FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 8 No. 3, June, (Special Issue) 2024, pp 249 - 256
DOI: https://doi.org/10.33003/fjs-2024-0803-2549

BEYOND THE DUMP: UNMASKING THE CUMULATIVE HEALTH RISKS OF HEAVY METALS IN GROUNDWATER SAMPLES NEAR GOSA DUMPSITE, FCT, ABUJA, NIGERIA

[1]Opasola, O. A., [2]Otto, E., *[2]Salami, J. T. and [1]Adiama, B. Y.

[1]Department of Environmental Health Science, Kwara State University, Malete, Nigeria.
[2]Department of Environmental Health Science, Ajayi Crowther University, Oyo, Nigeria.

*Corresponding authors' email: jt.salami@acu.edu.ng

ABSTRACT

Concerns about heavy metal (HM) contamination of groundwater from dumpsite leachate have global human health implications. The study assessed the concentration level of Manganese (Mn), Lead (Pb), Chromium (Cr), Cadmium (Cd), Copper (Cu) and Zinc (Zn) in the sampled well water near the Gosa dumpsite in FCT, Abuja. Water samples collected were taken to the laboratory in clean airtight plastic containers where HM analysis was performed on the water samples using atomic absorption spectroscopy (AAS) using standard procedures. The concentrations of the HM exceeded the recommended standards for drinking water by both the World Health Organization (WHO) and Standard Organization of Nigeria (SON) except Mn that was within the WHO permissible standard but exceeded the SON permissible limit. Regular consumption of well water near the Gosa dumpsite pose a carcinogenic health risk with respect to Pb, Cr and Cd exposure via oral routes. The cumulative non-carcinogenic risk effect of the HM as indicated by the Hazard Index (HI) exceeded a value of one (HQ>1) to both groups of consumers with children having higher values compared to adults. The study recommends the need to monitor the quality of water while ensuring proactive action is taken by environmental agencies to tackle the looming threat.

Keywords: Hazard quotient, Water quality, Groundwater, Heavy metals, Carcinogenic risk

INTRODUCTION

The persistent urban development and industrial growth in various parts of the globe especially in developing countries have caused significant contamination of HM in the soil and ground water (Mohammadi *et al*.,2019).The degradation of groundwater quality of raises serious concerns on human health (UNESCO,2003,Opasola and Otto,2023).According to Shams *et al*. (2022) and Rashid *et al*. (2021),the presence HMs like Pb, Mn and Cr poses a severe risk to both groundwater and the health of the public globally, this is primarily due to the adverse health effects caused by the contamination of these metals. Metals such Arsenic (As), Pb and Mercury (Hg) do not serve any beneficial purpose in the human body. They are recognized as toxic substances at low because they tend to accumulate and persist in vital organs such as the brain, liver, bones, and kidneys. As a result, they are likely to cause severe health consequences, including carcinogenic effects (Dashtizadeh *et al*.,2019). Most HMs occurs in both ground and surface water (Mohammadi *et al*.,2019; Rashid *et al*.,2021). The contamination of ground water by HMs is widely recognised as a major environmental concern across the globe (Khan *et al*.,2022; Sikdar *et al*.,2020, Saxena *et al*., 2019). In Nigeria and other developing nations, most solid waste produced is typically disposed of in dumpsite (Okonofua *et al*.,2019). According to the studies conducted by Kamoru *et al.* (2019) and Benjamin *et al.* (2014), The problem of managing solid waste has become a prominent concern in the Abuja metropolis. Abuja municipal is grappling with problems such as unregulated dumping of waste, inconsistent waste collection practices and insufficient resources to effectively manage solid waste in a safe manner. Unregulated dumping of waste into dumpsites presents a significant health concerns to the environment, particularly to the land and groundwater (Kamoru *et al*.,2021). Chavan and Zambare (2014) reported that improper management and maintenance of dumpsites may result in soil and air degradation, and contamination of both surface and ground water.

The incessant need for provision of groundwater is on the rise as a result of urbanization and industrialization and expanding population. Prolonged consumption of harmful heavy metals may result in the build-up of these substances in the bones, brain, liver and kidney within the human body (Lu *et al*.,2015).Adverse health consequences, including damage to the nervous system, stunted growth, and developmental issues as well as potential fatality may occur based on the specific toxic element and its chemical composition (Lu *et al*.,2015; Dashtizadeh *et al*.,2019). According to Ritchie and Roser (2021), about 1.2 million deaths are reported annually due to the use of unsafe water sources. This study reveals contamination levels from toxic heavy metals in well water samples near Gosa dumpsite, aiding decision-makers in establishing regulations and monitoring to safeguard the health of the public.

