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Groundwater Quality Assessment for Drinking and Irrigation Purposes in Obuasi Municipality of Ghana, A Preliminary Study

[1]Anthony Ewusi, [2]Solomon Obiri-yeboah, [2]Hans-jürgen Voigt, [3]Stephen Boahen Asabere and [2, 4]Crentsil Kofi Bempah
[1]Department of Geological Engineering, University of Mines and Technology, P.O. Box 237, Tarkwa, Ghana
[2]Chair of Environmental Geology Erich-Weinert-Straße 1, 03046, Brandenburgische Technische Universität, Cottbus, Germany
[3]Department of Forest and Environment, Hochschule fűr Nachhaltige Entwicklung, Friedrich-Ebert-Strasse 28, D-16225, Eberswalde, Germany
[4]Nuclear Chemistry and Environmental Research Centre, National Nuclear Research Institute, Ghana Atomic Energy Commission, P.O. Box LG 80, Legon, Accra-Ghana

Abstract: Groundwater quality of the Obuasi municipality was assessed to understand the contamination processes due to the presence of various contaminant sources and complicated geochemical processes and the suitability of groundwater for irrigation and drinking purpose for a sustainable agriculture and basic human needs. Water samples were collected during the raining season when a rise in water table was expected and during the dry season. They were analyzed for major cations and anions. Parameters like sodium adsorption ratio, % sodium, electrical conductivity, total hardness, total dissolve solutes and stoechiometric relations were calculated on the basis of chemical data. A questionnaire was also used to investigate perception of consumers on taste and odour. Comparison of the concentration of the chemical constituents with World Health Organization (WHO) drinking water standards of 2004 and various classifications show that present status of groundwater in Obuasi is good for drinking and irrigation purposes. Concentrations of major cations and anions in the groundwater systems vary spatially and temporally. Abundance of these anions is in the following order: $Ca^{2+}>Na^{+}>Mg^{2+}>K^{+} = HCO_3^{-}>Cl^{-}> SO_4^{2-}>H_2SiO_4>Br^{-}>PO_4^{2-}>F^{-}$. In terms of rainy season impact, Obuasi groundwater shows dilution and flushing, however, samples show excessive leaching of different chemical components into the groundwater system leading to the enrichment of different anions and cations and this indicate pollution from extraneous sources. No clear correlation between the quality parameters and perceived quality in terms of satisfactory taste response were obtained at electrical conductivity values lower than the threshold minimum acceptable value.

Keywords: Drinking and irrigation water quality, Ghana, groundwater, Obuasi

INTRODUCTION

There has been a tremendous increase in demand for fresh water due to population growth and intense agricultural activities. Quality of groundwater is equally important as its quantity owing to the suitability of water for various purposes. Variation of groundwater quality in an area is a function of physical and chemical parameters that are greatly influenced by geological formations and anthropogenic activities (Subramani *et al*., 2005).

Groundwater has become the major source of water supply for domestic, industrial and agricultural sectors of many countries. It is estimated that approximately one-third of the world's population use groundwater for drinking (UNEP, 1999). Poor quality of water adversely affects human health and plant growth. In developing countries like Ghana, around 60% of all diseases are directly related to poor drinking water quality and unhygienic conditions. The World Health Organization (WHO) has repeatedly insisted that the single major factor adversely influencing the general health and life expectancy of a population in many developing countries is lack of ready access to clean drinking water (Davies, 1995).

Anthropogenic activities like mining, combustion, fuels, wood preservation, use of As based pesticides etc. have been a crucial factor for determining the quality of groundwater. Numerous works have reported in both developed and developing nations that urban

Corresponding Author: Anthony Ewusi, Department of Geological Engineering, University of Mines and Technology, P.O. Box 237, Tarkwa, Ghana

