Research Article

An assessment of the potability of groundwater from boreholes based on microbial quality and physical properties: case of Buea and Tiko Subdivisions, South West Region of Cameroon

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ABSTRACT

Groundwater from boreholes, though generally considered as potable water, is vulnerable to both microbial pollution and unsuitable physical characteristics. An assessment of the microbial quality and the physical properties of groundwater from boreholes was accordingly carried out in Buea and Tiko subdivisions to determine these parameters. In particular, the presence of coliform bacteria and an eventual isolation of *E. coli* and *Salmonella spp* which are faecal indicator organisms were carried out. A total of 46 samples were collected from 29 randomly selected boreholes and their physical parameters (temperature, pH, EC, TDS and turbidity), and microbial content analyzed. Physical parameters were measured in-situ using portable field devices while total coliform count and isolation of faecal coliforms (*E. coli* and *Salmonella spp*) were determined using standard microbiological methods with reagents, Violet Red Bile Agar, Mackonkey Agar and Salmonella Shigella Agar respectively. The results indicated that the physical characteristics of the water (pH range **4.9-8.4;** EC range **90µS/cm-2330µS/cm;** TDS range **61 mg/L-1630 mg/L**; Turbidity range **0.44NTU-59.80NTU)** were within WHO guidelines for potability except for the turbidity with barely two samples that fell within the acceptable range of 1.5NTU. Total coliform counts ranged from $1x10^0$CFU/ml to $3x10^3$CFU/ml and 72.41% of the samples exceeded the WHO recommended 0.0 CFU/100 ml. *E. coli* was isolated in 76.47 % while *Salmonella spp* was isolated in 82.35% of the samples. This pioneer study on groundwater quality from boreholes in the study area reveals that the water is vulnerable to bacteriological pollution and therefore not potable. This necessitates awareness creation of the community on the regular disinfection of groundwater from boreholes.

Keywords: Borehole water, groundwater, physical parameters, turbidity, microbial quality, coliform, faecal indicator organisms, Buea, Tiko

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RESUME

Les eaux souterraines des forages, bien que généralement considérées comme de l'eau potable, sont vulnérables à la fois à la pollution microbienne et à des caractéristiques physiques inappropriées. Une évaluation de la qualité microbienne et des propriétés physiques des eaux souterraines des forages a donc été réalisée dans les départements de Buea et Tiko pour déterminer ces paramètres. En particulier, la présence de bactéries coliformes et un éventuel isolement d'E. Coli et l'espèce de Salmonella qui sont des organismes indicateurs de contamination fécale ont été réalisés. Au total, 46 échantillons ont été prélevés dans 29 forages sélectionnés au hasard et leurs paramètres physiques (température, pH, CE, TDS et turbidité) et leur contenu microbien ont été analysés. Les paramètres physiques ont été mesurés sur place à l'aide d'appareils de terrain portables, tandis que le nombre total de coliformes et l'isolement des coliformes fécaux (E. coli et Salmonella spp) ont été déterminés à l'aide de méthodes microbiologiques standard avec des réactifs, la gélose violette rouge, la gélose Mackonkey et la gélose Salmonella Shigella respectivement. Les résultats ont indiqué que les caractéristiques physiques de l'eau (plage de pH 4,9-8,4; plage CE 90µ S/cm-2330µS/cm; plage TDS 61 mg/L-1630 mg/L; plage de turbidité 0,44NTU-59.80NTU) étaient conformes au directives de l'OMS pour la potabilité. Seul, la turbidité avait à peine deux échantillons qui se situaient dans la plage acceptable de 1,5NTU. Le nombre total de coliformes variait de $1x10^0$ CFU/ml à $3x10^3$ CFU/ml et 72,41% des échantillons dépassaient les 0,0 CFU/100 ml recommandés par l'OMS. E. coli a été isolé dans 76,47% tandis que l'espèce Salmonella a été isolée dans 82,35% des échantillons. Cette étude pionnière sur la qualité des eaux souterraines des forages dans la zone d'étude révèle que l'eau est vulnérable à la pollution bactériologique et donc non potable. Cela nécessite une prise de conscience de la communauté sur la désinfection régulière des eaux souterraines des forages.

Mots clés: eau de forage, eau souterraine, paramètres physiques, turbidité, qualité microbienne, coliformes, organismes indicateurs fécaux, Buea, Tiko

INTRODUCTION

Water is a basic natural resource that is essential to life, the social and economic development of a nation. According to the World Health Organization, about 1 billion people are without safe drinking water worldwide, with countless lives lost annually due to drinking and using contaminated water sources (WHO, 2006).

Society uses and pollutes water, or modifies the hydro-morphology of water courses in many ways like building dams, draining wetlands, rerouting water for irrigation and water supply, discharging industrial and municipal wastes, and applying fertilizer and pesticides into water sources and catchment areas, resulting in contaminated streams, rivers, lakes and groundwater sources **(IAHS, 1997; Moris *et al.*, 2003)**. As the pressures on surface water resources grow, the resources deplete and deteriorate over time whereas the demand for water of high quality for drinking, domestic purposes and economic activities increases **(Rodak and Silliman, 2011; Loucks and van Beek, 2017)**. This has increased reliance on groundwater resources thereby creating challenges among which are the provisions of adequate quantity and quality of potable water **(WWDR, 2011)**.

