ASSESSMENT OF HEAVY METALS IN GROUND WATER SOURCES IN AGONA DISTRICT IN THE CENTRAL REGION OF GHANA

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ABSTRACT: *This study was done to determine the concentration of trace metals in groundwaters in the Agona East district of the Central region of Ghana. Ground water samples were collected from 3 hand dug wells and 15 boreholes in the study area. All samples were analyzed for seven trace metals (Zn, Cu, Cr, Mn, Fe, Cd, Al) using Atomic Absorption spectrophotometer (AAS). The concentrations of the trace metals from the various areas range from 0.824 to 0.1.122 mg/L for Cu; 0.116 to 0.312 mg/L for Zn; <0.002 to 0.364 mg/L for Cr; <0.006 to 0.065 mg/L for Mn; 0.156 to 1.236 mg/L for Fe; <0.002 to 0.028 mg/L for Cd and 1.44 to 3.188 mg/L for Al. Four of the trace metals (Cu, Zn, Mn, and Cd) had their concentrations within the WHO standards for drinking water. Aluminium, Iron and chromium had their values above the WHO limits at most of the sampling sites.*

KEYWORDS: Trace metals, groundwater, concentration, toxicity, Atomic Absorption spectrophotometer (AAS).

INTRODUCTION

Water is one of the essentials that supports all forms of plant and animal life (Vanloon and Duffy, 2005) and it is generally obtained from two principal natural sources; surface water such as fresh water lakes, rivers, streams etc. and groundwater such as boreholes and well water (McMurry and Fay, 2004; Mendie, 2005). Water has a number of unique chemical properties that are essential to life and that determine its environmental behaviour. Water is able to dissolve, absorb, adsorb or suspend many different compounds (WHO, 2007), thus, in nature, water is not pure as it acquires contaminants from its surrounding and those arising from humans and animals as well as other biological activities (Mendie, 2005). One of the most important environmental issues today is groundwater contamination (Vodela *et al*, 1997) and between the wide diversity of contaminants affecting water resources, heavy metals receive particular concern considering their strong toxicity even at low concentrations (Marcovecechio *et al*, 2007).

Pollution of water bodies as a result of metal toxicity has become a source of concern among consumers. This concerns has become alarming in response to increasing knowledge on their toxicity to human health and biological systems (Anazawa *et al*, 2004). The toxicity of trace metals in water depends on the concentration of the metal below a certain level, which could be considered as essential for biochemical processes. However, in certain cases, high levels could bioaccumulate raising toxicity concerns (Ackah *et al* 2011).

Pollution of groundwater may come from urbanization, industrial development, agricultural and mining activities, and also from natural sources. The soil strata have the capacity to attenuate contaminants in the water passing through it. The chemical composition of groundwater is an indicator of its suitability as a source of water for human and livestock consumption, and for many other purposes. In the Agona district groundwater is the principal and sometimes the only source of potable water supply.

MATERIALS AND METHODS

Study Area.

Agona East District is situated within latitudes $5^0 30''$and $5^0 50''$N and longitudes $0^0 35''$ and $0^0 55''$W. It is bounded to the south by the Agona West Municipality and the Gomoa East District Assembly, to the north by the Birim South District and to the northeast by the West Akim District, both in the eastern region. The eastern part of the district is bounded by the Awutu Senya District and to the West by Asikuma-Odoben-Brakwa and Ajumako-Enyan-Essiam Districts.

The District lies in the wet semi-equatorial climatic zone. The granites form part of the basement rocks and Agona district is 100% underlain by granites. The Crystalline rocks in the district consist mainly of a series of granites. These rock bodies generally have no primary porosity. However, they have developed secondary and tertiary porosity as a result of faulting, jointing, fracturing and weathering, and have accumulated appreciable quantity of water. The deep ground water taps into these fractures (WRMS, 2008).

Generally, these rocks are well foliated, often migmatic, potash rich granitoids which come in the form of muscovite biotite granite and granodiorite, porphyroplastic biotite gneiss, aplites and pegmatites. They are often characterized by the presence of many enclaves of schist and gneisses. They also have a relatively high alkaline content.

