Scientific Research and Essays Vol. 7(11), pp. 1195-1211, 23 March, 2012
Available online at http://www.academicjournals.org/SRE
DOI: 10.5897/SRE11.1045
ISSN 1992-2248 ©2012 Academic Journals

Full Length Research Paper

Quality of water from dug wells and the lagoon in Lagos Nigeria and associated health risks

B. A. Adelekan[1]* and O. A. Ogunde[2]

[1]Department of Agricultural Engineering, Federal College of Agriculture,
Institute of Agricultural Research and Training (IAR&T), PMB 5029, Moor Plantation, Ibadan, Oyo state, Nigeria.
[2]Department of Agricultural and Mechanical Engineering, College of Engineering and Environmental Studies, Olabisi Onabanjo University, PMB 5026, Ibogun, Ogun state, Nigeria.

Accepted 10 January, 2012

The aim of this research work was to assess the quality of the water from dug wells and lagoon in Lagos, Nigeria, ascertain the contamination problems that may confront the consumers, determine the health risks and suggest appropriate remedies. Twenty (20) dug wells were randomly selected in Oworonshoki area of Lagos and water samples were collected during July to August 2010. The samples were checked for odour, colour and taste and these largely satisfied consumer preferences. Physico-chemical analyses were conducted to determine the concentrations of pH, total solids, total hardness, Cl, SO_4, NO_3, Mg, Ca, Mn, Na, Cu, Zn, Fe and Pb, while microbiological analyses were done to assess the levels of total viable count, total coliform count, faecal coliform count and faecal streptococci count. Most of the samples met WHO guideline values for these parameters, although the pH values were outside the recommended range. Maggots and entero bacteria were found in several well and lagoon samples thus confirming certain health risks associated with these samples. This study recommends that various states in Nigeria create agencies which can be effective in monitoring private water wells from a public health stand point and compel adherence to regulations on the part of the owners.

Key words: Dug wells, lagoon, water, physico-chemical analyses, microbial analyses.

INTRODUCTION

In most Nigerian cities, the supply of water for domestic purposes has several accompanying inadequacies. As earlier observed by Sangodoyin (1993), reasons for these inadequacies include enormous socio economic rate of development, a growing industrial base, poor planning, insufficient funding, haphazard implementation of programs, lack of maintenance culture as well as technically deficient personnel. Adedeji (2001) surveyed the water supply pattern in Lagos which is Nigeria's largest urban area and found that for households connected to the public water supply, just 75.2 L per capita per day were assured. Those not connected to the public supply had far less. This situation did not improve significantly over the past decade. Given such a grim situation, residents are left with no other choice than to seek sources of freshwater from rainfall, the lagoon and groundwater (by digging wells). The use of water wells for domestic water supply is practiced both in the developing and also the developed regions of the world. Swistock et al. (2009) observed that more than 3 million rural and suburban residents in the state of Pennsylvania, USA rely on a private well for drinking water and about 20,000 new wells are drilled each year in the state. Only the state of Michigan has a larger population served by private water supplies. Unlike residents that use community water systems, homeowners with private wells are not protected by any statewide regulations. This situation can exacerbate the problems associated with water supply for domestic use.

*Corresponding author. E-mail: jideadelekan@yahoo.com. Tel: +234-08062373443, 08023277499.

A dug well is a large diameter well constructed by excavating with hand tools or power machinery instead of drilling and driving and has the basic purpose of supplying water for domestic needs. It is distinct from a drilled well (commonly called borehole) which is constructed by cable tool or rotary drilling methods (Adelekan, 2010). The assessment of water quality in dug wells is essential because these are often the main sources of water for human consumption in both the rural and urban areas in the developing world. The well-being of people is dependent on the quality of water which they ingest or otherwise make use of. It has become imperative to assess the quality of the water obtained from these dug wells in Lagos and identify the various pollutants in order to ascertain the contamination problems that may confront the consumers. From results obtained, a scientific basis will then be provided for determining any associated health risks for residents that depend on the wells and finding appropriate remedies for these. It is with this objective in mind that the present study was undertaken in Oworonshoki area of the megacity of Lagos, Nigeria. Essentially, Lagos is a typical African city and findings regarding it can be of relevance in such large cities located all around the continent.

Reported researches in respect of groundwater in various locations in Nigeria include those of Alexander (2008) which evaluated groundwater quality in Mubi town situated in the northern Nigeria state of Adamawa; Adelekan (2010) which investigated water quality from dug wells in Ifo, Ibogun and Pakoto communities in Ogun state, Nigeria; Oluyemi et al. (2010) which studied the physico-chemical properties and heavy metal content of water from Ife North Local Government Area of Osun State, Nigeria. These natural waters are often subjected to pollution from various sources including household wastes (Ololade et al., 2009), heavy metals from refinery effluents in the Niger Delta (Nduka and Orisakwe, 2009), municipal refuse dumpsites (Adelekan and Alawode, 2011), contaminants released from automechanic workshops (Adelekan and Abegunde, 2011) and others. There is a pungent need for continual research and monitoring of these sources since they are very crucial to the provision of adequate water for Nigeria 150 million populations. According to WHO (2010), in the African continent, about 28% of the disease burden is attributable to the environment (of which a major part is consumption of poor quality water) and this reaches 36% in children under the age of 14 years. Main health outcomes affected by environmental risks in Africa include diarrhoea, respiratory infections and malaria; and these are jointly responsible for about 60% of all known environmental health impacts.

A comparison of world averages in exposure to main environmental risks shows that Africa faces poorer conditions as to the traditional risks from namely water, sanitation and hygiene (closely linked to malnutrition) and solid fuel use. It is estimated that in the African continent there are more than 1.3 million avoidable child deaths per year attributable to the environment. This highlights the importance of improving environmental conditions in order to meet Millennium Development Goals for example, those on child mortality, water and sanitation, and solid fuel use and other internationally agreed objectives (such as those on polio eradication (WHO, 2010). Rosenberg (2010) observed that in wealthy parts of the world, people turn on a tap and out pours abundant clean water. Yet, 900 million people in the world have no access to clean water and 2.5 billion people have no safe way to dispose of human waste. Dirty water and lack of a toilet and proper hygiene is implicated in the death of 3.3 million people around the world annually, most of them are children under the age of 5 years. The paper noted further that in much of the developing world, lack of water is at the center of a vicious circle of inequality. To live in good health, people need to have access to good quality water in adequate quantity. Parameters for drinking water quality typically fall under three categories namely physical, chemical and microbiological. Physical quality involves such parameters as odour, colour and taste. Chemical parameters include pH, total solids, nitrates, sulphates, chlorides, hardness, metals generally as well as some other elements. Microbiological parameters include coliform bacteria, streptococci, *E. coli* and parasites.

The aim of this research work was therefore to determine the concentrations of physical, chemical and microbiological parameters in the samples of water sourced from various dug wells and the Lagos lagoon at Oworonshoki, Lagos, Nigeria; compare those values to International Drinking Water Quality Guidelines of the World Health Organization ascertain the contamination problems that may confront the consumers, determine the health risks and suggest appropriate remedies.

MATERIALS AND METHODS

Sampling and description of sampling sites

Water samples from the selected dug wells were collected during July to August 2010 with a sample collected from each well. 20 dug wells were randomly selected in Oworonshoki area of Lagos giving a total of 20 water samples in all. All wells were located within 40 m of the bank of the Lagos lagoon. All the wells were between 5 and 10 m in depth. They are concrete lined with water recharge coming only from the bottom of the wells. The wells are covered with a low chance of contamination coming through their tops. The surrounding soil is basically sandy and well drained. Water samples were also obtained from 3 points in the lagoon since some residents do obtain water from this trapped inland lake for domestic use. pH and temperature were measured on site. Each sample was collected in a new factory-fresh 1.5 L plastic bottle with the cap securely tightened. After collection, the samples were immediately placed in ice coolers for transportation to the laboratory where they were then transferred to the refrigerator. Laboratory analyses commenced the same day and within 30 min of arrival at the laboratory in every case.

The analyses were conducted at Unilever and Alfa Laboratories

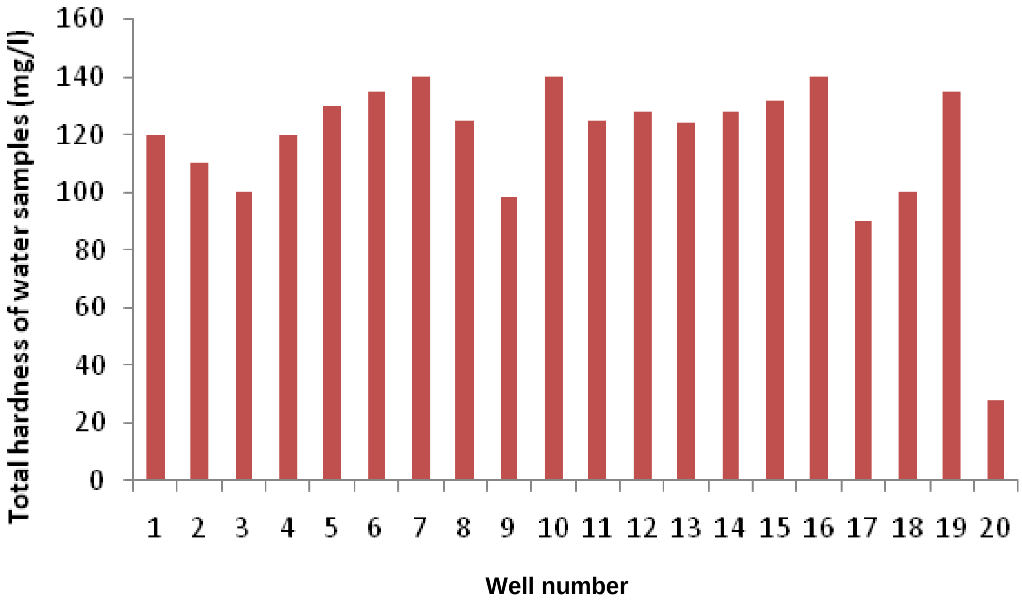

Figure 1. Total hardness of water samples.