In Sub-Saharan Africa, groundwater is the most reliable source of drinking water **(Idiata, 2011; Chidya *et al.*, 2016; Beyene *et al.*, 2019)**. It is a means of coping with water deficiencies in areas where rainfall is scarce or highly seasonal and surface water is extremely limited **(David, 2011)**. Although groundwater, particularly from deep sources, may provide water of good microbiological quality, its quality in any region changes with time **(IAHS, 1997)** and is largely determined by both natural processes such as dissolution and precipitation of minerals, its velocity, the rate of recharge waters, interaction with other types of water from other aquifers, and anthropogenic activities **(Andrade *et al.*, 2008; Devic *et al.*, 2014)**.

More than 60% of the rural and peri-urban populations of Buea and Tiko Sub-Divisions drink untreated water from community water sources and hand-dug wells. The unprecedented increase in population, urbanization, and agricultural activities in the fast-growing towns of Buea, Tiko and Mutengene within this study area in recent times, has resulted in an increased depletion and deterioration of the existing water resources. This problem is compounded by the low supply capacity of the public water supply network with dilapidated and poorly maintained facilities **(Dzekewong *et al.*, 2016; Huston, 2016)**. Faced with these difficulties, public and private entities drill boreholes as sources of water supply for drinking and for various domestic activities. In some communities, this water of questionable quality is sold to the public without reference and conformance to requisite quality standards such as those set by the WHO **(Masse and Ayonghe, 2016)**.

Although borehole water development is seen as more amenable to poverty targeting than surface water **(Kai and Jeroen, 2009; Xinghui *et al.*, 2009)** and a low cost option in the long run **(Dhawan, 1991; Bresline, 2007)**, the WHO specifies that water meant for drinking and other domestic activities must be free from contamination and organisms capable of causing water-borne diseases such as typhoid and paratyphoid fevers (salmonellosis), cholera, bacillary dysentery (shigellosis) and infectious hepatitis, as most of the enteric diseases are transmitted through water **(WHO, 2006)**.

Today's research efforts have shifted from problems of water supply to those of water quality, for instance **Temgoua, (2011)** carried out a study on the chemical and bacteriological analysis of drinking water from alternative sources in the Dschang Municipality; **Ako *et al.* (2012)** studied the quality and usability of spring water in the Mount Cameroon area; **Ako *et al.* (2013)** studied nitrate contamination of groundwater in two areas of the Cameroon Volcanic Line; **Wotany *et al.* (2013)** worked on the hydrogeochemical and anthropogenic influence on the quality of water sources in the Rio del Rey Basin, **Palamuleni and Akoth (2015)** worked on the physico-chemical and microbial analysis of selected borehole water in Mahikeng; and **Fantong *et al.* (2016)** studied the variation of hydrogeochemical characteristics of water in surface flows, shallow wells, and boreholes in the coastal city of Douala. The results of these studies were indicative of the fact that the quality of water was negatively affected by both physical and microbial parameters.

It is becoming difficult in many areas around the world to obtain a supply of potable groundwater for drinking and industrial purposes. This is mostly due to contamination as a result of extensive use of chemical and biological substances by agricultural and human activities, especially in shallow aquifer recharge zones **(Suthar *et al.*, 2009; Ngounou and Djoret 2010; Ako *et al.*, 2013)**. Buea and Tiko are areas of both subsistence and large-scale plantation agriculture where there is extensive application of fertilizers (containing the likes of nitrate, phosphate and potassium) and pesticides **(Mbua, 2013)**. In private homes or even commercial areas, external septic tanks are barely a few meters away from the water points, thus there is an inherent risk of pollution of the groundwater aquifers in these areas.

Studies carried out in and around the area by **Endeley *et al.* (2001), Lambi and Kometa (2009), Ako *et al.* (2011), Ako *et al.* (2012), Ako *et al.* (2013), Njunda *et al.* (2013), Wotany *et al.* (2013), Fogwe and Tanyi (2014), Wotchoko *et al.* (2016) and Fomenky *et al.* (2017),** address issues of quality of various water resources but none of these studies focused on the quality of groundwater from boreholes, despite the growing dependence of the population on such water sources for potable water supply.

Currently, no comprehensive study of the microbial quality of groundwater from boreholes has been carried out in the area. Therefore, an investigation of the microbial quality and physical parameters (pH, Temperature, TDS and EC) of the groundwater from boreholes in the study area is crucial. The results of this work could serve as baseline data for water resource managers and as a pointer to further research on groundwater from boreholes which are becoming main sources of potable water supplies within the study area.

THE STUDY AREA

The area under study is in the western slope of Mount Cameroon, in Fako Division of the South West Region of Cameroon (Fig. 1). With a humid coastal Equatorial climate, the area has two distinct seasons: a long rainy season of about 8 months and a short dry season of about 4 months. Annual rainfall ranges from 2,000mm to 5,000mm while annual temperatures range from 20°C to 33°C. The topography is largely a plain of low elevation in Tiko and rises to 1,500m above sea level in Buea (**Folifac *et al.*, 2009**; **Wanji *et al.*, 2012**)

The main land use practices here are agro-industrial activities, with over 90% of the population involved in subsistence agriculture with approximately 41,000 hectares exploited by the Cameroon Development Cooperation (CDC) for plantation agriculture and the "Plantation des Haut Plateau" (PHP) especially in Tiko Sub-Division **(Suh, 2016)**.

