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Risk assessment of heavy metal and trace elements contamination in groundwater in some parts of Ogun state

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Abstract: The present study was carried out to investigate the risk of heavy metal contamination in groundwater in Ota, Ogun state. Water samples were taken from seven (7) major groundwater sources popularly consumed by the population in the study area. The samples were analyzed for heavy metals and trace elements, which include K, Mn, Cr, and Cu at the ACME laboratory in Canada using ICP-MS. The average concentrations obtained for each metal are as follows: 0.30, 7.30, 0.85, 25.34 $\mu\text{g l}^{-1}$. This could be represented in this order, $\text{Cu} > \text{Mn} > \text{Cr} > \text{K}$. Furthermore, the average daily dose was determined for the heavy metal and Trace Elements in each sample, samples 1 and 7 reported higher results in Cu for adult male and female while samples 1, 2, 3 and 4 reported 3.878, 1.653, 1.980 and 4.467 $\mu\text{g (kg. day)}^{-1}$ for Cu in children. The concentration of these elements detected in the water samples could be as a result of the geology of the area of study or due to human actions. Further study revealed the values of hazard quotient to be less than the recommended safe limit of 1 for all the samples. The average hazard quotient also reported values lower than 1 for all the age group, but Cu was noticed to be prominent across all the estimation. Therefore, regular monitoring must be considered for groundwater samples in the study area in order to avoid possible health risk that may occur as a result of the increase in the concentration of these heavy metals and Trace Elements over a long period if their sources are not eliminated.

ABOUT THE AUTHOR

The authors are a group of young and dynamic researchers with common interest in conducting researches on subjects that directly affect man. They have published articles in different areas that are related to human safety and environment. The authors conducted this research in order to proffer solution to the untold hardship and risk people are exposed to as a result of building collapse in Nigeria. Other than geotechnical studies carried out in this article, the authors have also conducted researches in various areas of human concern such as, water contamination and remedy, heavy metal content in commonly consumed food items and the radionuclide contents in building tiles. The authors will always be committed to a safe environment and a quality life for all.

PUBLIC INTEREST STATEMENT

The authors are a group of young and dynamic researchers with a common interest in conducting researches on subjects that directly affect man. They have published research articles in different areas that are related to consumer and environmental protections. The research in this article was conducted in order to investigate and proffer solution to the health risk associated with the consumption of polluted water or water from contaminated sources. Besides the groundwater sample analysis carried out in this study, the authors have also conducted researches in various areas of human concerns such as causes of building collapse, foundation failures, water contamination and remedy, heavy metal content in commonly consumed food items and the radionuclide contents in building materials. The authors will always be committed to a safe environment and a quality life for all.

Subjects: Environment & Resources; Environment & Health; Environmental Change & Pollution

Keywords: ACME laboratory; ICP-MS; average hazard quotient; Canada; Ota

1. Introduction

The availability of groundwater for various purposes and its purity shifted the dependency of man from surface water to groundwater (Chabukdhara, Gupta, Kotecha, & Nema, 2017). Groundwater is globally recognized as one of the major sources of freshwater, which supplies about 30% of the earth's freshwater. In the last decades, there has been gradual deterioration in the quality of purity observed in groundwater because of so many human activities such as the rapid population growth, agricultural activities, urbanization and industrialization, which has exposed groundwater resource to the risk of contamination (Tirkey, Bhattacharya, Chakraborty, & Baraik, 2017). The quality of groundwater in a particular region is often influenced by both geogenic and anthropogenic activities. Some of the geogenic activities include both geochemical and hydrological processes, groundwater flow direction, aspect, slope, and other topographic features. Different rock types contribute to the heavy metals contamination found in the environment because all rocks originate from magma which has a large variety of different chemical elements which form during the cooling of the magma (Bradl, 2005). On the other hand, human activities such as mining, irrigation return flow, sewage, agro fertilizers, industrial wastes and animal wastes all contribute to the contamination of groundwater especially in a highly populated and heavily industrialized area (National Research Council (US), 2000, Abraham & Susan, 2017). Some heavy metals and trace elements are required to be in water for it to be fit for consumption, but when these constituents become higher than the standard considered safe for human consumption; it is then considered as toxic (de Meyer & Rodriguez et al., 2017; Samantara, Padhi, Sowmya, Kumaran, & Satpathy, 2017; Tchounwou, Yedjou, Patlolla, & Sutton, 2014). One of the major contaminants that affects groundwater quality and poses a health risk to mankind is heavy metals and trace elements because they are highly persistent and are bio-accumulative in nature. Toxic heavy metals possess harmful effects on plants, animals, human health and life in an aquatic environment especially fishes and populations that consume them. Lead (Pb), mercury (Hg), cadmium (Cd), chromium (Cr), beryllium (Be), cobalt (Co), manganese (Mn), etc., are few examples of heavy metals. When these metals are consumed in quantities higher than the recommended standard they can lead to very chronic diseases such as high blood pressure, liver crises, kidney problem, skin irritation and so on (USEPA (US Environmental Protection Agency), 2001, U.S Environmental Protection Agency (EPA), 2006, WHO, 2011).

