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Assessment of Drinking Water Quality of Groundwaters in Bunpkurugu-Yunyo District of Ghana

Maxwell Anim-Gyampo[1], Musah Saeed Zango[1] & Boateng Ampadu[1]

[1] Department of Earth and Environmental Science, University for Development Studies, Navrongo, Ghana

Correspondence: Maxwell Anim-Gyampo, Department of Earth and Environmental Science, University for Development Studies, P. O. Box 24, Navrongo, Ghana. Tel: 233-020-176-9817. E-mail: gyampom@gmail.com

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Abstract

Water quality assessment of nineteen (19) boreholes sampled during the two climatic regimes (raining and dry seasons) in Bunkpurugu-Yunyo District of Ghana has been carried out using standard methods. Analysis of results showed that all the parameters fell within World Health Organisation (WHO, 2008) acceptable limits with exception of turbidity, nitrates, lead and cadmium. The order of major cations and anions in water samples obtained during the raining and dry seasons were Na>Ca>Mg>K and HCO_3>NO_3>Cl>SO_4>F>PO_4, and Na>Ca>K>Mg and HCO_3>Cl>SO_4>F>PO_4>NO_3 respectively. Groundwaters were fresh (TDS< 1000mg/l) and generally of temporal hardness. High mean values of Pb and Cd above acceptable limits implied potential health hazards to inhabitants over a long period of water consumption. Agro-chemicals could be the major sources of Pb and Cd contamination to the groundwaters while the potential of contamination from natural sources may be a possibility. Assessment of water quality index (WQI) showed remarkable variation of water quality with respect to climatic conditions, with 94.7% samples falling within "Excellent" and "Good" categories in the raining season while conversely, about 89.5% fell within "Poor" and "Unsuitable" categories during the dry season.

Keywords: Bunkpurugu-Yunyo, Ghana, groundwater, lead, water quality index

1. Introduction

Groundwater plays a very pivotal role in the domestic water delivery system in Ghana as it is officially, the considered source of potable water for rural water supply delivery in Ghana (CWSA, 2009). The preference stems from the fact that groundwater is generally of better quality, less polluted and requires little or no bacteriological treatment prior to consumption. Furthermore, groundwater sources are more reliable for utilization in rural areas than surface water sources such as rivers, streams and dams in water-stressed semi-arid regions like northern Ghana. Bunkpurugu-Yunyo district in the north-eastern part of Ghana has about 90% of the population living in rural areas. The area falls within a semi-arid region with very little surface water resources, and where available, it is mostly unreliable throughout the greater part of the year; highly polluted by grazing cattle and other livestock thus rendering it very unsuitable for human consumption. Groundwater sources are therefore the most reliable and sometimes, the only source of potable drinking water for the inhabitants as well as livestock. Despite the general acceptance of groundwater as the preferred source of potable drinking water for rural communities in Ghana (MWWH-NWP, 2007), the qualities of some sources had been found to be unacceptable for domestic use with attendant adverse health implications due to either natural and/or anthropogenic factors that have the potential to adversely affect the health of consumers. Natural factors may include the dissolution of several anions and cations into groundwaters in an aquifer system due to groundwater-rock interactions and weathering of rocks. For instance, groundwaters in parts of northern Ghana including the Bongo, Tongo, Talensi and Bolgatanga districts in upper east regions (Apambire et al., 1997; Anongura, 1995) and Gushiegu, Karaga, Saboba, Yendi and Chereponi districts of northern region of Ghana Anongura et al. (2003) and Anim-Gyampo et al. (2012) have been found to contain excessive fluoride up to a level of over 4.5mg/l. Climatic variations (rainy and dry seasons) may have impact on groundwater quality either positively or negatively making it suitable or otherwise for human consumption. Anthropogenic activities such as the use of agro-chemicals (i.e. chemical fertilisers, weedicides, and pesticides), release of toxic heavy metal and non-metals during mining activities, industrial and domestic waste disposals can in the long term contribute to the deterioration in the quality of groundwater resources (Todd, 1980). The Bunkpurugu-Yunyo District is predominantly a rural district with crop farming being the main stay of the inhabitants. Cultivation of crops is achieved by the intense use of agro-chemicals such as weedicides, chemical fertilisers and pesticides, which contain some heavy metals such as Pb, Cd, As, Co, Hg etc as traces could infiltrate and contaminate the groundwaters, which is the only source of potable drinking water for the inhabitants in the area. This study therefore assesses the water quality of groundwater in aquifers in the Bunkpurugu district with the aim of ascertaining its suitability for human consumption throughout the year.

1.1 The Study Area

Bunkpurugu-Yunyo District in northeastern Ghana (Figure 1), carved out from the East Mamprusi District, was created in 2004 with the Bunkpurugu town as the capital. It covers an area of approximately 3079.7 km^2 and located between latitude 10° 14' 44.252 N to 10° 42' 34.087 N and longitude 0° 5' 15.485 W to 0° 18' 10.49 W. It is bounded in the north by Garu-Timpani, east with Republic of Togo, west by West Mamprusi and south by Gushiegu and Chereponi districts. It is predominantly a rural community and farming is the main occupation of the inhabitants with groundwater serving as the main source of potable drinking water, especially during the long dry season where almost all surface water sources dry-up. The position of the district as a border to north-western Togo affords it the opportunity as a potential business hub of the eastern corridor of Ghana and therefore attracts lots of mobile population. The study area falls within the tropical continental climatic region of Ghana and is influenced by the movement of the Inter-Tropical Convergence Zone (ITCZ) and it is among the areas with lowest rainfall values in Ghana with mean annual rainfall of about 100-115 cm. Rainfall is very erratic and intermittent droughts and floods within the season are quite common. The study area is characterised by generally high temperature and is among the driest places in Ghana. The highest mean monthly and daily temperatures of 33 and 42 °C, respectively are recorded in March-April; whilst the lowest mean monthly value of 26.5 °C is registered during the peak Harmattan season in December and January each year. Relative humidities of 70-90% are recorded during the rainy season and in the dry season; the lowest value of about 20% could be observed (Dickson & Benneh, 1985).

