Comparative analysis of the physico-chemical parameters and microbiological quality of well, borehole and sachet water in Kwale, Delta State, Nigeria

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This study assessed the physicochemical and microbial quality of different types of water available for consumption and utilisation in Kwale, Delta State. Three water samples viz; well water, borehole water and sachet water were collected aseptically into a container and transported to the laboratory for physicochemical and microbiological investigations. Physicochemical analysis was carried out for dissolve oxygen (DO), biochemical oxygen demand (BOD), pH, total alkalinity, water hardness salinity and conductivity. Microbiological analysis was carried out for the presence of total coliform bacterial. The results of physicochemical parameters analyzed for the different water samples showed that Well water ranged between 0.5–0.9mg/L, 0.50–0.65mg/L, 6.00-6.99, 9.90-10.20ppm, 0.04-0.10mg/L, 0.10-0.70mg/L and 10.0-10.40µS, borehole water raged between 0.3-0.9mg/L, 0.40-0.55mg/L, 8.00-9.00, 11.0-15.0, 0.14-0.18ppm, 0.10-0.30mg/L and 9.10-10.20µS while sachet water ranged between 1.19–1.27mg/L, 0.03-0.40mg/L, 8.74-8.90, 11.0-13.5, 0.10-0.10ppm, 0.10-0.30mg/L and 10.30-10.70µS for D.O., BOD, pH, alkalinity, water hardness, salinity and conductivity respectively. Two species of gram-negative bacteria which include Escherichia coli and Enterobacter aeruogenes were isolated and identified in the water samples. The prevalence of the bacteria in the different water samples showed that E. aeruogenes was most occurring in the water samples. E. aeruogenes was present in well, tap and sachet water samples but was most occurring in sachet water samples and tap water sample. Well water sample showed the presence of E. coli and E. aerogenes respectively.

Key words: Borehole, sachet water, microbial quality, physico-chemical parameters.

INTRODUCTION

Water is life and at such, drinking safe water is a very essential to humans' requirement as well as for other life forms, though it does not provide calories or organic nutrients (Betepe, 2015). In recent times, there has been provision and access to safe drinking water across different parts of the world. However, approximately one billion globally has little or no access to safe drinking water with poor sanitation recorded for about 2.5 billion people (WHO and UNICEF, 2012).

Aside the importance of water as a basic essential need for human existence, it is required for the day to day activities which are efficiently and effectively used by man as well as animals, plants and microorganisms (Oladipo et al., 2009).

Ideally, water available for drinking and human consumption in all forms is expected to be pure and free from microorganisms capable of causing diseases as well as harmful chemicals. It is expected to be tasteless, odourless and free from suspended materials (Maher et al., 2007). However, water available for consumption, especially in remote areas are associated with some level of impurities with substances such as metals including copper, iron, calcium, lead and some harmful bacteria (Maton et al., 2003).

The alarming rate of disease proliferation

has also been tied to the consumption of water resulting to the occurrence of diseases like typhoid fever, cholera, bacillary dysentery and diarrhoea (Mead et al., 2009). Waterborne diseases remain the major problem causing several health challenges among people in developing nations especially on the issue of safe drinking water quality (Mead et al., 2009). About two thirds of water available for drinking globally is obtained from different surface water sources including lakes, Rivers and open wells. This is an indication that this water sources can easily be polluted and contaminated by sewage discharges or fecal loading by domestic or wild animals (WHO, 2003).

Global estimate of 80% illnesses have been linked to consumption and utilisation of unsafe and microbiologically poor water quality (Mpenyana-Monyatsi et al., 2012). In developing countries, approximately 1.8 million deaths per year are attributed to unsafe water, sanitation and hygiene, mainly through infectious diarrhea (WHO, 2002).

The sale and consumption of water both from well, boreholes and packaged water continues to grow rapidly. Drinking water, regardless of its source, is usually subjected to one or more of a variety of treatment processes intended to improve its safety and aesthetic quality. In cities and towns today in Nigeria, water attracts rates and fees (Edema et al., 2011). With insufficient government supply of water, private sector participation has evolved and the idea of packaged drinking water popularly referred to as "pure water" is now a common phenomenon in the country. Drinking water is now commercially packed in easy-to-open 50-60ml polyethylene sacs are referred to as "sachet or pure water". This packaged water is cheap and convenient and have increasingly become popular (Edema et al., 2011). Due to the popularity of the packaged drinking water, so is the abuse of its production leading to a situation whereby the pure water is everything but pure.