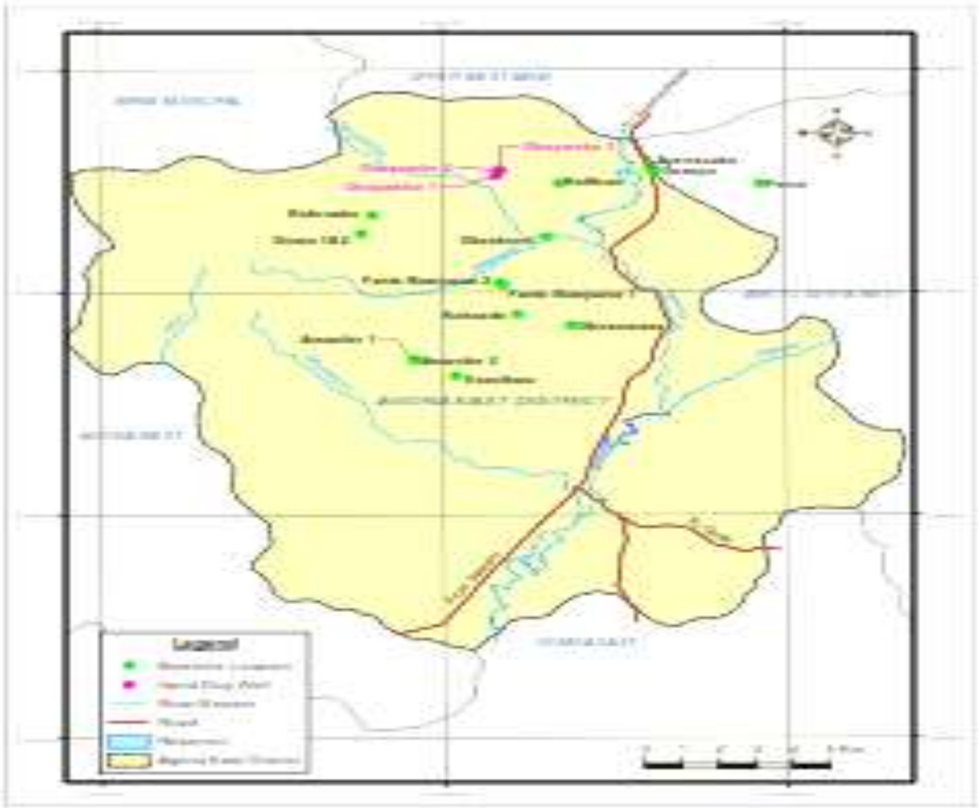

Figure 1: Agona East sampling map

Sampling and analysis

Eighteen groundwater samples (three hand dug wells and fifteen boreholes) were collected at various locations**.** The water samples were collected in 500 mL acid-washed high density polyethylene sampling bottles after filtering through 0.45µm filters on cellulose acetate with a hand operated vacuum pump. The filtered water samples were acidified with 1% HNO_3 to keep the metals in solution.

The water samples were then acid digested using an ETHOS 500 model microwave and filtered. The filtrate was analyzed for heavy metal using VARIAN AA 240FS- Atomic Absorption Spectrometer in an acetylene-air flame at the Chemistry Department, Ghana Atomic Energy Commission. Analytical grade reagents were used for all analysis and replicate measurements were done to ensure reproducibility and good quality control. The AAS working conditions were set as shown in Table 1.

Table 1: Instrument (AAS) operating conditions.

Element	Cu	Zn	Mn	Al	Cd	Cr	Fe
Lamp current (mA)	4	5	5	10	4	7	5
Fuel	Acetylene	Acetylene	Acetylene	Acetylene	Acetylene	Acetylene	Acetylene
Support/Oxidant	Air	Air	Air	Nitrous Oxide	Air	Air	Air
Wavelength (nm)	324.7	213.9	279.5	309.3	228.8	357.9	248.3
Slit width (nm)	0.5	1.0	0.2	0.5	0.5	0.2	0.2
Detection limit (ppm)	0.006	0.002	0.002	0.030	0.002	0.006	0.006

RESULTS AND DISCUSSION

The results obtained from the study are shown in Table 2 and the statistical summary of the results is shown in Table 3.

