Physico-chemical Assessment of Drinking Water with Special Emphasis on Fluoride Concentration in the Akatsi-North district in the Volta Region of Ghana

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Abstract

The present article has emerged from investigation into the water situation in three villages in the Akatsi-North district, to test the extent to which expectations of the United Nations (UN) Resolution 64/292 stipulations have been met in this part of the Volta region of Ghana. Thirty-six water samples were collected from twelve different boreholes (three villages) in the Akatsi-North district and analysed for their physico-chemical parameters using appropriate certified and acceptable international standards. Most of the physico-chemical parameters measured were within WHO guidelines for quality drinking water. The results showed that groundwater from two of the three villages were soft with pH ranging from 6.3 to 7.9. Cadmium concentrations for the groundwater samples analysed were above the critical value of 0.003 mg/L. Lead and nickel were not detected while the concentrations of phosphate (0.50 – 0.53 mg/L) and copper (0.32-0.37 mg/L) provided basis for the incidence of gastrointestinal and/or purgative effects experienced by most inhabitants prior to questionnaire analysis. Iron concentrations recorded for the three villages were within the ranges of 0.005-0.130mg/L, 0.13-0.23 mg/L, and 0.85-1.41 mg/L for Ave Xevi, Ave Afiadenyigba and Ave Etekorfe respectively. Mean concentrations of Ca^{2+}, Mg^{2+}, CO_3^{2-}, and total alkalinity obtained for the three villages were (112, 168, 517) mg/L, (68, 112, 208) mg/L, (49, 80, 256) mg/L, and (220, 260, 380) mg/L respectively. Fluoride concentrations were low (0.07 mg/L and 0.16mg/L) for two of the three villages which may be responsible for the incidence of tooth decay among the inhabitants.

Introduction

While the implementation per se of the right to clean water, as proposed by the UN Resolution 64/292 is devolved to local and national levels, World Health Organisation (WHO) specifications of *sufficiency, safety, acceptability, physical accessibility, and affordability* open the monitoring of improvements or otherwise to multiple possibilities (UNDP, 2004). Just the criterion of acceptability encompasses, amongst other things, the colour, odour, and taste of the water for each personal and domestic use (UNDP, 2006). Thus, each major criterion, as stipulated by WHO is, multinational and complex. Water is a polar inorganic compound that is tasteless and odourless at room temperature. This simplest hydrogen chalcogenide is by far the most studied chemical compound and is described as the "universal solvent" due to its ability to dissolve many substances. It is believed to be the most abundant chemical compound on earth and is required by almost all living organisms for growth and development (Helmenstine *et al*., 2018). Water can be put into two broad forms; that is, surface water and groundwater.

Groundwater and Surface water are fundamentally interconnected which makes it difficult to separate the two. Among the factors determining the quality of natural waters, particularly groundwater, are the chemical compositions of rocks (Van der Merwe, 1962). An interaction between these chemical components in rocks lead to soil formation.

One of the most commonly used forms of groundwater comes from unconfined shallow water table aquifers (Layperson's Guide to

Groundwater, 1993). These aquifers are major sources of domestic and irrigational activities. The suitability of groundwater for different purposes depends upon its intrinsic quality which reflects inputs from the atmosphere, soil, and rock weathering, as well as from anthropogenic activities (Jayaprakash M. *et al*., 2015). The value of groundwater lies not only in its widespread occurrence and availability but also in its consistent good quality (Rajmohan *et al*., 2000; UNESCO, 2000). One of the vital constituents of ground water is fluoride. Its occurrence is due to weathering and leaching of fluoride-bearing minerals from rocks and sediments. Fluoride levels less than 0.5 mg/L cause dental caries, levels between 0.5 mg/L to 1.5 mg/L are beneficial in promoting dental health by reducing dental caries, whereas higher concentrations (> 1.5 mg/L) may cause fluorosis (IS-10500:2012; WHO, 2006).

Borehole water, a groundwater source, has become the most widely used source of water dating from ancient China (202 BC- 220 AD); the Han dynasty used deep boreholes, reaching as deep as 600 meters (Loewe, 1968). In a borehole, water fills the spaces between the rocks and soils in the unconfined zone making an aquifer (Driscoll, 1986). Like all the other districts in the Volta Region, the Akatsi-North District depends solely on groundwater for domestic activities, yet very little quality data on the groundwater in this area is currently available. To fill in this gap, it is important that studies be carried out at Ave Xevi, Ave Etekorfe and Ave Afiadenyigba within the Akatsi-North District of the Volta region of Ghana.

Public ignorance of the environment and related considerations, indiscriminate disposal of increasing anthropogenic wastes, unplanned application of agrochemicals, and discharges of improperly treated sewage have resulted in the deterioration of surface and subsurface water (Singh and Hasmain, 1998; Mitra *et al*., 2007; Kumar *et al*., 2008; Ishaku, 2011). This has compelled the people of Akatsi-North District to resort to borehole as their main water supply. This, however, has not curbed all the problems associated with their water supply. The inability of the Ghana Water Company to adequately check the safety of the water and its suitability for consumption has been a major challenge.

For the purpose of health and well-being of the people, there is the need for them to drink good quality water and, thus, the need to ascertain the quality of the drinking water in the study area (Ifatimehin and Musa, 2008; Arshid *et al*., 2011). The present study aims at determining the concentrations of selected trace elements (Cadmium, Iron, Copper, Lead, and Nickel), and some other physicochemical parameters of water samples collected and to ascertain the level of fluoride content.

The overall goal of this study is to ascertain the safety of borehole water within the Akatsi-North District, its suitability for human consumption, and any tooth related disease associated with concentration of fluoride in the water. The study is also expected to equip the authority responsible with an in-depth knowledge of the quality of borehole water in the district for them to institute adequate treatment measures if necessary.

Material and methodology

Study area

The Akatsi-North district is one of the newly created districts in the Volta region of Ghana. Fig 1 shows a geographical map displaying sampling sites within the district. The coordinates of the District are latitudes 06°15'N and 06°20’30” N and between longitudes 0°46’0” E and 0°57’0” E. The present study deals with the analysis of water quality in terms of physicochemical parameters with emphasis on fluoride content from boreholes in the Akatsi-North District.

Akatsi-North district

The Akatsi-North district is located in the South-Eastern part of the Volta Region of Ghana and has a land area of 314.15 square kilometres. It is bounded on the south by Akatsi-south and to the east by Ketu north districts. The district is bounded on the west by Adaklu and shares boundary with Agortime-Ziope district and the Republic of Togo to the north. The population of the district according to the 2010 population census is 29,777 representing 1.4 percent in the region. The main agricultural activities within the district are crop production and livestock rearing. However, rapid population growth has affected land cover, wildlife, soil and water resources (Composite budget, 2016). The land is made up of peculiar coastal savanna soil, laterites, and tropical black soil (Tay, 2007). The average temperature varies during the year by 3.5 °C with minimum values ranging from 21.8 °C to 23.8 °C and maximum from 27.9 °C to 32.5 °C. The district experiences a minimum rainfall in January and maximum rainfall in May, June and July. The average annual rainfall is 994 mm.