Several studies on the physicochemical and microbial quality of well, bottled and sachet water have reported violations of international quality standards (Oyedeji et al., 2009). The determination of the microbiological quality of water is essential in testing for the overall quality of water, which often involves the enumeration of bacteria of faecal origin (Luksamijarulkul, 2004). Various factors predispose water to contamination. These include contaminated sources of water ranging from rain water, shallow well water, and rusty unwashed tanker to other contaminated sources (Dibua et al., 2007). Some contaminants enter packaged water through seepage of sewage and rainfall runoffs into well water and exposed boreholes (Adegoke et al., 2012) introduction of contaminants during the process of production due to contaminated materials or external introduction of contamination from vending machines (Omalu et al., 2010). Even if no sources of anthropogenic contamination exist, there is the potential for natural levels of minerals and other chemicals to be harmful to human health (Anawara et al., 2002). Chemical parameters of drinking water have the tendency to pose more of a chronic health risk, even though some components like nitrates and nitrites may have an acute impact. Thus, water used for sachet water production must be adequately treated to ensure acceptable levels of these minerals and other chemicals remain in the water. It is in the light of this that this study was conducted to assess the physicochemical and microbiological quality of well and sachet water sold in Kwale community in Delta State, Nigeria.

MATERIALS AND METHODS

Description of the study area

Water samples (well, borehole and sachet water) used for the study were collected from different locations in Kwale, Ndokwa West Local Government Area of Delta State. The area is located between Latitude 50 15N, $50^0$5N and Longitude 60-5E, 6045E (Figure 1) (Odemerho and Ejemeyovwi, 2007).

Collection of water samples

Three (3) different source samples of water (well, borehole and sachet water) were collected and used for the study. Three samples of hand dug well water samples were collected from two different locations; three samples of borehole water were collected from two different locations. Both well water and borehole water samples were

Figure 1. Map of Ndokwa West Showing Kwale the study area.
Source: Otuya (2006).

collected in residential areas within the study area using clean and sterilized plastic containers around Owessie and Christ Anglican Church in Kwale. Three samples of sachet water used were purchased at Donmac water factory, Kwale, Delta State.

The water samples collected were transported to the Pharmaceutical Chemistry Laboratory of the Department of Pharmacy, Faculty of Pharmacy, Delta State University, Abraka. Microbiological investigations and assessment were carried out.

Determination of physicochemical parameters

Dissolved oxygen

Dissolved oxygen of the water was estimated using the modified wrinkler's method. The water was collected using a narrow neck 250ml reagent bottle, firmly stopped under water without trapping any air bubble. On collection, each sample was immediately fixed in the field by adding 2.0ml of wrinkle's solution A and B each with a pipette. The stopper was then replaced and mixed. A brown precipitate was formed. This was dissolved in the laboratory by adding 2ml of concentrated tetra-oxosulphate VI acid (H_2SO_4) which turns the brown precipitate into a golden straw coloured solution.

100ml of the resultant straw coloured solution was titrated against 0.8N sodium thiosulphate ($Na_2S_2O_3$) solution until a pale straw colour was obtained. One to two drops of starch indicator was added to flask and titration continued until

the complete disappearance of the blue-black colouration which indicated the endpoint. The dissolved oxygen was then calculated using this formula:

$$DO = \frac{Va \times Ma \times 8 \times 100}{Vs \times 100}$$

Va = volume of thiosulphate
Ma = Molarity of thiosulphate
Vs = volume of water sample

Biochemical Oxygen Demand (BOD)
Water sample for BOD determination was collected in 250ml bottle. The water samples were fixed with 2ml of Winkler's A and B reagent by the same method used in the measurement of dissolved oxygen while the other non-fixed water samples were taken to the laboratory and incubated in dark cupboard for 5 days. The amount of dissolved oxygen in the fixed and non-fixed incubated samples was determined by winkler titrimetric method. The difference between the amounts of oxygen in the fixed and non-fixed incubated samples given the BOD value the result is expressed in MgO^2/L/5days.

Hydrogen Ion Concentration (pH)
The pH was measured with a pH meter. The electrode was first standardized and calibrated using three set of buffer solution at pH of 4.00, 6.8 and 9.2. The electrode was then rinsed thoroughly and immersed in distilled water. The pH electrode was gently placed in the beaker and rotated gently to stir the content and the meter was switched on to read. When a steady state was reached, the reading was taken as the pH value.

Total alkalinity
50ml of the water sample was measured into 250ml conical flask and alkalinity was determined titrimetrically. Two drops of methyl orange indicator was added and the sample was titrated against 0.02N H_2SO_4 till the colour turned pink orange which indicates the end point. The alkalinity value was calculated using the formula

$$\text{Alkalinity} = \frac{A \times N \times 50,000}{\text{Volume of sample}}$$

Where A = volume of acid used (ml)
N = normality of the acid used
VS = volume of sample
50,000 = constant

This is also known as total alkalinity determined using methyl orange indicator method.

Hardness of water
25mL of the samples was placed in different clean 250mL conical flask. To this were added 3mL of ammonium chloride in concentrated ammonia buffer (NH_4CL/conc.NH_3) and 2 drops of Eriochrome Black T indicator. This was titrated against 0.01M EDTA solution until there was a color change from violet to blue.

