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Seasonal Variation in Heavy Metal Content of Lake and Underground Water in Some Selected Towns around the Bosomtwe Crater Lake

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Abstract
The levels of Arsenic, Iron, Lead, Zinc, Chromium, Cadmium and Nickel in water samples from Lake Bosomtwe and Bore Holes in some towns around the Lake have been determined using Atomic Absorption Spectrophotometer (Varian AAS 220). The levels of Arsenic, Cadmium and Nickel were generally small and were below the detection limit of the instrument. The results showed seasonal variations in the mean levels of Pb, Fe, Zn and Cr in water from the Bosomtwe Crater Lake. There were significant correlations between the mean levels of Fe and Pb in the underground water in the two seasons whilst Zn and Cr showed weak correlation in underground water for the wet and dry seasons. The levels of the metals in the bore holes were generally below the WHO standard values compared to the levels of the metals in the water samples from the lake. The mean pH values for water samples from the bore holes in the towns around the Bosomtwe Crater Lake were within the WHO standard of 6.50-8.50.
Keywords: Lake Bosomtwe, Borehole, Crater, Heavy metals, Atomic Absorption Spectrophotometer.

1. Introduction

Water is super abundant on earth but fresh portable water is not always at the right time or right place for human ecosystem. The importance of water is underscored by the fact that many great civilization in the past is sprang up along or near water bodies. The development of water resources has often been used as a yardstick for socio-economic and health status of many communities and nations worldwide. However pollution of water often negates the benefits obtained from development of these water resources (Ansah-Asare *et al.* 2004). With ever – expanding population and increasing ecotourism, concern about the impact of man's activities on the environment is very important. Any change in the environmental components of air, water and land is bound to affect the environment as a whole since the natural environment is an integrated system (Ntow 1993).

The concern posed by heavy metals in the aquatic environment creates an immense threat to the existence of organisms thriving in the area and the ecological integrity of the habitat, particularly as heavy metals may enter the food chains, persist in the environment, bioaccumulate and bio-magnify, then increase exposure of consumers of aquatic products to serious health risks. Metals enter rivers and lakes through a variety of sources such as eroded minerals within sediments, leaching of ore deposits, decomposing dead organic matter, fallout of atmospheric particulate and volcanism extruded products or anthropogenic sources including the discharge of liquid and solid waste, industrial or domestic effluents, channel and lake dredging etc.(Marcovecchio *et al.* 2007). Though some heavy metals are essential to sustaining life e.g. cobalt, copper, iron, manganese and zinc are needed at low levels as catalysts for enzyme activities (Adepoju-Bello *et al.* 2009), excess exposure to heavy metals results in toxicity. A special feature of heavy metal toxicity is that they are not biodegradable but instead undergo biogeochemical cycles with different residence times in the various spheres and compartment in the environment. Individuals may therefore be exposed to them occupationally or through other factors such as consumption of contaminated food and water. A number of heavy metals including Cd, Pb, Hg, As, etc are toxic to the human body and interfere with functioning and undermine health. Background of natural level of lead in surface and ground water are generally low. According to the occupational safety and health administration (OSHA) of the United States Department of Labour lead exposure both acute (few days) and chronic (several years) adversely affect body system and cause many forms of health impairment and diseases (Pinkey 1989).

Lake Bosomtwe is a natural inland freshwater lake that originated from meteorite impact (Koeberl *et al.* 1997). It is located in the Ashanti Region of Ghana in West Africa. It is situated about 32km east of the regional capital town of Kumasi. It forms part of the Pra Basin located between Latitudes 50 N and 70 30' N, and Longitudes 20 30' W, and 00 30' W, in south-central Ghana. The Pra River, together with its tributaries, forms the largest river basin of the three principal south-western basins systems of Ghana (i.e. Ankobra, Tano and Pra). It occupies an area of approximately 23,200 km² and extends through almost 55% of Ashanti, 23% of Eastern, 15% of Central and 7% Western Regions (Figure 1). The basin is endowed with a number of tourist attractions, which includes National parks (Kumasi Zoo), Lake Bosomtwe site, and Cultural heritage sites (chieftaincy institution, traditional durbars/festivals, art and craft villages etc). Harnessing these opportunities and dealing with the challenges of catchment degradation and water pollution from increased tourism is of utmost importance, and is particularly significant for sustainable natural resources management.

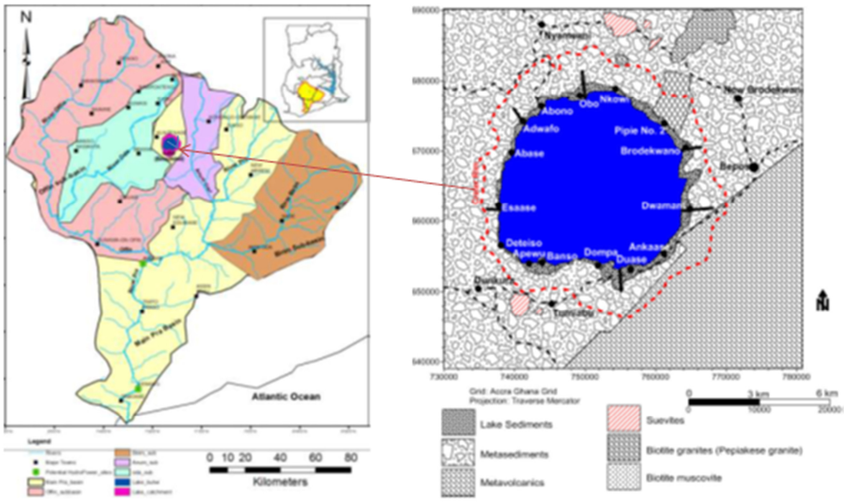

Figure 1. Map of the Pra river basin of Ghana showing the location of the Bosumtwi Crater Lake and the Geological profiles Bosumtwi crater area (Modified from Koeberl and Reimold 2005)

The hydrogeology of the basin is dominated by aquifers of the crystalline basement rocks and the Birimian Province. Groundwater occurs mainly in the Birimian geological formations, which comprise of the Lower Birimian (metasediment rocks) and the Upper Birimian (metavolcanic rocks). The Lower Birimian underlies over 80% of the total landmass of the basin while the Upper Birimian crops out in the eastern and extreme southern sections of the basin. A major concern is that, the lake is a hydrological basin (Turner *et al*. 1996) and all pollutants remain in the lake. The lakes have a complex and fragile ecosystem as they do not have self-cleaning ability and therefore readily accumulate pollutants (Lokeshwari *et al.* 2006). Therefore there is the need for comprehensive research on the state of the water quality around the lake.

The work presents the levels of lead, arsenic, cadmium, chromium, nickel, zinc and iron in water from the Bosomtwe crater lake and from Bore Hole in the catchment area of the lake. The present study was carried out to evaluate seasonal variability in level of some common heavy metal pollutants (cadmium, chromium, lead, copper and zinc)

2. Materials and methods

2.1 The study area

The Bosomtwe structure is centred at 06° 32́N and 1°25́W. Lake Bosomtwe is one of the nineteen (19) confirmed impact structures known on earth. It is associated with one of the four tektites strewn fields (the Cote d'Ivoire tektite field) (Koeberl *et al.* 1997). Lake Bosomtwe has an age of about 1.07 million years and it is completely filled with water in a circular structure of roughly 8.5 km diameter and rim-to-rim diameter of about 10.5 km and it is about 78 – 80 cm deep in its central part (Watkins, 1994). The region around there is widely covered by dense tropical rainforest which represent patches of agricultural activities. The lake is surrounded by about 22 towns which history shows that the inhabitants migrated from different areas to protect the lake from being taken by enemies as their property. The main occupation of the people is fishing and cultivation of cash and food crops like shallots, onions, tomatoes, plantain, cocoa etc.

