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REVIEW ARTICLE

POLLUTION EVALUATION AND HEALTH RISK ASSESSMENT OF HEAVY METALS IN STREAM WATER AT EAST AKIM MUNICIPAL ASSEMBLY, GHANA

Douglas Siaw Baah[a], Eric Boateng Acheampong[b], Afua Amponsah Amankwah[c*]

[a] *Council for Scientific and Industrial Research-Forestry Research Institute of Ghana, Kumasi, Ghana. P. O. Box UP 63, KNUST-Kumasi*
[b] *Department of Land, Environment, Agriculture, and Forestry, University of Padova, Italy Eric Boateng Acheampong*
[c] *Department of Materials Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*
Corresponding author email: baahdouglas1@gmail.com

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ABSTRACT

Water contamination with toxic chemicals such as heavy metals continue to rise globally and particularly in developing countries due to mining, urbanization, and industrialization. In this study, a total of 10 stream water samples were collected from the mining environment. Physicochemical parameters such as pH and heavy metals; arsenic (As), chromium (Cr), nickel (Ni), and lead (Pb) were examined using standard procedures. The study assessed heavy metals concentrations, evaluated the pollution indices, and the health risk (carcinogenic and non-carcinogenic) for the populace (both adult and child) through direct oral intake and dermal contact of stream water in East Akim Municipal Assembly. The results of the concentrations of As (0.114 mg/kg), Cr (0.00000605 mg/kg), Ni (0.025 mg/kg), and Pb (0.257 mg/kg) revealed that they were within acceptable limits prescribed by World Health Organization (WHO) and Water guidelines. Heavy metal evaluation index (HEI) and degree of contamination (C_d) values obtained indicated that all the examined samples were categorized as low ($C_d < 1$ and HEI < 10). Non-carcinogenic risk indicated that stream water consumption via ingestion and dermal pathways were below the oral reference dose for their respective heavy metals indicating that both age groups may be ingesting safe levels of heavy metals. Furthermore, the non-carcinogenic risk assessment suggest that children are more susceptible to health threats than adults considering both exposure pathways. Also, the hazard quotient and hazard index were < 1 inferring that there is a tolerable degree of non-carcinogenic health risk for both adults and children in the research area. In addition, average values (1.86×10^{-5} and 7.12×10^{-5} for adults and children) obtained for the assessment of cancer risk (CR) for $CR_{ingestion}$ were within the safe range of 1×10^{-6} to 1×10^{-4} while $CR_{dermal\ contact}$ average values (4.52×10^{-8} and 2.53×10^{-7} for adults and children) were above the range recommended by US Environmental Protection Agency. Regardless of the relatively safe indices recorded, precautionary measures are necessary to sustain the aquatic ecosystem and its quality. Efforts must be made to ensure that heavy metals that can pose health risks even in their low concentrations are monitored and kept as low as possible to ensure safety and reduced human health risks.

KEYWORDS

Contaminants, Ingestion, Dermal contact, Carcinogenic, Non-carcinogenic

1. INTRODUCTION

Water is one of life's important components. Hence access and the safe consumption of water is the human birthright (Schmidt, 2019; Roy and Bhaumik, 2018). Human life depends on access to safe drinking water, which should not have any significant consequences for human health (Zhang et al., 2010). Globally, there has been an increasing trend of water shortages most particularly on the African continent (Ashton, 2002). These shortages have negatively impacted environmental quality, economic development, and livelihoods around the world (Vörösmarty et al., 2010). Aside from the water shortages and their related impacts, the consumption of contaminated water has direct impacts on the economic conditions and health of the consumers (Rose et al., 2015, Hasan et al., 2019). For example, an average of 6 million children dies annually from waterborne diseases (Halvorson et al., 2011).

Water contaminants may include organic and inorganic compounds, heavy metals, viruses, nitrates, and bacteria which are attributed to improper waste disposal and water treatment (Ali, 2012; Sharma and Bhattacharya, 2017). Among these contaminants, much emphasis is given to heavy metals because they are the most persistent, harmful, and risky element found in drinking water (Ali et al., 2019). Industrialization, the surge in population, and rapid economic development all over the world including Ghana have put water bodies under pressure, contributing to the release of high levels of heavy metals into the soil, surface waters, and groundwater (Ketemepi, 2017). In recent years, contamination of ground and surface water resources from the release of heavy metals due to anthropogenic activities represents one of the major environmental problems (Lu et al., 2015).

It is worth noting that, though some heavy metals are essential and thus promote health, growth, and development, while others such as copper (Cu), cadmium (Cd), lead (Pb), and arsenic (As) are classified as toxic in living organisms (Jaishankar et al., 2014). Large quantities of heavy metals

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which emanate from anthropogenic activities such as vehicular emissions, fertilizer and pesticide application, improper disposal of waste, agriculture, smelting, and mining operations may be released into water bodies (Masindi and Muedi, 2018). Mining operations, among the aforementioned human activities, represent the most significant source of heavy metals (Wei et al., 2018). The generation of heavy metals from mining activities are deposited into the soils and surface waters, consequently affecting human health once they find their way into the body via passageways such as inhalation, direct consumption, and dermal contact (Ramlogan, 1997).