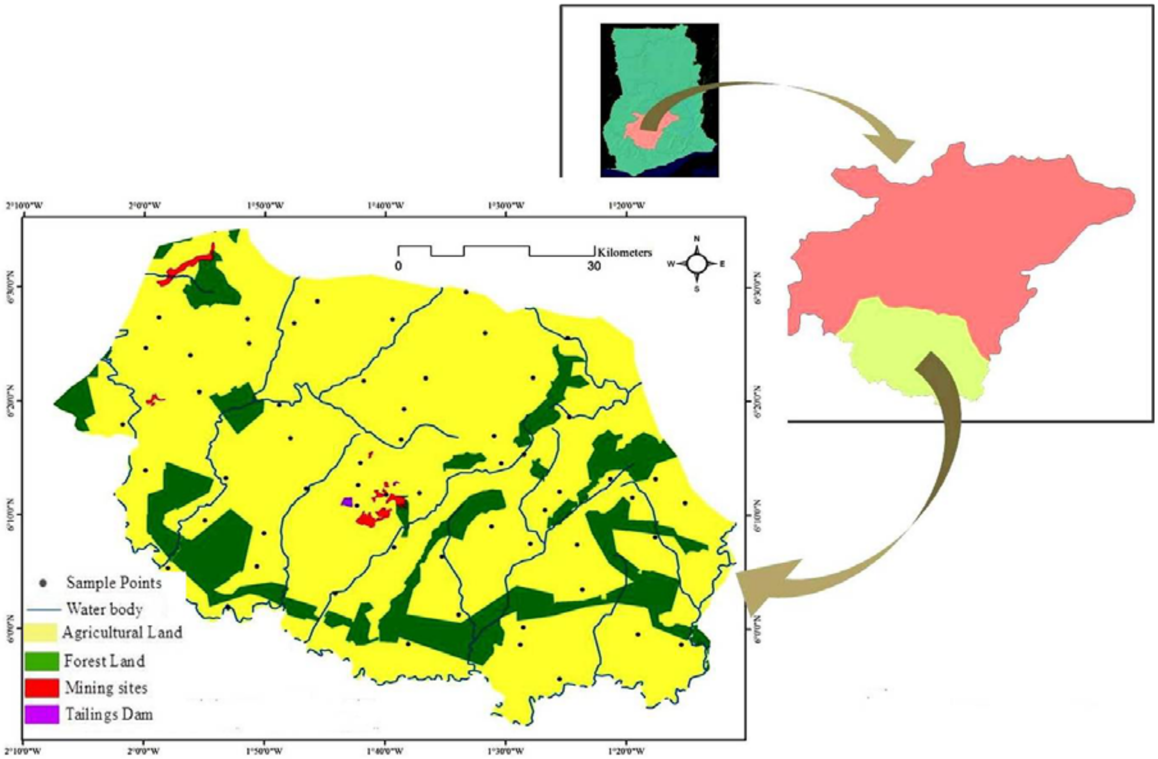

Fig. 1: Location and land use map of the area showing sampling points

development, industrial and agricultural activities directly or indirectly affect groundwater quality (Singh and Chandel, 2006; Gupta *et al*., 2008; Srinivasamoorthy *et al*., 2011). In contrast, there is very little information on groundwater quality data in developing countries, like Ghana as well as lack of comprehensive data which is based on the assessment of water quality criteria with particular emphasis on the consideration of physicochemical properties of the soil and the impact on crop yield. This may be due to lack of financial support for scientific research, environmental policy and regulations for control and monitoring of groundwater. In countries where these exist, agencies responsible lack the required capacity to ensure compliance and enforcement of regulations (Bempah *et al*., 2011).

An appropriate assessment of the suitability of groundwater requires the determination of concentrations of some important parameters like pH, Electrical Conductivity (EC), Total Dissolve Solutes (TDS), total hardness, Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Cl^{-}, HCO_3^{-}, SO_2^{-4}, F^{-} and PO_4^{3-} and comparing with the guideline values set for potable water (WHO, 2004; ISO 10500, 1991).

The color and taste of water are the two basic criteria for a consumer to decide the suitability of water for drinking without considering other lethal chemical contaminations like arsenic, nitrate, fluoride and other heavy metal contaminations (Kumar *et al*., 2007). As groundwater in Obuasi municipality is intensively exploited for water supply, it therefore becomes essential to determine the present status of groundwater on the basis of its quality and suitability for drinking and irrigation. Hence the present work has the objective of understanding the groundwater contamination processes in the Obuasi area, due to the presence of various contaminant sources and complicated geochemical processes and the suitability of groundwater for irrigation and drinking purpose for a sustainable agriculture and basic human needs.

Physiography: Obuasi is located in the Ashanti region of Ghana (Fig. 1) and is about 64 km south of Kumasi, the regional capital and 300 km northwest of Accra, the capital of Ghana. It is situated at latitude 6° 12’ 00’’ North and longitude 1° 40’ 00’’ West. It is located in the tropical evergreen rain forest belt. It covers an area of about 162.4 km^2 and is bounded on the south by Upper Denkyira District of the Central Region, east by Adansi South District, west by Amansie Central District and north by Adansi North District (Mensah, 2006-10-11).

The area is characterized by double rainfall maxima involving a double wet season in April to June and October to November and the main dry season from December to March. The average daily rainfall is 10 mm whilst the mean annual rainfall is about 1480 mm (Asamoah, 2004). The area on the average has

