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SPRING WATER CONTAMINATION BY HEAVY METAL AND HUMAN HEALTH RISK ASSESSMENT AT EZEANI, SOUTHEAST NIGERIA

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ABSTRACT

The quest to meet the needs of humans globally has led to contamination of different matrixes of our environment by hazardous substances. In this study, the levels of six heavy metals including Cd, Mn, Cr, Ni, Zn, and Pb, and pH and electrical conductivity were characterized in water samples obtained from Adoka spring and the results were used to evaluate the potability of the water resource and human health risk assessment. Except for Zn, the levels of other heavy metals did not comply favorably with drinking water standards. Hazard quotient values of the oral route for both children and adults were < 1 for Mn, Zn, and Ni while for the dermal route, the values were < 1 for all heavy metals except Cd. The hazard index values for both children and adults via the oral and dermal indicated high chronic risk. The Incremental Lifetime Cancer Risk values indicated that the levels of Cd, Cr, and Ni in water pose a high risk of cancer to the populace. We recommend that an ex-situ removal of heavy metals from water via the use of residuals from treatment plants could be employed to reduce the heavy metal concentration in water before use.

Keywords: Carcinogenic risk; Incremental lifetime cancer risk; Hazard quotient; Hazard index; non-carcinogenic risk; Principal components analysis

INTRODUCTION

Significant population of human residents in developing countries do not have access to municipal water supply networks. Thus, they are compelled to get water from other sources including, streams, rivers, shallow wells, boreholes, and springs. These water sources are often subjected to contamination by biophysical or chemical elements in levels excess of natural background loads which make them unsafe for domestic and agricultural purposes (Eneji et al., 2019; Astatkie et al., 2021). These elements could be harmful microorganisms, microplastics, heavy metals, organic and inorganic compounds, etc. Just of recent, human activities have altered the background levels of chemical constituents of the environment, and heavy metals are very important in this regard since they could be harmful to humans and are persistent nature (Fazlzadeh et al., 2017; Jafari et al., 2018). Generally, water used for domestic purposes (especially drinking and processing of foods) with low concentrations of some heavy metals known as trace elements (zinc, copper, chromium, cobalt, manganese, and molybdenum) is vital for the normal functioning of the human body, but exposure to high concentrations that are above safe levels for a long time can be toxic to human health (Wada, 2004; Islam et al 2017).

The quest for development has often been at some costs to human welfare and in most cases, the impacts are felt some distance away from the point of initiation. Speedy economic development and industrialization for the few pasted decades has facilitated the incidences of heavy metal contamination of the environmental matrices including soil, sediment, surface and groundwater water resources in many parts of the world (Rashed, 2010; Chowdhury et al., 2016). Previous studies revealed that public health issues such as vascular disease, hypertension, restrictive lung disease, cancer, neurological disorder, gastrointestinal ulcer, reproductive failure etc. may occur due to exposure to water contaminated with heavy metals (Bodrud-Doza et al., 2019; Naseri et al., 2021). Thus, it is essential to do periodic assessment due to exposure different environmental toxicant in order to ensure human welfare and sustainability of the environmental. Risk assessment of heavy metals as pertains to human health can be conducted to evaluate the total exposure to human residents in a defined geographical location (Mohammadi et al., 2019). In this regard, it could be hypothesized that heavy metal exposure could either result to carcinogenic or non-carcinogenic effects to humans (Dorne 2011). Inhalation, dermal, and ingestion pathways are the routes of exposure of human and other animals to physical and chemical contaminants in the different matrixes of the environment (Achary et al, 2016).

Effective evaluation of water quality is important to explore the possible live threatening issues associated with the contaminants in water destined for human consumption and other domestic purposes. Simple outline of hazard levels and further ranking of contaminants of significant by the traditional practice of estimating health impacts through direct comparison of analytical values with guideline limits is not effective (Hashmi et al., 2014). Thus, it is important that any study of this kind should explore details of various health related issues in reference to quantifiable values of contaminants. To this effect, development of models to evaluate such issue has improved such task. Health risk assessment models such as hazard quotient, hazard index, lifetime cancer risk etc. are indispensable techniques for simultaneously evaluating the possible health effects of exposure to contaminants in the various matrixes of our environment and consumables (Radfard et al., 2018).15 Also, for a purpose of evaluating the quality of water, some indices can be employed to express the degree of contamination/pollution of different water sources (Ayobahan et al., 2014; Idehen and Ezenwa, 2019; Nnoli et al., 2021). Likewise multivariate statistical technique such as principal components analysis (PCA) is crucial to source identification of environmental pollutants (Mustapha and Nabegu, 2011; Paladino et al., 2017; Yang et al., 2020; Bu et al., 2010). With the aid of the scores of eigenvalues from PCA, contamination sources in the aquatic system can be identified. This is because high eigenvalues within the significant components of PCA draw high influence on the quality of the environmental matric (Bu et al., 2010; Felipe-Sotelo et al, 2007).

