

Water Quality Evaluation and Human Risk Assessment Using Cancer and Non-Cancer Index for Metal Pollution around Abakaliki Metropolis, Nigeria

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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 location in Abakaliki metropolis of Nigeria. This is aim to evaluate the human health risk of metals via oral and dermal exposure to drinking groundwater using non-cancer and cancer health risk in Abakaliki metropolis of Nigeria.

There was 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 analysed 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 to non-carcinogenic adverse health effect, especially to 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 hazard from groundwater intake around Abakaliki region via oral ingestion.

Keywords

Metals, Risk Evaluation, Hazard Quotient, Policy, non-carcinogenic risk and carcinogenic risks

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 wastewaters 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 (IgwenyiandAja-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 (Igwenyiand Aja-Okorie 2014).

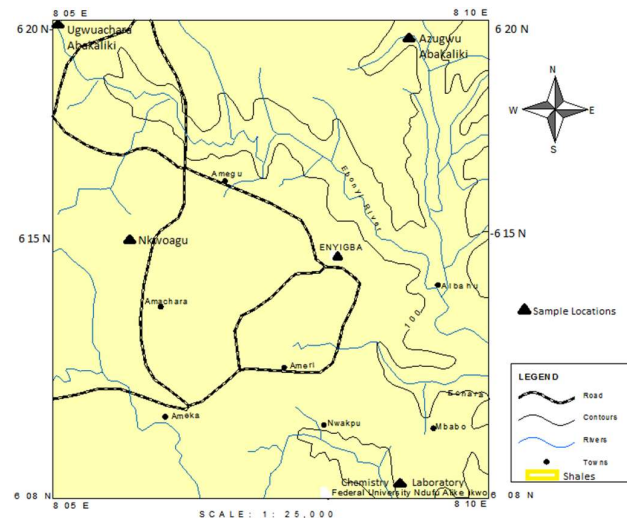
In Nigeria, groundwater from hand dug wells, and deep groundwater sources (boreholes) are often used for drinking and several domestic processes. However, due to often presume good quality of groundwater, most of the communities and individuals that depend on groundwater pay no attention to the quality 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 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). The 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).

Water-related diseases that are prevalent in the study area has 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 levels of metal 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.

Materials and Methods

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. Water samples were collected from five communities (Ikwo, Enyigba, Nkwo-agu, Azugwu and Ugwu-Achara) in Abakaliki metropolis (Fig 1).



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

Before water samples were transported to the laboratory, the plastic containers for water samples collection were acidified *in situ* with 10% solution of HNO₃, sealed, and labelled. Inductively coupled plasma optical emission spectrometry, ICP-OES (Perkin Elmer 8000 ICP-

OES USA) was used to analyze the water samples, which include: 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).

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 doubly deionised 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.

Human health risk assessment

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 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.

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).

$$ADD_{oral} = \frac{C_w \times IR \times ED \times EF}{Bw \times AT}$$

where ADD is the exposure expressed as 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.

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 uptake of potentially toxic metals by the human body via 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:

$$DAD_{dermal} = \frac{C_w \times SA \times Kp \times ED \times EF \times ET \times CF}{Bw \times AT}$$

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

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 <i>et al.</i> (2009)
Body weight (BW)	Kg	70	US EPA (2004)

Hazard Quotient

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 characterise 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:

$$HQ_{oral} = \frac{ADD}{RfD_{oral}}$$

Where HQ oral is defined as the non-carcinogens oral hazard quotient via ingestion of water (HQ values is non-dimensional); ADD is 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 dose of both non-carcinogenic and carcinogenic health risk are presented in Table 3.

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 <i>et al.</i> (2009)
Body weight (BW)	Kg	70	US EPA (2004)

Incremental Lifetime Cancer Risk (ILCR)

Carcinogenic risk also known as the ILCR was estimated in the current study. ILCR is used to investigate the carcinogenic risk of daily exposure of individuals to a carcinogenic contaminant in the environment (especially drinking water and food crops) over a lifetime and the probability of that expose individual developing cancer (Li andZhang 2010;Orisakwe et al. 2017; Nkpaa et al. 2018). Cancer Slope Factor (CSF) utilised during ILCR evaluation assess the probability of excess lifetime cancer risk of an individual due to oral exposure to an environmental contaminant (carcinogens) during a lifetime period (ATSDR2007). It is noteworthy to know that ILCR is highly contaminant specific (Pepper et al. 2012). As, Pb, Ni, Cd and Cr investigated in this study are considered as carcinogenic elements(USEPA 2004). ILCR of As, Pb, Ni, Cd and Cr were evaluated for single exposure pathway (i.e. ingestion), and thereafter the values were used to determine the ILCR. The range of carcinogenic risks tolerable or acceptable by the USEPA is 1 × 10⁻⁶ mg/L to 1 × 10⁻⁴ mg/L). Risk above 1 × 10⁻⁴ is viewed as unacceptable while risks below 1 × 10⁻⁶ mg/L are not likely to pose great health risks. The ingestion cancer slope factor is presented in

Table 3 as revised from USEPA (2004). ILCR was calculated using the equation below:

$$ILCR = ADD_c \times CSF$$

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).

Data processing and Statistical Analysis

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

Results and Discussion

Metal concentrations in groundwater

In this study, heavy metal contents were analysed in the collected water samples, in order to ascertain their concentration levels (Table4).All the metals analysed were detected in the water samples in varying concentrations. The concentration of the metals was found in the rangeof0.13 – 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 were in the following decreasing order Ca>K>Mn>Mg>Na> Pb > Zn > As > Cd >Cr > Se > V > Ni. There was significant (p ≤ 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 area 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).