Figure 1. Location of the study area showing sampling sites

The major river draining the study area is the White Volta, which enters the region in the northeast after it has been joined by the much smaller and shorter minor rivers (Nawonga and Moba) draining the southwestern part. All the rivers in the study area dry up during greater part of the year (approximately five months) except the White Volta, which is perennial. The area is semi-arid and experiences very short wet (raining) seasons to a maximum of about four months, followed by a prolonged dry season of approximately seven to eight months. The prolonged dry season renders many people in the area seasonally unemployed because farming activities are basically rainfall dependent. The total number of wet days in a year has been estimated to about 44 (Anim-Gyampo et al., 2013), which are woefully inadequate to support plant life, resulting in low agricultural productivity and consequential high poverty levels. The vegetation type is the Interior Savannah Woodland, which is characterised by tall grass interspersed with drought-resistant trees such as Neem, Shea, Dawadawa, Baobab, Acacia and Mahogany. Grasses grow in tussocks and can reach a height of approximately three meters or more. There is a marked change in vegetation depending on the prevailing climatic conditions (dry and wet). The vegetation is largely affected by indiscriminate and uncontrolled bush fires, indiscriminate felling of trees for housing, charcoal production for fuel wood especially during the dry periods (Anongura et al., 2003). The topography is generally gently rolling with the Nakpanduri (formerly Gambaga) escarpment marking the northern limits of the paleozoicvoltaian sedimentary basin. Apart from the mountainous areas bordering the escarpment, there are generally little runoffs when it rains and the greater part of rainwater seeps into the ground to recharge aquifers, which had resulted in the development of relatively good groundwater aquifers and therefore forming part of the areas with high groundwater potential in northern part of Ghana. According to Obeng (2000), two main types of soils are found in the study area namely, the Savannah Onchrosols and the Groundwater Laterites. The Savannah Ochrosols which covers almost the entire district is moderately well drained and is developed mainly within the quartzites. The texture of the surface soil is loamy sand with good water retention. Savannah Ochrosols has high potential for wide range of crops. Some areas do not appear to be fully utilized though some lands are under considerable pressure in the district. The Groundwater Laterites type of soils covers a relatively smaller portion of the study area, and is found mainly in the north- eastern parts. These are concretionary soils developed mainly in the shale, mudstone and argillaceous sandstone materials. The concretionary soils are associated with frequent exposures of iron pan and boulders. The soils are perfectly drained during the wet season with perched water tables developing in some areas, and become extremely dry during the dry season. Exposure enhances the formation of ironstone (fericate); which can result in soil degradation by capping potential arable soils. Geologically, the area is underlain by the neo-proterozoic Voltaian sedimentary formation of Ghana (Figure 2). The area is predominantly (about 60% of the study area) underlained by the Panabako group, which consists of medium-grained quartzites with distinctive structural feature of cross-bedding. South of the Panabako group is a relatively thin belt of the Kodjari formation, which consists of silliceous tuff and fine-grained laminated arkosicsanstones. South of the Kodjari formation is the Oti-Penjari group, which consists of mudstones and siltstones, weakly micaceous thin-bedded arkosic and lithic sandstones (Griffiths et al., 2002).

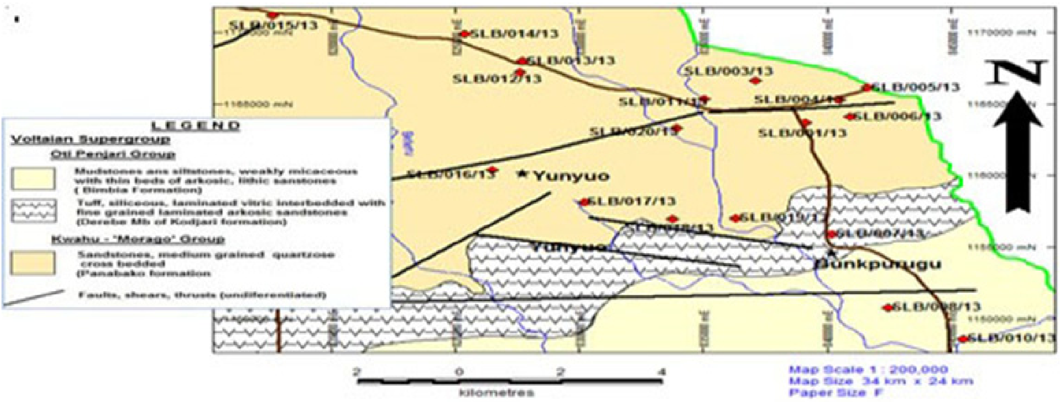


Figure 2. Geological map of the study area showing sampling sites

2. Materials and Methods

2.1 Water Samples Collection

A total of nineteen (19) groundwater samples (Figure 1) were collected from identified boreholes in 0.5 litre polythene bottles and their respective geographical locations (i.e. elevation, longitude and latitude) were measured. Sampling was carried out in accordance with protocols described by (Claasen, 1982) and (Barcelona et al., 1985). Sampling bottles were initially conditioned by washing with detergent, then with ten per cent (10%) nitric acid, and finally rinsing several times with distilled water. This was carried out to ensure that the sample bottles were free from contamination, which could affect the concentrations of various ions in the groundwater samples. Boreholes were pumped for at least five minutes to purge the aquifer of stagnant water so as to acquire fresh samples for analysis. Hand-held syringes fitted with a filter head with 0.45 µm cellulose filter membrane were used to filter the water samples in the field. Two samples were collected at each site; one was acidified by adding 2% of concentrated nitric acid (HNO_3). The acidified water samples were used for metal analysis while the non-acidified water samples were used for physico-chemical analysis. The sampled waters were tightly capped and preserved in an ice-chest at a temperature of 4 °C and transported to the laboratory of the Ghana Atomic Energy Commission at Kwabenya within the shortest time for analysis.