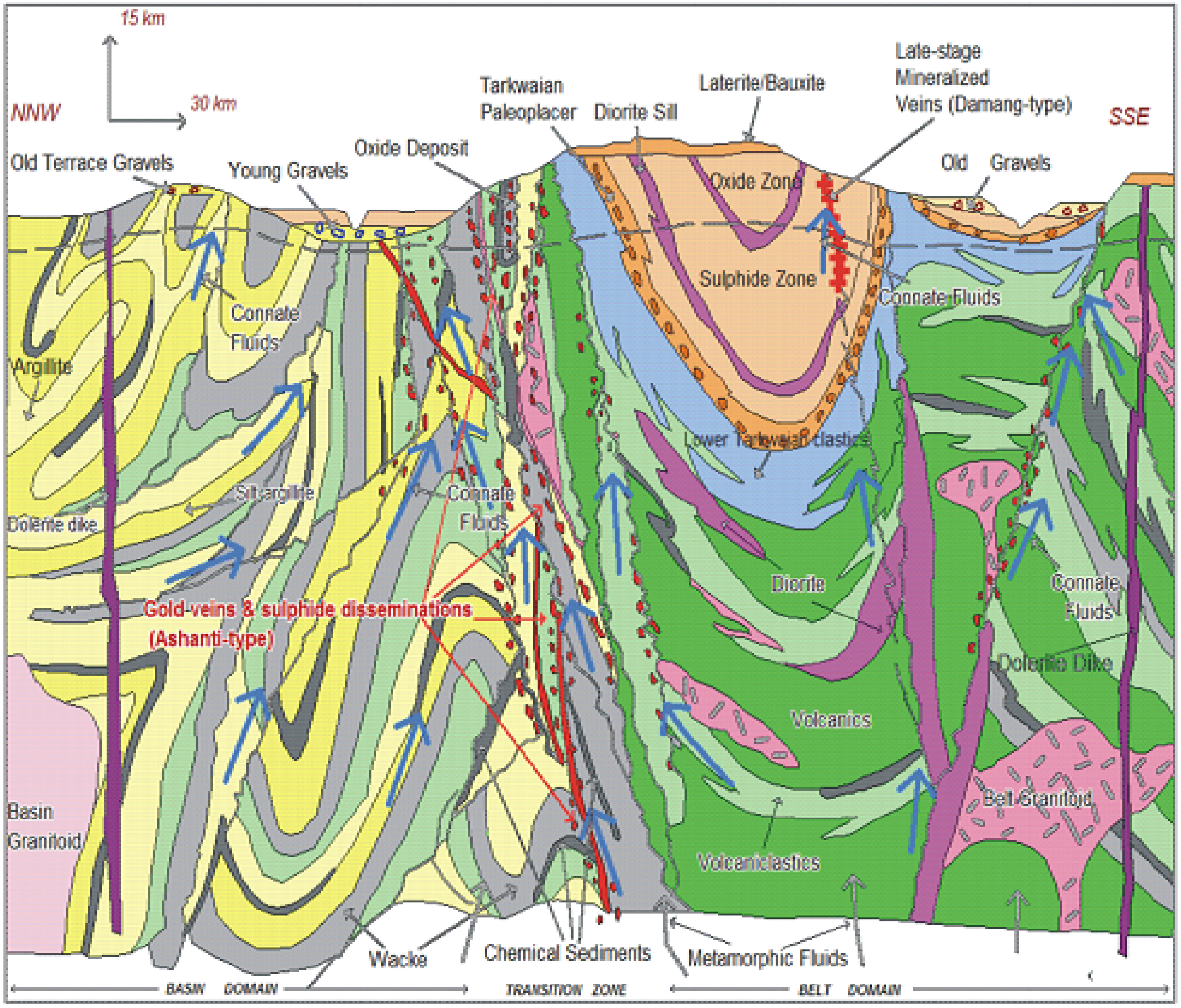

Fig. 2: Schematic cross sectional geology of Obuasi

minimum of 10 continuous rainy months, with December-February as the driest months. Temperatures are uniformly high all year, with an annual mean value of about 27.4°C. February and March are the hottest months registering temperatures of 28.5 and 28.9°C respectively. During this period, maximum daily temperatures may rise as high as 36.5°C with a minimum temperature of 18°C. The coldest month is August; and temperature increases as one move northwards. Wind directions are predominantly Southwest/Northwest throughout the year. The average wind speed is 3.4 km/h. Apart from the natural drainage line, the municipality also has thirteen rivers and streams that drain the area: Pompo, Nyamso, Akapori, Kwabrafo, Nyam, Kwaw, Nyamso, Enewopeanom, Nkesu and Gyimi. Others include Wheaseamo, Konka, Nyame and Nyankuma streams.

Geology and hydrogeology: The geology of Obuasi consists of Proterozoic rocks of the Birimian (metasedimentary and metavolcanic) rocks and Takwaian systems (Kesse, 1985). The metavolcanic Birimian rocks consists of black slates, sericite schist and phyllites, with subordinate grey, sandy phyllites and greywackes, whereas the metasedimentary Birimian rocks consist of black phyllites, metasiltstones, metagreywackes, tuffaceous sediments, tuffs and hornstones (Fig. 2). The Tarkwaian system is mainly a thick series of white and grey quartzites with a few intercalated bands of bluish and pink mudstone and phyllite containing chlorite, magnetite, etc., (Kesse, 1985).

Groundwater is the major source of water supply for communities in and around the Obuasi municipality. The occurrence of groundwater depends on the geology and areas where the rocks are highly weathered, fractured or inter-bedded with quartz veins. The groundwater flow is mostly restricted to joints, fractures or other openings within the crystalline rock formations and borehole yields are therefore often limited. In some areas, the regolith provides potential for increased groundwater storage (Kesse, 1985). The bedrock is not inherently permeable but secondary permeability or porosity has developed because of fracturing and weathering. In general, two types of aquifers are identified: weathered rock aquifers and fractured rock aquifers that can be categorized as confined or semi confined. The aquifers are perennial and may go dry in the dry season.

MATERIALS AND METHODS

A groundwater inventory was carried out in the raining and dry seasons in the Obuasi municipality. Electrical Conductivity (EC) and pH were measured on the field. Sampled groundwater sources were selected to represent different geological formations, mining sites as well as land-use pattern and different depths of the aquifer. Fifteen groundwater samples were collected at monthly intervals, each from twelve communities beginning from early April to late September for the raining season and December to March, 2011 during the dry season. The monthly rainfall pattern in the Obuasi municipality is shown in (Fig. 3).

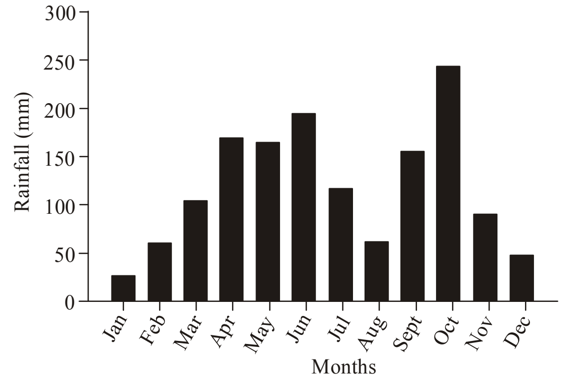

Fig. 3: Monthly rainfall pattern in Obuasi municipality

The samples were collected using acid washed polypropylene bottles to avoid unpredictable changes in characteristic as per standard procedures (APHA *et al*., 1998). At the time of sampling, bottles were thoroughly rinsed two to three times with groundwater to be sampled. In the case of wells which have been installed with hand pumps, the water samples were collected after pumping for sometime as part of the quality control measures to remove casing storage water and obtain representative groundwater samples. Low-flow purging and sampling techniques were developed in a manner to minimize sample disturbances that may likely affect analysis.

In situ measurements of physicochemical parameters including temperature, Total Dissolved Solids (TDS), Electrical Conductivity (EC), pH, Dissolved Oxygen (DO), redox potential (Eh), Total Suspended Solids (TSS), total hardness and alkalinity were determined as per APHA *et al*. (1998) recommendations during both field and laboratory works. The parameters were selected based on their relative importance in acid mine drainage/leachates composition and their pollutional potential on groundwater resource in particular (Bagchi, 1989; Lee and Jones-Lee, 1993b). Some parameters were analyzed on site as these parameters change with the storage time. Others were collected, stored in cooler boxes and analyzed the same day. Samples collected were sent to the laboratory and were filtered using 0.45 μm Millipore filter paper acidified with nitric acid (Ultrapure Merck) for cation analyses and HBO_3 acid was used as preservative for nitrate analysis as prescribed by Kumar (2004). For anion analyses, the samples were stored below 4°C. Major anions (F^-, Cl^-, NO^-_3, SO_4^{-2}) were analyzed by ion chromatograph (Dionex Metrohm 761 Compact IC) with suppressed module equipped with an anion-separator column (Dual 2). A combination of Na_2CO_3 and $NaHCO_3$ was used as an eluent maintained at flow rate of 1.15 mL/min.

