^1-6.2×10^1
	Mean	45.86×10^1

Table 5: Distribution and density of bacteria and yeast in the selected borehole waters

	Distribution				
				Density	
Microbial group	No. of boreholes examined	No. of boreholes with group present	%	A.M	G.M
Presumptive coliform	15	14	93.3%	18.93	1.069
Faecal coliform	15	9	60.0%		
Heterotrophic plate count (aerobic) bacteria	15	15	100%	52.20	4.23
Total coliform plate count bacteria (on MacConkey agar)	15	15	100%	45.33	37.96
Yeast	15	15	100%	45.86	43.67

The yeast colony counts results are represented on Table 4 while the distribution and densities of the microbial groups enumerated in the fifteen selected boreholes are shown on Table 5.

The results of the MPN tests for occurrence of the presumptive coliforms shown on Table 6 and while the result of the analyzed physico-chemical parameters of the selected borehole water samples is shown in Table 7.

Table 6: Occurrence of presumptive coliform in tubes of the MPN

Samples	50 mL	10 mL	1.0 mL	MPN Index per 100 mL
RDA	0	0	0	
		0	0	010
		0	0	
		0	0	
		1	0	1 coliform
CGBU	1	0	0	120
		1	0	
		0	0	
		1	0	
		0	0	5 coliforms
RFD	0	1	0	050
		1	0	
		1	0	
		1	0	
		1	0	5 coliforms
OLFRK	1	1	0	151
		1	0	
		1	1	
		1	0	
		1	0	35 coliforms
TIMB	1	0	0	120
		1	0	
		0	0	
		1	0	
		0	0	5 coliforms
P/S	1	0	0	110
		1	0	
		0	0	
		0	0	
		0	0	3 coliforms
DOT	1	1	1	042
		1	1	
		1	0	
		1	0	
		0	0	20 coliforms
HLTHRD	1	1	0	110
		0	0	
		1	0	
		1	0	
		1	0	3 coliforms
ABTR	0	0	1	005
		0	1	
		0	1	
		0	1	
		0	1	5 coliforms
LKWA	0	0	1	021
		1	0	
		1	0	
		0	0	
		0	0	3 coliforms
RDO	1	0	0	111
		1	0	
		0	1	
		0	0	
		0	0	5 coliforms
OPT	0	0	0	000
		0	0	
		0	0	
		0	0	
		0	0	0 coliform
NNKWA	1	0	1	125
		1	1	
		0	1	
		0	1	
		1	1	> 12 coliforms
LYMN	0	0	0	011
		0	0	
		1	1	
		0	0	
		0	0	2 coliforms
UMUH	1	1	1	155
		1	1	
		1	1	
		1	1	
		1	1	> 180 coliforms

Table 7: The high level of conductivity analysed bore hole water samples

	Taste	Odour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
WHO guidelines			15TCU	0.5NTU	(250 ms cm^{-1})	1000	200 (0-5)		NG		12-28	100	400	6.5-8.5	200	10	NG	250
*RDA			6	0.002	250	585	0.4	4	0.6	1.2	25	78	205	7.2	240	61	0.2	240
CGBU			7	0.0320	300	590	0.3	9	1.0	0.8	26	90	250	6.9	230	52	0.2	220
RFD			7	0.038	200	580	0.3	5	1.5	0.6	27	79	240	7.1	221	65	0.3	209
OLFRK			8	0.005	245	586	0.2	2	1.0	0.1	25	85	220	6.8	240	70	0.1	300
TIMB			6	0.015	255	595	0.4	6	2.1	0.6	27	88	260	7.05	230	66	0.4	250
P/S	Unobjectionable	Unobjectionable	7	0.019	330	601	0.3	4	2.0	1.0	28	95	240	7.1	270	67	0.3	241
DOT			8	0.008	350	590	0.2	3	2.2	0.8	26	90	251	6.8	251	68	0.2	260
HLTH			8	0.004	260	596	0.3	7	1.3	0.7	25	89	260	7.1	230	59	0.2	271
ABTR			7	0.003	370	605	0.4	3	2.0	0.9	26	90	270	7.2	240	70	0.5	288
LKWA			6	0.002	340	582	0.4	6	1.9	0.6	25	79	300	6.7	260	72	0.3	248
RDO			6	0.011	280	591	0.3	4	2.0	1.0	26	86	209	6.8	230	66	0.2	290
OPT			7	0.018	310	599	0.3	5	1.1	0.8	27	88	290	7.2	260	65	0.2	301
NNKW			8	0.073	320	600	0.3	2	0.3	0.8	26	92	285	7.0	280	65	0.2	275
LYMN			6	0.046	360	605	0.3	5	1.5	0.7	25	77	275	6.9	271	77	0.2	280
UMUH			7	0.039	300	592	0.3	8	0.8	0.6	26	91	260	7.1	250	59	0.2	250
Range			8.0	0.002-0.073	200-370	580-605	0.2-0.4	2.0-9.0	0.3-2.2	0.1-1.2	25-28	77-95	205-300	6.8-7.2	221-280	52-77	0.1-0.5	209-301
Mean			6.93	0.021	298.0	593.13	0.31	4.87	1.42	0.75	26.0	86.4	254.3	7.01	248.2	65.4	0.25	261.5

