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Groundwater Quality Assessment: A physicochemical properties of drinking water in a rural setting of developing countries

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Abstract

This study determined and characterized the quality of underground water in Twifo Hemang Lower Denkyira District (THLDD) of the central region of Ghana. The research involved the determinations of levels of copper (Cu), iron (Fe), manganese (Mn), zinc (Zn) (using mixed acid microwave digestion with Varian AA-240FS Atomic Absorption Spectrometer) and other physico-chemical properties of well water samples. About 40% of the pH values were below the WHO recommended minimum allowable value of 6.5 whiles most of the physical parameters fell within the recommended guideline values of WHO. Elevated concentrations of Fe, Zn and Mn were found in all the water samples. In general, the water quality of the studied wells can be said to be fairly good with respect to the monitored elements and physicochemical characteristics except for iron which needs some form of treatment before use. Therefore, most of the water from these wells is suitable for domestic use and it is unlikely to pose a major health risk to consumers. This research may serve as a reference data for future studies on the assessment of well water quality in the study area which depends heavily on these groundwater sources as a means of their portable water supply.

Key words: Groundwater quality, Synthetic chemicals, Health

INTRODUCTION

Water pollution (surface and ground) may be considered as a naturally induced change in water quality or conditions induced directly by man's numerous activities which render it unsuitable for food, human health, industry, agriculture or leisure per suit (Dix 1981). Toxic chemicals in water pose the greatest threat to the safety of (drinking) water and their effects are enormous of which can cause damage to human health, crops and aquatic organism.

Synthetic chemicals such as herbicides and insecticides as well as fertilizer runoffs from agricultural farmlands and industrial discharge have the potential to impact negatively on human health since they block vital metabolic processes in the body. Runoffs from domestic houses, solid waste dumps and commercial establishments may contain detergents and nutrients, which causes algae blooms in water bodies leading to eutrophication. Human waste excreta may contain a concentrated population of bacteria, pathogenic bacteria in untreated sewage and may cause acute gastrointestinal illness. These phenomenon has rendered most surface water bodies polluted in Ghana (Anim et al., 2010; Osei & Duker 2008; Asante et al. 2008).

Groundwater has become one of the most important water sources in Ghana (Kortatsi 1994; Xu & Usher 2006). In many rural- urban communities in the Twifo Hemang Lower Denkyira District (THLDD) in the Central Region of Ghana, utilization of water for domestic, irrigation and industrial are primarily dependant on (existing) groundwater resources. However, groundwater resources are under a serious threat due to increasing population density, growing interest in mechanized agricultural practices and rapid urbanization as well as domestic and industrial usage.

Groundwater provision is sometimes unsustainable because of poor water productivity of wells, drying of wells after prolonged drought and sometimes due to poor water quality. These problems are usually caused by the lack of understanding of the hydrological regime (Kortatsi 1994; Xu & Usher 2006).

The idea of providing groundwater as an alternative for seemingly polluted (pathogen infested) surface water resource was mooted from the fact that groundwater being scheduled from the atmosphere would be less vulnerable to pollution. Nevertheless, Ghana water management study in 1997 revealed that groundwater is also vulnerable to pollution due to anthropogenic and natural processes. Additionally, groundwater from hard rock areas are known to be vulnerable to low quality, a problem that has seriously impacts on human health since the rocks are often carbonate-deficient leading to poorly buffered groundwater (Kortatsi 2007). Information on groundwater recharge, storage, circulation and chemical evolution in THLDD is barely known.

Contaminated water resources have important implications on health and the environment (Peterson et al. 1971). The importance of water quality in human health has recently attracted a great deal of interest. In the developing world, 80% of all diseases are directly related to poor drinking water and unsanitary conditions (Olajire and Imeokparia, 2001). Groundwater quality can be affected by varied pollution sources. For example, Hamilton and Helsel (1995), stated that a connection between agricultural and groundwater pollution is well established. According to Chandio (1999), applications of nitrogen-phosphorous-potassium (NPK) fertilizers have been increasing in Pakistan over the last few decades, with applications of nitrogen fertilizers reaching an excess of 2 million tonnes by the late 1990s. As a result, high concentration of NO_3-N has been reported to be common in groundwater sources in Karachi – Pakistan. Mahmood et al., (1997) and Tasneem et al., (1999) found NO_3-N concentration ranging from 1- 171 mg/L in the Kasur area of Punjab. Tahir et al. (1999) also noted that concentration of nitrate was up to 111 mg/L NO_3-N in groundwater from Awalpindi District. Chandio (1999) found concentration of NO_3-N mostly less than 6 mg/L in hand-dug wells and tube-wells from canal-irrigated areas of Pakistan, although concentrations up to 210 mg/L of nitrate were found to have been directly contaminated by sewage.

