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Water quality analysis and human health risk assessment of groundwater from open-wells in the vicinity of a cement factory at Akporkloe, Southeastern Ghana

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Abstract

The influence of the Diamond Cement (DIACEM) factory at Akporkploe, Volta Region of Ghana on groundwater quality within the environs of the factory was investigated. During the study, groundwater samples were collected from six drinking water supply wells in the east, north-east, north and north-west directions of the cement facility. Quality parameters including temperature, pH, salinity, conductivity and TDS were measures in-situ and XRF analysis was used in the measurement of some heavy metals (As, Cr, Ni and Pb). The study detected that parameters including temperature, salinity, alkalinity and nutrients fell below the WHO permissible level for drinking water. However, some parameters like pH, conductivity, turbidity and TDS adversely deviated from the WHO recommended standards. The high TDS and conductivity levels detected is an indication of high salt content which was attributed to cement dust intrusion. Since, the inhabitants of the study area depends heavily on these wells for drinking and other domestic uses, human health risk assessment studies was also carried out in respect of the heavy metals on the water samples. Apart from arsenic, all the concentrations of the other metals were above stipulated levels specified by the WHO. No non-carcinogenic effects were detected regarding the use of the water from ingestion and dermal contact pathways point of view. Aggregate situation regarding ingestion and dermal contact specified that cancer risk due to the use of the groundwater is possible. Based on these findings the study recommended among others that health authorities should have the groundwater treated before public use.

Key words: Groundwater, Water quality, Heavy metals, Cement factory, Health risk assessment, Cancer risk

INTRODUCTION

Water is vital for life, well-being, food security and socio-economic development of mankind. In many developing countries, availability of water has become a critical and urgent problem and it is a matter of great concern to families and communities depending on non-public water supply system (Okonko *et al.*, 2008). Increase in human population has exerted an enormous pressure on the provision of safe drinking water especially in developing countries (Umeh *et al.*, 2005).

Water can be found both underground and on the surface of the earth (Aremu *et al*, 2011). Groundwater, surface waters (e.g. rivers, streams and ponds), rain-water and springs are the main sources of water available to the rural dwellers in Ghana (Tay, 2008). Rural communities in Ghana, which forms about 56.0% of the total population, rely mostly on groundwater as the main source of drinking water (Ghana Statistical Service, 2002). The term groundwater is usually reserved for the subsurface water that occurs beneath the water table in soils and geologic formation that are fully saturated (Chanda, 1999). According to Arya *et al* (2012) ground water plays a vital role in the development of arid and semi-arid zones. It is believed to be comparatively much clean and free from pollution than surface water (Dahiya and Kaur, 1999; Agbaire and Oyibo, 2009; Efe, 2002). However, it is susceptible to pollution and once polluted restoration is difficult and long term measures are needed (Henry and Heinke, 2005). Gradually, groundwater resources in Ghana are experiencing an increase threat of pollution from urbanization, industrial development, agriculture and mining activities (Oluseyi *et al*, 2011). Generally, the major causes of aquatic pollution include the discharge of sewage, industrial and agricultural waste, both organic and inorganic, mining, cement production, dredging and china day waste; fertilizers and pesticides washed off the land by rain; spills of oil, radioactivity; atmospheric fall-out, acid rain and irrigation (Nwanjei *et al*., 2012).

It has occasionally been highlighted that cement industries are generally associated with high dust emissions into the atmosphere (Bilen, 2010; Isikli *et al*, 2003; Schuhmacher *et al*, 2002). Emitted dusts are naturally eliminated as deposits to the earth surface through dry or wet deposition in rainfall (Olaleye, 2005; Asubiojo *et al*., 1991). Cement dust spreads along large area through rain, wind etc., and are accumulated in and on plants, animals and soils and can have adverse effects on human health (Ayvaz, 1992). The damaging effects of dust fall, is characterized by enriched toxic heavy metals such as Arsenic (As), Lead (Pb), Nickel (Ni), Chromium (Cr), Copper (Cu), Zinc (Zn), Manganese (Mn) and Cadmium (Cd) (Adejumo et al., 1994; Schuhmacher *et al*, 2002). While some of these elements are essential for humans, at high levels they can also mean a toxicological risk (Domingo, 1994; Chang, 1996).