Chromium (Cr) is a heavy metal that occurs naturally in the earth. Its state of oxidation range from chromium (II) and chromium (VI), which is more toxic. Chromium (Cr) can be found in many environments as they mix up with water, soil and air, although their largest release comes from industrial wastes (Agency for Toxic Substances and Disease Registry (ATSDR), 2008, Samantara et al., 2017). The health hazard associated with exposure to chromium (Cr) depends on its oxidation state, ranging from the low toxicity of the metal form to the high toxicity of the hexavalent form (Costa, 1997; Shelnutt, Goad, & Belsito, 2007; World Health Organization, 1998). Chromium (Cr) can be ingested through food and water. Acute and chronic exposure to this metal can result in neurological effects, renal, hepatic, hematological, gastrointestinal, cardiovascular and even death. Similarly, copper occurs naturally, it is a reddish metal which is found in rocks, soil, water, sediments, and air (Teh, Nik Norulaini, Shahadat, Wong, & Mohd Omar, 2016). Copper (Cu) has many applications as it is used in electrical wiring, in the production of coins and pipes. It is a very important element that is required in small quantity by living organisms, including humans, to ensure good health. However, too much exposure to this metal can lead to adverse health effects, which could include diarrhea, vomiting, stomach cramps, liver damage, nausea and kidney disease (National Research Council (US), 2000, Abraham & Susan, 2017). In a similar development, manganese occurs naturally in rocks and soil. It is found mainly in iron-bearing waters because it occurs in much similar form as iron. It has been discovered that high exposure to manganese affects the nervous system. Moreover, it has

been established that high exposure to this metal can affect learning and behavior in infants according to (NRC (National Research Council) Copper, 1977, EPA (U.S. Environmental Protection Agency), 1987, ATSDR (Agency for Toxic Substances and Disease Registry), 1990), and the World Health Organization's International Programme on Chemical Safety (IPCS (International Programme on Chemical Safety), 1998). Furthermore, potassium occurs naturally in water and it is very essential in order for the body to function properly. It becomes toxic when it is consumed in a concentration higher than the standard recommended by the world health organization and other drinking water regulatory bodies. High exposure to potassium can lead to nerve impulses, which affects the heart, stomach complaints and nausea.

(Abraham & Susan, 2017) found that mining activities as well as natural processes such as geological weathering contributed to groundwater contamination by Al, Fe, and Mn in a number of public water sources. Mineral crystallization in rocks is a function of both temperature and pressure conditions and different minerals in rocks are precipitated according to their stability fields. The trace elements being considered in this study (K, Mn, Cr, and Cu) are often embedded in rock types of intermediate and easy resistance to weathering especially in a sedimentary terrain as the area of study. As a result of the proneness of the source rocks to weathering, these metals can easily migrate from one point to another thereby resulting in groundwater contamination. It is worthy of note to state at this point that no study in open literature as considered the possible sources of groundwater contamination from both natural and anthropogenic sources in the area of study. Therefore, this study was conducted in order to carry out an investigation on the quality of the groundwater that is being consumed by this innocent population, using chemical analysis and comparing the results with regulatory guidelines and indices established by the government body and international organizations for water quality so as to ascertain its suitability for drinking.