2.2 Sampling and procedure

Water samples were collected from the lake and bore holes from seven towns around the Bosomtwe crater lake in the Bosomtwe District of the Ashanti region namely at Anyinatiase, Nkowi, Adwafo, Abrodwum, Obo, Abono and Abease. Figure 2: shows the towns where sampling was done. Sampling was done every three months from the month of November, 2012 to August, 2013.

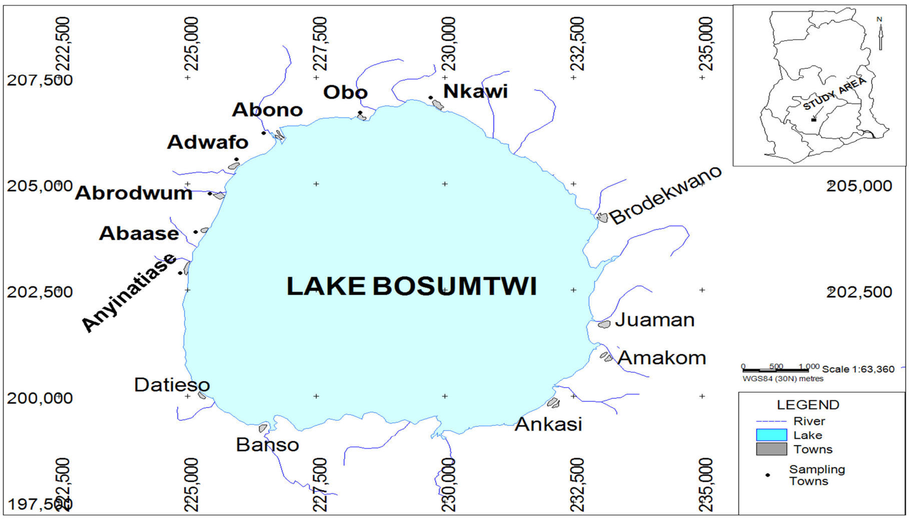

Figure 2. Map of study area showing towns where samples were taken in the Bosomtwi Crater Lake area

Samples were collected into sterile screw capped plastic containers. Prior to sample collection, all bottles were washed with detergents, dilute nitric acid (about 4.0 moldm^{-3}) solution and distilled water and dried in an oven. Before taking the water samples, the containers were rinsed three times with the water to be collected. The sampling bottles were labelled with dates and sampling source. Collected samples water samples were stored in a cooler at 4 °C. Temperature, conductivity and pH of the samples were measured on site. All the analyses were done by standard methods in accordance with APHA (2005). Samples collected were labelled and stored in a refrigerator before digestions were made.

2.3 Digestion of samples for As, Fe, Pb, Zn, Cr, Cd and Ni determination

The water samples were digested using concentrated Analar nitric acid according to Zhang (2007). 100 ml of each sample was measured and transferred into a 250 ml beaker. 5 ml of concentrated $HNO_{3(aq)}$ (Analar, 98 %) was added. The mixture was gently heated on a hot plate after adding few boiling chips, and evaporated down to about 20 ml. Another 5 ml of the concentrated HNO_3 was added and then heated for another 10 min and allowed to cool. About 5 ml of HNO_3 was used to rinse the sides of the beaker, the solution was quantitatively transferred into a 100 ml volumetric flask and made up to the mark with distilled water. A blank solution was prepared in a similar way. Calibration curves for each of the elements As, Fe, Pb, Zn, Cr, Cd and Ni were prepared using standard calibration solutions. The standard solutions were prepared from the stock solutions for the elements using the dilution constant. Heavy metal analysis was done using Atomic Absorption Spectrophotometer (Model; Varian 220). Calibration curves were drawn for each metal by running suitable concentrations of their standard solutions, from which the concentrations of the elements were obtained by extrapolation. Average values of three replicates were taken for each determination. The absorbance of the blank was taken before analysis of the samples. The samples were introduced through plastic capillary at 5.8 ml per minute by direct aspiration into air-acetylene flame with a temperature of about 2300 °C. Various hollow cathode lamps (HCL) for each of the elements As, Fe, Pb, Zn, Cr, Cd and Ni were employed as common radiation source. They operate at various current intensities and were monitored by wavelength resonance lines as shown in Table 1.

Table 1. The operational current intensities and wavelengths for the various heavy metals determined

HOLLOWCATHODE LAMP(HCL)	CURRENT USED/mA	WAVELENGTH/nm
Arsenic(As)	10.0	193.7
Iron(Fe)	5.0	248.3
Lead(Pb)	10.0	217.0
Zinc(Zn)	5.0	213.9
Chromium(Cr)	7.0	357.9
Cadmium(Cd)	4.0	228.8
Nickel(Ni)	4.0	232.0

2.4 Statistical analysis

Statistical analysis of the results were carried out using both Microsoft Excel (2010 edition) and statistical Package for Social Science (IBM SPSS version 20) software. The relationship between the elemental concentrations in water samples at each site were evaluated by linear regression and the determination of

Pearson correlation coefficients. All errors were calculated at 95 % confidence level.

3. Results and discussion

Tables 2 to Table 5 show the mean pH, temperature and conductivity of water samples from Lake Bosomtwe and Bore Holes in some towns around the lake in November 2012, February 2013 May 2013 and August 2013.

Table 2. Mean values of some physical parameters in lake and borehole water samples collected from seven towns along the Bosomtwe Crater Lake in November 2012

TOWN	LAKE WATER			UNDERGROUND WATER		
	pH	TEMPERATURE	CONDUCTIVITY	pH	TEMPERATURE	CONDUCTIVITY
ANYINATIASE	9.72	32.0	1246.6	6.80	29.0	1462.5
NKOWI	9.80	32.0	1238.1	6.99	31.0	1279.8
ADWAFO	9.86	31.0	1195.1	7.20	29.0	1371.3
ABRODWUM	9.80	32.0	1252.3	7.42	28.0	1201.2
OBO	9.75	32.0	1269.2	7.15	30.0	1280.0
ABONO	9.49	30.0	1252.5	7.20	30.0	1260.3
ABEASE	9.85	32.0	1257.5	7.32	29.5	1220.5

Table 3. Mean values of some physical parameters in water samples collected from seven towns along the Bosomtwe Crater Lake in February 2013

TOWN	LAKE WATER			UNDERGROUND WATER		
	pH	TEMPERATURE	CONDUCTIVITY	pH	TEMPERATURE	CONDUCTIVITY
ANYINATIASE	9.87	35.0	1237.1	6.96	29.0	1249.8
NKOWI	9.82	34.0	1291.7	6.98	32.0	1274.3
ADWAFO	9.91	34.0	1230.2	7.08	30.0	1413.45
ABRODWUM	9.88	34.0	1267.7	7.53	28.0	1235.5
OBO	9.80	34.0	1270.3	7.11	30.0	1284.6
ABONO	9.72	33.0	1234.5	7.12	30.0	1260.8
ABEASE	9.87	34.0	1258.8	7.17	30.0	1256.1

Table 4. Mean values of some physical parameters in lake and borehole water samples collected from seven towns along the Bosomtwe Crater Lake in May 2013