In addition to their adverse effects on human health, heavy metals can cause extensive ecological damage due to their characteristics such as non-biodegradability, bioaccumulation, and toxicity (Maurya et al., 2019). Prolonged and continuous consumption of heavy metals results in its accumulation in body tissues posing serious health threats such as brain, bones, kidney, and liver diseases (Jaishankar et al., 2014, Rehman et al., 2018). Kibi, which is the capital of East Akim Municipal of Ghana depends on various sources of water for domestic purposes. Within the municipality, 19.6% of urban dwellers rely on protected well, 18.4% depend on pipe-borne outside dwellings, and 16.6% depend on pump/bore-hole as their main sources of drinking water whiles 53.3% of the rural residents depend either on pump/bore-hole and 29.6% depend on stream/river (Philomena, 2014).

These percentages clearly show that a significant number of the residents depend on streams or rivers as their main source of drinking water. With farming and mining as the major economic activities in the district, there is a likelihood of the presence of contaminants in the streams or rivers. However, an assessment of the quality of water from these streams/rivers and the health risk they pose to the populace has not been carried out. A group researchers in a preliminary study assessed trace metals concentrations in soils, stream water, and selected food crops within the Kibi municipality (Siaw et al., 2020). The results indicated that As and Pb content exceeded the maximum contamination limit (MCL) guidelines. Furthermore, the geochemical process model indicated that As and Pb were adsorbing whiles Cr and Ni were desorbing from the stream.

The study thus concluded that the stream water was not safe for drinking purposes because of the harmful threats to human health. Therefore, this study seeks to assess the health risk of the populace associated with the direct consumption of stream water in East Akim Municipal of Ghana. The study was focused on two objectives; 1) to assess the concentrations of heavy metals such as Arsenic (As), Chromium (Cr), Nickel (Ni), and Lead (Pb) in stream water, and 2) to evaluate cancer and non-cancer health risk from the daily consumption of the stream water within Kibi goldfields environment. The findings of this research will provide baseline information on heavy metal concentrations in stream water to enhance effective monitoring and management of water resources as well as help health professionals in decision making on public health management.

2. Methods

2.1 Study Area

Geographically, East Akim Municipal Assembly lies on 6° 10' 0" north and 0° 33' 0" west. It covers approximately 725 km^2. It is bordered by other six different administrative districts of Ghana (on the north by Atiwa District, on the northwest by West Akim District, on the east by Fanteakwa District, on the south by New Juaben, on the southeast by Yilo Krobo District, and the west by Suhum-Kraboa-Coaltar District). The landscape is undulating and rises between 240 and 300 meters above sea level (ASL). Within the municipality, there is a different form of rock types that give rise to relief topographies ranging from flat-bottom valleys to steep-sided highlands covered with iron pans, bauxite, and kaolin. The Apedwa Forest Ranges contain the catchment areas of rivers such as the Birim, Densu, and Bompong. The west semi-equatorial region where the municipality is situated has two major rainfall seasons that occur between June and October. From May to June, the municipality experiences its first rainy season and in September, the second rainy season begins which ends in October. The annual rainfall averages between 125 and 175 millimeters. Between November and late February forms the major dry season. The municipality is surrounded by a humid semi-deciduous forest that covers a total of 108.8 square kilometers. In the municipality, farming is the most common livelihood, with around 65% of the working inhabitants engaged in it. Cocoa and coffee are the two most important cash crops, followed by staples such as banana, plantain, corn, oil palm, and cassava.

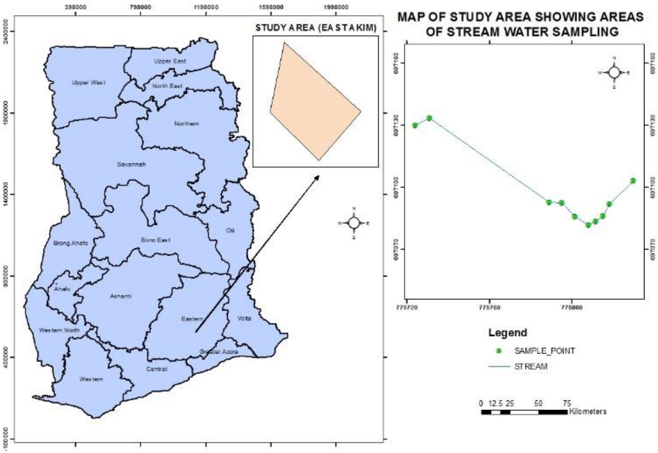


Figure 1: Map of the study area showing areas of sampling

2.2 Data Sampling

Stream water draining through the mining community was sampled. Stream water samples were taken with 3 to 4 m intervals between each sampling point. Using a 500 ml-sized clean plastic bottle, stream water samples were collected. Before water sampling, the sampling plastic bottles were first rinsed with some of the stream water to maintain the physical and chemical characteristics of the sample. In total, 10 stream water samples were taken from the site. The sampling bottles were covered with a lid and appropriately labeled. Samples were transported to the laboratory at a room temperature of 4 °C for analysis. The stream water sampling followed the procedure described (Bartram and Balance, 1996).