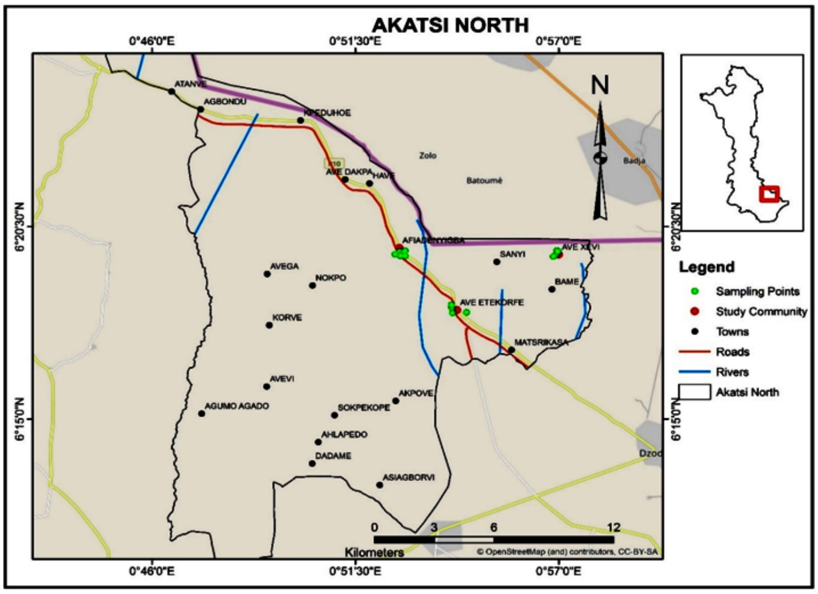

Figure 1: A map showing sampling sites within the Akatsi-North district in the Volta Region of Ghana

Sample collection

The sampling locations for the groundwater are presented in Fig 1. Thirty-six groundwater samples from twelve different locations (three villages) within the Akatsi-North District were collected. All the sampling points were selected within the chosen villages. Sampling bottles were thoroughly washed and rinsed with deionised water. At each sampling site, water from the boreholes were allowed to run for two to three minutes before collection, the sampling bottles were rinsed with water from the boreholes and filled without allowing the interference of atmospheric oxygen (Nielsen *et al*., 2000). Water samples for trace metal analysis were collected in plastic vials and fixed with 5 mL of concentrated nitric acid. Water samples collected on the field were stored in an ice chest containing ice. Chemical parameters of the water samples were determined at the Ecological laboratory of the Institute of Environment and Sanitation Studies (Ecolab), and the Chemistry Department, University of Ghana, Legon.

Analytical procedure

The parameters determined were Nitrate-Nitrogen, Phosphate-Phosphorus, Total Alkalinity, Total Hardness, and Total suspended solids, Chemical Oxygen Demand, Chloride, Fluoride, Calcium, Magnesium, and Sulphate. All the laboratory measurements were done under an established standard method (APHA, 1995; WHO, 2005 and UNESCO/WHO 1978). Temperature, pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), Salinity, and Total Dissolved Solids (TDS) were measured in situ using HANN Temp/pH/EC/TDS/DO/ Salinity meter (Model HI 9930). Parameters such as Chemical Oxygen Demand (COD) was determined by employing complexometric titration (Baumann, 1974). Chloride (Cl^-) was determined titrimetrically with standard $AgNO_3$ solution using potassium chromate as indicator (Tay, 2012). Total Hardness (TH) as $CaCO_3$, and Calcium (Ca^{2+}) were analysed titrimetrically (back titration), with standard EDTA at pH 10 using Eriochrome Black-T as indicator. Magnesium (Mg^{2+}) was calculated by taking the differential value between the Total Hardness (TH), and Calcium (Ca^{2+}). Carbonate (CO_3^{2-}) concentration was calculated from Alkalinity using titration method (strong acid titration).

Concentrations of phosphate, Nitrate, and Sulphate were determined using Ultra-Violet Spectrometry following Bartošová, Michalíková (2012) method. Fluoride concentration was determined using Sulfanilic acid-azochromotrop; 1,8-Dihydroxy-2-(4-sulfophenylazo) naphthalene-3,6-disulfonic acid trisodium salt (SPADNS) reagent following Marques and Coelho (2013) method. In this method, 25 mL of the water sample was pipetted into dry sample cell and 5 mL of SPADNS reagent added and swirled to mix. After allowing a minute of reaction period, the mixer in the sample cell was placed in a sample holder of the spectrophotometer and the concentration was determined at 580 nm wavelength.

Standard methods for the examination of water and waste water from the US Environmental Protection Agency (USEPA, 1986) were used for the determination of trace elements. All elements were analysed using atomic absorption spectrophotometer (VARIAN AA 240FS). Lenntech WHO/EU drinking water standards were used for comparison. The parameters were determined three times and the mean taken. The concentrations were determined in mg/L.

Quality control and quality assurance

To minimize random error, prevent contamination of samples, and ensure the accuracy of results, sampling protocols were observed (Alpha, 2005). Triplicate analyses were done for every determination to minimise random error and ensure reproducibility. Each reported result was the average value of triplicate measurements. Standard Reference Materials (SRMs) used were treated as the samples themselves to check for efficiency of the equipment used and further validate the procedure. Also, Microsoft Excel 2016 and Statistical Package for Social Scientists (SPSS) were employed in the computation and statistical analyses of results. The results obtained were compared with the WHO, United State Environmental Protection Agency (USEPA) and Ghana EPA standards for natural and effluent water.

Results and discussion

Demographic status of respondents

This section presents information about respondents in a survey on the usage and quality of the water in the selected villages in the Akatsi-North district. The demographic status of the three communities (Ave Xevi, Ave Etekorfe, and Ave Afiadenyigba) interviewed revealed that the majority of respondents were the youth, while the minority formed the adult and highest age bracket. Most of the respondents had attained at least basic education while few had no formal education. The main occupations of the inhabitants are farming, trading and teaching (Table 1). The female respondents use the water for domestic activities more than their male counterparts (Table 2). The water is readily available but becomes scarce during the dry season. It becomes dirty during the rainy season, making it unsuitable for drinking; its inability to lather with soap and the formation of scales in vessels on boiling are due to its hardness (Table 3). The water is basically used for cooking, drinking and washing purposes. The youths are more prone to tooth decay/ache as compared to the adults and highest age bracket (Table 4).

Physical parameters

The temperature was found to be in the range of 28.7 ^{0}C - 34.0 ^{0}C during the study (Table 5-7&14). The higher value of water temperature observed in the present study could either be attributed to intense sunlight which prevailed during the period of investigation or high concentration of dissolved solids (Shyamala *et al.*, 2008) (Fig 5).

Electrical conductivity is a measure of the capacity of water to conduct electric current. Electrical conductivity value of the study area varied from 890 - 961µS/cm for Ave Xevi, 1250 - 1800 µS/cm for Ave Afiadenyigba, and 1385 - 1890 µS/cm for Ave Etekorfe with mean values of 920, 1500, and 1600 µS/cm respectively (Table 5-7&14). Generally, groundwater tends to have high electrical conductivity due to the presence of a high amount of dissolved solids (Surekha *et al.,* 2015), and this was evident from the results for Total Dissolved Solids (TDS) (Fig 2, 3&4). TDS is the term used to describe the inorganic salts and small amounts of organic matter present in water. High values of TDS (whose principal constituents are usually calcium, magnesium, sodium, and potassium cations, and chloride, sulphate, nitrate, and carbonate anions) typically indicate hard water and may lead to scale build-up in pipe, and aesthetic problems such as bitter or salty taste (Surekha *et al.*,2015). TDS values of two of the three villages in the district exceeded acceptable limit of 500 mg/L (IS-10500:2012; WHO, 2006) with values ranging from 401-436 mg/L for Ave Xevi, 658-720 mg/L for Ave Afiadenyigba and 690-835 mg/L for Ave Etekorfe (Table 5-7&14).

Turbidity may not have any direct effect on human health but can provide a medium for microbial growth. The observed values of turbidity in the study area are between 0.8 to 2.4 NTU with values ranging from 0.8-1.4 NTU for Ave Xevi, 0.4- 1.6 NTU for Ave Etekorfe, and 1.2-2.4 NTU for Ave Afiadenyigba. In some location of the study area, turbidity values exceeded the acceptable limit of IS-10500 standard of 1.0 NTU, which is indicative of the presence of suspended solids (TSS) and colloidal particles (Prasad *et al.*, 2015), (Table 5-7&14).

