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Full Length Research Paper

Non-cancer risk assessment from exposure to mercury (Hg), cadmium (Cd), arsenic (As), copper (Cu) and lead (Pb) in boreholes and surface water in Tinga, in the Bole-Bamboi District, Ghana

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The study assessed non-cancer human health risk from exposure to mecury (Hg), cadmium (Cd), arsenic (As), copper (Cu), and lead (Pb) in surface and groundwater in Tinga, in the Bole-Bamboi District. A total of 42 water samples were collected for a period of six months. Mean concentration of Hg, Cd, and Pb were found to be (0.050 ± 0.04 mg/L), (0.031 ± 0.02 mg/L) and (0.07 ± 0.05 mg/L), respectively. These were all above the World Health Organization (WHO) recommended guideline values for drinking water. Non-cancer human health risk as a result of exposure to Hg and Cd through ingestion of borehole water was found to be high. Hazard quotients (HQ) as a result of exposure to mercury for adults and children ranged from 2.5 to 30 through central tendency exposure (CTE) and 4.6 to 60 through reasonable maximum exposure (RME). For Cd, CTE ranged from 0.96 to 2.7 and RME ranged from 1.8 to 5.4. The HQ for exposure to Hg and Cd through ingestion of ground water exceeded the acceptable United States Environmental Protection Agency (USEPA) value of 1.0. This implies that resident children and adults are likely to develop diseases (such as low intelligent quotient, tremor, kidney failure, increased hypertension and cardiovascular diseases) associated with long term exposure to Hg and Cd.

Key words: Small-scale mining, Tinga, non-cancer, health risk, hazard quotient, borehole, surface water.

INTRODUCTION

Water is necessary for most life on earth. Humans can survive for several weeks without food, but for only a few days without water.

Water has always been an important and life-sustaining drink to humans. Although water forms a major part of the earth surface, much of it is not available to humans in a form that can readily be used, as a source of drinking water or for other purposes (Bartram and Balance, 2001; Spellman and Drinan, 2000; Price, 1998). In many parts of the world, humans have inadequate access to potable water and use sources contaminated with dissolved heavy metals and other chemicals or suspended solids. Such water is not potable and drinking or using such water in food preparation leads to widespread acute and chronic illnesses, and this is a major cause of death in many countries. Today, virtually every country faces severe and growing challenges in their efforts to meet the rapidly escalating demand for water that is driven by burgeoning populations (Ashton et al., 2001; Gleick,

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1998). Mining is one of the main economic activities done in Ghana since colonial times. Gold is the largest contributor to the economy, accounting for about 38% of total merchandise and 95% of total mineral exports (Aryee, 2001). Gold mining is basically made up of large and small-scale mining. Large scale mining is usually more organized and done with advanced technology to help minimize pollution of the environment. Small-scale mining, however, is largely poverty-driven and practiced mainly in remote and poor rural communities. Miners usually lack modern equipment and technology and they have little financial backing. They however, have the requisite permits that allow them to operate. Small-scale mining serves as a ready source of employment for thousands of indigenous people and also an important source of foreign exchange (Donkor et al., 2006; Amankwah and Anim-Sackey, 2003; Hilson, 2001). Despite its importance to economic development, small-scale mining pose serious environmental challenges, the most widespread being land degradation, subsidence and water pollution leading to ill health (Manaf, 1999; Hilson, 2002; Akabzaa et al., 2005).

During the mining process, ore is processed to remove valuable materials on-site, in a process called milling. Waste from the milling or other processing is usually called "tailings", which is most frequently a liquid or slurry material. These tailings are often known to be contaminated with toxic metals, and may continually produce sulfuric acid as they degrade. Exposed mine rocks release heavy metals from the bed-rock into the environment (Lei et al., 2010; Lim et al., 2009). The waste rocks are known to contain arsenic (As), mercury (Hg), cadmium (Cd), lead (Pb) and other toxic metals (Chapman, 1996; Donato et al., 2007). Most of these chemicals are released into nearby water bodies which result in surface water pollution. When the leaked chemicals slowly percolate through the layers of the earth, they reach groundwater and pollute it. Mining operations may affect drinking water, especially in the rural areas that are largely dependent on hand-dug wells, boreholes or surface water. Many researchers have indicated that the presence of heavy metals in surface and groundwater cause serious health problems (Obiri et al., 2010; Koger et al., 2005; Weiss, 2000; Porterfield, 2000; Myers and Davidson, 2000).

