African Journal of Environmental Science and Technology Vol. 5(7), pp. 522-529, July 2011
Available online at http://www.academicjournals.org/AJEST
ISSN 1996-0786 ©2011 Academic Journals

*Full Length Research Paper*

# Public health risk status of the water supply frame work at Kwame Nkrumah (Postgraduate) Hall, University of Nigeria, Nsukka and environs

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Accepted 30 May, 2011

**The aim of the study is to assess the public health risk status of the potable water supply framework at the Kwame Nkurumah Postgraduate Residence (PG) Hall, University of Nigeria, Nsukka, (UNN), Enugu State, Nigeria, and environs. Four potable water supply frame-works at the PG Hall, UNN, and exposed stagnant water were sampled and analysed in accordance with the Association of Official Analytical Chemists (AOAC) Official Method of Analysis to detect their limits of chemical and microbial constituents with high public health risk. The samples comprised of tap water (A), tap-to-reservoir water (B), commercial sachet water (C) commercial bottled water (D) and exposed stagnant water (E). The nitrate levels of all the sources (except 'B') were above the World Health Organisation (WHO) limit (10.00 mg/L). Thus they could cause methaemoglobinemia in infants. Nitrate content of 'B' (6.99 mg/L) was significantly ($p < 0.05$) low, relative to that of 'A' (23.08 mg/L); and indicated microbial action. The physicochemical and microbial quality of the tap water differed significantly ($p < 0.05$) from that of the tap-to-reservoir water. All the pH, except that of 'D', were below WHO recommended pH range (6.5 to 8.5) for drinking water. 'D' was more or less a mineral concentrate, as its chemical constituents were significantly ($p < 0.05$) higher than those of other samples. Total viable count (TVC) and coli form count of the reservoir water and sachet water (0.17 to 0.20 and 0.11 to 0.09 cfu/ml, respectively), indicated heavy microbial contamination. While 'D', was devoid of biological contamination. *Escherichia coli, Staphylococcus aureus and Pseudomonas aeruginosa* were among the bacteria isolated. Taken together, the sampled potable water (except 'A' and 'D') was generally, of poor chemical and microbial quality; and may be considered unacceptable.**

**Key words:** Public health risk, potable water, physicochemical and microbial water quality, water pollution.

## INTRODUCTION

Water is a basic human need and is next to oxygen in order of importance. An abundant natural resource, water is critical for the sustenance of human life (Egboh and Emeshili, 2007). About two-thirds of the human body is made up of water (Ayode and Akintola, 2008). It is a key determinant of sustainable development that should be carefully managed to make for suitable and sustainable human health and general well being. In homes, water is indispensably required for drinking, bathing, cooking and general sanitation such as laundry, flushing of closets and other household chores (Ogunnawo, 2004). Thus an

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assured supply of water both qualitatively and quantitatively for these purposes will greatly improves the health, economic and social aspects of human life. In this regard, studies have been directed towards the evaluation of physical, chemical and biological quality standards of potable and other water supplies in order to design an effective management system for user acceptance (Langenegger, 1994; de Vet et al., 2010).