High concentrations of suspended solids cause many problems for stream health and aquatic life. High TSS can block light from reaching submerged vegetation. As the amount of light passing through the water is reduced, photosynthesis by plants in the water slows down. Reduced rate of photosynthesis causes less oxygen to be released into water by the plants. TSS values of the study area range between 0-2.8 mg/L with mean values of 1.0 mg/L, 2.2 mg/L, and <0.06 mg/L for Ave Xevi, Ave Etekorfe, and Ave Afiadenyigba respectively. High TSS can cause an increase in surface water temperature, because the suspended particles absorb heat from sunlight. This results in the decrease of DO level (Fig 5). The DO values recorded at the study area were within the ranges of 10.7 to 18.9 mg/L with mean values of 17.02 mg/L, 11.63 mg/L, and 12.00 mg/L respectively for the three villages. Experimental results (for DO) agreed with the temperatures of the water samples collected from the three villages.

In the present study, Chemical Oxygen Demand (COD) values of the various groundwater samples obtained for the three villages within the district were in the ranges of 56 to 175 mg/L. These values were within WHO permissible limit of 250 mg/L for quality drinking water (WHO, 2006) (Fig 6).

Chemical parameters

pH is an important parameter in a water body

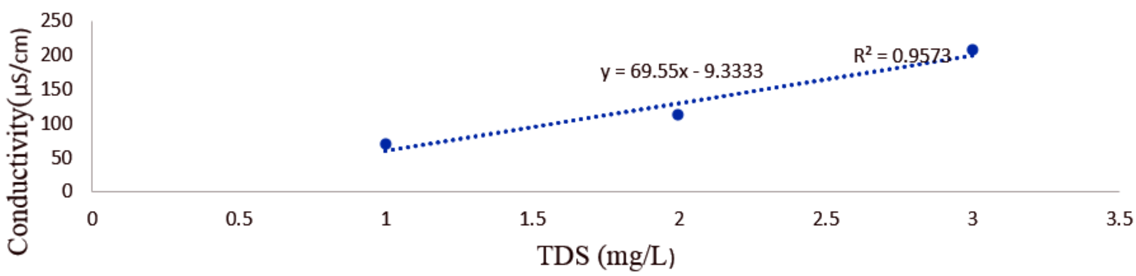

Figure 2: Correlation between Electrical conductivity and Total Dissolved Solids in groundwater in Ave Afiadenyigba.

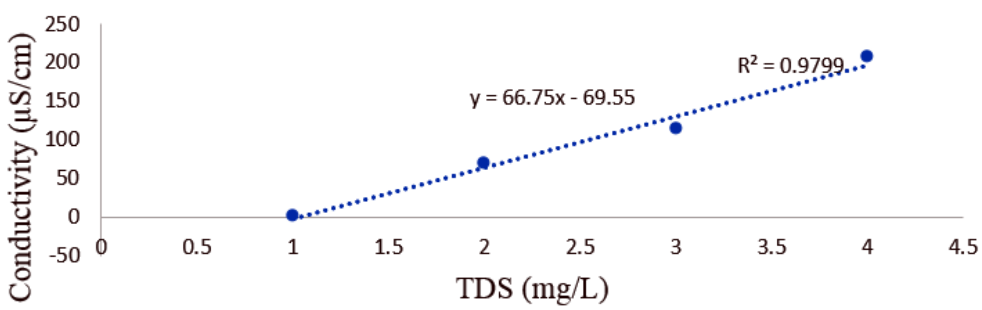

Figure 3: Correlation between Electrical conductivity and Total Dissolved Solids in groundwater in Ave Xevi.

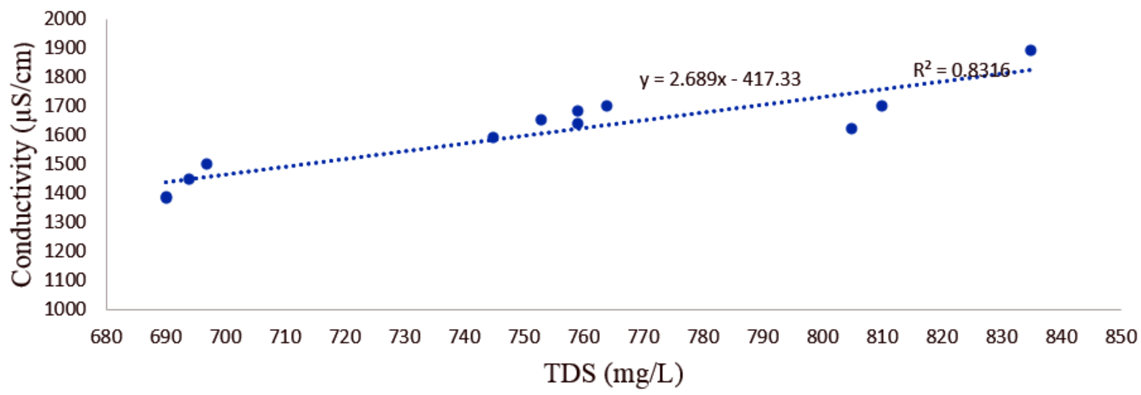

Figure 4: Correlation between Electrical conductivity and Total Dissolved Solids in groundwater in Ave Etekorfe

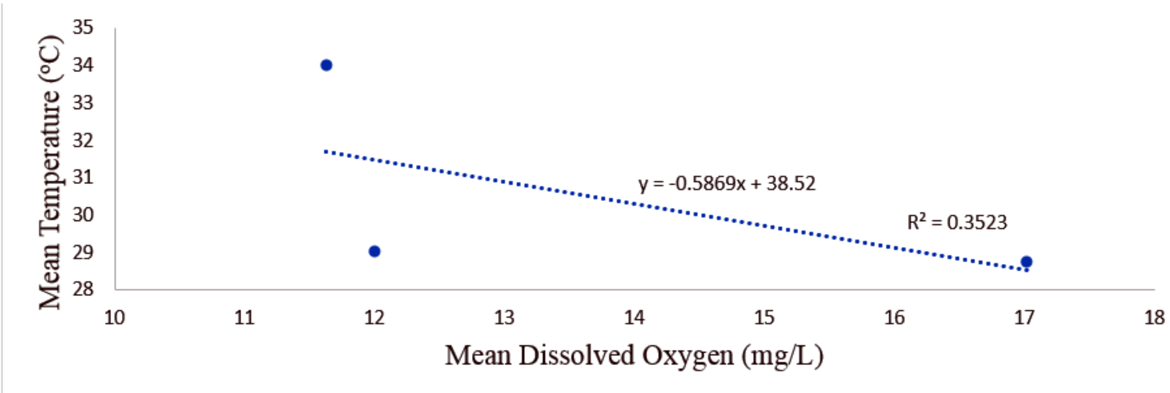

Figure 5: Correlation between Temperature and Mean Dissolved Oxygen in groundwater in the Akatsi-North district