For a little over the past decade, a cement factory, Diamond Cement (Ghana) Limited (DIACEM), has been operating between two rural communities, Akplorkploe and Duta, near the Aflao in the Volta Region of Ghana. Dust emissions from the factory have not only affected the environment, but water from open-wells has visibly suffered surface contaminations from cement dust deposition. These wells are the main source of drinking water and other domestic chores for inhabitants of the area surrounding the cement factory. This should elicit a concern since the water quality may experience undesirable changes as the result of cement dust intrusion. The quality of water influences the health status of any populace, hence, analysis of water for physical, biological and chemical properties including trace element contents are very important for public health studies (Chinedu *et al*, 2011). Furthermore, Amira (2002) had indicated that cement dust is capable of changing salt content of water leading to serious disruption of aquatic communities and also decrease quality of water used for drinking. Thus, the current situation of the wells within the vicinity of the cement facility necessitate a study aiming at evaluation the health risk of the population which depend on the wells for drinking and other domestic use.

The study serves to determine the physico-chemical water characteristics and the heavy metal contamination status of the waters of the open-wells in the vicinity of the Diamond Cement Factory. In addition, the study seeks to assess the health risk of heavy metals for the inhabitants surrounding the cement facility who drink water from the designated wells. The findings of the study would be informative for future scientific work as the results would serve as a baseline data upon which possible water management measures would be initiated to enhance good quality of these water sources.

MATERIAL AND METHODS

Study Area

The study area is located in the south eastern part of Ghana in the Ketu South District of the Volta region. The area is geographically enclosed between Latitudes 06.13400 N and 06.16650 N and Longitudes 01.16100 E and 01.19911 E which is part of Ketu-South Municipal Assembly. The area is bounded on the: north by the eastern boarder of the Republic of Togo; east by the Aflao township; west by Akplorkploe; and south by the lagoonal floods. The DIACEM factory is located 3 km north of the Aflao Township (Figure 1).

The cement factory plays a significant role in the local building industry and in the economy of Ghana. The Indian-owned factory was established in 2002 and was a major employer in the area. The area lies within the dry equatorial climate of the region. It has two rainy seasons with the major rains in April to June, and the minor rains between September and November. Minimum temperatures in the investigated area are 13.5°C and occur between the months of August and September, and average maximum of 40°C is experienced between February and March.