Since drinking-water plays an important role for health and well-being, several epidemiological investigations over the last half century have demonstrated a relation between risk for cardiovascular disease and drinking-water hardness or its content of magnesium and calcium (Rylander, 2008). The acid-base conditions of drinking-water also touch on human and animal health; as the parameter influences the homeostasis of minerals (Remer and Mantz, 1995). Hydrogen carbonate content of drinking-water has been identified to be critical in the reduction of the risk of cardiovascular disorders in human. As drinking-water devoid of adequate amount of hydrogen carbonate possess high acidity and may enhance urinary excretion of minerals (calcium and magnesium) from the body with its attendant health risks (that is, increased incidence of cardiovascular diseases) (Rylander et al., 2006). According to Rylander and Amaud (2004), drinking-water containing 403 mg/L hydrogen carbonate was found to reduce the blood pressure in a group of 20 subjects with mild hypertension; while the risk for health infraction was lower with levels of hydrogen carbonate higher than 110 mg/L (Rubenowtiz et al., 1996). However, one of the foremost reports demonstrating relation between water quality, other than microbial contamination, and health risks came from Japan (Kobayashi, 1957). The study related the death rate in apoplexy (sudden death) in different parts of Japan to the acidity of river waters. This was followed by a number of studies in different countries where other water physicochemical parameters were used as criteria for water quality. Critical evaluations of these data have been presented (WHO, 2005). Bardsen et al. (1999) in this regard identified groundwater with moderate to high fluoride content as the most important factor in the development of dental fluorosis, and concluded that in order to prevent dental fluorosis, groundwater wells should routinely be analysed for fluoride. A survey of the nitrate content of drinking water from deep boreholes, shallow wells and running stream at Bama Local Government Area of Borno State, Nigeria, revealed that the nitrate load of the water samples were within the acceptable limits, and decreased on storage. The presence and effect of organic contaminants in drinking-water is equally a growing medical concern. Benjamin (2010) highlighted the presence of organic contaminants in water by assessing the estrogenic activity of US drinking-water. While non-organic secondary contamination of drinking-water (that is, contamination during distribution and storage), was indicated by Carolyn et al. (2010). With the existing plumbing materials and codes, it is not possible to put forth protocols and standards that guarantee compliance with 15 µg/L US Environmental Protection Agency (USEPA) action limit or the 20 µg/L Lead Contamination Control Act guideline level in a newly installed tap (Carolyn et al., 2010). Ogbulie et al. (2009), reported that the physicochemical parameters of municipal groundwater in Imo State, Nigeria, were mostly within the WHO standards; but those of magnesium and phosphorous were specifically above the limits recommended for human and animal consumption and may have deleterious effects on health.

From time immemorial, researches have focused on the evaluation of water quality status for domestic and industrial use (Ogbulie et al., 2009; Okonkwo et al., 2007; Adekunle and Mojisola, 2007; Duru et al., 2008; Aiyesanmi, 2008; Egboh and Emeshili, 2008). Many of these articles focused on the measurement of water pH, chloride ($Cl^-$), nitrate ($NO_3^-$), bicarbonate ($HCO_3^-$), total alkalinity, total hardness, total dissolved solids (TDS), sulphate ($SO_4^{2-}$), iron ($Fe^{2+}$), biochemical oxygen demand (BOD), micro-organisms, among other water quality indices. In this direction, World Health Organization (WHO) set an international reference point as standard for drinking-water safety (WHO, 2004). The standard prescribed “good-water” as a term described as being wholesome and palatable. To be wholesome, water must be free from disease causing organisms, poisonous substances and excessive amount of minerals and organic matter. To be palatable it must significantly be free from colour, turbidity, taste, and must be well aerated.

Since safe drinking water must be among the topmost priorities of all, it became imperative that the water which humans use must be free from pathogens and toxic chemicals that may pose a threat to public health (Third World Academy of Science (TWAS), 2002). This research work therefore focused on the analysis of the most available sources of drinking-water at the PG Hall, UNN, and environs to ascertain their impact on public health.

## MATERIALS AND METHODS

### Sample description

Water supply at the Kwame Nkrumah, Post-graduate (PG), Hall of the University of Nigeria, Nsukka (UNN) is from the university’s water scheme; serviced by ground water bore-holes. In order to ensure 24-h availability of water, at the PG Hall, supply is segmented into two. One runs directly from the mains, while the other fills a surface metal reservoir tank. The metal reservoir seems to be poorly managed, as there is no framework for its routine maintenance and sanitation. Water taken from it tends to have metallic odour and taste as well as astringent effects. Thus it is suspected that the internal environment of the reservoir has a significant impact on the water quality. The dangers to public health became heightened, as the reservoir (many times) serves as the major source of water for domestic activities at the residence hall;

because, water flow from the parallel supply depends on a complicated network of factors that many at times (up to months) do not guarantee adequate supply.

