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Human risk assessment using cancer and non-cancer index for metal pollution around Abakaliki metropolis, Nigeria: Underground water quality evaluation.

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Abstract

Groundwater is considered a good source of water for drinking and other domestic purposes because of its perceived low contamination. This study investigated metal concentrations in groundwater from five randomly selected locations in the Abakaliki metropolis of Nigeria. This is aimed to evaluate the human health risk of metals via oral and dermal exposure to drinking groundwater using non-cancer and cancer health risks in the Abakaliki metropolis of Nigeria.There was a significant ($p \leq 0.05$) difference between the mean concentration of As, Pb, Ni, Cd, Cr, Mn, Se, and K in all the study area compared with the permissible limit. None of the metals analyzed was detected in the treated water used as a standard. Average Daily Dose (ADD) values were 100 to 150 times higher than Dermal Daily Dose (DAD) contact pathway, indicating that human exposure to these metals via ingestion is the most significant exposure pathway. Hazard quotient (HQ) values of As, Pb, Cd, Cr, Mn, V, and Se far exceeded the safe reference dose (HQs > 1). This study indicated that the exposed population in the area are at risk of non-carcinogenic adverse health effect, especially Pb and Cd with the highest total HQ (12 – 83% above 1). The estimated Lifetime of Carcinogenic Risks (LTCR) for all the analyzed metals exceeded the predicted lifetime risk for carcinogens from the ingestion pathway. This study indicates potential non-carcinogenic and carcinogenic human health hazards from groundwater intake around the Abakaliki region via oral ingestion.

Keywords: Metals, Risk-Evaluation, Hazard-Quotient, non-carcinogenic-risk, carcinogenic-risks

1.Introduction

Groundwater is conventionally considered as a safe reserve of good quality water and the preferred source of drinking water supply, because of its perceived good microbiological quality in the natural state (Edokpayi *et al*., 2018). Despite the supposed safety of the groundwater, several studies have revealed that groundwater can also be susceptible to contamination (Majolagbe *et al.,* 2016, Indelicato *et al*., 2017, Edokpayi *et al*., 2018). Recent findings have implicated both biological and chemical sources among prominent groundwater pollution agents (Ebokaiwe and Farombi 2016; Nkpaa *et al*., 2018; Ebokaiwe *et al*., 2018). Environmental problems associated with groundwater pollution is on the rise globally and has received considerable attention by scientists all over the world (Muhammad *et al.* 2011; Singh *et al*., 2014; Chappells *et al*., 2014). The impact of natural disasters (earthquake, volcanos, etc.) and anthropogenic (wastewater effluent, mining, landfill disposals, agricultural chemicals, industrial discharge and crude oil spill) activities are now subjects of investigations into groundwater pollutions (Ritter *et al*., 2012; Saha *et al*., 2017). The infiltration of heavy metal-bearing waste waters to the aquifer system is of considerable concern because they are highly toxic, non-biodegradable and probably carcinogenic (Bhutiani *et al*., 2016). Although some metals, such as Cr, Cu, Mn and Fe, serve as micronutrients to maintain animal and human health, they can become toxic after exceeding tolerable levels. Heavy metal accumulation in tissues over time can reach a toxic level, the concentration much beyond the acceptable level (Bhutiani *et al*. 2016). Therefore, human health risk assessment through water consumption has become the primary focus of environmental researchers globally.

Several reports have accentuated health risk to animals and human health due to elevated levels of metals concentration in groundwater supplies (Khan *et al.,* 2014; Sultana *et al*., 2014). Considerably the ill health which affects people, particularly in rural areas of most developing/underdeveloped countries, can be linked to non-availability of potable water (Igwenyi and Aja-Okorie 2014). There is potential for natural levels of metals to be harmful to humans when in remarkable higher concentrations and this may occur when polluted groundwater sources are used for drinking and other domestic purposes without detailed chemical investigations (Igwenyi and Aja-Okorie 2014).