TOWN	LAKE WATER			UNDERGROUND WATER		
	pH	TEMPERATURE	CONDUCTIVITY	pH	TEMPERATURE	CONDUCTIVITY
ANYINATIASE	9.82	30.0	12573.0	6.58	29.0	1501.4
NKOWI	9.76	30.0	1255.6	7.40	30.0	1279.9
ADWAFO	9.80	30.0	1171.8	7.28	28.0	1376.55
ABRODWUM	9.74	30.0	1256.3	7.30	28.0	1249.2
OBO	9.72	29.0	1664.9	7.16	30.0	1285.95
ABONO	8.98	28.5	1271.0	7.25	30.0	1268.4
ABEASE	9.80	30.0	1240.2	7.50	29.0	1221.15

Table 5. Mean values of some physical parameters lake and borehole in water samples collected from seven towns along the Bosomtwe Crater Lake in August 2013

TOWN	LAKE WATER			UNDERGROUND WATER		
	pH	TEMPERATURE	CONDUCTIVITY	pH	TEMPERATURE	CONDUCTIVITY
ANYINATIASE	9.83	30.0	1269.5	6.55	29.0	1808.3
NKOWI	9.77	30.0	1359.0	7.46	30.0	1317.4
ADWAFO	9.83	30.0	1230.4	7.30	28.0	1420.6
ABRODWUM	9.75	30.0	1244.6	7.30	28.0	1266.9
OBO	9.70	29.0	1909.2	7.11	30.0	1298.15
ABONO	8.98	28.5	1261.45	7.27	30.0	1280.9
ABEASE	9.83	30.0	1154.5	7.50	29.0	1222.15

Table 6: Mean concentrations some heavy metals in water samples collected from seven towns along the Bosomtwe Crater Lake in November 2012.

TOWN	LAKE WATER							UNDERGROUND WATER						
	As	Fe	Pb	Zn	Cr	Cd	Ni	As	Fe	Pb	Zn	Cr	Cd	Ni
ANYINATIASE	<0.01	0.215	0.164	0.132	0.026	<0.01	<0.01	<0.01	0.856	0.120	0.143	0.014	<0.01	<0.01
NKOWI	<0.01	0.315	0.010	0.205	0.012	<0.01	<0.01	<0.01	0.311	0.099	0.278	0.020	<0.01	<0.01
ADWAFO	<0.01	0.234	0.121	0.102	0.010	<0.01	<0.01	<0.01	0.523	0.156	0.253	0.021	<0.01	<0.01
ABRODWUM	<0.01	0.305	0.115	0.141	0.041	<0.01	<0.01	<0.01	0.200	0.146	0.130	0.019	<0.01	<0.01
OBO	<0.01	0.415	0.069	0.202	0.010	<0.01	<0.01	<0.01	0.452	0.093	0.200	0.020	<0.01	<0.01
ABONO	<0.01	0.386	0.076	0.129	0.022	<0.01	0.018	<0.01	0.322	0.085	0.182	0.023	<0.01	0.020
ABEASE	<0.01	0.284	0.140	0.115	0.019	<0.01	0.020	<0.01	0.219	0.138	0.110	0.019	<0.01	0.021

Table 7. Mean concentrations some heavy metals in lake and borehole water samples collected from seven towns along the Bosomtwe Crater Lake in February 2013

TOWN	LAKE WATER							UNDERGROUND WATER						
	As	Fe	Pb	Zn	Cr	Cd	Ni	As	Fe	Pb	Zn	Cr	Cd	Ni
ANYINATIASE	<0.01	0.191	0.178	0.117	0.032	<0.01	<0.01	<0.01	0.276	0.121	0.141	0.014	<0.01	<0.01
NKOWI	<0.01	0.423	0.103	0.213	0.012	<0.01	<0.01	<0.01	0.254	0.107	0.279	0.025	<0.01	<0.01
ADWAFO	<0.01	0.207	0.141	0.100	<0.01	<0.01	<0.01	<0.01	0.630	0.177	0.250	0.042	<0.01	<0.01
ABRODWUM	<0.01	0.251	0.162	0.144	0.049	<0.01	<0.01	<0.01	0.190	0.178	0.129	0.020	<0.01	<0.01
OBO	<0.01	0.347	0.074	0.222	<0.01	<0.01	<0.01	<0.01	0.391	0.106	0.204	0.025	<0.01	<0.01
ABONO	<0.01	0.323	0.095	0.138	0.026	<0.01	0.022	<0.01	0.250	0.103	0.191	0.029	<0.01	0.027
ABEASE	<0.01	0.255	0.170	0.120	0.019	<0.01	0.024	<0.01	0.202	0.178	0.123	0.024	<0.01	0.026

Table 8. Mean concentrations some heavy metals in lake and borehole water samples collected from seven towns along the Bosomtwe Crater Lake in May 2013

TOWN	LAKE WATER							UNDERGROUND WATER						
	As	Fe	Pb	Zn	Cr	Cd	Ni	As	Fe	Pb	Zn	Cr	Cd	Ni
ANYINATIASE	<0.01	0.191	0.135	0.158	0.021	<0.01	<0.01	<0.01	0.108	0.119	0.145	0.015	<0.01	<0.01
NKOWI	<0.01	0.336	0.101	0.150	0.011	<0.01	<0.01	<0.01	0.347	0.097	0.278	0.017	<0.01	<0.01
ADWAFO	<0.01	0.253	0.110	0.105	0.016	<0.01	<0.01	<0.01	0.560	0.137	0.250	0.016	<0.01	<0.01
ABRODWUM	<0.01	0.328	0.086	0.139	0.030	<0.01	<0.01	<0.01	0.276	0.133	0.132	0.018	<0.01	<0.01
OBO	<0.01	1.444	0.067	0.181	<0.01	<0.01	<0.01	<0.01	0.423	0.088	0.170	0.018	<0.01	<0.01
ABONO	<0.01	0.431	0.053	0.123	0.019	<0.01	0.016	<0.01	0.329	0.064	0.207	0.021	<0.01	0.019
ABEASE	<0.01	0.286	0.125	0.101	0.019	<0.01	0.017	<0.01	0.238	0.114	0.150	0.016	<0.01	0.019

Table 9. Mean concentrations some heavy metals in lake and borehole water samples collected from seven towns along the Bosomtwe Crater Lake in August 2013

TOWN	LAKE WATER							UNDERGROUND WATER						
	As	Fe	Pb	Zn	Cr	Cd	Ni	As	Fe	Pb	Zn	Cr	Cd	Ni
ANYINATIASE	<0.01	0.357	0.091	0.199	0.011	<0.01	<0.01	<0.01	1.939	0.116	0.149	0.016	<0.01	<0.01
NKOWI	<0.01	0.249	0.098	0.086	0.010	<0.01	<0.01	<0.01	0.439	0.086	0.276	0.008	<0.01	<0.01
ADWAFO	<0.01	0.299	0.079	0.109	0.021	<0.01	<0.01	<0.01	0.491	0.007	0.258	0.042	<0.01	<0.01
ABRODWUM	<0.01	0.404	0.010	0.134	0.011	<0.01	<0.01	<0.01	0.362	0.016	0.141	0.020	<0.01	<0.01
OBO	<0.01	2.540	0.060	0.139	0.012	<0.01	<0.01	<0.01	0.494	0.057	0.127	0.007	<0.01	<0.01
ABONO	<0.01	0.539	0.018	0.107	0.012	<0.01	<0.01	<0.01	0.402	0.031	0.223	0.015	<0.01	<0.01
ABEASE	<0.01	0.316	0.010	0.081	0.018	<0.01	<0.01	<0.01	0.275	0.014	0.178	0.009	<0.01	<0.01