In Ghana, the presence of Hg and other heavy metals in the environment may be attributed to the use of Hg in gold recovery processes as well as leachate from exposed mined waste rocks, where the inorganic form of the metal either is washed into rivers or is vaporized readily into the atmosphere (Obiri, 2005). Hg is toxic to the central and peripheral nervous system. Health problems associated with Hg include personality changes, deafness, changes in vision, loss of muscle coordination or tremors, loss of sensation and memory Hg can be passed from pregnant mothers to unborn children and also to babies through breast feeding (Obiri et al., 2010; Agency for Toxic Substances and Disease Registry (ATSDR), 1999).

Besides Hg, other harmful chemicals are known to leach into the environment through mining and are deleterious to humans. Ingestion of elevated levels of Cd results in kidney and skeletal system toxicity, increased hypertension and cardiovascular diseases. As is neurotoxic and may also cause skin pigmentation such as hyperkerotosis, melanosis, blackfoot disease and reproductive problems. High intake of Cu may cause liver and kidney damage and even death. Pb is toxic to both the central and peripheral nervous system, inducing neurological and behavioral effects. Pb is a general toxicant that accumulates in the skeleton as well. Infants, children up to six (6) years of age and pregnant women are most susceptible to its adverse effects (Obiri et al., 2010; Centeno et al., 2002; ATSDR, 2007).

Tinga is one of the few areas in the northern part of Ghana where small-scale mining is done. Mining of gold is done in Kue from where gold-bearing ores are transported to Tinga for crushing, milling and gold extracted with Hg after the formation of an amalgam. Roasting is done to concentrate the gold extracted. These activities readily make available toxic chemicals like Hg from the extraction process, Cd, As, Cu and Pb leached from heaped mined waste. This study therefore seeks to: (1) assess levels of these toxicants in surface and groundwater in the study area and; (2) evaluate the non-cancer human health risk associated with exposure to these toxicants through ingestion and dermal contact of water in the study area.

MATERIALS AND METHODS

Study area

Tinga is located in the Bole-Bamboi district (Figure 1) of Northern Region, Ghana within the Guinea Savannah Agro-ecological zone. It is located at N 8° 35' 59" and W -2° 13' 0". Tinga is located at the extreme western part of the Northern Region of Ghana. The main types of rocks which underline the community are predominantly granite and metamorphic rocks (Kesse, 1985).

Sampling technique

Water samples were collected from the only stream in the community which is also used for the washing of gold-bearing ores. Four boreholes which serve as a source of drinking water for the community were selected for sampling. Sampling was done on monthly basis for a period of six months (October, 2011 to April, 2012). All vessels used for the collection of water samples were soaked in dilute acid and rinsed several times with distilled water. Groundwater from boreholes was allowed to flow for about seven minutes before samples were collected. Immediately before sample collection, sample bottles were rinsed several times with water to be sampled. A total of 7 samples were collected every month from surface and groundwater sources, 3 samples from the stream (labeled BWP-before washing point, WP-washing point and AWP-after washing point), and 4 from boreholes (labeled BH1, BH2, BH3 and BH4). A total of 42 samples were collected for analysis during the study period.

Sample collection, preparation and storage

Water samples were collected into plastic bottles that had been pre-washed with detergents and tap water, and later rinsed with 1:1 concentrated nitric acid and distilled water. Samples were acidified with 1 ml nitric acid for samples meant for heavy metal analysis. This treatment was used to minimize adsorption of metals on the container walls. The samples were stored in an ice-chest at a temperature of 4°C and later conveyed to the laboratory for analysis. Samples were stored in the refrigerator at 4°C upon arrival at the laboratory for further analysis (United States Environmental Protection Agency (USEPA), 2004; American Public Health Association (APHA), 1998).