In Nigeria, groundwater from hand dug wells, and deep groundwater sources (boreholes) are often used for drinking and several domestic processes. However, due to often presumed good quality of groundwater, most of the communities and individuals that depend on groundwater pay no attention to the quality of water they drink. The sole dependent on groundwater sources such as wells, boreholes, ponds, streams and rivers for daily water supplies, by inhabitants of the study area is similar to other rural areas of developing/underdeveloped countries of the world (Ojobor and Nnabo 2014). Geological estimations showed that movement of water through soil and rock usually dissolves metals and holds them in solution (Abida *et al*., 2009; *Bhutianiet et al.,* 2016), particularly in areas with high mineral deposits such as Abakaliki metropolis in Nigeria. Previous studies showed that drinking of water containing significant amounts of heavy metals may cause severe health defects such as cancer among others like neuronal and hepatotoxicity, shortness of breath, intravascular hemolysis, hypertension, skin lesions, melanosis, peripheral gastrointestinal bleeding, vascular disease, etc. (Dogan *et al*., 2005, Kavcar *et al*., 2009). Earlier reports revealed that metal levels in groundwater (drinking water) around locations of the present study exceeded the WHO recommended permissible limit for potable water (Ojobor and Nnabo 2014). However, the associated health risk levels of the resident of Abakaliki metropolis have not been investigated.

Water-related diseases that are prevalent in the study area have been suspected to be due to heavy metal-laden underground water as the only source of drinking and domestic use (Afiukwa 2013).This study is therefore designed to (1) investigate the concentration of metals in groundwater of Abakaliki metropolis and compare these measurements to the allowable value for drinking water, (2) evaluate a natural route of human exposure through dermal exposure and drinking contaminated underground water and possible cancer and non-cancer health risk.

2.Materials and Methods

2.1.Study Area

Abakaliki is a capital city among the eastern states of Nigeria. The region is notable for high agricultural practices and rich mineral deposit that attracts mining activities.

2.2..Sample collection and Analyses of heavy metals, by Inductively Coupled Plasma- Optical Emission Spectroscopy (ICP-OES)

Ikwo, Enyigba, Nkwo-agu, Azugwu, and Ugwu-Achara were the five communities in the Abakaliki metropolitan where water samples were taken (Fig.1).

Before water samples were transported to the laboratory, the plastic containers for water samples collection were acidified in situ with a 10% solution of HNO3, sealed, and labeled. Nickel (Ni), lead (Pb), cadmium (Cd), selenium (Se), vanadium (V), arsenic (As), chromium (Cr), manganese (Mn), magnesium (Mg), sodium (Na), calcium (Ca), potassium (K), and zinc (Zn) were among the metals that were analyzed in the water samples using ICP-OES (Perkin Elmer 8000 ICP-OES USA).

Preservation of water samples for metals analyses was done by adding 5 mL concentrated HNO3. This was to prevent metals from adhering to the container and then stored in the refrigerator. Water samples afterwards, were acidified with 10 mL conc. HNO3 evaporated to less than 25 mL and made up to the 25 mL mark in a standard flask. Sample blanks were prepared using 10 mL of doubly deionized water through the same process as the samples. A similar method was reported earlier (Okoye and Adiele 2014). The precision of the measurement ranged from 0.1 to 0.8 % RSD.