2. Geology and geographical location of the study area

The study was conducted in Ota, Ogun state, which falls within the eastern part of the Dahomey (Benin) Basin in south-western Nigeria (Figure 1). The basin stretches along the continental margin of the Gulf of Guinea. Rocks in the Dahomey basin are Late Cretaceous to Early Tertiary in age (Jones & Hockey, 1964; Olabode, 2006; Omatsola & Adegoke, 1981). The general sequence of the rock unit from the top are the Coastal plain sands, Ilaro formation, Oshosun formation, Akinbo formation, Ewekoro formation, and Abeokuta Group lying on the Southwestern Basement Complex of Nigeria. The Cretaceous Abeokuta Group consists of Ise, Afowo and Araromi Formations consisting of poorly sorted ferruginized grit, siltstone, and mudstone with shale-clay layers.

The Dahomey is one of the sedimentary basins on the continental margin of the Gulf of Guinea, extending from southeastern Ghana in the west to the western flank of the Niger Delta (Jones & Hockey, 1964; Omatsola & Adegoke, 1981). The basin is bounded in the west by faults and other tectonic structures associated with the landward extension of the fracture zone. Its eastern limit is similarly marked by the Hinge line, a major fault structure marking the western limit of Niger Delta (Omatsola & Adegoke, 1981). It is also bounded in the north by the Precambrian basement rock and the Bright of Benin in the south. Stratigraphic studies of Dahomey basin were conducted by various researchers among who are (Adegoke, 1972; Jones & Hockey, 1964; Omatsola & Adegoke, 1981). The population of the study area is about 700,000 people according to national population data of 2006. Furthermore, the study area is home to the Head Quarters of the Living Faith Church World Wide, the largest single church auditorium in the world, where about 400,000 people worship every Sunday.

3. Materials and methods

3.1. Sampling and sampling procedure

Samples were collected from seven groundwater sources, which are majorly consumed by the people in the area of study. The groundwater samples were collected from boreholes based on their availability in the location where sampling was done. At the point of collection of the water samples, the water was allowed to run for about 10–15 min so as to ensure that the sample was

from the borehole and not the one stored in the pipe. Also, the pH of each groundwater sample was measured by a CONSORT C931 instrument. Prior to sampling, the sampling bottles were rinsed about 3–4 times both with distilled water and the sampling water itself in order to get rid of any form of contaminant. The water samples were collected in airtight sampling plastic bottles with a capacity of 1 L each. At the instant of collection, the water samples were preserved by adding 15 ml of 1% nitric acid. The sampling bottles were immediately kept in the refrigerator at a temperature of 4°C before they were transported to the laboratory for analysis.

3.2. Heavy metal analysis

All the acidified water samples were analyzed using inductively coupled plasma mass spectrometry (ICP-MS) under standard operating condition. Each of the water samples was analyzed in triplicate in order to ensure data quality. One blank and another of 2.5 µg L⁻¹ of respective metal were analyzed on atomic adsorption. The confidence limit was found to be 95% for reproducibility. Therefore, further interpretations were done using the mean value of each water samples. Standard solutions of all eight elements were prepared by dilution of 1000 mg L⁻¹ certified standard solutions from the manufacturer for corresponding metal ions with double-distilled water. All the acids and reagents used were of analytical grade. All the analyses were conducted at the ACME laboratory in Canada.

3.3. Health risk assessment of heavy metal and toxic trace elements

The health risk from groundwater consumption was assessed; the adverse health effect due to exposure to heavy metal over a period of time is quantified in order to determine the magnitude of risk, which could be expressed in terms of carcinogenic and non-carcinogenic health effects (USEPA (US Environmental Protection Agency), 2009, Bortey-Sam et al., 2015). The toxicity risk factors estimated are the reference dose (RfD) for non-carcinogenic risk and slope factor for carcinogenic risk characterizations (International Agency for Research on Cancer (IARC), 1993). In order to adequately characterize these risks, the average daily dose (ADD) for the metals must be properly estimated. Average daily dose (ADD) is the estimations of the magnitude, frequency, and duration of human exposure to each heavy metal or metalloid in the environment as it is typically reported by (Taiwo & Awomeso, 2017) as expressed in Equation (1).

$$ADD = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (1)$$

where the average daily dose is measured in µg (kg-day)⁻¹, C is the concentration of each heavy metal and trace elements (µg L⁻¹), IR is the intake rate of water, which for the purpose of the present study is taken as 2.72, 2.13 and 1.80 L day⁻¹ for adult male, adult female and children, respectively, EF is the exposure frequency, that is (365 days/year), ED is the exposure duration, which is also taken to be 70 years for adults and 10 years for children also, BW is the average body weight, which is also taken to be 72 kg for adult male, 68 kg for adult female and 22 kg for children, respectively. The reason for the variation in the values of water intake rate and body weight is to be able to obtain clear distinction in the results from the three age groups. AT is the average time of exposure, which for adult and children are given as 70 years x 365 days year⁻¹ and 10 years x 365 days year⁻¹ respectively.