High salinity and high levels of physico-chemical parameters appear to be responsible for the poor quality of groundwater in the Accra Plains (Quist 1976; Amuzu 1978; Akiti 1986; Kortatsi & Jorgensen 2001). Hem, (1970), Drever, (1982), Matthess, (1990), Apello and Postman, (1993) stated that ground water typically have large range of chemical composition in relation to the diversity of factors that influence their quality. Kortatsi (2006) in his paper concluded that the chemical composition of groundwater in the Accra Plains is strongly influenced by halite dissolution from the soil zone; the processes that contribute to the concentration of major ions in the groundwater also depend on carbonate dissolution and precipitation, seawater intrusion, cation exchange, evaporative concentration of solutes and to a minor extent aluminosilicates dissolution.

Ganyaglo et al., (2008), studied the hydrogeo-chemistry of groundwater in the Eastern region and reported that groundwater in the region was good for irrigation. In Sekyere East District of the Afram Plains, groundwater was found to be predominantly of $CaCO_3$ facies with a pH range of 5.40 - 8.00. A comprehensive study of the relationship between land use and groundwater quality in six districts of the Eastern region have been undertaken (Fianko et al. 2009). The study found groundwater in the region to be fresh and weakly mineralized. The groundwater was characterized by chemical facies of Ca-HCO_3, NaCl and Na-Ca-HCO_3 types and anthropogenic activities found to have impacted negatively on the groundwater quality.

Although groundwater is extensively used in communities and towns in Ghana, it is estimated that over 40 % of drilled wells are either abandoned at drilling or rejected by the intended beneficiaries on grounds of very high levels of iron (Fe: >0.3 mg/L) and manganese (Mn: 0.1 mg/L). Moreover, due to high levels of Fe and Mn, over 60 % of the groundwater drilled is used only for purposes other than drinking, cooking or laundry (Schäfer, et al. 2009). Other contaminants plaguing water delivery process includes fluoride (Fl), arsenic (As), heavy metals due to acid mine drainage and chlorides found in the Northern/Upper regions, mining areas and the coastal belt respectively.

The study however assessed the water quality of boreholes (physicochemical properties) in the Twifo Hemang Lower Denkyira District of the central region of Ghana which uses groundwater as the main source of their water supply.

MATERIALS AND METHODS

The study area

The study area (Fig 1) is the Twifo Heman Lower Denkyira District (THLDD) in the Central Region of Ghana. It is bounded to the south by the Cape Coast Metropolitan Assembly (CCMA) and Komenda Edina Aguafo Abrem (KEEA) districts, the West by Western Region, the East by Assin North and Assin South Districts and to the North by Upper Denkyira District. Twifo Praso is the District capital of the district (THLDD) the district can be located on Latitudes 5^{o}26'S and 6^{o} 8N, and Longitudes 0^{o} 30'W and 0^{o} 40E.

The average annual minimum and maximum temperature is about 24.6^{o}C and 35.6 ^{o}C respectively. The hottest months are February to March with a little variation throughout the year. The district has two main rain seasons, major and minor. The major one is around April-July and the minor between September-November. Across the country, the dry dusty Harmattan wind blows from the northeast from December to March, lowering the humidly. The effect is felt in the study area around December. April being a transition month between the dry season and the major rain season experience, depending upon a particular year, there are variations of rain output thus from no rain, isolated rains or fair to heavy rains.