Geology and hydrology

The study area falls within the Cameroon Volcanic Line (CVL) and is composed mainly of sedimentary rocks which are mainly sandstones in the Tiko Plain and volcanic rocks at Mutengene and Buea. The volcanics range from massive basaltic lava flows and aa lava flows around the upper slopes of Mt. Cameroon to pyroclastic materials further down slope (**Endeley *et al.*, 2001; Manga *et al.*, 2013)**.

The soils have been weathered and partly covered by more recent deposits, thus the soils are black and in these areas are well drained due to the generally hilly nature of the terrain and the fact that they are free-draining **(Fomenky *et al.*, 2017)**. Buea consists mainly of older lava flows of unknown age while Tiko consists of volcanic turfs and Paleocene to Holocene sediments. In these volcanic terrains (such as the Cameroon Volcanic Line) the solute composition of waters is principally controlled by the silicate hydrolysis of the rock minerals. (**Kips *et al.*, 1991**; **Tanyileke *et al.*, 1996).**

MATERIALS AND METHODS

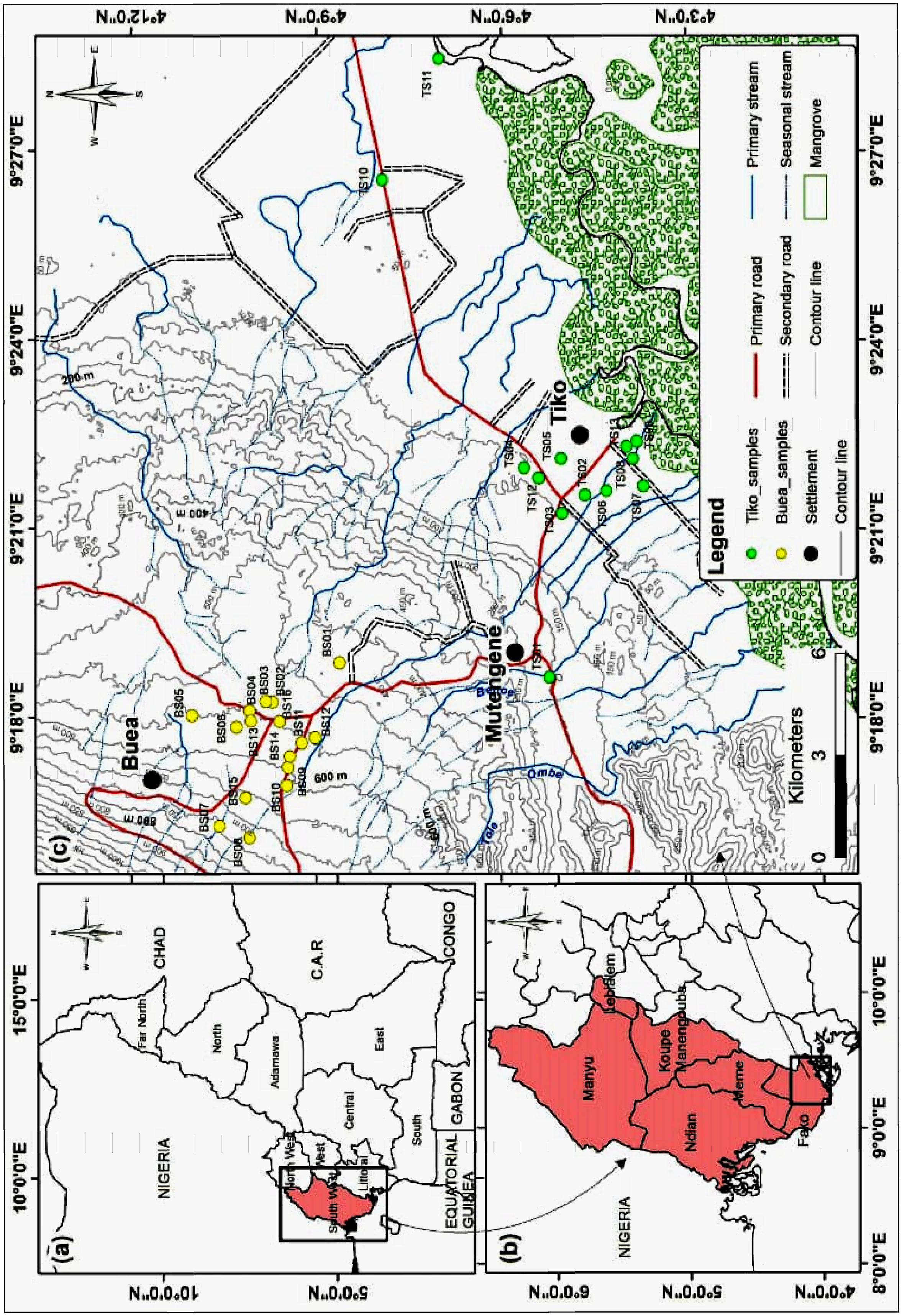
Fieldwork and sample collection

Fieldwork and sampling were conducted in May and in July, 2018. The locations and elevations of the selected boreholes were obtained with the aid of a portable Garmin GPSMaps 86 GPS. The elevations ranged from 8m above sea level in Tiko to 743m in Buea. Sixteen (16) samples were collected in Buea and 13 in Tiko in the month of May. After the initial analysis for Total Coliform Counts, thirteen (13) purposive samples were collected in Buea and four (04) in Tiko in the month of July for the isolation of faecal indicator organisms. Sampling procedures were carried out as described by the guide book. STI/PUB/1238 **(IAEA, 2006)**. Land use pattern, environmental management and other features capable of polluting the borehole were also noted. All 16 boreholes in Buea were electric driven with submerged pumps while the 13 boreholes in Tiko where equipped with manual hand pumps.