Digestion of samples for the analyses of Cd, Cu, As and Pb

One hundred (100) ml of acidified water sample was mixed with 5 ml concentrated trioxonitrate (V) acid (HNO_3) and 5 ml concentrated tetraoxosulphate (VI) acid (H_2SO_4). To allow the acids to become concentrated, the mixture was heated until the volume was reduced to about 15 to 20 ml. The digested sample was allowed to cool to room temperature. It was then filtered through Whitman's 0.45 µm filter paper. The final volume was adjusted to 100 ml with double distilled water and stored for analysis (APHA, 1998).

Digestion of samples for the analyses of mercury (Hg)

One hundred (100) ml water sample was transferred into a 150 ml beaker, and 5 ml of concentrated sulphuric acid added. A 2.5 ml volume of concentrated nitric acid was added and mixed thoroughly after each addition. A 15 ml volume of 5% w/w potassium permanganate was added to the mixture. The solution was shaken and additional portions of potassium permanganate added until the purple colour persisted for at least 15 min. About 8 ml of 5% w/w potassium persulphate was then added and the solution heated for 2 h on a water bath at 95°C. It was cooled and 6 ml of 12% w/v hydroxylamine hydrochloride added to the resulting solution to reduce the excess permanganate. The digested solution was then stored for analysis (American Water Works Association (AWWA), 1998).

Water quality analyses

The analyses of water samples in this work were based on standard methods for analysis of heavy metals adopted by the US Environmental Protection Agency and American Water Works Association (APHA, 1998). Concentrations of Cd, Cu and Pb were determined using an Atomic absorption spectrophotometer (AAS), Shimadzu AA 6300, after double distilled water has been used to zero the instrument. Initially, concentrations of Cd, Cu and Pb in blank were measured, followed by the determination of concentrations of Cd, Cu, and Pb in the digested samples. The concentration of As in water samples were determined using an AAS coupled with an arsine gas generator. In the determination of As concentrations in water samples, 5 ml of 0.5% sodium borohydride (a reducing agent) and 5 ml of 0.5 M hydrochloric (HCl) acid were added to each of the digested sample to convert arsenic in samples to an arsine gas, in the arsine generator, which was coupled to the AAS.

Analyses of water samples for mercury (Hg)

Double distilled water was first used to zero the AAS, concentration of mercury in the blank was determined as follows:

1. A carrier solution containing 3% v/v HCl and a reducing agent 1.1% m/v $SnCl_2$ in 3% v/v HCl were automatically sucked into a mixing chamber to reduce the mercury in the +2 state to its elemental state as the concentration of mercury in digested water samples were taken through the same process;
2. The mercury vapour generated was directed to the cold vapour cell mounted on the AAS, the mercury concentration in the blank was measured automatically.

Recovery and reproducibility studies were conducted during water quality analysis to check the sensitivity and efficiency of the method used in the chemical analysis. The percentage of Hg, Cd, Cu, As and Pb recovered in the recovery studies were 98, 93, 94, 100 and 95%, respectively. Similar results were recorded for the reproducibility studies. Statistical analysis was performed using Statistical package for social sciences (SPSS) version 16.0 software for Windows. The Pearson's rank correlation was used to examine correlation between trace metals; all tests were two tailed.

Health risk assessment process

This is the process of estimating the health effects that might result from exposure to carcinogenic and non-carcinogenic chemicals (Obiri et al., 2007; Artiola et al., 2004; USEPA, 2001). In this study, non-carcinogenic health risk refers to harm done to the central nervous and other adverse health effects (except cancer) due to exposure to neurotoxic chemicals such as Hg and Pb. The risk assessment process is made up of four iterative steps namely, hazard identification, exposure assessment, dose-response assessment and risk characterization (Obiri et al., 2006; USEPA, 2001; Asante-Duah, 1996).

Hazard Identification

Hazard identification basically defines the hazard and nature of the harm. This is the first step of the risk assessment process that was used to establish a link between the toxic chemicals identified and their health effects on residents in the study area (Obiri et al., 2010). In this study, Hg, Cd, As, Cu and Pb were identified as possible hazards that the community are confronted with as a result of the activities of small-scale miners.