Adoka spring is the primary source of water for domestic and agricultural purposes for dwellers in Ezeani town (a rural settlement situated at Southeast part of Nigeria). Review of literatures showed absolutely no data on physicochemical characteristics of the Adoka spring. Equally, there is no information available on the health risk assessment of potential non-carcinogenic and carcinogenic contaminants in this water resource which is destined for domestic and agricultural uses. For these reasons, this study was set to address the following objectives (i) determine levels of six heavy metals including cadmium (Cd), manganese (Mn), chromium (Cr), nickel (Ni), zinc (Zn), and lead (Pb) in the Adoka spring, (ii) use the levels of these heavy metals to determine potability of the spring, (iii) evaluate health risks of non-carcinogenic (Cd, Mn, Cr, Ni, Zn, and Pb) and carcinogenic (Cd, Cr, Ni and Pb) metals in reference to daily drinking of spring water and dermal exposure for children and adults in the community and (iv) identify potential sources for heavy metal contamination of the aquifer.

2. MATERIALS AND METHODS

2.1 Study area description

The study area is positioned by geographic coordinates of N06˚50.169’ E007˚20.709’, located in Ezeani town in Nsukka, Southeast of Nigeria. Nsukka is in derived savannah vegetation zone of southeast Nigeria which is positioned approximately 60km away from Enugu Metropolis, the capital city of Enugu State (Ezenwa et al., 2021). In this area, there is minimal or absence of rainfall at the beginning and end of the year, the peak of rainfall occurs in September with 108.55mm (Onyenucheya and Nnamchi, 2018). Ezeani town is on an elevation of 418 m above sea level. Farming is the major occupation of the dwellers. The farmers irrigate their crops by extracting water from the spring using petrol powered pumping machine. The water from the spring furnishes a gallery forest as it follows through and also forms pools which herders depend on to feed their cattle.

2.2 Sample collection

Sampling bottles were pre-washed by rinsing in metal-free soapy water followed by soaking and rinsing in 10% HNO3 before sample collection. After the bottles were washed with deionized water and at each of the spring outlet (3 in total and are clustered within a space of 15 m2), the bottle was further rinsed with sample water before filling. Samples were collected fortnightly for a period of three months (March to May, 2021). Fifteen water samples were collected. For each sampling event, samples were stored at 4℃ and transported to the National Center for Energy Research, University of Nigeria, Nsukka for laboratory analyses.

2.3 Sample analysis

The collected samples were analyzed for hydrogen ion concentrations (pH), electrical conductivity (EC), and six heavy metals including Cd, Mn, Cr, Ni, Zn, and Pb using standard methods for the examination of water and wastewater. pH and EC were determined in-situ with a multiparametric probe (6920 V2-1 Multiparameter Water Quality Sonde, Xylem Analytics, USA). Concentrations of the heavy metals in all samples were measured using an atomic absorption spectrophotometer (Model AA-7000, Shimadzu Corporation, Japan) connected to an air-acetylene flame burner. The standard solutions of the heavy metals to be determined were used to calibrate the equipment.

2.4 Quality control

Each procedure was repeated thrice to ensure the precision and accuracy of the atomic absorption spectrophotometer method. Certified reference documentation by Federal Environmental Protection Agency (2003) were adopted as a reference guide. The recovery rates which ranged from 93–96%, with standard deviations <5% indicate high data integrity. From a stock solution containing 1000 mg L–1 of the heavy metals analyzed, the solutions which serves as reference for standardization of the curves were prepared. By adopting the methods used for the samples, the blanks and reference solutions were analyzed, and the concentrations were expressed in mgL-1.

Based on the standard deviation of 12 readings obtained for the analytical blanks and the slopes of analytical curves, the limits of detection (LoD), and limits of quantitation (LoQ) were quantified. LOD = 3σ/slope, and LOQ = 10σ/slope, where σ is the signal of the blank. The LoD values (mgL-1) for the metals were 0.00001 (Cd), 0.00001 (Mn), 0.00001 (Cr), 0.00001 (Ni), 0.00001 (Zn), and 0.0001 (Pb). While the LoQ values (mgL-1) were 0.0001 (Cd), 0.0001 (Mn), 0.0001 (Cr), 0.0001 (Ni), 0.0001 (Zn), and 0.001 (Pb).

