academicJournals

Vol. 5(4), pp. 106-112, April, 2013
DOI: 10.5897/JECE2012.0260
ISSN 2141-226X © 2013 Academic Journals
http://www.academicjournals.org/JECE

Journal of Environmental Chemistry and Ecotoxicology

Full Length Research Paper

Non-cancer human health risk assessment from exposure to Cadmium, Copper, Lead and Mercury in surface water and ground water in Konongo-Odumasi Municipality, Ghana

Lawrence Ofosu-Asiedu[1], Samuel Jerry Cobbina[1] and Samuel Obiri[2]

[1]Department of Ecotourism and Environmental Management, Faculty of Renewable Natural Resources, University for Development Studies, P. O. Box TL 1882, Nyankpala, Ghana.
[2]Environmental Chemistry Division, CSIR Water Research Institute, P. O. Box M32, Accra, Ghana.

Accepted 25 February, 2013

A wide range of water quality parameters were measured from different water sources in the Konongo Odumasi Municipality. Physicochemical parameters were within the World Health Organization's recommended limits for drinking water except turbidity. Values ranged from 66.4 to 360 mg/L; 111.1 to 603 µS/cm; 7.02 to 8.04; 4.4 to 40.2 mg/L; 1.25 to 7.07 mg/L and 4.5 to 370 NTU for total dissolve solids, conductivity, pH, sulfate, nitrate and turbidity respectively. Non-cancer human health risk assessment from exposure to Cd, Cu, Pb and Hg by resident children and adults from different water sources were also measured in accordance with the United States Environmental Protection Agency's Human Health Risk Assessment guidelines. Cd ranged from 0.03 to 0.06 mg/L, Cu (0.02 to 3.5 mg/L), Pb (0.27 to 0.4 mg/L) and Hg (0.01 to 0.03 mg/L). Generally groundwater in the study area recorded hazard quotient (HQ) greater than 1. This implies that resident children and adults were at risk to non-cancer health diseases from consumption of groundwater. Hazard quotients (HQs) for surface water were however lower than 1, indicating low non-cancer human health risk.

Key words: Non-cancerous, risk assessment, Cadmium, Copper, Lead, Mercury, surface water, ground water, small scale mining, Konongo-Odumasi, Ghana.

INTRODUCTION

The study of hydrology is an increasingly important one. Freshwater is a valuable resource but regardless of its quantity, it is not always available when or where it is needed (Garrett, 2003). As the world's population and standard of living increases, the demand for water will continue to rise. Water, like air is one of the most important natural resources of man, without which life cannot exist. Besides, domestic, agricultural and industrial uses, water sources have been used for fishing, navigation, recreation and many other vital services.

Mining activities can generate large amounts of highly soluble inorganic matter, some of which are considered toxic to life and the environment as a whole (Ramani, 2001). Generation of chemical waste as a result of mining activities occurs world-wide and may severely affect natural resources such as vegetation, streams and the ecosystem in general (Ramani, 2001). Ghana is an important gold-producing country with mining operations

*Corresponding author. E-mail: abeultimate27@yahoo.com.

dating back to the 19th century. It produces about one third of the world's yearly gold production (Griffis et al., 2002). After the extraction of precious metals from ores, varying amounts of other undesirable inorganic elements such as Arsenic, Copper, Lead, Zinc, Iron, Sulphate, Cyanide, Mercury and Magnesium are usually passed into tailings (Cunninghan, 1995). These metals are released and end up contaminating the environment. Water resources which are intended to provide relief and comfort for humans and animals are contaminated. According to Obiri (2007), surface water in most mining communities in Ghana has become unfit for human consumption due to chemical contamination from gold mining and processing activities.

In the Konongo-Odumasi municipality, pipe-borne water and boreholes have been provided to deter people from drinking directly from surface water bodies. Though the community has been provided with portable drinking water, these facilities are inadequate due to increase in population. Residents are known to rely on untreated surface water and questionable groundwater sources. Ground water in most mining communities is known to be contaminated due to the chemical nature of the aquifer host rock in these areas (Amasa, 1996; Amonoo-Neizer and Amekor, 1993; Smedley, 1996; Obiri, 2007).