Exposure assessment

Exposure assessment is the process of measuring or estimating the intensity, frequency, and duration of human exposures to an environmental agent. It also helps in estimating the rate of intake of a contaminant by the target organism. In the exposure assessment, the average daily dose (ADD) of Hg, Cd, As, Pb and Cu ingested from drinking of borehole and stream water in the study area was calculated using:

$$ADD = \frac{EPC \times IR \times ED \times EF \times 10^{-6}}{BW \times AT \times 365} \quad (1)$$

Where, EPC is exposure point concentration of toxicant in the drinking water (mg/L), IR is the ingestion rate per unit time (L/day), ED is the exposure duration (years), EF is the exposure frequency (days/year), BW is the body weight of receptor (kg) and AT is the averaging time (years) which is equal to the life expectancy of a resident Ghanaian. 365 is the conversion factor from year to days. The ADD is the quantity of Hg, Cd, As, Pb and Cu ingested per

Table 1. Mean concentration (mg/L) of trace metals in water in Tinga (number of samples= 42).

Parameter	Range	Mean	SD	WHO
Mercury	0.010-0.172	0.050	0.04	0.006
Cadmium	0.002-0.103	0.031	0.02	0.003
Arsenic	<0.001-0.003	0.0015	0.0007	0.01
Copper	0.030-0.143	0.0828	0.0305	2.0
Lead	<0.001-0.188	0.07	0.05	0.01

SD, Standard deviation.

kilogram of body weight per day (Obiri et al., 2010; Asante-Duah, 2002; Kollunu et al., 1996). With the exception of EPC and BW, the rest were default values in the Risk Integrated Software for Clean up (RISC 4.02) developed by the USEPA. Body weights of 13.5 and 58.6 kg were used for resident children and resident adults, respectively in line with Ghana Statistical Service (GSS, 2002). For dermal contact, average daily dose was calculated using the formula:

$$ADD = \frac{C_{max} \times SA \times AAF \times ET \times PC \times EF \times ED \times 10^{-3}}{LT \times BW \times \text{365 days/year}} cm^{-3} \quad (2)$$

Where, C_{max} is the maximum 7-year average concentration of chemical in drinking water (mg/L), SA is the total skin surface area (cm^3), AAF is the dermal-water chemical specific absorption adjustment factor (mg/mg), ET is the bath or shower duration (h/day), PC is the chemical specific skin permeability constant (cm/h), EF is the exposure frequency (events/years), ED is the exposure duration (years), LT is the lifetime = 70 years by definition and BW is the body weight.

Dose-response assessment

Dose-response assessment is basically the quantitative relationship that indicates a contaminants degree of toxicity to exposed species. In this study, oral reference dose values for Hg, As, Cd, Cu, and Pb from RISC 4.0 software were used in characterizing non-cancer health risk from exposure to the aforementioned toxic chemicals in the study area (USEPA, 2008).

Risk characterization

Risk characterization 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. In line with USEPA risk assessment guideline, the risk characterization process incorporated all the information gathered from hazard identification, exposure assessment and dose-response assessment to evaluate the potential non-cancerous health risk of resident children and adults in the study area from exposure to the toxicants in drinking water (USEPA, 2008). In this study, the extent of the harm incurred was expressed in terms of hazard quotient:

$$Hazard\ Quotient(HQ) = \frac{ADD}{RfD} \quad (3)$$

Where, ADD is the average daily dose a resident adult or child is exposed to via drinking water or dermal contact with water containing Hg and Cd. RfD is the reference dose which is the daily dosage that enables the exposed individual to sustain level of exposure over a prolonged time period without experiencing any harmful effect.

In this study, oral reference doses (RfD_{oral}) for the respective toxicants were used.