Table 2: Mean heavy metal concentrations in groundwater samples from various communities.

	Concentration of Heavy Metals (mg/L)							
Location	Cu	Zn	Mn	Al	Cd	Cr	Fe	pH
Oboyambo (HDW2)	1.044	0.204	<0.002	1.440	0.012	0.248	0.852	5.50
Kofikum (BH)	1.084	0.20	<0.002	1.692	0.008	0.364	0.534	5.85
Kokroabo (BH)	1.112	0.204	<0.002	1.652	<0.002	0.072	0.656	6.2
Amanfor (BH2)	1.108	0.164	0.011	2.044	<0.002	<0.006	0.492	4.88
Ayensuako (BH)	0.996	0.136	0.004	2.008	<0.002	<0.006	0.452	6.92
Obosomase (BH)	1.024	0.196	0.008	2.488	<0.002	0.148	0.512	6.61
Kokoado (BH)	0.944	0.116	0.043	2.372	<0.002	0.252	0.540	6.22
Doato (BH2)	0.916	0.128	<0.002	2.276	<0.002	<0.006	0.560	5.20
Osimpo (BH)	0.824	0.128	<0.002	2.692	<0.002	0.124	0.632	5.53
Oboyambo (HDW3)	1.048	0.160	<0.002	2.648	<0.002	0.256	0.736	5.50
Okaekrom (BH)	0.96	0.196	0.065	2.864	<0.002	0.224	0.680	6.08
Esselkwa (BH)	1.028	0.140	0.060	2.988	<0.002	0.068	0.156	6.02
Amanfor (BH1)	0.88	0.176	<0.002	3.188	<0.002	0.136	0.752	5.59
FanteBawjuase(BH2)	1.00	0.156	0.011	2.628	<0.002	0.252	0.768	5.79
Oboyambo (HDW1)	0.888	0.236	0.027	2.920	0.020	0.092	1.236	5.39
Penin (BH)	0.864	0.204	<0.002	2.832	0.016	0.144	0.764	5.46
Doato (BH1)	1.040	0.312	<0.002	3.036	0.024	0.180	0.684	5.20
FanteBawjuase (BH1)	1.00	0.180	0.012	3.160	0.028	0.112	0.820	6.36

Table 3: Statistical summary of the mean concentrations of heavy metals in some groundwater sources in the Agona East in the Central region of Ghana. (Units: mg/L)

Parameters	Minimum	Maximum	Mean	Median	Std	WHO Guideline Limit
Cu	0.824	1.122	0.987	1.00	0.086	2.00
Zn	0.116	0.312	0.1798	0.178	0.047	3.00
Mn	<0.002	0.065	0.0134	0.002	0.021	0.500
Al	1.44	3.188	2.496	2.638	0.539	0.200
Cd	<0.002	0.028	0.006	<0.002	0.010	0.030
Cr	<0.006	0.364	0.148	0.140	0.1028	0.050
Fe	0.156	1.236	0.657	0.668	0.220	0.300

DISCUSSION

Iron

The iron concentration in the water samples ranged from 0.156 to 1.236 mg/L with a mean and median values of 0.657 and 0.668 mg/L respectively. The WHO guideline maximum for iron in drinking water is 0.300 mg/L but an upper limit of 1.00 mg/L should suffice for most purposes (WHO, 2004; Kortatsi, 2007). In the study area, all the water samples had their iron concentrations above the WHO recommended level except for one well at Esselkwa which has Fe^{2+} value of 0.156 mg/L. This does pose a major aesthetic problems to groundwater usage for domestic purposes in the Agona district as it may lead to consumer complaints and indeed some boreholes has already been abandoned. Laundry and sanitary ware will stain at iron concentrations above 0.3 mg/L. Iron is an essential element in human nutrition. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status, and iron bioavailability and range from about 10 to 50 mg/day (Department of National Health and Welfare, 1990).