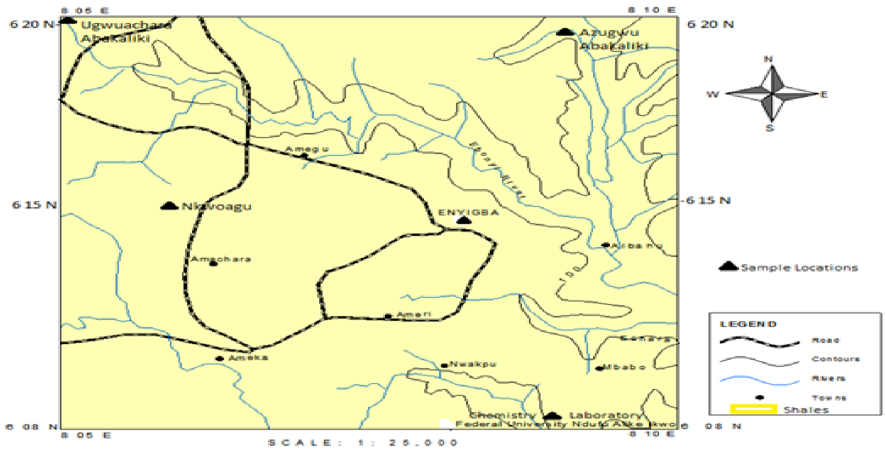

Figure 1: Map of the study area: Ikwo (08°08' 18.4"E; 06°08' 01.3'' N): Enyigba (008°07' 33.4"E; 06° 12' 03.8" N): Nkwo-Agu (008°06' 24.0" E; 06° 15' 08.0" N): Azugwu (008°08' 03.8" E; 06° 20' 02.0" N): Ugwu-Achara (08° 04' 24.8" E; 06° 21' 17.9" N)

2.3.. Risk Assessment for human health

Human health risk assessment (HHRA) was explored in the current study to estimate the chronic adverse effects of non-carcinogenic and carcinogenic heavy metals (As, Pb, Ni, Cd, Cr, Mn, Zn, V and Se) on the human health in the study areas. Threshold limits or reference dose provided by USEPA was used to determine the chronic adverse effects on the population exposed to metals in groundwater in the study locations. Evaluation of the potential human health risk of heavy metals concentrations in groundwater was investigated using the following HHRA indices such as: Average Daily Dose (ADD) (mg/kg/day), Dermal Absorbed Dose (DAD) (mg/kg/day), hazard *3* quotients (HQs) and incremental lifetime cancer risk (ILCR). These were calculated for the individual heavy metals mentioned above via the oral and dermal contact pathway.

2.3.1.Drinking water pathway. The absorption of potentially toxic heavy metal entering the body advertently, by drinking water pathway can be expressed as Average Daily Dose (ADD). The formula for calculating intake is as follow according to USEPA, (1991).

$$ADDoral = \frac{Cw \times IR \times ED \times EF}{Bw \times AT}$$

where ADD is the exposure expressed as the mass of a substance contacted per unit body weight per unit time (mg/kg/day); the health risk assessment parameters used in this study are defined in Table 1.

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Table 1: Input parameters for exposure assessment of metals via oral ingestion pathway

Input parameters	Units	Values	References
Concentration of heavy metals in water (C_w)	mg/L	-	-
Ingestion rate (IR)	L/day	2.0	
Exposure duration (ED)	Year	30	US EPA (2004)
Exposure frequency (EF)	Days/year	350	US EPA (2004)
Average time (AT)	Days	10950	US EPA (2004)
Body weight (BW)	Kg	70	US EPA (2004)

Dermal contact pathway. Dermal Absorbed Dose (DAD) calculations were used to estimate the uptake of potentially toxic metals by the human body via the dermal contact pathway. Derived values from DAD can be defined as the quantity of chemical substance absorbed via dermal contact per kilogram of body weight per day (mg/kg/day). The formula used for calculating DAD was adopted from USEPA (2004). It is represented as shown below:

$$DADdermal = \frac{Cw \times SA \times Kp \times ED \times EF \times ET \times CF}{Bw \times AT}$$

Where DAD is the dermal absorbed dose (mg/kg/day); the health risk assessment parameters used for DAD are presented in **Table 2.**

Hazard Quotient (HQ) has been reported by many researchers (Zeng *et al*., 2009; Alves *et al*., 2014; Chappells et al., 2014) as a means to characterize and quantify non-carcinogenic risk in human health assessment. HQ is a ratio between the dose of a pollutant to the reference dose level (RfD) (Zeng *et al*. 2009).