2.5 Data analyses

Data obtained from the field were subjected to descriptive statistics including mean and range. PCA was used to reduce the dimensionality of the field data and for source identification of the heavy metal contaminations via psych package in R version 4.0.2 (2020). Using the screen plot, eigenvalue ≥ 1 was used as the benchmark for selection of the rotated components (RCs) (Figure 1). The selected RCs were subject to varimax rotation to further differentiate the loadings on the parameters (Ogwueleka et al., 2020). According to Ayobahan et al. (2014) rate and weak factor loading respectively. A scatter plot was prepared according to RC1 and RC2 to reflect the relationship among the heavy metal concentrations, electrical conductivity and pH of the water spring water samples. The q graph package was used to define the strength and sign of correlations among the variables and rotated components.

2.6 Water quality evaluation indices

Heavy metal evaluation index (HEI), and Nemerow pollution index (NI) were used to determine the potability of the spring.

By relying on the concentration of heavy metal, HEI evaluates the overall quality of the water (Edet and Offiong, 2002). HEI is calculated by following

$$\text{HEI} = \sum_{i=1}^{n} \frac{Hc}{Hmac} \qquad (1)$$

Where, *Hc* is analytical value of the heavy metal, *Hmac* is maximum permissible concentration of the heavy metal according to NSDWQ (2007) of the ith parameter and n = the number of parameters which was used in the computation.

The HEI values are categorized into three including low contamination HEI ≤10, medium contamination HEI <10–20 and high contamination HEI>20 (Bodrud-Doza et al., 2016).

NI parameterized by heavy metals was applied to estimate the contributions of the metals to contamination of the water by adopting Equation 2 (Zhong et al., 2015).

$$\text{NI} = \left(\frac{[(\frac{1}{n}) \sum (Ci/Si)]^2 + [\max (Ci/Si)]^2}{2} \right)^{1/2} \qquad (2)$$

where, n=number of heavy metals used for the calculation, Ci= analytical value of the heavy metal i, Si=standard value according to NSDWQ (2007) for the various heavy metals characterized. In line with NI, the degrees of heavy metal pollution of groundwater are divided into 6 which included no pollution: ≤0.5, clean: 0.5–0.7, warm: 0.7–1.0, polluted: 1.0–2.0, medium pollution: 2.0–3.0, and severe pollution> 3.0 (Zhong et al., 2015).

2.8 Human health risk assessment

2.8.1 Chronic risk assessment

Risk assessment which depends on hazard and exposure entails the procedures of estimating probability of occurrence of any given likely magnitude of adverse health conditions over a specific time period (Achary et al., 2016). The health risk assessment is usually quantified at various risk levels and expressed in terms of carcinogenic or non-carcinogenic health risk (Bodrud-Doza et al., 2019). The reference dose (RfD) which represent non-carcinogen risk characterization and incremental lifetime cancer risk (ILCR) representing carcinogen risk characterization respectively are two main toxicity risk factors evaluated for both organic and inorganic contaminants (Lim et al., 2008). Human body is exposed to the contaminants via three main pathways including direct ingestion, dermal absorption and inhalation through mouth and nose (Achary et al., 2016). For this study, both oral and dermal exposure pathway were considered for the risk assessment. Chronic daily intake (CDI) of heavy metal through oral and dermal pathways were calculated by adopting Equations 3 and 4 respectively (USEPA 1989; Karim, 2011).

$$CDI_{oral} = \frac{(CW*IR*EF*ED)}{(BW*AT)} \quad (3)$$

$$CDI_{dermal} = \frac{(CW*SA*Kp*ET*EF*ED*CF)}{(BW*AT)} \quad (4)$$

where, CDI_{oral} and CDI_{dermal} indicate the exposure dose (mg/kg/day) through oral ingestion and dermal pathway respectively and were calculated using the values of parameters presented in Table 1.

Table 1: Parameters for exposure assessment via oral ingestion and dermal absorption pathway

Parameters	Unit	Oral values	Dermal values	References
CW (Concentration of heavy metal in water)	mg/l			Study data
IR (Ingestion rate)	L/day	2.2 (Adult) 1 (Children)		Karim (2011); Rahman et al (2019)
EF (Exposure frequency)	days/year	365	350	Karim (2011); Bodrud-Doza et al (2019)
ED (Exposure duration)	year	70 (Adult) 10 (Child)	30 (Adult) 6 (Child)	Karim (2011); Bodrud-Doza et al (2019)
ET (Exposure time)	h/event		0.58 (Adult) 1.0 (Child)	Bodrud-Doza et al (2019)
BW (Body weight)	kg	70 (Adult) 25 (Child)	70 (Adult) 25 (Child)	Karim (2011); Bodrud-Doza et al (2019)
AT (Average time)	days	25,550 (Adult) 3,650 (Child)	25,550 (Adult) 3,650 (Child)	Karim (2011); Bodrud-Doza et al (2019)
SA (Skin-surface area)	cm^2		18,000 (Adult) 6600 (Child)	Bodrud-Doza et al (2019)
Kp (Permeability coefficient)	cm/hr		0.001(Mn) (Cd) (Cr), 0.0002 (Ni), 0.004 (Pb), 0.0006 (Zn)	Bodrud-Doza et al (2019)
CF (Conversion factor)	L/cm^3		0.001	Karim (2011)