Dissolution of iron can occur as a result of oxidation and decrease in pH. Oxidation and dissolution of pyrites and arsenopyrites should naturally be major sources of iron and sulphate ($SO_4^{2-)}$ in the groundwaters (Kortatsi, 2007). However, there is no petrographic evidence that pyrites and arsenopyrites occur in the rock matrix in the Agona district. As indicated by White and Yee (1985), Fe^{3+} is reduced to Fe^{2+} at the mineral surface. Geothite, hematite and magnetite are the main iron species present in the rock matrix within the study area. Iron may therefore, been derived from the reductive dissolution of hematite and to a limited extent magnetite in the presence of organic matter. The reduction is likely microbially mediated. Hematite dissolution in the presence of protons (acid) is extremely slow. However, in the presence of organic ligands the reaction can be fast (Appelo and Postma, 1999). The presence of organic matter in the soil zone of the study area is indicated by the brown colouration of rivers and streams. An additional source of iron could be the leaching from ferromagnesian silicates, such as hornblende and pyroxenes (Kortatsi, 2007).

Cadmium

Cadmium concentration of groundwaters in the study area ranged from <0.002 (below detection limit) to 0.028 mg/L with a mean value of 0.006mg/L. Cd^{2+} concentration in the water samples are below the WHO maximum acceptable limit of 0.003 mg/L for drinking water (WHO, 2004). Thus Cd^{2+} does not pose any serious health problems to the communities in which these boreholes occur. Sources of Cd^{2+} included wastes from Cd-based batteries, incinerators and run-off from agricultural soils where phosphate fertilizers are used since Cd^{2+} is a common impurity in phosphate fertilizers.

The solubility of cadmium in water is influenced to a large degree by its acidity; suspended or sediment-bound cadmium may dissolve when there is an increase in acidity (Ros & Slooff, 1987). Cadmium concentrations in unpolluted natural waters are usually below 1 µg/l (Friberg et al., 1986).

Cadmium buildup in the kidneys hinders their filtration systems. This problem can persist because cadmium does not exit the kidneys very quickly and will begin to accumulate. This can ultimately lead to kidney failure. Other adverse health effects from cadmium include stomach pains and infertility, and cadmium is considered a carcinogen. It can also harm the central nervous and immune systems as well as damage DNA. Cadmium has to be ingested or inhaled to be harmful to humans (Lenntech, 2011e).

Chromium

Cr^{3+} ion concentration in the water samples varies from <0.006 mg/L (below detection limit) to 0.364mg/L with mean and median values of 0.148 mg/L and 0.140 mg/L respectively. Approximately 83% of the water samples have Cr^{3+} concentration exceeding the WHO limit of 0.050 mg/L. High levels of chromium could pose serious health problems.

Manganese

Mn^{2+} concentration varies from < 0.002 mg/L (below detection limit) to 0.065 mg/L with a mean value of 0.0134 mg/L. None of the water samples in the Agona district have Mn^{2+} concentrations above the WHO permissible limit for portable water of 0.500 mg/L. Thus the manganese concentration in the groundwaters does not pose any major quality problem in the Agona district.

Manganese is necessary for human survival but toxic when consumed at high concentrations. Manganese is most commonly consumed by eating spinach, grains and rice, eggs, green beans, nuts, and oysters. Manganese deficiency can lead to health issues, including obesity, glucose intolerance, low cholesterol, and blood clotting (Lenntech, 2011g).