2.3 Analysis of Heavy Metals in Stream Water

To prevent metals from precipitating, water samples were acid digested and vacuum filtered through cellulose nitrate membrane filters with pore sizes of 0.45 mm. They were then acidified with concentrated HNO_3 and HCl and heated to 90-95°C at a pH of 2. After that, the water samples were put into a volumetric flask filled to the acceptable level and analyzed. The examined elements which include As, Cr, Ni, and Pb were measured with an atomic absorption spectrophotometer (AAS) (VARIAN Spectra AA 220) and an air acetylene flame. The standard method used for the analysis of the heavy metals in stream water followed the procedure prescribed (Association et al., 1912).

2.4 Determination of pH in Stream Water

In a 50 ml beaker, 10 ml of stream water was poured and mixed with 10 ml of distilled water. After 5 minutes of stirring, the mixture was set aside for 30 minutes. By dipping the electrode of a Eutech 510 pH meter in the top portion of the mixture, the pH of the suspension was determined. The determination of pH in the stream water samples followed the method used (Kulkarni and Shaw, 2015).

2.5 Pollution Evaluation Indices

In general, pollution indices are calculated based on the unique use of water under consideration (Kumar et al., 2019). Using heavy metal evaluation index (HEI) and degree of contamination (C_d), the quality of drinking water was assessed. The HEI method is the ratio of the observed concentration value of the number of the analyzed parameter to their respective maximum permissible concentration parameter to determine the overall quality of the water in terms of heavy metal (Maskooni et al., 2020). The C_d method is the sum of all calculated contamination factors of each component that exceeds the upper permissible limit. The method evaluates water quality by calculating the extent of contamination (Boateng et al., 2015). As a result, the C_d represents the sum of the effects of the number of quality indicators that are deemed dangerous to household water.

2.6 Heavy Metal Evaluation Index (HEI)

The heavy metal evaluation index (HEI) is calculated by measuring the overall quality of water with respect to the examined heavy metals using Equation 1 below (Ghaderpoori, 2018):

$$HEI = \sum_{i=1}^{n} \frac{H_c}{H_{mac}} \tag{1}$$

where Hc and Hmac are the measured value and the maximum allowable concentration (MAC) of the ith parameter, respectively.

2.7 Degree of Contamination (C_d)

A group researchers estimated the degree of contamination index (C_d), which highlights the cumulative impacts of different characteristics that are deemed detrimental to domestic water as presented in the equations below (Backman et al., 1998):

$$C_d = \sum_{i=1}^{n} C_{fi} \tag{2}$$

where $$C_{fi} = \frac{C_{Ai}}{C_{Ni}} - 1 \tag{3}$$

The contamination element, analytical value, and upper permissible concentration of the ith component are represented by Cf_i: CA_i, and CN_i, respectively. The 'normative value' which is the evaluating standard is denoted by N, and the MAC is denoted by CN_i.

2.8 Health Risk Assessment

The process of evaluating the chance of any given number of negative health impacts occurring over a particular period of time is referred to as risk assessment (Gerba, 2019). Threat detection, exposure assessment, dose-response, and risk characterization are all part of risk assessment (Ben et al., 2019). Each contaminant's health risk assessment which is commonly based on an estimate of the risk level, and health hazards are categorized as carcinogenic (a substance that is capable of causing cancer over time resulting from continuous exposure) or non-carcinogenic (a chemical that is not known to cause cancer). In the Kibi setting, the contamination of heavy metals and their associated carcinogenic and non-carcinogenic health risks generated by dermal absorption and ingestion of heavy metals in surface water were estimated using Hazard Index (HI), Hazard Quotients (HQ), and the Incremental Lifetime Cancer Risk (ILCR). Adults and children were the subjects of this research.