The non-carcinogenic risk due to exposure to groundwater consumption was calculated as the hazard quotient (HQ) and was expressed in the form of Equation (2).

$$HQ = \frac{ADD}{RfD} \quad (2)$$

Both average daily dose (ADD) and reference dose (RfD) are in µg kg⁻¹ day⁻¹, where the reference dose for K, Mn, Cr, and Cu are 5.0 × 10⁰, 1.4 × 10², 1.5 × 10³ and 4.0 × 10¹ µg kg⁻¹ day⁻¹ respectively (USEPA, 2001). If the value of HQ is greater than unity, that is, 1, there is possibility of non-carcinogenic effects on health while HQ value less than 1 implies that the exposure to

groundwater consumption would not likely have any effect on the residents (USEPA (US Environmental Protection Agency), 2001, Yuan, Xiang, Liu, and Theng (2017), Maxwell, Adewoyin, Joel, and Ehi-Eromosele et al. (2018), Joel et al., 2018).

3.4. Statistical analysis

The statistical analysis for this study was conducted using the Statistical Package for Social Science software (SPSS) version 20.0.

4. Results and discussion

4.1. Heavy metal concentration

The concentrations obtained from the analysis of the water samples for this study are presented in Figure 2. The concentration appeared to be the highest in all the water samples when compared with other metals considered for this study followed by Manganese (Mn), while the concentration of Potassium (K) was found to be the least in the samples. The concentration of the heavy metal and trace elements in the water sample followed the following trend of $\text{Cu} > \text{Mn} > \text{Cr} > \text{K}$. The concentration was observed to vary from 0.13 to $0.93 \mu\text{g L}^{-1}$ for Potassium (K) with a mean of $0.30 \mu\text{g L}^{-1}$. The concentration reported for Manganese (Mn) ranged between 0.57 and $10.50 \mu\text{g L}^{-1}$ with an average value of $7.30 \mu\text{g L}^{-1}$. Furthermore, the concentrations that ranged between 0.40 and $1.50 \mu\text{g L}^{-1}$, and 6.90 and $54.60 \mu\text{g L}^{-1}$ were noted for Chromium (Cr) and Copper (Cu) with mean values of 0.85 and $25.34 \mu\text{g L}^{-1}$ respectively. The concentration reported for Manganese was less than the recommended standard of 500 ppb permissible for safe drinking water according to (WHO, 2011). The concentrations obtained for Chromium (Cr) and Copper (Cu) were also less than 100 and 1300 ppb, which are the recommended permissible limit for safe drinking water. This suggests that the concentration of these metals in the borehole water in the study area is below the recommended safe limit (WHO, 2011). Naturally, metals occur in varying quantities in rocks depending on the geochemical composition of the geological formation. As a result of the mobility of these metals in soil, they flow from the surface to the water-bearing formation below (IPCS (International Programme on Chemical Safety), 1998). Also, these metals can also result from anthropogenic sources such as improper waste disposal and the application of insecticides (Samantara et al., 2017). The low concentration noticed in the water samples collected from the area could be as a result of the depth to the aquifer, which prevented the water-bearing formation from every form of an external pollutant that could influence the purity of the water.

Figure 1. Geological map of the area of study (Joel et al., 2016).