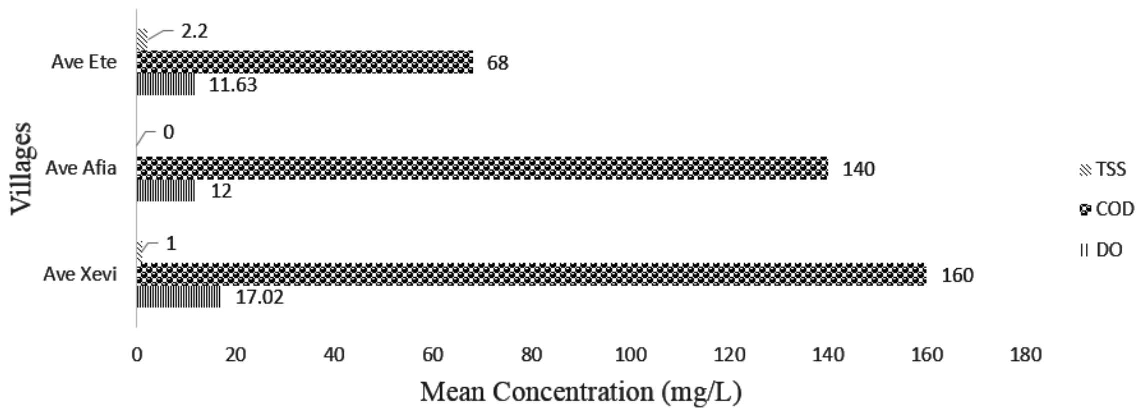

Figure 6: Cluster graph of mean concentration of DO, COD and TSS for the study area

since most of the aquatic organisms are adapted to an average pH and do not withstand abrupt changes (Mini *et al.*, 2003). The pH of the boreholes in Ave Xevi varied from 6.3 to 6.9; 6.5 to 7.5 for Ave Afiadenyigba while boreholes in Ave Etekorfe recorded pH varying from 6.3 to 7.9. Boreholes in the district generally had pH range of natural water (Stumn *et al.,* 1981). Ave Xevi recorded the minimum mean pH of 6.6 while Ave Etekorfe recorded the highest mean pH of 7.2 for the study area (Fig 7; Table 8-10&14). These values were found to be within the permissible limit for quality drinking water (WHO, 2006).

The major cations that cause hardness of water are magnesium, strontium, calcium and manganese ions. Water hardness in Ave Etekorfe varied widely with values ranging from 1023 to 1198 mg/L and mean 1120mg/L. However, boreholes in Ave Xevi and Ave Afiadenyigba recorded a narrow range of values from 258 to 306 mg/L, and from 407 to 441 mg/L with mean values as 280.4 mg/L and 430.1 mg/L respectively. The results indicate that groundwater in the study area exceeds the acceptable limit of 200 mg/L. However, boreholes in Ave Xevi and Ave Afiadenyigba were within the maximum acceptable limit of 600 mg/L while that of Ave Etekorfe exceeded this limit (ISS-10500:2012). Magnesium and Calcium concentrations of the study area increased respectively from Ave Xevi (55-80 mg/L, and 102-124 mg/L) through Ave Afiadenyigba (103-125 mg/L, 149-189 mg/L) to the highest in Ave Etekorfe (196-216 mg/L, and 501-530 mg/L). The high values for total hardness explain the higher concentration of dissolved Magnesium and Calcium in the groundwater of Ave Etekorfe than in Ave Xevi and Ave Afiadenyigba (Fig 8; Tables 8-10&14). The alkalinity of groundwater in the study area exceeded the ISS-10500 and WHO acceptable limits for drinking water standard with values ranging from 206 to 281 mg/L. Ave Etekorfe recorded the maximum mean concentration of 264.8 mg/L, while Ave Xevi recorded the minimum mean concentration of 220.1 mg/L (Table 14).

Groundwater from the three villages within the study area recorded high phosphate ion concentration exceeding acceptable limit for quality drinking water with values ranging from 0.39-0.69 mg/L for Ave Xevi, 0.41-0.62 mg/L for Ave Etekorfe, and 0.35-0.60 mg/L with means 0.53 mg/L, 0.50 mg/L, and 0.51 mg/L respectively. High concentration

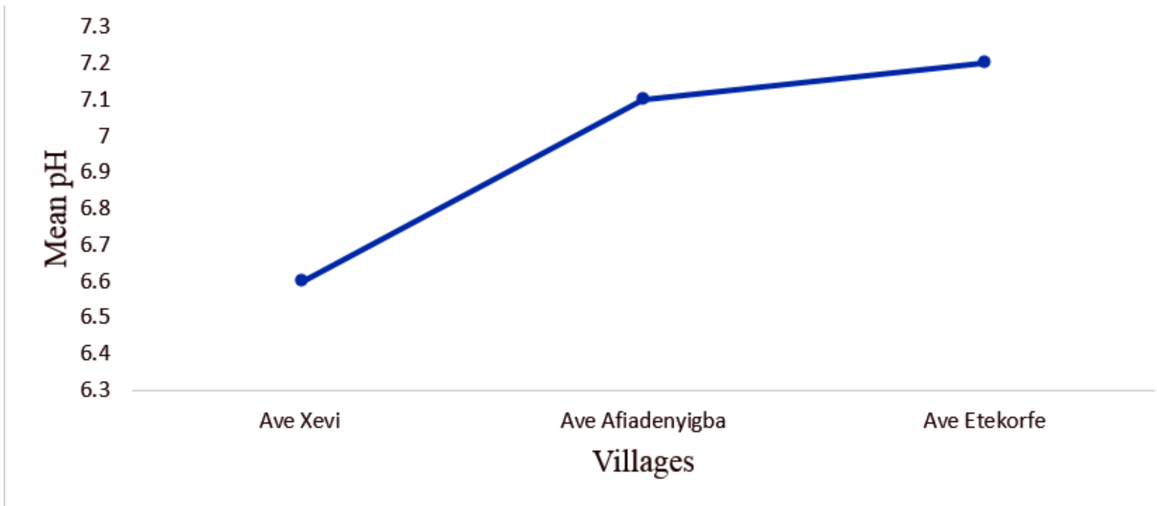

Figure 7: Variations in pH within the three villages under study

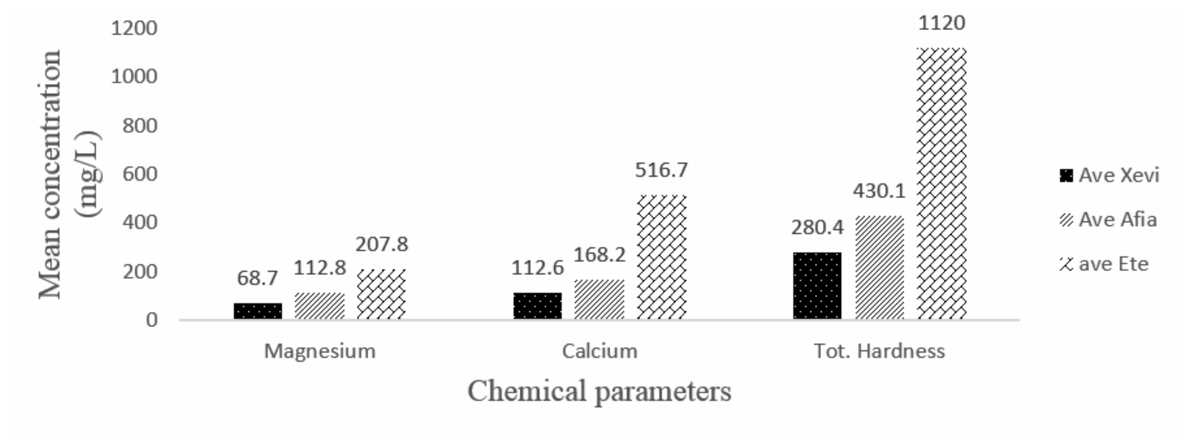

Figure 8: Variation in mean concentrations of physicochemical parameters contributing to water hardness