2.9 Non-carcinogenic Analysis

The analysis of non-carcinogenic health risk was done using chronic daily intake values obtained through dermal absorption and ingestion. Using Equations 1 and 2, the estimation of the Chronic Daily Intake (CDI) through ingestion and dermal pathways followed the procedure adopted by US EPA (Wu et al., 2009; USEPA, 1997).

$$CDI_{ingestion} = \frac{C_{w}.DI.ABS.EF.EP}{BW.AT} \tag{4}$$

$$CDI_{dermal} = \frac{C_w.SA.K_p.ABS.ET.EF.EP.CF}{BW.AT} \tag{5}$$

where C_w (mg/L) represents heavy metals content in water, DI (L/day) represents the ingestion rate of water in a given area, Dermal absorption factor (ABS, unitless), the yearly exposure frequency is represented as EF (in days/years), EP which is expressed in years is represented as the exposure period, SA (in cm^2) represents the area of the skin available to make contact, K_p (cm/hour) is the permeability coefficient, ET (hours/day) represents the exposure time, CF is taken as the conversion factor (L/cm^3), BW (Kg/person) represents the body weight, and the average time (days) is AT. In order to calculate chronic daily consumption via ingestion and dermal absorption, the input assumptions and their values summarized in Table 1 were used.

Table 1: Heavy metals through ingestion and dermal passageways: input parameters and assumptions (Mohammadi et al., 2019).

Exposure parameters	Symbols	Units	Values	
			Consumption	Dermal adsorption
Heavy metal content	C_w	mg/L	NA	
Daily average intake	DI	L/day	Children (1.8), Adults (2.2)	
Skin area	SA	Cm^2	NA	Children (6600) Adults (18000)
Permeability coefficient	K_P	Cm/hour		Cr (0.002), Ni (0.0002), As, Pb (0.001)
Conversion factor	CF	L/cm^3		0.001
Exposure frequency	EF	Day/years	365	350
Exposure duration	EP	Year	Children (6) Adults (70)	Children (6) Adults (70)
Bodyweight	BW	Kg	Children (15) Adults (70)	Children (15) Adults (70)
Average time	AT	Days	Children (2190) Adults (25550)	Children (2190) Adults (25550)
Exposure time	ET	Hours/day	NA	Children (1.0) Adults (0.58)

2.10 Hazard Quotient (HQ)

The HQ for each heavy metal was calculated by dividing the computed average of the chronic daily intake (CDI, mg/kg/day) of metal ingested with polluted water by the reference oral dosage (RfD) (Kamunda et al., 2016).

$$HQ = \frac{CDI}{RfD} \tag{6}$$

where CDI and RfD are measured in milligrams per kilogram of body weight per day. The RfD (mg kg^{-1} day^{-1}) is an oral reference dose that shows the maximum daily amount to which the human population might be continually exposed for a lifetime without causing significant harm. The RfD of each factor in this study was taken from US EPA screening levels as indicated in Table 2 (USEPA, 2014).

Table 2: The cancer slope factor (CSF) and oral reference dosage (RfD) for the heavy metals studied

Heavy metals	RfD_{oral}	Rfd_{dermal}	CSF (kg/day/mg)
As	0.0003	0.03	1.5
Cr	3	0.015	41
Ni	20	5.4	0.84
Pb	1.4	0.42	8.5

2.11 Hazard Index (HI)

To determine the non-carcinogenic health consequences of a mixture of heavy metals in water, the hazard index (HI) for four heavy metals was calculated for health risk assessment using the equation (7) below (Mohammadi et al., 2019).

$$HI = \sum_{k=1}^{n} HQ = HQ_{As} + HQ_{Cr} + HQ_{Ni} + HQ_{Pb} \tag{7}$$

The calculated HI is linked to standard values: when HI > 1, non-carcinogenic effects can occur in the populaces, while when HI < 1, the individual who has been exposed is unlikely to suffer any serious health consequences (Huang et al., 2018).

2.12 Carcinogenic Analysis

The cumulative risk of acquiring any sort of cancer over the course of a lifetime as a result of twenty-four hours per day exposure to a certain daily dose of a carcinogenic agent for seventy years is known as the incremental lifetime cancer risk (Mohammadi et al., 2019). The ILCR can be used to estimate the cancer risks associated with a specific level of heavy metal in drinking water (Hu et al., 2019). The ILCR was calculated as shown in equation (Eq. 8).

$$ILCR = CDI \times CSF \tag{8}$$

where CSF stands for cancer slope factor, a contaminant-specific risk posed by a lifetime average of one mg/kg/day of carcinogenic chemical. For single-element carcinogens and multi-element carcinogens, the allowable ranges from 10^{-6} to 10^{-4} (Najmeddin et al., 2018). Table 2 shows the CSF values for several heavy metals.

2.13 Statistical Analysis of Data Acquired

Basic descriptive statistics such as means and their standard deviations were used to highlight variations. The IBM Statistical Package for Social Sciences (SPSS) for standard windows version 23 (IBM Corporation, Armonk, NY, US) and Microsoft Excel 2007 was used to complete all calculations and analyses. Values for calculated parameters were compared with WHO Guideline values (WHO, 2011).