This study thus seeks to assess the non-cancer human health risk as a result of consumption of water from these untreated water sources. The main aim of this study is to:

(i) Assess the non-cancer human health risks associated with exposure to Cd, Cu, Pb and Hg in surface and ground water in the study area,
(ii) Evaluate the human health risk associated with ingestion of Cd, Cu, Pb and Hg in surface and ground water,
(iii) Recommend to the Municipal assembly and other stakeholders various ways of reducing non- cancer human health risk associated with ingestion of Cd, Cu, Pb and Hg in surface and ground water.

MATERIALS AND METHODS

Study area

The Asante Akim North Municipal assembly is one of the 27 Districts in the Ashanti Region. It was carved out of the erstwhile Asante Akim District Council in 1988 as part of Ghana's decentralization process. It has Konongo-Odumasi as its twin Capital Town. The Municipality is located in the eastern part of Ashanti Region and lies between latitude 6° 30' North and 7° 30' North and longitude 0° 15' West and 1° 20' West. It covers a land area of 1,160 sq. km with an estimated population of 169,976 (GSS, 2012). The Municipality shares boundaries with Sekyere East in the North, Kwahu South in the East, Asante Akim South in the South and Ejisu-Juaben in the West (Asante Akim North Municipal Assembly, 2011).

Description of sampling sites in the study area

Apebooso (L1) was the site of River Owere chosen as downstream, Italy (L2) was the site chosen as midstream, Zongo (L3) was a shallow well in the study area, Islamic (L4) was a deep dug – out well, Lowcost (L5) was a borehole and Owereso (L6) was upstream of River Owere.

Sampling techniques and sampling collection

Random sampling techniques were used in collecting water samples from different points for laboratory analyses. Water samples were collected from upstream, midstream and downstream sections of the Owere River. Water samples were also collected from some streams, wells and mine pits in the study area. Water samples were collected into 1.5 L plastic bottles which had been rinsed thoroughly with nitric acid and double distilled water. Samples for trace metal analyses were put into 250 ml plastic bottles and 2 ml concentrated nitric acid added to it. Thirty six samples were collected from November, 2011 to April, 2012. Samples were stored in an ice-chest at a temperature of 4°C and transported to the laboratory for analyses.

Analyses of Cadmium, Copper, Lead and Mercury

100 ml of the acidified sample was mixed with 5 ml concentration H_2SO_4 and 2.5 ml concentrated HNO_3. The mixture was heated until the volume was reduced to about 15 to 20 ml on a hot plate. The digested samples were allowed to cool to room temperature and then filtered through a 0.45 µm Whatman filter paper. The final volume was adjusted to 100 ml with double – distilled water and stored for analysis (USEPA, 1991; APHA, 1998). The concentrations of Cd, Cu and Pb were determined using flame Atomic Absorption Spectrophotometer (AAS) Shimadzu model AA 6300. For the analysis of Hg, 5 ml of concentrated H_2SO_4 and 2.5 ml of concentrated HNO_3 were added to 100 ml of water samples and thoroughly shaken to get a homogeneous mixture. 15 ml of 5% (w/w) of $KMnO_4$ and 8 ml of 5% (w/w) potassium persulphate were added to the mixture and heated at 95°C for 2 h. The mixture was then allowed to cool to room temperature and 6 ml of 12% (w/w) hydroxylamine hydrochloride were added to the resulting solution to reduce the excess permanganate. The digested solution was stored for analysis (APHA, 1998). In the Hg determination, a carrier solution containing 3% (v/v) HCl and a reducing agent 1.1% (m/v) $SnCl_2$ in 3% (v/v) HCl was added to digest sample to generate Hg vapour which was determined by cold vapour using a Shimadzu model AA 6300.

Human health risk assessment

This is defined as the process of estimating and quantifying the probability that an event will occur and the probable magnitude of its adverse effects with a given exposure over a specified period. It is also a process of estimating the health effects that might result from exposure to carcinogenic and non – carcinogenic chemicals (Asante-Duah, 1996; Obiri et al., 2010a; USEPA, 2001a, b). The risk assessment process as proposed by the US Environmental Protection Agency, consist of four basic steps namely: 1) Hazard identification, 2) Exposure assessment, 3) Dose response/ toxicity assessment and 4) Risk characterization.