### Materials

The sample containers (2.00 L plastic container with double cap devices) were washed properly with detergent, leached with 10 % HCl, rinsed with distilled water until acid free. Water samples were collected at 06:00 h on 4th June, 2009, from four potable sources (tap water, tap-to-reservoir water, commercial sachet water and commercial bottled water) at PG Residence Hall, University of Nigeria, Nsukka, into the prepared containers manually. Exposed stagnant water ("E" sample) was also sampled, manually, as positive control in the physicochemical and bacteriological evaluations. The containers were labeled with sticky labels containing sample number, date, time and kept in the laboratory refrigerator at 4°C prior to the analysis over 72 h period. The water samples for bacteriological evaluation were collected in properly sterilized neutral glass bottles of 120 ml capacity with ground stoppers and kept in the refrigerator pending the evaluation within 24 h of sampling.

### Physicochemical analysis

The pH was determined using a Phillips model PW 9418 pH meter after the meter has been duly calibrated with standard buffers of pH 4.00, 7.00 and 9.00 (Ademoroti, 1996). Alkalinity was done by titrating 100 ml of the samples with 0.02 M HCl solution using methyl orange as indicator and chloride by titrating 100 ml of the samples with a standard solution of 0.0257 M $AgNO_3$ solution using 1.00 ml solution of 5.00% $K_2Cr_2O_4$ as indicator (AOAC, 1984). Total dissolved solids were estimated by gravimetric method described by Trivedi and Raj (1997). EDTA titration method as described by the American Public Health Association, APHA (1992) was used to determine the hardness of the water samples. The sulphate turbidimetric method of APHA (1992) was used, while nitrate was determined by spectrophotometric method at 555 nm using Uv-visible light PC UNICO 2102, USA, spectrophotometer (APHA, 1992). Bicarbonate content was evaluated by titrimetry and dissolved oxygen determined by Winkler's Iodimetric method (APHA, 1992). The 5-day approach was used to evaluate the biochemical oxygen demand (BOD) of the water samples, while their iron (II) content was determined by $KMnO_4$ titrimetry.

### Bacteriological evaluation

#### *Preliminary assay*

A 1.00-ml aliquot of the test water was placed in 9.00 ml of sterile water in a sterile test tube. 1.00-ml portion of the prepared sample was then transferred to another sterile test tube containing 9.00 ml of sterile water. The second dilution was further diluted 10-folds to obtain a final dilution factor (DF) of $10^{-3}$.

From the final dilution, 0.10 ml was inoculated separately into a sterile over-dried agar and MacCorkey agar plates and spread evenly using sterile bent glass rod. All plates were incubated at 37°C for 24 h. After incubation, the colonies on the nutrient agar plates were counted and recorded as total viable count (TVC); while the colonies of lactose fermenting organisms (red or pink colonies) on MacCorkey agar plates were also counted and recorded as coli form bacteria. All bacterial counts were expressed as original viable count (OVC) in terms of colony forming units/ml (cfu/ml). That is:

$$OVC = (X * DF)/C_v \text{ cfu/ml}$$

where X is the average colony count; DF is the dilution factor ($10^{-3}$) and $C_v$ indicates the cultured volume (0.10 ml).

### Purification of the isolated colonies

Each of the colonies on the nutrient agar and MacCorkey agar plates was sub cultured and pure cultures were obtained.

### Identification

The isolates were identified by a variety of tests which included: Gram staining, catalase, coagulase, citrate utilization, oxidase, indole production, methyl red, voges proskauer, starch hydrolysis and sugar fermentation tests.

Coli forms and *Escherichia coli* were determined specifically on MacCorkey agar and the pink/red colonies with precipitation were sub cultured by streaking. Indole, methyl red, voges proskauer and citrate tests were performed to identify and differentiate *E. coli* from enterobacteria aerogenes.

Deep yellow pigment suspected to be *Staphylococcus* was inoculated on mannitol salt agar. Coagulase and catalase tests were performed to determine coagulase positive *Staphylococcus aureus*. Oxidase positive colonies were considered in the identification of *Pseudomonas aerogenosa* among other tests. While starch hydrolysis, sugar fermentation and nitrate reduction, were among the tests carried out in the identification of *Bacilus subtilis*, *Lactobacilus* spp. and *Klebsiella* spp.

### Statistical analysis

The chemical and microbial quality indices, of three replicate tests, expressed as Mean ± SEM were analysed, statistically, with the student's t-test. Results were considered significant at $p < 0.05$.