Table 4: Metal concentrations(mg/L) in groundwater around Ikwo, 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	0.53	0.92	0.22	0.13	0.00	0.001
Pb	2.78	1.71	2.75	2.36	3.28	0.00	0.01
Ni	0.32	0.28	0.39	0.34	0.29	0.00	0.02
Cd	0.72	1.52	0.57	0.23	0.52	0.00	0.003
Cr	0.53	0.70	0.39	0.35	0.49	0.00	0.05
Mn	8.62	6.80	7.70	8.70	9.20	0.00	0.5
Zn	1.70	1.60	1.10	1.10	1.40	0.00	3
V	0.32	0.30	0.40	0.34	0.73	0.00	-
Se	0.42	0.51	0.44	0.45	0.50	0.00	0.05
Mg	6.60	4.50	5.40	6.20	6.70	0.00	100
Na	3.30	2.10	5.20	3.70	3.00	0.00	250
Ca	9.10	7.10	11.3	9.30	7.70	0.00	75
K	7.60	5.40	5.70	6.80	5.70	0.00	-

This suggested that the use of groundwater for domestic purposes without treatment is unsafe for the resident of Abakaliki metropolis. 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 by 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).

**Human health risk assessment
Average daily dose (ADD)**

The metals concentrations analysed in the groundwater samples around Ikwo, Enyigba, Nkwo-agwu, Azugwu, Ugu-achara were used to determine the average daily dose (ADD) via ingestion and dermal contact pathway. In this study, only the adult's population were 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**.

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.

Metals	ADD (mg/kg/day)				
	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

The range of ADD values for groundwater in this study were 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 – 4.65E-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 residence 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 drinking, cooking and bathing source may elicit significant health effect except Zn, Mg, Na and Ca.

Dermal absorbed dose (DAD)

The DAD values of the analysed heavy metals in groundwater from the study areas (Ikwo, Enyigba, Nkwo-agwu, Azugwu, Ugu-achara) via dermal contact pathway are presented in **Table 6**.

Table 6: Dermal absorbed dose (DAD) of metals (mg/kg/day) in groundwater around Ikwo, Enyigba, Nkwo-agwu, Azugwu and Ugu-achara, Ebonyi State, Nigeria.

Metals	DAD (mg/kg/day)				
	Ikwo	Enyigba	Nkwo-agwu	Azugwu	Ugu-achara
As	1.12E-4	7.90E-5	1.37E-4	3.28E-5	1.94E-5
Pb	4.15E-5	2.55E-5	4.10E-5	3.52E-5	4.89E-5
Ni	9.55E-6	8.35E-6	1.16E-5	1.04E-5	8.65E-6
Cd	1.07E-4	2.27E-4	8.50E-5	3.43E-5	7.78E-5
Cr	1.58E-4	2.09E-4	1.16E-4	1.04E-4	1.46E-4
Mn	1.29E-3	1.01E-3	1.15E-3	1.30E-3	1.37E-3
Zn	1.52E-4	1.43E-4	9.84E-5	9.84E-5	1.25E-4
V	9.55E-5	8.94E-5	1.19E-4	1.01E-4	2.18E-4
Se	6.26E-5	7.61E-5	6.50E-5	6.71E-5	7.46E-5

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 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 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 analysed in this study. This agrees with other reports on water exposure routes (Shah et al. 2012Alves et al. 2014). Comparing oral and dermal contact pathway 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 dermal contact pathway

was negligible. Among all the metals analysed, the populace was more exposed to As, Pb, Cd, Cr and Se because of their relatively higher concentration in Ikwo, Nkwo-agwu and Enyigba.

Hazard Quotient (HQ)

The deterministic estimates of HQ for nine metals in the groundwater samples around Ikwo, Enyigba, Nkwo-agwu, Azugwu, 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**).

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

Metals	HQ oral				
	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

The exposed population in all the area are at risk to 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.

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 adult due to ingestion exposure to groundwater were estimated for As, Pb, Ni, Cd and Cr by the deterministic approach and the ILCR value are presented in **Table 8**.

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

Metals	ILCR				
	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

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 area 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 due to 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 level 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).

Policy Analysis

The government policy on groundwater supplies and usages in Abakaliki are analysed based on the results obtained from the heavy metal analyses of the groundwater samples around Ikwo, Enyigba, Nkwo-agwu, Azugwu, Ugu-achara and treated water along with their permissible limits presented in Table 4. There is an active policy drive for the digging of bore-holes for the supply of groundwater to the population. The government policy benchmarks on groundwater supplies are critically justified and determined upon the numbers of bore-holes dug for every 100 persons of the population. Analysis of available government documents shows that the channeling of groundwater and/or the provision of underground water in forms of artificial ponds or bore-holes are merely calculated to be the fulfilment of political campaign promises and the provisioning of democracy dividends to the population. The high ADD as shown in Table 5 by the population is

poor or no public policy frameworks on both the environmental implications and the health implication of heavy metal in groundwater use by the population via oral and dermal pathways.

Conclusions

This study reveals the present state of metal contents of groundwater sources in the studied area. The results of the analysed 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 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 standard. 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 on pollution of drinking water by stakeholders should be given priority. An awareness of the health risks associated with the drinking of 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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