Hazard identification

This defines the hazard and nature of the harm. For example, identifying a chemical contaminant (Pb, Hg, pesticide etc) and documenting its toxic effects on human beings. It also involves the characterization of potential contaminants and their relative mobilities (Obiri et al., 2010a; Artiola et al., 2004). A toxicant like Cadmium may cause lung damage, kidney diseases, weaker bones, stomach irritation, vomiting and diarrhea (Obiri et al., 2010b). Long term exposure to Copper may lead to irritation of the nose, mouth and eyes. The intake of Mercury can lead to sensory impairment, disturbed sensation and a lack of coordination (Clifton, 2007).

Lead is a poisonous metal that can damage nervous connections (especially in young children) and cause blood and brain disorders (Agency for Toxic Substances and Disease Registry/Division of Toxicology and Environmental Medicine, 2006). In pregnant women, high levels of exposure to Lead may cause miscarriage. Chronic, high-level exposures have been shown to reduce fertility in males (Golub, 2005). High levels of lead in blood are associated with delayed puberty in girls because this might suppress the ovary's production of hormones that prepare a young girl's body to ovulate, or release an egg, for the first time (Schoeters et al., 2008). Lead has been shown many times to permanently reduce the cognitive capacity of children at extremely low levels of exposure (Needleman et al., 1990).

Exposure assessment

This is the process of measuring or estimating the intensity, frequency, and duration of human exposures to an environmental agent (USEPA, 2001a, 1997, 1989). It also helps in estimating the rate of intake of a contaminant by the target organism.

In this study, non-cancer human health risk associated with oral and dermal exposure to Cd, Cu, Pb and Hg in ground and surface water were determined. The exposure scenario evaluated was a residential setting. In this scenario, ingestion and dermal contact of ground and surface water in the study area by resident children and adults were evaluated based on both central tendency exposure (CTE) and reasonable maximum exposure (RME) parameters respectively. CTE parameters were used so that health risk associated with typical constituents of concern can be calculated. RME parameters were also used so that health risk associated with high-end exposures can be calculated.

The potential receptors evaluated in this study are resident children and adults aged between 2 to19 years and 20 to 80 years respectively. The intake of Cd, Cu, Pb and Hg from ingestion of surface and ground water in the study area were calculated using the formula:

$$\text{Intake (mg/kg/day)} = (EPC \times IR \times EF \times ED \times 10^{-6}) / (BW \times AT) \quad (1)$$

Where, EPC (mg/L) is exposure point concentration for Cd, Cu, Pb and Hg, IR (mg/day) is ingestion rate of water samples, EF (day-equivalent/year) is exposure frequency, ED (year) is exposure duration, BW is body weight (kg) and AT is averaging time (day). The intake of Cd, Cu, Pb and Hg from dermal contact with surface and ground water in the study area by resident children and adults were calculated using the formula:

$$\text{Intake (mg/kg/day)} = (EPC \times Kp \times SA \times EF \times ED \times 10^{-6}) / (BW \times AT) \quad (2)$$

Where, Kp is the skin permeability constant, SA is the skin surface area exposed to Cd, Cu, Pb and Hg in water samples. The other terms in Equation (2) have the same meanings described in Equation (1).

Dose-response / toxicity assessment

This is a quantitative relationship that indicates a contaminants degree of toxicity to exposed species. It also involves the identification of the toxicity criteria used to evaluate human health risk associated with the chemical of concern in the study area.

Risk characterization

This is the final phase of the risk assessment process. In this phase *exposure* and *dose–response* assessments are integrated to yield probabilities of effects occurring in human beings under specific exposure conditions. It can also be the incorporation of information from hazard identification, exposure assessment, toxicity assessment and risk estimation to evaluate the potential risk residents of the study area are exposed to. This study followed the USEPA risk assessment guidance to evaluate the potential non-cancerous health risk of resident children and adults in the study area from exposure to Cd, Cu, Pb and Hg in drinking water (USEPA, 2008). The non-carcinogenic health risk in this study refers to harm done to the central nervous system due to exposure to neurotoxic chemical, and other toxic end-points such as skin hyper pigmentation, mild tremor, respiratory tract infections, sensory impairment etc. The extent of harm sustained is expressed in terms of hazard quotient as shown in Equation (3):

$$\text{Hazard quotient (HQ)} = ADD / RfD \quad (3)$$

Where ADD is the average daily dose that a resident child or adult is exposed to via drinking water containing Cd, Cu, Pb and Hg. RfD is the reference dose which is the daily dosage that enable the exposed individual to sustain this level of exposure over a long period of time without experiencing any harmful effects. The oral reference doses (RfD_{oral}) for respective toxicants were used.