## RESULTS

The physicochemical characteristics of the sampled potable water sources were presented in Table 1. It indicated sample 'D' (commercial bottled water) as more or less a mineral concentrate. Table 2 revealed the total viable count (TVC) and coli form count of the water samples; while the isolated colonies were presented in Table 3. From both tables, 'D' was devoid of bacteriological contamination.

The colonial characteristics of the isolates were presented in Table 4. While Tables 5 and 6 respectively, indicated the cell characteristics and spore staining properties of the isolates. Result of the biochemical identification tests were outlined in Table 7; and Table 8 showed the particular organisms isolated and identified.

## DISCUSSION

pH value of the water samples ranged between 4.10 and 7.00. All the recorded pH, except foe 'D', were below the WHO (2004) and Standard Organisation of Nigeria, SON, (2003) recommended and approved optimal pH range of 6.5 to 8.5. The pH of samples 'A' and 'C' were typical for

**Table 1.** Levels of the physicochemical parameters of the sampled drinking-water sources.

| Inorganic constituent | A | B | C | D | E | WHO recommended limit |
|---|---|---|---|---|---|---|
| pH | 5.36 | 4.01 | 5.32 | 7.00 | 5.87 | 6.50 – 8.50 |
| Chloride (mg/L) | 18.46 ± 1.20 | 15.62 ± 0.90 | 17.04 ± 1.10 | 200.22 ± 1.59 | 17.04 ± 1.15 | 250.00 |
| Nitrate (mg/L) | 1.08 | 6.99 | 23.78 | 30.36 | 34.97 | 10.00 |
| Bicarbonate (mg/L) | 56.00 | 28.00 | 24.00 | 236.00 | 144.00 | N/A |
| Total alkalinity ($Na_2CO_3$) (mg/L) | 40.00 | 28.00 | 36.00 | 276.00 | 156.00 | N/A |
| Total dissolved solids (mg/L) | 0.38 | 0.04 | 0.06 | 0.48 | 0.23 | <600.00 |
| Total hardness ($CaCO_3$) (mg/L) | 16.00 | 3.20 | 3.20 | 243.00 | 6.40 | 500.00 |
| Sulphate (mg/L) | 12.98 | 12.52 | 12.52 | 15.28 | 11.90 | 500.00 |
| Iron (mg/L) | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.50 |
| Dissolved oxygen (mg/L) | 0.20 | 0.10 | 0.10 | 0.30 | 0.30 | N/A |
| Biochemical oxygen demand (mg/L) | NIL | 1.60 | 1.60 | 0.02 | NIL | N/A |

ground water generated from rocks containing acidic minerals of the sulphate type. Careful attention to pH control is necessary at all stages of water treatment to ensure satisfactory water clarification and disinfection. For effective disinfection with $Cl_2$, the pH should preferably be less than 8.00; however, lower-pH water is likely to be corrosive. Failure to minimize corrosion can result in the contamination of drinking-water and adverse effects on its taste and appearance. These dangers are eminent in the distribution of 'A' and 'C' through metal fittings. The pH (4.01) of the tap-to-reservoir water ('B') was significantly ($p < 0.05$) lower than that of 'A' (5.36). This is due to high incidence of acid producing microbes in the water-holding tank. The high acidity of 'B' also significantly ($p < 0.05$) decreased its total alkalinity (TA) and bicarbonate content, while its total hardness (TH) remained low at 3.20 mg $CaCO_3$/L The combined effects of low pH and TH of 'B' will cause leaching of metals into the water sample; possibly leading to heavy metal contamination with attendant impacts on the sample's palatability. Chloride content of 'A', 'B' and 'C' (18.46, 15.62 and 17.04 mg/L, respectively) were below the 'maximum permissible limit of 25.00 mg/L (Ademoroti, 1996); and did not influence their taste. However, the commercial bottled-water ('D') chloride content (200.22 mg/L) lied in the taste threshold range of 200 to 300 mg/L for chloride ions associated with $Na^+$, $K^+$, and $Ca^{2+}$ cations (WHO, 2004). Thus it possessed a slight salty taste.