Limited both located in Lagos, Nigeria.

Methods for physico-chemical analyses

The samples were first checked for odour, colour and taste. Afterwards, they were analyzed for major physical and chemical water quality parameters namely pH, total dissolved solids (TS), total suspended solids (TSS), total hardness (TH), chlorides, sulphate, nitrates, nitrite, magnesium, calcium, manganese, copper, zinc, iron and lead. Samples were subjected to filtration prior to chemical analysis. The determination of TS was done by a gravimetric process, while the total hardness was carried out by EDTA complexometric titration method. Nitrate was determined by colorimetric procedure. The methods of analyses were those detailed in APHA et al. (1998).

Methods for bacteriological analyses

Total viable count, total coliform count, total streptococci count, *E. coli*, maggots and entero bacteria were determined. For the preparation of sterile water, 9 ml distilled water was pipetted into a clean dry test tube plugged with clean cotton wool and wrapped with aluminium foil. The test tube was placed inside an autoclave and sterilized by autoclaving at 121°C for 15 min. The media were afterwards prepared as follows. For preparation of nutrient agar (NA), 28 g of powdered commercially prepared nutrient agar was weighed on a Mettler analytical balance into a clean dry 1-L conical flask and 100 ml of distilled water was added. The flask was then placed inside a water bath set at 90°C to allow the agar dissolve. The solution was then measured into Macconkey bottles and the bottles placed for 15 min inside autoclave set at 121°C. For preparation of Macconkey agar (MCCA), 55 g of commercially prepared agar was weighed into a 1-L conical flask and gradually heated to dissolve the agar. It was then distributed into Macconkey bottles and autoclaved as for nutrient agar. For preparation of potato dextrose agar (PDA), 39 g of commercially prepared agar was weighed into a 1-L conical flask and gradually heated to dissolve the agar. The solution was then distributed into Macconkey bottles and autoclaved as for nutrient agar. In all the cases, after autoclaving, the media were placed inside a water bath set at 45°C to maintain the media in a molten state. 1 g of each sample was weighed into a test tube containing 9 ml of sterile distilled water and serially diluted.

The media were individually poured into separate plates and were duplicated. After solidifying, the plates were incubated at 37°C for nutrient agar and Macconkey agar while potato dextrose agar was incubated at 30°C. All the plates were incubated invertedly. The plates were counted at 48 h for Nutrient Agar and Macconkey Agar while it was read for potato Detrose Agar at 72 h. The pathogens were identified using cultural and morphological features. Isolation and identification of bacteria in the water samples were done using methods detailed in Collins and Lyne (1984), Adegoke et al. (1993) and APHA et al. (1998). The procedures for the biochemical characterization of the isolates which includes: 1) cultural profiles on different culture media; 2) growth in air; 3) gram staining; 4) coagulase, catalase and oxidase tests, and 5) carbohydrate fermentation were strictly followed.

RESULTS

Results of the physico-chemical and bacteriological analyses are presented in the figures and tables. Total hardness in the water samples ranged from 28 to 140 mg/l (Figure 1). The concentration of hardness in 85% of the samples was found to be 100 mg/l or more. The range of electrical conductivity measured in the samples was 26 to 51 US/cm (Figure 2). 40% of the water samples had electrical conductivity in the range 30 to 40 US/cm. 50% were 50 US/cm or above while 25% were below 30 US/cm. The range of total solids measured in the samples was 114.5 to 700 mg/l (Figure 3). 35% of the samples had total solids concentration higher than 500

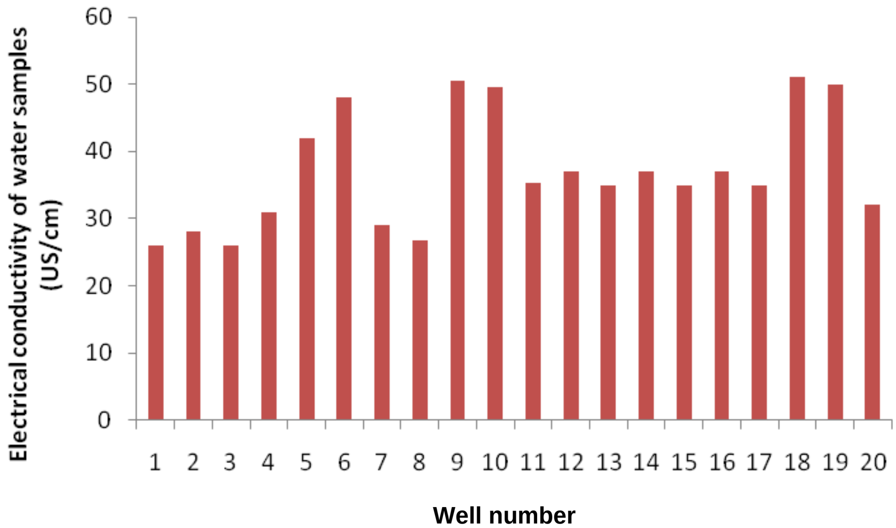

Figure 2. Electrical conductivity of water samples.

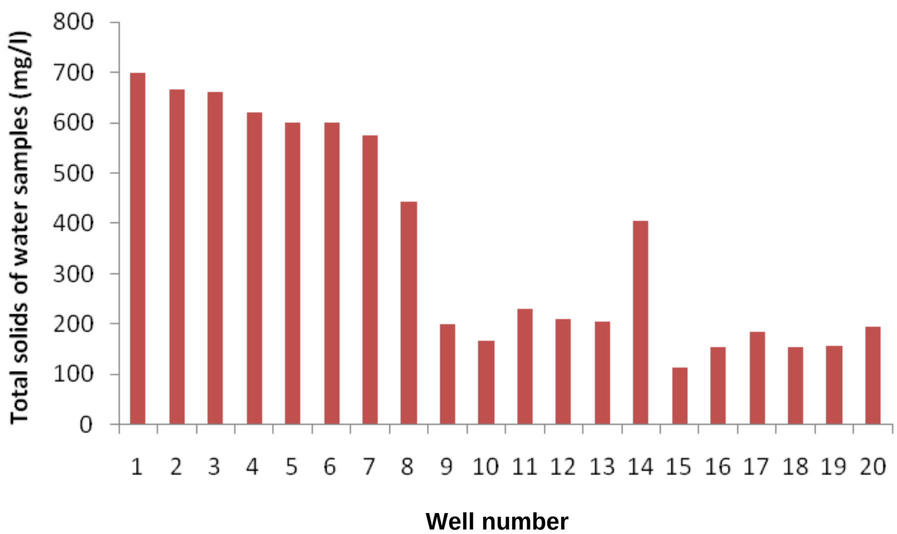

Figure 3. Total solids of water samples.

mg/l. For 80% of the samples, the concentration of total dissolved solids was lower than that of total suspended solids (Figure 4). The range of total dissolved solids was 44 to 250 mg/l while that of total suspended solids was 50 to 450 mg/l. The pH of the water samples ranged from 5.53 to 8.16 (Figure 5). 75% of the samples fell outside the range 6.5 to 8.5. 20% of the water samples had a pH above 7. Chloride was not detected in 50% of the samples (Figure 6). In the other 50%, the range found for chlorides was 0.15 to 0.88 mg/l. The concentration of nitrates in the water samples ranged from 10.2 to 25.7 mg/l (Figure 7). For 90% of the samples, the concentration of nitrates was less than 20 mg/l. The concentration of magnesium in the water samples ranged from 18.9 to 33.9 mg/l with 55% being within the 20 to 30 mg/l range (Figure 8). The range of sulphate concentration was found to be 75 to 300 mg/l in the water samples (Figure 9). 40% of the samples had a sulphate concentration of 100 mg/l or less.

The concentration of Ca in the samples ranged from 75 to 120 mg/l (Figure 10). 85% of the samples had Ca concentration which is less than 100 mg/l. Values of magnesium and those of calcium were plotted on the same graph to obtain Figure 11. The higher curve is that of Ca while the lower curve is that of Mg. In 80% of the samples, the ratio of Ca to Mg was a factor between 3

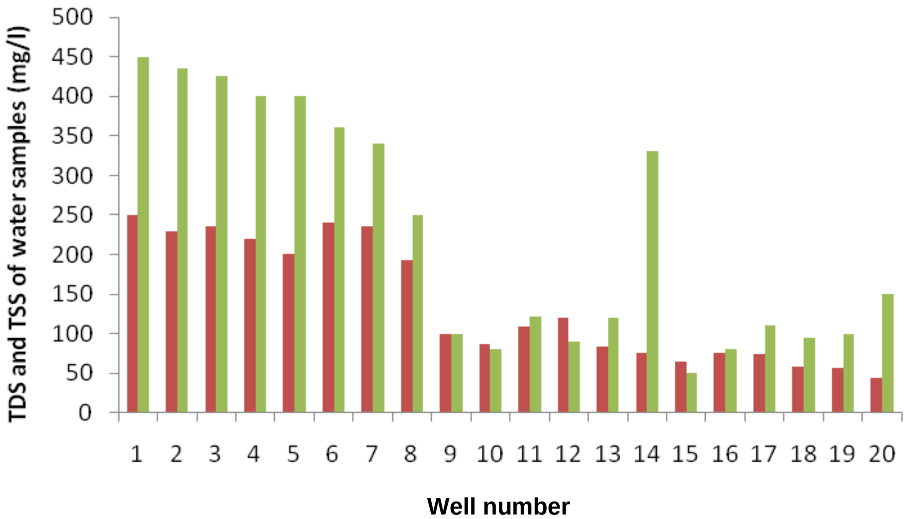

Figure 4. Total dissolved solids (TDS) and total suspended solids (TSS) of water samples.