Aluminium

Aluminium ion (Al^{3+}) varies in concentration in the groundwater samples from 1.44 mg/L to 3.188 mg/L with a mean value of 2.496 mg/L and a median value of 2.638 mg/L. All the water samples had the Al^{3+} ion concentrations above the WHO maximum acceptable limit of 0.200 mg/L for drinking water (WHO, 2004). This will pose a risk of significant aesthetic problem to groundwater usage. Concentrations of Al^{3+} in groundwater are strongly pH dependent (Nordstrom, 1982) and as expected boreholes with pH < 6 have high concentrations of Al^{3+}. However, some water samples with pH > 6 also have high concentrations of Al^{3+} ions. According to Kortatsi (2007), dissolution of kaolinite or alunite , to provide extra acid neutralisation capacity to the groundwater, appears to be the main source of Al^{3+} in the low pH waters. The typical kaolinite dissolution reaction in low pH water is given by the equation:

$$Al_2SiO_5(OH)_4 + 10H^+ \rightarrow 2Al^{3+} + 2H_2SiO_4 + 5H_2O$$

Copper

The concentration of Cu^{2+} ions in the water samples from the Agona district ranged from 0.824 to 1.122 mg/L with a mean value of 0.987 mg/L. All the water samples have Cu^{2+} concentration below the WHO recommended limit of 2.00 mg/L.

Copper is an essential element in plants and animals (including humans), which means it is necessary for us to live. Therefore, plants and animals must absorb some copper from eating, drinking, and breathing. Copper is an essential nutrient that is incorporated into a number of metalloenzymes involved in hemoglobin formation, drug/xenobiotic metabolism, carbohydrate metabolism, catecholamine biosynthesis, the cross-linking of collagen, elastin, and hair keratin, and the antioxidant defense mechanism. Copper-dependent enzymes, such as cytochrome-c oxidase, superoxide dismutase, ferroxidases, monoamine oxidase, and dopamine β-monooxygenase, function to reduce activated oxygen species or molecular oxygen (ATSDR, 2004). Although copper homeostasis plays an important role in the prevention of copper toxicity, exposure to excessive levels of copper can result in a number of adverse health effects including liver and kidney damage, anemia, immunotoxicity, and developmental toxicity (ATSDR, 2004).

Zinc

All the water samples have Zn^{2+} concentration below the WHO recommended limit of 3.00 mg/L. Zn^{2+} concentration in the water samples varies from 0.116 to 0.312 mg/L with mean and median values of 0.1798 mg/L and 0.178 mg/L respectively.

Zinc is an essential trace element, necessary for plants (Broadley *et al*., 2007), animals (Prasad, 2008) and microorganisms (Sugarman, 1987). Zinc is found in nearly 100 specific enzymes (other sources say 300), and serves as structural ions in transcription factors and is stored and transferred in metallothioneins. It is the only metal which appears in all enzyme classes (Broadley *et al.*, 2007). Zinc is distributed throughout the human body (Rink & Gabriel, 2000). Most zinc is in the brain, muscle, bones, kidney, and liver, with the highest concentrations in the prostate and parts of the eye (Wapnir, 1990). Semen is particularly rich in zinc, which is a key factor in prostate gland function and reproductive organ growth (Berdanier *et al.*, 2007). Although zinc is an essential requirement for good health, excess zinc can be harmful. Excessive absorption of zinc suppresses copper and iron absorption (Fosmire, 1990). Certain metals such as Cu and Co are classified as essential to life due to their involvement in certain physiological processes. Elevated levels of these, however, have been found to be toxic (Sear, 1981).

CONCLUSION

The trace metal loading of the groundwater is not high. Aluminium, iron, and cadmium showed concentrations significantly above their detection limits in most of the water samples. All the water samples had the Al^{3+} ion concentrations above the WHO maximum acceptable limit of 0.200 mg/l for drinking water. The level of Zn^{2+} and Cu^{2+} in all the water samples is below WHO limit of 3.00 mg/L and 2.00 mg/L respectively. None of the water samples in the Agona district have Mn^{2+} concentrations above the WHO permissible limit for portable water of 0.500 mg/L.

All the groundwater samples had their Fe^{2+} concentration greater than the WHO guideline maximum value of 0.300 mg/l in drinking water except one borehole at Esselkwa which had a value of 0.156 mg/L. None of the water samples have Cd^{2+} concentration above the WHO maximum acceptable limit of 0.003 mg/L for drinking water.

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