3. Results and Discussion

3.1 Heavy Metals Content and pH values in Stream Water

The mean concentration of heavy metals and pH values recorded for stream water in the East Akim Municipal Assembly are presented in Table 3.

Table 3: Heavy metals concentration (mg/l) and pH values in stream water of the study area. Means and standard deviations (in parenthesis) are shown.

Locations	pH	Cr	Ni	As	Pb
1	6.9	0.00077	0.031	0.046	0.31
2	6.8	0.00046	0.031	0.103	0.23
3	7.0	0.00058	0.030	0.088	0.24
4	7.0	0.00071	0.031	0.115	0.11
5	7.1	0.00032	0.024	0.095	0.11
6	6.9	0.00072	0.023	0.128	0.28
7	7.3	0.00054	0.022	0.110	0.30
8	7.2	0.00059	0.015	0.101	0.24
9	7.3	0.00056	0.028	0.166	0.41
10	6.8	0.00024	0.020	0.185	0.34
Mean	7.03(0.19)	0.00000605	0.0255	0.1137	0.257
Standard Deviation	0.19	0.000171	0.005563	0.039311	0.094287
(WHO, 2011)		50	70	10	10
(Water, 2012)		100	20	10	15

WHO, 2011 and Water, 2012 provide globally accepted permissible limits for heavy metals concentrations in drinking water.

pH is one of the most essential parameters that affect heavy metals and can influence metal migration and transformation (Guo et al., 2021). The low concentrations of heavy metals recorded for the surface water are most likely due to the near-neutral mean pH of 7.03. The concentration of chromium (Cr) ranged from 0.00024 mg/l to 0.00077 mg/l with a mean concentration of 0.00000605 mg/l (Table 3). The mean concentration recorded for Cr was below guidelines provided. Comparatively, high Cr concentrations of 5.08 mg/l were recorded by who investigated the carcinogenic and non-carcinogenic health effects of heavy metals in Khorramabad, Iran's drinking water (WHO, 2011; Water, 2012; Mohammadi et al., 2019).

Chromium is a mineral that the human body requires for insulin to operate properly, allowing carbohydrates, proteins, and fats to be used more efficiently (Bin-Jumah et al., 2020). It has been used as a dietary supplement to help diabetics regulate their blood sugar and can lower cholesterol and blood pressure (Ngala et al., 2018). Chromium improves insulin sensitivity by boosting insulin receptor kinase activity, insulin receptor number, and insulin binding to cells (Turgut et al., 2018). High dosages of chromium and long-term exposure to it, on the other hand, can cause cytotoxic and genotoxic effects that compromise the immune system (Wang et al., 2017). The concentration of nickel ranged from 0.015 mg/l to 0.031 mg/l with an average value of 0.026 mg/l. Similarly, the average mean nickel content was below the stipulated limits (WHO, 2011; Water, 2012).

In a study carried out by which assessed the contamination of heavy metal and associated health risks in the vicinity of tailings ponds in Guandong, China, the mean nickel concentration in surface water recorded was below the reference point (Liang et al., 2017). The continuous exposure of humans to nickel is due to the abundance of nickel in the Earth's crust (Genchi et al., 2020). Naturally, lack of nickel does not easily occur in food, therefore, a nickel-deficient diet is difficult to maintain. Nickel and nickel compounds have been related to various detrimental health effects in humans, including lung fibrosis, kidney and cardiovascular illness, and respiratory tract cancer (Genchi et al., 2020). Studies have reported that people who were exposed to nickel and nickel compounds had a high rate of nasal and lung cancer (Jose et al., 2018). The concentration of arsenic ranged from 0.046 mg/l to 0.185 mg/l with a mean of 0.114 mg/l which was below the stipulated limit of 10 mg/l (WHO, 2011; Water, 2012).

The low levels of arsenic concentration in the stream water could be due to little to no level of asenopyrite in their mining operation. A similar low arsenic concentration in surface water was recorded in Guangdong, China (Liang et al., 2017). Long-term exposure to arsenic contamination in drinking water can result in skin, lung, bowel, and kidney cancer. Skin changes, such as thickening and pigmentation can also occur (Chakraborti et al., 2017). The probability of effects is proportional to the amount of arsenic in the environment, and in places where drinking water is highly polluted. These effects have been observed in a large number of people (Ayotte et al., 2017). People who consume water that have arsenic concentrations of 50 g/l or lower have been linked to an increased risk of lung and bladder cancer as well as skin changes (Cheung, 2017).