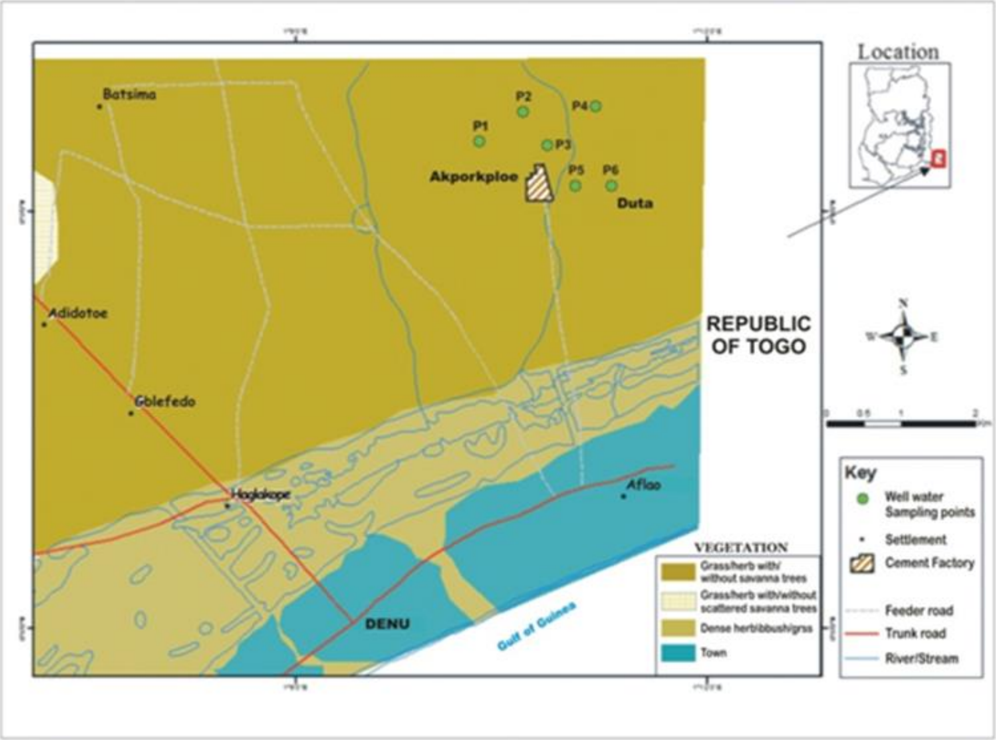

Fig 1: Map of study area showing cement factory and experimental sites

The factory's surrounding area is essentially rural with minor agricultural activities. Settlements are scattered houses at varying distances with the nearest settlement at about 300m from the factory. The surrounding vegetation is made up of several shrubs and grasses and lies within the Coastal Savanna agro-ecological zone. The geological formations of the investigated area are rocks of the Dahomeyan series of the Precambrian age. These rocks consist of dense aggregate of essential stable minerals which are bounded and have medium to coarse-grained granite texture. The Dahomeyan series are seismically stable and therefore there is no history of earthquake in the area. The soil types are mainly lateritic sandy soils, tropical black clays, tropical grey earths, and Sodium vleisols. These soil types are suitable for the cultivation of different types of crops (NDPC, 2010).

The hydro-geological setting of the investigated area can be discussed from a broader perspective under the Lower Voltaian Basin. Groundwater occurrence in this hydro-geological province is controlled by the development of secondary porosities, e.g. fractures, faults, points and the associated weathered zones since the rocks are inherently impermeable (Kortatsi *et al*, 2008).

Available data suggest that borehole yield within the lower Voltaian sub-province ranged between 1 and 9 m^3/h with an average of about 6.2 m^3/h. On the basis of available data from drilling projects in this sub-province, success rate for prolific wells is about 55% (Dapaah-Siakwan and Gyau-Boakye, 2000). Furthermore, in a more broader sense borehole data suggest that wells and boreholes in the Voltaian Province are slightly deeper and ranged between 45 m and 75 m with a mean depth of 55 m. Fractured rock aquifers in the Voltaian aquifers generally have a low to moderate productivity and overall transmissivity ranges from 0.3 m^2/d to 267 m^2/d with a mean yield of 11.9 m^3/d (Carrier *et al*, 2008).

Sample Collection and Analysis

A reconnaissance survey was embarked upon between, 16-18 January, 2012 to establish the land-use and importance of water from open well water in the study area. Water samples were collected in March, 2012 from six water wells within the study area using sterilized bottles. The sampling points were located in the east, north-east, north and north-west of the predetermined directions of the cement factory. The sampling points were chosen on the basis of their coincidence with the cardinal directions from the cement factory and their possible contamination with cement dust. Samples were also collected from two open wells at a controlled area which is approximately 7.9 km south-west of the factory where no cement dust emission was experienced.

A plastic bucket was used to collect the water samples. The bucket was thoroughly washed and sterilized to avoid extraneous contamination of the samples. The samples were transferred to 15 cleaned sterilized plastic bottles. Two 1.5 litres of water were collected from each well for subsequent analysis.

A geographical positioning system (GPS), German 76 model was used for recording the geographical coordinates of the sampling points. Because the chemistry of water is sensitive to environmental changes, unstable parameters such as pH, temperature, total dissolve solids (TDS), dissolved oxygen (DO), conductivity and salinity were measured in-situ at the point of collection. A mercury-bulb thermometer was used to measure the temperature, whilst HACH 2000 water quality meter was used to measure the other parameters. To maintain quality assurance, triplicate determination of the samples were made and the data presented as means.

The water samples for chlorine and nutrients which were analysed in the laboratory were treated without any preservation. However, the samples meant for heavy metal analysis were adulterated with dilute nitric acid.

The concentrations of major ions sulphate (SO_4^{2-}), nitrate (NO_3-N), nitrite (NO_2-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. The analysis of heavy metals, namely, arsenic (As), chromium (Cr), nickel (Ni) and lead (Pb) were carried out using Energy Dispersive X-Ray Fluorescence (EDXRF) method.

Quality assurance

Proper quality assurance procedures and precautions were taken to ensure the reliability of the results. Samples were carefully handled to avoid contamination. Glasswares were properly cleaned, and reagents were of analytical grades. Deionized water was used throughout the study. For the X-Ray analysis reagent blank determinations were used to correct the instrument readings. For validation of the analytical procedure, repeated analysis of the samples against internationally certified/standard reference material (SRM-1570) of National Institute of Standard and Technology were used. The analytical results obtained were compared with recommended values as shown in Table 1. 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 7%.