At each sampling site the borehole was run for 3-5 minutes to remove all stagnant water in the pipeline. The outlet was disinfected with cotton swab soaked in 95% alcohol to eliminate any contamination due to anthropogenic activity or any external natural occurrence. The water was then pumped out again for 3-5 minutes to wash off any excess alcohol on the outlet before pumping directly into the 100 ml pre-cleaned plastic bottles that were thoroughly rinsed with the water to be sampled. The operator equally carried out thorough hand washing each time to minimize contamination of the sampling bottles as well as the sample. An air space of about 2.5cm was left at the top of each bottle to create space for oxygen such that organisms did not die before testing in the laboratory.

A total of forty six (46) samples were collected for the study from twenty-nine (29) randomly selected boreholes (Fig. 1) with depths ranging from 40 – 80 m. The samples were stored in a cooler containing ice pack to maintain a suitable low temperature of 4°C. Temperature, electrical conductivity (EC), and pH were measured in the field respectively, using a CT-450WR thermometer; a portable electrical conductivity meter (pH/EC waterproof HANNA, Dist 5 and Water proof Eco Tester EC Low) and a portable pH meter (Shindengen, ISFET pH meter KS723 and Water proof Eco Tester pH2). The samples were transported to the Microbiology Laboratory of the University of Buea, Cameroon for microbial quality analysis before bacterial multiplication or colony decline could occur. Violet Red Bile Agar was used as differential medium for enumeration of total coliforms (TC) using the pour plate technique, while MacConkey Agar and Salmonela Shigella Agar (ss Agar) were respectively the differential media used for the isolation and culture of fecal coliform indicator organisms (*E. coli* and *Salmonella species*). Results of TC counts were expressed in Coliform Forming Units per milliliter of water sample (CFU/ml).

Figure 1: Location map indicating the various Sample points (From Author's field data)



PRESENTATION OF RESULTS

Table 1: Profile of parameters evaluated in the Buea Area

Sample ID	Temp. (°C)	pH	EC (µS/cm)	TDS (mg/L)	Turbidity (NTU)	Total Coliforms (CFU/mL)	Faecal indicator Organisms isolated	
							E. coli	*Salmonella spp*
BS01	26.7	7.8	270	176	2.95	180	+	+
BS02	23.5	7.8	260	167	2.80	1340	+	+
BS03	27.3	6.6	200	136	3.81	380	+	+
BS04	26.6	6.6	220	135	23.2	12	0	0
BS05	25.7	7.7	240	162	13.05	840	X	X
BS06	25.9	7.3	160	97	10.5	20	X	X
BS07	24.3	7.1	180	118	3.31	41	0	0
BS08	23.6	7.2	240	146	7.20	50	0	+
BS09	28.7	7.2	270	150	5.10	0	-	-
BS10	26.7	7.2	330	182	0.71	47	+	+
BS11	25.1	7.3	260	168	31.5	0	-	-
BS12	25.5	7.2	310	115	33.1	13	0	0
BS13	26.5	6.9	200	124	0.44	19	+	+
BS14	25.9	6.9	290	140	25.4	0	-	-
BS15	27.3	7.2	310	204	3.65	1280	+	+
BS16	25.3	7.7	270	177	9.3	3000	X	X
WHO Limit	30.0	8.5	250	1000	1.5	0.0 CFU/ 100mL	00	00

NB: **0:** Indicates absence of microbe in the sample;
+: Indicates presence of microbe in the sample;
X: site inaccessible during sampling for microbial isolation.

Table 2: Profile of parameters evaluated in the Tiko Area

Sample ID	Temp (°C)	pH	EC (μS/cm)	TDS (mg/L)	Turbidity (NTU)	Total Coliforms (CFU/mL)	Faecal indicator Organisms isolated	
							E. coli	*Salmonella spp*
TS01	27.5	8.0	320	215	9.5	0	-	-
TS02	28.7	7.4	300	206	3.94	9	+	+
TS03	28.7	8.0	340	114	48.5	1	-	-
TS04	29.5	7.0	320	210	13.7	0	-	-
TS05	29.5	6.6	220	132	47.9	190	+	+
TS06	29.5	8.0	360	223	9.36	1	-	-
TS07	29.1	7.9	330	219	9.7	0	-	-
TS08	29.7	8.0	400	267	29.9	88	+	+
TS09	29.3	7.7	430	232	19.6	0	-	-
TS10	30.5	4.9	90	61	17.7	1	-	-
TS11	29.7	6.8	1590	1630	41.6	1	-	-
TS12	29.2	8.4	370	240	11	190	0	0
TS13	30.0	7.2	530	197	59.8	0	-	-
WHO Limit	30.0	8.5	250	1000	1.5	0.0 CFU/100mL	00	00

NB: **0:** absence of microbe in the sample;
+: presence of microbe in the sample;

Physical parameters of the borehole water

The physical parameters analyzed included temperature, pH, EC, turbidity, and TDS. The results of these parameters for all 29 analyzed samples collected during the study are presented on Tables 1 and 2. The temperature range for all the water samples varied from **23.5°C** to **30.5°C** and only one sample, (TS10) fell above the WHO standard (WHO, 2011) of 30°C (Fig. 2). The least temperature, **23.5°C** was registered at BS08. The pH value of the samples ranged from **4.9** to **8.4** with the exception of TS10 (Fig. 3) that had a pH of 4.9 which falls below the **6.5** lower limit for the **WHO** standard. Electrical conductivity (EC) ranged from **90μS/cm** to **2330μS/cm** with two samples; (TS11 and TS13) recording values above the WHO standard of **500μS/cm** (Fig. 4). TDS values for the samples ranged from **61 mg/L** to **1630 mg/L**. All samples except TS11 (**1630 mg/L**) had TDS values within the acceptable limit of 1000 mg/L as set by WHO. A turbidity range of **0.44NTU** to **59.80NTU** was registered in the samples where only two samples; (**BS10** and **BS13)** registered values within the WHO permissible limit of **1.5NTU** (Fig. 6). The rest fell beyond the permissible limit.