RESULTS AND DISCUSSION

Physicochemical parameters

Total dissolved solids (TDS) in water samples from Konongo Odumasi ranged from 66.4-360 mg/L (Table 1). The levels of TDS measured were within the World Health Organization (WHO) guidelines for drinking water quality. According to WHO (2008), no health risk limit exist for TDS in drinking water. However, water with TDS level below 500 mg/L is considered to be good. TDS greater than 1200 mg/L may be objectionable to the consumer, since it depicts high mineralization of the water body.

Electrical conductivity of the samples was in the range of 111 to 603 µS/cm. Electrical conductivity (EC) is a measure of water's ability to conduct electricity. This is

Table 1. Results of physico-chemical analyses of water samples from Konongo-Odumasi.

Parameter	Min	Max	Mean	SD	WHO
TDS	66.4	360	179.33	105.5	1000
EC (µS/cm)	111.1	603	300.44	176.61	1500
pH	7.02	8.04	7.46	0.38	6.5 - 8.5
Turbidity (NTU)	4.5	370	131.75	147.3	5
SO_4	4.4	40.2	21.55	15.35	400
NO_3	1.25	7.07	3.67	2.49	10

All units are in mg/L unless otherwise stated.

Table 2. Descriptive statistical analysis on concentration (mg/l) of Cd, Cu, Pb and Hg.

Parameter	Min	Max	Mean	SD	WHO
Cadmium	0.002	0.078	0.05	0.02	0.003
Copper	0.014	0.172	0.07	0.01	2
Lead	0.27	0.37	0.33	0.01	0.5
Mercury	0.002	0.066	0.02	0.01	0.01

usually as a result of the presence of dissolved minerals in the water. Electrical conductivity does not give an indication of which element is present but it indicates the presence of minerals. High EC is an indication of the presence of contaminants such as sodium, potassium, chloride and sulfate (Orebiyi et al., 2010). The pH of the samples ranged between 7.02 to 8.04. All samples analyzed were within WHO's admissible limit (6.5 to 8.5) for drinking water quality.

Turbidity indicates measure of cloudiness of water and the ability of the sample to reflect light. It has no health effects. However, it can interfere with disinfection and provide a medium for microbial growth. The level of turbidity in water samples from Konongo-Odumasi ranged from 4.5 to 370 NTU. The mean level of turbidity in all sampling points exceeded the maximum admissible limit for drinking water quality set by World Health Organization (WHO). High turbidity in surface water could be caused by run-offs made possible by disturbance of the soils in the mining zones and waste water from the extraction of gold. High turbidity could be as a result of inorganic particulate matter from the weathering of rocks. Mean concentration of each toxicant during the study period are presented in Table 2. Generally, the levels of Cd and Hg in water bodies sampled during the study period were above the recommended WHO standard of 0.003 and 0.01 mg/L respectively (Table 2). The levels of Cu and Pb were within the WHO limit of 2.0 and 0.5 mg/L, respectively.

Mean Cadmium concentration measured was lowest at sampling point L4 (0.03 mg/L) and highest at L5 (0.06 mg/L) and L6 (0.06 mg/L) as shown in Table 3. Mean mercury concentration was lowest at sampling sites L2, L3, L4 and L6 (0.01 mg/L) and highest at sites L1 and L5 (0.03 mg/L). High levels of Cd may be as a result of leaching of mined rocks and ore stockpiles heaped close to these water sources. The continuous use of water from these sources by residents could lead to health problems such as lung damage, kidney diseases, weaker bones, stomach irritation, vomiting and diarrhea. High levels of mercury recorded at sites L1 and L5 may be as a result of the use of mercury by the small-scale miners in extracting gold. Water from the river is used extensively during the processing of gold by the small scale miners. Mean copper concentration recorded at the study area was lowest at L6 (0.02 mg/L) and highest at L4 (3.5 mg/L). Mean lead concentration was highest at L4 (0.4 mg/L) and lowest at L5 (0.27 mg/L) (Table 3).