2.2 Sample Analysis

2.2.1 Physico- Chemical Parameters

Unstable hydrochemical parameters such as electrical conductivity (EC), pH and alkalinity were measured in situ (in the field) immediately after collection of samples, using a WTW field conductivity meter model LFT 91, WTW field pH meter model pH 95 and a HACH digital titrator respectively, that had been calibrated before use. Major ions such as Sodium (Na^+) and Potassium (K^+) were analyzed in the laboratory using the flame photometer. Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) were analyzed using the AA240FS Fast Sequential Atomic Absorption Spectrometer. The ICS-90 Ion Chromatograph (DIONEX ICS -90) was employed in the analysis of Chloride (Cl^-), Fluoride (F^-), Nitrate (NO_3^-), and Sulphate (SO_4^{2-}). Phosphate (PO_4^{3-}) was determined by the ascorbic acid method using the ultraviolet spectrophotometer (UV-1201). A multipurpose electronic DR/890 Colorimeter was used to measure the color, turbidity, total dissolved solids and a HACH SEN 523 pH meter was used to measure the pH and temperature. An electronic HACH SEN ION 5 conductimeter was used to measure the conductivity, salinity and total dissolved solids of all the samples.

2.2.2 Heavy Metal Analysis

5 ml of each acidified water sample was measured and 6 ml of nitric acid, 3 ml of HCl and 5 drops of hydrogen peroxide (H_2O_2) were added for acid digestion and placed in a milestone microwave lab station ETHOS 900. The digestate was then assayed for the presence of Zinc (Zn), lead (Pb), Copper (Cu), Chromium (Cr) and Cobalt (Co) using VARIAN AAS240FS Atomic Absorption Spectrum in an acetylene-air flame. Arsenic (Ar) and Mercury (Hg) were determined using argon-air flame.

3. Results

Table 1. Statistical summary of physico-chemical parameters from sampled wells

Parameter	Wet Season			Dry Season			WHO, 2008
	Min	Max	Mean	Min	Max	Mean	
pH	5.77	7.36	6.76	4.96	8.3	6.97	6.5-8.5
Temperature	23.5	25.9	24.49	23.5	25.9	24.49	n.a
Conductivity	57.9	830	413.46	47.6	709	356.86	250
TDS	34.8	502	248.83	23.9	355	178.51	1000
TSS	0	75	13.57	0	75	13.57	n.a
Turbidity	1	73	8.81	0	96	13.24	5
Colour	0	30	13.09	0	30	3.29	15
Alkalinity	16	302	163.21	24	352	183.14	1000
Hardness	20	214	97.33	10	218	87.43	500
Calcium	2.4	49.7	18.69	3.2	77	26.4	200
Magnesium	2.4	36.9	12.96	0	1.3	0.4	150
Sodium	3.9	150	51.44	2.1	78.1	30.9	200
Potassium	1.3	8.3	4.1	2.9	20.5	9.7	30
Chloride	6	67.5	19.65	3.2	48.1	15.6	250
Bicarbonate	19.5	368	199.62	29.3	429.2	212.6	n.a
Sulfate	1.6	16.7	6.46	0.4	32.9	8.4	400
Nitrate	0.01	118.7	20.69	0	0.2	0.1	10
Phosphate	0.01	0.14	0.05	0	0.5	0.1	30
Fluoride	0.1	0.13	0.34	0.1	0.6	0.3	0.5-1.5

As shown in Table 1, the statistical summary of the results of the physico-chemical analysis of water samples from nineteen (19) boreholes obtained from the study area during the two climatic regimes (wet and dry seasons), show that the pH of the groundwater samples ranged from 5.77 to 7. 36 with a mean of 6.76, and 4.96 to 8.3 with a mean of 6.96, EC ranged between 57.9-830 with a mean of 413.46 and 47.6-709 with a mean of 356.86μS/cm, Turbidity ranged from 1-73 with a mean of 8.81 and 0-96 with a mean of 13.24NTU for wet and dry seasons, respectively. All anions and cations were within permissible levels for human consumption except nitrate. Nitrate concentration in the wet season varied from 0.01 to 118.7 mg/l with a mean of 20.69 mg/l.

Table 2. Statistical summary of trace metals of sampled wells in the study area

Parameter	Wet Season			Dry Season			WHO, 2008
	Min	Max	Mean	Min	Max	Mean	
Zinc	0.007	0.077	0.028	0.008	0.092	0.046	5
Copper	0.013	0.114	0.045	0.044	0.044	0.044	1
Cobbolt	0.048	0.144	0.096	0.048	0.140	0.096	n.a
Arsenic*							0.01
Chromium	0.028	0.064	0.04	0.028	0.064	0.04	n.a
Cadmium	0.001	0.01	0.003	**0.064**	**0.12**	**0.092**	0.003
Mercury*							0.05
Lead				**0.16**	**0.78**	**0.34**	0.001

*measured concentrations were below detection limit.