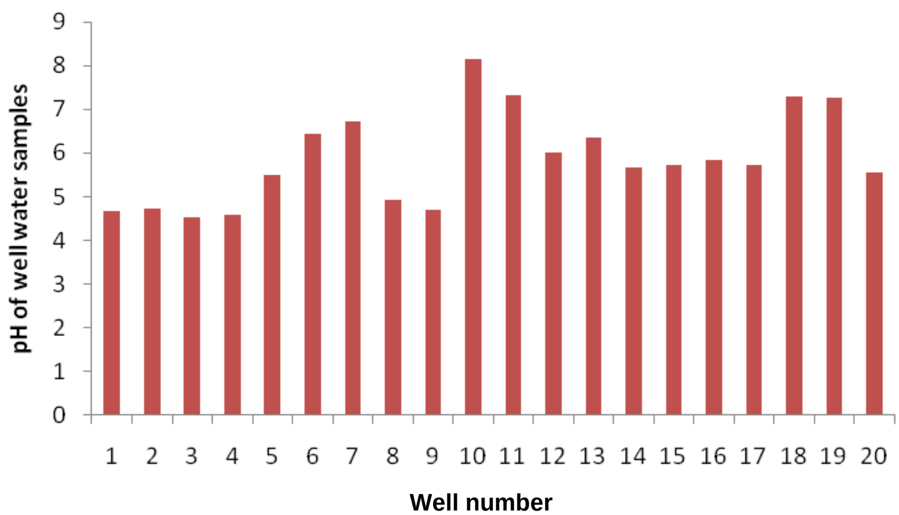

Figure 5. pH of water samples.

and 5. Table 1 shows that for most of the parameters, 100% of the well samples meet the guidelines of the World Health Organization (2004a). Table 2 shows that there are significant levels of risks associated with these well water samples as shown by the presence of maggots, enterobacteria and faecal streptococci detected. *E. coli* was not found in the majority of the samples. As shown in Table 3, as regards colour, odour and taste, all the lagoon samples are definitely objectionable to the consumers. Values higher than the WHO (2004a) guidelines were also found in the case of nitrates and total solids. The concentration of nitrates in all the samples was higher than 50 mg/L. The concentration of total solids (TDS + TSS) was higher than 1000 mg/l in all the lagoon water samples. As shown in Table 4, maggots were found in 66% of lagoon samples.

There were high faecal streptococci counts. Dissolved Oxygen (DO) was low and biochemical oxygen demand (BOD_5) was fairly high and this indicated high organic pollution of the lagoon. The lagoon samples qualify as polluted water as far as domestic use is concerned and should be purified before use.

DISCUSSION

According to WHO (2010), the most commonly reported cause of water pollution in African countries is inadequate

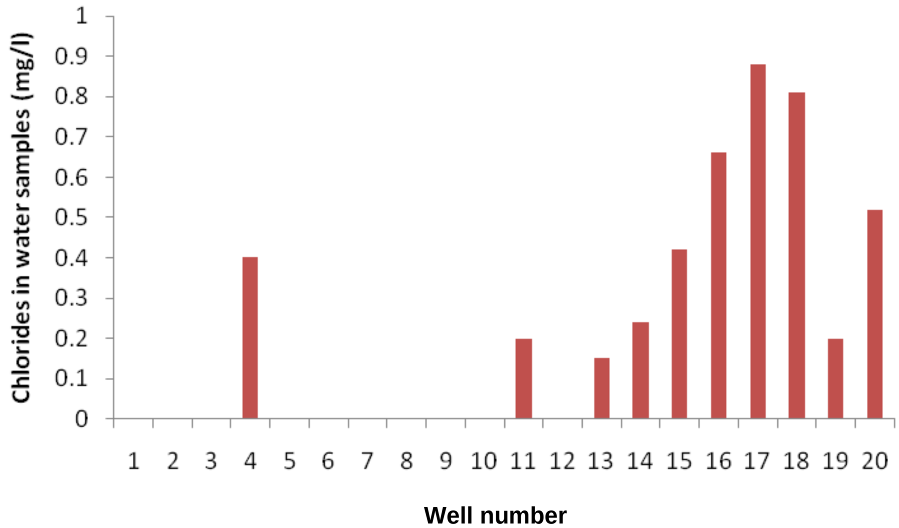

Figure 6. Chlorides in water samples.

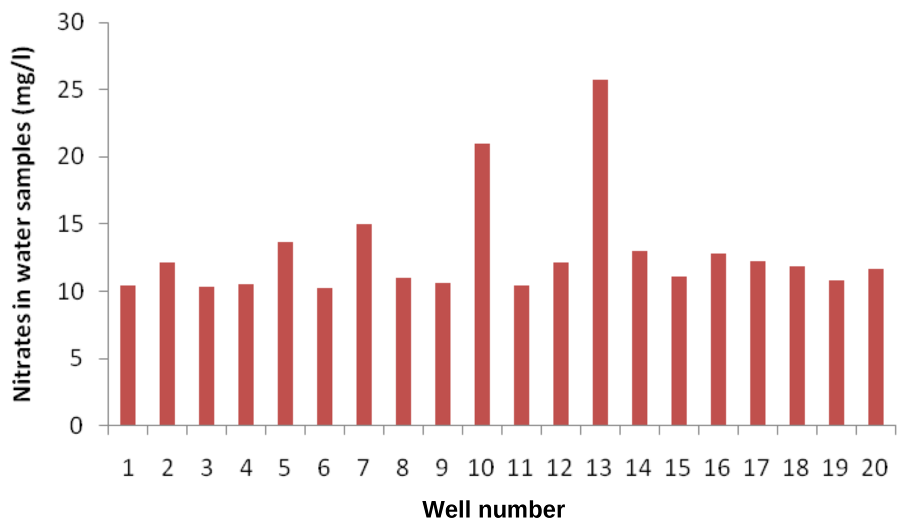

Figure 7. Nitrates in water samples.

waste management with significant proportions of the urban populations in such countries having poor access to proper solid waste management and sanitation. Ground water is commonly contaminated by pit-latrines and soak pits in most peri-urban and informal settlements, leading to potentially high levels of coliform counts in drinking water. This is primarily because untreated waste and waste that remains uncollected or improperly disposed off can be sources of chemical and organic contaminants and can become breeding sites for disease vectors. Such wastes contaminate drinking water and other water resources and contribute to diarrhoeal and vector-borne diseases.

Since people within the study area of Oworonshoki, Lagos, Nigeria use the untreated water for domestic purposes, results stated earlier are compared mainly with the World Health Organization (WHO) guidelines for drinking water quality (WHO, 1998, 2004a).

Physical characteristics of water samples studied

The physical characteristics of water considered in this research are colour, odour, taste and turbidity. The World Health Organization has no guideline values for colour, odour and taste (WHO, 2004a). However, a rule of thumb

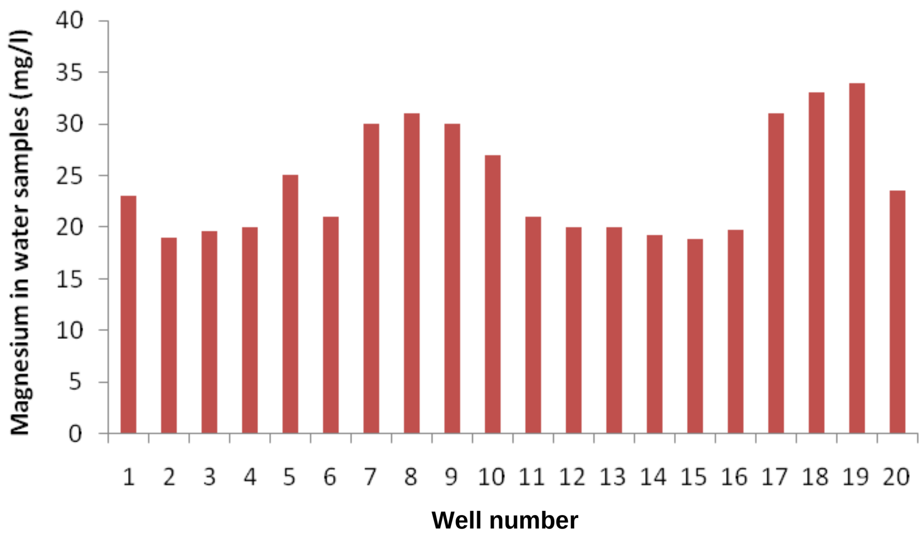

Figure 8. Magnesium in water samples.

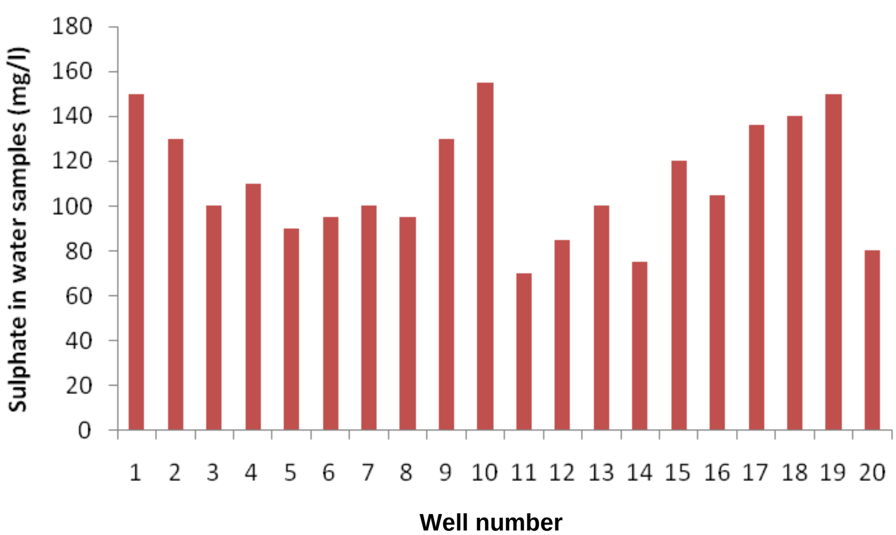

Figure 9. Sulphate in water samples.

is that the water must not be objectionable to consumers. One well sample was yellowish brown, while the rest of the samples were colourless. Most consumers prefer water to be colourless (Stoddard et al., 1999; USEPA, 2002). None of the lagoon samples was colourless. They were either yellowish brown or dark brown. 80% of the well samples were odourless while 20% had objectionable odour. All the lagoon samples had objectionable odour. None of the well samples had objectionable taste while the tastes of the lagoon samples were objectionable. Turbidity, which is a measure of water clarity as represented by total suspended solids (TSS) (APHA et al., 1998) was measured in the range 50 to 450 mg/l for the well samples and this explains why many of the well samples appeared very clear under visual observation. For the lagoon samples, TSS ranged from 500 to 530 mg/l. The lagoon samples appeared turbid.