Salinity of water
The chemical volumetric analysis method was used. Titration was carried out in a 150-mL Erlenmeyer flask with silver nitrate ($AgNO_3$) solution to precipitate out the chlorides in the sample. The silver nitrate was added until the faint reddish or orange tinge remains after stirring for 45 s. Observable flocs of silver chloride was observed at the end point. Thus, the salinity (S) was calculated (using the equation S ppt = 1.80655 Cl ppt; the chlorinity (Cl) of the artificial water should be about 19.05 ppt

Conductivity
The conductivity of the water sample was determined using the Jenway conductivity meter (4510 model). The conductivity meter was standardized using potassium chloride solution. The water sample was poured into a 100ml beaker and the probe was dipped into the beaker containing the sample until a stable reading was obtained and recorded at 14(S/m).

Microbiological analysis
Serial dilution
1ml of both the water sample and control was withdrawn aseptically with sterile 1ml syringe and used in a fivefold serial dilution respectively in accordance with the report of Cowan and Steel (2004).

Total Coliform Count (TCC)
This was done using the third and fourth tube in the fifth fold serial dilution. 1ml each was

dispersed into two sterile Petri dishes respectively. Using the pour plate technique about 15-20ml of sterilized nutrient Agar was poured on the Petri dish, swirled and allowed to set. The plates were then incubated in an inverted position at 37ºC for 24h in accordance with Cheesbrough (2000). Also using the pour plate technique, sterilized Macconkey Agar was poured on the Petri dish, swirled and allowed to set. The plates were incubated at 37ºC for 24h in accordance to Cheesbrough (2000).

Cultural and morphological analysis
The isolated colonies stored on agar slants were streaked into plate of different medium for morphological and cultural study of the organism. The cultural characteristic used for evaluation includes colony size, shape, colour, elevation surface texture etc. in accordance with Cowan and Steel (2004).

Isolation of organism
Identification of pure colonies of the isolates was carried out in accordance with the procedures reported in Cowan and Steel (2004). The following tests were carried out;

Catalase test
This test is used to differentiate *Staphylococcus* from *Streptococcus*. It is also useful in differentiating mycobacterium species. Most Gram-negative organisms also show catalase positive.

Principle: The enzyme catalase act as a catalyst in the breakdown of hydrogen peroxide to oxygen and water. When an organism containing catalase come in contact with hydrogen peroxide, bubbles of oxygen are given off.

$2H_2O_2$ - $2H_2O_2 + O_2$

Reagents: Hydrogen peroxide 3%

Method: three drops of $2H_2O_2$ solution was placed in test tubes and a sterile Pasteur pipette was used to add 2-3 drops of an overnight broth of the organism. Productions of gas bubbles indicate the presence of catalyse in a positive result.

Motility test
This test is performed to distinguish motile organisms from non-motile organisms. Motility is detected by microscopic examination - wet preparation (harging drop preparation). The harging drop is a microscopic technique used to determine the motility of bacteria when suspended in a fluid. True motility is when bacteria actively move from one position to another in a haphazard manner.

Method: A ring of vaseline (2 m) in diameter was made on a slide. A loopful of the broth culture (overnight) of the organism is placed in the center of a clean 22mm square cover slip. The ring of vaseline is pressed over the cover slip without touching the slide. The slide was inverted so that the cover slip is upper and then examined under a microscope using a low power objective lens (16mm) to focus on the edge of the drop, to observe motility with high power 40mm objective lens was used. Motility was observed by swimming movement for the bacteria.

Indole test
This test is used as an aid in differentiating gram-negative bacilli.

Principle: Some bacteria are able to break down the amino acid tryptophan present in peptone water to release indole.

Reagent: Indole is detected with Kovac's reagent. Kovac's reagent is composed of

Para-dimethylaminobenzeldelhyde - - - 5g
Iso – amyl alcohol- - - - - - 75ml
Hydrochloric acid- - - - 25ml

The aldehyde is dissolved in amyl alcohol by slow heating at 50ºC in a water bath. When cooled, concentrated HCl is added.

Method: The organism was grown in peptone water overnight. A few drops of Kovac's reagent were added to the broth culture and a red/pinkish

ring at the interface of the peptone water broth was observed, indicating a positive result. A yellow/orange colour indicates a negative result.

H_2S (Hydrogen Sulphide Test)
This test is used to assist the identification of enterobacteria. It is also occasionally used to differentiate some other bacteria such as bacteriodes and *Brucella* species.

Principle: Hydrogen sulphide is produced when a sulphur containing amino acid is decomposed by the enzymatic action of the bacterium.