Statistical Analysis

In this study, the experimental results obtained were statistically analyzed using Excel 2007 (Microsoft excel). The values were expressed as means which were obtained from a set of observations. The significance of the difference among the concentrations of water quality parameters and heavy metals at different sampling locations were assessed with independent student's t-test. A $p<0.05$ was considered statistically significant.

RESULTS AND DISCUSSION

Physico-Chemical properties of open-wells

Table 1 summarizes the results of the physicochemical properties of the six wells water samples collected in the vicinity of the Diamond cement (DIACEM) factory of the study area.

pH and temperature

The pH ranged from 4.9 to 7.6 with a mean value of 6.1 pH units. With the exception of samples from one well (P2), all other samples fell within the WHO range for portable water. The result of Well P2 is understandable because it was constructed only two months before sampling and therefore shifted into alkaline side (pH=7.2). This pH result shows that the well waters of the area is slightly acidic and therefore different from the controlled samples which showed alkali status with a mean of 7.3 pH units. However, similar values have been reported from other studies. Tay and

Kortatsi (2007) reported pH range of 4.37–7.40 in the Densu Basin and Nkansah and Ephraim (2009) reported a mean of 6.0 in the Bosomtwi-Atwima-Kwanwoma District. Tay (2008) reported 5.4-7.06 pH range with a mean of 6.42 pH unit in the same geographical area. pH values lower than 6.5 are considered too acidic for human consumption and can cause health problems such as acidosis which could have adverse effects on the digestive and lymphatic systems of human (Nkansah *et al*, 2010). Water temperature recorded during the sampling period for the various sites did not differ significantly. Temperature ranged from 26.9 to 28.9ºC with an average of 27.8ºC. The temperature values reported in this data are lower than 29°C WHO (1998) limit for drinking water. Temperature is a factor of great importance for aquatic ecosystem, as it affects the water organisms, as well as the physical and chemical characteristics of water (Delince, 1992). The values obtained are within the permissible level of WHO drinking water standards.

Conductivity and Dissolved Solids

Conductivity of the water samples ranged from 377 to 12,228 µS/cm with a mean value of 2969 µS/cm. These values far exceed the WHO regulatory limit of 500 µS/cm indicating relatively high salt contents. Conductivity is related to the concentration of Total Dissolved Solids (TDS). According to Chapman (1992), TDS may be obtained by multiplying the conductivity by a factor between the ranges of 0.55 to 0.75. Given these high conductivity values, it is not surprising that the TDS, which is an index of the amount of dissolved solids in water, which also determine the degree of salinity, would be high. Thus, the TDS which ranged between 187 to 8990 mg/L with a mean level of 1883 mg/L was obtained for the study. This is indicative for large variability in salinity of the groundwater. According to the study statistics, the TDS is directly an average multiplication factor of 0.5 of the conductivity values measured across all the sampling points investigated. A health-based value has not been proposed by the WHO, however, a TDS above 1,000 mg/l may be objectionable to consumers (Amoako *et al*, 2011). The high values in conductivity and TDS were obtained at sites close to the cement factory in the eastern and north-east direction and also far off in the northern direction where dust concentration is adjudged to be a maximum. The trend of concentration of salinity among the sampled wells is the same as the conductivity and TDS ranging from 2.0-12.0 with a mean of 4.6 mg/l.

The total suspended solid (TSS) relatively measures the physical or visual observable dirtiness of a water resource. The TSS of the water in the study area range from 10.0 – 141.0 mg/L with a mean of 46.2 mg/L indicating a good measure of quality as measured values were below the prescribed permissible limit of 500 mg/l according to the European Union (EPA, 2001). The low levels obtained were quite understandable as groundwater passed through some natural filters before collected in wells. Turbidity values ranged from 11.1 to 198.0 NTU with a mean of 57.96 NTU. Four borehole samples showed turbidities between 11.1 and 44.0 NTU. All the samples had their turbidity values exceeding 5.0 mg/l. The WHO guideline for turbidity in drinking water is 5 NTU. The high turbidity may be attributed to larger particles such as organic matter and dissolved solids. Schafer *et al.* (2010) found turbidities in the range of 2–266 NTU in most borehole water throughout Ghana. Therefore, the current results despite out of quality concerns can be regarded as normal in the Ghanaian contest.