The values of TDS ranged from 0.0353 to 0.4840 mg/L, with 'D' having the upper limit and 'B' the least. All TDS values were below the critical limit of 600 mg/L (WHO, 2004). Thus its impact on the samples' palatability was considered to be insignificant. Presence of bicarbonate in water samples may be from natural deposits, microbial fermentation/oxidation of organics and inorganic chemicals (WHO, 2004). High levels are usually detected in water samples with slightly acidic to neutral pH. The bicarbonate levels of 'D' and 'E' confirmed this assertion, as both with moderately acidic to neutral pH had the highest bicarbonate content (236 and 144 mg/L, respectively). Excessive amount of bicarbonates in natural water may indicate profound microbial activities; more so, whenever the source possessed other characteristics that indicated undue exposure to contaminant. Thus "E" is grossly polluted, since its bicarbonate, nitrate and total alkalinity contents were very unacceptable. All together, the bicarbonates content of 'A' to 'C' were fairly acceptable. That of 'D' was, definitely, a contributor to its taste.

The pH of samples 'A' to 'C' and 'E' were within the region (4.60 to 8.30), where there is equilibrium between bicarbonate ions and dissolved carbon (iv) oxide ($CO_2$). This implied that carbonate alkalinity is the prevailing alkalinity. High total alkalinity, usually, indicate chemical contamination and/or microbial actions. Thus a 'highest desirable' limit of 100 mg/L was established by WHO (2004). The total alkalinity of 'D' and 'E' (276 and 156 mg/L, respectivelly) were, well, above the WHO standard. This indicated that the treated commercial bottled-water ('D') contained strong alkalis, while 'E' was heavily contaminated by microbes.

With the exception of 'D', the total hardness of

**Table 2.** Bacterial load of the drinking-water sources.

| Sample | Coli form count (cfu/ml) | Total viable count (cfu/ml) |
|---|---|---|
| A | 0.00 | 0.05 ± 0.01 |
| B | 0.11 ± 0.01 | 0.17 ± 0.02 |
| C | 0.09 ± 0.01 | 0.20 ± 0.07 |
| D | 0.00 | 0.00 |
| E | 0.32 ± 0.10 | 0.47 ± 0.09 |
| WHO recommended limit | 0.00 | 0.00 |

**Table 3.** Bacterial colonies isolated from the drinking-water sources.

| Sample | Colonies |
|---|---|
| A | A1; A2 |
| B | B1; B2; B3 |
| C | C1; C2; C3 |
| D | 0.00; 0.00; 0.00 |
| E | E1; E2; E3; E4; E5 |

**Table 4.** Macroscopic characteristics of the isolated colonies.

| Isolate | Shape | Chromogenes | Opacity | Elevation | Surface texture | Edge | Odour |
|---|---|---|---|---|---|---|---|
| A1 | Irregular | - | Opaque | Flat | Rough/dull | Undulated | Present |
| A2 | Circular | Deep yellow | Opaque | Raised | Smooth shining | Entire | Present |
| B1 | Circular | - | | Convex | Smooth shining | Entire | Present |
| B2 | Circular | Deep yellow | Opaque | Raised | Smooth shining | Entire | Present |
| B3 | Irregular | - | Opaque | Flat | Rough/dull | Undulated | Present |
| C1 | Circular | Deep yellow | Opaque | Raised | Smooth shining | Entire | Present |
| C2 | Irregular | - | Opaque | Flat | Rough/dull | Undulated | Present |
| C3 | Circular | | Transparent | Convex | Smooth shining | Entire | Present |
| E1 | Circular | Deep yellow | Opaque | Raised | Smooth shining | Entire | Present |
| E2 | Circular | - | Opaque | Convex | Smooth shining | Entire | Present |
| E3 | Circular | - | Transparent | Convex | Smooth shining | Entire | Present |
| E4 | Circular | Greenish blue | Transparent | Convex | Smooth shining | Entire | Present |
| E5 | Irregular | - | Opaque | Flat | Rough dull | Undulated | Present |

all the samples was below the WHO limit of 100 mg/L. Thus they are classified as soft water. This revealed their low buffering capacity, and so could be more corrosive to water pipes and metal utensils leading to metal contamination. This may be aggravated by their low pH; especially in 'B'. The hardness of 'D', though above the official standard, was very much lower than the 'maximum permissible' limit of 500 mg/L (WHO, 2004). Boiling 'D' will cause scale deposition, which is usually observed with hardness values in excess of 200 mg/L.