The mean pH values for the water sample from bore holes are generally lower than those for the water samples from the lake. The mean pH values of water samples from the bore holes range from 6.55 in Anyinatiase in August, 2013 to 7.53 in Abrodwum in February, 2013. These values show that the pH of the water from bore holes are within WHO standards of 6.50-8.50. However the pH values for water from the lake are generally higher. The values range from 9.57 in Abono in February to 9.91 in Adwafo in February. The values show that the water from the lake is basic and the pH values are above the recommended WHO standards of 6.50 – 8.50.The basic nature of the lake water can be attributed to human activities in the lake. For example bathing, swimming and washing of things along the bank of the lake. The people use soap in these activities. The soap is a salt of weak acid and a strong base. Hydrolysis may occur to produce OH^- ions which make the water to be basic. Variations of the pH were 15.88 %, 16.68 %, 5.10 % and 15.34 %. These values indicate that there was not much difference in the pH in both the water from the lake and boreholes in the surrounding towns. The results also show that change in weather has little effect on the pH of the water in the lake and boreholes in the surrounding towns.

Because of its great impact on aquatic life, water temperature is an important component of a water quality assessment (Chapman and Chapman 1996). Temperature is a critical water quality parameter, since it directly influences the amount of dissolved oxygen that is available to aquatic organisms (APHA 2005). Temperature affects the distribution, health, and survival of aquatic organisms. While temperature changes can cause mortality, it can also cause sub-lethal effects by altering the physiology of aquatic organisms (Chapman and Chapman 1996). Temperatures outside of an acceptable window affect the ability of aquatic organisms to grow, reproduce, escape predators, and compete for habitat. The mean temperature of the water ranged from 35 °C to 28 °C in the lake water at Anyinatiase in February 2013. Almost all the water from the lake has the average temperature of 30 °C and the water from the boreholes has the average temperature of 29 °C. The standard deviations obtained for the water for November 2012, February 2013, May 2013 and August 2013 were 1.28, 2.36, 0.82, and 0.82 and respectively with corresponding coefficient of variation of 4.22 %, 7.45 %, 2.80 % and 2.80 %. These values show that the temperature was almost the same and there was not much difference. The standard deviations obtained for the pH of the water samples are 1.32, 1.39, 1.25, and 1.27 for November, 2012, February, 2013, May, 2013 and August respectively. The corresponding coefficients of Electrical conductivity is the numerical expression of an aqueous solution to carry electrical current and is a useful indicator of the mineralization in a water sample (Jain *et al*. 2005). Conductivity is the ability of the water to conduct an electrical current, and is an indirect measure of the ion concentration (APHA 2005). The more ions present, the more electricity can be conducted by the water. The major salts that contribute to the measurement of conductivity are the positively charged ions calcium and magnesium. Other ions that contribute to conductivity to a smaller degree are sulphate, chloride, carbonate, bicarbonate, nitrate, and phosphate (Chapman and Chapman 1996). Generally the mean conductivities were high indicating that the water contains large amounts of ions which were responsible for such conductivities. In February 2013, the highest conductivity was 1418.10 μscm^{-1} and the lowest conductivity was 1228.20 μscm^{-1} from bore holes in Adwafo and lake water from Abono. The average conductivity was about 1200 μscm^{-1}. The standard deviation was 53.81 and corresponding coefficient of variation was 4.22 % indicating that there was not much difference in the conductivities of the water samples. In May 2013, the conductivities generally increased a little and the highest mean value was 1664.90 μscm^{-1} for lake water from Obo and the lowest was 1157.70 μscm^{-1} for lake water at Abono. The standard deviation was 125.74 and coefficient of variation was 9.65 %. The increase may be due to rainfall which could make some ions drain into the lake and others dissolve into water in the ground. In August 2013, the mean conductivities increased a little over those of May 2013. The highest value was 1909.20 μscm^{-1} from lake water from Obo and the lowest was 1122.20 μscm^{-1} from lake water at Abono. There were heavy rains in June and July that might account for more ions getting into the water bodies to increase the conductivities. The standard deviation of the conductivity was 205 and coefficient of variation was 15. 27 %.

In November 2012, the conductivities generally fell, with the highest mean value of 1462.50 μscm^{-1} from boreholes in Anyinatiase and lowest value of 1142.60 μscm^{-1} from lake water at Abono. The standard deviation was 77.99 and coefficient of variation of 6.13 %. In November the harmatan or dry season approached and rainfall pattern changed which might not add more ions into the water bodies. With the exception of values obtained for water samples from Obo in February 2013, borehole water from Anyinatiase in August 2013 and lake water from Obo in August 2013 as 1664.90 μscm^{-1}, 1808.30 μscm^{-1}, and 1909.20 μscm^{-1} respectively, the values were above WHO standard value of 1500 μscm^{-1} (1993). Health effects in humans consuming water with high conductivity include disturbances of salt and water balance and adverse effect on certain myocardic patients and individuals with high blood pressure (Fatoki and Awofolu 2003)

Mean concentrations of Arsenic, Iron, Lead, Zinc, Chromium, Cadmium and Nickel in water samples from Lake Bosomtwe and Bore Holes in some towns around the Lake in November 2012, February 2013, May 2013, and August 2013 are shown in Tables 6 to Table 9. The levels of the metals arsenic, cadmium, and nickel were generally small and were below the detection limit of the instrument, Varian AAS 220 used which is 0.01 mg/L. This shows that their levels may be below those of WHO standard values of 0.01 mg/L for As, 0.003 mg/L for Cd and 0.02 mg/L for Ni. Widespread arsenic contamination in drinking water had led to massive epidemic of arsenic poisoning in Bangladesh and neighbouring countries (Meharg 2005). Forty-two (42) major incidents around the world have been reported on groundwater arsenic contamination. It is estimated that approximately 57 million people are drinking groundwater with concentration elevated above W.H.O standard of 0.01 mg/L. The arsenic in groundwater is of natural origin and is released from sediments in the groundwater owing to anoxic conditions of the subsurface. Studies conducted in US drinking water suggests that people exposed to arsenic in drinking water may be at risk for more serious illness or death in response to infections from H1N1 or Swine flu (Courtney, *et al*. 2009). Man contributes arsenic to the environment through agricultural practices involving the use of insecticides, herbicides and pesticides. Arsenic and many of its compounds are potent poisons. Many water supplies close to mines are contaminated by these poisons. It disrupts ATP production through several mechanisms. The International Agency for Research on Cancer (IARC) recognizes arsenic compounds as group 1 carcinogens. Arsenic is known to cause arsenicosis (Croal *et al*. 2004). High amount of arsenic intake is important in cancer etiology. Long term exposure to arsenic has been linked to bladder and kidney cancer in addition to the cancer of the liver, prostrate, skin, lung and nasal cavity (The Tox Guide for Arsenic 2007). International Cancer Research Centrum has explained that inorganic arsenic components are responsible to skin, urethra and lung carcinogens (Faron *et al.* 1995; Lu *et al*. 1993). Cadmium tends to accumulate in the kidneys and is associated with renal damage (Alloway 1990). Even at low concentrations found widely in the general population, cadmium can result in kidney diseases and both lower bone mineral density (BMD) and increased risk of fractures, both signs of osteoporosis (Alloway 1996). Along with the kidneys and bones, the other major target organs for cadmium toxicity are the lungs. Acute exposure is associated with bronchitis, pulmonary oedema, and chemical pneumonitis (DHHS 2002; Heyes *et al*. 2007) Cadmium causes thyroid hormone deficiency by interfering with the function of an important enzyme required for their synthesis. Cadmium exposure is a risk factor associated with early atherosclerosis and hypertension which can lead to cardiovascular disease (Friberg 1983).