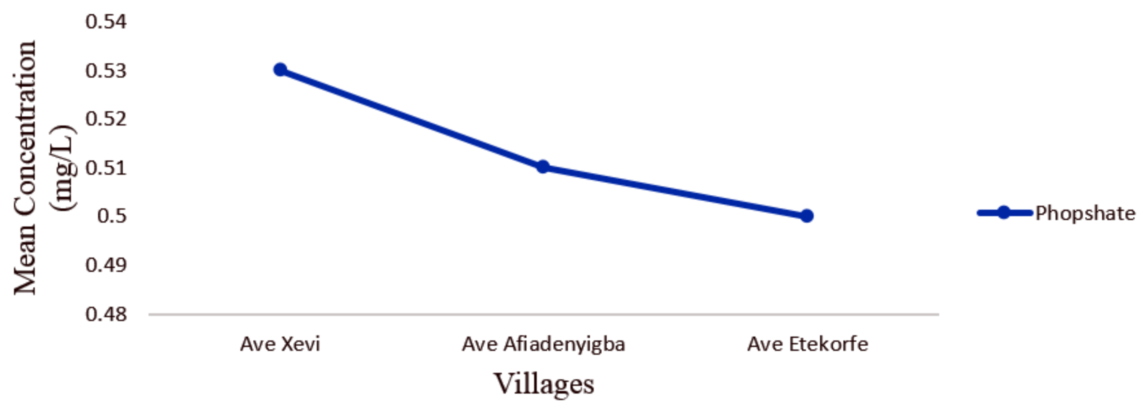

Figure 9: Mean concentration of Phosphate in the study area

of phosphate in water contributes greatly to gastric irritation and/or purgative effect. Fig 9 gives the trend in the phosphate concentration of the three villages. However, sulphate and nitrate concentrations determined were within the acceptable limit of 200 mg/L and 45 mg/L respectively. Ave Xevi recorded the minimum nitrate concentration of 2.04 mg/L (with range 1.3-3.0 mg/L), and Ave Etekorfe recorded the maximum concentration of 4.08 mg/L (with range 3.2-4.9 mg/L). Sulphate concentration varied significantly with Ave Etekorfe recording the maximum mean concentration of 164 mg/L and Ave Afiadenyigba recording the minimum concentration of 34.4 mg/L.

Fluoride is an essential element but deficiency or excess fluoride in drinking water may lead to serious health effect like dental caries/ tooth decay or dental fluorosis respectively. Concentrations below the minimum acceptable limit of 0.5 mg/L generally contribute to dental caries (WHO, 2006). Fluoride concentration determined for two of the three villages within the study area were below the minimum acceptable limit. Ave Xevi recorded the minimum mean concentration of 0.07 mg/L (with the range 0.03-0.10 mg/L) (Table 10), while Ave Afiadenyigba recorded a mean concentration of 0.16 mg/L (with the range 0.08-0.25 mg/L) (Table 9). Concentration between 0.5-1.5 mg/L is a safe limit for bone and teeth (IS-10500 Standard: 2012). Ave Etekorfe recorded a mean concentration within this range (0.60 mg/L) with values varying from 0.51-0.68 mg/L (Fig 10; Tables 8 &14).

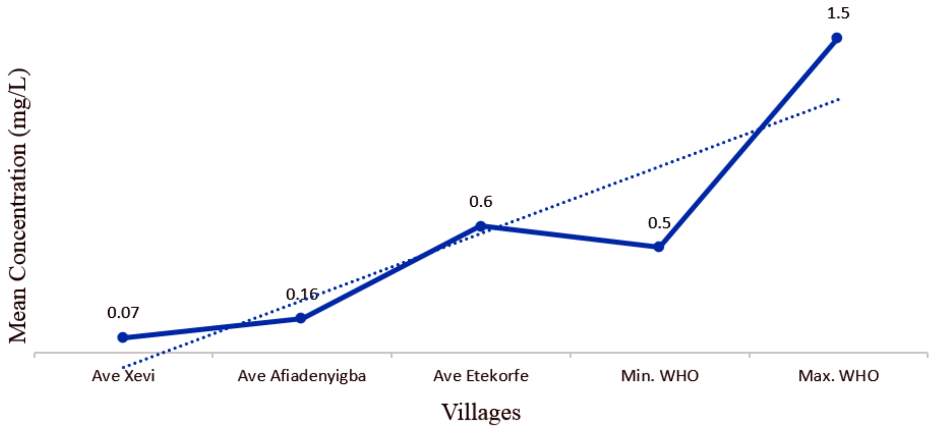

Figure 10: Variation of Fluoride concentration (mg/L) of water sampled compared with WHO standard

Groundwater contamination with trace metals is one of the most important environmental issues as most of them are toxic even at low concentration. Results for trace metal analysis in the present study show that copper, iron, and cadmium were detected while lead and nickel were not. The concentration of copper in the study area exceeded WHO and IS-10500 acceptable drinking standard of 0.05 mg/L but were within the maximum permissible limit (IS 3025: 1992) with values ranging from 0.16-0.43 mg/l for Ave Xevi, 0.18-0.42 mg/L for Ave Afiadenyigba, and 0.26-0.46 mg/L for Ave Etekorfe (Fig 11; Tables 11-13). High concentration of copper like those recorded in the present study could cause adverse health effects such as vomiting, stomach cramps, diarrhoea, and nausea (Minnesota Department of Health, 2005). However, concentration of iron (Fe) from two of the three villages were within WHO permissible limit (0.30 mg/L) with values ranging from 0.005-0.130 mg/L for Ave Xevi, and 0.13-0.23 mg/L for Ave Afiadenyigba. Ave Etekorfe recorded the highest Fe concentration within the range 0.85-1.41mg/L which exceeded WHO permissible limit for quality drinking water (Fig 12; Table 11-14). Cadmium concentration for the study area exceeded WHO and IS-10500 acceptable limit (0.003 mg/L) with concentrations varying significantly from 0.21-0.41 mg/L for Ave Xevi, and narrowly from 0-0.03 mg/L for Ave Afiadenyigba, and 0-0.04 mg/L for Ave Etekorfe (Fig 13; Tables 11-14).

Experimental results and data analysed

Concentrations of some cations (Magnesium

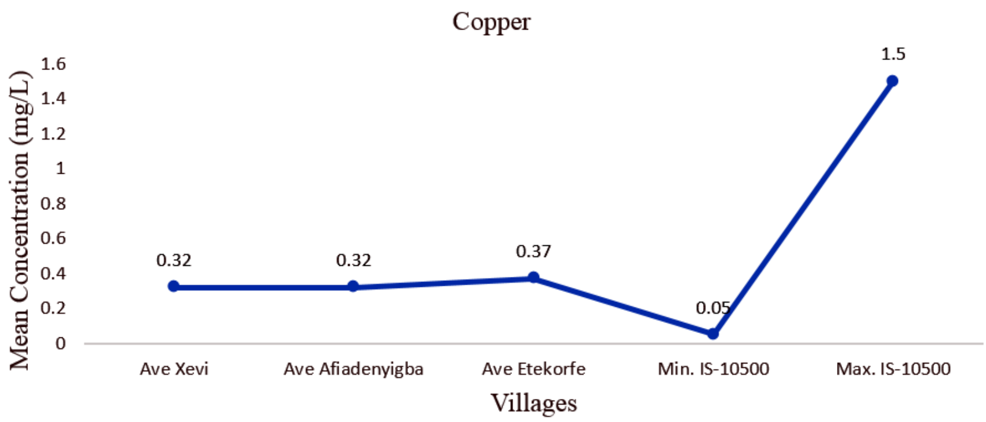

Figure 11: Bio-statistical analysis of mean concentration of Copper in boreholes from villages within Akatsi-North district compared with IS-10500 drinking standard