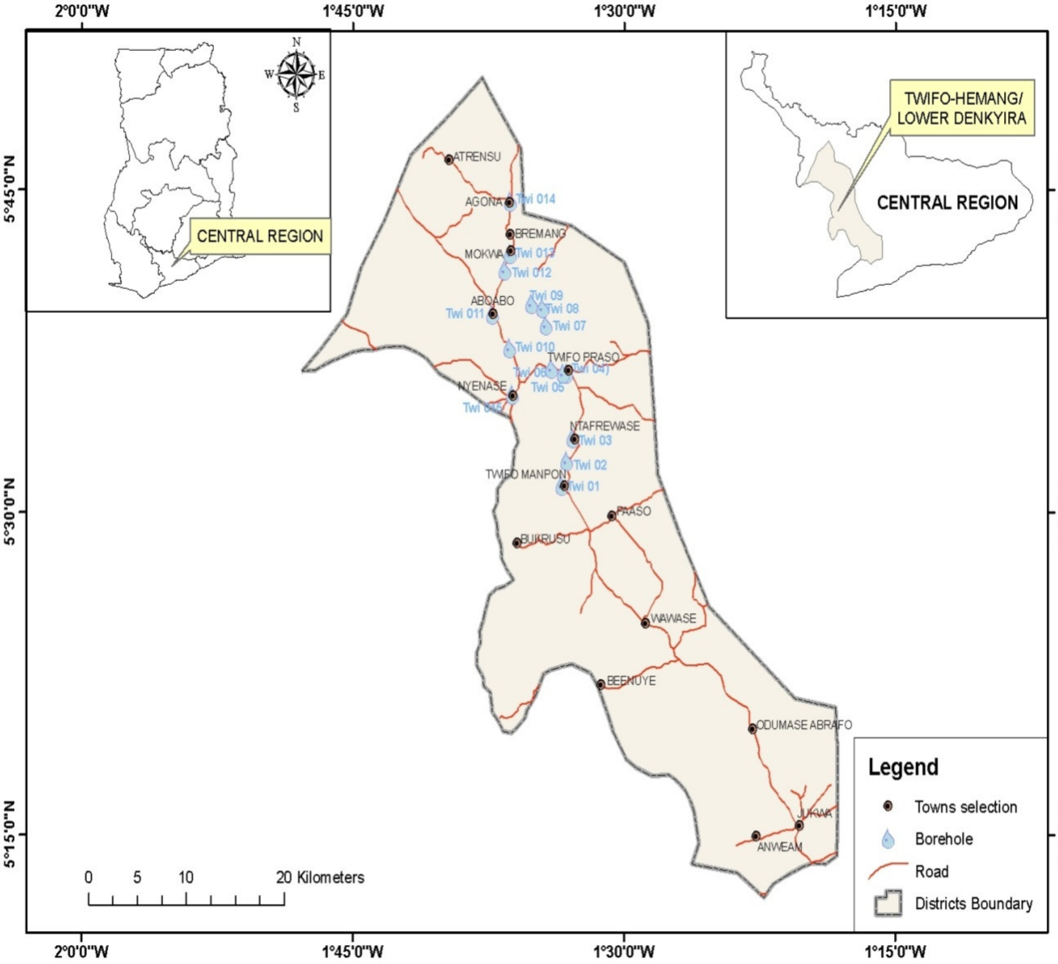

Fig: 1 Map of the study area

The Landscape of the District is generally undulating with hills of variable slopes. Some of the hill slopes are steep in many areas and tend to affect-physical mobility. In between the hills are valleys of various shapes, some occupied by rivers and streams, including the Pra and Offin Rivers. These rivers brings significant amount of fresh water annually, part of which is used in the Sekyere Hemang Water Supply Scheme. The runoff from these rivers and many of the minor streams end up in Wetlands and lagoon in Western region.

The vegetation can be described as secondary forest in the south and relatively heavily forested in the north. The hydrogeological conditions prevailing are governed by the geological and tectonic structures of the area. The cultural life of people in THLDD is linked to farming, mining exploration and small scale palm oil industries.

Selection of sample sites

A short-term field survey was conducted in the study area. The survey also sought to ascertain the water quality problems, major activities; (farming, mining and small scale palm oil factories) type and sources of pollution. Topographic and geological maps, as well as aerial photographs and satellite images of the study area were acquired and studied. Lineaments were inferred and areas of intense anthropogenic activity were demarcated for groundwater quality monitoring. In addition, available data and information on hydrometeorology, water quality and geology of the area were collected and compiled. Reconnaissance field visits were undertaken to the entire Twifo Hemang Lower Denkyira District (study area) to identify sampling locations and sites. The choice of sampling sites and locations was due to their strategic location, the bulk of human activities as well as population densities. Fifteen sampling points in fourteen communities within the District were finally earmarked for groundwater sampling. These points (communities) were located along Cape Coast-Twifo Praso route (Table 1.)

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Sampling

Groundwater samples were collected individually from a combination of domestic and municipal water points (15) including boreholes and hand-dug wells into acid cleaned high-density 1-L linear polyethylene sampling bottles with strict adherence to the sampling protocol as described by Barcelona et al. (1995) and Standard methods (1998) and analyzed independently. The sampling was over a period of six (6) months on monthly basis. Water samples from the boreholes were pumped out using existing infrastructure for over 20 minutes before samples were taken. Samples were filtered in the field using Sartorius polycarbonate filtering apparatus and 0.45µm cellulose acetate filter membranes. At each point, two samples were collected for major ions and trace metal analyses. Samples for trace metal analyses were acidified to $pH < 2$ after filtration with 10% analytical-grade HNO_3. On-site analyses of temperature, electrical conductivity, total dissolved solids (TDS), and pH were conducted using portable HACH conductivity meter and Metrolin model

691-pH meter, respectively. Alkalinity was also determined on – site using HACH Digital Multi-sampler titrator Model 1690. Before taking readings, all equipments were adequately calibrated. The pH meter was calibrated with pH 4.0, 7.0, 12 buffers while the conductivity meter was calibrated using 10 μScm^{-1}, 500 μScm^{-1} and 1288 μScm^{-1} standard KCl solutions. Water samples were transported in ice cooler on ice to the laboratory and stored at 4 ^{o}C prior to analyses.