Non-cancer human health risk assessment

Generally hazard quotients estimated for exposures to the toxicants in this study were lower than 1, implying low risk to non-cancer diseases (Tables 4 and 5). However, Hazard quotients (HQs) for the Zongo (L3) and Islamic (L4) sites recorded, were higher than 1 for exposures to Cd, Cu, Pb and Hg. At the Zongo (L3) site HQs of 2.6 was recorded for Cd through CTE and 5.2 through RME. For Hg a HQ of 1.2 was recorded for RME but 0.62 was recorded through CTE. For the Islamic (L4) site HQs recorded through CTE for Cd, Cu, Pb and Hg were 2.5,

Table 3. Mean concentration (mg/L) of toxicants at each sampling point in the study area.

Sample location	Cd	Cu	Pb	Hg
L1	0.04	0.1	0.37	0.03
L2	0.04	0.1	0.37	0.01
L3	0.04	0.09	0.37	0.01
L4	0.03	3.5	0.4	0.01
L5	0.06	0.03	0.27	0.03
L6	0.06	0.02	0.31	0.01
WHO limit	0.003	2	0.5	0.01

NB: All units are in mg/L unless otherwise stated, L1: Apebooso – Downstream, L2: Italy – Midstream, L3: Zongo – Shallow well, L4: Islamic – Deep dug-out well, L5: Lowcost – Borehole, L6: Owereso – Upstream.

Table 4. Hazard quotient of resident child from exposure to toxicants in water samples from the study area.

Parameter	Child (CTE)		Child (RME)	
Apebooso (L1)	**INGESTION**	**DERMAL**	**INGESTION**	**DERMAL**
Cadmium	0.009	0.0013	0.07	0.01
Copper	0.000066	0.000045	0.0024	0.00035
Lead	0.0024	0	0.088	0
Mercury	0.00099	0.0011	0.036	0.0088
Italy (L2)				
Cadmium	0.009	0.0013	0.07	0.01
Copper	0.000066	0.000045	0.0024	0.00035
Lead	0.0024	0	0.088	0
Mercury	0.00099	0.0011	0.036	0.0088
Zongo (L3)				
Cadmium	2.6	0.0043	5.2	0.0076
Copper	0.079	0.00013	0.16	0.00023
Lead	0.33	0	0.66	0
Mercury	0.62	0.0017	1.2	0.0031
Islamic (L4)				
Cadmium	2.5	0.004	4.9	0.0071
Copper	3	0.0049	6	0.0088
Lead	3.6	0	7	0
Mercury	1.3	0.0036	2.6	0.0064
Lowcost (L5)				
Cadmium	0.0027	0.0018	0.097	0.014
Copper	0.000016	0.000011	0.00058	0.000084
Lead	0.0018	0	0.064	0
Mercury	0.002	0.0023	0.072	0.018
Owereso (L6)				
Cadmium	0.0026	0.0018	0.095	0.014
Copper	0.000012	8.3E-06	0.00044	0.000064
Lead	0.002	0	0.074	0
Mercury	0.00083	0.00095	0.03	0.0074

Table 5. Hazard Index of resident adults from exposure to toxicants in water samples from the study area.

Parameter	Adult (CTE)		Adult (RME)	
Apebooso (L1)	**INGESTION**	**DERMAL**	**INGESTION**	**DERMAL**
Cadmium	0.0017	0.0031	0.015	0.0069
Copper	0.000057	0.0001	0.00051	0.00023
Lead	0.0021	0	0.019	0
Mercury	0.00085	0.0027	0.0076	0.006
Italy (L2)				
Cadmium	0.0017	0.0031	0.015	0.0069
Copper	0.000057	0.0001	0.00051	0.00023
Lead	0.0021	0	0.019	0
Mercury	0.00085	0.0027	0.0076	0.006
Zongo (L3)				
Cadmium	1.2	0.0025	2.2	0.0052
Copper	0.037	0.000074	0.067	0.00015
Lead	0.15	0	0.28	0
Mercury	0.29	0.001	0.53	0.0021
Islamic (L4)				
Cadmium	1.2	0.0023	2.1	0.0048
Copper	1.4	0.0029	2.6	0.006
Lead	1.7	0	3	0
Mercury	1.1	0.0021	6.1	0.0043
Lowcost (L5)				
Cadmium	0.0023	0.0042	0.021	0.0095
Copper	0.000014	0.000025	0.00012	0.000057
Lead	0.0015	0	0.014	0
Mercury	0.0017	0.0054	0.016	0.012
Owereso (L6)				
Cadmium	0.0023	0.0042	0.02	0.0094
Copper	0.00001	0.000019	0.000094	0.000043
Lead	0.0018	0	0.016	0
Mercury	0.00071	0.0022	0.0064	0.005