Nickel plays an important role in the biology of the micro-organisms and plants (Helmot *et al*. 2008). Example urease, an enzyme that assists in the hydrolysis of urea contains nickel. High concentrations of nickel for a wide range of life forms make nickel to be toxic and have carcinogenic effects (ATSDR 2000; Goyer 1996). Sensitized individuals may show an allergy to nickel affecting their skins-dermatitis (skin itch). Once a person is sensitized to nickel, any further contact will produce a reaction and adverse health effects can occur at far lower concentrations compared to non-sensitized individuals (ATSDR 2000). International Agency for Research on cancer lists certain nickel compounds as human carcinogens (IARC 1990). Upon release to the environment nickel compounds can exist as soluble species or bound to particulate. In natural waters nickel is a fairly mobile metal though concentrations are generally low compared with the amount of nickel associated with suspended and bottom sediments (ATSDR 2000). In soils nickel compounds are very persistent, though there is a potential for leaching through the soil and subsequently enter ground water (ATSDR 2000; Alloway 1990).

The Iron (Fe) mean levels in the water samples recorded were very high. The highest value recorded for Fe in February 2013 was 0.633 mg/L from borehole water at Adwafo and lowest was 0.191 mg/L for lake water at Anyinatiase. The mean levels of Fe in the other samples were quite appreciable with the average value of 0.323 mg/L. The highest mean value recorded for Fe in May 2013 was 1.444 mg/L lake water at Obo and the lowest was 0.204 mg/L for lake water at Abono. The mean levels of Fe in the other sample were very large with the average value of 0.460 mg/L.

The highest mean level recorded for Fe in August 2013 was 2.540 mg/L for lake water at Obo and lowest 0.176 mg/L for lake water at Abono. The levels for Fe in the other sample were higher than in the other month with the average value of 0.606 mg/L. The highest level recorded for Fe in November 2012 was 0.856 mg/L for borehole water at Anyinatiase and the lowest was 0.155 mg/L for lake water at Abono. The average value of Fe for the month was 0.365 mg/L. From the values recorded the highest value for Fe was 2.540 mg/L for lake water at Obo in August 2013 and the lowest level was 0.155 mg/L for lake water at Abono in November 2012. The higher values were recorded from May to August, 2013 mostly in the water samples from the lake. This may be attributed to the rainfall pattern which is heavier in those months. During the rains, the Fe in the soil or rocks may dissolve and drain into the Lake. There are a lot of stones and rocks in the Obo Township and these stones may be rich in Fe which might increase the level of Fe in the water bodies around Lake Bosomtwe. With the exception of few samples 0.191 mg/L for lake water at Anyinatiase, 0.204 mg/L for borehole water at Abease, 0.207 mg/L for lake water at Adwafo, 0.190 mg/L for borehole water at Abrodwum and 0.199 mg/L for borehole water at Abease in February 2013; 0.176 mg/L for lake water at Abono in August 2013 and 0.155 mg/L for lake water at Abono in November 2012. The levels recorded for Fe in all the water samples were above the WHO standard (1993) of 0.3 mg/L. The standard deviation for levels of Fe for November 2012, February 2013, May 2013 and August 2013 are 0.182, 0.212, 0.330 and 0.509 respectively with the corresponding coefficient of variation being 65.63 %, 71.74 %, 83.99 % and 49.86 %. These values confirm the higher levels of Fe in the water bodies around Lake Bosomtwe. Large amount of ingested iron can cause excess iron in the blood. High blood levels of iron results in reaction of the iron with peroxides to produce free radicals which are highly reactive and can damage DNA, protein lipids and other cellular components. Iron typically damage cells in the heart, liver and elsewhere which can cause significant adverse effect including coma, metabolic acidosis, shock, liver failure, coaguloparthy, adult respiratory distress syndrome, long-term organ damage and even death (Dina *et al*. 2006; Alada 2000; Ferner 2001).

The Lead (Pb) levels in the water samples recorded were a little higher. The highest value recorded in February 2013 was 0.188mg/L for borehole water at Abease and the lowest was 0.074 mg/L for lake water at Obo. The other values were appreciable with an average value of 0.136 mg/L.

The highest value recorded in May 2013 was 0.142 mg/L for borehole water at Adwafo and lowest was 0.050 mg/L for lake water at Abono. The highest value recorded in August 2013 was 0.116 mg/L for borehole water at Anyinatiase and the lowest value was <0.01 mg/L for lake water at Abono. The highest value for the Pb in November 2012 was 0.16 mg/L for borehole water at Adwafo and the lowest value was 0.01 mg/L for lake water at Nkowi. For the levels of Pb recorded, the highest was 0.188 mg/L for borehole water at Abease recorded in February and lowest < 0.01 mg/L recorded in August 2013 for lake water at Abease. In all the water samples analysed, the levels of Pb in the bore hole water were higher than those in the lake water. Most of the common salts of Lead are insoluble and the $Pb^{2+}_{(aq)}$ in the lake may be precipitated by some anions like Cl^-, SO_4^{2-}, CO_3^{2-} etc. that may be present in the lake especially during rainy season when these ions from the rain water may drain into the lake. Thus the lowest levels were recorded for the lake water in May and August, 2013. The standard deviations for Pb in November 2012, February 2013, May 2013, and August 2013 were 0.040, 0.067, 0.062 and 0.040 respectively with the corresponding coefficient of variations of 38.83 %, 49.26 %, 49.21 %, and 59.70 %. These values show significant levels of Pb in these water samples. With the exception of the levels in lake water at Abease, <0.01 mg/L borehole water at Abease, <0.01mg/L recorded in August 2013 and lake water at Nkowi, 0.01 mg/L recorded in November 2012. All the recorded levels for Pb were above the WHO recommended standard of 0.01 mg/L. Lead damages the nervous connections especially in young children and cause blood and brain disorders. Lead poisoning typically results from injection of food and water contaminated with lead. Several studies have shown that chronic lead exposure reduces nerve conduction velocity in peripheral nerves in adult subjects without clinical symptom or sign of disease (Skerfring 1993). Long-term exposure to lead cause small increase in blood pressure especially middle-aged and older people and can cause anaemia. Exposure to high level can severely damage the brain and kidney in males (Golub and Mari 2005).