1. Colour, 2. Turbidity, 3. Conductivity µs cm^{-1}, 4. Total solids (mg L^{-1}), 5. Total hardness (g/cu.m) PPM, 6. Dissolved oxygen (mg L^{-1}), 7. Total acidity (titratable), 8. Dissolved solids, 9. Temperature (°C), 10. Calcium, 11. Sulphate (mg L^{-1}), 12. pH, 13. Sodium (mg L^{-1}), 14. Nitrate (g/cu.m) (mg L^{-1}), 15. Salinity, 16. Chloride (mg L^{-1}) * BORE HOLE WATER SAMPLES ARE CODED: RDA, CGBU, OLFRK , TIMB, P/S, DOT, HLTH RD, ABATR, RFD, LKWA, RDO, OPT, NNKWA, LYMN and UMUH

DISCUSSION

Fifteen selected water borehole samples from World Bank Housing Estate, Umuahia, were analysed for microbiological and physico-chemical qualities. Several bacterial isolates majority of the Enterobacteriaceae were identified which include *E. coli, Enterobacter aerogenes*, *Serratia*, *Klebsiell*a and *Citrobacter* sp. (Table 1).

The presence of indicator microorganisms is undesirable in drinking water. Among the bacteria isolated a well-defined pathogen and indicator in the family Enterobacteriaceae is the *Escherichia coli*. *E. coli* (serving as the indicator of faecal contamination) was found to be present in 60.0% of the 15 water samples tested. This is of a major health importance and calls for remedial attention in such water supplies. *E. coli* presence is an indication of the presence of other enteric pathogens such as *Salmonella typhii* and *Shigella dysentriae*. Moreover, *Escherichia coli* is known to cause many enteric diseases such as traveller's diarrhoea and other forms of diarrhoea (Pandey *et al*., 1999). Other important pathogens identified were *Streptococcus faecalis*, *Staphylococcus* sp., *Bacillus* sp., these organisms have been variously implicated in gastrointestinal disorders such as diarrhoea and other associated symptoms (Prescott *et al*., 2002) and upper respiratory tract infection.

Opportunistic pathogens such as *Klebsiella pneumonia* sp., *Serratia marcenscens*, *Proteus* sp., *Citrobacter* sp., *Enterobacter aerogenes* were also identified. Many of these organisms are considered opportunistic microorganisms responsible for up to 50% for nosocomial infection (hospital acquired infections) (Sloat and Ziel, 1991). Typical examples of such infections and their causative agents are lower respiratory infection (*Klebsiella pneumoniae*) gastroenteritis (*E. coli*) septicaemia, burns and wounds, (*E. coli*) and urinary tract infections (*Enterobacter aerogenes* and *E. coli*).

Another interesting organism identified is *Acinetobacter* sp. which has been known to give high coliform counts in sanitary analysis of bathing and portable water and is implicated in many infections of the immuno-compromised hosts (Pandey *et al*., 1999).

It is clear that members of the non-faecal coliform group of the Enterobacteriaceae, comprises a large part of the identifiable isolates usually detected as indicators of water quality in most instances however, they are undifferentiated. In one study in the United Kingdom, 33% of samples revealed the presence of *Klebsiella* sp. (Vanhooren *et al*., 2000). No official guideline regulations seem to exist at national or international level with regard to specific *Klebsiella* and other coliforms selection enumeration or threshold numbers as the case with *E. coli*. This study confirms the presence of these potential pathogens and the need to have them regulated, which hitherto is overlooked.