The higher the TSS, the murkier the water appears. The WHO guideline value for TSS is 500 mg/l (WHO, 2004a).

Chemical characteristics of water samples

The pH of most raw water normally ranges from 6.5 to

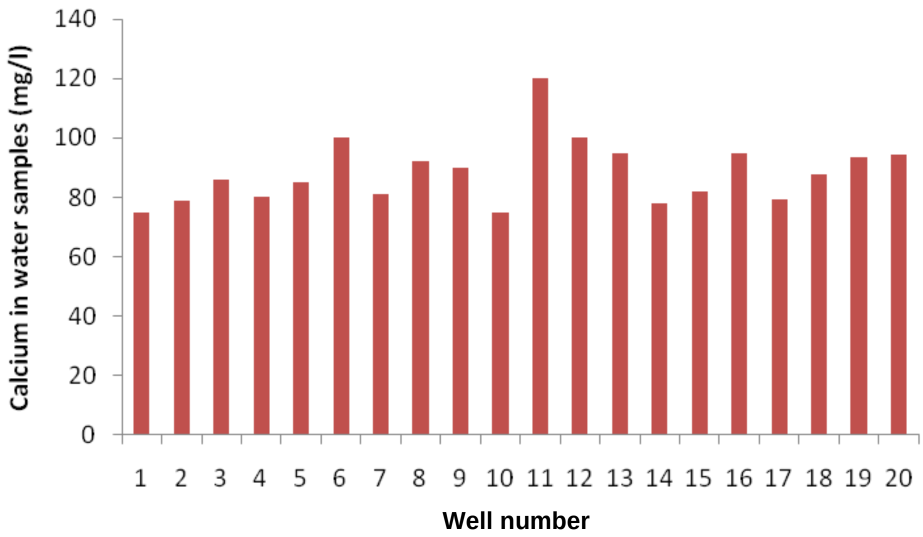

Figure 10. Calcium in water samples.

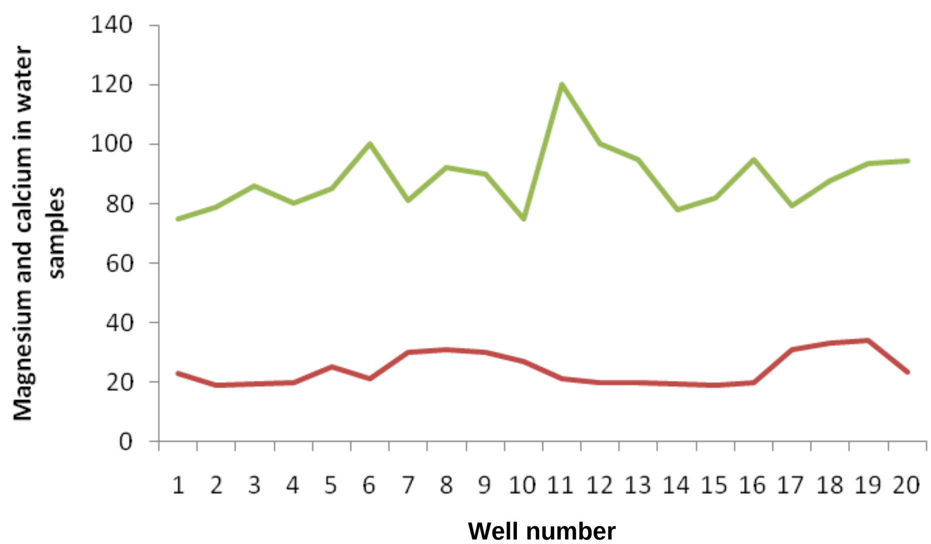

Figure 11. Magnesium and calcium in water samples.

8.5. At pH levels of less than 7.0, corrosion of water pipes may occur, releasing metals into the drinking water. This is undesirable and can cause other concerns if concentrations of such metals exceed recommended limits (WHO, 2003a). The results of this research revealed a pH range of 4.53 to 8.16 as shown in Table 1 and this indicated mild to moderate acidity of the well waters for the majority of cases. About 75% of the water samples obtained from wells fall outside the range of 6.5 to 8.5. A pH of 7.79 to 7.83 was measured for all the water samples obtained from the lagoon. This finding meets the demand of aesthetics as regards domestic use and the requirements for biological productivity of an aquatic ecosystem. Although the tolerance of individual species varies, pH values between 6.5 and 8.5 usually indicate good water quality and this range is typical of most major drainage basins of the world. The pH is classified as a secondary drinking water contaminant whose impact is considered an aesthetic concern. As noted by Government of Saskatchewan (2008), a low pH has the potential to cause the erosion of tooth enamel in extreme cases, although this is more of an issue with the pH values encountered in soft drinks than in drinking water.

Corrosion effects may become significant below pH 6.5, and the frequency of incrustation and scaling

Table 1. Comparative analysis of measured parameters in well water samples with WHO guidelines.

Parameter	WHO guideline value (mg/l)	Highest value measured (mg/l)	Least value measured (mg/l)	Percent meeting WHO value
Colour	None	Colourless	Yellowish brown	-
Odour	None	Odourless	Off	-
Taste	None	Tasteless	Off	-
Hardness	100-200	140	90	100
Total solids	1500	700	114.5	100
Total dissolved solids	1000	250	44	100
Total suspended solids	500	450	50	100
pH	6.5-8.5	8.16	4.13	30
Chlorides	250	0.88	0	100
Nitrite	3.0	0.9	0	100
Nitrate	50	25.7	10.3	100
Sulphate	250	155	75	100
Manganese	0.1	0	0	100
Magnesium		33.9	19	
Calcium		120	75	
Iron	0.3	0.8	0	95
Zinc	3.0	0	0	100
Copper	2.0	0	0	100
Lead	0.01	0	0	100

Table 2. Microbiological analysis of the well water samples.

Well Number	Total viable count (No/100 ml)	*E. coli* (No/100 ml)	Total coliform count (No/100 ml)	Faecal streptococci count (No/100 ml)	Others
1	5	NIL	NIL	4	Maggots
2	30	NIL	5	10	Maggots
3	20	NIL	2	8	Maggots
4	60	NIL	10	15	1 entero bacteria
5	7	NIL	10	18	Nil
6	2	NIL	NIL	5	Maggots
7	12	NIL	1	6	Maggots
8	2	NIL	6	20	Nil
9	10	NIL	1	>50	Nil
10	11	NIL	1	10	1 entero bacteria
11	18	NIL	2	10	Maggots
12	NIL	5	NIL	>50	Nil
13	1	NIL	20	12	Nil
14	10	NIL	2	10	Nil
15	NIL	7	1	10	Nil
16	16	NIL	15	25	2 entero bacteria
17	30	NIL	NIL	5	Maggots
18	8	NIL	5	12	Nil
19	8	NIL	25	NIL	Nil
20	10	NIL	NIL	12	Nil

problems may be increased above pH 8.5. With increasing pH levels, there is also a progressive decrease in the efficiency of chlorine disinfection processes. World Health Organization Working Group

Table 3. Physico-chemical analysis of lagoon water samples.

Parameter (mg/l)	Sample 1	Sample 2	Sample 3
Colour	Dark brown	Yellowish brown	Yellowish brown
Odour	Off	Off	Off
Taste	Off	Off	Off
Hardness	35	35	30
Conductivity (µs/cm)	53.81	53.81	53.70
Total dissolved solids (TDS)	520	514	505
Total suspended solids (TSS)	500	530	510
pH	7.79	7.83	7.82
Chloride	0.31	2.0	1.6
Nitrite	3.0	2.87	2.0
Nitrate	53.50	54.60	52.00
Manganese	0.03	0.02	0.01
Magnesium	39.0	39.50	38.20
Calcium	165.0	162.0	160.0
Sulphate	300.0	310.0	280.0
Iron	1.20	1.23	0.22
Zinc	2.0	2.0	1.58
Copper	0.70	0.50	0.40
Lead	0.00	0.00	0.00

Table 4. Microbiological analysis of the lagoon water samples.

Sample	Total viable count (No/100 ml)	*E. coli* (No/100 ml)	Total coliform count (No/100 ml)	Faecal streptococci count (No/100 ml)	Dissolved oxygen (mg/l)	BOD_5 (mg/l)	Others
1	23	NIL	3	18	0.02	4.0	NIL
2	15	NIL	30	15	0.01	2.0	Maggots
3	18	NIL	2	20	0.02	6.0	Maggots

(1986) further pointed out that exposure to extreme pH values results in irritation to the eyes, skin and mucous membranes; and that eye irritation and exacerbation of skin disorders have been associated with pH values greater than 11. In addition, the study stated that solutions of pH 10 to 12.5 have been reported to cause hair fibres to swell; while in sensitive individuals, gastrointestinal irritation may also occur. Exposure to low pH values can also result in similar effects. Below pH 4, redness and irritation of the eyes have been reported, the severity of which increases with decreasing pH below pH 2.5, damage to the epithelium is irreversible and extensive. In addition, because pH can affect the degree of corrosion of metals as well as disinfection efficiency, it may have an indirect effect on health. This present research however found no extreme values of pH in any of the water samples analysed from Oworonshoki, Lagos and hence the risk of occurrence of these ailments in the studied population appears to be low. Dissolved salts and minerals are necessary components of good quality water as they help maintain the health and vitality of the organisms that rely on the ecosystem (Stark et al., 2000). From the human health stand point, water in which the concentration of essential minerals is zero has limited value.