The sulphate levels (11.904 to 15.590 mg/L) of the water samples were generally low, and lie within the official prescribed limit of 250 mg/L (WHO, 2004). It was not suspected to have impacted taste of the samples. On the other hand, the nitrate content (23.08 to 34.97 mg/L) of the samples, except 'B', were above the 'highest desirable' limit of 10.00 mg/L (WHO, 2004). Nitrate may arise in water from animal waste, fertilizer, natural deposits, septic tanks, sewage and decaying organics. High levels of nitrate in natural water sources, indicates microbial actions, as certain nitrogen dependent microbes survive by reducing nitrate to nitrite. Thus the environmental and chlonogical induced nitrate variation in water sources is very critical in assessing their public health risk status. In this regard, the significantly ($p < 0.05$) low nitrate of 'B' with respect to 'A', indicated microbial depletion (transformation) of nitrate ions; thus confirming microbial contamination. All the samples will cause methaemoglobulinemia in infants (EPA, 2010) and may as well lead to goiter and birth defects (Ajibola and

**Table 5.** Microscopic (cell) characteristics of the isolated colonies.

| Isolate | Shape | Arrangement | Stain characteristics | Colour |
|---|---|---|---|---|
| A1 | Rod | Long chain | Gram positive | Purple |
| A2 | Cocci | Clusters | Gram positive | Purple |
| B1 | Rod | Single cell | Gram negative | Purple |
| B2 | Cocci | Clusters | Gram positive | Purple |
| B3 | Rod | Long chain | Gram positive | Purple |
| C1 | Cocci | Clusters | Gram positive | Purple |
| C2 | Rod | Long chain | Gram positive | Pink |
| C3 | Rod | Singly arranged | Gram negative | Pink |
| E1 | Cocci | Clusters | Gram positive | Purple |
| E2 | Rod | Chains | Gram negative | Pink |
| E3 | Rod | Single cell | Gram negative | Pink |
| E4 | Rod | Short chains | Gram negative | Pink |
| E5 | Rod | Chains | Gram positive | Purple |

**Table 6.** Spore staining characteristics of the isolated colonies.

| Isolate | Spore characteristics |
|---|---|
| A1 | Spore former |
| A2 | Non spore former |
| B1 | Non spore former |
| B2 | Non spore former |
| B3 | Spore former |
| C1 | Non spore former |
| C2 | Spore former |
| C3 | Non spore former |
| E1 | Non spore former |
| E2 | Non spore former |
| E3 | Non spore former |
| E4 | Non spore former |
| E5 | Spore former |

**Table 7.** Biochemical characteristics of the isolated colonies.

| Isolate | *Mot. | Cat. | Coag. | Oxid. | Cit. | Indole | Vp | Methyl red | DNase | Mannitol |
|---|---|---|---|---|---|---|---|---|---|---|
| A1 | -Ve | -Ve | -Ve | | | | | | -Ve | +Ve |
| A2 | -Ve | +Ve | +Ve | | | | | | +Ve | +Ve |
| B1 | -Ve | -Ve | | | -Ve | +Ve | -Ve | | -Ve | -Ve |
| B2 | -Ve | +Ve | -Ve | | | | | | | |
| B3 | -Ve | -Ve | -Ve | | | | | | | |
| C1 | -Ve | +Ve | +Ve | | | | | | | |
| C2 | -Ve | -Ve | -Ve | | | | | | | |
| C3 | -Ve | -Ve | -Ve | | | | | | | |
| E1 | -Ve | | +Ve | | | | | | +Ve | +Ve |
| E2 | -Ve | -Ve | -Ve | | | | | | | |
| E3 | -Ve | -Ve | -Ve | | -Ve | +Ve | -Ve | | | |
| E4 | Motile | -Ve | -Ve | | -Ve | +Ve | +Ve | | | |
| E5 | -Ve | -Ve | -Ve | | -Ve | | | | | |

Mot: Motility test; Cat: Catalase test; Coag: Coagulase test; Oxid: Oxidase test; Cit: Ctrate test; Vp: Voges-Proskauer test; DNase: Deoxyribonuclease test; Mann: Mannitol test.