Major cations (Na^+, K^+, Mg^{2+} and Ca^{2+}) were also measured on ion chromatograph (Dionex 4500i IC) system with Dionex columns, conductivity detector and computer interface. The entire system was operated using the Dionex AutoIons program (version 3.2) and Cation Self-Regenerating Suppressor (CSRS) in recycle mode. The analytical precision was maintained by running a known standard after every ten samples. An overall precision, expressed as percent Relative Standard Deviation (RSD), was obtained for the entire samples. Analytical precision for cations (Na^+, K^+, Mg^{2+} and Ca^{2+}) and anions (F^-, Cl^-, NO^-_3, SO_4^{-2} and HCO_3^-) were verified using Ionic Balance Error (IBE) on the basis of ions expressed in meq/L (Appelo and Postma, 1999). IBE was observed to be within a limit of ±5% for the entire investigated sample and so the results were deemed acceptable.

A simple questionnaire, consisting of five questions in yes/no format, was used to investigate residence (consumers) perceptions of taste and odor. Randomly twenty people who are regular consumers of that particular groundwater source were interviewed on each location. The questionnaire also included a provision for the research team's observations on the color of water, general state of water point and location. Different instruments were used to measure the same parameter for quality assurance and deviations did not exceed 5%.

RESULTS AND DISCUSSION

The classical use of water analyses in groundwater hydrology is to produce information concerning the water quality. This may yield information about the environments through which the water has circulated and give an understanding of the suitability of the

Table 1: Summary statistics of chemical constituents of groundwater in 12 communities in Obuasi municipality during the rainy season 2010 (April-September)

Groundwater parameters	Min	Max	Avg.	Median	S.D.
pH	4.07	7.10	5.01	4.97	0.58
EC (µS/cm)	112.42	407.28	178.40	128.51	103.20
Eh	-37.30	203.60	181.00	193.70	72.63
TSS (mg/L)	1.00	2.40	1.63	1.73	1.42
TDS (mg/L)	44.03	432.71	146.00	133.63	85.50
TH (mg/L)	8.30	144.73	58.25	42.43	29.83
SAR	0.87	2.24	1.68	1.23	0.83
% Na	37.33	62.43	44.82	34.36	31.28
DO (mg/L)	2.64	51.66	17.32	9.43	11.06
SO_4^{2-} (mg/L)	12.41	167.13	8.21	4.03	27.51
Cl^- (mg/L)	9.62	68.21	6.40	3.60	8.20
F^- (mg/L)	0.13	0.69	0.37	0.33	0.15
Br^- (mg/L)	3.12	17.09	9.15	9.16	3.27
HCO_3^- (mg/L)	13.42	373.22	76.74	39.32	11.63
PO_4^{3-} (mg/L)	0.09	1.17	1.03	0.84	0.15
H_2SiO_4 (mg/L)	5.73	27.48	12.30	10.42	7.57
Na^+ (mg/L)	3.46	58.32	9.63	6.72	7.37
K^+ (mg/L)	1.30	28.40	8.60	6.43	4.40
Mg^{2+} (mg/L)	0.95	13.09	5.04	3.16	3.03
Ca^{2+} (mg/L)	7.04	39.09	9.15	7.06	5.14

S.D.: Standard deviation; pH: Hydrogen ion concentration; EC: Electrical conductivity; Eh: Electrode potential; TSS: Total suspended solids; TDS: Total dissolved solids; TH: Total hardness; DO: Dissolved oxygen; SAR: Sodium adsorption ratio; Min: Minimum; Max: Maximum; Avg.: Average

Table 2: Summary statistics of chemical constituents of groundwater in 12 communities in Obuasi municipality during the dry season (December, 2010-March, 2011)

Groundwater parameters	Min	Max	Avg.	Median	S.D.
pH	4.10	7.62	5.33	5.32	0.76
EC (µS/cm)	187.30	538.60	192.30	142.03	141.38
Eh	-27.93	171.01	142.01	152.12	67.12
TSS (mg/L)	1.09	1.35	1.10	1.12	0.19
TDS (mg/L)	38.92	375.70	121.72	137.63	87.30
TH (mg/L)	7.43	98.21	32.13	28.14	19.03
SAR	0.17	1.41	1.22	0.98	0.73
% Na	10.51	51.11	47.33	39.25	37.53
DO (mg/L)	1.31	32.14	11.09	7.11	8.14
SO_4^{2-} (mg/L)	9.03	145.07	5.01	3.70	12.01
Cl^- (mg/L)	7.05	53.04	4.09	3.11	9.05
F^- (mg/L)	0.03	0.07	0.05	0.01	0.06
Br^- (mg/L)	1.43	13.68	7.48	7.56	0.13
HCO_3^- (mg/L)	11.06	217.21	46.21	27.32	7.01
PO_4^{3-} (mg/L)	0.13	2.37	1.84	1.36	0.18
H_2SiO_4 (mg/L)	3.09	19.15	9.09	7.11	4.23
Na^+ (mg/L)	1.12	46.01	4.78	4.91	5.02
K^+ (mg/L)	0.42	22.05	6.74	4.81	2.05
Mg^{2+} (mg/L)	2.62	18.30	8.72	6.48	3.60
Ca^{2+} (mg/L)	10.30	46.84	12.32	8.10	7.29

S.D.: Standard deviation; pH: Hydrogen ion concentration; EC: Electrical conductivity; Eh: Electrode potential; TSS: Total suspended solids; TDS: Total dissolved solids; TH: Total hardness; DO: Dissolved oxygen; SAR: Sodium adsorption ratio; Min: Minimum; Max: Maximum; Avg.: Average

groundwater for drinking, domestic, agricultural and industrial purposes. The results of the physicochemical analysis of groundwater collected from different locations within the rainy and dry seasons in Obuasi are summarized in Table 1 and 2. The physicochemical analytical results were transformed into descriptive statistical parameters such as maximum, minimum, average and standard deviation for the entire study period.