RESULTS AND DISCUSSION

Concentration of Hg, Cd, As, Cu and Pb

The mean concentration of Hg, Cd, As, Cu and Pb in both surface water and boreholes are presented in Table 1. Generally, mean concentration of Hg, Cd and Pb in water in the study area exceeded the WHO limits. Hg ranged from 0.01 to 0.17 mg/L with a mean of 0.050 ± 0.04 mg/L. Cd ranged from 0.002 to 0.103 mg/L with a mean of 0.031 ± 0.02 mg/L and Pb recorded a minimum of < 0.001 mg/L and a maximum of 0.188 mg/L with a mean of 0.07 ± 0.05 mg/L (Table 1). The highest Hg level (0.17 mg/L) was recorded in BH1 (Table 2) which is closer to WP where gold bearing rocks are washed and Hg added to extract gold. The lowest Hg levels were recorded in BH4 (0.01 mg/L) and AWP (0.01 mg/L). BH4 is the borehole located furthest from WP. Generally, BH1 (0.031 mg/L) and BH3 (0.031 mg/L) recorded the highest mean Hg concentrations during the study. Mean Hg levels were observed to be above WHO recommended guideline limit (WHO, 2006) at all sampling sites during the study period. It was observed that surface water before the washing point (BWP) recorded mean Hg concentration (0.03 mg/L) higher than the WHO limit (Table 2). This implies that Hg levels recorded in the stream does not emanate solely from the activities of small-scale miners in Tinga, but also from mining activities upstream.

The high concentrations of Hg measured in boreholes (especially BH1), may be from the percolation of wastewater released from the ore washing point and also to some extent the Hg within the earth crust. Hg is found in soils and rocks typically as an ore known as cinnabar, consisting of insoluble mercuric sulphide. In Ghana, the presence of Hg in the environment is attributed to the use of Hg in gold recovery processes where the inorganic

Table 2. Mean concentration (mg/L) of heavy metals in borehole and surface water.

Site	Hg	Cd	Cu	As	Pb
Borehole 1					
Min-Max	(0.057-0.17)	(0.01-0.07)	(0.04-0.13)	(0.001-0.003)	(0.001-0.01)
Mean±SD	0.13±0.09	0.04±0.03	0.09±0.04	0.002±0.0008	0.008±0.004
Borehole 2					
Min-Max	(0.009-0.16)	(0.002-0.07)	(0.05-0.14)	(0.001-0.003)	(0.001-0.02)
Mean±SD	0.07±0.01	0.04±0.03	0.09±0.03	0.002±0.001	0.01±0.001
Borehole 3					
Min-Max	(0.056-0.30)	(0.002-0.10)	(0.002-0.06)	(0.01-0.002)	(0.001-0.01)
Mean±SD	0.13±0.02	0.03±0.01	0.03±0.02	0.0014±0.0005	0.008±0.004
Borehole 4					
Min-Max	(0.001-0.09)	(0.002-0.06)	(0.04-0.124)	(0.001-0.003)	(0.001-0.02)
Mean±SD	0.04±0.01	0.034±0.02	0.08±0.03	0.002±0.001	0.01±0.002
BWP					
Min-Max	(0.003-0.06)	(0.002-0.02)	(0.062-0.12)	(0.001-0.003)	(0.009-0.06)
Mean±SD	0.03±0.02	0.011±0.009	0.09±0.003	0.0014±0.001	0.035±0.01
WP					
Min-Max	(0.02-0.040)	(0.002-0.01)	(0.043-0.09)	(0.001-0.002)	(0.024-0.17)
Mean±SD	0.03±0.01	0.004±0.002	0.073±0.001	0.001±0.0005	0.07±0.03
AWP					
Min-Max	(0.001-0.06)	(0.002-0.01)	(0.03-0.143)	(0.001-0.007)	(0.024-0.17)
Mean±SD	0.03±0.002	0.004±0.001	0.078±0.04	0.003±0.001	0.07±0.01
WHO (2004)	0.006	0.003	2.0	0.01	0.01

Table 3. Correlation matrix for trace metals in water at Ting.

Metal	Hg	Cd	As	Cu	Pb
Hg	1	-0.084	0.005	0.220	-0.340
Cd		1	0.153	-0.620	0.081
As			1	-0.241	-0.031
Cu				1	-0.278
Pb					1

form of the metal either is washed into rivers or is vaporized readily into the atmosphere (Obiri, 2005; 2007; Chapman, 1996).

From Table 3, it was observed that Hg had a weak correlation with other trace metals measured during the study, implying that they seem not to emanate from the same source. Also there were variations in Hg concentrations in borehole with distance from the WP. Boreholes closer to the WP recorded higher mercury levels than those further from it. This is because washing and roasting of ores and amalgam are done closer to the water source where Hg is used and disposed off. BH3 however, did not follow this trend, since mean Hg concentration was higher than in BH2.