***Materials*:** Lead acetate, paper strips.

Test: The organism was inoculated in peptone water and a lead acetate paper strip (white) was inserted in the neck of the tube above the medium and stoppered well. The broth culture and strip were incubated at 37ºC for 24 to 48 h. At the end of the incubation period, a blackening of the lead acetate paper showed the presence of H_2S production.

Methyl Red Test (MR)
This test is used to differentiate enterobacteria. It detects the production of sufficient acid during the fermentation of glucose.

Principle: In the fermentation of glucose, different organisms produce different end products at different pH levels. Some bacteria with longer incubation times are liable to maintain the pH level at below 4.5. This is shown by a change in colour of methyl red indicator which is added at the end of the incubation period.

Test: MR-VP broth medium is incubated with an overnight culture of the bacteria and incubated at 35ºC for two days. Five drops of methyl red indicator is added and a red colour indicates a positive (acid) reaction.

Citrate test
The citrate utilisation test is one of the important tests used in the identification of enterobacteria.

Principle: The test is based on the ability of an organism to utilize citrate as its only source of carbon and ammonia as its only source of nitrogen. The citrate is metabolized to acetone and CO_2. Medium used is Simmon's citrate agar.

Test: 2.4g of Simmon's citrate agar was weighed and dissolved in 100ml of distilled water. This was sterilized by autoclaving at 121ºC for 15 min on cooling; the agar was poured into plates and allowed to set. The overnight broth of the organism is used to inoculate the citrate agar and incubated for 24 h at 37ºC. A growth of blue colour indicates a positive result and citrate has been utilized. If the citrate agar does not change in colour, it indicates a negative result.

Urease test
This is also a very important test for differentiating enterobacteria.

Principle: The enzyme urease is possessed by some bacteria. The urease is able to decompose urea by hydrolysis to give ammonia and carbon dioxide. This reaction turns the medium alkaline which is shown by a change in colour of the indicator to red-pink.

Test: 3.87g of urea broth is dissolved in 100ml distilled water I sterilized glassware. The medium is sterilized by filtration and wt by autoclaving. 5ml of broth medium is dispensed into tubes and inoculated with an overnight broth culture of the organism. The inoculated tubes are incubated for 24 h at 37ºC. A red-pink colour of urease shows a positive test. If the colour is unchanged, it shows a negative result.

Oxidase test (Cytochrome Oxidase)
Principle: The enzyme oxidase oxidizes a redox dye such as tetramethyl paraphenylene diamine dihydrochloride (TMPPDH) to deep purple colour. The enzyme is produced by some aerobic bacteria as part of their respiratory oxidation mechanism.

Test: 2.8g of nutrient agar is dissolved in 100ml distilled water, sterilized by autoclaving at 121ºC for 15 min and poured into plates. The plates are incubated with overnight broth culture of the organism for 24 h at 37ºC. A few drops of 1%

TMPPDH (oxidase reagent) are added to distirase colonies or the plate and a blue to deep purple colouration indicates the positive reaction.

Carbohydrate fermentation test

Principle: Bacteria can breakdown carbohydrate fermentatively depending on the enzymes they can be produce. Ability to ferment a range of carbohydrates is used as an identification tool for many bacteria. The carbohydrate to be tested is added in 0.5 to 1% concentration to peptone water base containing an acid-base indicator – phenol red or Andrade's indicator. Fermentation is indicated by change of colour due to acid production. Gas may or may not be produced during fermentation. An inverted Durham's tube added to the medium can trap the gas produced.

Test: 1.5g of peptone water was weighed and dissolved in 100ml distilled water. 5ml of the peptone water solution was dispersed in tubes labeled glucose (G), lactose (L) and sucrose (S). 0.5g of each of the sugar (carbohydrate) that is glucose, lactose and sucrose were weighed and dissolved in 50ml of distilled water (that is, 1%) and 2ml of each sugar solution was added to the respective tubes with their label. 2 to 3 drops of phenol red indicator was added to each tube and a Durham's tube was inverted so that the medium fills it. The tubes were sterilized at 121ºC for 15 min. On cooling, the tubes were inoculated with the test organisms and incubated for 48 h. Change of colour from straw to yellow indicates fermentation of the sugars and gas production is indicated by trapped air in the Durham's tube.

Statistical analysis

The results obtained from the study were subjected to statistical analysis using Microsoft Office Excel, Version 2016. Analysis of Variation (ANOVA) was used to determine the differences between samples and the mean ± Standard Deviation of the values were computed.

RESULTS

Physicochemical parameters

The results of physicochemical parameters analyzed for the different water samples in terms of Dissolved oxygen (DO), Biological oxygen demand (BOD), Hydrogen ion concentration (pH), Alkalinity, Water hardness, Salinity and Conductivity showed variations in the different samples collected. The results obtained from the physicochemical analysis are presented in Table 1. The variations are more appreciated in the Figures.

Table 1. Summary of range and mean values of the physico-chemical parameters of water samples obtained from Kwale, Delta State.