By adopting hazard quotient (HQ) (Equation 5), non-carcinogenic risks for exposure to heavy metals were estimated (USEPA, 1989). HQ value greater than 1 implies an unacceptable risk of adverse non-carcinogenic effects and contrariwise (Giri and Singh, 2015).

$$HQ = \frac{CDI}{RfD} \quad (5)$$

where RfD = the reference dose (µg/Kg/day). The recommended RfD for the metals are presented in Table 2.

Table 2: RfD and Slope factor of the heavy metals

	RfD oral (mg/kg/day)	RfD dermal (mg/kg/day)	CSF (mg/Kg/day)
Cd	5.00E–4	5.00E–6	3.80E–1
Mn	1.40E–1	8.00E–4	
Cr	3.00E–3	1.20E–2	5.00E-2
Ni	2.00E–2	5.40E–3	9.10E–1
Zn	3.00E–1	6.00E–2	
Pb	3.50E–3	5.25E–4	8.50E–1

Source: USEPA, 2018; Ukah et al., 2019

To evaluate the overall potential for non-carcinogenic effects posed by all the heavy metals, the HQs calculated for each of the heavy metals are summated (equation 6) and expressed as hazard index (HI) (USEPA, 1989).

$$HI = \sum_{i=1}^{n} HQ = HQ_{Cd} + HQ_{Mn} + HQ_{Cr} + HQ_{Ni} + HQ_{Zn} + HQ_{Pb} \quad (6)$$

If $HI > 1$ implies an unacceptable risk of non-carcinogenic health effects, and vice versa.[37]

2.8.2 *Carcinogenic risk assessment*

Estimates of incremental Lifetime Cancer Risk (ILCR) was determined for carcinogenic risk assessment. ILCR expresses an incremental likelihood of a person developing any form of cancer over lifetime due to exposure to a given daily amount of a carcinogenic substance for seventy years (Gržetić and Ghariani, 2008). Carcinogenic risk index was calculated for the carcinogenic elements characterized (which include Cd, Cr, Ni and Pb) using Equation 7.

$$ILCR = CDI_{oral} \times CSF \quad (7)$$

where CSF is cancer slope factor which is defined as the risk generated by a lifetime average amount of one mg/kg/day of carcinogen chemical (Mohammadi et al 2019). The cancer slope factors adopted for our study are included in the Table 2 while the scales for chronic and carcinogenic risk assessment are shown in Table 3.

Table 3: Scales for chronic and carcinogenic risk assessment.

Risk level	*HQ/HI*	Chronic risk	Calculated cases of cancer occurrence	Cancer risk
1	<0.1	Negligible	<1 per 1000,000 inhabitants (10^{-6})	Very low
2	≥0.1 < 1	Low	>1 per 1000,000 inhabitants (10^{-6}) <1 per 100,000 inhabitants (10^{-5})	Low
3	≥1 < 4	Medium	>1 per 100,000 inhabitants (10^{-5}) <1 per 10,000 inhabitants (10^{-4})	Medium
4	≥4	High	>1 per 10,000 inhabitants (10^{-4}) <1 per 1000 inhabitants (10^{-3})	High
	-	-	>1 per 1000 inhabitants (10^{-3})	Very high

Bortey-Sam et al (2015)

3. RESULT AND DISCUSSION

3.1 *Heavy metal concentrations*

The summary of the characterized parameters and the drinking water standards are in presented in Table 4. The pH values of the spring water samples varied from 6.30 to 7.30 with a mean value of 6.95. The EC with the mean value of 14.70 μScm^{-1} ranged from 10.70 μScm^{-1} to 35.30 μScm^{-1}. The maximum concentration of Cd, Mn, Cr, Ni, Zn, and Pb was 0.71 mgL^{-1}, 0.97 mgL^{-1}, 0.47 mgL^{-1}, 1.13 mgL^{-1}, and 0.87 mgL^{-1} respectively; the mean values in the sequence were 0.39, 0.74, 0.27, 0.41, 0.44, and 0.28 respectively.

Table 4: Summary of the characterised parameters with the drinking water standards.