Bacteriological analysis of the borehole water

Microbial analysis included Total Coliforms (TC) and isolation of Faecal Coliforms (FC – *E. coli* and *Salmonella spp*). The microbial results of all the 29 samples are presented on Tables 1 and 2. The total coliform bacteria count ranged from 0 CFU/mL to $3x10^3$ CFU/mL. Overall, 21 (72.41%) out of the 29 samples tested exceeded the WHO recommended 0.0 CFU/100 mL for coliforms, indicating the presence of bacterial contaminants in the borehole water. Seventeen

(17) boreholes randomly selected from the samples that tested positive for total coliforms were sub-cultured for possible presence of feacal indicator organisms. *E. coli* and *Salmonella spp* were effectively isolated in 10 (58.82%) out of the 17samples (Table 1 &2). *E. coli* was isolated in 76.47 % of the test samples while *Salmonella spp* was isolated in 82.35% (Fig. 7).

DISCUSSION

An assessment of the potability of the borehole water based on physical properties

Temperature

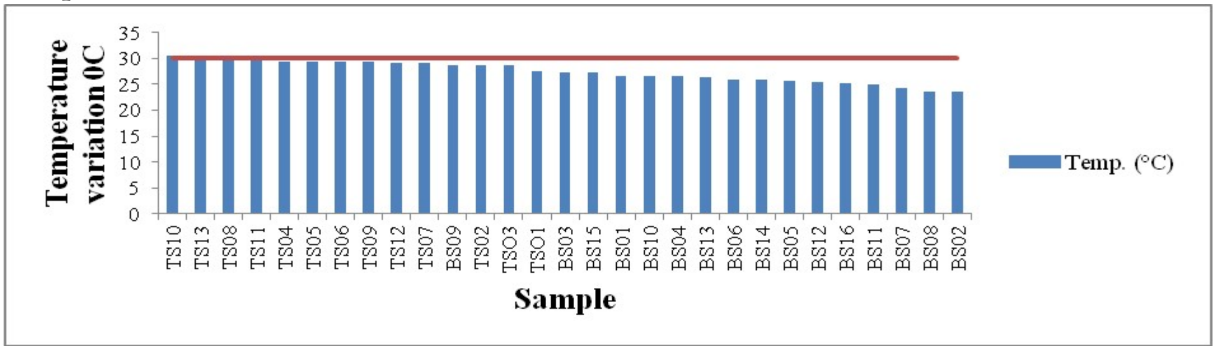


Figure 2: Variation of Temperature in the samples

High water temperature may facilitate growth of microorganisms and can also impart undesirable taste and odour as well as the corrosive ability of the water, hence affecting water quality (WHO 2011). In this study, the temperature ranged from **23.5°C** to **30.5°C** (Tables 1 & 2) and only one sample fell above the WHO standard of 30°C (Fig. 2). The higher temperatures observed in samples from Tiko can be attributed to the environmental temperature and other climatic conditions prevailing at the time of sampling given that Tiko normally records higher temperatures compared to Buea owing to its coastal Equatorial climate and sandy belts **(Fraser *et al.*, 1998; Neba, 1999)**. Hence, the water temperatures recorded here may only highlight environmental characteristics without any suggestion for adverse effects on human health.

pH

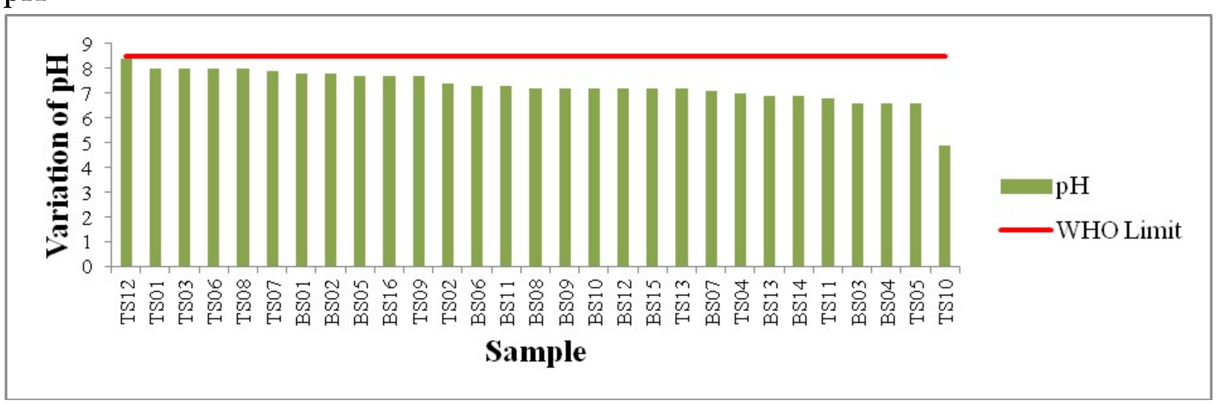


Figure 3: Variation of pH in the samples

The pH values of all the samples ranged from **4.9** to **8.4** (Tables 1 & 2) and these could be classified as suitable for drinking purposes except TS10 (Fig. 3) with a pH of 4.9. The WHO Minimum pH value is 6.5. According to **Sabrina *et al.* (2013)** at low pH, water can be corrosive and cause damage to equipment, since it can increase metal leaching from pipes and fixtures, such as copper and lead lined. Low pH values indirectly affect human health by attacking the mucous membranes of cells **(Nishtha *et al.*,**