Oral hazard quotient: Oral hazard quotient for heavy metals for non-carcinogenic risk in health risk assessment is expressed as:

$$HQoral = \frac{ADD}{RfD\ oral}$$

Table 2: Input parameters for exposure assessment of metals via dermal absorbed dose pathway

Hazard Quotient

Input parameters	Units	Values	References
Concentration of heavy metals in water (C_w)	mg/L	-	-
Skin-surface Area (SA)	cm^2	18000	US EPA (2004)
Skin permeability coefficient (Kp)	cm/hr	As=1×10^{-3} Pb=1×10^{-4} Ni=1×10^{-4} Cd=1×10^{-3} Cr=2×10^{-3} Mn=1×10^{-3} Zn=6×10^{-4} V=2×10^{-3} Se=1×10^{-3}	US EPA (2004)
Exposure duration (ED)	Year	30	US EPA (2004)
Exposure time (ET)	h/event	0.58	US EPA (2004)
Exposure frequency (EF)	Days/year	350	US EPA (2004)
Average time (AT)	Days	10,500	US EPA (2004)
Conversion factor (CF)	L/cm^3	1/1000	Wu *et al.* (2009)
Body weight (BW)	Kg	70	US EPA (2004)

2.4.Incremental Lifetime Cancer Risk (ILCR)

Where HQ oral is defined as the non-carcinogen oral hazard quotient via ingestion of water (HQ values are non-dimensional); ADD is the average daily dose intake (mg/kg/day), and RfD oral is the reference dose of heavy metals via ingestion of water (mg/kg/day).

In the present study, only the adult population of groundwater consumers in the study areas was considered as a receptor. HHRA parameters evaluation in this study depends mainly on data and information from reference data published in recent years by researchers and regulatory bodies. It is essential to note that the exposure parameter values recommended by the United States environmental protection department (USEPA) were followed mainly in the present study. The groundwater or drinking water reference doses of both non-carcinogenic and carcinogenic health risks are presented in **Table 3**. The latter is further explained under ILCR below.

$$ILCR = ADDc \times CSF$$

CR is the probability of Excess Lifetime Cancer Risk (or simply risk), ADD (mg/kg/day) is the average daily dose for carcinogenic elements while CSF is the Carcinogenic Slope Factor (mg/kg/day).

Table 2: Input parameters for exposure assessment of metals via dermal absorbed dose pathway

Input parameters	Units	Values	References
Concentration of heavy metals in water (C_w)	mg/L	-	-
Skin-surface Area (SA)	cm^2	18000	US EPA (2004)
Skin permeability coefficient (Kp)	cm/hr	As=1×10^{-3} Pb=1×10^{-4} Ni=1×10^{-4} Cd=1×10^{-3} Cr=2×10^{-3} Mn=1×10^{-3} Zn=6×10^{-4} V=2×10^{-3} Se=1×10^{-3}	US EPA (2004)
Exposure duration (ED)	Year	30	US EPA (2004)
Exposure time (ET)	h/event	0.58	US EPA (2004)
Exposure frequency (EF)	Days/year	350	US EPA (2004)
Average time (AT)	Days	10,500	US EPA (2004)
Conversion factor (CF)	L/cm^3	1/1000	Wu *et al.* (2009)
Body weight (BW)	Kg	70	US EPA (2004)

2.5.Data processing and Statistical Analysis

The data were statistically analyzed by SPSS software version 26. One-way ANOVA was applied for evaluating the significant difference between the metal's concentration in groundwater in the study area and their permissible limit.

3.0. Results and Discussion

3.1.Metal concentrations in groundwater

In this study, heavy metal contents were analyzed in the collected water samples, for ascertaining their concentration levels (Tableb4). All the metals analyzed were detected in the water samples in varying concentrations. The concentration of the metals was found in the range of 0.13 – 0.92, 1.71 – 3.28, 0.28 –0.39, 0.23 – 1.51, 0.35 – 0.70, 6.80 – 9.20, 1.10 – 1.70, 0.30 – 0.73, 0.42 –