The flowchart below shows how the samples were sampled and analysed.

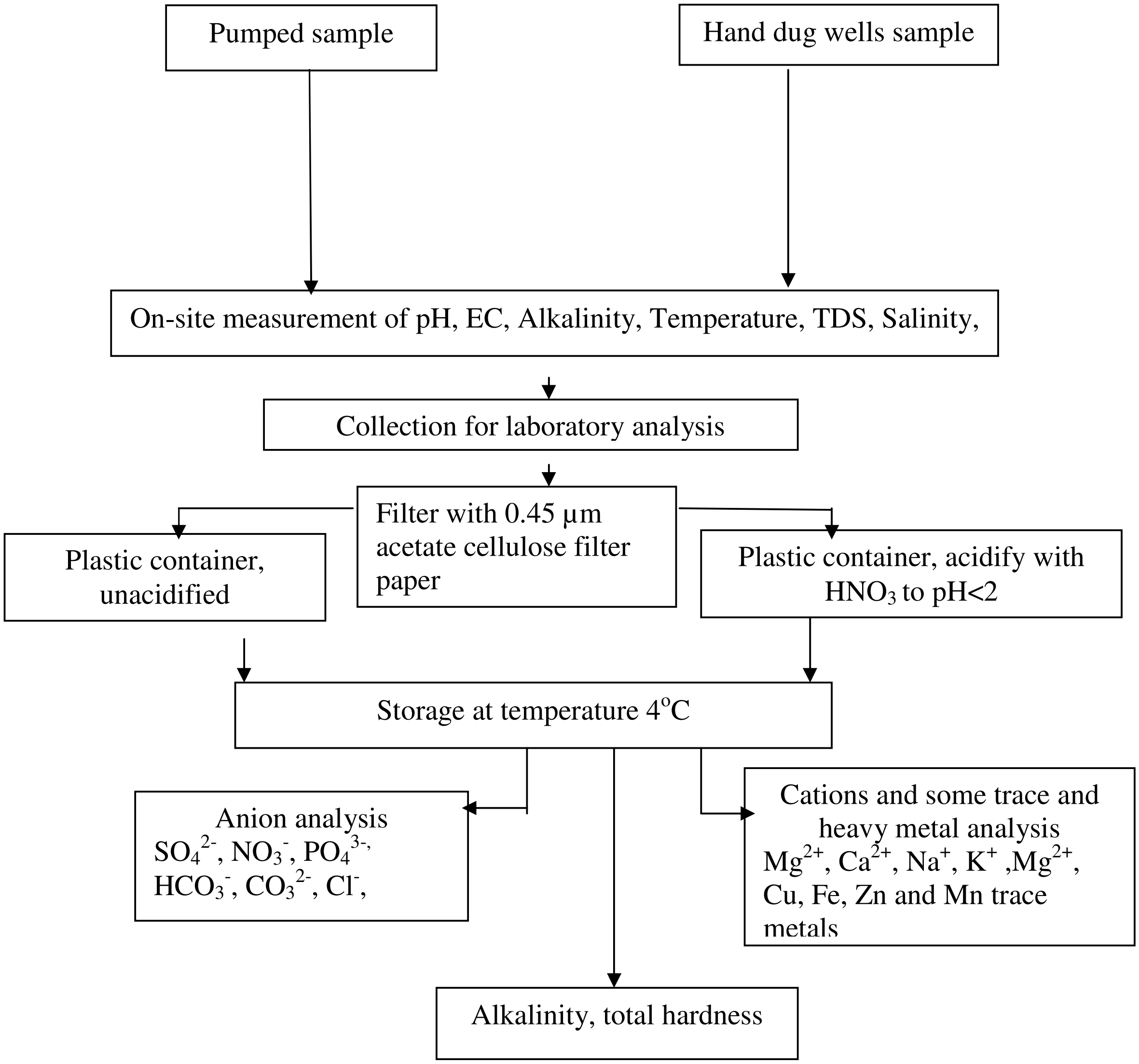

Fig. 2. Framework of laboratory analyses

Physico-chemical analyses

Water samples collected were analysed by both classical and automated instrumental methods prescribed by the standard methods for the analysis of water and wastewater and United State Environmental Protection Agency (Standard Methods, 1999). The concentrations of major ions sulphate (SO_4^{2-}), nitrate (NO_3^- -N), chloride (Cl^-) and phosphate (PO_4^{3-}) were determined spectrophotometrically in the laboratory using portable HACH DR/890, Data logging colorimeter and double column Dionex ICS-90 ion chromatograph. Sodium (Na) and potassium (K) were measured using Sherwood model 420 flame photometer while the Varian AA-240FS Atomic Absorption Spectrometer was used to carry out trace metal analyses.