As shown in Table 2, the heavy metals detected during the analysis were zinc, copper, cobbolt, chromium and lead. Arsenic and mercury were not detected at all while lead was detected only during the dry season. The concentrations of lead in sampled waters in the dry season ranged from 0.16-0.78 mg/l with a mean value of 0.34 mg/l. The ranges of concentrations of cadmium, chromium, cobbolt, copper and zinc in wet and dry seasons were 0.001-0.0l0 & 0.064-0.120, 0.028-0.064 & 0.028-0.064, 0.048-0.144 & 0.048-0.140, 0.013-0.114 & 0.044-0.044, and 0.007-0.070 & 0.008-0.092mg/l respectively, while their mean concentrations were 0.003 & 0.092, 0.04 & 0.04, 0.096 & 0.096, 0.045 & 0.044, and 0.028 & 0.046 mg/l respectively.

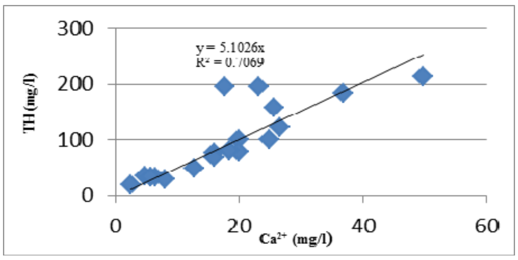
4. Discussion

4.1 Physico-Chemical Parameters

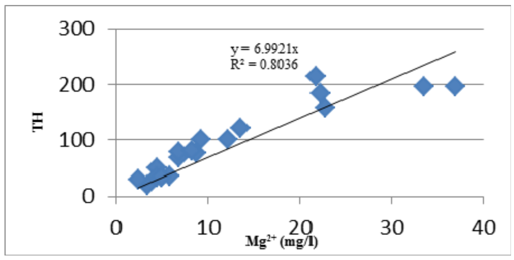
According to the classification based on (Hounslow, 1995), three (3) wells representing 15.8% were moderately acidic (i.e. pH of 4-6.5) while the remaining sixteen (16) wells were neutral (pH 6.5-7.8) in the wet season. On the other hand, during the dry season, four (4) wells, representing 21% were moderately acidic (pH 4-6.5), eleven (11) out of nineteen samples representing 58% were neutral (pH 6.5-7.8) while four (4) out of nineteen (19) were moderately alkaline (pH 7.8-9). However, majority of the wells (79%) and (89.5%) in the dry and wet seasons respectively, had pH values falling within the acceptable range (pH 6.5-8.5) for human consumption (WHO, 2008). Freeze and Chery (1979), classified groundwater on the basis of TDS as fresh when values range 0-1 000 mg/L as fresh, 1 000-10 000 mg/L as brackish, 10 000-100 000 mg/L as saline and greater than 100 000 mg/L as brine. In this study, TDS of all the samples ranged between 34.8-502 mg/l and 23.9-355 mg/l in wet and dry seasons respectively, which obviously were less than 1 000 mg/l implying fresh waters in all the wells. Electrical conductivity (EC) of groundwater ranged from 47.6 µS/cm to 709 µS/cm, with a mean of 356.86 µS/cm for the dry season while it ranged from 51.9 µS/cm to 830 µS/cm with a mean of 413.46 µS/cm in the wet season. Approximately 84.2% and 79% of the analysed samples in the wet and dry seasons respectively had EC values above the (WHO, 2008) maximum allowable limit of 250 µS/cm. Water hardness is the soap consuming property of water caused by the presence of alkali earth metals (calcium and magnesium), and to a lesser extent, the salts of other metals such as iron and manganese. Where these metals combine with bicarbonates they form temporal hardness which can easily be removed by heat, but when in combination with nitrates, they form permanent hardness which is not easily removable by heat (Freeze & Cherry, 1979). According to McGoowan (2000), groundwater with hardness between 0-60 mg/l is considered as soft; between 61-120 mg/l as moderately hard; 121-180 mg/l as hard and greater than 181 mg/l as very hard. In this study, values of hardness of all samples were within permissible limit (< 500 mg/l) (WHO, 2008). Values ranged from 20-214 mg/l with a mean of 93.7 mg/l and 10-218 mg/l with a mean of 87.43 mg/l for samples in wet and dry seasons, respectively.

Generally, hardness in the study area could be described as soft to moderately hard as approximately 69% of the samples had values ranging between 0-120 mg/l while 31% were hard to very hard.

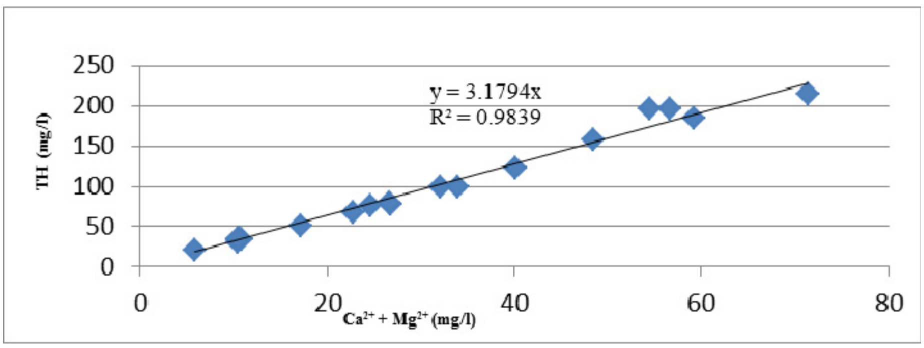
The EC and TDS values along with relatively low-medium total hardness (TH) values suggest a low-m edium mineralized soft-moderately hard fresh groundwater system. The total concentration of alkaline ea rth metal ions, such as calcium and magnesium are determinants of the hardness of water during the w et season as depicted by the relatively strong correlations (0.848 and 0.928) with Total Hardness respec tively, as seen from the cross plot of Ca^{2+} + Mg^{2+} (mg/L) versus TH (mg/L) with correlation coefficien t of 0.984 (Figure 3a). However, as can be observed from Figure 3b, Ca^{2+} appeared to be the major d eterminant of total hardness (with a correlation of 0.98), which almost equals the correlation between to tal hardness and the combined alkali earth metals (Ca^{2+} + Mg^{2+}). This must have been due to higher m obility of Mg^{2+} and a possible cationic exchange between Na^+ and Mg^{2+} and could be seen from the in creased correlation of total hardness with Na^+ from 0.107 to 0.463. The increased correlation with Na^+ could be a possible cause of the decrease in the mean total hardness of water from 97.33 mg/l to 87.4 3 mg/l (Table 1). Thus, the possible source of hardness in the groundwaters could be as a result of ge ogenic introduction of Ca^{2+} and Mg^{2+} ions into water by leaching of rock minerals within the aquifer, which agrees with the findings of Talabi (2013).