Table 1: Physico-chemical characteristics of open-well water samples of the study area

Parameters	Units	Minimum	Maximum	Mean	EU Standards	WHO Standards
pH	-	4.90	7.60	6.09	6.5-9.5	6.5-8.5
Temperature	°C	26.90	28.90	27.77	-	22-29
Conductivity	µS/cm	377.0	12228.0	2969.33	2500	500
TDS	mg/l	187.0	8990.0	1883.0	-	1000
TSS	mg/l	10.0	141.0	46.0	500	NA
Salinity	$^{o}/_{oo}$	2.0	12.0	4.6	-	200
DO	mg/l	4.30	5.70	5.06	8.5 (24°C)	7.5
Turbidity	mg/l	11.10	198.0	57.96	5.0	5.0
COD	mg/l	12.16	39.52	22.50	-	-
Total Hardness	mg/l	200	3400	1080	-	500
Alkalinity	mg/l	12.0	128	47.6	-	400
Nitrate	mg/l	0.688	1.405	1.133	50	10
Flouride	mg/l	0.01	0.04	0.018	1.5	1.0-1.5
Chloride	mg/l	155.95	165.95	159.59	250	-
Sulphate	mg/l	22.48	998.65	233.47	250	250
Phosphates	mg/l	0.001	0.024	0.007	-	<3.0
Bicarbonetes	mg/l	14.63	156.06	62.81	-	-

NA: not available

Dissolve Oxygen and Chemical Oxygen Demand

Dissolved oxygen (DO) measured in milligram/litre ranged between 4.30 and 5.70 with a mean of 5.06. Similar values of 3.42 – 6.84 mg/l were reported by Efe *et al*. (2005) for open well-water in Western Niger Delta, Nigeria. The results showed no significant difference with what was obtained for the controlled samples which registered a mean of 5.1 mg/l. The WHO has set a provisional health-based guideline value of 7.5 mg/l for DO which should be adequate to protect public health (WHO, 1995). Dissolved oxygen (DO) is very crucial for survival of aquatic organisms and it is also used to evaluate the degree of freshness of a river. The measured value was; however, lower than the WHO's standard. Very low DO may result in anaerobic conditions that can cause bad odour in water. The low DO levels situation may result through the decomposing organic matter, dissolved gases, industrial waste, mineral waste and landfill leachate.

Chemical Oxygen Demand (COD) is one of water quality parameters in determining the oxygen consuming potential of a water resource. COD measured for the water samples ranged from 12.16 to 39.52mg/l with a mean of 22.50mg/l which is similar to what was recorded (mean=21.28mg/l) for the control samples. The WHO and EU have no safe guideline for COD in respect of drinking water. However, the values should be a concern to health as the safe limit according to Bangladesh Standard for drinking water should be at 4.0 mg/l (Rasul and Jahan, 2010). The situation could be a possibility of effluent seepage to the open water wells indicating the presence of high organic load in the underground water system in the area.

Total Hardness and Total Alkalinity

The levels of total alkalinity and total hardness for a good drinking water according to the WHO should be at 400mg/l and 500mg/l respectively. The cause of alkalinity is the minerals which dissolve in water from soil. The various ionic species contribute to alkalinity include bicarbonate, hydroxide, phosphate, borate and organic acids (Shyamala et *al*., 2008). Alkalinity of 500 mg/l is also acceptable by the Ghana Water Company (GWC) and USEPA standards. Based on these standards, the level of alkalinity for all the samples can be said to be within safe limits. It is imperative to state that the range of 12.0-128.0mg/l recorded in this study is similar to what Nkansah *et al* (2010) recorded in a similar study for hand-dug wells in the Kumasi Metropolis and far less than 220.4mg/l recorded by Tay (2008) in Ketu District which is in the same geographical area.

However, the range of 200-3400mg/l with a mean of 1080mg/l for total hardness is unacceptable from the medical and economic point of view. Because, hardness is the property of water which prevents the lather formation with soap and increasing the boiling points of water (Trivedi and Goel, 1986). Since, the water is also used for washing, then more or expensive soap would be needed to do good washing, a situation apart from health considerations would be economically detrimental to the well being of these rural folks. Therefore, the situation calls for the treatment of the well waters to address this hardness concerns to improve health and at the same time alleviate poverty.