Trace Metal Analysis

Samples for trace metal analysis were digested before analysed. 5 mL of water samples, blank and standards were measured into individual Teflon vessel and 3.0 mL of 37% HCl, 6 mL of 65 % nitric acid and 0.25 mL 30% H_2O_2 were added and thoroughly mixed. The mixtures were then digested in ETHOS 900 microwave digester for 26 minutes. The digested samples were allowed to cool in a water bath for 30 minutes and the level of metals determined using flame photometer for Na and K while the Varian AA-240FS AAS was used to determine the levels of Ca, Mg, Fe, Zn, Cu and Mn. (Broekaert 1998; Sperling & Welz 1999; Sood et al. 2004; [Eaton et al. 2005). All reagents used were of analytical grade and equipment pre-calibrated appropriately with standard solutions prior to measurement. Replicate analyses were carried out for each determination to ascertain reproducibility and quality assurance.

Quality assurance

The accuracy and precision of the analytical techniques were assessed by the analyses of reference materials and reagent blank before the samples were analysed using deionised water and reagent blank. Calibration of equipment with standard and measuring a minimum of four different fresh dilutions of relevant standards regularly before the start of sample analysis. Also the some of the standards were read as a sample.

Results of Quality assurance of chemical analyses

The analytical results obtained at the Ghana Atomic Energy Commission (GAEC) laboratory for the reference materials compared with recommended values are shown in Table 1. The values compare favourably well with the recommended values for (Cu, Zn, Mn, Mg, Ca) ions and pH. The precision was also calculated as a percentage relative standard deviation (%RSD) of replicate analysis of the prepared standard, and was found to be less than 5%.S

Table 2: Analytical results of Standard Reference Materials, showing local laboratory values and recommended values.

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RESULT AND DISCUSSION

Physicochemical characteristics of well water samples

The results of 13 physicochemical properties of 15 wells (water samples) from the study area are presented in Table 3.

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Electrical conductivity (EC)

The Electrical conductivity (EC) for all the sampling sites varied between 90.53 ± 49.31 and 556.90 ± 303.34 µS/cm. The highest EC value was recorded at sampling point (Twifo Somnyamekodu) whereas Twifo Damam registered the lowest value. The measured EC values indicate that all the 15 examined boreholes had values which were within the WHO maximum allowable EC level of between 50-1500 µS/cm for drinking water. This also shows that contaminations due to dissolve ions are low.

pH and Temperature

The pH values of the well water samples varied between 5.89 ± 0.46 and 7.86 ± 0.61 as shown in Table 3. pH values below 6.0 were recorded at Twifo Nyenase (5.89±0.46), Twifo Kwaanyako and Twifo Praso 001 (5.99±0.47). However, quite a number of the groundwater had pH values below the acidic limit of 6.5 and as a result had high levels of total iron in the well water. The slightly acidic nature of the water samples from the wells might be due to drainage of metal rich rocks in the wells. It is also possible that there is some contamination from landfill leachates which may also lower the pH.

The measured temperature values of the well water samples were between 23.2 ±0.9 and 26.4 ±1.0^{O}C. The small variation in temperatures in the well water shows some uniformity of the groundwater temperature in the study area.

Total dissolved solids (TDS)

The total dissolved solids (TDS) obtained for the water samples of the wells varied between 56.64 ± 32.65 and 351.2 ± 202.64 mg/L (Table 3). These amount of

TDS measured in the monitored wells are within acceptable levels recommended by WHO. According to WHO (2004), the palatability of water with a TDS level less than 600 mg/L is generally considered to be good and becomes significantly and increasing unpalatable at TDS level greater than 1000 mg/L.

Ions and nutrients

The amounts of chloride ions found in the samples of the well water were between 5.0 mg/L and 74.98 mg/L. These amounts of chloride ions are within the WHO allowable levels in ground water 10 – 250 mg/L. Natural background of chloride in drinking water is usually 10 mg/L and anything above that is an indication of human influence. Those that had chloride levels a bit above 10 mg/L may have been contaminated by septic systems, landfill, fertilizers or animals.

The concentration of sodium ions in the well water samples varied between 30.1 ± 15.31 and 119.6 ± 60.82 mg/L. The sampling site Twifo Somnyamekodu recorded the highest Na^+ value of 119.6 mg/L. The maximum permissible level of sodium ion in drinking water is 200 mg/L and therefore all the wells were within the acceptable level. The low levels of Na^+ and Cl^- in the well water samples from the study area may indicate that there is a low or no saline intrusion from sea water.

The concentration of potassium ion in the wells varied between 5.95 mg/L and 16.35 mg/L (Table 3). Alkalinity levels of the well water samples were found to be between 15.0 mg/L and 180.0 mg/L. All the wells recorded potassium ions and alkalinity levels within the acceptable WHO standard of 30 mg/L and 400 mg/L respectively. Sodium was the dominant cation in all the well water samples monitored (Table 3). The order of the relative abundance of cations, as measured in the studied wells is as follows: $Na^+ > K^+ > Ca^{2+} > Mg^{2+}$.