The possible means of administration of such organisms into a deep aquifer of selected boreholes is not far-fetched. Apart from having faecal origin, some of these coliforms are natural inhabitants of soil, water, plants, human skin and animal. Some of the selected boreholes are situated in environments close to contamination sources such as refuse dumps; soak away pits, abattoirs (mini-slaughter), bird (pigeon) keepings and livestock grazing.

The yeast identified is the lactose-fermenting yeast *Kluyveromyces* sp. and the well-known *Saccharomyces* sp. (Table 2). Yeasts are normal flora of the terrestrial habitat, fruits, citrus and juicy plants (Barnett *et al*., 1990). The presence of yeast (100%) in all the water samples tested (Table 4) is very significant and is of much interest. Most of the boreholes have possible plants and fruit trees around them which could provide sources of these organisms which were found to be very close and could be washed below the ground level, thereby leach into the aquifer.

The presence of these yeasts and bacteria can be attributed to the possibility of leakage in the manholes of the boreholes, which could have resulted from maintenance practices and repairs over the years. However, such organisms were also identified in newly constructed boreholes (CGBU, RDA and P/S). This confirms the desirability of thorough flushing (and chlorination) of new water systems prior to their being put into use in line with British Standard (1997) (BS6700) and WHO (2004) stipulation.

The result of the Total Heterotrophic Plate Count (Table 3) gave counts of aerobic bacteria higher than the stipulations of NAFDAC (2004) (100CFU mL^{-1}) and WHO (1,000CFU mL^{-1}). The range of THPC is between 1.1×10^{4}-2.03×10^{5}CFU mL^{-1}.

The THPC counts were significantly high in two of the boreholes; they are HLTH (1.05×10^{5}CFU mL^{-1}) NNKWA (2.03×10^{5}CFU mL^{-1}) well above the mean value of 5.2×10^{4}CFU mL^{-1}. The THPC was very low in some water samples; they are CGBU (2.8×10^{4}CFU mL^{-1}) RDO (1.1×10^{4}CFU mL^{-1}) and RFD (2.6×10^{4}CFU mL^{-1}).

The possible reason for such differences is not easily identifiable; however, boreholes NNKWA (2.03×10^{5}CFU mL^{-1}) and HLTH (1.05×10^{5}CFU mL^{-1}) are two of the oldest borehole sampled of all selected boreholes (over 6 years old). A gross contamination of the reservoir tanks and distribution system may have accounted for the high counts of aerobic bacteria. Also, older boreholes should be expected to have undergone several repairs in the drill holes or manholes, which might result to leakage and consequently contamination, by surface infiltration and percolation of rain and surface waters. Also HLTH (1.05×10^{5}CFU mL^{-1}) borehole is situated on a major road and the busiest in the World Bank Housing Estate and the high anthropogenic, that is, human activities in the area could have contributed to the high counts obtained.

From Table 3, the Total Coliform Plate Count (TCPC) gave a range of 1.1×10^{3}-8.5×10^{3}CFU mL^{-1} and a mean of 4.5×10^{3}CFU mL^{-1} for the fifteen boreholes tested. Highest counts were obtained in RDO (8.5×10^{3}CFU mL^{-1}) and HLTH (8.0×10^{3}CFU mL^{-1}). These are supposed non-faecal since the resultant faecal coliform counts for these boreholes gave presumptive counts of 3 coliforms per 100 mL and 5 coliforms per 100 mL, respectively (Table 6). The high counts of RDO (8.5×10^{3}CFU mL^{-1}) could be as a result of improper or lack of disinfection of the new borehole system before use. The borehole was less than 6 months old as at the time of the analysis.

The yeast plate count was obtained in all the boreholes analysed with 72 h of incubation (Table 4). This is remarkable as moulds were not detected within this period of incubation on the SDA for all the samples analyzed. This calls for a further study on this and a focus on the presence of yeasts in boreholes in World Bank Housing Estate, Umuahia, Abia State. This finding is highly subject to further investigation. The yeasts found are known to occur in terrestrial environments such as soil, water and vegetations (Batt, 2000). The range of 2.1×10^{1}-6.2×10^{1} CFU mL^{-1} was obtained with a mean of 4.58×10^{1} CFU mL^{-1}.