The total dissolved solids (TDS) test measures the total amount of dissolved minerals in water. The solids can be iron, chlorides, sulfates, magnesium, calcium or other minerals found on the earth’s surface. The dissolved minerals can produce an unpleasant taste or appearance and can contribute to scale deposits on pipe walls. As shown in Table 1, the range of TDS measured in the well samples was 44 to 250 mg/l. For the lagoon samples shown in Table 4, the range was 505 to 520 mg/l. Therefore, the ranges measured for both the well and lagoon samples were far below the WHO guideline value of 1000 mg/l. The higher ranges obtained in the lagoon samples account for the dark brown and yellowish brown colours observed in those samples. Based on taste, water with a TDS content of 500 mg/l is regarded as good quality water (Bruvold and Daniels, 1990), although water with a TDS content of up to 1000 mg/L is acceptable in many communities. Turbidity refers to water clarity; the greater the amount of suspended solids in the water, the murkier it appears and the higher the measured turbidity. Turbidity is often expressed as total suspended solids (TSS).

As regards water hardness, WHO has a guideline value of 100 to 200 mg/l. The values determined in this study ranged from 90 to 140 and 30 to 35 mg/l for well and lagoon water samples respectively. As a rule, the lagoon samples recorded lower values of hardness than the well samples. The reason for this is that hardness is linked to the presence of rocks which are more associated with geologic formations found inland rather than alluvial soil of the lagoon.

According to WHO (2003b), there does not appear to be any convincing evidence that water hardness causes adverse health effects in human beings. In contrast, the results of a number of epidemiological studies have suggested that water hardness may protect against disease. However, the available data are inadequate to prove any causal association. Some data suggest that very soft waters with a hardness of less than 75 mg/l may have an adverse effect on mineral balance, but detailed studies are not available. Depending on the interaction of other factors such as pH and alkalinity, water with hardness above approximately 200 mg/l may cause scale deposition in the distribution system, as well as increased soap consumption. In contrast, soft water with hardness less than about 100 mg/l has a greater tendency to cause corrosion of pipes, resulting in the presence of certain heavy metals such as cadmium, copper, lead, and zinc, in drinking water. The degree to which this corrosion and solubilization of metals occurs also depends on the pH, alkalinity and dissolved oxygen concentration. Water hardness is classified by the US Department of Interior and the Water Quality association as follows: Soft, 0 to 17.1 mg/l; slightly hard, 17.1 to 60 mg/l; moderately hard, 60 to 120 mg/l; hard, 120 to 180 mg/l; very hard, 180 mg/l and over. Other organizations may use slightly different classifications.

Kozisek (2006) as well as Monarca and Donato (2005) provide comprehensive reviews of the health significance of Mg and Ca in drinking water. According to Kozisek (2003) in low and medium-mineralized underground and surface waters, calcium and magnesium are mainly present as simple ions Ca^{2+} and Mg^{2+}, the Ca levels varying from tens to hundreds of mg/l and the Mg concentrations varying from units to tens of mg/l. This was found to be the case in this present research as well. As shown in Figure 11, magnesium is usually less abundant in waters than calcium, since magnesium is found in the Earth’s crust in much lower amounts as compared with calcium. In common underground and surface waters, the mass concentration of Ca is usually several times higher compared to that of Mg, the Ca to Mg ratio reaching up to 10. Nevertheless, a common Ca to Mg ratio is about 4 which correspond to a substance ratio of 2.4 (Pitter, 1999). The Ca to Mg ratio measured for this study is approximately 3.3 for the well samples (Figure 11) and 4.3 for lagoon samples (Table 3). As noted by Kozisek (2003), both Ca and Mg are essential for the human body. Calcium is part of bones and teeth. In addition, it plays a role in neuromuscular excitability (decreases it), proper functioning of the conducting myocardial system, heart and muscle contractility, intracellular information transmission and blood coagulability. The most common manifestations of calcium deficiency are osteoporosis and osteomalacia. A less common but proven disorder linked to Ca deficiency is hypertension. The recommended Ca daily intake for adults ranges between 700 and 1000 mg (Scientific Committee for Food, 1993; Committee on Dietary Reference Intake, 1997). Some population groups may need a higher intake.

Magnesium plays an important role as a cofactor and activator of more than 300 enzymatic reactions including glycolysis, ATP metabolism, transport of elements such as Na, K and Ca through membranes, synthesis of proteins and nucleic acids, neuromuscular excitability and muscle contraction and others. It acts as a natural antagonist of calcium. Magnesium deficiency increases the risk in human beings of developing various pathological conditions such as vasoconstrictions, hypertension, cardiac arrhythmia, atherosclerotic vascular disease, acute myocardial infarction, eclampsia in pregnant women, possibly diabetes mellitus of type II and osteoporosis (Rude, 1998; Innerarity, 2000; Saris et al., 2000; Sherer et al., 2001). The recommended magnesium daily intake for an adult is about 300 to 400 mg (Scientific Committee for Food, 1993; Committee on Dietary Reference Intake, 1997). Chlorides were found in particularly low concentrations in all the water samples with the well samples ranging from 0 to 0.88 mg/L (Table 1) while the lagoon samples ranged from 0.31 to 2.0 mg/l (Table 3). Therefore, concentration of chlorides in water from these wells and lagoon are well below the WHO guideline value for chlorides which is 250 mg/l. According to WHO (2003c), chloride concentrations in excess of 250 mg/l can give rise to detectable taste in water, but the threshold depends upon the associated cations.

Consumers can, however, become accustomed to concentrations in excess of 250 mg/L where chloride content is known to be low, a noticeable increase in chloride concentrations may indicate pollution from sewage sources. According to WHO (2003c), chlorides are widely distributed in nature as salts of sodium (NaCl), potassium (KCl) and calcium ($CaCl_2$). Chloride levels in unpolluted waters are often below 10 mg/l and sometimes below 1 mg/l. Chloride increases the electrical conductivity of water and thus increases its corrosivity. In metal pipes, chloride reacts with metal ions to form soluble salts, thus increasing levels of metals in drinking water. In lead pipes, a protective oxide layer is built up, but chloride enhances galvanic corrosion. It can also increase the rate of pitting corrosion of metal pipes. Chloride is needed for good health and may be important for kidney health, the nervous system and nutrition. There are no known health effects associated with chloride. However, the sodium often associated with chloride can be a concern to people suffering from heart disease or kidney disease (Government of Saskatchewan, 2010). Regarding the quality of water in respect of chloride, a classification uses good, marginal, poor and very poor for concentrations of 0 to 250; 250 to 500; 500 to 750 and >750 mg/L respectively.

According to Meletis (2003), chloride is an "essential" mineral for human beings. It is abundant in ionic trace mineral preparations. It is a major mineral nutrient that occurs primarily in body fluids. Chloride is a prominent negatively charged ion of the blood where it represents 70% of the body's total negative ion content. On average, an adult human body contains approximately 115 g of chloride, making up about 0.15% of total body weight. The suggested amount of chloride intake ranges from 750 to 900 mg per day based on the fact that total obligatory loss of chloride in the average person is close to 530 mg per day. Specific conductance, or conductivity, measures how well the water conducts an electrical current, a property that is proportional to the concentration of ions in solution. Conductivity is often used as a surrogate of salinity measurements and is considerably higher in saline systems than in non-saline systems (Dodds, 2002). Municipal, agricultural and industrial discharges can contribute ions to receiving waters or can contain substances that are poor conductors (organic compounds) changing the conductivity of the receiving waters. Thus, specific conductance can also be used to detect pollution sources (Stoddard et al., 1999). In this present study, the range for conductivity was 53.70 to 53.81 µS/cm in the water samples and by implication all the conductivity values fell within the 'no effect' range of 0 to 70 µS/cm for drinking water use pointed out by WRC (2003). This indicates that no adverse health effects associated with the electrical conductivity of water from these sources were expected. However, since all the conductivity values were higher than the taste threshold of 45 µS/cm, a slight salty taste was expected.

There was a positive correlation between conductivity and chlorides ($r = 0.913$, $P < 0.05$). This is consistent with the fact that the properties of conductivity are governed by the characteristics of the constituents of inorganic salts dissolved in water. Sulphate values measured from the wells and lagoon ranged from 75 to 155 and 280 to 310 mg/L respectively. The WHO guideline value is 250 mg/l. Therefore, the well samples were below the guideline value while the lagoon samples were above the guideline value. Natural deposits of magnesium sulphate, calcium sulphate or sodium sulphate cause sulphates in groundwater. In the case of the higher concentrations measured for the lagoon samples, this can be due to industrial deposition of sulphate-containing compounds over time into the lagoon. Sulphates, when added to water, tend to accumulate to progressively increasing concentration (WRC, 2003). The values measured in the lagoon samples probably would have been higher than these, if not for two reasons. Firstly, as reported by Mathuthu et al. (1997), sulphate easily precipitates and settles to the bottom sediment of a river or lagoon. These samples were obtained at a point closer to the water surface than the bottom of the lagoon and the sulphate deposited at the bottom of the lagoon was out of reach. The second reason is the fact that under anaerobic conditions, bacteria use sulphate as an oxygen source (Peirce et al., 1998).

Near anaerobic conditions were observed for the lagoon and dissolved oxygen measured in the samples ranged from 0.01 to 0.02 mg/L (Table 4). It is preferable that concentrations of sulphate in water meant for domestic use should be below 250 mg/L. Higher concentrations are undesirable because of their laxative effects. Sulphates cannot be economically removed from drinking water. According to USEPA (2004), manganese is an essential element for many living organisms including humans. It is necessary for proper functioning of some enzymes (manganese superoxide dismutase) and for the activation of others (kinases, decarboxylases and so forth). Adverse health effects can be caused by inadequate intake or over exposure. The concentration of manganese measured in all the well samples was 0 mg/l while the lagoon samples ranged from 0.01 to 0.03 mg/l. These low values however should not be of much concern since manganese deficiency in human beings appears to be rare because manganese is present in many common foods. According to WHO (2004b), a health-based guideline value of 0.4 mg/L should be adequate to protect public health. It should be noted that the presence of manganese in drinking-water will be objectionable to consumers if the manganese is deposited in water mains and causes water discoloration. Concentrations below 0.05 mg/l are usually acceptable to consumers, although this may vary with local circumstances.