MATERIALS AND METHODS

Study Location description

The study was carried out in Gosa, a municipality in Abuja, Nigeria, falls under the jurisdiction of the Abuja Municipal Area Council (AMAC) in the Federal Capital Territory (FCT). The capital city of Nigeria, FCT, is located in the central Nigeria bordered by Kogi, Plateau, Kaduna, Kwara and Niger States. FCT falls within the latitude of 8.25 to 9.20 North and longitude of 6.45 to 7.39 East from the Greenwich Meridian.Six local councils currently comprise the territory: Abaji, Gwagwalada, Kuje, Bwari, Kwali, and AMAC.

Gosa dumpsite serves as the primary disposal site for household and industrial waste in Abuja, situated in a remote Gosa village, the dumpsite is certainly the biggest in Abuja. The dumpsite covers about 90 hectares of land dumpsite located within AMAC. According to a 2007 report by Bureau of Statistics in Nigeria, the population of AMAC was documented at 776,298 during the 2006 census. As of 2022, the projected population is set to be about 1,693,400, showing a 5% annual growth rate (City Population, 2024).

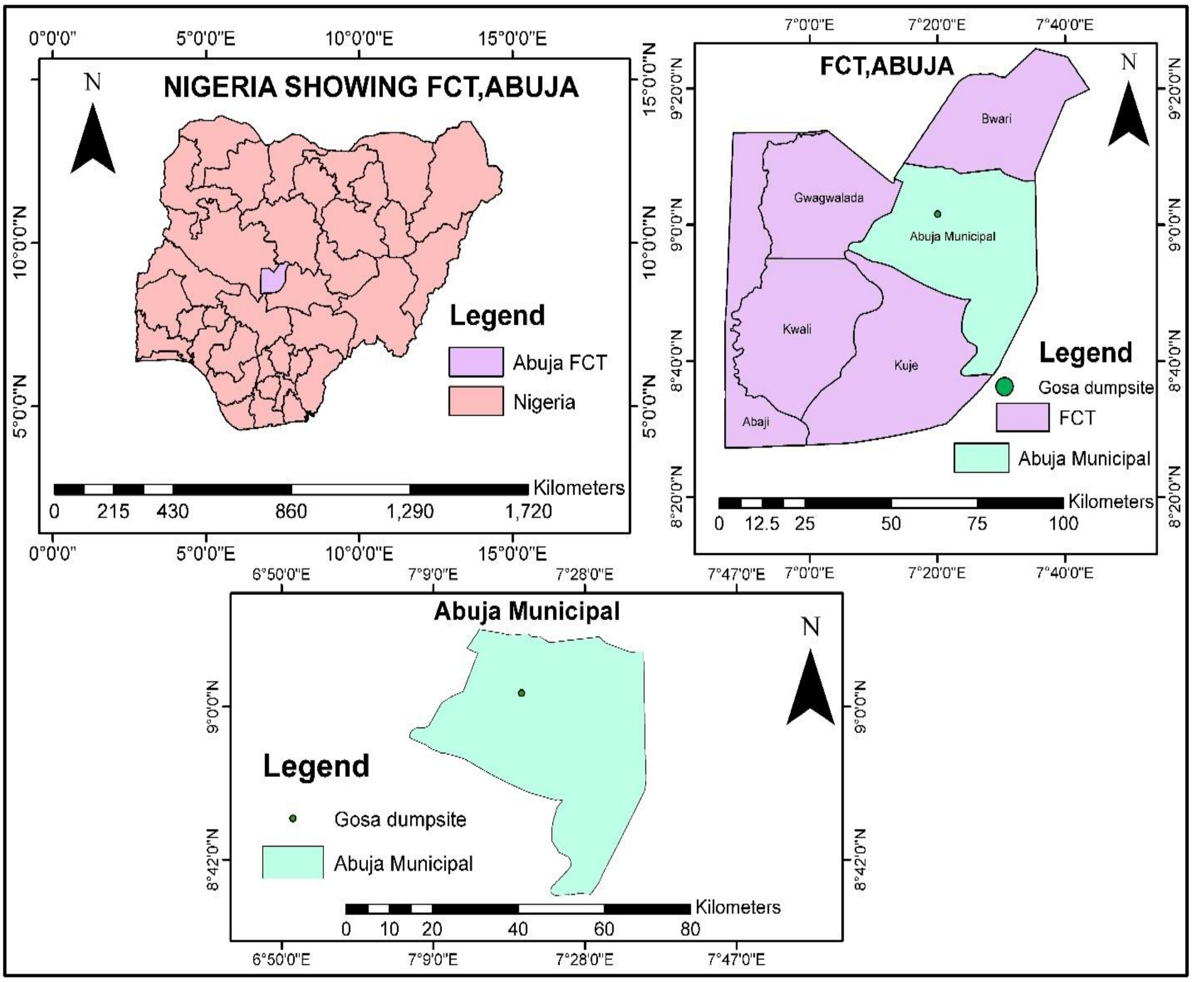

Figure 1: Study Area Map

Sample Collection and Preparation

Four wells near the Gosa dumpsite were selected for water sample collection. A total of eight samples were gathered from these hand-dug wells, with two samples being taken from each well.Before water sample collection,thorough cleaning of the sampling bottles and laboratory glassware was carried out by sequentially rinsing them with deionized and double-distilled water, 10% nitric acid, and sample water. Immediately water samples had been collected,the addition of pure nitric acid (HNO3) was made to the samples to preserve the integrity of the samples by lowering the pH, thus helping to prevent precipitation of metal that might alter the composition of the water sample. This helped to prevent precipitation of metal in the water sample likewise preserving the samples until analysis. The pH meter model E-744 from Metrohm was employed to test the pH of the mixture. Proper labelling was done for the sampled water after collection to prevent confusion, Until they were transported to the laboratory for analysis, the samples were stored in sampling kit at temperature of 4°C.

Water Sample Analysis (Heavy Metal Analysis)