0.51, 4.50 – 6.70, 2.10 – 5.20, 7.10 – 11.3 and 5.40 – 5.70mg/L for As, Pb, Ni, Cd, Cr, Mn, Zn, V, Se, Mg, Na, Ca and K, respectively. The mean metal concentration (mg/L) in groundwater was in the following decreasing order Ca>K>Mn>Mg>Na> Pb > Zn > As > Cd >Cr > Se > V > Ni. There was a significant ($p \leq 0.05$) difference between the mean concentration of the following metals (i.e As, Pb, Ni, Cd, Cr, Mn, Se, and K) in all the study areas when compared with the permissible limit by USEPA (2004). Contrary to the perceived safety associated with groundwater (Edokpayi *et al*. 2018), the concentration of Pb, As, Cd, Mn, Cr, Se, and Ni in the water sample from all the sampled locations was extremely higher than that of the control and also exceeded the permissible limits for drinking water (Table 4). This suggested that the use of groundwater for domestic purposes without treatment is unsafe for the resident of the Abakaliki metropolis. This could result in an adverse health issue when ingested by the residents around the Abakaliki metropolis. Although no major industrial activities were going on in the study area, the higher level of some of the heavy metals could be due to some other activities such as storm runoff, leaching of the disposed municipal waste, and municipal landfill which are common practices in the study area (Asare-Donkor *et al*. 2016). The impact of environmental pollution of groundwater as a result of biological and chemical origin poses a serious global health concern to humans in recent times. This has generated a lot of attention from researchers around the world, especially in pollution (i.e by heavy metals, polycyclic aromatic hydrocarbon, etc.) laden environment (Singh *et al*., 2014; Gul *et al*., 2015; Nkpaa *et al*., 2018).

, Enyigba, Nkwo-agwu, Azugwu, Ugu-achara and treated water, along with the permissible limits (USEPA, 2004, 2007) and WHO (2006).

Metals (mg/L)	Ikwo	Enyigba	Nkwo-agwu	Azugwu	Ugu-achara	Treated water	Permissible Limits
As	0.75 ^{a,b}	0.53 ^{a,b}	0.92 ^{a,b}	0.22 ^{a,b}	0.13 ^{a,b}	0.00	0.001
Pb	2.78 ^{a,b}	1.71 ^{a,b}	2.75 ^{a,b}	2.36 ^{a,b}	3.28 ^{a,b}	0.00	0.01
Ni	0.32 ^{a,b}	0.28 ^{a,b}	0.39 ^{a,b}	0.34 ^{a,b}	0.29 ^{a,b}	0.00	0.02
Cd	0.72 ^{a,b}	1.52 ^{a,b}	0.57 ^{a,b}	0.23 ^{a,b}	0.52 ^{a,b}	0.00	0.003
Cr	0.53 ^{a,b}	0.70 ^{a,b}	0.39 ^{a,b}	0.35 ^{a,b}	0.49 ^{a,b}	0.00	0.05
Mn	8.62 ^{a,b}	6.80 ^{a,b}	7.70 ^{a,b}	8.70 ^{a,b}	9.20 ^{a,b}	0.00	0.5
Zn	1.70 ^{a}	1.60 ^{a}	1.10 ^{a}	1.10 ^{a}	1.40 ^{a}	0.00	3
V	0.32 ^{a}	0.30 ^{a}	0.40 ^{a,b}	0.34 ^{a,b}	0.73 ^{a,b}	0.00	-
Se	0.42 ^{a,b}	0.51 ^{a,b}	0.44 ^{a,b}	0.45 ^{a,b}	0.50 ^{a,b}	0.00	0.05
Mg	6.60 ^{a}	4.50 ^{a}	5.40 ^{a,b}	6.20 ^{a}	6.70 ^{a}	0.00	100
Na	3.30 ^{a}	2.10 ^{a}	5.20 ^{a}	3.70 ^{a}	3.00 ^{a}	0.00	250
Ca	9.10 ^{a}	7.10 ^{a}	11.3 ^{a}	9.30 ^{a}	7.70 ^{a}	0.00	75
K	7.60 ^{a}	5.40 ^{a}	5.70 ^{a}	6.80 ^{a,b}	5.70 ^{a}	0.00	-

Table 4: Levels of heavy metals in the studied area compared with the treated portable water and permissible limits (USEPA, 2004, 2007, and WHO 2006). ^{a}= significant difference at $p < 0.05$ relative to treated water. ^{b}= significant difference at $p < 0.05$ relative to permissible limits.