Manganese is an essential metal that at excessive levels in the brain produces extra pyramidal symptoms similar to those in patients with Parkinson's disease (Stredrick et al., 2002), and decreased learning ability in school age children and increased propensity for violence in adults (Finley, 2004). According to the Department of Health and Family Services (2010), manganese levels below 300 µg/L are generally not a health concern. Infants should not drink water that is above the health advisory level of 300 µg/l. Many years of exposure to high levels of manganese can cause harm to the nervous system. A disorder similar to Parkinson's disease can result. This type of effect is most likely to occur in the elderly. Nitrate is a commonly used fertilizer. It is also a chemical formed in the decomposition of human waste. If infants under 6 months of age drink water or formula made with water that contains more than 10 mg/l of nitrates, they are susceptible to methemoglobinemia, a disease that interferes with oxygen transport in the blood. High nitrate levels also suggest that other contaminants may be present. Nitrite is an unstable form of nitrogen which may be found in small amounts along with nitrate. WHO (2004a) guidelines for nitrates and nitrite are 50 and 3 mg/l respectively. The current U.S. Environmental Protection Agency maximum contaminant level (MCL) for public drinking water supplies is 10 mg/l nitrate.

In Oworonshoki, Lagos, the values measured for nitrates and nitrite in the well samples ranged from 10.3 to 25.7 and 0 to 0.9 mg/l respectively and these were below the WHO guideline values. For the lagoon samples, the values were 52.0 to 54.6 mg/l and 2.0 to 3.0 mg/l for nitrates and nitrite respectively. Therefore, the nitrate values of the lagoon samples were higher than the WHO guideline value. A possible explanation for this is that nitrates that are not fixed in the soil or used by plants can leach into shallow groundwater or run off into surface water during rainfall events. Also, waste deposition which is rampant in the Lagos lagoon can also result in elevated nitrate levels in the water. Other sources of nitrate include animal waste from livestock operations and urban areas, and human waste from septic systems and municipal wastewater treatment plants. Exposure to nitrate per se is not of particular interest with respect to human health. However, nitrate can be reduced endogenously (within the human body) to nitrite through bacterial and other reactions; nitrite can be further reduced to N-nitroso compounds (NOCs). Infant (<6 months of age) exposure to nitrite has been linked to development of methemoglobinemia. NOCs are some of the strongest known carcinogens (National Academy of Sciences, 1981) can act systemically (Tricker and Preussmann, 1991) and have been found to induce cancer in a variety of organs in more than 40 animal species including higher primates (Bogovski and Bogovski, 1981).

While some vegetables (lettuce, spinach, celery, greens, etc.), contaminated drinking water, cigarette smoking and certain medications all contribute to daily nitrate intake in the U.S. population (Walker, 1990) drinking water can account for a substantial portion of that intake. While nitrate from food is a main source for human exposure, nitrate from drinking water also plays an important role. Elevated nitrate levels in drinking water may result in higher body burdens of nitrate in people consuming that water. For example, compared to persons who are not exposed to nitrate in drinking water, persons consuming water with 10 mg/l nitrate have about twice the total nitrate intake. At 20 mg/l nitrate, the total intake is threefold and above 20 mg/l nitrate drinking water is estimated to contribute over 80% of dietary nitrate intake (Moller et al., 1989). Nitrate in drinking water is positively associated with urine nitrate levels as well as excretion of nitrosoproline, a biomarker of endogenous nitrosation (Moler et al., 1989; Mirvish et al., 1992). Other dietary variables and lifestyle factors can impact nitrate in the body. Cigarette smoking accelerates nitrosation reactions while intake of vitamin C or E within 1 to 2 h of consumption of a nitrate source inhibits these reactions (Mirvish et al., 1995). Mammalian metabolic processes can form nitrate endogenously. It has been estimated that about 1 mg/kg body weight/day is formed in humans; that amount may be substantially increased by the presence of bacterial infection (Gangolli et al., 1994). The process of nitrosation is a complex series of chemical reactions which ultimately results in the production of NOCs.

In essence, nitrate is a precursor to nitrite which forms through bacterial reduction in the saliva, stomach, large intestine or infected urinary bladder. Nitrite then reacts with nitrosable substrates (amines, amides and amino acids) to produce NOCs. Ingested nitrate is readily absorbed from the small intestine and rapidly distributed through the body (Balish et al., 1981; Bartholomew and Hill, 1984). Blood nitrate is selectively transported and secreted in the saliva by an active transport system (Fritsch et al., 1985). An estimated 25% of ingested nitrate is secreted in the saliva (Speigelheder et al., 1976). In addition, almost 65 to 70% of orally ingested nitrate is excreted in the urine (Bartholomew and Hill, 1984). Thus, about 5% of total dietary nitrate is available for reduction to nitrite in the saliva. Iron in drinking water can be objectionable because it can give a rusty color to laundered clothes and may affect taste. Frequently found in water due to large deposits in the earth's crust, iron can also be introduced into drinking water from iron pipes in the water distribution system. In the presence of hydrogen sulfide, iron causes sediment to form that may give the water a blackish color. WHO (2004a) has a guideline value of 0.3 mg/l of iron. A range of 0 to 0.8 mg/l was measured for the well samples in Oworonshoki, while the range measured in the lagoon samples was 0.22 to 1.23 mg/l.

Definitely, concentrations of iron in some of these samples were higher than the guideline value. The Illinois Environmental Protection Agency (IEPA) has established a maximum concentration for iron in drinking water of 1.0 mg/l. According to WHO (2004c), anaerobic groundwaters may contain iron (II) at concentrations up to several milligrams per litre without discoloration or turbidity in the water when directly pumped from a well. Taste is not usually noticeable at iron concentrations below 0.3 mg/l, although turbidity and colour may develop in piped systems at levels above 0.05 to 0.1 mg/l. Laundry and sanitary ware will stain at iron concentrations above 0.3 mg/l. Iron is an essential element in human nutrition. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status, and iron bioavailability and range from about 10 to 50 mg/day. As a precaution against storage of excessive iron in the body, a provisional maximum tolerable daily intake (PMTDI) was established in 1983 of 0.8 mg/kg of body weight (FAO/WHO, 1983) which applies to iron from all sources except for iron oxides used as colouring agents, and iron supplements taken during pregnancy and lactation or for specific clinical requirements. Allocation of 10% of this PMTDI to drinking water gives a value of about 2 mg/l, which does not present a hazard to health.

The taste and appearance of drinking water will usually be affected below this level, although iron concentrations of 1 to 3 mg/l can be acceptable for people drinking anaerobic well water. According to Colter and Mahler (2006), iron is a harmless, though sometimes annoying element present in public and private water supplies. High concentrations of dissolved iron can result in poor tasting, unattractive water that stains both plumbing fixtures and clothing. When iron rich waters mix with tea, coffee, or alcoholic beverages, they assume a black, inky appearance with an unpleasant taste. Vegetables cooked in iron-rich waters will also become dark and unappetizing. Concentrations of iron as low as 0.3 mg/l will deposit reddish-brown stains on fixtures, utensils and clothing, all of which can be difficult to remove. Ferric iron deposits within corroded pipes can break free and generate rusty tap water. Iron bacteria gives water a disagreeable taste and causes yellow stains on laundry. This bacterium can also clog water systems, plug filters, or envelop pump screens, resulting in expensive repairs. Some heavy metals such as Cu, Ni and Zn are essential to plants and animals in very low concentrations by serving as components of enzymes, structural proteins, pigments and also helping to maintain the ionic balance of cells (Kosolapov et al., 2004). However, metals tend to bioaccumulate in tissues and prolonged exposure or exposure at higher concentrations can lead to illness.

Elevated concentrations of trace metals can have negative consequences for human beings. The WHO guideline values for Zn, Cu and Pb are 3.0, 2.0 and 0.01 mg/l respectively. The concentrations of Zn, Cu and Pb measured in all the well samples in this research were 0 mg/l. Concentrations of Pb in the lagoon samples were also found to be 0 mg/l. Also, for the lagoon samples, the measured ranges of Zn and Cu were 1.58 to 2.0 and 0.40 to 0.70 mg/l respectively. The reason for the higher values of metals measured in the lagoon samples is that metals tend to be strongly associated with sediments in rivers, lakes, and reservoirs and their release to the surrounding water is largely a function of pH, oxidation-reduction state and organic matter content of the water (UNEP, 2006). Pb is a particularly dangerous metal which has no biological role (Sobolev and Begonia, 2008). Its excessive accumulation in living organisms is always detrimental. Furthermore, Pb exposure can damage the brain, kidney, nervous system, and reproductive system thereby causing seizures, mental retardation and behavioral disorders in human beings. It is a greater hazard to young children, infants and fetuses than to adults. High concentrations of lead in groundwater are rare. However, lead is still a significant health hazard in drinking water.

Microbiological characteristics of the water samples

Microbial contamination of surface and ground waters by pathogenic organisms is probably the most important water quality issue in the developing world, where access to safe, clean water for drinking, bathing and irrigation is often unavailable. The World Health Organization identifies the greatest human health risk of microbial contamination as being through the consumption of water contaminated by human or animal faeces (WHO, 2003d). As pointed out by saline, Stoddard et al. (1999) when testing for bacteria in water, two results must be included namely total coliform and *E. coli*. The first, total coliform is a test for coliform bacteria which are distributed widely in the environment. They are on animals, plants, and in the soil, but are in large numbers in the faeces of warm-blooded animals. When a reading is positive for total coliform bacteria, it means that the water supply has been affected by the environment, and disease-causing organism may or may not be present. However, it is a cause for concern and corrective action such as well chlorination should be taken. *E. coli* is a species of bacteria found in the intestinal tract of warm-blooded animals. When a sample is positive for *E. coli*, it means there is feacal contamination in the well water. This could be human or animal, but its implications are more serious than total coliform. The well's construction should be reviewed and the well chlorinated, with a follow-up test done 10 days after chlorination. A negative reading means none of the above bacteria were found in the sample.