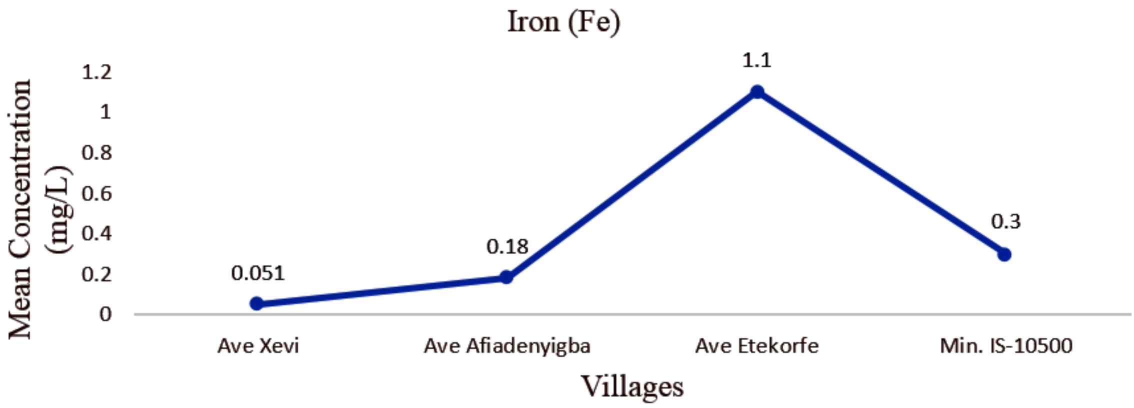

Figure 12: Bio-statistical analysis of mean concentration of Iron in boreholes from villages within Akatsi-North district compared with IS-10500 drinking standard

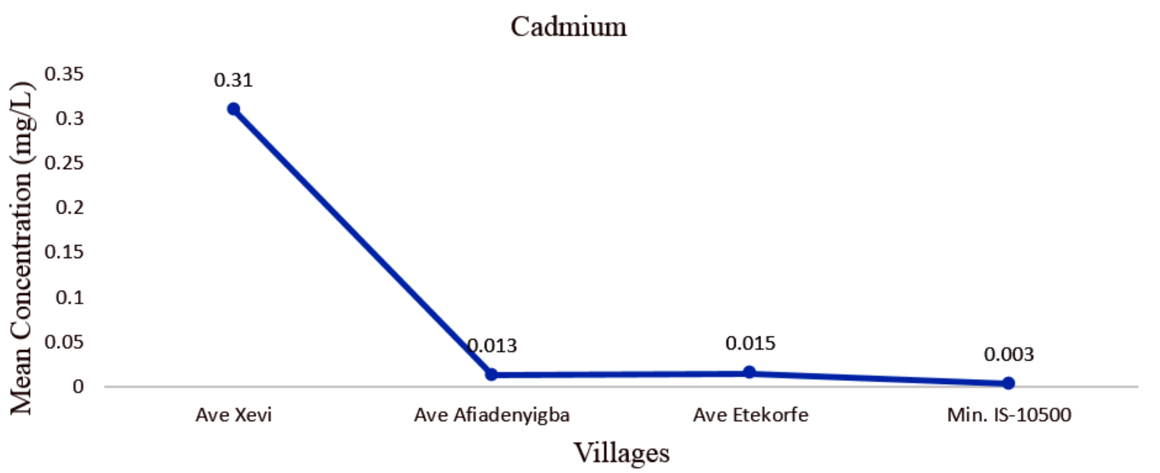

Figure 13: Bio-statistical analysis of mean concentration of Cadmium in boreholes from villages within Akatsi-North district compared with IS-10500 drinking standard

and Calcium) and some anions (Chloride and Sulphate) recorded relatively high values. The concentrations of these cations contribute greatly to the value of the total hardness which was validated by respondents' confirmation of the water being hard. High concentrations of phosphate and copper for the three villages which exceeded WHO limit may be responsible for the gastric irritation and purgative effect experienced by most inhabitants prior to response from administered questionnaires (Cocchetto *et al,* 1981). Salinity determined for the study area accounted for the salty nature of the water as posited by respondents. The fluoride content in the water might be a possible factor contributing to tooth decay among inhabitants of Ave Xevi and Ave Afiadenyigba.

TABLE 1
Demographic Status of Respondents

Variable	No. of Respondents	Percentage (%)
Ave Afiadenyigba	20	33.3
Ave Etekorfe	20	33.3
Ave Xevi	20	33.3
Total	60	100.0
Sex		
Male	16	26.7
Female	44	73.3
Level of Education		
None	9	15
Basic	30	50
High School	13	21.7
Tertiary	8	13.3
Total	60	100
Age		
16-25	8	13.3
26-35	19	31.7
36-45	9	15.0
46-55	9	15.0
56-65	7	11.7
66-75	8	13.3
Total	60	100
Occupation		
Teaching	7	11.7
Student	5	8.3
Seamstress	3	5.0
Farming	27	45.0
Others	18	30.0
Total	60	100.0

TABLE 2
Usage of Water relative to sex of Respondents

			Use of Water			
			Drinking	Cooking	Washing	Irrigation
Sex	Female	Count	36	44	37	1
		%	81.8	100.0	84.1	2.3
	Male	Count	16	16	16	0
		%	100.0	100.0	100.0	0.0

TABLE 3
Characteristics of the Water

Variable	Yes		No	
	Frequency	Percentage	Frequency	Percentage
Is the Water Salty	58	96.7	2	3.3
Does it lather easily with soap	6	10.0	54	90
Does the water form scale	52	86.7	8	13.3

TABLE 4
Ages of respondents compared to the risk of Tooth Decay/Ache

			Do you suffer from any toothache/decay	
			Yes	No
Age Groups	16-25	Count	3	4
		%	13.0	11.4
	26-35	Count	5	14
		%	21.7	40.0
	36-45	Count	4	5
		%	17.4	14.3
	46-55	Count	2	6
		%	8.7	17.1
	56-65	Count	5	2
		%	21.7	5.7
	66-75	Count	4	4
		%	17.4	11.4

TABLE 5
A summary of physical parameters analysed in groundwater samples collected from Ave Xevi in the Akatsi-North District

Sampling Sites	Temp. (^{o}C)	Turb (NTU)	Colour (Hz)	Cond. (µS/cm)	TDS (mg/L)	COD (mg/L)	TSS (mg/L)	DO (mg/L)	Sal. (ppt)
Xe_1	28.7	0.8	0	961	418	156	0.6	16.8	0.29
Xe_2	28.3	0.9	0	958	422	142	0.9	17.5	0.38
Xe_3	28.6	1.3	0	904	426	159	0.8	14.3	0.42
Xe_4	29.5	1.2	0	938	436	173	1.3	18.9	0.46
Xe_5	30.1	0.9	0	922	403	145	0.7	16.9	0.36
Xe_6	28.6	0.8	0	934	410	175	1.3	17.5	0.44
Xe_7	29.4	1.4	0	896	424	164	1.2	17.3	0.35
Xe_8	28.7	1.1	0	900	435	166	1.1	18.2	0.54
Xe_9	28.5	0.9	0	905	401	159	1.0	16.4	0.33
Xe_{10}	28.3	1.2	0	940	412	164	1.3	16.0	0.42
Xe_{11}	28.6	0.8	0	890	425	156	0.9	17.6	0.39
Xe_{12}	27.9	1.2	0	896	432	165	1.3	16.8	0.38

Xe – Ave Xevi Afia – Ave Afiadenyigba Ete – Ave Etekorfe

TABLE 6
A summary of physical parameters analysed in groundwater samples collected from Ave Afiadenyigba in the Akatsi-North District