SN	Parameters	Well water	Borehole water	Sachet water	WHO standard
1	Dissolved Oxygen (mg/L)	0.70±0.20	0.60±0.30	1.23±0.04	6.0
2	Biological Oxygen Demand (mg/L)	0.55±0.05	0.45±0.05	0.07±0.03	40
3	pH	6.09±0.54	8.50±0.50	8.82±0.08	6.4-8.5
4	Alkalinity (mg/L)	10.1±0.15	13.0±2.00	12.5±1.25	600
5	Water Hardness (ppm)	0.07±0.03	0.16±0.02	0.10±0.00	600
6	Salinity (%)	0.30±0.30	0.20±0.10	0.1±0.11	200
7	Conductivity (µS)/cm	10.20±0.30	9.80±0.40	10.50±0.20	1.0

Results are presented in Mean±SD.

Dissolves oxygen (mg/L)

The level of dissolved oxygen ranged from 0.5mg/L – 0.9mg/L in Well water sample. The highest value was recorded to be 0.9mg/L while the least value was 0.5mg/L. Borehole water sample recorded dissolved oxygen value which ranged between 0.3mg/L – 0.9mg/L with a mean value of 0.60mg/L/ the highest value recorded was 0.65mg/L while the least was 0.55mg/L. Also, sachet water recorded dissolved oxygen which ranged between 1.19mg/L – 1.27mg/L with highest value of 1.27mg/L and lowest value of 1.19mg/L respectively (Table 1 and Figure 2).

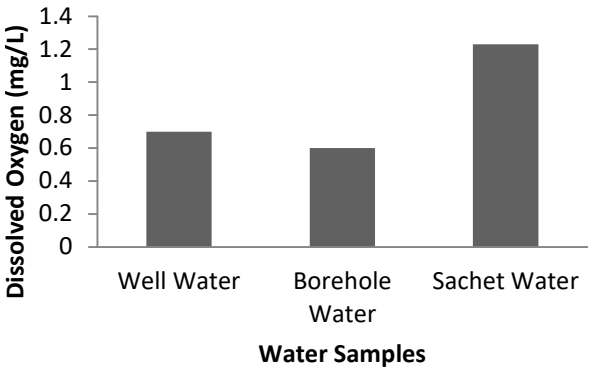

Figure 2. Dissolved oxygen values of different water samples.

Biological oxygen demand (mg/L)

Biological oxygen demand recorded well water sample ranged between 0.50mg/L – 0.65mg/L. A mean value of 0.5mg/L was recorded in the sample with the highest value of 0.65mg/L and lowest value of 0.55mg/L. Borehole water was observed to range between 0.40mg/L – 0.55mg/L with a mean value of 0.45mg/L. The highest value was recorded to be 0.55mg/L while the least was recorded to be 0.40mg/L. Sachet water recorded values which ranged between 0.03mg/L – 0.10mg/L with a mean value of 0.07mg/L (Table 1 and Figure 3).

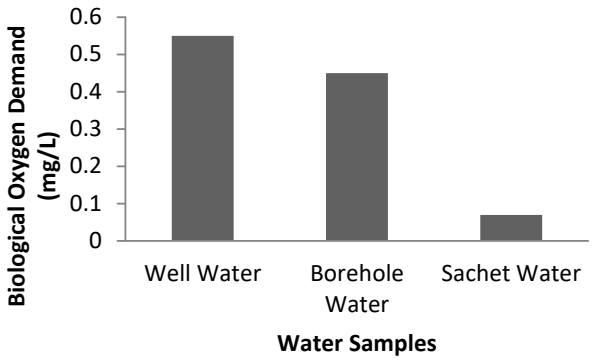

Figure 3. Biological oxygen demand values for different water samples.

Hydrogen ion concentration (pH)

The pH (hydrogen ion concentration) recorded in the samples was observed to range between 6.00 – 6.99 in Well water sample with a mean of 6.09. The highest value was recorded to be 6.99 while the least was 6.00. The values recorded for borehole water sample ranged between 9.00 – 8.00 with a mean value of 8.50. Also, the value recorded for sachet water sample ranged between 8.74 – 8.90 with a mean value of 8.82 respectively (Table 1 and Figure 4).