	Descriptive statistics (n=15)			Drinking water standards		
Parameters	Mean	Min	Max	NSDWQ (2007)	USEPA (2018)	WHO (20011)
pH	6.95	6.30	7.30	6.5 - 8.5	6.5 - 8.5	6.5–8.5
EC (μScm^{-1})	14.70	10.70	35.30	1000	Not stated	Not stated
Cd (mgL^{-1})	0.39	0.14	0.71	0.003	0.005	0.003
Mn (mgL^{-1})	0.74	0.32	0.97	0.2	0.05	Not stated
Cr (mgL^{-1})	0.27	0.12	0.47	0.05	0.1	0.05
Ni (mgL^{-1})	0.41	0.13	1.13	0.02	Not stated	0.07
Zn (mgL^{-1})	0.44	0.14	0.87	3	5	Not stated
Pb (mgL^{-1})	0.28	0.15	0.45	0.01	0	0.01

NSDWQ = Nigerian Standard for Drinking Water Quality; USEPA = U.S. Environmental Protection Agency; WHO = World Health Organization.

The pH and EC values were compatible with stipulated drinking water standards adopted for this study. The pH which was was slightly acidic to alkaline showed that the water is suitable for diverse uses including domestic, recreational, and agricultural purposes. The field records for the pH were basically consistent to the range of 6.3 to 7.2 recorded by Uzoije et al. (2014) from the shallow aquifer in Nsukka. The EC values which are low indicate low concentration of dissolved solids and low ionic strength of the aquifer (Ahmed et al., 2019). This study showed relatively low EC values which is ideal of freshwater. The range of EC obtained were significantly lower than the range of 403.00 μScm^{-1} to 1080.00 μScm^{-1} obtained by Bodrud-Doza et al. (2019) for groundwater polluted by heavy metals in the central west part of Bangladesh.

The order of the heavy metals according to mean concentrations measured in spring water samples obtained from the studied area was Mn > Zn > Ni > Cd > Pb >Cr. The concentrations of heavy metals characterized in Adoka spring water are of significant health consideration. This is because the concentrations of the heavy metals (except for Zn) did not comply favorably with drinking water standards including, NSDWQ (2007), WHO (2011), and USEPA (2018). Aluko and Emofurieta (2014) in their studies that involved hydrogeochemical evaluation of groundwater in Edo State, recorded high values of Pb and Ni that exceeded WHO permissible limit while Mile et al. (2013) reported high concentrations of Cr, Cd, Fe and Cu higher than WHO prescribed limit for potable water in groundwater source at sources at Benue State. The results of this study showed that the consumers of the water from Adoka Spring are highly predisposed to several health risks attributable to excesses of Cd, Mn, Cr, Ni, and Pb in water. Long term exposure to Cd can cause adversely affect the kidneys and lungs (Dutta et al. 2015); exposure to Pb is associated with multiple health effects including, seizures, different neurological and developmental disorders (Akoto et al., 2019); Mn, Cr, and Ni are categorized as essential in the trace amounts to metabolic processes in the human body but higher levels of them are considered toxic and can adversely affect the nervous system, liver, kidneys, and bones (Naseri et al., 2021).

3.2 Principal component analysis

The screen plot indicated that three of the eight rotated components with eigenvalues greater than one were considered important in explaining the basic nature and configuration of the water quality parameters. (Figure 1). These three RCs accounted for 70% of total variance in the characterised parameters. A cumulative variance of ≥ 70% has been expressed to be relied upon to draw meaningful and reliable conclusions about the properties of the overall dataset (Keke et al., 2021). RCs 1 and 2 accounted for 27.2% and 24% of the variance respectively, while the third RC explained 18.8% of the variance. The scatter plot (Figure 2) followed RC1 and RC2 to show the relationship among the parameters: with the exception of Zn, Cd and Mn were positively correlated with other heavy metals. For the first RC, Pb and Ni had moderate positive loadings while Cr and Zn had strong positive negative loadings respectively (Figure 3). Cd and Mn had strong positive loadings for RC2 and RC3 respective (Figure 3). Altogether, the three RCs of principal component analysis potentially represented different heavy metal contamination sources. Although the anthropogenic sources of heavy metal (examples including improper management of heavy metal laden waste, uses of agro-chemicals, mining activities, use of Pb laden gasoline etc.) could not be rule out as potential sources of heavy metal contamination of the aquifer(s) that supplies the spring, there is possibility of terrigenous sources or leaching of these heavy metals from the rock that surrounding the aquifer. It is important to study the soil mineralogy of this area in order to properly delineate the heavy metal sources. Mile et al. (2013) attributed heavy metal contamination of groundwater to soil mineralogy and use of agro-chemicals.