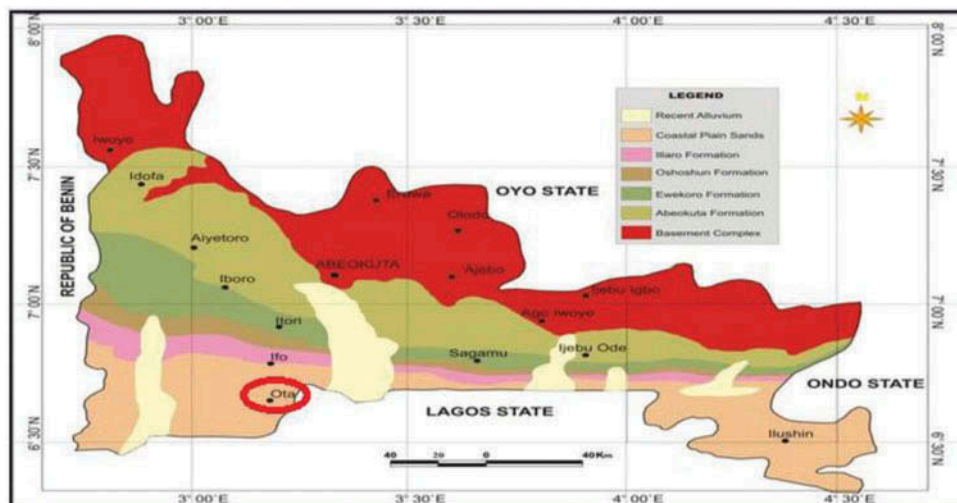
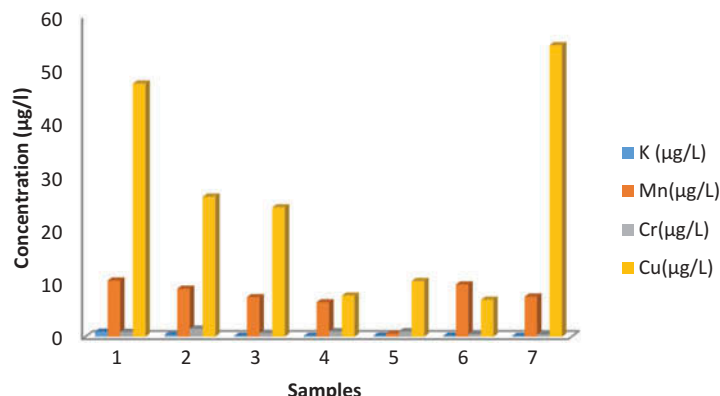


Figure 2. Concentration of Heavy Metal and Trace Elements observed in seven water samples.