Regarding lead (Pb), similarly low concentrations (0.257 mg/l) that fell below prescribed limits of 10 mg/l and 15 mg/l were recorded (WHO, 2011; Water, 2012). Comparatively, recorded Pb concentrations below the reference limit provided by WHO (Mohammadi et al., 2019). Despite the low concentrations of Pb recorded, there is still the potential of detrimental health implications especially for children within the vicinity. According to Pb causes a number of asymptomatic abnormalities in a number of physiological systems, even at low levels of exposure (Charkiewicz and Backstrand, 2020). At large concentrations, lead poisoning damages the brain and central nervous system, resulting in unconsciousness, convulsions, and even death (Sachdeva et al., 2018). Pb, in particular, disrupts the brain development of children, resulting in lower IQ and behavioral abnormalities such as a shorter attention span, greater antisocial behavior, and worse educational performance (Santa Maria et al., 2019). Children who survive lead poisoning may experience mental impairment and behavioral issues (Finlay, 2019).

3.2 Pollution Evaluation Indices of Stream Water

Table 4: Water pollution indices

Pollution indices	Heavy metals				
		Cr	Ni	As	Pb
Degree of contamination	-3.93				
Heavy metal evaluation index		2.1E-07	3.64E-04	1.13E-02	2.57E-02

Table 4 shows the heavy metal evaluation index and the degree of contamination. Chromium recorded the least HEI of 2.1E-07 while Pb recorded the highest HEI of 0.0257. The proposed heavy metal evaluation index criteria are as follows: HEI is considered low when it is less than 10 (HEI < 10), medium when it is between 10 and 20 (HEI 10-20), and high when it is above 20 (HEI > 20) (Ghaderpoori, 2018). The HEI results from the study for all examined heavy metals fall within the low zone. The degree of contamination (Cd) is a unit of measurement used to determine the extent of metal pollution (Zhao et al., 2018). The C_d for the stream water was -3.93 (Table 4). According to the description given by, the degree of contamination may be categorized into three classifications as follows: low degree of contamination (C_d < 1), medium degree of contamination (C_d 1 = 3), and a high degree of contamination (Cd > 3) (Rahman et al., 2020). Per the above classification, the results (Table 4) show that the stream water under investigation had a low degree of contamination.

3.3 Health Risk Assessment

3.3.1 Non-carcinogenic Analysis of Heavy Metals

Using the mean concentrations of Cr, Ni, As, and Pb found earlier, the associated human health risk with the average chronic daily intake of heavy metals (CDI) in stream water was computed for the target population.

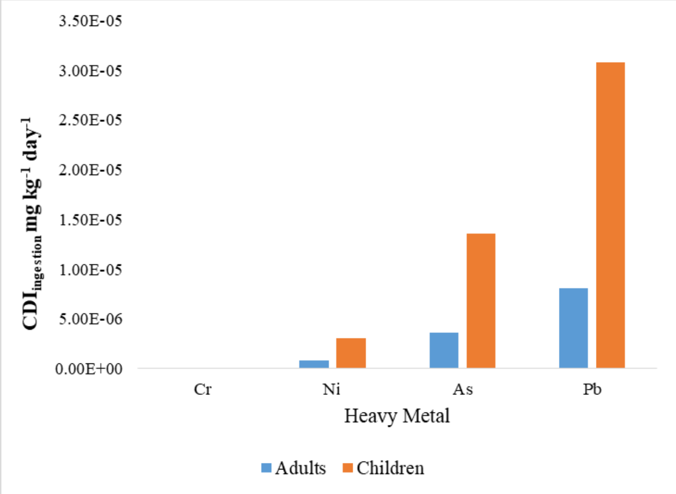
Table 5: Heavy metals chronic daily intake (CDI) for adults and children (mg kg-1 day-1) by ingesting and dermal adsorption

Age group	Intake of heavy metals on a daily basis (ingestion and dermal)			
	Cr	Ni	As	Pb
Adults				
$CDI_{ingestion}$	1.90E-10	8.0E-07	3.57E-06	8.06E-06
CDI_{dermal}	7.42E-13	3.12E-10	6.97E-09	2.0E-08
Children				
$CDI_{ingestion}$	7.26E-10	3.06E-06	1.36E-05	3.08E-05
CDI_{dermal}	5.10E-12	2.15E-09	5.0E-08	1.1E-07

The average chronic daily intake (CDI) is determined by the weight of the individual and the volume of water consumed. One of the most pressing issues in environmental science is heavy metal pollution. Drinking water contaminated with heavy metals is a public health concern; therefore, health risk evaluations and environmental health consequences should be investigated (Rai et al., 2019). The chronic daily intake (CDI) of the four heavy metals investigated in the research area was assessed by ingestion (drinking) and dermal absorption pathways (through washing, swimming, and bathing) (Table 5). The United States Environmental Protection Agency, for example, is a globally recognized regulatory body (USEPA), which has defined acceptable oral and dermal reference doses of heavy metals that pose no health threat during a lifetime.