3.0, 3.6 and 1.3, respectively (Table 3). That recorded through RME were Cd (4.9), Cu (6.0), Pb (7.0) and Hg (2.6). It was observed that exposures that recorded HQs higher than 1 were through the ingestion route, while dermal contact recorded HQs lower than 1 (Table 3). This implies that resident children at site L3 and L4 may be at risk from direct ingestion of water from these two water points than through dermal contact.

For resident adults HQ as a result of exposures to Cd at the Zongo (L3) site through CTE was 1.2 and 2.2 through RME. Hazard quotients of 1.2, 1.4, 1.7 and 1.1 were recorded for Cd, Cu, Pb and Hg respectively at the Islamic (L4) site through CTE. However, through REM, Cd (2.1), Cu (2.6), Pb (3.0) and Hg (6.1) were recorded for the same sampling site (Table 5). Generally, higher HQs were recorded for resident children compared to that recorded to resident adults (Tables 4 and 5). These observations are significant judging from the fact that children have low body weights coupled with the fact that most of their organs responsible for detoxifying toxic chemicals are not well developed. Hence, they stand high risk of showing symptoms of non-cancer related diseases. Such results compare well with work done by Cobbina et al. (2012) and Obiri et al. (2010a).

Conclusion

The study evaluated the non-cancer health risk associated with resident children and adults in the study area to; Cd, Cu, Pb and Hg. Generally, resident children and adults are at high risk from exposure to Cd, Cu, Pb, and Hg in groundwater through ingestion. From the study conducted by Obiri et al. (2010b), human health risk from exposure to toxic chemicals such as Hg, Cd and Pb are as a result of the mining activities. This was in line with the situation at Konongo-Odumasi Municipality. Resident children are at risk of contracting non-cancerous diseases such as asthma, low intelligent quotients, mild tremor, diabetes, among others as a result of ingestion of water from sites at Zongo (L3) and Islamic (L4). Although, a study conducted by Afrikids, attributes high school dropout rate in some mining areas to the desire of children to work as small-scale miners to get quick money (Hilson, 2010), there may be a relationship between exposure to these toxicants and their IQs. The level of risks associated with resident adults was lower compared to that of resident children studied, which may be as a result of the difference in body weight. Due to the dangers associated with the exposure to these toxicants, the Government through the Municipal Assembly should help in the provision of more portable water facilities so as to discourage inhabitants from patronizing these contaminated water points.

ACKNOWLEGEMENT

The team is grateful to Michael Kumi, Millicent Adu-Boakye, Zita Naangmeneyele and Latif Abdul Latif of the Water Quality Laboratory of the CSIR Water Research Institute for analyses of the samples.

REFERENCES

Agency for Toxic Substances and Disease Registry/Division of Toxicology and Environmental Medicine (2006). ToxFAQs: CABS/Chemical Agent Briefing Sheet: Lead.

Amasa SK (1996). Arsenic pollution at Obuasi gold mine, Town and surrounding countryside. Environ. Health Perspect. 12:131-135.

American Public Health Association (APHA) (1998). Standards methods for the examination of waste water. APHA–AWWA–WEF, 20th Ed. Washington DC. pp. 320-330.

Amonoo-Neizer EH, Amekor EMK (1993). Determination of total arsenic in environmental samples from Kumasi and Obuasi, Ghana. Environ. Health Perspect. 101(1):46-49.

Artiola JF, Pepper IL, Brusseau ML (ed) (2004). Environmental Monitoring and Characterization, Academic Press, P. 410.

Asante Akim North Municipal Assembly (AANMA) (2011). Municipal Profile. 2011 Annual Report.

Asante-Duah DK (1996). Managing Contaminated Sites. Problem Diagnosis and Development of Site Restoration. John Wiley, West Sussex, UK. pp. 183-180.

Clifton JC (2007). Mercury exposure and public health. Pediatr. Clin. North Am. 54(2):273-269.