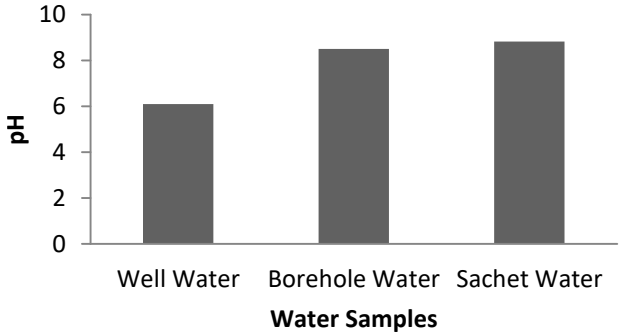

Figure 4. Hydrogen ion concentration (pH) of water samples

Alkalinity (mg/L)

Water alkalinity recorded in the study ranged between 9.90mg/L – 10.20mg/L for well water sample with a mean value of 10.1mg/L. The highest value was recorded to be 10.20mg/L while the least was recorded to be 9.90mg/L. Borehole water samples recorded alkalinity which ranged between 11.00mg/L – 15.00mg/L with a mean value of 13.00mg/L. The highest value recorded was 15.00mg/L while the least was recorded to be 11.00mg/L. Also, sachet water recorded values which ranged between 11.00mg/L to 13.5mg/L with a mean value of 12.5mg/L respectively (Table 1 and Figure 5).

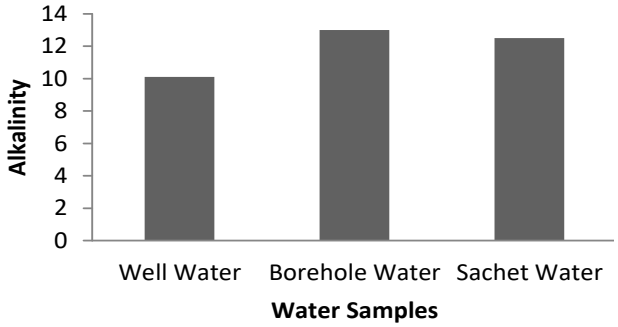

Figure 5. Alkalinity values of different water samples

Water hardness (ppm)

The values recorded for water hardness in the samples collected for well water ranged between 0.04ppm – 0.10ppm with highest value of

0.10ppm and lowest value of 0.04ppm. The water hardness recorded mean value of 0.07ppm for well water sample. The borehole water samples obtained ranged between 0.14ppm to 0.18ppm respectively with a mean value of 0.16ppm. Also, sachet water samples obtained was observed to be 0.10ppm in all the samples collected (Table 1 and Figure 6).

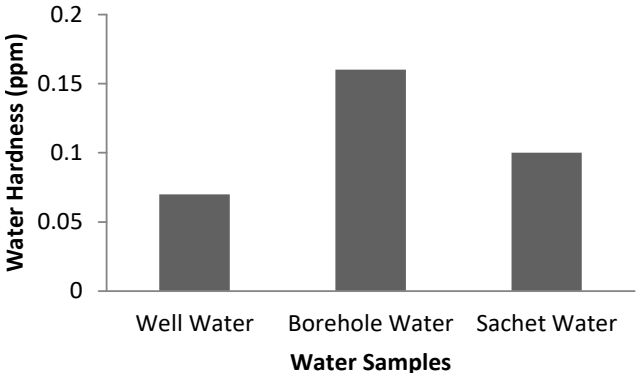

Figure 6. Water hardness values obtained from different water samples.

Salinity (mg/L)

Water salinity recorded for well water in the study ranged between 0.10mg/L – 0.70mg/L across the three water samples analyzed in the study. The salinity for well water had a mean value of 0.30. The result obtained for borehole water recorded a range of 0.10mg/L – 0.30mg/L with a mean of 0.20mg/L. Also, the values obtained from the sachet water recorded a range of 0.10mg/L – 0.30mg/L with the highest value of 0.30mg/L and lowest value of 0.10mg/L. The sachet water salinity had a mean of 0.1mg/L respectively (Table 1 and Figure 7).

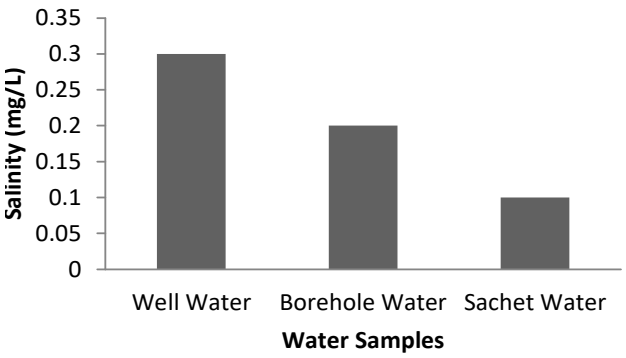

Figure 7. Salinity values recorded for different water samples.

Conductivity (µS)

The values recorded for water conductivity in the well water samples collected ranged from 10.0µS – 10.40µS across the three different samples obtained from the study area with a mean value of 10.20µS. The results obtained from the borehole water sample showed that the conductivity value ranged between 9.10µS – 10.20µS with a mean value of 9.80µS. Also, borehole water sample recorded conductivity value which ranged between 10.30µS – 10.70µS with a mean value of 10.50µS respectively (Table 1 and Figure 8).