(a_w)

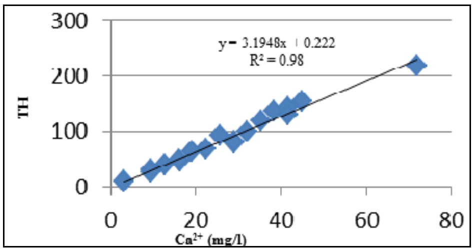


(b_w)

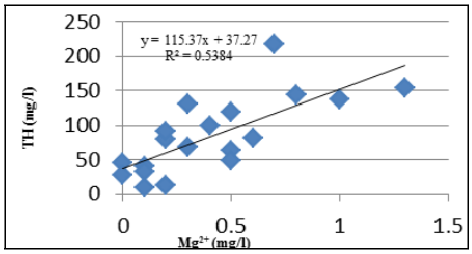


(c_w)

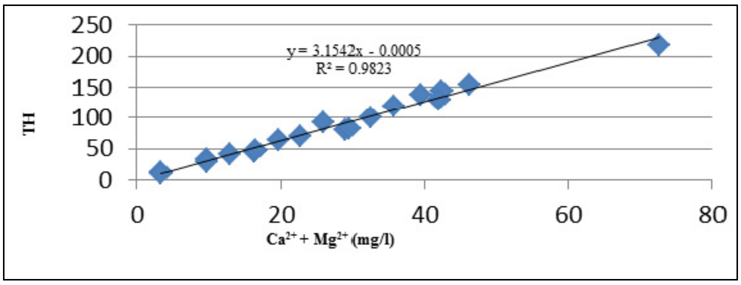
Figure 3a. Plots of Alkali earth metals with total hardness for wet season water samples



(a$_d$)



(b$_d$)



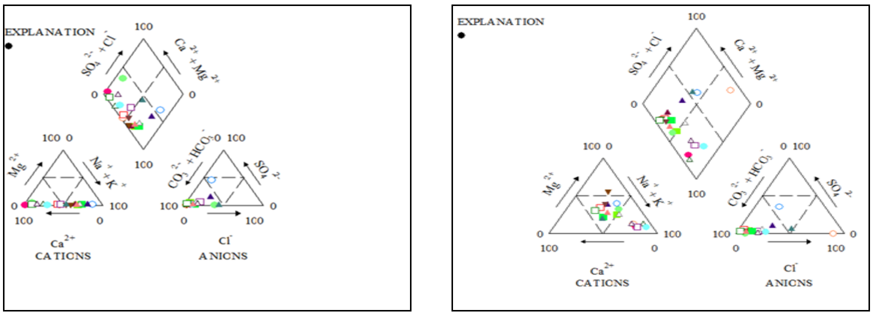
(c$_d$)

Figure 3b. Plots of Alkali earth metals with total hardness for dry season water samples

On the other hand, with the exception of high nitrate concentrations in three wells, namely Tambing (85.1 mg/l), Naajong-2 (23.04 mg/l) and Yunyo (118.7 mg/l), which exceeded the (WHO, 2008) permissible limit of 10 mg/l, all the anions analysed fell within the acceptable limit for human consumption. The presence of high nitrate concentrations in the three relatively shallow wells (depth of aquifers range between 18-30 m) in the wet period could be an indication of a possible contamination from the extensive use of chemical fertilizers (NPK-fertilizers) for farming during the raining (wet) period, since rain-fed agriculture is the major occupation of the inhabitants in the study area, and this agrees with Yidana & Yidana (2009) who indicated that most nitrate water comes from either agro-chemical or from industrial and also organic sources and findings of Hem (2002). This could be very true due to the realization that nitrate concentrations of all water samples in the dry season were found to be extremely very low, ranging from 0-0.2 mg/l with a mean of 0.1 mg/l as there is little or no rain during this period and no farming takes place. This clearly suggests that groundwater contamination of nitrate during wet (rainy) season is due to infiltrating rain water which is contaminated with chemical fertilizers applied to crops by farmers (anthropogenic). Thus, the consumption of groundwater during the wet period by the inhabitants in the three affected communities exposes the inhabitants to such diseases as methaemoglobinemia in children (WHO, 2008).