From Tables 2 and 4, *E. coli* was found in 2 well samples while it was absent in all the remaining samples. *E. coli* was also not found in any lagoon sample. In contrast, faecal streptococci were present in all the water samples with the exception of 1 well sample and the counts ranged from 4 to > 50 per 100ml. As regards total coliform, the counts ranged from 1 to 30 per 100ml, all samples considered; while the reading was nil in 5 well samples. Maggots were found in 7 well samples and 2 lagoon samples while entero bacteria were found in 3 well samples. This situation should be given closer scrutiny. UNEP (2006) noted that although water from natural sources almost always contains living organisms that are integral components of the biogeochemical cycles in aquatic ecosystems, however, some of these, particularly bacteria, protists, parasitic worms, fungi, and viruses can be harmful to humans if present in water used for drinking. While not a health threat in and of itself, the presence of coliform bacteria (feacal coliform and *E. coli*) in water indicates the presence of other potentially harmful bacteria (USEPA, 2002). Both feacal coliform and *E. coli* “only come from human and animal feacal waste” (USEPA, 2002) and the World Health Organization (WHO) drinking water quality guidelines specify that total coliforms “must not be detectable in any 100-ml sample” (WHO, 1998).

According to the USDA (1992), the level of oxygen depletion depends primarily on the amount of waste added, the size, velocity and turbulence of the stream, the initial dissolved oxygen (DO) level in the water and in the stream and the temperature of the water. Oxygen that is dissolved in the water column is one of the most important components of aquatic systems because oxygen is required for the metabolism of aerobic organisms and it influences inorganic chemical reactions. Oxygen is often used as an indicator of water quality such that high concentrations of oxygen usually indicate good water quality. This research found a DO range of 0.01 to 0.02 mg/l in water samples from the Lagos lagoon. This low value is consistent with the fact that a lot of wastes are continually deposited into this inland lagoon. From an environmental standpoint, this definitely has put aquatic life in the lagoon at risk. Another reason for the low DO values measured in samples from the Lagos lagoon is salinity. Salinity influences dissolved oxygen concentrations such that oxygen is low in highly saline waters and vice versa. Furthermore, the amount of any gas including oxygen dissolved in water is inversely proportional to the temperature of the water; as temperature increases, the amount of DO decreases (UNEP, 2006). Biochemical oxygen demand (BOD) is a common measure of water quality that reflects the degree of organic matter pollution of a water body.

As regards BOD_5, this study found a range of 2.0 to 4.0 mg/l in the lagoon samples. BOD is a measure of the amount of oxygen removed from aquatic environments by aerobic micro-organisms for their metabolic requirements during the breakdown of organic matter and systems with high BOD tend to have low dissolved oxygen concentrations. This is consistent with the findings in this research. Nigeria’s Federal Environmental Protection Agency (2006) prescribed maximum concentrations of DO and BOD of 2.0 and 30.0 mg/L respectively for surface waters. Therefore, the values measured for the lagoon samples still fall within these limits.

Conclusion

The quality of water found in these city wells are poorer than those found in wells from three rural communities reported by Adelekan (2010). This finding is consistent with the knowledge that urban environments are exposed to more pollution sources and the pollution loads are definitely higher than those received by rural environments. According to WHO (2010), against the evidence gathered from 12 countries on environmental determinants and the related national management systems and taking into consideration the political commitments made in the Libreville Declaration through its 11 priority actions, it is recommended that African governments should continue to maintain their focus on the provision of safe drinking water and sanitation, and the management of air pollution, chemicals, waste, disease vectors, soil degradation and pollution, and the risks due to climate variability and change, in the context of national strategies for primary prevention and as integral components of National Plans of Joint Action. This study concludes that wells and the lagoon in Oworonshoki, Lagos are efficacious sources, the potential of which should be further developed for providing domestic water for the population of this city. It recommends that in order to reduce any health risk to consumers, some form of local treatment particularly boiling of the water should be done at home.

A study by Swistock et al. (2009) on drinking water quality in rural Pennsylvannia and the effect of management practices suggested a combination of educational programs for homeowners and new regulations to overcome the largest barriers to safe drinking water. Regulations are warranted to increase mandatory testing of private water wells at the completion of new well construction and before finalization of any real estate transaction. For existing well owners, this study demonstrated the effect education can have to increase the frequency of water testing, the use of certified labs and awareness of water quality problems. Presently, the impact of Nigeria’s Federal Environmental Protection Agency (FEPA’s) regulations in monitoring domestic wells in Nigeria is weak due to the remoteness of Federal presence. This study recommends that various states in Nigeria create agencies which can be more effective in monitoring private water wells from a public health stand point and compel adherence to regulations on the part of the owners. Furthermore, using the United States as a point of reference, private well owners are responsible for the quality of their drinking water. The U.S. Environmental Protection Agency (EPA) does not regulate private wells. Homeowners with private wells are generally not required to test their drinking water, although local Boards of Health or mortgage lenders may require well water testing.

While there is also no state requirement to have your well water tested, the Massachusetts Department of Environmental Protection (MassDEP) recommends that all homeowners with private wells do so and use a state certified testing laboratory (USEPA, 2007). This is an example that can also be followed at the state level in Nigeria’s 36 states and the Federal Capital Territory, Abuja.

REFERENCES

Adedeji AO (2001). Quality of drinking water in Lagos state. Discovery innovation, 7: 56.

Adegoke GA, Ashaye OA, Shridar MKC (1993). Microbiological and Physico-chemical Characteristics of Water Used by Some Brewery, Bakery and Soft Drinks Plants in Oyo state, Nigeria. J. Agric. Sci. Technol., 3(1): 92-95.

Adelekan BA (2010). Water quality of domestic wells in typical African communities: Case studies from Nigeria. Int. J. Water Resour. Environ. Eng., 2(6): 137-147. September. Available online at www.academicjournals.org/ijwree.

Adelekan BA, Abegunde KD (2011). Heavy Metals Contamination of Soils and Groundwater in Auto-mechanic Villages: Case Studies from Ibadan, Nigeria. Int. J. Phys. Sci., 6(5): 1045-1058.

Adelekan BA, Alawode AO (2011). Contributions of municipal refuse dumps to heavy metals concentrations in soil profile and groundwater in Ibadan, Nigeria. J. Appl. Biosci., 40: 2727-2737.

Alexander P (2008). Evaluation of Groundwater quality in Mubi town, Adamawa state, Nigeria. Afr. J. Biotechnol., 7(11): 1712-1715.

APHA, AWWA, WPCF (1998). Standard methods for the examination of water and wastewater, 20th edn. Washington, DC.

Balish E, Witterm JP, Gatley SJ (1981). Distribution and metabolism of nitrate and nitrite in rats. Banbury Report, 7: 305-309.

Bartholomew BA, Hill MJ (1984). The pharmacology of dietary nitrate and the origin of urinary nitrate. Food Chem Toxicol., 22: 789-795.

Bogovski P, Bogovski S (1981). Animal species in which N-nitroso compounds induce cancer. Int J. Cancer, 27: 471-474.

Bruvold WH, Daniels JI (1990). Standards for Mineral Content in Drinking Water. J. Am. Water Works assoc., 82: 59-65.

Collins CH, Lyne PM (1984). Microbiological Methods. 5th Ed. Butterworth and Co. Publ. Ltd., London. pp. 331-345.

Colter A, Mahler RL (2006). Iron in Drinking Water. A Pacific Northwest Extension Publication, PNW 589. University of Idaho, USA.

Committee on Dietary Reference Intake (1997). Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride. National Academy Press, Washington DC.

Department of Health and Family Services, DHFS (2010). Human Health

Hazards. Manganese in Drinking Water. Wisconsin Department of Health and Family Services, State of Wisconsin, USA. Available online at http://dhfs.wisconsin.gov/eh.

Dodds WK (2002). Freshwater Ecology. Concepts and Environmental Applications. Academic Press, USA.

FAO/WHO (1983). Toxicological evaluation of certain food additives and food contaminants. Joint FAO/WHO Expert Committee on Food Additives. Cambridge, Cambridge University Press. WHO Food Additives Series. p. 18.

Federal Environmental Protection Agency, FEPA (2006). Guidelines for Contaminant Content of Natural Waters. Federal Ministry of Environment, Abuja, Nigeria.

Finley JW (2004). Does Environmental Exposure to Manganese Pose a Health Risk to Healthy Adults? Nutr. Rev. 62: 148-153.

Fritsch P, de-Saint-Blanquet G, Klein D (1985). Excretion of nitrate and nitrites in saliva and bile in the dog. Food Chem. Toxicol., 23: 655-659.

Gangolli SD, van den Brandt PA, Feron VJ, Janzowsky C, Koeman JH, Speijers GJ, Spiegelhader B, Walker R, Wisnok JS (1994). Nitrate Nitrite, and N-nitroso Compounds. Eur. J Pharmacol., 292(1): 1-38.

Government of Saskatchewan (2010) Chloride for Private Water and Health Regulated Public Water Supplies. Fact Sheet. Available online at www.SaskH2O.ca.

Government of Saskatchewan (2008) pH for Private Water and Health Regulated Public Water Supplies. Fact Sheet. Available online at www.SaskH2O.ca.

Innerarity S (2000). Hypomagnesemia in Acute and Chronic Illness. Crit. Care Nurs. Q. 23: 1-19.