Cobbina SJ, Dagben JZ, Obiri S, Tom-Dery D (2012). Assessment of non- cancerous health risk from exposure to Hg, As and Cd by resident children and adults in Nangodi in the Upper East Region, Ghana. Water Qual. Expo. Health, 3:225-232. DOI 10.1007/s12403-012-0059-x.

Cunninghan WP (1995). Environmental Science, a global concern. Wm.C. Brown Publishers of Wm.C. Brown communications inc. USA. pp. 343-344.

Garrett N (2003). Access to Geography. Rivers and water management. P. 1.

Ghana Statistical Service- GSS (2012). 2010 Housing and Population Cencus: Summary Report of Final Report, GSS, Accra. P. 120.

Golub MS ed (2005). “Summary” Metals, fertility and reproductive toxicity, CRC press, Taylor and Francis Group P. 153.

Griffis RJ, Barning K, Agezo FL, Akosah FK (2002). Gold Deposits of Ghana. Mineral Commission of Ghana, Accra. P. 9.

Hilson G (2010). Child Labour in African artisanal mining communities. Experiences from Northern Ghana. Dev Change 41(3):445-473.

Needleman HL, Schell A, Bellinger D, Leviton A, Allred EN (1990). The long term effects of exposure to low dose of lead in childhood, an 11 –year follow up report. N. England J. Med. 322(2):83-88.

Obiri S (2007). Determination of heavy metal in water from boreholes in Dumasi in the Wassa West District of Western Region of Republic of Ghana. Environ. Monit. Assess. 130:455-463.

Obiri S, Asante E, Nyieku FE, Armah FA (2010b). Human Health Risk Assessment and Epidermiological Studies from exposure to toxic chemicals in the Tarkwa – Nsuem municipality, Prestea Huni Valley District and Cape Coast Metropolis, Ghana. Center for Environmental Impact Analysis (CEIA) Reoprt. pp.13-16.

Obiri S, Dodoo DK, Essumang DK, Armah FA (2010a). Cancer and noncancer risk assessment from exposure to arsenic, copper, and cadmium in borehole, tap, and surface water in the Obuasi Municipality, Ghana. Hum. Ecol. Risk Assess. 16(3):651-665.

Orebiyi EO, Awomeso JA, Idowu OA, Martins O, Oguntoke, Taiwo AM (2010). Assessment of Pollution hazards of shallow well water in Aeokuta and its environs, Southeast, Nigeria. Am. J. Environ. Sci. 6(1):50-56.

Ramani RV (2001). Environmental Planning in the Mining Industry - Progress and Prospects. IMM 41:5-9.

Schoeters G, Den HE, Dhooge, W, Van LN, Leijs M (2008). Endocrine Disruptors and Abnormalities of Pubertal Development. Basic Clin. Pharmacol. Toxicol. 102(2):168-175.

Smedley PL (1996). Arsenic in rural ground water in Ghana. J. Afr. Earth Sci. 22(4):459-470.

United States Environmental Protection Agency (1989). Risk Assessment Guidance for Superfund. (RAGS), Vol. 1, Human Health Evaluation Manual (Part A). OWSER Directive 9285. 7-01A. EPA-540/1-89-002. Office of Emergency and Remedial Response,Washington, DC, USA.

United States Environmental Protection Agency (1991). Methods of determination of metals in environmental samples. Office of research and development. Cincinnati, Ohio.

United States Environmental Protection Agency (1997). Exposure Factor Handbook, NCEA-W-005. 1995.107. USEPA: Exposure Factors Handbook, Vol. I: General Factors. Office of Research and Development, Washington, DC, USA.

United States Environmental Protection Agency (2001). Integrated risk information system (IRIS). National Centre for Environmental Assessment, Office of Research and Development, Washington.

United States Environmental Protection Agency (2001a). Derivation of Acute and Subchronic Oral RfD Doses for Inorganic Arsenic. USEPA Region 8, Kansas City, KS, USA.

United States Environmental Protection Agency (2001b). Integrated Risk Information System (IRIS). National Centre for Environmental Assessment, Office of Research and Development, Washington, DC, USA.

United States Environmental Protection Agency (2008). Child-specific exposure factors handbook. General Factors, Office of Research and Development, Washington.

World Health Organisation (2008). Guidelines for drinking water quality, World Health Organization, Geneva.