Major groundwater ion chemistry: In general, temperature of groundwater sampled ranged from 19.7 to 32.6°C, with a mean of 27.4°C (approximately 123.3°F). These low temperatures suggest quick infiltration and a shallow flow-path. Furthermore, it negates any possibility of magmatic heating, as suggested at other volcanic areas (Rose *et al*., 1996). The rainy season had a mean pH value of 5.01 (between 4.07 and 7.10). The values of the physical parameters in the dry season (Table 2) indicate that pH ranges from 4.10 to 7.62 with an average of 5.32. The groundwater was acidic with pH levels lower than permissible limit (6.5-9.2) for esthetic reasons. It has been noted in the WHO and UNICEF (2003) guidelines statement that pH usually does not have a direct bearing on consumers of water. It might, however, affect the esthetic value or lead to the dissolution of heavy metals in the rocks. As yet, there have been no concerns about heavy metal contamination of aquifers in this area.

The Electrical Conductivity (EC) ranged from 187.3 to 538.60 µS/cm with a mean of 142.03 and 112.42 to 407.28 µS/cm with a mean of 178.4 µS/cm for dry and rainy seasons, respectively. The higher average value of EC in the rainy season suggests the enrichment of salt due to evaporation effect in the rainy season followed by subsequent dilution through rainwater.

Unlike pH, EC is higher in rainy season than that of dry season, perhaps because of additional leaching derived from sand dunes, anthropogenic sources and intense agricultural activities compared to dry season as a result of lack of rainfall. Very high standard deviation in EC for dry season suggests local variation in point sources, soil type, multiple aquifer system and other agriculture related activities in the area (Kumar *et al*., 2007).

The redox potential is not directly related to any health effects; rather, it is monitored as an indication of whether the subsurface environment is conducive to removing electrons from materials (high Eh) or adding electrons to material (low Eh). Higher Eh values are often found in recently recharged waters, while lower Eh values are found in older waters that have been exposed to more organic matter, carbonates, or bacteria (Drever, 1988). The redox potential of water is an important control on geochemical processes and the determination of Eh can indicate which ions are likely to be mobile in the system.

Total Suspended Solids (TSS) does not have a health based guideline, but it is recommended that it should be below 500 mg/L for effective disinfection. All the groundwater samples were below this guideline and the TSS was generally low in most of the groundwater samples analyzed, although high values were also found in wells in the rainy season as compared to the values attained in the dry season.

The Total Dissolved Solids (TDS) estimated by residue on evaporation method range from 44.03 to 432.71 mg/L with a mean of 146 mg/L and from 38.92 to 375.70 mg/L with a mean of 121.72 mg/L for groundwater samples in rainy and dry seasons, respectively. The increase of TDS in rainy season is on the higher side than the dry season due to mixing of surface pollutants during the infiltration and percolation of rainwater. Salts, which held back in the interstice or pores in clay/shale while groundwater is evaporated or water table falls, get leached back to the groundwater during the rainy period. Hence the groundwater samples in rainy season in the Obuasi municipality of Ghana have higher TDS levels when compared to dry season. The analytical results have been evaluated to ascertain the suitability of groundwater for human consumption, by comparing with the specifications of TDS set by WHO (2004).

Total Hardness (TH) of water depends mainly upon the amounts of divalent metallic cations of which Ca^{2+} and Mg^{2+} are more abundant in groundwater. The hardness values in water samples range from 8.30 to 144.73 mg/L, the average being 58.25 mg/L $CaCO_3$ in the rainy season whiles that for the dry season is between 7.43 to 98.21 mg/L with an average of 32.13 mg/L. The low values of TH recorded in the dry season might be as a result of flushing and dilution. The most recommended limit of total hardness is 80 mg/L-100 mg/L $CaCO_3$ (Mohsen, 2010). Groundwater exceeding the limit of 300 mg/L $CaCO_3$ is considered to be very hard (Sawyer *et al*., 2003). The maximum permissible limit of TH for drinking water is 500 mg/L and the most desirable limit is 100 mg/L as per the WHO international standards. The results indicate that none of the water sampled in the study period fall in the very hard water category and below the maximum permissible limits.

Threshold for Dissolve Oxygen (DO) is 5.0 mg/L for drinking water and should be more than 5 mg/L for agricultural and domestic purposes (Cruise and Miller, 1994). Very low DO may result in anaerobic conditions that cause bad odours. Results revealed that water quality with respect to DO in rainy season is 17.32 mg/L (2.64 to 51.66 mg/L) while that for dry season is 11.09 mg/L (1.31 to 32.14 mg/L) indicating the suitability of the groundwater for agricultural and high to prevent anaerobic conditions in drinking water.

Na^+ is higher in rainy season (6.72 mg/L) as compared to 4.78 mg/L recorded in the dry season. The high values observed in the rainy season might be derived from weathering of feldspar (plagioclase bearing) rocks and also due to over exploitation of groundwater resources (Hem, 1985).

K^+ is higher in the rainy season (8.60 mg/L) due to weathering of K-feldspars and clay minerals from aquifer matrix than the 6.74 mg/L concentration value recorded in the dry season (Lakshmanan *et al*., 2003).

Ca^{2+} is lower during the rainy season (9.15 mg/L) than 12.32 mg/L recorded in the dry season, due to dissolution of $CaCO_3$ and $CaMg\ (CO_3)_2$ during recharge (Datta *et al*., 1996a). Mg^{2+} concentration is higher during dry season (8.72 mg/L); derived from dissolution of magnesium calcite, gypsum and/or dolomite from source rock (Garrels and Mackenzie, 1967).

Low concentration value of 46.21 mg/L of HCO^-_3 was observed in the dry season; however, residual concentration of 76.74 mg/L was achieved during rainy season due to action of CO_2 upon the basic material of soil and granitic rock.

Cl^- is higher in rainy season (6.4 mg/L) than 4.09 mg/L registered in the dry season due to industrial, domestic wastages and/or leaching from upper soil layers in dry climates (Srinivasamoorthy *et al*., 2008). SO_4^{2-} is higher in rainy season (8.21 mg/L) due to action of leaching and anthropogenic process in metamorphic environment by release of sulphur gases from industries and utilities get oxidized and enter into the groundwater (Saxena, 2004). However, low value of 5.01 mg/L was recorded in the rainy season.

The PO_4^{3-} in the study area was very low, possibly because of phosphate adsorption by soils as well as its limiting factor nature due to which whatever PO_4^{3-} is applied to the agricultural field is used up by the plants. Within the study area are some cash crop farms including wheat which might consumes more PO_4^{3-}. However, PO_4^{3-} is within the permissible limit for both the seasons.