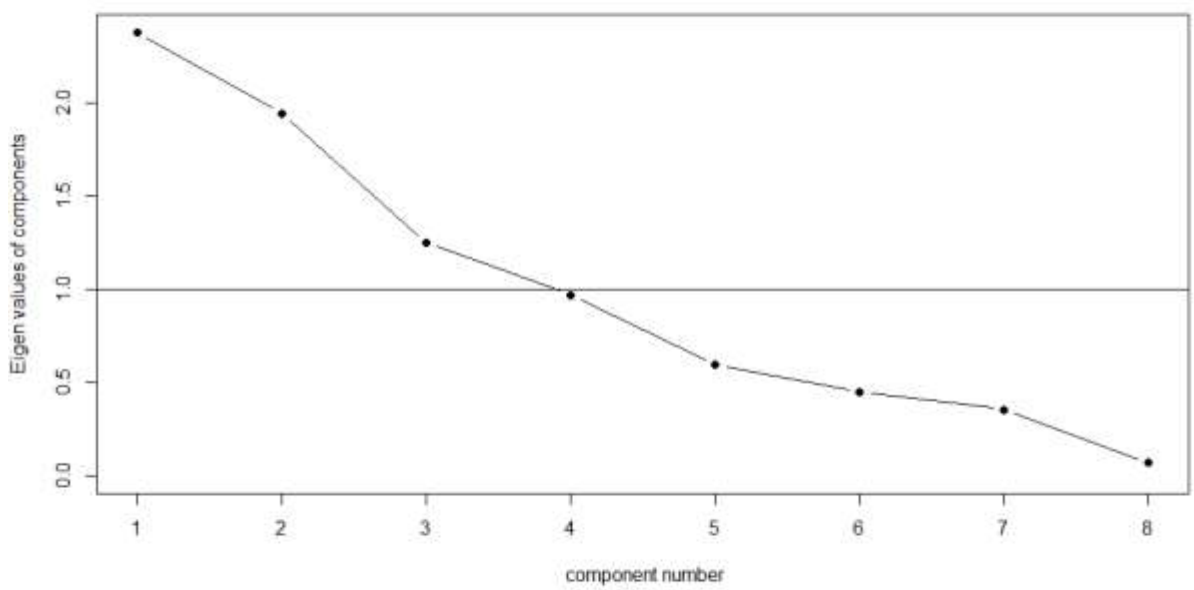

Figure 1: Screen plots of the eigenvalues showing extraction of rotated components of the PCA.

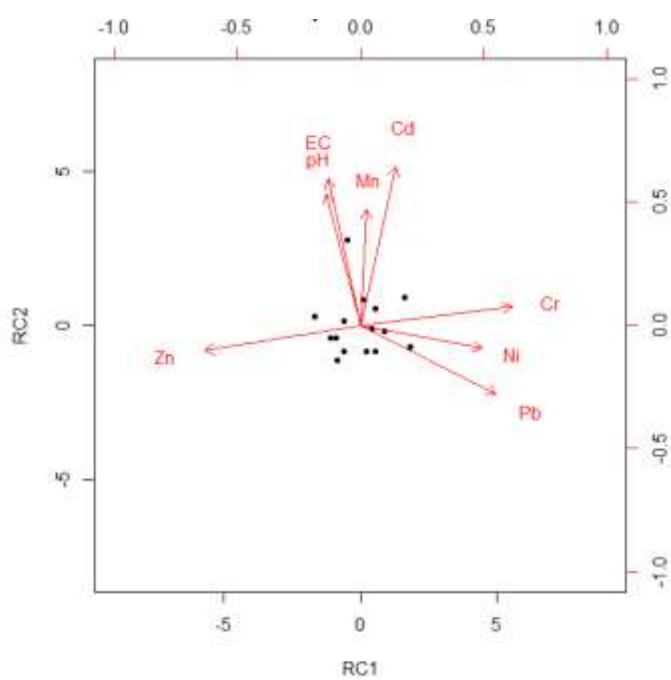

Figure 2: Screen plots of the eigenvalues showing extraction of rotated components of the PCA.

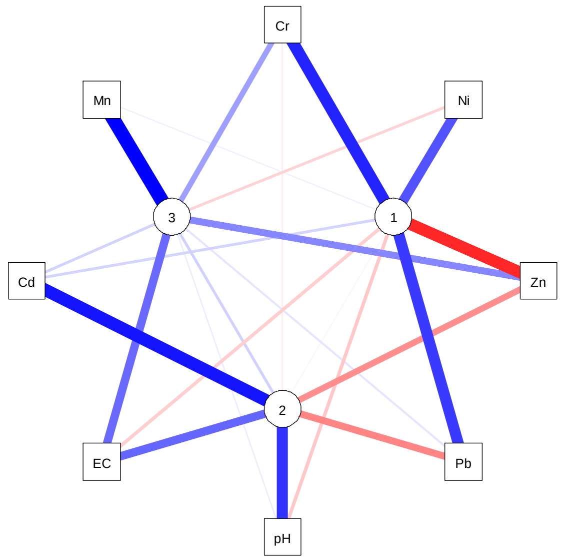

Figure 3: graph plot of the varimax rotated component loadings of the 8 parameters. Blue lines indicate positive loadings while the red lines indicate negative loadings. EC = electrical conductivity.