Ions and Nutrients

Levels of anions determined in the water samples are shown in Table 1. According to Amoako *et al* (2011), chloride and sulphate have similar health-based guidelines, but may cause concern due to taste if found at higher concentration. Evidence relating to chronic human health effects to specific drinking water contamination is very limited. In the absence of exact scientific information, scientists predict the likely adverse effects of chemicals in drinking water using laboratory animal studies and, when available, human data from clinical reports and epidemiological studies (Nkansah and Ephraim, 2009). The standard development process was assumptions that are protective of public health in that they tend to err on the side of caution in assessing potential health risk (Nkansah and Ephraim, 2009).

The amount of chloride ions found in the water samples were between 87.97 and 5142.1 mg/l with a mean of 1348.18 mg/l which is five times higher than the WHO permissible safe limit of 250 mg/l and also three time higher than the mean value obtained for the controlled samples. Levels at these measurements may decrease the availability of water due to taste, as well as leading to the corrosion of metals (Amoako *et al*, 2011). The high chloride levels may be attributed to natural geochemical activities.

As mentioned earlier, sulphate does not have a health-based guideline value. However, the WHO recommends that values higher than 250mg/l should be reported to “the health authorities” due to problems to the gastro-intestinal track (WHO, 2003). Sulphate occurs naturally in water as a result of leaching from gypsum and other common minerals (Manivaskam, 2005). However, source to such levels could be traced to the natural or industrial. The concentration of sulphate in the subject samples ranged from 22.84mg/l to a high of 998.65mg/l with a mean of 233.47mg/l which was two times higher than what was measured for the controlled samples. The upper level measurement was recorded from only one well apart from that none of the samples exceeded the WHO recommended guideline.

The maximum concentration of fluoride (F^-) was observed to be 0.04 mg/l. Permissible limit for F^- concentration is 1.0–1.5 mg/L according to WHO guideline (WHO, 2006). Fluoride (F^-) has a significant mitigating effect against dental caries if the concentration is approximately 1.0 mg/L. However, continuing consumption of higher concentrations of 4 mg/L or more can cause dental fluorosis and in extreme cases even skeletal fluorosis (Nkansah *et al*, 2010). The measured level indicates acceptable situation in which the water samples may encourage healthy teeth if the well waters are used for drinking. The values obtained for the controlled samples compare favourably with those from the study area.

Nitrate (NO_3-N) is a contaminant that is regulated as it has significant health risks associated with excess nitrate consumption in the human diet. Nitrites are veritable indication of biological pollution in natural waters (Addo *et al*, 2011). The presence of nitrates and nitrites in elevated concentrations is an indication of organic pollution in the water body. Levels in excess of 5.0 mg/L indicate pollution (McCutcheon *et al.*, 1989). The WHO has adopted the 10 mg/l standard as the maximum contaminant level (MCL) for nitrate–nitrogen. Nitrate levels averaged 1.13 mg/l and varied between 0.69 to 1.41 mg/l. these concentration levels are not alarming and therefore the wells were free from organic pollution.

Phosphorous (PO_4-P) is a limiting nutrient for algal growth and therefore controls the primary productivity of a water body (Karikari *et al*., 2007). It is also an essential nutrient and another indicator of anthropogenic biological pollution. In most natural waters, PO_4-P concentration range from 0.005 to 0.020 mg/l (Addo *et al*, 2011). In pristine waters, PO_4-P concentrations may be as low as 0.001 mg/l (Karikari *et al*., 2007). Levels of PO_4-P in this study varied between 0.001 and 0.024 mg/l with a mean concentration of 0.007 mg/L, which is less than levels in most natural waters.

Heavy Metal Contamination and Health Risk assesssment

The results of the descriptive statistics, minimum, maximum, mean and median of each metal concentration in water samples of open-wells in the study area are presented in Table 2. The median values which are not affected by extreme values were taken into consideration as characteristic values to analyze the differences among the sampling sites.

Table 2: Heavy metal levels (mg/l) in open-well water of study area.