The levels of Zinc recorded were almost the same as Lead and were significant. The highest mean value recorded for zinc was in February 2013 was 0.269 mg/L for borehole water at Nkowi and lowest was 0.086 mg/L for lake water at Abease. The other values were appreciable with an average value of 0.166 mg/L. The highest value of Zn recorded in May 2013 was 0.330 mg/L for borehole water at Adwafo and the lowest was 0.083mg/L for lake water at Abease. The average value for the levels was 0.156 mg/L. The highest value of Zn recorded in August 2013 was 0.419 mg/L for borehole water at Adwafo and the lowest was 0.080 mg/L for lake water at Abease. The average value for the other values was 0.160 mg/L. The highest value recorded for Zn in November 2012 was 0.295 mg/L for borehole water at Adwafo and lowest was 0.084 mg/L for lake water at Abease. The average value for the levels of Zn was 0.167 mg/L. In general the levels of Zn in the water samples from Bore holes were higher than those in the water samples from the lake. Though the values were significant as those for the other metals; Iron and Lead, they were far below the WHO standard value of 3 mg/L. The standard deviations for Zn in the water samples in November 2012 February 2013, May 2013, and August 2013 were 0.059, 0.059, 0.060 and 0.085 respectively, with the corresponding coefficient of variations of 38.46%, 51.88%, 35.33%, and 35.54%. The values show significant levels of Zn, they are far below the WHO standard values which may not cause any harm. Zinc is an essential mineral of exceptional biological and public health importance (Hambridge *et al.* 2007). Zinc is believed to possess antioxidant properties, which may protect against accelerated aging of the skin and muscles in the body. It also helps to speed up the healing process after injury (Milbury *et al.* 2008). Zinc toxicity can occur in both acute and chronic forms. Acute adverse effects of high intake of zinc include nausea, vomiting, loss of appetite, abdominal cramps diarrhoea and headache (Prasad 2005). Excessive amount of zinc is harmful as it suppresses copper and iron absorption (Fosmire 1990). It can also cause ataxia, lethargy and copper deficiency. Zinc deficiency is associated with chronic liver disease, chronic renal disease, sickle cell disease, diabetes, malignancy and other chronic illness (Prasad 2005).

The highest mean value of Cr recorded in February 2013 was 0.062 mg/L for borehole water at Adwafo and the lowest was <0.01 mg/L for both lake water at Adwafo and lake water at Obo. The average value for Cr was 0.025 mg/L. The highest value recorded in May 2013 was 0.030 mg/L for lake water at Abrodwum and the lowest was <0.01 mg/L for lake water at Obo. The average value for Cr was 0.017 mg/L. The highest value recorded in August 2013 was 0.021 mg/L for lake water at Adwafo and the lowest was <0.01 mg/L for borehole water at Obo. The average value was 0.012 mg/L.

The highest mean value recorded for November 2012 was 0.041 mg/L for lake water at Abrodwum and lowest value was 0.01 mg/L for both lake water at Adwafo and lake water at Obo. The average value was 0.020 mg/L. The levels of Cr in the samples from the lake were generally significant than those in the samples from the bore holes. With the exception of water sample from borehole water at Adwafo whose Cr level was 0.062 mg/L, the levels of Cr in the water sample were all below WHO standards of 0.05 mg/L. The standard deviation of levels of Cr in November 2012, February 2013, May 2013 and August 2013 were 0.010, 0.013, 0.004, and 0.004 respectively with the corresponding coefficient of variations of 50 %, 52.0 %, 23.53 %, and 34.78 % These values indicate the lower values of the levels of Cr in the water samples. Chromium has no verified biological role and has been classified as not essential for mammals (Bona *et al*. 2010). Cr (VI) is very toxic and mutagenic but has not been established as a carcinogen when in solution although it may cause allergic contact dermatitis (ACD) (Bona *et al*. 2010). Several *in vitro* studies indicated that high concentration of Cr (III) in the cell can lead to DNA damage (Eastmond *et al*. 2008). In 2010 the Environmental working group studied the drinking water in 35 American cities and found measurable Cr (VI) in tap water in 31 of the cities, 25 cities had levels exceeded California's proposed limit (AFP 2010).

Figures 3 to 6 show graphically the variation in iron, lead, zinc and chromium contents between wet and dry seasons for lake and borehole water in some towns around the Bosomtwe crater lake. The heavy metal content showed generally no significantly differences between lake and underground water or during the dry and wet seasons. Mean Fe level in the lake water at Obo was relatively higher in the dry season than the wet season. Pb levels at Anyinatiase, Adwafo, Abrodwum, Abono and Abease were also relatively higher in the wet season than the dry season. Zn levels at Nkowi and Obo were similarly higher in the wet season as compared to the dry season. Mean levels of Cr were also relatively high at Abrodwum and Abono in the wet season. Mean levels of Fe for underground water was observed to be relatively high at Anyinatiase in the dry season. Mean Pb levels were higher at Adwafo, Abrodwum, and Abease in the wet season and Cr levels were also high at Nkowi, Obo, Abono and Abease in the wet season. The correlations between the mean levels of the heavy metals in the lake water in the two seasons were weak as indicated by their, r, values (Table 10). There were however statistically significant correlation between the mean levels of Pb and Fe in the underground water in the two seasons as indicated by their, r, values (Table 10). Zn and Cr showed weak correlation in underground water for the two seasons. These significant correlations of the metals are indicative of a common source of pollution in underground water and is not influenced by seasonal changes.

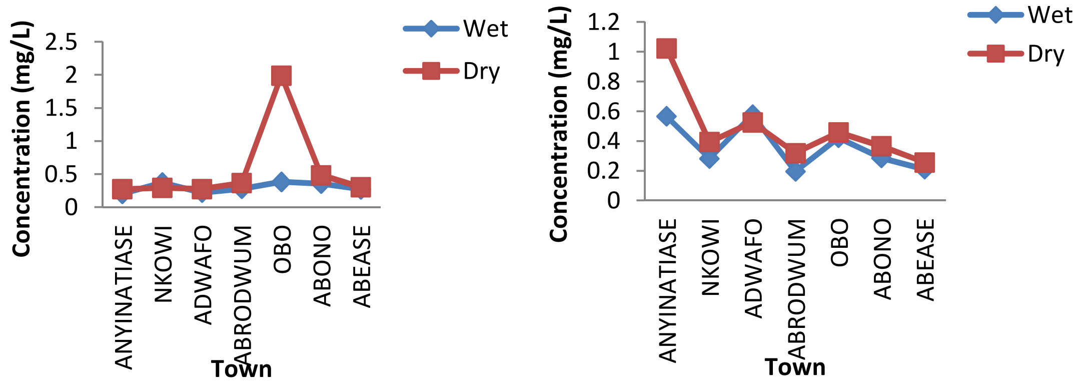

Figure 3. Mean levels of iron in (a) lake and (b) underground water for wet and dry seasons

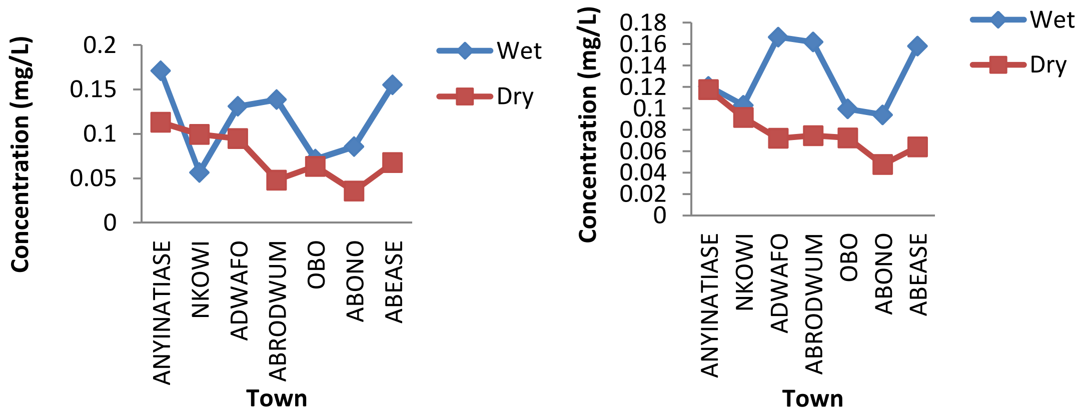

Figure 4. Mean levels of lead in (a) lake and (b) underground water for wet and dry seasons