The dominant anion was also found to be sulphate and the sequence of abundance is as follows (Table 3): $SO_4^{2-} > HCO_3^- > Cl^- > NO_3^- > PO_4^{3-}$. The sulphate contents of all the wells were within the WHO recommended guideline (250 mg/L) except that of Twifo Somnyamekodu which recorded the highest value of 1796.67 mg/L (Fig.3). The high sulphate content of Twifo Somnyamekodu could be due to evaporated minerals gypsum ($CaSO_4.2H_2O$), and anhydride ($CaSO_4$) (Jalali et al, 2006). It may also be due to oxidation of pyrite. The Groundwater may also contain other minerals like $MgSO_4.7H_2O$ (Epsom salt) and $Na_2SO_4.10H_2O$ (Glauber's salt).

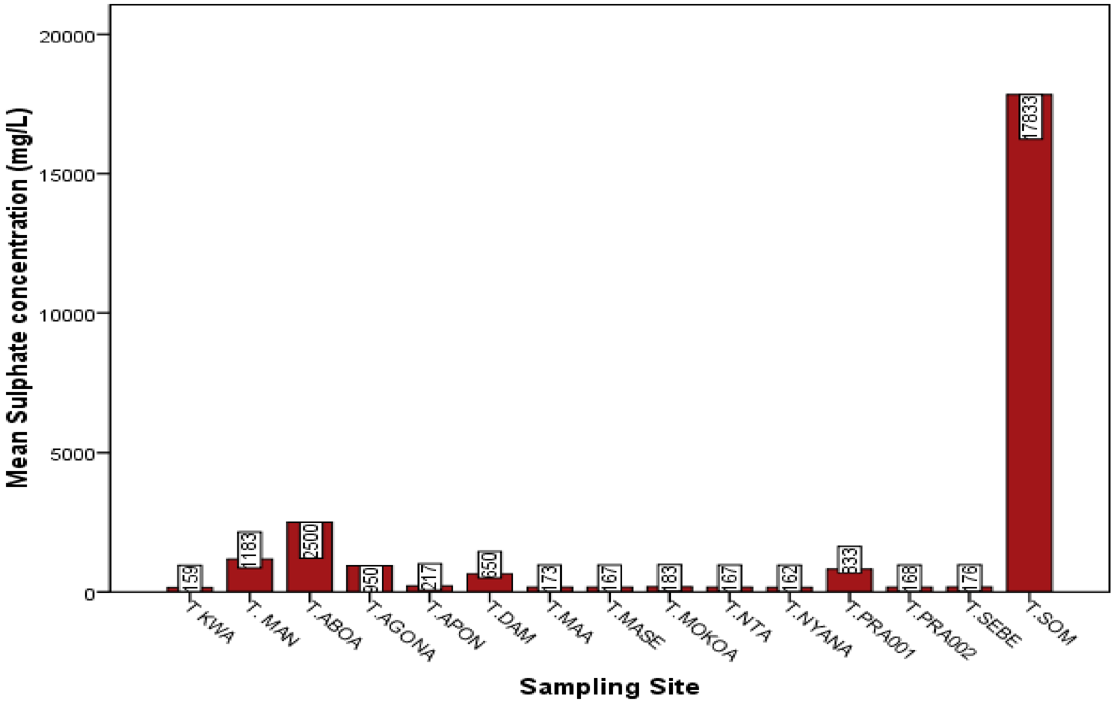

Fig.3. Variation of the level of sulphate in well water samples of study area

These anion levels indicate the weathering effects of silicates and other rock compounds on the quality of the well water samples of the study area. The nitrate concentrations obtained in the wells of the sampling area were very low (i.e.: between

0.18 mg/L and 0.34 mg/L). Fig. 4 is a comparison of the nitrate concentrations in the water samples from the sampling sites. All the examined wells recorded nitrate concentrations values within the acceptable level (50.0 mg/L) recommended by WHO (2004) for drinking water.