Low concentration value of 0.05 mg/L of F^- was recorded in dry season indicating limited lithogenic input of this ion, whiles high value of 9.48 mg/L was achieved during rainy season. This high value of F^- in the rainy season is as a result of leaching from fluoride rich rocks and easier accessibility of rain water to weathered rock, long-term irrigation processes, semi-arid climate and long residence time of groundwater (Datta *et al*., 1996a; Srinivasamoorthy *et al*., 2008). This value of F^- is however lower than its respective WHO (2004) standard of 1.5 mg/L.

The concentration (mg/L) of individual ions in the rainy season varied as Ca^{2+} from 7.04 to 39.09; Mg^{2+}, 0.95 to 13.09; Na^+, 3.46 to 58.32; K^+, 1.30 to 28.40; Cl^-, 9.64 to 68.21; SO_4^{2-}, 12.41 to 167.13; HCO_3^-, 13.42 to 373.22; F^-, 0.13 to 0.69; Br^-, 3.12 to 17.09 and PO_4^{2-}, 0.09 to 1.17. The chemical composition reflects a low mineralization of the groundwater. The values of pH are almost the same in both seasons. The other parameters had a decrease trend in dry season compared to rainy season.

In the rainy season, no cation exceeded 50% of the total cations (Tcations) in all the groundwater samples. The order of the relative abundance of major cations in the rainy season, expressed in percent of meq/L, were Ca^{2+} (30.21%) >Na^{2+} (28.75%) >K^+ (27.51%)> Mg^{2+} (13.52%) while that of the anions was HCO_3^- (84.0%) >Cl^- (7.0%) >SO_4^{2-} (8.99%). In dry season, the order was: Ca^{2+} (37.84%) >Mg^{2+} (26.78%) >K^+ (20.70%) >Na^+ (14.68%) for the cations and HCO_3^- (83.55%) >SO_4^{2-} (9.05%) >Cl^- (7.39%) for the anions.

Stoechiometric relations: The compositional relations among the dissolved ions have been calculated by means of stoichiometric relations to assess the processes that result in water composition. The ratios between dissolved ions (meq/L) are shown in Table 3. The ratio (Ca^{2+} + Mg^{2+}) / Tcations is ranged between 0.38-0.63 and 0.49-0.89 in rainy season and dry season, respectively. The ratios lower than 0.5 denotes the contribution of alkalis to Tcations. This is supported by (Na^+ + K^+) /Tcations ratio, which varied from 0.37 to 0.62 in rainy season and from 0.11 to 0.51 in dry season. This results therefore corroborate the findings of Matini *et al*. (2012) suggesting some groundwater samples have (Na^+ + K^+) /Tcations ratio equal or higher than 0.5 in both seasons, reflecting the contribution of cations via silicate weathering.

The nature and the extent of water/rock interaction were assessed by plotting some relations between major ions. The relation between Ca and Mg in the groundwater samples shows that the Ca^{2+}/Mg^{2+} ratio ranged between 2.98 and 7.40 in rainy season and between 2.56 and 3.98 in dry season. Low ratio in dry season can be explained by a low residence time of water in the aquifer, which does not favor the weathering process. The ratio of Ca^{2+}/Mg^{2+} less than 1 explains that groundwater is more enriched in Mg^{2+} and the ratio higher than 1 explains the increasing of Ca^{2+} in relation with Mg^{2+} in the groundwater (Matini *et al*., 2012).

The Na^-Cl relationship has often been used to identify the reasons of salinity in groundwater (Banton and Bangoy, 1997). In rainy season, groundwater samples had Na^+/Cl^- ratio ranged from 0.36 to 0.86, while it varied from 0.16 to 0.87 in dry season. A Na^+/Cl^- ratio equal to 1 is attributed to the dissolution of NaCl while a ratio greater than 1 reflects a release of Na^+ from silicate weathering (Meybeck, 1987).

In the two seasons, Na^+/Cl^- ratio varied spatially and the increase in Na^+ concentration was associated with an increase in Cl^- concentration. This result does not support a cation exchange process has been suggested by Wayland *et al*. (2003).

Ion exchange can be a source of sodium in the groundwater by releasing of Na^+ from clay products. In order to confirm the ion exchange process taking place, Na^+/Ca^{2+} and $Na^+/(Na^+ + Cl^-)$ ratios are also computed. In the study area, the groundwater shown Na^+/Ca^{2+} ratio between 0.49-1.49 and 0.11-0.98 in rainy and in dry

Table 3: Stoechiometric relations between the observed solutes in the groundwater samples

Ionic ratio	Range: Rainy season	Dry season
(Ca^{2+} + Mg^{2+}) /T cations	0.38-0.63	0.49-0.89
(Na^+ + K^+) /T cations	0.37-0.62	0.11-0.51
Ca^{2+}/Mg^{2+}	2.98-7.40	2.56-3.93
Na^+/Cl^-	0.36-0.86	0.16-0.87
HCO_3^-/Na^+	3.90-6.40	4.72-9.88
Na^+/Ca^{2+}	0.49-1.49	0.11-0.98
$Na^+/Na^+ + Cl^-$	0.26-0.46	0.14-0.46
HCO_3^-/Tcations	0.58-0.82	0.63-0.80
Cl^-/Tanions	0.10-0.22	0.12-0.22

Table 4: Threshold values of water quality parameters for taste and color as per WHO

Parameter	% of groundwater sample: Rainy season	Dry season
Objectionable taste (μS/cm)	3	1
Color complain (NTU)	7	9

The threshold value is the minimum value of the parameter at which an objection or complain is raised by the consumer

Table 5: Highest analytical results found in groundwater samples from Obuasi municipality compared with WHO Permissible Limit (PL) guideline values for the drinking water