Heavy metal	Unit	Minimum	Maximum	Mean	Median	WHO Standard
Arsenic	mg/l	0.003	0.007	0.0048	0.005	0.01
Chromium	mg/l	0.073	0.132	0.1042	0.103	0.05
Nickel	mg/l	0.024	0.103	0.0726	0.082	0.02
Lead	mg/l	0.033	0.450	0.2642	0.323	0.01

Of all these trace metals, only arsenic in all the wells were below WHO permissible level of 0.01 mg/kg. The concentrations of all the other metals are higher than the tolerated level proposed by WHO for domestic water use. The order of pollution of these contaminants of the well waters is As>Ni>Cr>Pb. Lead the most concentrated (0.323 mg/kg) metal is about thirty times concentrated in the water samples compared to the WHO guideline limit. These results indicated that the well waters are not desirable for consumption, because Pb alone even at low concentration could be toxic to the human system. It is important to trace the contribution of these contaminants which is affecting the water quality. The source to indict is the cement dusts which are clearly visual on the surface water of the wells. However, the contamination levels are so high enough not to limit the allegation to the dust alone and that other anthropogenic sources might be at play. However, in a similar study to evaluate the ground water quality for the Kwahu West District of Ghana, Nkansah *et al*, (2010) recorded average values of Pb (0.270) and Ni (0.413) which exceeded the recommended values for these metals. Therefore, the local geology could also be a good contribution factor of the groundwater under the current study.

Based on the metal concentration, non-carcinogenic risk assessment was carried out according to the usual reliable exposure pathways of contaminants recommended by USEPA (2001). The potential exposure pathways of the water included: direct ingestion of the water; and dermal absorption of contaminants in water adhered to exposed skin (Liu *et al*, 2012).

For direct exposure, the following equation (1) was used for calculation:

$$D_{ing} = C \times \frac{ingR \times EF \times ED}{BW \times AT} \times 10^{-6} \qquad [1]$$

Whilst the following equation (2) was used for dermal absorption:

$$D_d = \frac{C \times SA \times Kp \times ET \times EF \times ED \times 10^{-6}}{BW \times AT} \qquad [2]$$

Where IngR: ingestion rate, in this study, 2.2 l/d was used (USEPA, 2001). EF: exposure frequency, in this study, 180 day/year (Ferreira-Baptista and De Miguel, 2005). ED: exposure duration, in this study, 24 years for adults (USEPA, 2001). SA: exposed skin area; in this study, 5700 cm^2 for adults (USEPA, 2001). Other symbols are Kp: known as dermal permeability coefficient given as 0.2 cm/h; ET is exposure time during bathing and shower which is 0.6 h/d. (USEPA, 2001). BW: average body weight; in this study, 70 kg for adults (USEPA, 1989). AT: averaging time; for non-carcinogens, ED×365 days; for carcinogens, 70×365=25,550 days. The symbol C represents the heavy metal concentration in mg/l content in the water samples. It is important to note that all values provided are for adults groups who consumed or used the water.

Before a risk is characterized, the hazard quotient (HQ) of the individual metal is computed using the following equation (Wongsasuluk *et al*, 2011):

$$HQ = \frac{Exposure}{RFD}$$

Where Exposure represents both D_{ing} and D_d (ADD) for each metal in mg/l/d and RfD is the oral reference dose mg/l/d.

For non-carcinogenic risk If; HQ > 1 Adverse non-carcinogenic effects of concern
HQ < 1 Acceptable level (no concern).

For the carcinogenic effect, calculated Cancer Risk used the following equation:
Cancer Risk = Exposure x SF
SF = Slope Factor (per mg/l/day) for a metal.
If acceptable level is 10^{-6}, means the probable possibility that about 1 cancer patients among 1,000,000 people happen.
If, Cancer Risk > 10^{-6} Carcinogenic effects
Cancer Risk < 10^{-6} Acceptable level (no concern)
In this study, quantified risk or Hazard Indexes for both carcinogenic and noncarcinogenic effects was applied to each exposure pathway in the analysis. The doses thus calculated for each element and exposure pathway are subsequently divided by the corresponding reference dose to yield a hazard quotient (HQ), whereas for carcinogens the dose is multiplied by the corresponding slope factor to produce an estimate of cancer risk. Hazard index (HI) is equal to the sum of HQ (Zhang *et al*, 2010).