Table 4: Metal concentrations(mg/L) in groundwater around Ikwo **Human health risk assessment**

3.2. Average daily dose (ADD)

The metal concentrations analyzed in the groundwater samples around Ikwo, Enyigba, Nkwo-agwu, Azugwu, and Ugu-achara were used to determine the average daily dose (ADD) via ingestion and dermal contact pathway. In this study, only the adult population was considered throughout the analyses. Also, adult exposure and risk assessments were conducted by a deterministic approach only for the thirteen metals. The ADD results are presented in Table 5. The range of ADD values for groundwater in this study was as follows: 3.56E-3 – 2.05E-2, 4.71E-2 – 8.99E-2, 7.67E-3 – 1.07E-2, 6.30E-3 – 4.16E-2, 9.59E-3 – 1.42E-2, 1.86E-1 – 2.38E-1, 3.01E-2 – 4.65-2, 8.22E-3 – 2.00E-2, 1.15E-2 – 1.40E-2, 1.23E-1 – 1.84E-1, 5.75E-2 – 1.84E-1, 1.95E-1 – 3.10E-1 and 1.48E-1 – 2.08E-1 mg/kg/day for As, Pb, Ni, Cd, Cr, Mn, Zn, V, Se, Mg, Na, Ca and K, respectively. The human exposure to metals via ingestion pathway in the study area is in the following increasing order: Ikwo > Nkwo-agwu > Enyigba > Azugwu >Ugu-achara. The local populace in the study areas makes use of groundwater for drinking, bathing, and industrial purposes. The metal concentrations found in the groundwater samples were notable and significantly exceeded the USEPA (USEPA1991, 2004) and WHO (WHO 2006) permissible limits except Zn, Mg, Na, and Ca. The means of As and Cd concentrations (ranging between 0.13 – 0.92 mg/L for As and 0.23 – 1.52 mg/L for Cd) were 130 – 920 and 77 – 507 times higher respectively than the provided permissible limits by WHO (WHO 2006) and . USEPA (USEPA1991, 2004). The estimated risk through average daily dose for the residents of the study area indicated 'high' cancer risk as per prescribed scale by USEPA (1999), because of the significantly higher concentration of metals recorded in groundwater. All the metals analyzed in groundwater in the study area, which is used by most of the populace as a drinking, cooking, and bathing source may elicit significant health effects except Zn, Mg, Na, and Ca.

Table 5: Average daily dose (ADD) of metals (mg/kg/day) in groundwater around Ikwo, Enyigba, Nkwo-agwu, Azugwu and Ugu-achara, Ebonyi State, Nigeria.

		ADD	**(mg/kg/day)**		
Metals	Ikwo	Enyigba	Nkwo-agwu	Azugwu	Ugu-achara
As	2.05E-2	1.45E-2	2.52E-2	6.03E-3	3.56E-3
Pb	7.61E-2	4.71E-2	7.53E-2	6.47E-2	8.99E-2
Ni	8.77E-3	7.67E-3	1.07E-2	9.32E-3	7.95E-3
Cd	1.97E-2	4.16E-2	1.56E-2	6.30E-3	1.42E-2
Cr	1.45E-2	1.91E-2	1.07E-2	9.59E-3	1.34E-2
Mn	2.36E-1	1.86E-1	2.11E-1	2.38E-1	2.52E-1
Zn	4.65E-2	4.38E-2	3.01E-2	3.01E-2	3.84E-2
V	8.77E-3	8.22E-3	1.10E-2	9.32E-3	2.00E-2
Se	1.15E-2	1.40E-2	1.21E-2	1.23E-2	1.37E-2
Mg	1.81E-1	1.23E-1	1.48E-1	1.70E-1	1.84E-1
Na	9.04E-2	5.75E-2	1.42E-1	1.01E-1	8.22E-2
Ca	2.49E-1	1.95E-1	3.10E-1	2.54E-1	2.11E-1
K	2.08E-1	1.48E-1	1.56E-1	1.86E-1	1.56E-1