2012). The heavy metals released by the pipes into water can equally have adverse consequences on the water quality and the consumers. Damaged metal pipes within the well due to acidic pH values can also lead to aesthetic problems, causing water to have a metallic or sour taste **(Sabrina *et al.*, 2013)**.

Electrical conductivity (EC) and Total Dissolved Solids (TDS)

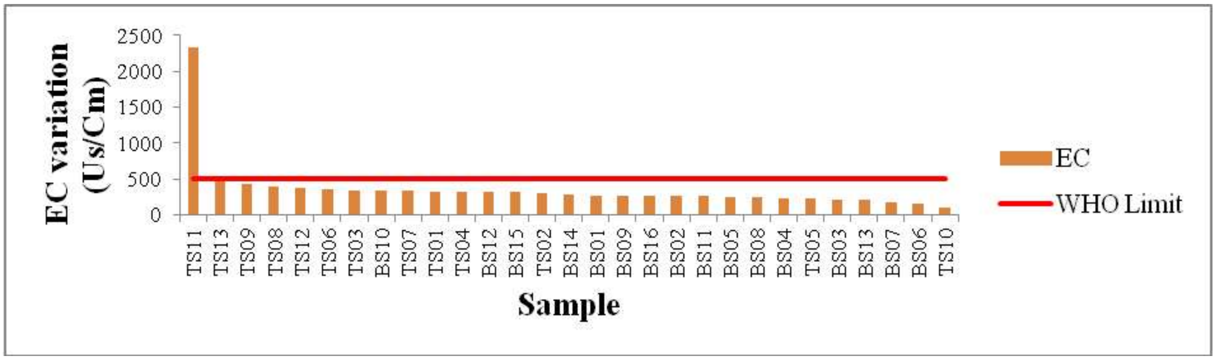


Figure 4: Variation of EC in the samples

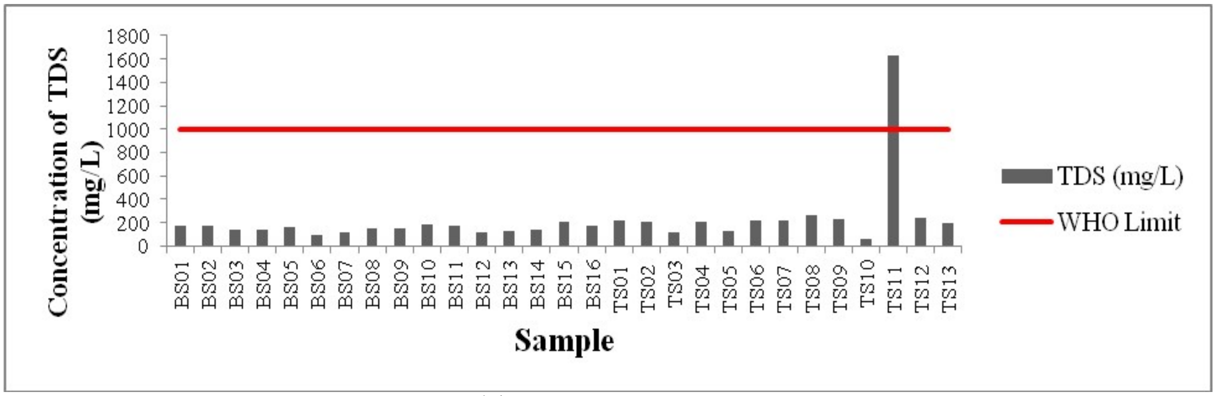


Figure 5: TDS variation in the samples

Two samples (TS11 and TS13) recorded EC values above the WHO standard of 500µS/cm (Fig. 4). TDS values ranged from **61 mg/L** to **1630 mg/L** (Table 1 & 2) and following Todd's (1980) water classification on the basis of TDS values, 28 samples had values < 1000 classifying them as fresh water while 01 sample (TS11) had value >1000 classifying it as brackish water; and being the only sample that fell outside the WHO permissible limit of 500mg/L (Fig. 5). The sample, TS11 with a high EC value (>1000) is a borehole found in a creek (<5m from the ocean) and the high EC could be attributed to sea water intrusion based on the proximity of the borehole to the sea. The electrical conductivity of water estimates the total amount of solids dissolved (TDS) in it. The concentration of TDS is related to EC which increases as TDS increases.

The inter-linkage between TDS and EC observed in this analysis is a similar result to that of **Shigut *et al.* (2016)** who carried out a separate assessment of borehole and spring water in Ethiopia and observed that TDS and EC of borehole water were inter-linked. Moreover, increase in TDS and EC increases the corrosive nature of water. Unusual taste, odour and feel problems usually due to TDS and higher EC indicate the presence of dissolved minerals (WHO, 2011).