4.2 Hydrochemical Facies

From Table 1, it was observed that all the cations irrespective of the climatic period fell within the acceptable limits (WHO, 2008) for human consumption. Sodium appears to be the dominant cation followed by calcium while bicarbonate is the dominant anion irrespective of the climatic period. The concentrations of sodium varied from 3.9 to 150 mg/l with a mean of 51.44 mg/l while potassium was least ranging from 1.3-8.33 mg/l with an average of 4.1 mg/l with the order of dominance of major cations in the wet and dry periods being Na>Ca>Mg>K and Na>Ca>K>Mg, respectively. On the other hand, bicarbonate appeared to be the major anion irrespective of the climatic regime of the study area. Its concentration in the wet period varied from 19.5 to 368 mg/l with a mean of 199.62 mg/l while in the dry period, the concentrations of bicarbonate ranged from 29.3-429.2 mg/l with a mean of 212.6 mg/l. The orders of dominance of the major anions in the wet and dry periods were HCO_3>NO_3>Cl>SO_4>F>PO_4 and HCO_3>Cl>SO_4>F>PO_4>NO_3, respectively. The major ionic compositions of groundwaters in the dry and wet seasons of the study area are presented in the Piper trilinear diagram (Piper, 1944) in Figure 4. From Figure 4a and 4b, it can be observed that climate variability has profound influence on the cations composition of groundwaters in the study area. The cationic distribution of water samples obtained during the wet period appeared more mixed (Figure 4b) while water samples obtained during the dry period (Figure 4a) appeared to be depleted in magnesium. The major water types of the groundwaters within the study area were Na-Ca-Mg-HCO_3 and Na-Ca-K-HCO_3 for the wet and dry seasons, respectively.



(a) (b)

Figure 4. Piper plot of major ions of groundwaters in the dry (a) and wet (b) seasons

4.3 Heavy Metals

From Table 2, the mean concentrations of all the heavy metals analysed in the sampled waters during the raining and dry seasons fell within the acceptable limits of WHO (2008) standards with the exception of cadmium and lead. Generally, the orders of dominance of the concentration of heavy metals in the analysed groundwater samples were Pb>Co>Cd>Zn>Cu>Cr and Co>Cu>Cr>Zn>Cd>Pb in the dry and wet seasons, respectively. According to van Assche (1998) apart from the natural dissolution of cadmium from rocks and soils into groundwater, much could be released into the environment from anthropogenic activities which may include but not limited to the use of agro-chemicals (like phosphate fertilizers), burning of coal, manufacturing of iron, steel and cement, and disposal of waste. Cadmium may enter water and soil in waste from industries or waste disposal plants, or from leaching from landfill sites. The study area is characterised with long periods of bushfires during every dry season as well as the use of agrochemicals such as phosphate fertilizers, weedicides and pesticides which have cadmium as trace constituents. The concentrations of cadmium ranged from 0.001 to 0.12 mg/l with a mean of 0.092 mg/l and 0.001 to 0.01 mg/l with a mean of 0.0033 mg/l for dry and wet seasons, respectively. Analyses of samples derived in the dry season showed that two (2) well had Cd concentration above recommended level while in the wet season; five well had higher Cd concentration. The high Cd concentrations in the identified wells could therefore be due to the intense use of phosphate fertilizers in the study area and possibly from burnt crops and plant which had assimilated Cd which then may be leached during the rainy season to the groundwaters in the aquifers beneath the ground. The ingested cadmium into the human body may expose them to adverse health effects (Forstner & Wittmann, 1983). Ingestions of high doses of cadmium can affect the kidney, lungs and bones of humans. According to Green (2011), the human kidney is the main organ commonly affected by cadmium. Cadmium is known to be able to accumulate in the human up to 20-30 years before producing adverse health effects on the respiratory system as well as the weakening of the bones.

The concentrations of lead in all the sampled waters in the study area during the rainy season were below detection limit, which agrees with the findings of Yidana and Yidana (2009). They concluded that Pb concentrations of groundwaters in the southern part of the voltaian basin of Ghana were generally very low. However, analyses of results of water samples obtained during the dry period showed that concentrations of Pb in all the boreholes exceeded the WHO (2008) permissible limit of 0.01 mg/l. Pb values ranged from 0.016 to 0.77 mg/l with a mean of 0.335 mg/l which clearly contradicts the conclusion established by Yidana and Yidana (2009). The presence of high Pb in groundwaters in the dry periods is rather a disturbing situation as far as exposure to adverse health condition to inhabitants is concerned. This is due to the fact that the period of dry season in the study area is about seven months with groundwater serving as the only source of potable water for the inhabitants. The study area is also located in the hottest parts of Ghana (the three northern regions) and the consumption of water is therefore very intense during the dry period. According to WHO (2008), Green (2011) and Reeves and Vanerppool (1997) the ingestion of water contaminated with Pb at concentrations above the permissible limit may expose humans to cause damage to the brain, kidneys, the central nervous system, the cardiovascular system and the immune system. According to CDC (2000), the most vulnerable group to the effects of Pb ingestion are children and Pb has been shown in several instances to permanently reduce the cognitive capacity of children even at extremely low levels of exposure. Lead is generally known to occur naturally and also exist in old pipes, lead-combining solders, exhaust from motor fumes containing leaded gasoline as well as from industrial sources such as smelters and lead manufacturing and recycling industries and waste sites such as contaminated landfill sites (Jin et al., 2006). According to van Assche (1998), Pb and Cd concentrations in freshwater can be impacted by agricultural activities such as the use of agro-chemicals in farming. Anim-Gyampo et al. (2013), concluded that chemical fertilisers such as phosphate fertilisers, weedicides and pesticides which are massively being utilized in dry-season irrigation farming activities in northern Ghana contain heavy metals such as Pb, Cu, Zn and Cd as trace components, therefore may be leached into the underlying groundwater by infiltrating rainwater and irrigation water. The low concentration levels of Pb in the raining season could be due to dilution by rainwater which readily recharges the groundwater system due to existence of preferred pathways while during the long dry season, no recharging groundwater exist, and coupled with unfavourable climatic conditions such as extremely high evapotranspiration and high temperature, the abstraction frequency is huge. These factors could enhance the concentrations of heavy metals per unit volume of water within the aquifers as could be observed from Table 2. Notwithstanding the above enumerated anthropogenic activities, there is the possibility of increased dissolution of heavy metals into the groundwater system during the dry season by virtue of groundwater-rock interaction as a result of reduced groundwater flow coupled with increased ambient temperatures which can enhance the dissolution processes.