An evaluation of the noncancer risk to human health associated with the consumption of the water from the investigated area was undertaken and the results are summarized in Table 3. For noncancer effect, dermal contact of water through bathing appears as the dominant route of exposure to underground water that result in health risk for Pb, Cr and As followed by ingestion. The Hazard Indexes (HIs) for all the metals indicate safe levels and decrease in the order Pb>Cr>As>Ni. Regarding noncancer effect, Pb exhibit high HI although lower than safe limit (1) but the greater contributor (62.7%) of the average HI of the groundwater and Ni is the least contributor (2.7%). Though, HI for Pb indicates safe level, it is a cumulative toxic metal and the kidney is the main target for Pb toxicity (Zhang *et al*, 2010). So Pb exposure to the drinking water in the investigated area cannot be overlooked, and its ecological and health implications need further detailed investigations. HIs for As, Pb, Cr and Ni on contaminated water exposure to adults in the study are lower than 1, indicating that there is little adverse health risk due to open well water.

Table 3: The estimated average daily dose and hazard quotient of metal non-carcinogenic risk

parameter	Pathway	Heavy metal contaminants			
		As	Cr	Ni	Pb*
ADD	Ingestion	5.18 x 10^{-8}	1.07 x 10^{-6}	8.49 x 10^{-7}	3.34 x 10^{-6}
	Dermal	1.61 x 10^{-5}	3.32 x 10^{-4}	2.64 x 10^{-4}	1.03 x 10^{-3}
Hazard quotient	Ingestion	1.73 x 10^{-5}	3.56 x 10^{-4}	4.24 x 10^{-5}	9.55 x 10^{-4}
	Dermal	5.40 x 10^{-2}	1.11 x 10^{-1}	1.30 x 10^{-2}	2.97 x 10^{-1}
Hazard Index (Non-carcinogenic)		**0.054**	**0.110**	**0.013**	**0.298**
Cancer risk	Ingestion	7.77 x 10^{-8}	5.35 x 10^{-7}	1.44 x 10^{-6}	-
	Dermal	2.42 x 10^{-5}	1.66 x 10^{-5}	4.49 x 10^{-4}	-
Carcinogenic		2.42 x 10^{-5}	1.71 x 10^{-5}	4.50 x 10^{-4}	-

- No reference slope factor dose for Pb

For carcinogenic effect, the average values was calculated for As, Cr and Ni, whilst Pb did not show carcinoginity due to lack of information. The results indicated that the risk in respect of ingestion for all the metals would pose no health problems since the values are below acceptable level. However, the reverse is the situation in the case of the dermal dose where a health implication can be deduced for the population who utilized the water. Therefore, the aggregate situation with respect to cancer risk specified that the water on the whole could be dangerous to human health.

CONCLUSION

Physico-chemical characteristics of six selected open-well water resources were examined in the area surrounding the Diamond Cement Facility to assess potential quality of water samples. The open wells were dominant source over boreholes which were the main source of water for the inhabitants of the investigated area. In most of the analysis, the results fell within the safe limits set by the WHO for water used for drinking and other domestic purposes. Parameters in this category include temperature, TSS, DO, alkalinity and fluoride. However, some parameters including pH, TDS, turbidity and COD deviated from recommended standards of WHO. For instance the pH indicated slightly acidic nature of the well waters making the water available in the area a potential health hazards for the local inhabitants.

In addition to the physico-chemical analysis, human health risk assessment studies was conducted for trace metals (As, Cr, Pb and Ni) toxicity in the water samples. The contamination results indicated that apart from As, all the other trace metals show potential toxicity in the water samples. Nevertheless, the estimation of non-carcinogenic risk conducted by this study show that adverse health effects may not occur when considering the domestic use of the well water. However, cancer risk due to As, Ni and Cr exposure though the water consumption may have the probability of contracting cancer over a long lifetime in the future.

In a survey, it was revealed that over 68% which constitute a population of 1064 of the local inhabitant use this well water. Therefore, the current water quality situation and the health risk evaluation mean that government intervention to ensure portable quality of water for the people in the area.

Meanwhile, it is recommended that more intensive study is needed in order to determine the metals in open wells from the study area, and not only to report levels of contaminants but also to compare them with health criteria values to be easily understood by the general population. Furthermore, it is well known that as the result of cement dust contamination the water may contain a variety of bio-accumulative organic chemical contaminants such as dioxins/furans and polychlorinated biphenyls (PCBs) that are a health concern. Therefore, in addition to metal studies, other chemical organic water contaminants of concern must be evaluated in the open wells. The overall implication of this observation calls for an urgent water resources management strategy (including treatment of the water) in the area in order to circumvent the fast deteriorating water resources quality, which may pose associated health risk and environmental hazards.

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