The distribution of the microbial populations detected as shown in Table 5, shows a 100% distribution of Total Heterotrophic Plate Count (THPC) Total Coliform Count (TCPC) and Yeast Plate Count (YPC) in 15 of the 15 analysed boreholes while 9 of (60%) of the 15 boreholes tested showed the presence of faecal coliform and 14 (93.3%) of the 15 were positive for the presumptive coliform.

From the statistical analysis, using the arithmetic and geometric mean measures (Table 5) the density of THPC bacteria was as high 52.2 [Arithmetic Mean (A.M)] and 41.23 [Geometric mean (G.M)] with the TCPC giving 45.33 (A.M.) and 37.96 (G.M.) while presumptive faecal coliform gave 18.93 (A.M.) and 1.069 (G.M.). This can be interpreted to mean that the coliforms and presumptive faecal coliforms are inclusion fractions of the Total Heterotrophic Plate Count Bacteria. This implies that the presence of the bacterial group decreases in their distribution and densities thus; Heterotrophic Bacteria> Total Coliform>Presumptive Coliform>Faecal Coliform.

The result of the presumptive coliform in Table 6 indicates a gross coliform contamination in three boreholes (UMU = >180 coliforms, DOT = 20 and OLFRK= 35 coliforms per 100 mL). Proper investigations on the environmental conditions of the three boreholes were carried out and possible contamination sources were identified.

The borehole UMUH (>180 coliform 100 mL^{-1}) gave the highest and this can be attributed majorly to the contamination of the reservoir by the faecal droppings of the birds (pigeons) kept in the same building. This is a major possibility since it is a relative new borehole

(less than 2 years old) and may not have undergone repairs of the manholes; also the number of positive tubes for faecal coliform obtained is quite significant in table 8 of results. The DOT (20 coliforms per 100 mL) borehole is a relatively new borehole as well ($1^1/_2$ years old) and has no obvious environmental sources of contamination, however, its situation has a history of use as a refuse dump before the establishment of the borehole. The accumulation of the coliforms in this environment over the years may have been introduced into the borehole system during drilling and unfortunately these boreholes are not treated before first use. Most interestingly is the history of the borehole OLFRK (35 colonies per 100 mL). Established last 6 years, the borehole had the World Health Organisation/Local Water Board Abia State certification (publicly displayed) which evidenced their conformation to the guidelines of the above authorities. However, from the current analysis of the borehole, it is obvious that the water quality has gone below the acceptable limits standards of which it was once acceptable. The presumptive coliform is approximately 12 times grossly contaminated than that permissible by both the Local Water Board authority and WHO's limits of 3 coliforms in 100 mL for presumptive coliform and 0 for faecal coliform (Table 6). This also emphasizes the need for maintenance of good water quality through routine analysis and surveillance.

From the results of the faecal coliform presence in the analysed water samples 9 (60.0%) of the 15 boreholes showed the presence of *E. coli* / faecal coliform. The nine boreholes are CGBU, RFD, OLFRK, P/S, DOT, ABATR, NNKWA, LYMN and UMUH. Three (33.3%) of the nine were situated less than 15 m from a refuse dump. CGBU (<8m), RFD (<10 m), LYMN (<13 m) are the boreholes and the distances between them and the refuse dumps while one of the nine boreholes is situated less than 10m from a mini-slaughter (goat market mini-slaughter). The situation of these boreholes close to potential sources of drinking water pollutions is against the NAFDAC's stipulated minimum distance of 30 m (NAFDAC, 2004). These findings are major concerns for consumers because of the effect of these microorganisms on the health of the consumers.

Other boreholes of which their specific sources of contamination were not identified could be as a result of indiscriminate situation of borehole depth or other hydrological factors such as, porous semi-consolidated sandy stone fractures or pores in the soil layers. The well-head integrity and the integrity of the soil around the borehole (placement and integrity of sheets, clay layer or concrete slab) are also issues in contamination of boreholes (Rose *et al*., 2000).

It was also confirmed that high counts in THPC usually affects coliform recovery in such water supplies. Case studies are that obtained in boreholes NNKWA that gave THPC of 2.03×10^5 CFU mL^{-1} and coliform recovery of 12 coliform per 100 mL of sample and borehole HLTH which gave a THPC count of 1.05×10^5CFU mL^{-1} and a coliform recovery of only 2 coliform per 100 mL of sample. However, in borehole UMUH (180 coliform per 100 mL) and OLUFRK (35 coliforms per 100 mL) gave lower HPC counts of 5.4×10^4 and 3.3×10^4CFU mL^{-1}, respectively. There was no interference in coliform recovery by the heterotrophic bacteria here. This suggests a correlation between the heterotrophic group of bacteria and coliform presence in water quality assessment (Pandey *et al*., 1999).