Sampling Sites	Temp. (°C)	Turb (NTU)	Colour (Hz)	Cond. (µS/cm)	TDS (mg/L)	COD (mg/L)	TSS (mg/L)	DO (mg/L)	Sal. (ppt)
$Afia_1$	28.7	1.9	0	1250	658	135	0	11.7	0.48
$Afia_2$	27.9	2.4	0	1460	698	136	0	13.2	0.36
$Afia_3$	29.3	1.3	0	1800	720	129	0.60	11.4	0.53
$Afia_4$	29.5	1.5	0	1700	712	146	0.06	11.5	0.63
$Afia_5$	30.1	1.2	0	1485	700	151	0	10.8	0.61
$Afia_6$	28.9	1.9	0	1300	670	135	0	12.6	0.54
$Afia_7$	29.0	1.8	0	1506	685	142	0.09	12.4	0.59
$Afia_8$	29.8	1.7	0	1620	705	139	0	11.5	0.43
$Afia_9$	28.1	2.0	0	1400	688	142	0.03	12.0	0.49
$Afia_{10}$	28.7	1.6	0	1640	690	133	0	11.9	0.51
$Afia_{11}$	29.1	1.5	0	1330	678	150	0	11.9	0.34
$Afia_{12}$	29.3	1.9	0	1400	680	148	0	13.2	0.60

TABLE 7
A summary of physical parameters analysed in groundwater samples collected from Ave Xevi in the Akatsi-North District

Sampling Sites	Temp. (°C)	Turb (NTU)	Colour (Hz)	Cond. (µS/cm)	TDS (mg/L)	COD (mg/L)	TSS (mg/L)	DO (mg/L)	Sal. (ppt)
Ete_1	33.6	0.8	0	1590	745	56	1.7	12.1	0.25
Ete_2	35.6	0.6	0	1385	690	59	2.3	11.7	0.34
Ete_3	34.2	1.2	0	1450	694	69	1.3	11.4	0.38
Ete_4	32.1	1.5	0	1890	835	75	2.7	10.5	0.26
Ete_5	34.3	0.4	0	1701	764	86	2.4	12.1	0.42
Ete_6	36.5	0.6	0	1650	753	82	2.6	11.3	0.21
Ete_7	34.7	0.9	0	1680	759	58	2.8	11.9	0.31
Ete_8	33.9	1.6	0	1500	697	67	1.9	10.7	0.32
Ete_9	35.0	1.1	0	1640	759	60	1.8	12.6	0.34
Ete_{10}	33.0	0.9	0	1390	690	63	1.6	11.0	0.31
Ete_{11}	34.2	1.4	0	1620	805	75	2.7	11.3	0.25
Ete_{12}	34.8	0.9	0	1700	810	65	2.1	12.5	0.24

Temp. – Temperature Turb – Turbidity Cond – Conductivity Sal – Salinity

TDS – Total Dissolved Solid TSS – Total Suspended Solid DO – Dissolved Oxygen

TABLE 8
A summary of chemical parameters analysed in groundwater samples collected from Ave Etekorfe in the Akatsi-North District

Sampling Sites	CO_3^{2-} (mg/L)	SO_4^{2-} (mg/L)	PO_4^{3-} (mg/L)	NO_3^- (mg/L)	F^- (mg/L)	Cl^- (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	T.H (mg/L)	T.A (mg/L)	pH
Ete_1	265	156	0.41	4.70	0.54	270	196	530	1125	261	7.3
Ete_2	266	152	0.51	4.90	0.68	266	198	501	1136	259	7.6
Ete_3	269	172	0.53	4.20	0.64	271	213	523	1023	263	6.9
Ete_4	275	170	0.52	4.90	0.63	270	215	524	1156	257	6.8
Ete_5	275	165	0.62	3.60	0.65	270	209	513	1198	265	6.6
Ete_6	279	162	0.53	3.40	0.62	261	199	510	1100	267	7.3
Ete_7	230	163	0.46	3.80	0.67	263	212	519	1098	268	7.8
Ete_8	257	174	0.42	3.20	0.51	256	209	514	1126	264	7.5
Ete_9	243	159	0.43	3.60	0.54	254	216	518	1124	260	6.3
Ete_{10}	239	166	0.53	4.30	0.53	253	213	519	1123	279	7.9
Ete_{11}	238	168	0.54	4.10	0.61	269	215	526	1117	266	7.0
Ete_{12}	233	156	0.55	4.20	0.62	275	198	503	1114	268	6.9

TABLE 9
A summary of chemical parameters analysed in groundwater samples collected from Ave Afiadenyigba in the Akatsi-North District

Sampling Sites	CO_3^{2-} (mg/L)	SO_4^{2-} (mg/L)	PO_4^{3-} (mg/L)	NO_3^- (mg/L)	F^- (mg/L)	Cl^- (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	T.H (mg/L)	T.A (mg/L)	pH
Afia1	73	35	0.53	2.00	0.20	96.5	106	185	425	241	6.8
$Afia_2$	75	29	0.57	1.90	0.11	99.3	111	189	421	252	6.5
$Afia_3$	94	33	0.46	1.70	0.22	109.3	112	154	441	259	7.4
$Afia_4$	91	37	0.38	1.20	0.13	102.3	114	179	433	279	7.5
$Afia_5$	73	39	0.35	3.10	0.19	103.7	121	176	438	281	6.9
Afia6	89	43	0.45	2.70	0.10	95.3	125	162	436	268	7.3
$Afia_7$	71	46	0.48	2.30	0.21	89.5	104	168	419	243	7.5
$Afia_8$	86	38	0.56	1.60	0.25	123.1	103	149	435	245	7.2
$Afia_9$	83	41	0.55	1.40	0.09	114.3	105	153	432	261	7.0
$Afia_{10}$	74	44	0.57	1.90	0.08	103.1	117	154	407	275	6.9
$Afia_{11}$	79	35	0.59	2.30	0.17	92.4	120	176	432	254	7.1
$Afia_{12}$	76	29	0.60	2.60	0.13	90.5	115	173	441	256	7.3

TABLE 10
A summary of chemical parameters analysed in groundwater samples collected from Ave Xevi in the Akatsi-North District

Sampling Sites	CO_3^{2-} (mg/L)	SO_4^{2-} (mg/L)	PO_4^{3-} (mg/L)	NO_3^- (mg/L)	F^- (mg/L)	Cl^- (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	T.H (mg/L)	T.A (mg/L)	pH
Xe_1	43	31	0.56	2.10	0.07	56	65	114	297	231	6.3
Xe_2	63	41	0.57	1.80	0.05	81	62	106	276	229	6.8
Xe_3	57	38	0.49	1.60	0.08	66	66	121	258	219	6.7
Xe_4	48	27	0.46	1.30	0.10	69	75	113	259	218	6.6
Xe_5	55	29	0.39	3.00	0.09	65	56	103	281	224	6.9
Xe_6	51	39	0.45	2.80	0.05	73	77	106	291	228	6.3
Xe_7	53	37	0.51	2.20	0.08	71	73	102	304	230	6.5
Xe_8	52	40	0.59	1.60	0.04	55	80	120	306	215	6.8
Xe_9	39	42	0.56	1.50	0.04	58	77	124	287	209	6.7
Xe_{10}	41	46	0.58	1.70	0.03	78	65	118	275	214	6.8
Xe_{11}	43	29	0.59	2.40	0.08	80	73	114	263	206	6.4
Xe_{12}	45	33	0.61	2.50	0.05	73	55	110	268	218	6.8

F^- - Fluoride Cl^- - Chloride T.H – Total Hardness T.A – Total Alkalinity CO_3^{2-} - Carbonate ion SO_4^{2-} - Sulphate ion PO_4^{3-} - phosphate-phosphorus NO_3^- - Nitrate-Nitrogen Ca^{2+} - Calcium Mg^{2+} - Magnesium

TABLE 11
A summary of trace metals analysed in groundwater samples collected from Ave Xevi in the Akatsi-North District