Contamination level of spring water

The result of contamination evaluation indices showed that the heavy metal evaluation index (HEI) ranged from 5.15 to 272.07 with a mean value of 116.30. Figure 4 shows the attributes of individual heavy metals to the value of the HEI, Cd contributed most significantly to the overall value of HEI. A mean value of 64.14 and a range of 3.49 to 171.32 were recorded for the Nemerow pollution index.

The wide ranges of the pollution evaluation indices adopted for this study are indications that the concentrations of heavy metals in the aquifer that recharge Adoka springs is influenced either by natural or anthropogenic activities. The mean value of the heavy metal evaluation index which is greater than 20 indicates that the spring is highly contaminated (Bodrud-Doza et al., 2016). The evaluation according to the Nemerow pollution index indicated that the spring is severely polluted since the value of the index was greater than bench value of 3 (Zhong et al., 2015). The wide ranges of these indices were functions of the elevated levels of Cd, Ni, and Pb in the spring water samples. In the toxicological profiles of the priority list of 275 most hazardous substances in our environment, Pb, Cd and Ni are categorized as the 2nd, 7th, and 58th, respectively (ASTDR, 2020). Thus, the toxicity of Pb and Cd is of great health concern and the error bars in Figure 4 showed that their input varied significantly.

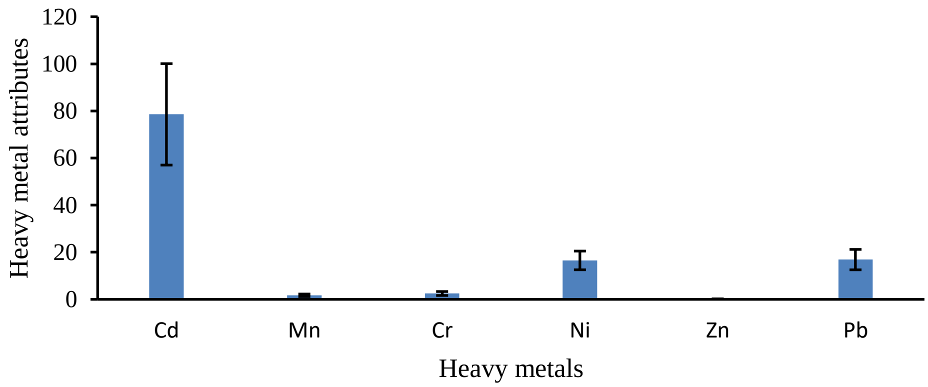

Figure 4: Attributes of the heavy metals to value of the heavy metal evaluation index

Human health risk assessment

Human chronic health risk (hazard quotient - *HQ* and hazard index *HI*) of the spring water through the exposure of oral and dermal pathway for children and adults are summarized in Tables 5 and 6 respectively. For children, the mean values of *HQ* for oral and dermal pathways varied from 5.89E-02 (for Zn) to 3.14E+01 (for Cd) and 6.71E-04 (for Zn) to 1.19E+01 (for Cd) respectively. The scale of *HI* was high and the values are 3.88E+01 and 1.24E+01 for the oral and dermal pathways respectively.

Table 5: Summary of non-carcinogenic children health risks posed by heavy metals in spring water of study area via oral and dermal pathways

Heavy metals	HQ_{oral}	Chronic risk scales	HQ_{Dermal}	Chronic risk scales
Cd	3.14E+01	High	1.19E+01	High
Mn	2.12E-01	Low	1.41E-01	Low
Cr	3.11E+00	Medium	3.38E-03	Negligible
Ni	8.27E-01	Low	2.33E-03	Negligible
Zn	5.89E-02	Negligible	6.71E-04	Negligible
Pb	3.22E+00	Medium	3.26E-01	Low
HI	3.88E+01	High	1.24E+01	High

For the adults, varying values of *HQ* and *HI* were recorded. The values for the oral pathway varied from 2.95E-01 (for Zn) to 1.12E+01 (for Cd) while those of the dermal pathway varied from 2.71E-04 (for Zn) to 4.81E+00 (for Cd). Generally, the *HI* values were high for both pathways (1.40E+01 and 5.00E+00 for the oral and dermal pathways respectively).