The physico-chemical parameters of the 15 boreholes sampled were compared with the World Health organization guidelines of such parameters for drinking water. The physico-chemical parameters tested were within the permissible limits as prescribed by the World Health Organisation, (1998, 2004) with the exception of sodium, chloride, nitrate concentrations and conductivity, which were higher than the specifications.

The guideline for sodium in potable water is 200 mg L^{-1} (g/cu.m). However, all the boreholes exceeded this guideline value with an arithmetic mean of 248.2 mg L^{-1} and a range of 221-280 mg L^{-1} (Table 7). Sodium is a principal cation from the hydrosphere and may have been introduced into the aquifer by geological leaching of surface and underground deposits of salts (example sodium chloride) and from the decomposition of sodium aluminium silicates and similar minerals occurring naturally. In the study area, there is no possible contribution of human activities to the high concentration of sodium in the water. It appears that insufficient evidence available to conclude whether or not sodium in drinking water causes an elevation of blood pressure in the general population. There is the estimate that 90% of sodium daily intake is from food while the remaining 10% is contributed by drinking water (Shelton, 2003). However, the healthy persons, the sodium content of water is unimportant because the intake from salt (Table salt) is so much greater, but for persons placed on sodium diet because of heart, kidney, circulatory ailments or complications in pregnancy sodium in water must be considered. Therefore, the 15 boreholes analyzed in World Bank Housing Estate, Umuahia is not safe for such individuals and their intake is not encouraged/ recommended.

High chloride concentration above 250 mg L^{-1} was recorded in 8 (53.3%) of the 15 analyzed boreholes (Table 7). The taste of water may become objectionable

above the 250 mg L^{-1} guideline, however, in the analyzed water sample, the concentration of chloride was not reflected on the taste. Chloride concentration gave a range of (209-301 mg L^{-1}) and mean of 254.15 mg L^{-1}. High chloride concentration in water may also be associated with the presence of sodium in drinking water. In addition to these adverse effects, the high concentration level of sodium in water lead to deterioration of domestic plumbing, water heaters and municipal water works equipment (Shelton, 2003).

Nitrate concentration range falls between 77-51 mg L^{-1} for the analysed samples of water with a mean concentration of 65.4 mg L^{-1}. There is no low cost removal process. Nitrates are known to occur in ground water in high amounts, due to its potential toxicity and widespread occurrence it is regulated. Its toxic effects in infants have been demonstrated. The precise potential anthropogenic activity aiding the high concentration of nitrate in water is not clear since there is no active agricultural activity which could supply nitrogenous compounds that might be washed into the boreholes. Shelton (2003) reports high concentration of nitrates in groundwater of shallow aquifer beneath areas of extensive development; this could be a possible explanation for the high concentration level of nitrate in the analyzed boreholes. Moreover, nitrates occur naturally in mineral deposits (generally sodium or potassium nitrate), in soil, seawater, freshwater system, the atmosphere and biota.

The conductivity is another parameter of the tested boreholes that exceed the WHO permissible limit of 250 μs cm^{-1}. 11 (80%) of the 15 samples of water exceeded the 250 μs cm^{-1}. Conductivity is a numeric measure of the capacity of an aqueous solution to pass electric current. Pure water is not expected to conduct electricity. The capacity depends on the ions present in the solution, their concentration, mobility, valency and temperature. This evaluates the concentration of dissolved minerals in raw water. The high level of conductivity analysed ranging from 200-370 μs cm^{-1} with a mean value of 298 μs cm^{-1} should be expected since ions such as sodium ions (Na^+), Chloride Ions (Cl^-) and Nitrates (NO_3^{2-}) are present in high concentration level. The presence of these ions aided by other dissolved solids gave a concomitant high numeric value of electric conduction. It is important to note that the borehole HLTH RD located on a major road, possibly had its physico-chemical properties affected by fumes and exhaust released by passing vehicles.