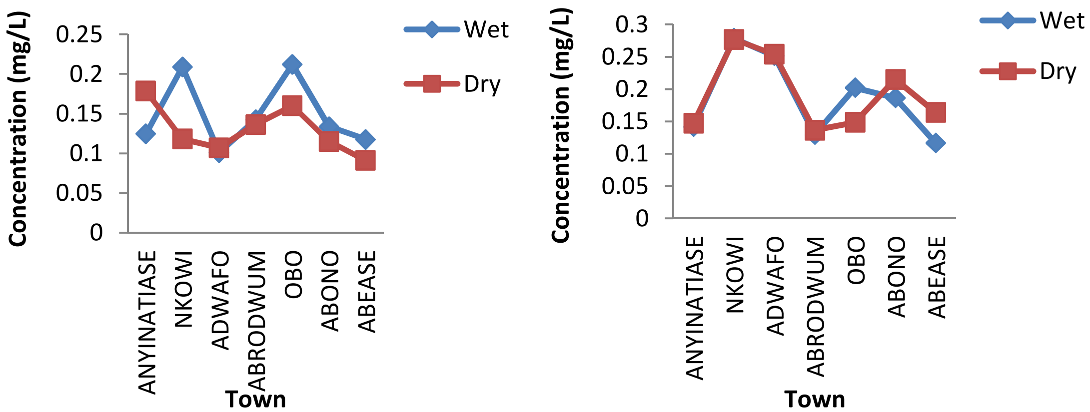

Figure 5. Mean levels of zinc in (a) lake and (b) underground water for wet and dry seasons

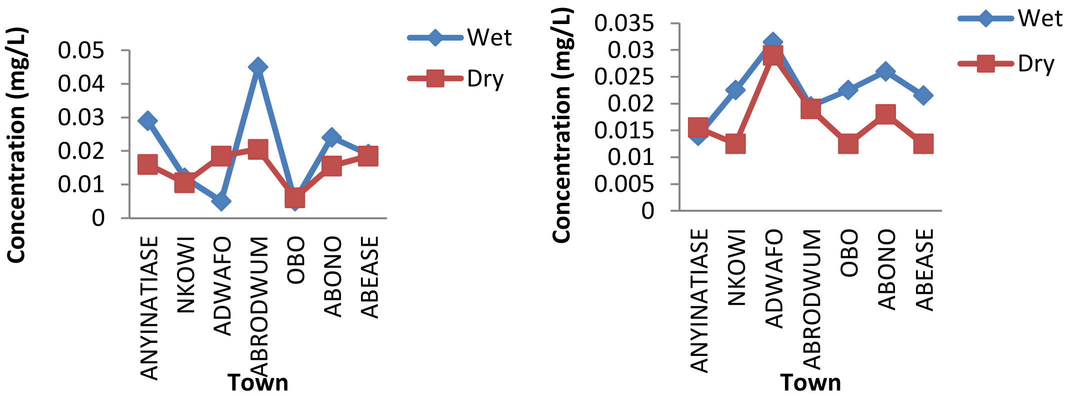

Figure 6. Mean levels of chromium in (a) lake and (b) underground water for wet and dry seasons

Table 10. Correlation analysis of concentration in dry and wet seasons

	Fe	Pb	Zn	Cr
Lake	0.570	0.229	0.306	0.598
Underground	0.794*	-0.048	0.866*	0.639
Wet Lake-Under	-0.080	0.837*	-0.527	-0.531
Dry Lake-under	-0.480	0.693	0.428	-0.583

* Correlation is significant at 0.05 level (2-tailed)

Possible metal-metal, metal-pH and metal EC relationships were investigated using the Pearson correlation coefficient, r, p 0.05 and 0.01 significant levels. For lake water in the wet season EC correlated significantly with Zn and Pb showed significant correlation with Fe (Table 11). For lake water in the dry season EC also correlated significantly with Zn and Cr showed significant correlation with Fe (Table 12). For underground water in the wet season EC correlated significantly with Fe (Table 13) and for underground water in the dry season EC correlated significantly with Pb and Fe, Pb correlated significantly with Fe and pH showed significant correlation with Fe (Table 14). The significant correlations between Fe and Pb for both wet and dry seasons are indicative of a common source of pollution of these metals in the lake.

Table 11. Correlations of different heavy metals, pH and EC for Lake water in the wet season

	pH	EC	Fe	Pb	Zn	Cr
pH	1.000					
EC	-0.122	1.000				
Fe	-0.526	0.658	1.000			
Pb	0.437	-0.393	-0.918**	1.000		
Zn	-0.166	0.755*	0.817	-0.796	1.000	
Cr	-0.109	0.171	-0.281	0.476	-0.294	1.000

* Correlation is significant at 0.05 level (2-tailed) ** Correlation is significant at 0.01 level (2-tailed)

Table 12. Correlations of different heavy metals, pH and EC for Lake water in the dry season

	pH	EC	Fe	Pb	Zn	Cr
pH	1.000					
EC	0.235	1.000				
Fe	-0.046	-0.112	1.000			
Pb	0.664	0.584	-0.270	1.000		
Zn	0.167	0.756*	0.418	0.277	1.000	
Cr	0.048	-0.003	-0.772*	-0.108	-0.376	1.000

* Correlation is significant at 0.05 level (2-tailed)

Table 13. Correlations of different heavy metals, pH and EC for underground water in the wet season

	pH	EC	Fe	Pb	Zn	Cr
pH	1.000					
EC	-0.631	1.000				
Fe	-0.630	0.960**	1.000			
Pb	0.547	0.083	-0.200	1.000		
Zn	-0.416	0.432	0.312	-0.330	1.000	
Cr	0.190	0.256	0.112	0.153	0.599	1.000

** Correlation is significant at 0.01 level (2-tailed)

Table 14. Correlations of different heavy metals, pH and EC for underground water in the dry season

	pH	EC	Fe	Pb	Zn	Cr
pH	1.000					
EC	-0.908**	1.000				
Fe	-0.947**	-0.990**	1.000			
Pb	-0.695	0.801*	0.802*	1.000		
Zn	0.418	-0.111	-0.178	-0.117	1.000	
Cr	0.018	0.117	0.086	-0.180	0.327	1.000

* Correlation is significant at 0.05 level (2-tailed) ** Correlation is significant at 0.01 level (2-tailed)

4. Conclusion

The mean pH values for water samples from the bore holes in the towns around the Bosomtwe Crater Lake were within the WHO standard of 6.50-8.50. However the pH values for the water sample from the lake were generally higher and above the WHO standards. With the exception of the mean conductivity values of a few samples: Obo lake water in February 2013, 1664.90 μscm^{-1}, Anyinatiase borehole water in August, 1808.30 μscm^{-1} and Obo lake water in August 2013, 1909.20 μscm^{-1} the values were below the WHO standards value of 1500 μscm^{-1} (1993). The levels of Arsenic, Cadmium and Nickel were generally small and were below the detection limit of the instrument used Varian AAS 220 and are below the WHO standard values of 0.01 mg/L for As; 0.003 mg/L for Cd and 0.02mg/L for Ni. The mean levels of Fe and Pb were above the WHO values for both lake and underground water for both wet and dry seasons whereas the mean levels of Zn, Cr and Cd were below the WHO values for both lake and underground water for both seasons. The statistically significant correlation between Fe and Pb in underground water is indicative of a common source of pollution and is not influenced by seasonal changes. The weak correlation between the mean values of the metals in the lake in the two seasons is indicative of significant seasonal variations in the water from the Bosomtwe impact crater lake.