Groundwater parameters	WHO standard (1996a, b, 2004) Desired Limit (DL)	WHO standard Max Permissible Limit (PL)	ISO: 10500: 1991 standard DL	ISO PL	Max analytical results[a] Rainy season	Max analytical results[a] Dry season
pH	7.0-8.5	9.2	6.5-8.5	No relax	7.10	7.64
EC (μS/cm)	500	1,400	500	1000	407.28	538.60
TH (mg/L)	1000	500	300	600	144.73	98.21
Na^+ (mg/L)	-	200	-	-	58.32	46.01
Ca^{2+} (mg/L)	75	200	75	200	39.09	46.84
Mg^{2+} (mg/L)	50	150	30	100	13.09	18.30
Cl^- (mg/L)	200	600	250	1000	68.21	53.04
SO_4^{2-} (mg/L)	200	400	200	400	167.13	145.07
F^- (mg/L)	-	1.5	1.0	1.5	0.69	0.07

[a]: Values are given in comparison to WHO guideline not ISO standard; Max: Maximum

seasons, respectively. The ion exchange process was also highlighted by Na^+/ (Na^+ + Cl^-) ratio, which varied in the range 0.26-0.49 and 0.14-0.46 in rainy season and in dry season, respectively. A ratio of Na^+/ (Na^+ + Cl^-) was lower than 0.5 in rainy and dry season groundwater samples, suggesting clearly that ion exchange process was absent.

The ratio HCO_3^-/Na^+ can also be used to assess the weathering process that occurs in groundwater. When the HCO_3^-/Na^+ ratio is greater than 1, carbonate weathering occurs; while a ratio less than 1 allows the conclusion that silicate weathering occurs. In both seasons, silicate weathering appears to be the main weathering process controlling the groundwater chemistry. Taking in account HCO_3^-/Na^+ ratio, varied in the range 3.90-6.40 and 4.72-9.88 in rainy season and in dry season, respectively. These findings characterize silicate and carbonate weathering in the groundwater samples in both seasons. On the whole, the groundwater samples have the concentration of Na^+ higher than that of K^+ in the two seasons as shown in Table 1 and 2, because of the greater resistance of K^+ to chemical weathering and its adsorption on clay minerals (Subba Rao, 2008).

The ratio (HCO_3^- + SO_4^{2-}) /Tanions, where Tanions indicates total anions, are ranged from 0.58 to 0.82 and 0.63 to 0.80, in rainy season and in dry season, respectively. On the whole, the ratio (HCO_3^- + SO_4^2) /Tanions in groundwater samples is lower than 1, this denotes a deficit of HCO_3^- and SO_4^{2-}. The effect of the rain on the water/rock interaction is obvious.

Meanwhile Cl^-/Tanions ratio is lower than 1 in all the groundwater samples in both rainy and dry seasons. In all the two seasons, the ionic ratio (HCO_3^- + SO_4^2) /Tanions is greater than the ratio Cl^-/Tanions in the analyzed groundwater samples. This therefore suggests a reverse trend of lack of rain, which enhances the decomposition of organic matter by bacterial organisms in the soil which tend not to provide the appropriate CO_2 to the rock/water interaction in the two seasons.

Drinking water quality: Groundwater is the main source of safe and reliable drinking water for the Obuasi municipality and its satellite areas. Various measured parameters are regarded as important in groundwater quality analysis. Kumar *et al*. (2007) cited WHO (1996a, b), the physical parameters that are likely to raise complaints from end users (color, taste, odour, temperature and turbidity). WHO (1996a, b) suggests that Total Dissolved Solids (TDS) greater than 1,000 mg/L and high pH results in taste complaints while low pH causes corrosion.

The palatability of drinking water rated by panels of tasters in relation to its TDS level is as follows: excellent, less than 300 mg/L; good, between 300 and 600 mg/L; fair, between 600 and 900 mg/L; poor, between 900 and 1,200 mg/L; and unacceptable, greater than 1,200 mg/L (WHO, 1996a, b). Water with extremely low concentrations of TDS may also be unacceptable because of its flat, insipid taste (Kumar *et al*., 2007). The most commonly used method of determining TDS in water supplies is the measurement of specific conductivity (WHO, 1996a, b). Conductivity measurements are converted to TDS values by multiplying EC by a factor that varies with the type of water. Sawyer (1994) suggests a range of 0.6-0.9 for this factor. Consumer perceptions investigated by their response to a questionnaire, which included questions on taste, odor and perceived clarity of water are presented in Table 4. The relationship between measured and perceived water quality are also presented.

Relationship between perceived water quality and measured water quality: The analytical results of physical and chemical parameters of groundwater were compared with the standard guideline values recommended by the World Health Organization (WHO, 1996a, b, 2004) for drinking and public health purposes (Table 5). The table shows the most desirable limits and maximum allowable limits of various parameters. In general, objectionable taste and unclear color perceptions were common for the threshold minimum values.

Taste and conductivity WHO (1996a, b) suggests a threshold limit of 1,000 mg/L for TDS, which should correspond to about 1,380 μS/cm as explained above.

Table 6: Suitability of groundwater for drinking based on several classification

Suitability of groundwater based on TDS (mg/L) with reference to water class		Based on total hardness as $CaCO_3$ (mg/L) after Sawyer and Mc Cartly (1967)		Nature of groundwater based on TDS (mg/L) values	
TDS (mg/L)	Water class				
		<75	Soft	0-1,000	Fresh
<300	Excellent	75-150	Moderately hard	1,001-10,000	Brackish
300-600	Good	150-300	Hard	10,001-100,000	Salty
600-900	Fair	>300	Very hard	>100,000	Brine
900-1,200	Poor	-	-	-	-

In all well locations the threshold EC value for taste objections was lower than the derived threshold EC of 1,380 μS/cm. Taste can also be a problem even if the TDS concentration is lower than the threshold value especially when the individual ion concentrations exceed their threshold (WHO, 1996a, b). The individual ion concentrations are a function of the geology and other factors such as irrigation. Nevertheless, all the analyzed groundwater samples were far below the threshold values of individual concentrations.

Turbidity and color (WHO, 1996a, b) suggests that the appearance of water with a turbidity of less than 5 NTU is usually acceptable to consumers, although this may vary with local circumstances. The consumption of highly turbid water may cause a health risk as excessive turbidity can protect pathogenic microorganisms from the effects of disinfectants and also stimulate the growth of bacteria during storage. Storage of water is a common practice in Obuasi and its satellite communities. The minimum turbidity at which the color was unclear (brownish, cloudy or rusty) ranged from 1 to 15 NTU. The fraction of sample with turbidity lower than the minimum detection limit was least for wet season (83%) and highest for dry season (96%). It is possible that the color in some water samples could have been as a result of rust and other dissolved substances resulting from the storage material.