The adopted tolerable intake for chromium (Cr) both oral and dermal is 3 and 0.015 mg kg^{-1} day^{-1}, respectively (USEPA, 2014). The results obtained for oral and dermal chromium intake for adults (1.90E-10 mg kg^{-1} day^{-1} and 7.42E-13 mg kg^{-1} day^{-1}, respectively) and children (7.26E-10 mg kg^{-1} day^{-1} and 5.10E-12 mg kg^{-1} day^{-1}, respectively) were below the reference point. This suggests that the people living in the research area are not consuming dangerous levels of chromium. The average CDI for nickel for both adults (8.0E-07 mg kg^{-1} day^{-1} and 3.12E-10 mg kg^{-1} day^{-1}) and children (3.06E-06 mg kg^{-1} day^{-1} and 2.15E-09 mg kg^{-1} day^{-1}) were also found to be below the stipulated limit of 20 mg kg^{-1} day^{-1} and 5.4 mg kg^{-1} day^{-1} for ingestion and dermal adsorption, respectively indicating that the local population may be ingesting safe levels of Ni (USEPA, 2014). For arsenic, the recorded CDI of 3.57E-06 mg kg^{-1} day^{-1} and 1.36E-05 mg kg^{-1} day^{-1} by ingestion for adults and children and 6.97E-09 mg kg^{-1} day^{-1} and 5.0E-08 mg kg^{-1} day^{-1} by dermal was below the oral reference dose of 0.0003 mg kg^{-1} day^{-1} and 0.03 mg kg^{-1} day^{-1} for ingestion and dermal, respectively, indicating that both age groups may be ingesting safe levels of arsenic through oral intake.

The Pb values obtained from this study were below the safe recommended oral (1.4 mg kg^{-1} day^{-1}) and dermal (0.42 mg kg^{-1} day^{-1}) reference level for both adults and children in the study area. This indicates that the general public is absorbing a safe oral and dermal reference dose of Pb that will not cause a health risk over the course of their lives. From Figure 2, the estimated results show that the exposure pathways for the examined heavy metals in drinking water that occurs through oral ingestion indicate that on average, children ingest more heavy metals (0.014) than adults (0.000012). This suggests that children are more susceptible to health threats through ingestion compared to their adult counterparts. Similar findings were reported by who investigated eight heavy metals content in surface and groundwater around Dhaka Export Processing Zone (DEPZ) in Bangladesh (Saha et al., 2017). Also, the exposure pathway through dermal contact was found to be high in children than in adults for all heavy metals analyzed.



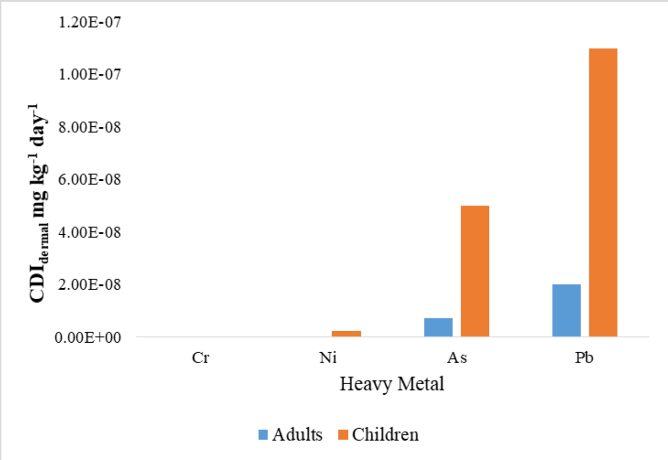


Figure 2: Estimated Chronic Daily Intake (CDI) for ingestion and dermal contact water usage in adults and children

Table 6: Non-carcinogenic health risk (hazard quotient, HQ) and overall toxic risk (hazard index, HI) of stream water from East Akim Municipal Assembly

Heavy metal	HQ_{ing}		HQ_{dermal}	
	Adults	Children	Adults	Children
Cr	6.33E-11	2.42E-10	4.95E-11	3.40E-10
Ni	4.00E-08	1.53E-07	5.78E-11	3.98E-10
As	1.19E-02	4.53E-02	2.32E-07	1.67E-06
Pb	5.76E-06	2.20E-05	4.76E-08	2.619E-07
HI	1.19E-02	4.54E-02	2.80E-07	1.93E-06

The hazard quotient (HQ) and hazard index (HI) for all heavy metals evaluated in stream water in adults and children via ingestion and dermal contact are presented in Table 6. The HQ, on the other hand, does not reflect the magnitude (in quantitative terms) to which a targeted population is exposed to health risk, and so does not show the levels of concern. Generally, where HQ < 1, it means that the current amount of heavy metals exposure poses no significant health risk and that the study population can be considered safe, whereas HQ ≥ 1, suggests that the population is exposed to an unacceptable degree of non-carcinogenic adverse health risk. From Table 6, for both adults and children, the $HQ_{ingestion}$ and $HI_{ingestion}$ values from ingesting exposure did not surpass the HQ and HI thresholds. This means that the analyzed heavy metals' daily intake levels were lower than the level of concern. In the case of the dermal passageway, the HQ_{dermal} and HI_{dermal} values recorded for adults were also less than the threshold for concern (HQ < 1). As a result of water consumption through the dermal channel, it can be inferred that there is a tolerable degree of non-carcinogenic health risk for both adults and children in the research area. It is worth noting that the differences in HQ and HI values through different pathways can be attributed to heavy metals variations in water consumption, exposure time, and body weight of adults and children.