4.4 Chemical Quality of Water for Drinking Purposes

Water Quality Index (WQI), which is a quantitative means of evaluating the quality of water, offers a useful representation of overall quality of water. According to Sahu and Sikdar (2008), WQI is defined as a reflection of composite influence of individual quality characteristics on the overall quality of water. WQI is used to assess water quality trends for management purpose. The estimation of WQI requires the selection of parameters of great importance since the selection of many number of parameters widen the water quality index. The importance of selecting parameters depends on the intended use. In this study, ten physico-chemical parameters namely pH, Electrical Conductivity (EC), Zinc, Lead, Cadmium, Fluoride, Chloride, Sulphate, Sodium, and Calcium were used to calculate WQI. According to Yidana and Yiadana (2009), the highest weight of five is assigned to parameters which have the major effects on water quality. In this study, lead, nitrate, and fluoride were assigned the highest weight of 5 because of their importance in the water quality assessment in that order as shown in Table 2. The assessment of the suitability of groundwaters in the study area for human consumption throughout the whole year which is characterised by two climatic seasons (i.e. raining and dry seasons) was achieved by estimating the WQI using Equations (1), (2) and (3) and comparing the results to the criteria defined by Sahu and Sikdar (2008) and using influential parameters defined by Yidana and Yiadana (2009). Weights (W) were assigned to each influential parameter based on their perceived effects on primary health. The Relative Weight (W_i) of each influential parameter was estimated using Equation (1);

$$W_i = \frac{w_i}{\sum w_i} \tag{1}$$

where$\sum w_i$ = sum of the weights of all parameters and the weights are shown in Table 3 below.

Table 3. Assigned weights and estimated relative weights of influencial parameters (wet season)

Parameters	WHO (2008)	Wet Season		Dry Season	
		Wi	W	Wi	W
pH	7.5	4	0.13	4	0.14
SO_4^-	250	3	0.09	3	0.1
Cl^-	250	3	0.09	3	0.1
F^-	1.5	5	0.15	5	0.17
Ca	75	2	0.06	2	0.07
Mg	30	2	0.06	2	0.07
Na	200	2	0.06	2	0.07
Cd	0.003	3	0.09	3	-
Cu	2	5	0.06	5	
Zn	5	2	0.06	2	0007
NO_3^-	50	5	0.15	5	-
Pb	0001	5	-	5	0.17
	Sum	41	1.0	41	0.89

Determination of WQI in this study was done using Equations (2), (3) and (4) in the proceeding steps. In the third step, a quality rating scale, q_i, was computed for each parameter using Equation 2 below;

$$qi = (Ci / Si) \times 100 \tag{2}$$

where C_i and S_i respectively, refer to the concentration and the WHO standard for each parameter, in mg/l.

The water quality sub index for each influential parameter (SI_i) was then calculated using Equation 3 below;

$$SI_i = q_i \times W_i \tag{3}$$

The water quality index (WQI) was estimated using Equation (4) below;

$$WQI = \sum SI_i \tag{4}$$

Table 4 below shows the results and Figures 4 & 5 show spatial variations of the estimated water quality indices for groundwater in the study area during the rainy and dry seasons;

Table 4. Values of Water Quality Index (WQI) of groundwaters in the Wet Season

Community	Wet Season		Dry Season	
	WQI	**Classification**	**WQI**	**Classification**
Bunkpurugu	18.85	Excellent Water	385.94	Unsuitable water
Poiga	36.36	Excellent Water	104.39	Poor Water
Naanyar	22.76	Excellent Water	100.99	Poor Water
Sakbouk	21.20	Excellent Water	782.37	Unsuitable water
Paknaatik	20.21	Excellent Water	41.30	Excellent Water
Toogeng	20.87	Excellent Water	71.44	Good Water
Gbankpurugu	22.38	Excellent Water	1339.9	Unsuitable water
Naaban	23.61	Excellent Water	609.44	Unsuitable water
Tambing	13.44	Excellent Water	283.74	Very Poor Water
Jilick 1	30.18	Excellent Water	704.97	Unsuitable water
Naajong 1	31.04	Excellent Water	553.83	Unsuitable water
Binde	20.90	Excellent Water	820.53	Unsuitable water
Naaniac	19.56	Excellent Water	1000.51	Unsuitable water
Jimbale	27.85	Excellent Water	647.87	Unsuitable water
Mangor	18.65	Excellent Water	646.30	Unsuitable water
Bunbuna	23.98	Excellent Water	813.30	Unsuitable water
Jilick 2	31.20	Excellent Water	126.31	Poor Water
Naajong 2	82.56	Good Water	554.82	Unsuitable water
Yunyoo	202.34	Very Poor Water	786.97	Unsuitable water

The assessment of water quality based on WQI is usually achieved by using the criteria developed by Yidana and Yiadana (2009), which defines WQI values of less than 50 as excellent water, between 50-100 as good water, 100-200 - poor water, 200-300 - very poor water and WQI values above 300 as unsuitable for human consumption. It can be observed from Table 4 and Figure 5a that groundwater quality in the study area was generally excellent for human consumption during the wet season except one well in Yunyo community that had an estimated WQI of 202.34, far exceeding 100.