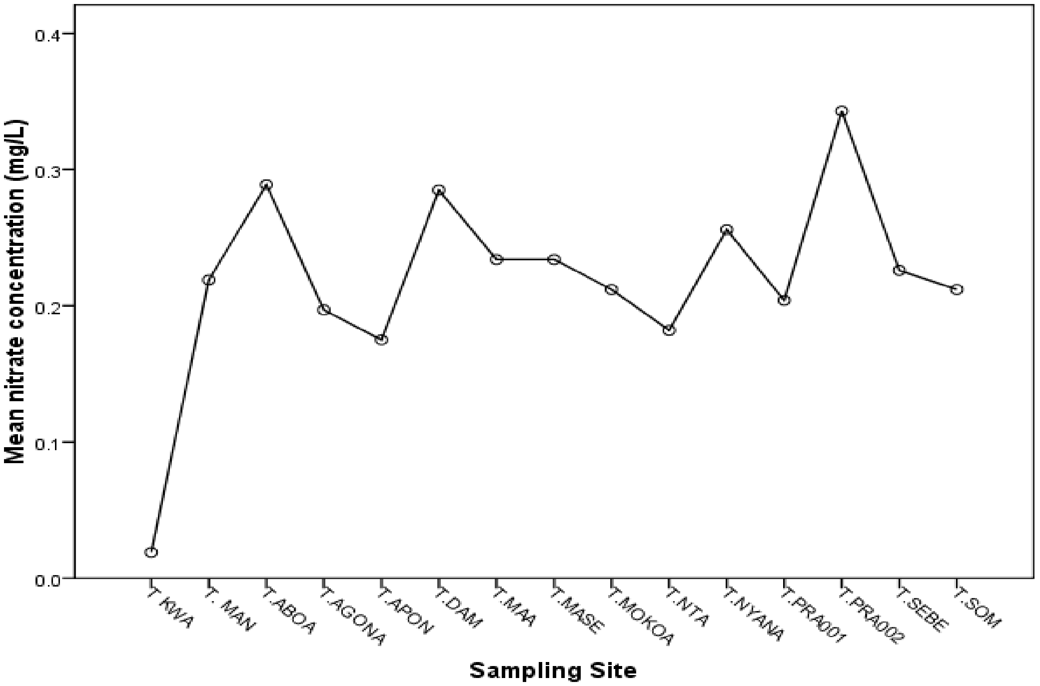

Fig.4. Variation of nitrate levels across the sampling sites

The phosphate levels recorded in the study areas were also very low ranging from 0.01 to 0.23 mg/L. The variation of the phosphate levels in the water samples in all the examined wells is depicted by Fig. 5. The low concentration of the phosphate in the well water samples might be due to the geology of the area. It also shows that addition of nutrient from anthropogenic sources to the well water is minimal.

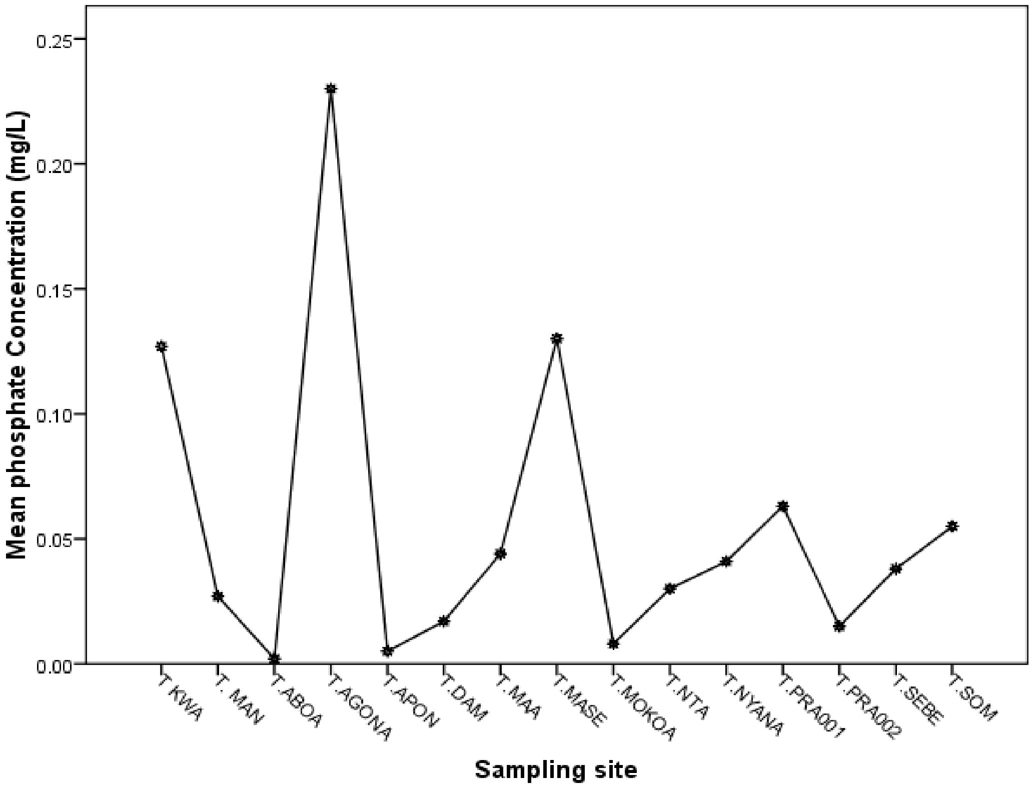

Fig.5. Variation of phosphate levels across the sampling sites

Total hardness

The highest total amount (32.98±4.7 mg/L) of well water hardness was recorded at Twifo Somnyamekodu whereas the lowest value of 19.21±2.7 mg/L was found at Twifo Nyenase. According to WHO (2004) water hardness classification, water can be classified as; Soft (0 — 50 mg/L$CaCO_3$); Moderate Soft (50 — 100 mg/L$CaCO_3$); Slightly Hard (100 — 150 mg/L$CaCO_3$); Moderate Hard (150 — 200 mg/L$CaCO_3$); Hard (200 — 300 mg/L$CaCO_3$) and Very Hard (over 300 mg/L$CaCO_3$). Using the above water hardness classification by WHO, all the 15 wells monitored can be classified as fresh and soft.