Turbidity

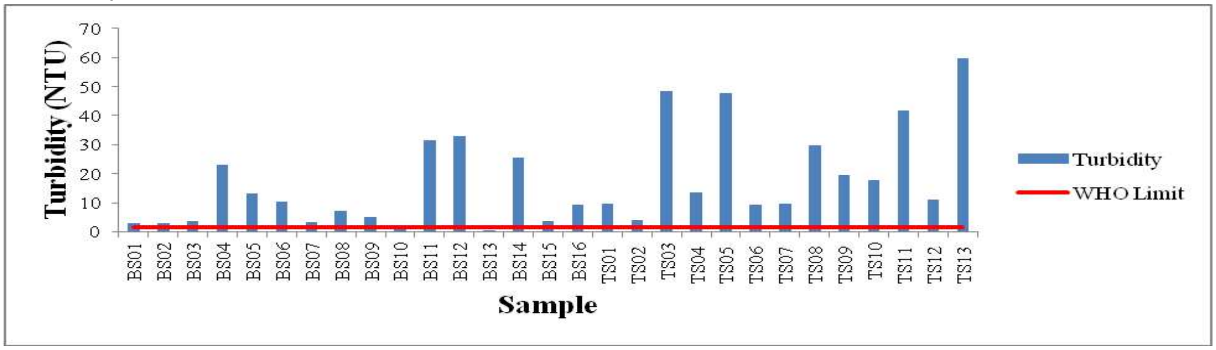


Figure 6: Variation of turbidity in the samples

Turbidity is one of the important physical parameters for water quality. It is indicative of the presence of suspended solids in water and causes the muddy or turbid appearance of the water body (WHO, 2017). **BS10** and **BS13** are the only two samples that registered turbidity values within the WHO permissible limit of **1.5NTU** (Fig. 6). This result goes to confirm the observations made during field work where most of the boreholes had turbid water. Turbidity of water can possibly be due to underground clay contamination, presence of inorganic particulate matter and non-soluble metal oxides. Based on the evaluation of turbidity, all the boreholes except BS10 and BS13 are not good sources for drinking water according to the WHO standard as high turbidity is an indication of increased TDS which might include microorganisms like bacteria and other parasites and even increased concentration of minerals **(Shen *et al.*, 2008; Oluyemi *et al.*, 2010)**. Excessive turbidity can protect pathogenic microorganisms from effects of disinfectants and consumption is a risk to human health **(Singh *et al.*, 2013; Tiwari and Singh, 2014)**. The high turbidity observed in some boreholes in this study could be resulting from corrosion due to the use of a hand pump. Corrosion may cause permeability of the hand pump such that soil particles seep into the water thereby causing high turbidity levels **(Ibe et al., 2002)**. Moreover, the loose and porous soil nature of the area can easily allow seepage of contaminants.

The microbial quality of the water

A wide range of microorganisms can be present in drinking water and it is often impossible to test for all of these microorganisms (WHO 2011). However, to monitor microbial quality of drinking water, certain indicator microorganisms can be measured to test for faecal contamination as is the case with the present study where the presence of common bacterial contaminants in the borehole water samples (*E.coli, Salmonella spp*) were studied.

Total Coliforms

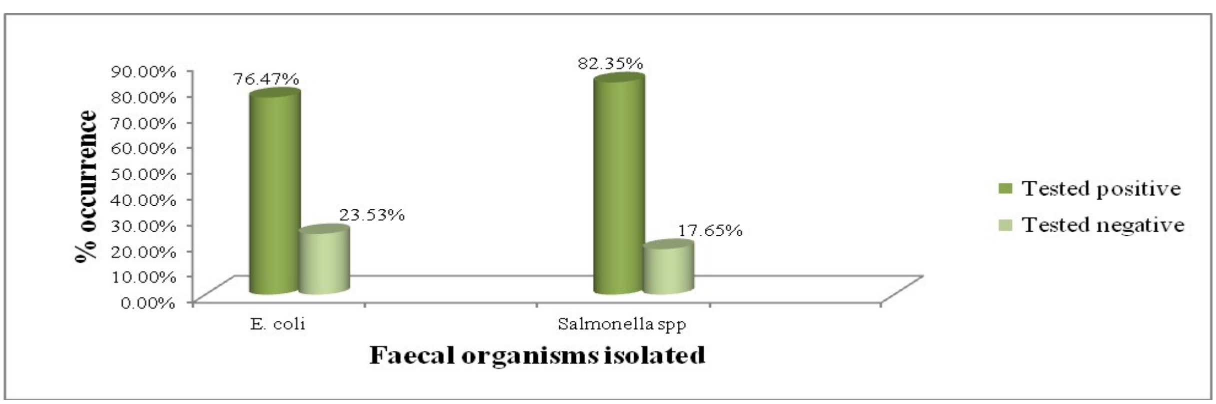


Figure 7: Percentage occurrence of faecal coliforms in water samples

There was a considerable variation in the bacteriological quality of the water samples from the 29 boreholes. The total coliform bacteria count ranged from 0 CFU/mL to 3x10^3 CFU/mL (Table 1&2). Overall, 21 out of the 29 (72.41%) samples tested exceeded the recommended 0.0 CFU/100 mL for coliforms by the WHO, indicating the presence of bacterial contaminants in the borehole water. Furthermore, many more boreholes in Buea had higher coliform numbers than those in Tiko (Table 1&2). This is probably due to the fact that the public boreholes in Tiko were funded by Government and it is a usual procedure in their protocol to systematically disinfect the borehole before it is put into public use. This might have accounted for the low coliform counts obtained from the Tiko samples. This is not the case in Buea where most of this practice is inexistent.