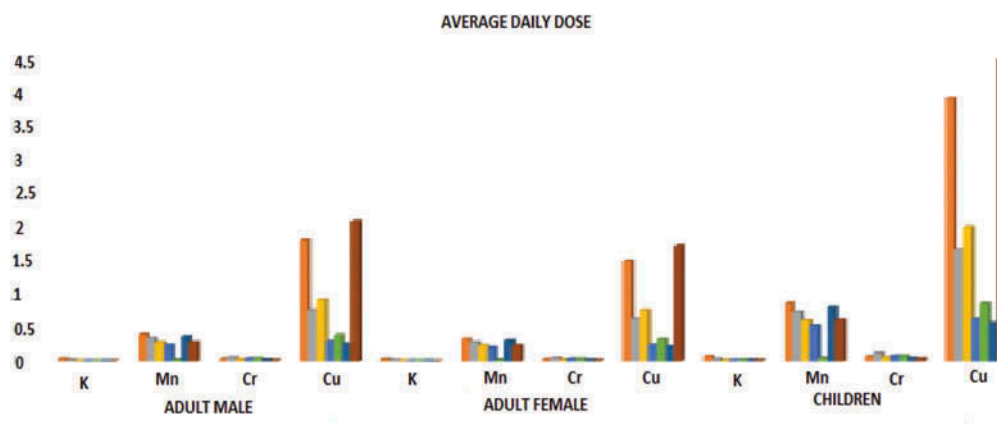


4.2. Health risk assessment

4.2.1. The average daily dose

A summary of the average daily dose for the individual metals in the study samples across the different age groups are presented in Figure 3. For K, the average daily dose estimated ranged from 0.005 to 0.035, 0.00041 to 0.03 and 0.01 to 0.08 $\mu\text{g kg}^{-1} \text{day}^{-1}$ with mean values of 0.011, 0.009 and 0.024 $\mu\text{g kg}^{-1} \text{day}^{-1}$ for adult males, adult females, and children. Similarly, the estimated average daily dose for Mn varied from 0.02 to 0.40, 0.02 to 0.33 and 0.05 to 0.86 $\mu\text{g kg}^{-1} \text{day}^{-1}$ with average values of 0.28, 0.23 and 0.60 $\mu\text{g kg}^{-1} \text{day}^{-1}$ for adult males, females and children, respectively. Furthermore, the calculated average daily dose for adult males ranged between 0.01 and 0.06 $\mu\text{g kg}^{-1} \text{day}^{-1}$, while it ranged between 0.01 and 0.05 $\mu\text{g kg}^{-1} \text{day}^{-1}$ for adult females and it varied between 0.03 and 0.12 for Children with average values of 0.32, 0.27 and 0.070 $\mu\text{g kg}^{-1} \text{day}^{-1}$ for Cr in the three classifications. Finally, the average daily dose for Cu revealed a range of 0.26 to 2.06 $\mu\text{g kg}^{-1} \text{day}^{-1}$ for adult males with a range of 0.22 to 1.71 $\mu\text{g kg}^{-1} \text{day}^{-1}$ for adult females while in children a range of 0.57 to 4.47 $\mu\text{g kg}^{-1} \text{day}^{-1}$ was estimated. The average values of 0.92, 0.77 and 2.00 $\mu\text{g kg}^{-1} \text{day}^{-1}$ were noticed for each classification, respectively. The mean average daily dose was noticed to be higher in children than adult males and females for all the metal samples considered. It was also observed that the mean average daily dose for adult males is higher than what was recorded in adult females. Moreover, the mean average daily dose for copper was far higher than what was estimated in other metals, giving a trend of $\text{Cu} > \text{Mn} > \text{Cr} > \text{K}$ for the mean average daily dose. Furthermore, all the values of the average daily dose in all the samples analyzed were found to be less than 1, as shown in Table 1,

Figure 3. The average daily dose for adult males, females and children for all the Heavy metal and Trace Elements considered.



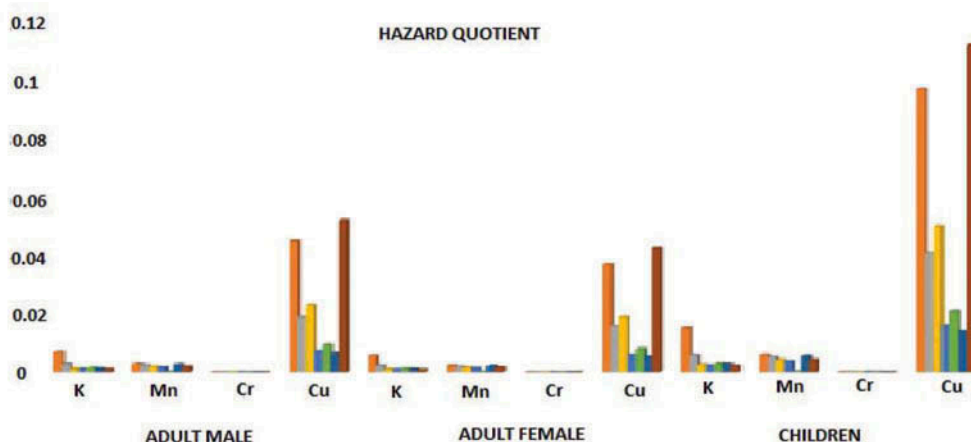
except for Cu in adult males and females as noticed in samples 1 and 7 for both sex classifications, respectively. It was also noticed that in children, samples 1, 2, 3 and 7 reported values higher than 1 for Cu, with samples 1 and 7 in children having the highest values. The area of study is close to an industrial estate where aluminum roofing sheets, paints, pigments, and other finished goods are produced. Improper disposal of wastes and sewage from these companies could serve as an anthropogenic source of some of these metals especially Cu, this could be why the metal is more significant among the heavy metal and trace elements considered for this study (Tchounwou et al., 2014). Similarly, insecticides and fungicides have been noted to influence the concentration of heavy metal and trace elements in groundwater. This could also be a factor that would contribute to the heavy metal concentration in the study area as large-scale farming is a major occupation of the residents (IPCS (International Programme on Chemical Safety), 1998).