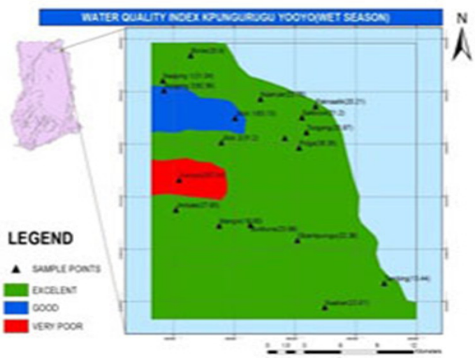


Figure 5a. Variation in water quality (wet)

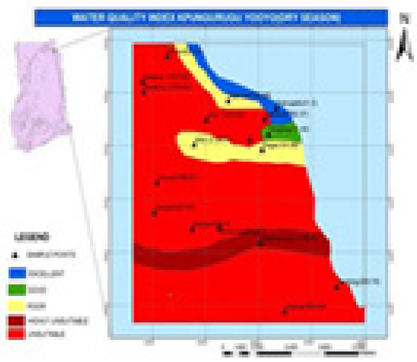


Figure 5b. Variation in water quality (dry)

On the contrary, there is a dramatic change in the quality of groundwaters during the dry season (Figure 5b). With the exception of two wells located at Paknaatik and Toogeng with WQI below 100 (41.3 - excellent and 71.4 - good water) the remaining 17 wells had quality being poor water, very poor and unsuitable. It is observed from Table 4 that 13 out of the 19 sampled wells, representing about 68.4% had their water quality changing from excellent water to unsuitable water; 3 wells changed from excellent water to poor water whilst one well located in Yunyo community changed from very poor to unsuitable. This observation clearly shows that among other factors controlling groundwater in the Bunkpurugu-Yunyo District of Ghana, climatic conditions (rainfall) plays a critical role. Only one community (i.e. Paknaatik) has excellent water quality throughout the year with insignificant effect from climate. The seemingly deterioration in the quality of groundwaters in the wells during the dry season could be due to elevations in the concentrations of Pb in almost all the sampled wells from below detection levels in the wet seasons up to 0.776 mg/l in the dry season. The very poor quality of groundwater in Yunyo community could be due to the extremely high levels of nitrate in the wells.

5. Conclusion

The water quality of nineteen (19) boreholes in the Bunkpurugu-Yunyo district of north-eastern Ghana had been assessed from the analyses of their hydrochemistry and the use of WQI. Generally, the physico-chemical parameters of most groundwater samples fell within WHO acceptable limits with exception a few parameters, namely Turbidity and Nitrates. Two wells in Tambing and Binde representing 10.5% had turbidity values above WHO (2008) guideline values during the wet season while five wells in Tambing, Binde, Bunkpurugu, Sakbouk and Naaniac representing 21% had turbidity values exceeding acceptable limit for potable drinking water. Hardness of groundwaters in the study area varied significantly with about 36.8% (majority) being soft in both seasons while 5.3% and 21.1% were very hard during the dry and wet seasons (see Table 3). Hardness of waters could be predominantly temporal, due to the dominance of HCO_3^- as the major anion in all samples irrespective of the climatic season while permanent hardness is expected on a minor scale due to the presence of nitrates and sulphates. Majority (84.2%) of the groundwaters are neutral while all samples were fresh (TDS < 1000 mg/l) making the waters generally acceptable for human consumption. The ionic composition and relative dominance varied with prevailing climatic conditions, with Na^+ and HCO_3^- being the dominant cation and anion in the raining season Ca^{2+} and HCO_3^- are the dominant ions in the dry period with corresponding water types of Na-Ca-Mg-K-HCO_3 and Ca-Mg-(Na-K)-HCO_3 for wet season and dry seasons respectively. The concentrations of major cations are in the order of Na>Ca>Mg>K. and Ca>Na>K>Mg while the in the case of the anions, the order was HCO_3>NO_3>Cl>SO4>F>PO_4 and HCO_3>Cl>SO_4>F>PO_4>NO_3 respectively, for wet and dry seasons. The orders of heavy metals in the groundwater sampled in the study area were Pb>Co>Cd>Zn>Cu>Cr and Co>Cu>Cr>Zn>Cd>Pb in the dry and wet seasons respectively. The concentrations of heavy metals were generally acceptable for drinking water except Cd in four samples which had value slightly above the WHO (2008) and recommended limit of 0.003 mg/l in the wet season while the concentrations of Pb in all the nineteen samples were above the recommended value of 0.01 mg/l and Cd values in two samples exceeded the recommended of 0.003 mg/l in the dry season. The high Pb concentrations in all the water samples could be due to the intensive use of agro-chemicals such as phosphate fertilizers, weedicides and pesticides which contain Pb and Cd as traces but the low mobility of Pb in groundwater could account for the very high concentrations as compared to Cd which is relatively much mobile. The occurrence of the high Pb in the dry season presents a serious health issues due to the fact that groundwater is the only available potable water for human consumption in the study area with little or no alternative. Thus, the inhabitants stand the risk of kidney damage, weakening of the nervous system and cardiovascular infections. The public health directorate of the Ministry of Health in Ghana must as a matter of necessity carry out monitoring of the health of inhabitant in the study area to ascertain the current health status of the people and also sensitise them on the potential health implications that would likely affect consumers. The quality of groundwaters in the study area and its surroundings must continuously be monitored and if conditions do not improve public awareness must be created to alert inhabitants of the potential health implication associated with the consumption of groundwater in the study area.

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