3.3.Dermal absorbed dose (DAD)

The DAD values of the analyzed heavy metals in groundwater from the study areas (Ikwo, Enyigba, Nkwo-agwu, Azugwu, Ugu-achara) via dermal contact pathway are presented in Table 6. The DAD values for the water sample ranged between 1.94E-5 – 1.37E-4, 2.55E-5 – 4.89E-5, 8.35E-6 – 1.16E-5, 3.45E-5 – 2.27E-4, 1.04E-4 – 2.09E-4, 1.01E-3 – 1.37E-3, 9.84E-5 – 1.52E-4, 8.94E-5 – 2.18E-4 and 6.26E-5 – 7.61 mg/kg/day for As, Pb, Ni, Cd, Cr, Mn, Zn, V and Se, respectively. Comparing ADD to the DAD contact pathway, ADD values were 100 to 150 times higher than DAD, indicating that human exposure to these metals via ingestion is the most *Int.* significant exposure pathway while DAD could be considered negligible. Among the different exposure routes of water, ingestion played a prominent role in total ADD (i.e ingestion and dermal combined) for metals analyzed in this study. This agrees with other reports on water exposure routes (Shah *et al.* 2012Alves *et al*. 2014). Comparing oral and dermal contact pathways in this study indicates that ADD values via ingestion were 100 to 150 orders of magnitude higher. This confirmed that human exposure to metals via the dermal contact pathway was negligible. Among all the metals analyzed, the populace was more exposed to As, Pb, Cd, Cr, and Se because of their relatively higher concentration in Ikwo, Nkwo-agwu, and Enyigba.

3.4.Hazard Quotient (HQ)

The deterministic estimates of HQ for nine metals in the groundwater samples around Ikwo, Enyigba, Nkwo-agwu, Azugwu, and Ugu-achara via exposure to ingestion contact with adults are presented in Table 7. In human health risk assessment, HQs > 1 indicates a potential risk for a non-carcinogenic adverse health risk to occur in an exposed population and the need for further research. In the sampled area via oral ingestion pathway, the HQ values of As, Pb, Cd, Cr, Mn, V, and Se far exceeded the safe reference dose (HQs > 1) (Table 7). The exposed population in all the area are at risk of a non-carcinogenic adverse health effect, especially to Pb and Cd because they contributed the most to the total HQ (12 – 83% above 1) followed by As, Cr, Mn, V, and Se. Although Ni and Zn have relatively high ADD values, they pose no non-carcinogenic health risk due to their relatively high reference dose values. The non-carcinogenic health risk of metals determined suggests the probability of adverse health effects, which agrees with the report of Leung *et al*. (2008). In this study, HQ values indicate that the concentration of the metals may pose a significant health risk to the exposed populace in the study areas. The HQ value via oral ingestion for As, Pb, Cd, Cr, Mn, V, and Se far exceeded the safe reference dose of 1 (i.e. HQs > 1) when compared with the USEPA34 except for Ni and Zn.

Table 7: Hazard Quotient (HQ) of groundwater around Ikwo, Enyigba, Nkwo-agwu, Azugwu and Ugu-achara, Ebonyi State, Nigeria

			HQ oral		
Metals	Ikwo	Enyigba	Nkwo-agwu	Azugwu	Ugu-achara
As	5.87	4.14	7.20	1.72	1.02
Pb	21.1	13.1	20.9	17.9	24.9
Ni	0.44	0.38	0.54	0.47	0.40
Cd	39.5	83.2	31.2	12.6	28.4
Cr	4.83	6.37	3.57	3.20	4.47
Mn	9.83	7.75	8.79	9.92	10.5
Zn	0.16	0.15	0.10	0.10	0.13
V	1.25	1.17	1.57	1.33	2.86
Se	3.83	4.67	4.03	4.10	4.57