4.2.2. Hazard quotient

The summary of the hazard quotient for each metal considered in the present study is presented in Figure 4. The estimated hazard quotients for Potassium (K) in adult males, females and children are found to vary between $9.8\text{E-}04$ and $7.00\text{E-}03$, $8.20\text{E-}04$ and $5.80\text{E-}03$ and $2.2\text{E-}03$ and $1.52\text{E-}02$, with average values of $2.27\text{E-}03$, $1.80\text{E-}03$, and $4.90\text{E-}03$, respectively. In a similar development, the hazard quotient noticed for Manganese (Mn) in the selected groundwater samples were found to vary between $1.00\text{E-}04$ and $2.90\text{E-}03$ with a mean of $2.00\text{E-}03$, $1.00\text{E-}04$, and $2.40\text{E-}03$ with an average value of $1.6\text{E-}03$ and $3.00\text{E-}04$ and $6.1\text{E-}03$ and an average of $4.30\text{E-}03$ for adult males, females and children, respectively. In Chromium (Cr), the following values were estimated for the different age classifications, $7.3\text{E-}06$ – $3.80\text{E-}05$, $8.67\text{E-}06$ – $3.13\text{E-}05$ and $2.20\text{E-}05$ – $8.20\text{E-}05$ with average values of $2.10\text{E-}05$, $1.80\text{E-}05$ and $4.70\text{E-}05$ for adult males, females and children, respectively. Finally, the hazard quotient was determined for Copper in the water samples and the following values were obtained for adult males, females and children; $6.50\text{E-}03$ – $5.20\text{E-}02$, $5.40\text{E-}03$ – $4.28\text{E-}02$ and $1.40\text{E-}02$ – $1.12\text{E-}01$ with average values of $2.32\text{E-}02$, $1.92\text{E-}02$, and $5.01\text{E-}02$, respectively. It was noted from the average values of Hazard quotient estimated for K, Mn, Cr, and Cu in the selected groundwater samples were within the permissible level for drinking water, i.e. $HQ < 1$ as presented in Table 2. In summary, the average hazard quotient of heavy metal and trace elements considered in this study with respect to drinking water quality were in the order of $\text{Cu} > \text{K} > \text{Mn} > \text{Cr}$. The result obtained agreed with the result obtained by a similar study conducted on sachet water in the area of study.

In general, the results of hazard quotient for individual metal for adult males, females and children were found to be less than 1, which could imply that the consumption of individual metal

Figure 4. Hazard quotient for all studied metals in each sample across age classification.



via oral ingestion of this water within the area of study may not pose any significant health risk to the people that depend on it. Moreover, since these metals are already being noticed in small quantity in the groundwater samples in the study area, the possibility that the concentration will increase with time cannot be ignored as long as the anthropogenic sources have not been totally eliminated from the area.

4.2.3. Average hazard quotient

The average hazard quotient was obtained by summing up the hazard quotient for each metal and dividing it by the number of samples. This is expressed mathematically as shown in the equation below:

$$AHQ = \sum_{n=1}^7 \frac{HQ}{n} \quad (3)$$

The average hazard quotient for each metal in all the samples were estimated for the adult males, females and children. The result is presented in the Table 3, 2.28E-03, 1.89E-03, and 4.89E-03 were reported for K in adult male, female and children accordingly. Similarly, for Mn, the observed result revealed 1.97E-03, 1.64E-03, and 4.27E-03 for adult male, female and children, respectively. Furthermore, for Cr in adult male, female and children, the following values of average hazard quotient were observed which are 2.12E-05, 1.79E-05, and 4.69E-05. Finally, the average hazard quotient noted for Cu in the samples for an adult male, female and children were 2.30E-02, 1.91E-02, and 5.01E-02, respectively. In all, the average hazard quotient was noted to be highest in children for all the metals, which could be as a result of their small body weight especially for Cu in the water samples. Therefore, effort must be made to balance the intake of these metals especially copper so that the body does not consume beyond what is needed, which could lead to adverse health effects such as vomiting, stomach cramps, and nausea.

5. Conclusions

The present study was conducted in order to assess the risk of exposure to heavy metal and trace elements by the population in the study area. Water samples from groundwater sources popularly consumed by the residents in the area of study were collected for analysis at the ACME laboratory in Canada for K, Cu, Mn, and Cr. The average concentrations of 0.30, 0.85, 7.30 and 25.34 $\mu\text{g L}^{-1}$ were observed for K, Cr, Mn, and Cu, respectively, in the water samples. Furthermore, the average daily dose for each metal in all the samples were estimated to be mostly less than 1 in all the samples except for Cu in adult male and female in samples 1 and 7 while 3.878, 1.653, 1.980 and 4.467 $\mu\text{g (kg-day)}^{-1}$ were noticed for Cu in Children for samples 1, 2, 3 and 7, respectively.