**Table 8.** Identity of the isolated colonies.

| Colony | Identity |
|---|---|
| A1 | *Bacilus subtilis* |
| A2 | *Staphylococcus aureus* |
| B1 | *Echerichia coli* |
| B2 | *Stapti. Saprophyticus* |
| B3 | *Bacilus subtilis* |
| C1 | *Staphylococcus aureus* |
| C2 | *Bacilus subtilis* |
| C3 | *Klebsiella spp* |
| E1 | *Staphylococcus aureus* |
| E2 | *Echerichia coli* |
| E3 | *Klebsiella spp* |
| E4 | *Pseudomonas aeruginosa* |
| E5 | *Bacilus subtilis* |

Uli, 1998).

The iron (II) ion content (0.0193 to 0.0250 mg/L) of the water samples were very low and may be due to extensive oxidation of iron (II) to iron (III) by 'iron bacteria'. However, the total iron content of the drinking-water sources was low; since they were devoid of the objectionable reddish-brown colour and turbidity associated with iron concentration of 0.30 mg/L and above. Also, there were no noticeable impact on the taste of 'A', 'C' and 'D'; which suggested that their acceptability was not affected. Iron concentrations in excess of 0.30 mg/L are known to impart bitter taste on drinking-water; thus reducing their palatability and overall acceptability (WHO, 2004). The National Secondary Drinking Water Regulations, therefore, recommended a non-enforceable iron limit (standard) of 0.30 mg/L (WHO, 2004; EPA, 1991).

Low levels of dissolved oxygen (DO), in drinking-water, can encourage the microbial reduction of nitrate to nitrite and sulphate to sulphide (WHO, 2004). This was true for 'B', since its nitrate limit was significantly ($p < 0.05$) lower than the corresponding value for 'A'.

According to WHO, the most common and widespread health risk associated with water is microbial contamination, the consequences of which mean that its control must always be of paramount importance. In this regard, the Environmental Protection Agency (EPA) establish a 'maximum contaminant level goal' (MCLG) of zero (0.00) total coli form in drinking-water (WHO, 2004) (EPA, 2010). The 'maximum contaminant level' (MCL) of < 5% positive samples is, however, enforced in the USA (EPA, 2010). With the exception of 'D', all other water samples had inadequate microbial quality. The contaminated sources, especially 'B', 'C' and 'E' have the potential to cause large outbreaks of water borne disease. Thus they should be adequately disinfected before utilization for domestic operations.

## Conclusion

Our findings, demonstrated that the tap-to-reservoir water at the PG Hall, UNN, possessed unacceptable physicochemical and microbial qualities; and thus is a challenge to public health. Sustainable efforts should be developed and directed towards adequate and effective sanitation of the water-holding tank. If possible, the present metal tank should be replaced with a high density polypropylene tank with sustainable sanitary considerations and provisions. The physicochemical quality of the commercial sachet-water is minimally good, but is contaminated by microbe; therefore, requiring adequate disinfection before use. The pH of 'A' and 'C' have to be altered to a value within 6.50 to 8.50, possibly 7.20 or thereabout. The commercial bottled-water is a 'mineral concentrate' and possessed acceptable physicochemical and biological quality. However, its taste may be considered objectionable by some consumers. With the exception of pH and nitrate content, other quality indices of 'A' were appreciably acceptable. This identifies it as a good source of drinking-water. However, efforts should be intensified to render it 100% free from microbes.

## ACKNOWLEDGEMENTS

We are grateful to Messer Chijioke Muogbo of the Division of Pharmaceutical Microbiology, Department of Pharmaceutics, Faculty of Pharmaceutical Sciences, University of Nigeria, Nsukka, for technical assistance. Also, the efforts and contributions of Mr. Ikechukwu Okoye, University of Nigeria, Nsukka, Water Resources Management Laboratory Ltd is acknowledged.

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