3.5. **Incremental lifetime cancer risk (ILCR/LTCR)**

The ILCR of As, Pb, Ni, Cd, and Cr via consumption of groundwater from the study areas (Ikwo, Enyigba, Nkwo-agwu, Azugwu, Ugu-achara) following exposure to ingestion contact with adults was considered. Oral slope factors have been derived for As, Pb, Ni, Cd, and Cr. Therefore, the risk of cancer for an adult due to ingestion exposure to groundwater was estimated for As, Pb, Ni, Cd, and Cr by the deterministic approach and the ILCR value is presented in Table 8. The average ILCR ranged between 6.05E-3 – 3.74E-2, 4.00E-4 – 7.04E-4, 6.44E-3 – 8.99E-3, 2.39E-3 – 1.58E-2 and 4.80E-3 – 9.53E-3 for As, Pb, Ni, Cd, and Cr, respectively, with As showing the highest ILCR value. The present study indicates substantial lifetime cancer risk from As, Pb, Ni, Cd, and Cr in the study sites as their LTCR values in all the study areas were > 10-4. The value of LTCR for As was even > 10-2 in all the study areas. LTCR which is expressed as a probability of contracting cancer over a lifetime conducted in this study in comparison with established guideline values indicates that groundwater from Ikwo, Enyigba, Nkwo-agwu, Azugwu, Ugu-achara, around Ebonyi State may not be suitable for human consumption because consumers may have the probability of contracting cancer due to hazardous metals exposure. Chronic and acute health effects from exposure to carcinogenic metals (especially As) in groundwater in the communities investigated may pose an environmental health concern. Reports have indicated that acute and chronic health effects such as black foot disease conditions are possible at a daily intake level of 10 to 50 µg/kg/day of As (ATSDR1991). Cardiac or kidney disease, skin lesions, lung, skin, respiratory and bladder cancer, and many other cancer types have been reported even with As levels as low as 10 to 40 µg/kg/day (Lasky *et al*., 2004; Indelicato *et al*., 2017). All the metals have their possible health effect when exposed to them. Moreover, it has been reported that the latency time between exposure onset and chronic disease endpoint appearance like cancer is between 15 to 30 years depending on daily intake dose for many carcinogens like As, Pb, Ni, Cd, and Cr (ATSDR 2007).

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Table 8: Incremental lifetime cancer risk (ILCR/LTCR) of groundwater around Ikwo, Enyigba, Nkwo-agwu, Azugwu and Ugu-achara, Ebonyi State, Nigeria

			ILCR		
Metals	Ikwo	Enyigba	Nkwo-agwu	Azugwu	Ugu-achara
As	3.49E-2	2.47E-2	3.74E-2	1.03E-2	6.05E-3
Pb	6.47E-4	4.00E-4	6.40E-4	5.50E-4	7.04E-4
Ni	7.37E-3	6.44E-3	8.99E-3	7.83E-3	6.68E-3
Cd	7.49E-3	1.58E-2	5.93E-3	2.39E-3	5.40E-3
Cr	7.25E-3	9.55E-3	5.35E-3	4.80E-3	6.70E-3

Conclusions

This study reveals the present state of metal contents of groundwater sources in the studied area. The results of the analyzed metal in the investigated area indicated that the use of groundwater for drinking and other domestic purposes without treatment is unsafe for the resident of the Abakaliki metropolis. The measured concentration of Pb, As, Cd, Mn, Cr, Se, and Ni were higher than the permissible limits for domestic use. The HQ value via oral ingestion and dermal adsorption of the groundwater far exceeded the safe reference dose of 1 (i.e. HQs > 1) when compared with the USEPA. The main contributors to non-carcinogenic risk were Pb and Cd because they contributed the most to the total HQ (12 – 83% above 1) followed by As, Cr, Mn, V, and Se. It is therefore recommended that an aggressive move to seek redress for the pollution of drinking water by stakeholders should be given priority. Awareness of the health risks associated with drinking metal-laden water by the populates of these locations and every other rural area of the developing countries is strongly advised.

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