It is also important to mention that generally, the borehole RDA is of better bacteriological and physico-chemical quality than all the analysed boreholes this is not surprising when related to the depth of the aquifer which is 210 feet. However, such physico-chemical parameters as dissolved oxygen gave a poor result of 4 mg L^{-1}. This can be attributed to the confined aquifer from which the water is obtained, which creates a problem of reduced dissolved oxygen concentration. Other boreholes whose aquifer depth data could not be assessed that gave dissolved oxygen concentration of as low as 2 mg L^{-1} are NNKW, TIMB and DOT (3 mg L^{-1}). The highest dissolved oxygen concentration is given by CGBU (9 mg L^{-1}) which is the newest borehole of all the tested borehole supplies (less than 6 months old as at the time of analysis). The range of dissolved oxygen in the fifteen analysed boreholes is 2 mg L^{-1}-9 mg L^{-1}. There is need for aeration in some of the analysed water supplies; this is a known problem in waters sourced from confined aquifers (Mbagwu, 2003; Prescott, 2002)

CONCLUSION

The usefulness of water as a drink and use for domestic activities underlines its potability, which has been the main focus of this research project. Water is life and access to good quality water cannot be overemphasized. Human activities in World Bank Housing Estate, Umuahia, particularly location of waste and refuse disposal near boreholes, compartment of buildings, high automobile traffic, proximity of houses to roads, indiscriminate situation of boreholes in areas without proper environment conditions suitable for such, lack of treatment of water before use all contribute to the non-potability of borehole water in the area. Consequently, the boreholes are contaminated with abnormal levels of dissolved ions (sodium, nitrate and chlorides) and microorganisms (Table 1 and 7). Therefore, the treatment of borehole water supplies before consumption is highly recommended. This may not be affordable by the private-owned boreholes as it entails considerably high cost especially for such contaminants as nitrate which can only be removed from water by very expensive methods such as Reverse Osmosis (RO) and Ultrafiltration (UF). The provision of good quality drinking water is a responsibility of the government to her citizenry. Therefore, the government should intervene by shouldering the cost and responsibility of providing potable pipe-borne water to her populace. The resuscitation of pipe-borne water services in World Bank Housing Estate, Umuahia, will go a long way in reducing the indiscriminate situation of boreholes and the over dependence of the population on these borehole water supplies.

On the other hand, the borehole owners are advised to adopt cost-effective methods of water treatment, which would involve aeration (to improve dissolved oxygen,

concentration, most of the analyzed borehole water have low dissolved oxygen concentration), precipitation (to eliminate the dissolved ions (Na and Cl)) and chlorination (to kill pathogenic and opportunistic organisms) stages. Along with or in the absence of water such treatment measures boreholes with high coliform and faecal coliform counts as well as new boreholes are required to flush the entire water system (including the storage tanks and distribution pipes) with super-chlorinated water (having up to 40 ppm free residual chlorine) for 30 min and followed by overnight soaking of the entire system with super-chlorinated water in line with WHO (2004) stipulation.

Subsequent and consistent surveillance and monitoring of the borehole water supplies should be taken up by the appropriate local authority to ensure the maintenance of a good drinking water quality and effective health education for the public conducted to enlighten on the issues of effect of drinking water on health. All these together with the monitoring human activities in the area will proffer a sustainable solution to the problem of good drinking water in World Bank Housing Estate, Umuahia, Abia State., Nigeria.

RECOMMENDATIONS

Based on the findings of this research project, I recommend that the consumers of water from boreholes in World Bank Housing Estate, Umuahia should treat the water before drinking by boiling to kill harmful bacteria and agitation to aerate thereby improving the oxygen content of the water. Also further investigations to determine the health implications of the unacceptable levels of dissolved ions (Na^+, Cl^- and NO_3^-) and the microbial contaminants (*Escherichia coli* and others) of the groundwater observed in the study is recommended. This would involve the determination of the blood levels of the ions and the blood titre of pathogenic organisms of the individuals living in the area.

Furthermore, sanitary analysis involving both the use of indicators (such as *E. coli*) for assessment of water quality and also the detection, enumeration and identification of specific pathogens (such as *Vibrio cholera*, *Salmonella typhi*) in the water. Moreover, an enhanced sampling and quantitative methods which may include larger range of samples with replications and the adoption of more accurate newer methods for water analysis such as Membrane Filtration Technique.

Finally, a hydrological survey of the soil and aquifers to pinpoint and better assess the sources of the high levels of mineral salts and to identify areas with unsuitable aquifers for sourcing drinking water.

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