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References

Adepoju-Bello, A.A., Ojomolade, O.O., Ayoola, G.A. and Coker, H.A.B. (2009), "Quantitative analysis of some toxic metals in domestic water obtained from Lagos metropolis", *The Nig. J. Pharm*. 42(1), 57-60.

AFP (2010), US water has large amounts of likely carcinogen study.

Alada, A.R. (2000), "The haematological effects of Telfairia occidentalis diet preparation", *Afri J Biomed Res* 3,185-186.

Alloway, B.J. (1990), "Heavy Metals in Soil". John Wiky and Sons Inc. New York.

Alloway, B.J. (1996), "Soil Pollution and land contamination", In Pollution, causes effects and control 3rd Edn. Harrison R.M. (Ed). (2002), The Royal Society of Chemistry, Cambridge UR.

Ansah-Asare, O.D. and Karikari, A.Y. (2004), "Physio-Chemical and Microbial Water Quality Assessment of Densu River of Ghana", *West African J Appl Econom* 10, 87-100

APHA, A.D. (2005), Eaton, American Public Health Association, Mary Ann H. Franson, American Water Works Association (Ed.), "Standard Methods for the Examination of Water and Wastewater".

ATSDR (2000), "ATSDR's toxicological profiles on CD-Rom", CRS Press, Boca Raton FL.

Bona, K.R., Love, S., Rhodes, N.R., McAdory, D., Sinha, S.H., Kern, N., Kent, J., Strickland, J., Wilson, A., Beaird, J., Ramage, J., Rasco, J.F. and Vincent, J.B. (2010), "Chromium is not an essential trace element in mammals. Effects of low – chromium diet", *Journal for Biological Inorganic chemistry* 16(3), 381.

Chapman, D. and Chapman, D.E. (1996), "Water Quality Assessments. A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring", 2nd Edition, Chapman & Hall, London.

Courtney, D., Ely, K.H., Enelow, R.I. and Hamilton, J.W. (2009), "Low Dose Arsenic Compromise the Immune Response to influenza A infection in vivo", *Environmental Health Perspective* 117(9), 1441 – 1447.
Croal, L.R., Gralnick, J.A., Malasaru, D. and Newman, D. (2004), "The Genetic of Geochemistry", *Annual Review of Genetics* 38, 175 – 206.
DHHS (2002), "10th Report on Carrinogens", *US Department of Health and Human Services* 263.
Dina, O.A., Adedapo, A.A., Oyinloye, O.P. and Saba, A.B. (2006), "Effect of Telfairia occidentalis extract on Experimentally-induced anaemia in domestic animals", *Afri J Biomed Res* 3, 181-183.
Eastmond, D.A., MacGregor J.T. and Slesinki, R.S. (2008), "Trivalent Chromium: Assessing the Genotoxic Risk of an Essential Trace Elements and Widely used Human and Animal Nutrition Supplement", *Critical Review in Toxicology* 38(3), 173-190.
Faron, O.M., Williams, M. and O'Conner, R. (1995), "A Review of The Carcinogenicity of Chemicals most frequently found at National Priorities List Sites", *Toxicol Indus. Health* 251, 52 – 60.
Fatoki, O.S., Awofulu, R. (2003), "Levels of Cd, Hg and Zn in some syrface waters from Eastern Cape Province", South Africa. SA 29(4), 375-379.
Ferner, D.J. (2001), "Toxicity of heavy metals", *eMed J* 2, 1-5.
Fosmire, G.J. (1990), "Zinc toxicity", *American Journal of Clinical Nutrition* 57(2), 225 –27.
Friberg, L. (1983), "Cadmium", *Annual Review of Public Health* 4, 367-373.
Golub, M.S. (2005), "Summary", Metal, fertility and reproductive toxicity. Boca Raton; *Florida*: Taylor and Francis 153.
Goyer, R.A. (1996), "Toxic effects of metals", In Casarette and Doull's Toxicology. The Basic Science of Poisons. Fifth Edition Klaossen, GD. (Ed). McGraw – Hill Health Professions Division
Hambridge, K.M. and Krebs, N.F. (2007), "Zinc deficiency a special challenge", *J. Nutrition* 137(4), 1101– 1105.
Helmot, S. and Roland, K.O.S. (2008), "Nickel and Its Surprising Impact in Nature", Metal ions in Life Science 2 Willey.
Heyes, A.W. (2007), "Principle and Methods of Toxicology", Philadelphia CRC Press 850 –851.
IARC (1990), "Nickel and nickel compounds", In Chromium, Nickel and Welding. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Humans, vol. 49. Lyon, France: International Agency for Research on Cancer, 257-445.
Jain P., Sharma, J.D., Sohu, D., Sharma, P. (2005), "Chemical analysis of drinking water of villages of Sanganer Tehsil, Juipur District", *Int. J. Environ. Sci. Tech*. 2(4):373-379.
Koeberl, C. and Reimold, W.U. (2005), Bosumtwi impact crater: An updated and revised geological map, with explanations. Jahrbuch der Geologischen Bundesanstalt, Wien (Yearbook of the Austrian Geological Survey), 145, 31-70.
Koeberl, C., Reimold, W.U., Pesones, L.J. and Brand, L.D. (1997), "New studies of Bosomtwe Impact Structure Ghana-Meteorites and Planetary Science", 32, A72 – A72.
Lokeshwari, H., and Chamdrappa, G.T. (2006), "Impact of heavy metal contamination of Bellandur Lake on soil and cultivated vegetation", *Current science* 91(5).
Lu, F.J., Hong, C.L., Luo, M.F. and Shimizu, H. (1993), Mutagenicity of Drinking Well Water, Environ. Contam Toxicol 545-550.
Marcovecchio, J.E., Botte S.E. and Freije, R.H. (2007), "Heavy Metals, Major Metals, Trace Elements", In: Handbook of Water Analysis. L.M. Nollet, (Ed.). 2nd Edn. London: CRC Press, 275-311.
Meharg, A. (2005), "Venomous Earth-How Arsenic caused the world worst mass poisoning", Macmillan Science.
Milbury, P.E. and Richer A.C. (2008), "Understanding the Antioxidant Controversy": Scrutinizing the "fountain of youth", Greenwood Publishing Group, 99.
Ntow, J.W. (1993), "Determination of some environmental pollutants in the environs of Konongo in the Ashanti region of Ghana". Department of Chemistry, KNUST. Master's Thesis.
Pinkey, D. (1989), "Lead poisoning problem still far from Solved", *Arm Med News* 21, 36
Prasad, A.S. (2005), "Zinc deficiency, This has been known for 40 years but ignored by health organization", *British Medical Journal* 326(7386), 409–10.
Skerfring, S. (1993), "Biological monitoring of inorganic lead," *Scnd. J. Work Env. Health* 19, 59-64.
The Tox Guide for Arsenic (2007), "The Agency for Toxic Substances and Diseases Registry.
Turner B. F., Gardner, L. R. and Sharp, W. E. (1995), "The hydrology of Lake Bosomtwe, a climate sensitive lake in Ghana", West Africa. *Journal of hydrology* 183, 213 – 261.
Watkins, A. P. (1994), "The Structure Stratigraphy and Mineralization of the Bonnata–Beposo Region NW Ashanti Belt". Ghana, West Africa.
WHO (1993), "Guidelines for Drinking Water Quality", World Health Organization, Genava, Switzerland.
Zhang, C. (2007), "Fundamental of environmental sampling and analysis", John Wiles & sons 109.