Sampling Sites	Fe (mg/L)	Cu (mg/L)	Cu (mg/L)	Pb (mg/L)	Cd (mg/L)
Xe_1	0.020	0.22	BD	BD	0.22
Xe_2	0.070	0.39	BD	BD	0.39
Xe_3	0.130	0.36	BD	BD	0.33
Xe_4	0.009	0.30	BD	BD	0.29
Xe_5	0.030	0.27	BD	BD	0.22
Xe_6	0.050	0.29	BD	BD	0.21
Xe_7	0.120	0.42	BD	BD	0.41
Xe_8	0.090	0.43	BD	BD	0.33
Xe_9	0.005	0.16	BD	BD	0.38
Xe_{10}	0.010	0.33	BD	BD	0.36
Xe_{11}	0.020	0.26	BD	BD	0.28
Xe_{12}	0.060	0.35	BD	BD	0.26

BD – Below Detection

TABLE 12
A summary of trace metals analysed in groundwater samples collected from Ave Afiadenyigba in the Akatsi-North District

Sampling Sites	**Fe (mg/L)**	**Cu (mg/L)**	**Cu (mg/L)**	**Pb (mg/L)**	**Cd (mg/L)**
$Afia_1$	0.21	0.27	BD	BD	0.02
$Afia_2$	0.19	0.36	BD	BD	0.01
$Afia_3$	0.15	0.39	BD	BD	0.03
$Afia_4$	0.20	0.30	BD	BD	0.01
$Afia_5$	0.18	0.27	BD	BD	0.03
$Afia_6$	0.16	0.29	BD	BD	0.02
$Afia_7$	0.14	0.42	BD	BD	-
$Afia_8$	0.23	0.41	BD	BD	-
$Afia_9$	0.19	0.18	BD	BD	-
$Afia_{10}$	0.16	0.30	BD	BD	0.01
$Afia_{11}$	0.21	0.25	BD	BD	0.02
$Afia_{12}$	0.13	0.36	BD	BD	0.01

TABLE 13
A summary of trace metals analysed in groundwater samples collected from Ave Etekorfe in the Akatsi-North District

Sampling Sites	**Fe (mg/L)**	**Cu (mg/L)**	**Cu (mg/L)**	**Pb (mg/L)**	**Cd (mg/L)**
Ete_1	0.98	0.29	BD	BD	0.03
Ete_2	1.36	0.29	BD	BD	0.01
Ete_3	1.03	0.39	BD	BD	0.04
Ete_4	0.99	0.38	BD	BD	-
Ete_5	0.88	0.46	BD	BD	0.03
Ete_6	1.41	0.45	BD	BD	0.02
Ete_7	1.29	0.28	BD	BD	0.01
Ete_8	1.36	0.25	BD	BD	-
Ete_9	0.93	0.44	BD	BD	0.02
Ete_{10}	1.32	0.42	BD	BD	0.01
Ete_{11}	0.85	0.39	BD	BD	-
Ete_{12}	0.96	0.33	BD	BD	0.01

Fe – Iron Cd – Cadmium Pb – Lead Cu – Copper Ni – Nickel

TABLE 14
Results of physicochemical parameters and trace metals analysed in water samples collected from selected villages within the Akatsi-North District and compared with WHO, USEPA and IS-10500:2012 Standard

Parameters	Observed Range			Mean			Drinking Standard (IS-10500:2012) WHO (2006); USEPA(2002)	
	Ave Xevi	Ave Ete…	Ave Afia…	Ave Xevi	Ave Ete…	Ave Afia…	Acceptable Limit	Maximum Permissible Limit
pH	6.3-6.9	6.3-7.9	6.5-7.5	6.6	7.2	7.1	6.5 – 8.5	N.R
Temperature (oC)	27.8-30.1	32.1-36.5	27.9-30.1	28.7	34.3	29.0		
Colour (Hz)	<5	<5	<5	<5	<5	<5	5	15
E.C (µS/cm)	890-961	1385-1890	1250-1800	920	1600	1500	1500	3000
Alkalinity (mg/L)	206-231	257-279	241-281	220.1	264.8	259.5	200	600
Tot. Hardness (mg/L)	258-306	1023-1198	407-441	280.4	1120	430.1	200	600
Turbidity (NTU)	0.8-1.4	0.4-1.6	1.2-2.4	1.0	1.0	1.70	1	5
TSS (mg/L)	0.6-1.3	1.3-2.8	0-0.6	1.0	2.2	<0.06		
TDS (mg/L)	401-436	690-835	658-720	420.0	750	690	500	2000
DO (mg/L)	14.3-18.9	10.7-12.6	10.8-13.2	17.02	11.63	12.0		
COD (mg/L)	142-175	56-86	129-151	160.0	67.9	140.0	250	
Salinity (ppt)	0.29-0.54	0.21-0.42	0.34-0.63	0.40	0.30	0.50		
Carbonate (mg/L)	39-63	230-279	71-94	49.2	256	80.3		
Calcium (mg/L)	102-124	501-530	149-189	112.6	516.7	168.2	75	200
Magnesium (mg/L)	55-80	196-216	103-125	68.7	207.8	112.8	30	100
Sulphate (mg/L)	27-46	152-174	29-46	36.0	164	34.4	200	400
Nitrate (mg/L)	1.3-3.0	3.2-4.9	1.2-3.1	2.04	4.08	2.06	45	N.R
Phosphate (mg/L)	0.39-0.69	0.41-0.62	0.35-0.60	0.53	0.50	0.51		0.30
Chloride (mg/L)	55-81	253-275	89.5-123.1	68.8	264.8	101.6	250	1000
Fluoride (mg/L)	0.03-0.10	0.51-0.68	0.08-0.25	0.07	0.60	0.16	0.5 – 1.5	> 1.5
Iron (mg/L)	0.005-0.130	0.85-1.41	0.13-0.23	0.051	1.11	0.18	0.30	NIL
Copper(mg/L)	0.16-0.43	0.26-0.46	0.18-0.42	0.32	0.37	0.320	0.05	1.5
Lead (mg/L)	BDL	BDL	BDL	BDL	BD	BDL	0.01	N.R
Cadmium (mg/L)	0.21-0.41	0-0.04	0-0.03	0.31	0.015	0.013	0.003	N.R
Nickel (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	0.02	N.R

N.R – No Relaxation BDL – Below Detection Limit NIL- Not Available
Ete… - Ave Etekorfe Afia… - Ave Afiadenyigba

Conclusion

The physico-chemical parameters of water samples collected from different boreholes from three villages within the Akatsi-North district were determined. Emphasis was placed on fluoride concentration to determine whether or not its content was responsible for the dental caries among inhabitants within the district. Experimental results revealed low concentration of fluoride in two of the three villages with mean values 0.07 mg/L for Ave Xevi and 0.16 mg/l for Ave Afiadenyigba. Ave Etekorfe, however, recorded values which were above the minimum WHO and IS-10500 drinking water standard but were within the acceptable limit. Most of the physical and chemical constituents of groundwater within the study area (Akatsi-North district) were generally within acceptable limit for quality drinking water. Phosphate and copper concentrations obtained for the three villages in the study area exceeded acceptable limit for drinking water standard (IS-10500:2012; WHO, 2006; USEPA, 2002), contributing to gastrointestinal irritation and purgative effects experienced by most inhabitants prior to first-hand information. Elevated levels of magnesium and calcium might be responsible for the laxative effects, scale formation in utensils, aesthetic effect, and increased requirement of soap to lather as posited by some inhabitants during questionnaire analysis.

Further research

Although the present study has shown to some extent the safety of selected boreholes within the district, it would be an over generalization to say the borehole water within the entire district is safe for consumption. It is therefore necessary for similar studies to be carried out in other villages within the district since very little work has been done to assess the water quality within the district. There is also the need to carry out comprehensive social study to determine the number of people suffering from diseases related to water quality problems identified in the study area. Water quality assessment could also be done within the district from time to time to help moderate certain nutrients whose elevated concentrations in the water make it unsuitable for consumption.

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