Kosolapov DB, Kuschk P, Vainshtein MB, Vatsourina AV, Wiebner A, Kasterner M, Miler RA (2004). Microbial Processes of Heavy Metal Removal from Carbon Deficient effluents in constructed wetlands. Eng. Life. Sci., 4(5): 403-411.

Kozisek F (2006). Health effects of long term consumption of water low in calcium, magnesium or TDS: studies from Eastern Europe. Paper presented at the International Symposium on Health Aspects of Calcium and Magnesium in Drinking Water, Baltimore, Maryland, USA, 24-26 April.

Kozisek F (2003). Health Significance of Drinking Water Calcium and Magnesium. National Institute of Public Health, February.

Mathuthu AS, Mwanga K, Simoro A (1997). Impact assessment of industrial and sewage effluents on the water quality of the receiving Marimba River in Harare. In Lake Chivero: A Polluted Lake. (Moyo NAG, ed.), pp. 43-52. University of Zimbabwe Publications, Harare, Zimbabwe.

Meletis CD (2003). Chloride: The Forgotten Essential Mineral. Elete Water. Mineral Resources International. 1990 West 3300 South Ogden, UT84401 USA. Available online at www.eletewater.com.

Mirvish SS, Grandjean AC, Reimers KJ, Connelly BJ, Chen SC, Gallagher J, Rosinsky S, Nie G, Tuatoo H, Payne S, Hinman C, Ruby EI (1995). Dosing time with ascorbic acid and nitrate, gum and tobacco chewing, fasting and other factors affecting N-Nitrosoproline formation in healthy subjects taking proline with a standard meal. Cancer Epidemiol. Biomarkers Prev., 4: 775-782.

Mirvish SS, Grandjean AC, Moller H, Fike S, Maynard T, Jones L, Rosinsky S, Nie G (1992). Nitrosoproline excretion by rural Nebraskans drinking water of varied nitrate content. Cancer Epidemiol. Biomarkers Prev., 1(6): 455-461.

Moller H, Landt J, Jensen P, Pedersen E, Autrup H, Moller-Jensen O (1989). Nitrate exposure from drinking water and diet in a Danish rural population. Int. J. Epidemiol., 18: 206-212.

Monarca S, Donato F (2005). Drinking water hardness and cardiovascular diseases: A review of the epidemiological studies 1979-2004. University of Perugia and University of Brescia, Italy.

National Academy of Sciences (1981). The health effects of nitrate, nitrite and N-nitroso compounds. National Research Council Academy of Life Sciences. Washington DC. National Academy Press.

Nduka JK, Orisakwe OE (2009). Effect of effluents from Warri Refinery Petrochemical Company WRPC on Water and Soil Qualities of ‘Contiguous Host’ and ‘Impacted on Communities’ of Delta State, Nigeria. The Open Environ. Pollut. Toxicol. J., 1:11-17.

Ololade IA, Adewunmi A, Ologundudu A, Adeleye A (2009). Effects of household wastes on surface and underground waters Int. J. Phys. Sci., 4(1): 022-029. Available online at www.academicjournals.org/IJPS.

Oluyemi EA, Adekunle AS, Adenuga AA, Makinde WO (2010). Physico-chemical properties and heavy metal content of water sources in Ife North Local Government Area of Osun state, Nigeria. African J. Environ. Sci. Technol., 4(10): 691-697. Available online at www.academicjournals.org/AJES.

Peirce J, Weiner R F, Vesilind P A (1998). Environmental Pollution and Control, 4th edn. Butterworth-Heineman, Boston, p. 400

Pitter P (1999). Hydrochemistry. (in Czech). 3rd ed. Vydavatelství VŠCHT, Praha. Rosenberg T (2010). The Burden of Thirst. National Geographic. The Water Issue. Official Journal of the Nation. Geograp. Soc., 217(4): 102.

Rude RK (1998). Magnesium deficiency: A cause of heterogenous disease in humans. J. Bone Miner. Res., 13: 749-758.

Sangodoyin AY (1993). Consideration on contamination of groundwater by waste disposal systems in Nigeria. Environ. Technol., 14: 957-964.

Saris NEL, Mervaala E, Karppanen H, Khawaja JA, Lewenstam A (2000) Magnesium. An update on physiological, clinical and analytical aspects. Clin. Chim. Acta, 294: 1-26.

Scientific Committee for Food (1993). Nutrients and energy intake for the European Community. Reports of the Scientific Committee for Food – 31^s series. Commission of the EC - DG Industry, Luxembourg

Sherer Y, Bitzur R, Cohen H, Shaish, A, Varon D, Shoenfeld Y, Harats D(2001). Mechanisms of action of the antiatherogenic effect of magnesium: Lessons from a mouse model. Magnes. Res., 14: 173-179.

Sobolev D, Begonia MFT (2008). Effects of Heavy Metal Contamination Upon Soil Microbes: Lead induced Changes in General and Denitrifying Microbial Communities as Evidenced by Molecular Markers. Int. J.Environ Res. Public Health, 5(5): 451.

Speigelhader R, Eisenbrand G, and Preussmann R. (1976). Influence of dietary nitrate on nitrite content of human saliva: Possible relevance to *in vivo* formation of N-nitroso compounds. Food Cosmet Toxicol., 14: 545-548.

Stark JR, Hanson PE, Goldstein RM, Fallon JD, Fong AL, Lee KE, Kroening SE, Andrews WJ (2000). 'Water Quality in the Upper Mississippi River Basin, Minnesota, Wisconsin, South Dakota, Iowa, and North Dakota, 1995-98.

United States Geological Survey, Circular 1211. Available online at http://pubs.usgs.gov/circ/circ1211/pdf/circular1211.pdf

Stoddard JL, Jeffries DS, Lukewille A, Clair TA, Dillon PJ, Driscoll CT, Forsius M, Johannessen M, Kahl JS, Kellogg JH, Kemp A, Mannio J(1999). Significance of inorganic chemicals in drinking Water. Salina County Water Facts Sheet. Salina-Saline County Health Department, 125, West Elms Street, Salina, Kansas, USA

Stredrick DL, Stokes AH, Worst TJ, Freeman WM, Johnson EA, Lash LH, Vahter M, Berglund M, Akesson A, Liden C (2002). Metals and Women's Health. Environ. Res., 88: 145-155.

Swistock BR, Stephanie MS, Clemens MS, Sharpe WE (2009). Drinking water quality in rural Pennsylvania and the effect of management practices. Pennsylvania State University. Center for Rural Pennsylvania, 200 North Third St., Suite 600, Harrisburg, PA 17101. Available online at www.ruralpa.org

Tricker AR, Preussmann R (1991). Carcinogenic N-nitrosamines in the diet: Occurrence, mechanisms and carcinogenic potential. Mutat Res., 259: 277-289.

United Nations Environment Programme, UNEP (2006). Water Quality for Ecosystem and Human Health. Prepared and published by United Nations Environment Programme Global Environment Monitoring System(GEMS)/Water Programme. ISBN 92-95039-10-6. Available online at www.gemswater.org

United States Department of Agriculture, USDA (1992). Agricultural waste management building design handbook. Soil Conservation Service, Washington, DC.

United States Environmental Protection Agency, USEPA (2007). pH – Acidity of private drinking water wells. Healthy Drinking Waters for Massachusetts. United States Environmental Protection Agency New England and University of Massachusetts Extension Services. Available online at www.capecoextension.org

United States Environmental Protection Agency, USEPA (2004). Drinking water health advisory for manganese. US Environmental Protection Agency Office of Water (4304T) Health and Ecological Criteria Division Washington, DC 20460. Available online at http://www.epa.gov/safewater/ EPA-822-R-04-003 January, Accessed December 8, 2010.

United States Environmental Protection Agency, USEPA (2002). List of Contaminants & their MCLs: Potential Health Effects from Ingestion of Water, Available at http://www.epa.gov/safewater/mcl.html

Walker R (1990). Nitrates, nitrites and N-nitroso compounds: A review of the occurrence in food and diet and the toxicological implications. Food Addit Contam, 7: 717-768.

Water Resources Commission, WRC (2003). Ghana Raw Water Criteria and Guidelines, Vol. 1. Domestic Water. CSIR-Water Research Institute, Accra, Ghana.

World Health Organization, WHO (2010). Environmental determinants and management systems for human health and ecosystem integrity in Africa. First Synthesis Report On the Situation Analysis and Needs Assessment for Implementation of the Libreville Declaration on Health and Environment in Africa. October, World Health Organization and United Nations Environment Program.

World Health Organization, WHO (2004a). Guidelines for drinking water quality, Third Edition. Volume 1: Recommendations. World Health Organization, Geneva.

World Health Organization, WHO (2004b). Manganese in drinking water. Background document for development of WHO Guidelines for Drinking water Quality. World Health Organization, Geneva, Switzerland.

World Health Organization, WHO (2004c). Iron in Drinking Water. Background document for development of WHO Guidelines for Drinking Water Quality. World Health Organization, Geneva, Switzerland.

World Health Organization, WHO (2003a). pH in Drinking Water. Background document for development of WHO Guidelines for drinking water quality. World Health Organization, 20 Avenue Appia, 1211 Geneva 27, Switzerland.

World Health Organization, WHO (2003b). Hardness in drinking water. Background document for development of WHO Guidelines for drinking water quality. World Health Organization, 20 Avenue Appia, 1211 Geneva 27, Switzerland

World Health Organization, WHO (2003c). Chloride in drinking water. Background document for development WHO Guidelines for Drinking water quality. World Health Organization, 20 Avenue Appia, 1211 Geneva 27, Switzerland.

World Health Organization, WHO (2003d). Emerging issues in water and infectious disease. World Health Organization, Geneva, Switzerland. http://www.who.int/water_sanitation_health/emerging/emerging.pdf

World Health Organization, WHO (1998). Guidelines for drinking water quality,

Available at

http://www.who.int/water_sanitation_health/GDWQ/Summary_tables/Tab1.htm

World Health Organization Working Group (1986). Health impact of acidic deposition. Sci. total environ., 52: 157-187.