The acidic digestion method adopted by Ogbonna (2022) was employed to determine the heavy metal content of water samples. To prepare each sample, 100 ml of each sample was mixed with 2 ml of concentrated HNO3 and 1 ml of concentrated HCL. The mixture was then heated until the volume reached around 20 ml (Nyambura *et al*., 2020). Furthermore, total digestion of the mixture was made evident by the distinctive colour. To enhance the elimination of any organic matter pollutants from the water samples, prevent any interference with the analysis, and increase the sensitivity of metal detection through atomic absorption spectrophotometry (AAS),digestion of the samples took place in a conical-shaped flask with a volume of 250 ml. This involved the addition of 10 ml of strong nitric acid and 50 ml of water. After digestion, the method of Alidadi *et al*. (2019) was adopted to filter the mixture using a 0.45-mm Whatman pore membrane and allowed to cool.

Plastic bottles were carefully used to preserve the samples that had been digested. The digested samples were carefully preserved in plastic bottles at 4°C until the time of analysis. Atomic Absorption Spectrophotometry (AAS) (Varian AA-240), as adopted by Emmanuel *et al*. (2022), was utilized to analyze the concentrations of Zn, Mn, Cu, Cd, Cr, and Pb in the acidified water samples, specifically focusing on HMs. The calibration curve was employed to compute the average metal concentration after the acidified water samples were examined twice. The WHO (2011) international standards and the lowest permissible limits of the Standard Organization of Nigeria (SON) (2007) were then compared to these values.

Data Analysis

Data obtained from various water samples were analysed with SPSS software ver.23, the result was presented as standard deviation (sd) and the mean, the graphical presentation of the result was done using Microsoft excel. Both Carcinogenic and Non-carcinogenic Risk, Hazard Index (HI), Hazard Quotient

(HQ) then Chronic Daily Intake represented by (CDI), were computed.

Analysis of Human Health Risk

Heavy metal determination

HM analysis of the water samples was assessed. The investigated HM include Cr, Cd, Zn, Pb, Cu and Mn. AAS was used to analyze the HMs and the process was performed twice after which the average concentration was obtained. The metal concentration was expressed as mg/L.A comparison was made between the results obtained and the drinking water standards established by the SON and WHO (Table 1) to evaluate the potential health risks faced by consumers of this water in the sampling location.