Excess coliforms may give an indication of the presence of other pathogens, which could cause waterborne diseases such as typhoid fever, hepatitis, gastroenteritis and dysentery **(Lawson 2011)**. Therefore, the presence of coliforms in infected boreholes renders the water unfit for human consumption, unless it is chlorinated. **Temgoua (2011)** also detected high faecal coliform contamination of borehole water in his study on alternative sources of drinking water in Dschang Municipality, Cameroon. Similar results were also obtained in separate studies on borehole water quality by **Adogo *et al* (2015)** on the bacteriological and physiochemical analysis of borehole water in Auta Balefi Community, Nigeria; **Palamuleni and Akoth (2015)** in the physico-chemical and microbial analysis of selected borehole water in Mahikeng, South Africa and **Saana *et al.* (2016)** on the assessment of the quality of groundwater for drinking purposes in the upper west and northern Regions of Ghana.

Isolation of faecal coliforms

E. coli and *Salmonella spp* were effectively isolated in 10 (58.82%) out of the 17samples (Table 1 &2) that were sub-cultured. *E. coli* was isolated in 76.47% of the test samples while *Salmonella spp* was isolated in 82.35% (Fig. 7). The isolation of *E. coli* and *Salmonella spp* (Table 1&2) in samples from borehole waters intended for human consumption is generally unacceptable and thus is a great cause for concern. These isolates may pose severe health complications to humans in future especially if they harbour virulent gene determinants, like *E. coli* O157:H7 and *E. coli* O104:H4 that have been reported to cause diseases in humans **(Ateba and Bezuidenhout, 2008)**. The presence of *Salmonella and Escherichia* suggests possible fecal contamination. Similar results were obtained by **Adogo *et al.* (2015), Palamuleni and Akoth (2015)** who respectively detected these organisms in separate studies on borehole water in Nigeria and in South Africa.
In a study on drinking water quality and prevalence of Cholera in Ndirande Malawi, the authors observed that pit latrines have the potential to contaminate groundwater **(Kamanula *et al.*, 2014)**. This might account for some of the cases in the study area where boreholes, around settlement zones, were found in close proximity to pit latrines (<45m); garbage sites; cemeteries, suck-away pits and septic tanks High water tables here could receive high loads of enteric bacteria through percolation, thus contaminating the drinking water sources. **Orji *et al.* (2006)** and several others have reported similar findings and recommended that household boreholes should be sited far away from suck-away pits and latrines.

All the boreholes in Buea were electrically powered such that the water is pumped into pipes for distribution. Though the type of pipes used was not assessed, it is possible that poor quality pipes can get rusty and affect the quality of water by allowing seepage and accumulation of microbial contaminants into the borehole. **Ekelozie *et al.* (2018)** in a study on the evaluation of *Salmonella spp* in water sources in Anambra State attributed the high prevalence of contamination in private boreholes to the fact that private individuals have little or no knowledge on the importance and role of depth in water sanitation. This observation affirms the field information gotten in the present study where most borehole owners just believed on the potability of groundwater irrespective of how shallow or deep the borehole was. They had little or no knowledge of the role that depth and other environmental factors had to play in ensuring water quality.

Though the average depth of the boreholes was 45m, the presence of microbial contamination could have been as a result of the fractured nature of the aquifers. Generally, microbial contamination from surface sources is removed within the first 30m of depth as water percolates through saturated sand and non-fissured rock and in unsaturated zone, no more than 3m may be necessary to purify groundwater **(Lewis *et al.*, 1982)**. However, in fractured aquifers, as may be the case in the present study area, microbial contaminants can rapidly pass through the unsaturated zone to the water table as equally described by **Moyo (2013)**.

It is important to emphasize here that public awareness is necessary on the dangers associated with constructing boreholes especially within households, where these facilities must be sited at appropriate distances away from pit latrines, garbage sites, septic tanks and suck-away pits to prevent infiltration and contamination of the groundwater. Regular monitoring and periodic treatment of the borehole water with chlorine is also recommended as an essential aspect that can improve on its quality

Conclusion

In this study 46 water samples of groundwater were collected from 29 boreholes in different locations of Buea and Tiko subdivisions and assessed for physical and microbial quality. Five (05) selected physical parameters (Temperature, pH, Turbidity, EC, TDS), were analyzed to assess the quality of the groundwater from these boreholes and their suitability as potable drinking water with respect to the WHO guidelines. The results of the physical parameters assessed showed that the majority of the samples were found to fall within WHO (2011) drinking water guidelines while for the turbidity, only two samples were compliant. The results of the microbial quality analysis indicated a total coliform range of $1x10^{0}$CFU/ml to $3x10^{3}$CFU/ml in more than 50% of the samples, while 72.41% exceeded the recommended 0.0 CFU/100 ml for total coliforms by the WHO. Faecal coliforms; *E. coli* and *Salmonella spp* were identified as the common microbial contaminants of the water from these boreholes. These results and interpretations thereof from the study have revealed that the microbial quality of groundwater from boreholes in the study area is a cause for concern in contrast to the physical properties. This calls for awareness creation and proper investigation of the sources of contamination.

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