Table 1. The average daily dose for adult males, females, and children for all the Heavy metals considered

AVERAGE DAILY DOSE ($\mu\text{g kg}^{-1} \text{ day}^{-1}$)

	ADULT MALE				ADULT FEMALE				CHILDREN			
s/n	K	Mn	Cr	Cu	K	Mn	Cr	Cu	K	Mn	Cr	Cu
1	0.035	0.40	0.034	1.79	0.029	0.329	0.028	1.485	0.076	0.859	0.074	3.878
2	0.014	0.34	0.057	0.76	0.012	0.281	0.047	0.633	0.030	0.734	0.123	1.653
3	0.006	0.28	0.026	0.91	0.005	0.231	0.022	0.758	0.013	0.605	0.057	1.98
4	0.0057	0.24	0.038	0.29	0.0047	0.201	0.031	0.241	0.012	0.526	0.082	0.63
5	0.0072	0.02	0.038	0.39	0.006	0.018	0.031	0.326	0.015	0.047	0.082	0.851
6	0.0064	0.37	0.019	0.26	0.0053	0.306	0.016	0.216	0.014	0.799	0.041	0.565
7	0.0049	0.28	0.011	2.06	0.0041	0.235	0.013	1.710	0.011	0.613	0.033	4.467

Table 2. Hazard quotient for all studied metals in each sample across age classification

HAZARD QUOTIENT												
s/n	ADULT MALE				ADULT FEMALE				CHILDREN			
	K	Mn	Cr	Cu	K	Mn	Cr	Cu	K	Mn	Cr	Cu
1	0.007	0.00286	0.0000227	0.045	0.00580	0.00235	0.0000187	0.0371	0.0152	0.00614	0.0000493	0.097
2	0.0028	0.00242	0.0000380	0.019	0.00240	0.00201	0.0000313	0.0158	0.00600	0.00524	0.0000820	0.041
3	0.00120	0.00200	0.0000173	0.023	0.00100	0.00165	0.0000147	0.0190	0.00260	0.00432	0.0000380	0.050
4	0.00114	0.00171	0.0000253	0.00725	0.000940	0.00144	0.0000207	0.00603	0.00240	0.00376	0.0000547	0.016
5	0.00154	0.000143	0.0000253	0.00975	0.00120	0.000129	0.0000207	0.00815	0.00300	0.000336	0.0000547	0.021
6	0.00128	0.00264	0.0000127	0.00650	0.00106	0.00219	0.0000107	0.00540	0.00280	0.00570	0.0000273	0.014
7	0.00098	0.00200	0.00000733	0.052	0.000820	0.00168	0.00000867	0.0428	0.00220	0.00438	0.0000220	0.112

Table 3. Average hazard quotient for all metals across age groups

AVERAGE HAZARD QUOTIENT												
ADULT MALE				ADULT FEMALE				CHILDREN				
s/n	K	Mn	Cr	Cu	K	Mn	Cr	Cu	K	Mn	Cr	Cu
1	2.28E-03	1.97E-03	2.12E-05	2.32E-02	1.89E-03	1.64E-03	1.79E-05	1.91E-02	4.89E-03	4.27E-03	4.69E-05	5.01E-02

Moreover, the hazard quotient was also estimated and they were found to be less than 1 for all age groups and in the order of Cu > K > Mn > Cr, which implies that exposure of residents to the groundwater may not result in any health effects. Finally, the average hazard quotient was estimated for all the samples and the values were found to be higher in children especially in Cu, but the observed values were still less than 1; therefore, no threat to life is suspected from the consumption of the groundwater at the time of study, but the improper disposal of waste from the industrialized estate and the application of insecticides and fungicides to farming could result in major health risks in future. Although presently Cu appeared pronounced in all the assessment conducted, therefore, efforts must be made to regularly monitor the concentration of these heavy metal and trace elements, especially Cu intake from groundwater so that it does not exceed the limits required by the body in order to avoid the possible health challenges such as vomiting, nausea and stomach cramps particularly in children that may result.

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