Cd concentrations recorded during the study were all above WHO's guideline limits at all sampling points (Table 2). The highest was recorded in BH3 (0.10 mg/L) while high mean values were recorded for BH1 (0.04 mg/L) and BH2 (0.04 mg/L). It was observed that Cd levels were higher in boreholes closer to WP. This was because most of the waste materials generated after washing of ore and extraction of gold are deposited at WP where washing is done. Cd is leached into nearby water bodies in the process. Cd has been shown to be toxic to human populations from ingested food and drinking water. Ingestion of elevated levels of cadmium results in kidney and skeletal system toxicity, increased hypertension and cardiovascular diseases.

The source of Cd may not necessarily be as result of the mining activities but it may occur naturally with zinc and sulphide ores since the lowest level was recorded in the stream at the point where the major mining activities take place. From Table 2, significant levels of Pb were detected in the samples collected from the stream as compared to samples collected from boreholes, thus high mean levels above the permissible WHO limit (0.01 mg/L) were recorded in the stream. The maximum mean concentration in the stream was measured at the point where most of the mining activities are done (WP, 0.07 mg/L) and after the washing point (AWP, 0.07 mg/L). The high lead concentrations recorded in the stream may be as a result of weathering and leaching of Pb metals from waste rocks dumps (Ashanti Goldfields Company (AGC), 2001). Other sources may be improper disposal of acid lead batteries and wind-blown dust into the stream. Children and pregnant women who ingest water directly from the stream without treatment for a period of time are susceptible to Pb contamination (ATSDR, 2007). Correlation matrix shows that trace metals measured in the study area were not highly correlated to each other, which seems to suggest that most of them were not from the same source. There was however, a moderate correlation between Cu and Cd (r = -0.620).

Cu and As were generally lower than the WHO standards. The maximum copper concentration recorded in the study area (0.143 mg/L) was within the WHO guideline value of 2.0 mg/L. Arsenic concentrations detected throughout the study period ranged from > 0.001 to 0.003 mg/L, which were within the permissible guideline value of 0.01 mg/L. These may be as result of insignificant constituents of copper and arsenic in the mined rocks in the area.

Non-cancerous health risk assessment

Hazard quotients from exposure to Hg, Cd, As, Pb and Cu via groundwater

The hazard quotients (HQ) through Central tendency exposure (CTE) and Reasonable maximum exposure (RME) to Hg by resident children and adults in the study area were greater than 1.0 for ground water (BH1 to BH4) via oral ingestion and lower than 1.0 via dermal contact. HQs through CTE and RME to Cd by resident children and adults in the study area were greater than 1 for groundwater via oral ingestion with the exception of BH3 (only CTE was higher than 1.0) (Figure 1). Through oral ingestion route by resident children in the study area, the maximum HQ were 2.7 and 5.4 through CTE and RME, respectively with minimum values of 0.0012 and 0.0551 correspondingly. Also, via oral ingestion by resident adults, HQ ranged from 0.0011 to 1.4 and 0.012 to 2.5 through CTE and RME, respectively. With regards to dermal route, all HQ through CTE and RME to Cd were less than 1.0. Similarly, the hazard quotients through CTE and RME to As, Cu and Pb in groundwater were less than 1.0 via both ingestion and dermal contact (Figure 1).

Generally, the HQs through CTE and RME to mercury and cadmium by resident children and adults in the study area were greater than 1.0 for the boreholes (ground

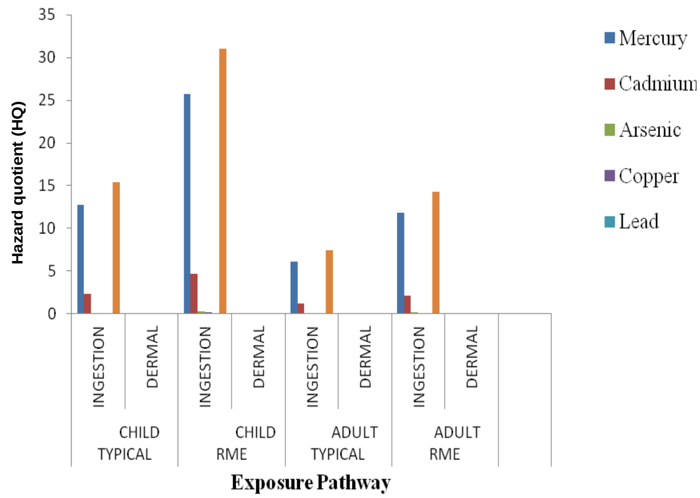

Figure 1. Hazard quotient (HQ) from exposure to trace metals by resident children and adults via ground water.