Trace metals in well water samples

The results of the AAS measurements (mg/L) of Fe, Mn, Zn and Cu in well water samples from the study area are presented in Table 4. The concentrations of copper in the samples were all less than the detection limit of 0.003 mg/L. The amount of Zn in the wells ranged between 0.03 to 0.09 mg/L which are below the WHO maximum permissible level (3 mg/L) in drinking water.

Table 4. Mean concentration (mg/L) of trace elements in well water samples.

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Iron

The highest total iron concentration of 4.53 ± 1.49 mg/L was recorded in water samples from Twifo Praso 002 and the lowest amount of 1.62 ± 0.53 mg/L was measured at Twifo Praso 001. All the water samples analysed had iron concentration greater the 0.3 mg/L, which is the WHO standard for iron in drinking water. Twifo Praso and surrounding areas have biotite and granite which might be the sources of high iron concentrations in the study areas. The other reason may be due to the low pH recorded. This means that the water should be treated for the removal of iron before use.

Manganese

The manganese concentration measured in the well water samples varied from 0.15 ± 0.19 mg/L to 0.25 ± 0.13 mg/L. All the concentration measured were greater than WHO permissible limit (0 .1 mg/L) for potable drinking water. The higher value from the study areas could also be from the natural sources.

CONCLUSION

The well water samples from Twifo Praso and the surrounding areas were obtained to investigate their quality in terms of their physicochemical properties and trace elements levels. The chemical analyses of the water samples were performed by Fast Sequential Atomic Absorption Spectrometer (FS240AAS),

The results revealed that well water in Twifo Praso and the surrounding areas is mildly acidic to basic. All the water samples recorded TDS values less than maximum allowable levels. Sodium ion concentration was generally high compared to other cations. With exception of the sampling site Twifo Somnyamekodu which recorded relatively higher sulphate, the general trends in sulphate concentration for the various wells monitored were good.

The amounts of manganese and iron in the water samples were higher than recommended maximum allowable levels. The occurrence of manganese and iron in the wells of the study area is most probably natural and is considered as a major problem in the area. This means that the water should be treated for iron and manganese before use. Manganese and iron are all parts of common minerals and they probably originated from the parent rocks. The measured concentrations of zinc in all the water samples were below maximum permissible levels. The concentrations of copper in all the water samples were below the detection limit of the analytical instrument used in this research. The groundwater in the Twifo Praso and the surrounding areas were good and fresh with exception of manganese and iron levels.

In general, the water quality of the fifteen studied wells can be said to be good with respect to the monitored elements and physicochemical characteristics. Therefore water source from these wells are suitable for domestic use and unlikely to pose a major health risk to consumers. This research may serve as a reference for future studies on the assessment of well water quality in the study area.

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APPENDICES

Appendix1. Mean concentrations parameters examined in the wells of the study area.

Parameters	Minimum	Maximum	Mean	Std.Deviation
Temperature (^{0}C)	23.2	26.4	24.41	1.497
pH	5.87	7.86	6.5	0.62
Conductivity(µS/cm)	90.53	556.9	201.08	770.45
Salinity (ppt)	0.05	0.36	0.13	0.41
TDS (mg/L)	56.64	351.2	121.87	348.6
Alkalinity (mg/L)	15	180	87	42.66
Mg^{2+}(mg/L)	1.38	2.54	1.86	4.7

Ca^{2+} (mg/L)	1.62	1.66	6.19	6.08
NO_3^- (mg/L)	0.18	0.38	0.23	2.46
SO_4^{2-}(mg/L)	1.67	1796.67	172.56	57.08
Cl^-(mg/L)	5	74.98	16.58	127.79
HCO_3^-(mg/L)	18.3	219.6	106.13	58.72
T.HDNESS(mg/L)	19.21	32.98	23.83	0
K^+(mg/L)	5.95	16.35	11.45	9.87
Na^+(mg/L)	30.1	119.6	45.03	126.59
Mn(mg/L)	0.15	0.25	0.21	0.01
Fe(mg/L)	0.03	0.09	0.06	0.001

Appendix 2: WHO (2004) who guideline for drinking water

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