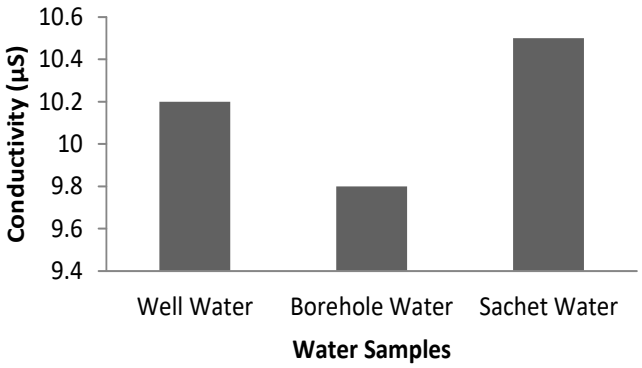

Figure 8. Conductivity values recorded in different water samples.

Microbiological analysis

From the result of microbial analysis carried out on the three samples of water, two species of gram-positive bacteria viz *Escherichia coli* and *Enterobacter aeruogenes* were isolated and identified. The prevalence of the bacteria in the different water samples showed that *E. aeruogenes* was most occurring in the water samples. *E. aeruogenes* was present in well, borehole and sachet water samples but was most occurring in sachet water samples and borehole water sample. Well water sample had mixed bacteria with both *E. coli* and *E. aerogenes* respectively. The morphological and biochemical characteristics of the isolated organisms are presented in Table 2.

The results obtained for the total coliform count for the water samples is presented in Table 3. For the well water sample, gas production was observed in 1 tube of 10ml and 1ml respectively but no gas production was produced in any tube of the 0.1ml. The most probable number of coliforms per 100ml from the statistical Table is

Table 2. Biochemical and morphological characteristics of bacteria isolates.

Sample	Gram Stain	Motility	Catalse	Indole	H_2S	Oxidase	Citrate	Urease	Glucose	Lactose	Sucrose	Organism
Well Water 1	-	+	+	+	-	-	-	-	NG	NG	NG	*E. coli*
Well Water 2	-	+	+	-	-	-	+	-	NG	NG	NG	*E. aerogenes*
Well Water 3	-	+	+	-	-	-	+	-	NG	NG	NG	*E. aerogenes*
Borehole Water 1	-	+	+	-	-	-	+	-	NG	NG	NG	*E. aerogenes*
Borehole Water 2	-	+	+	-	-	-	+	-	NG	NG	NG	*E. aerogenes*
Borehole Water 3	-	+	+	-	-	-	+	-	NG	NG	NG	*E. aerogenes*
Sachet Water 1	+	+	+	-	-	-	+	-	NG	NG	NG	*E. aerogenes*
Sachet Water 2	+	+	+	-	-	-	+	-	NG	NG	NG	*E. aerogenes*
Sachet Water 3	+	+	+	-	-	-	+	-	NG	NG	NG	*E. aerogenes*

Key: Mot: Motility; Ca: Catalase; H_2S: Hydrogen Sulphide; Oxid: Oxidase; Cit: Citrase; Glu: Glucose; Lac: Lactose; Suc: Sucrose; NG: No Gas; +: Positive; -: Negative.

Table 3. Summary of total coliform count.

Water sample	No. of tubes with positive reactions			MPN/100ml
	3 of 10ml each	3 of 1ml each	3 of 0.1ml each	
Well Water	1	1	0	7
Borehole Water	1	0	0	4
Sachet Water	1	1	0	7

7. In the borehole water sample, gas production was observed only in one tube of the 10ml but none in the 3 of the 1ml tubes and in the three of the 0.1ml tubes. The most probable number of coliforms per 100ml is 4 as it is obtained from the table. Also, for the sachet water sample, gas production was obtained in one tube of the 10ml and 1ml tubes respectively but no gas was produced in any tube of the 0.1ml. The most probable number of coliforms per 100ml from the statistical Table is 7.

DISCUSSION

The results obtained from the present study showed that the physicochemical parameters vary from the different water samples. The value obtained from dissolved oxygen was recorded to be higher in the sachet water compared to both well water and borehole water. Dissolved oxygen in drinking water adds taste and it is a highly variable factor in water (Ramachandra and Solanki, 2006). Although the WHO have not set any permissible limit for dissolved oxygen concentration in drinking water, the results could be classified as fairly good according to the classification by Ramachandra and Solanki (2006). Low levels of dissolved oxygen in water could indicate high levels of microbiological activity (WHO, 2007). Biochemical Oxygen Demand value can be used as a measure of the degree of water pollution and is useful in evaluating self-purification capacity of a water body (Akpen et al., 2016). However, the values of biochemical oxygen demand in the present study ranges from 0.07(mg/L) – 0.55(mg/L) in all samples. The pH is one of the most important determinants of water quality. International standards for drinking water suggest that pH less than 6.5 or greater than 8.5 would impair the portability of the water. The standard limit of the pH of water used in this research is between 6.09 to 8.82 (WHO, 2007). From the study, only sample of borehole water was within the pH values of the specified range. However, well water was lower slightly while sachet water was higher slightly than the specified range.