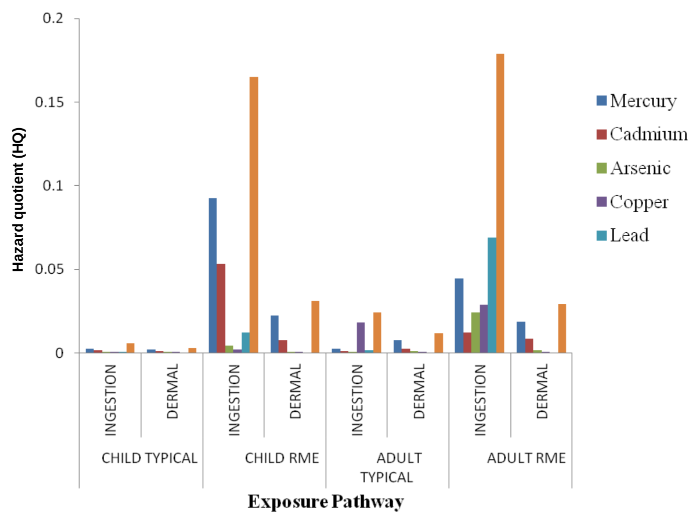

Figure 2. Hazard quotient (HQ) for exposures to trace metals by resident children and adults via surface water.

water) via oral ingestion rout. In accordance with USEPA risk assessment guidelines, a hazard quotient greater than 1.0 means that the probability for adverse health effects associated with exposure to such a chemical is high (USEPA 1989; 1997; 2001).

Hence, continuous ingestion of ground water by resident adults and children in the study area makes them susceptible to attracting diseases associated with exposure to mercury and cadmium. Examples of such diseases are low intelligent quotient among children, emotional disorders, gastrointestinal disorders, tremors, peripheral neuropathy, respiratory tract infection, diarrhea, skin hyper-pigmentation, kidney failures, and so on.

Generally, higher HQs were recorded for resident children compared to that recorded for resident adults (Figures 1 and 2).

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 Armah et al. (2012), Cobbina et al. (2012), Pokkamthanam (2011) and Obiri (2010).

Generally, the hazard quotients through CTE and RME to Hg, Cd, As, Cu and Pb in surface water (stream) by resident children and adults in the study area were less than 1.0 via both ingestion and dermal contact (Figure 2). In accordance with USEPA risk assessment guidelines, it implies that, resident children and adults in the study area stand very little chance of attracting diseases associated with Hg, Cd, As, Cu and Pb exposure through continuous use of surface water.

Conclusion

The study establishes that Hg, Cd and Pb levels in borehole water analyzed in the Tinga District were above World Health Organization's recommended guidelines. The contamination from Hg was mainly observed to be as a result of its use in the extraction of gold by small-scale miners. Cd and Pb may emanate from the leaching of such from heaped mined waste in the area. Non-cancer human health risk assessment revealed that exposure to Hg and Cd through ingestion of borehole water may affect resident children and adults adversely.

This was due to the fact that hazard quotients as a result of exposure to these toxicants were higher than 1.0. In line with USEPA (2001) risk assessment guidelines, resident children and adults may suffer from diseases such as low intelligent quotients, emotional disorders, gastrointestinal, tremors, peripheral neuropathy, respiratory tract infection, diarrhea, skin hyperpigmentation, kidney failures, and so on as a result of exposure to Hg and Cd through ingestion of borehole water in the study area.

Based on the results, it is recommended that the Environmental Protection Agency of Ghana and other regulatory agencies should embark on educational campaigns to sensitize people in the study area about the likely harm posed by activities of the small-scale miners. Government of Ghana and other stakeholders should provide safe drinking water sources such as tap water to help safeguard the health of the people.

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