3.3.2 Carcinogenic Analysis of Heavy Metals

Table 7: Adults and children's cancer risk and slope factor study of stream water through consumption and dermal contact

Cancer risk and slope factor by age groups	Heavy metals			
	Cr	Ni	As	Pb
Adults				
$CDI_{ingestion}$	7.7E-09	6.72E-07	5.36E-06	6.85E-05
CDI_{dermal}	3.04E-11	2.62E-10	1.05E-08	1.70E-07
Children				
$CDI_{ingestion}$	2.98E-08	2.57E-06	2.04E-05	2.62E-04
CDI_{dermal}	2.09E-10	1.81E-09	7.50E-08	9.35E-07

The cancer risk was calculated using inorganic Cr, Ni, As, and Pb intake levels. These are capable of increasing carcinogenic effects depending on the exposure dose. As a result, even low quantities of these hazardous metals can cause a variety of cancers when exposed over a lengthy time. The residents' cumulative exposure was calculated using Cr, Ni, As, and Pb as carcinogens, using the average mean CDI values calculated in Table 4. Cancer risk may be disregarded if the incremental lifetime cancer risk (ILCR) is less than 1×10^{-6}. An ILCR of greater than 1×10^{-4}, on the other hand, is deemed negative, indicating that cancer is a possibility. The optimal standard for the examined elements across the routes of exposure was 1×10^{-5} (Esmaeilzadeh et al., 2019).

The probability of developing $CR_{dermal\ contact}$ based on dermal exposure for all the examined elements ranged from 3.04×10^{-11} to 1.07×10^{-7} for adults and 2.09×10^{-10} to 9.35×10^{-10} for children with average values of 4.52×10^{-8} and 2.53×10^{-7} for adults and children, respectively. The results clearly show that the $CR_{dermal\ contact}$ values in adults and children are above the safe limit of 1×10^{-4} indicating the risk of developing cancer for life (70 years) concerning US EPA prescriptions. The calculated $CR_{ingestion}$ for all elements examined ranged from 7.7×10^{-9} to 6.85×10^{-5} for adults and 2.98×10^{-9} to 2.62×10^{-4} for children considering ingestion exposure pathways. The average $CR_{ingestion}$ values observed in adults and children were 1.86×10^{-5} and 7.12×10^{-5}, respectively. This indicated that carcinogenic risk for adults and children from drinking water obtained from East Akim Municipal Assembly was within the optimal US EPA's permissible range for all examined heavy metals.

4. Conclusion

In this research work, heavy metals associated with human health were analyzed for two different populations, that is, adults and children (as a sensitive population) based on daily consumption and exposure via dermal absorption and ingestion of drinking water. The heavy metals average mean content in stream water follows the decreasing order of Pb > As > Ni > Cr. The mean contents of heavy metals were all below the permissible threshold provided by WHO and Water. The study area's C_d and HEI concentration indices were categorized as low which may be due to a lack of or limited discharge of industrial wastewater into the stream. Heavy metals values for Chronic daily intake (CDI) via ingestion and dermal contacts were all below their respective reference limits. Ingestion of water was the most common means of heavy metal exposure for inhabitants of East Akim followed by dermal passageways. For the age groups, the CDI values indicated that children are more susceptible to non-carcinogenic risk through dermal and ingestion pathways.

The values obtained for hazard quotient (HQ) and hazard index (HI) for human health risk assessment through ingestion and dermal pathways were both < 1, indicating an appropriate degree of non-carcinogenic adverse risks. Carcinogenic risk levels particularly for $CR_{ingestion}$ for all examined heavy metals never surpassed the US EPA risk management standards except for $CR_{dermal\ contact}$ whose values were above the optimal standard suggesting a recognizable carcinogenic risk in water samples through dermal contact. However, despite the low concentration of heavy metals in water and the relatively safe levels of exposure for both ingestion and dermal contact, precautionary measures are necessary due to the increasing threat from mining activities. A monitoring system should be put in place to ensure the early detection of contaminants in aquatic ecosystems and enhance the development of strategies to sustain their quality for the wellbeing of the population.

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Authors Contributions

This multi-disciplinary research was conceived and undertaken by all authors. Douglas Siaw Baah was involved in data collection and experimental work. Afua Amponsah Amankwaah were involved in data analysis. Eric Accheampong Boateng proofread and made inputs to the first draft. All authors read and approved the final version of the manuscript.

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