Generally, turbidity is dependent on the optical refractive characteristics of colloidal matter. It appears therefore that generally color objections with a range of 2-12% are not a problem as compared to taste with objectionable taste ranging from 3% in rain season to 1% in dry season, respectively (Table 4). There was no clear linkage between color and turbidity.

From Table 6, based on TDS and taste, none of the analyzed samples fell under unacceptable class. It can be concluded that the groundwater samples were within the class of excellent to good based on TDS with reference to water class, soft to moderately hard base on total hardness and fresh with regards to the nature of groundwater based on TDS values. In all the two seasons, not a single sample showed any cation and anions concentration beyond permissible limit. As far as cations and anions are concerned, all the analyzed wells and boreholes were within the study area are almost safe. Thus, groundwater samples in the study area can deemed fit for drinking purposes but further exploitation may increase fluoride contamination and deteriorate the water quality in near future.

Table 7: Water quality classification (US Salinity Laboratory, 1954)

Quality of water	Electrical conductivity (μS/cm)	Sodium adsorption ratio (epm)
Excellent	Up to 250	Up to 10
Good	250-750	10-18
Fair	750-2, 250	18-26
Poor	>2,250	>26

Groundwater quality analysis for irrigation: The important chemical constituents that affect the suitability of water for irrigation are the total concentration of dissolved salts, relative proportion of bicarbonate to calcium, magnesium and relative proportion of sodium to calcium. Water quality problems in irrigation include salinity and alkalinity.

Total dissolved solids and EC: To ascertain the suitability of groundwater for any purposes, the TDS should be below 500 mg/L. The US Salinity Laboratory (1954) classified ground waters on the basis of electrical conductivity (Table 7). Based on this classification, the residual mean of the EC in both seasons are classified to be in excellent state. However, there are some cases where the EC in the groundwater samples far exceeded the 250 μS/cm stipulated by US Salinity Laboratory (1954). The differences between the values may reflect the wide variation in the activities and processes prevailing in the locations of the various wells in the municipality. The Obuasi groundwater is fresh water. Based on the EC none of the samples fall in either doubtful or unsuitable class for irrigation.

Sodium content: Sodium concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability (Janardhana, 2007). Sodium content is usually expressed in terms of percent sodium or soluble-sodium percentage (% Na). Sodium content expressed in terms of sodium percentage or soluble sodium percentage defined as:

$$\% Na = \frac{Na + K}{Ca + Mg + Na + K} \times 100$$

where, all ionic concentrations are expressed in milliequivalents per liter (meq/L).

Most of the Obuasi water samples in both seasons fall in excellent to good and good to permissible categories indicating their suitability for irrigation

Table 8: Suitability of groundwater for irrigation based on percent sodium after Wilcox (1955)

% Na (Eato, 1950)	Excellent	Good	Permissible	Doubtful	Unsafe
	<20	20-40	40-60	60-80	>80

Table 9: Suitability of groundwater for irrigation based on percent % Na (Eaton, 1950)

% Na (Eaton, 1950)	Safe	Unsafe
	>60	<60

(Table 7). No water sample is strictly unsuitable for irrigation based on classifications given by Wilcox (1955) and Eaton (1950) in Table 8 and 9, respectively.

When the concentration of sodium is high in irrigation water, sodium ions tend to be absorbed by clay particles, displacing Mg^{2+} and Ca^{2+} ions. This exchange process of Na^{+} in water for Ca^{2+} and Mg^{2+} in soil reduces the permeability and eventually results in soil with poor internal drainage. Hence, air and water circulation is restricted during wet conditions and such soils become usually hard when dry (Saleh *et al*., 1999).

Sodium Adsorption Ratio (SAR): Excessive sodium content relative to the calcium and magnesium reduces the soil permeability and thus inhibits the supply of water needed for the crops. The excess sodium or limited calcium and magnesium are evaluated by SAR which is expressed as:

$$\text{Sodium Adsorption Ratio (SAR)} = \frac{Na^{+}}{\sqrt{Ca^{2+} + Mg^{2+}/2}}$$

where all ionic concentrations are expressed in milliequivalents per liter (epm/L).

According to the SAR classification, 100% of Obuasi water samples in both the seasons fall within excellent to good category which can be used for irrigation on almost all soils. Therefore, none of the samples are of the poor category for irrigation in either of the seasons.

SAR can indicate the degree to which irrigation water tends to enter into cation-ex-change reactions in soil. Sodium replacing adsorbed calcium and magnesium is a hazard as it causes damage to the soil structure and becomes compact and impervious.

CONCLUSION

Interpretation of hydrochemical analysis of groundwater samples reveal that the groundwater in Obuasi municipality is within the class of excellent to good based on TDS with reference to water class, soft to moderately hard base on total hardness and fresh with regards to the nature of groundwater based on TDS. The pH values reveal that the groundwater is acidic in nature. The sequence of the abundance of the major ions is in the following order: Ca^{2+}>Na^{+}>K^{+}> Mg^{2+} = HCO_3^{-}>Cl^{-}>SO_4^{2-}>H_2SiO_4>Br^{-}>PO_4^{2-}>F^{-}. The concentrations of major ions in groundwater are within the permissible limits for drinking. Irrigation waters classified based on SAR has indicated that both seasons have excellent groundwater. The amount of total dissolved solids was less than 300 mg/L, indicating a “fresh environment”. The quality assessment shows that in general, the water is suitable for domestic purposes. The assessments of water for irrigation use also show that the water is of good to permissible quality. Silicate weathering, carbonate weathering and ion exchange have been identified as the hydrogeochemical processes controlling the chemical composition of groundwater in both seasons. The hydrochemical analyses reveal that the present status of groundwater in Obuasi is good for irrigation and drinking purposes. The overall quality of groundwater in Obuasi is controlled by lithology apart from other local environmental conditions.

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