Table 6: Summary of non-carcinogenic adult health risks posed by heavy metals in spring water of study area via oral and dermal pathways

Heavy metals	***HQ_{oral}***	**Chronic risk scales**	***HQ_{Dermal}***	**Chronic risk scales**
Cd	1.12E+01	High	4.81E+00	High
Mn	7.56E-02	Negligible	5.67E-02	Negligible
Cr	1.27E+00	Medium	1.36E-03	Negligible
Ni	2.95E-01	Low	9.38E-04	Negligible
Zn	2.10E-02	Negligible	2.71E-04	Negligible
Pb	1.15E+00	Medium	1.31E-01	Low
HI	1.40E+01	High	5.00E+00	High

The *HQ* values of the oral route for both children and adults were < 1 for Mn, Zn, and Ni while for the dermal route, the HQ values were < 1 for all the heavy metals except Cd. Heavy metals with *HQ* value > 1 could pose a low degree of hazards if they occurred independently in the study area (Giri ans Singh, 2015). In all cases, the potentially highest chronic risk was associated with Cd. From the calculation of *HI*, it can be concluded that the contributions of the six heavy metals to the non-carcinogenic health risk via the exposure of oral and dermal routes for children were in the order of Cd > Pb > Cr > Ni > Mn > Zn and Cd > Pb > Mn > Cr > Ni > Zn respectively. For the adults, the contributions via the exposure of oral and dermal routes were in the order of Cd > Cr > Pb > Ni > Mn > Zn and Cd > Pb > Mn > Cr > Ni > Zn respectively. The values of *HI* showed that dermal exposure has a relatively lower risk than oral exposure and children have a comparatively higher risk than adults.

The summary for the incremental lifetime cancer risk (ILCR) is presented in Table 7. The concentrations of the carcinogenic heavy metals characterized varied from 3.42E-05 (for Pb) to 5.37E-03 (for Ni). The values showed that Cd and Ni pose high health risk to the public.

The risk of cancer in humans can be enhanced by some heavy metals including, Pb, Cr (VI), Cd, and Ni (Tani and Barrington, 2005). Long-term exposure to low amounts of these metals could result in different manifestations of cancer (Cao et al., 2014). With exception of Pb, the ILCR values showed that concentrations of Cd, Cr, and Ni in the spring pose a high risk of cancer to the populace that depends on it for consumption. Among all the studied heavy metals, Ni has the highest chance of cancer risks, this was followed by Cd and then Cr. This contradicts the report of Ukah et al. (2019) and Mohammadi et al (2019) on similar researches conducted in Lagos State Nigeria and Iran respectively, Cr was identified as the element that posed the highest chance of cancer risks. These differences could be as results of spatial and temporal variances, as well as natural and anthropogenic activities.

Table 7: The incremental lifetime cancer risk (ILCR) values of carcinogenic human health risks via oral exposure to the spring water of the study area for adults.

Heavy metal	**ILCR**	**Cancer risk scales**
Cd	2.13E-03	Very high

Cr	1.90E-04	High
Ni	5.37E-03	Very high
Pb	3.42E-05	Medium

3.5 CONCLUSIONS

In this study, the levels of pH, EC, Cd, Mn, Cr, Ni, Zn, and Pb in water samples collected from Adoka spring located in Southeast Nigeria were evaluated to ascertain the health risk pose to the populace that depends on this water for domestic purposes. Except for Zn, the levels of all other heavy metals exceeded the standard permissible limits for drinking water. The wide ranges of the pollution evaluation indices indicate that the concentrations of heavy metals in the aquifer that recharges springs are influenced either by natural or anthropogenic activities. Apart from chronic illness which may be fatal at some cases, pollution of water may also result to ecological instability. The results of human health risk assessment regarding to carcinogenic and non-carcinogenic risk assessments further supported the health-threatening conditions the consumers of the water from Adoka spring would be predisposed due to excess of heavy metal in water. For *HQ* and *HI*, the potentially highest was associated with Cd for both children and adults while Ni, Cd, and Cr are of significance to the ILCR. This is a preliminary study that could be expanded via characterizing other heavy metals to have an all-inclusive knowledge of the water quality. Prevention of water contamination is more ideal compared to remediation. The preventive techniques include water policy formulation, monitoring of hazardous substances, proper waste disposal, periodic conducts of environmental audit, public sensitization and campaign on proper environmental management and intensification of health education. Considering the elevated levels of some of the heavy metals in the water samples from Adoka spring, we recommend that the people of the area need to find an alternative source of water for drinking and other domestic uses and avoid the direct use of the agricultural purposes excepted it is treated to reduce the heavy metal content. Residuals generated as a by-product from the water treatment plants have been proven effective for adsorbing heavy metals and metalloids from water (Wołowiecet al., 2019). Such an ex-situ technology which is cost effective could be employed for Adoka spring.

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