Alkalinity is not considered detrimental to humans but is generally associated with high pH values, water hardness and excess dissolved solids (WHO, 2009). High alkalinity waters may also have a distinctly flat, unpleasant taste (WHO, 2006). Alkalinity comes from rocks and soils, salts and certain plants activities. If an area‘s geology contains large quantities of calcium carbonate ($CaCO_3$, limestone), water bodies tend to be more alkaline. Samples obtained from the

study showed that they recorded low alkalinity values (< 50 mg/l). Total hardness in the sampled water varied from one sample to the other. All the values (0.07mg/l to 0.16mg/l) were less than the maximum allowable limit of 500 mg/l recommended by the WHO. Again, all the samples recorded total hardness values less than 100 mg/l; hence, the water can be described as soft drinking waters. Waters with hardness less than 100 mg/l have a little buffering capacity and may cause corrosion of metallic receptacles (WHO, 2006). Thus, these water samples have a great potential to contain higher concentration of toxic metals. Very soft waters may also have an adverse effect on mineral balance (WHO, 2006). Conductivity refers to a measurement of the ability of water to conduct electricity (APHA, 1992). Mean conductivity values recorded in the water samples were generally low (9.80 – 10.50 μS/cm) and were within the guideline value set by the WHO (2007) for drinking water. The low conductivity values indicate that contaminations due to ions are low and should not affect taste of the water.

The results obtained from the study showed that two bacteria species are associated with water samples collected from the study area. The presence of *E. coli* and *E. aeruogenes* in the water samples are indications of the presence of contaminant. However, the level of bacterial contamination is strongly attributed to poor quality of water source, improper pipeline maintenance, insufficient or lack of personal hygiene (Obiri-Danso et al., 2003; Olaoye and Onilude, 2009). The act of testing for the presence of coliform is a measure of the efficiency of the treatment process employed and the integrity of the water distribution system (Da Silva et al., 2008). It would not be out of place to state that the treatment process and distribution system employed by most of the water vendors are doubtful as it does not comply with standard operating procedure. The poor microbial quality observed in this present study has also been reported in some part of Nigeria and other part of the world (Ajayi et al., 2008; Dada, 2009; Cheabu and Ephraim, 2014). The result of well water and sachet water samples analysis showed that the water had total bacterial counts of 7 CFU/100ml while borehole water analyzed showed total bacterial counts of 7 cfu/100ml.

The result obtained in this work is appreciably low when compared with report from Canadian bottled water >100 cfu/100ml, Al-Gassin region of Saudi Arabia >180 cfu/100 ml and 104 cfu/ml for some part of Britain, United Kingdom (Ajayi et al., 2008). In this present study higher percentage of the bottled water were produced under good sanitary conditions. According to Da Silva et al., 2008, the singular fact that a number of this packaged water contains coliform, there is however the need for improved monitoring and supervision of the water processing industry to ensure 100% compliance as water meant for consumption must be free from any form of bacteria that might constitute health hazard. Faecal coliform is sub-division of total coliform bacteria. The presence of faecal coliform in drinking water represents a greater risk to infectious pathogens (Musa et al., 2014). The result of this study revealed that the water samples investigated were free from feacal coliform except for well water sample which showed the presence of *E. coli*. This result shows quantitative agreement with global and national standard for drinking water (WHO, 2008).

Physical observation of the turbid nature of the water samples revealed that well water sample was slightly turbid while borehole water and sachet water were not turbid. The Turbidity of drinking water is purely dependent on the amount of particulate matter present in it. The turbidity of water interferes with disinfections (Musa *et al.*, 2014). Turbidity is known to have effects on taste, odour and colour of water (Ndinwa et al., 2011). It also serves as a transport medium of *Giardia* and *Cryptosporidium cysts* in drinking water system (Jonatas et al., 2015). This value is however still within the recommended standard by World Health Organization (WHO).

Conclusion

This study assesses the physical-chemical quality and microbiological status of different types of water sources used by the people of Kwale for human consumption. As a consequence, this research provided baseline water quality data in this region. As regards physical-chemical parameters, the result was that drinking water

sources have a reasonably good chemical quality, with slight exceptions related to the pH. In respect to the microbial quality of the samples, the result showed that the samples harbor bacteria species of health importance. The presence of *E. coli* and *E. aerogenes* is an indication of microbial contamination which calls for necessary actions. Finally, further research in water quality would be very beneficial in the development of a future water resource program in the Kwale. Only by identifying the sources of contamination will it be possible to select and implement the most correct and appropriate solution to these quality issues.

CONFLICTS OF INTERESTS

The author has not declared any conflicts of interests.

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