Table 1: Heavy metal levels (mg/l) detected in the water samples

HM (mg/l)	WS1	WS2	WS3	WS4	RANGE	MEAN (mg/l)	STD. DEV	SON (2007)	WHO (2011)
Cr	0.03	0.02	0.50	0.002	0.002 - 0.500	0.138	0.24	0.05	0.05
Pb	0.18	0.07	0.07	0.002	0.002 - 0.180	0.081	0.07	0.01	0.01
Cd	0.01	0.006	0.004	0.005	0.006 - 0.010	0.006	0.002	0.003	0.003
Mn	0.23	0.90	0.25	0.09	0.09 - 0.900	0.368	0.36	0.2	0.4
Zn	2.90	2.10	8.95	3.50	2.100 - 8.95	4.363	3.11	3.0	3.0
Cu	0.22	0.19	0.02	0.001	0.001 - 0.220	0.108	0.11	1.0	2.0

HM = Heavy Metals; WS = Water Sample

Exposure Assessment

Chronic Daily Intake

According to Yu *et al*. (2014), CDI of HMs from drinking water was estimated for adults and children during the exposure period (mg/kg/day). Previous studies by Paul *et al.* (2019) and Egbueri and Mgbenu (2020) have reported that ingestion is the primary pathway for population exposure to these heavy metals. Hence, this necessitates the need assess the risks of non-cancer and cancer in both children and adult.

$$CDI = (C \times IR \times EF \times ED) \div (BW \times AT) \quad (1)$$

CDI is the abbreviation for chronic daily intake expressed as (mg/kg/day), IR represents the ingestion rate per unit time, EF describes the exposure frequency, where C stands for the concentration of HM in the water sample expressed as (mg/L), ED represent the duration of exposure, while BW signifies the body weight, and AT indicates the time of exposure. Table 2 contains the values utilised to determine human risk, and the oral referencing dose (RfD) for evaluating toxicity reactions of various HMs is outlined in Table 3.

Non-Cancer Risk Assessment

Several studies (Yu *et al*., 2014; Bamuwamye *et al*., 2015; Pepper *et al*., 2012; Yahaya *et al*.,2022; Muhammad *et al*.,2011) have utilized the non-cancer hazard quotient (HQ) to estimate the non-cancer hazards arising from the non-carcinogenic effects of HMs in drinking water. Equation 2 was used to calculate HQ

$$HQ = (CDI) \div (RfD) \quad (2)$$

The non-cancer hazard quotient is represented by HQ, Li *et al*. (2013) described RfD (mg/kg/day) as the maximum allowable risk to an individual from daily exposure for a sensitive group over a lifetime. CDI (mg metal/kg/day) is determined by Equation 1 (Yahaya *et al*., 2022; Bamuwamye *et al*., 2015; Pepper *et al*., 2012; Yu *et al*., 2014). Evaluation of the potential non-carcinogenic risks posed by HMs in water samples to consumer health was computed through the calculation of the hazard index (HI). The HI is determined by summing the HQ values assigned to each heavy metal (Pepper *et al*.,2012; Liu *et al*.,2013; Yahaya *et al*., 2022). The HI serves as a comprehensive indicator, quantifying the non-carcinogenic effects of consumption of drinking water contaminated by multiple HMs. It is obtained using Equation 3 as as adopted by Bamuwamye *et al*. (2015) and Eze *et al.* (2021). According to a study by Wei *et al*. (2015),if HI < 1 or HQ < 1, it suggests a non-significant non-cancer risk. Equally, if HI ≥ 1 or HQ ≥ 1, it signifies a significant non-cancer risk, which typically increases with higher values of HQ or HI.

$$HQ = \Sigma HQPb + HQCr + HQCd + HQMn + HQCu + HQZn \quad (3)$$

Hazard Quotient (HQ) of Zn, Cr, Cu, Pb, Cd and Mn are added together to get the Hazard Index (HI).

Table 2: Parameters used for calculating CDI from Exposure to HMs in drinking water

Exposure Variables	Unit of Expression	Values	
		Adult	Children
Ingestion Rate (IR)	L/day	2.2	1.8
Exposure Freq. (EF)	Day/year	350	350
Exposure Duration (ED)	Years	70	6
Body Weight (BW)	Kg	70	15
Average Time (AT)	Years	25550	2190

Source: (Opasola and Otto,2023; Wongsasuluk *et al*., 2014)

Assessment of Cancer Risk

HM related cancer risk was ascertained by estimating the human risk assessment from consuming the sampled water (USEPA, 2012). Cancer risk describes the probability of cancer developing in a population exposed to carcinogens, calculated through the Incremental Lifetime Cancer Risk (ILCR) (see Equation 4) (Opasola and Otto,2023; Sultana *et al*., 2017)

$$ILCR = (CDI \times CSF) \quad (4)$$

ILCR denotes incremental life cancer risk and is calculated using Equation 4 and ΣILCR is the combined risk of developing cancer due to exposure to various carcinogenic heavy metals in water. It is the summation of all the individual incremental life cancer risks is calculated using Equation 5 (Liu *et al*., 2013). CDI, on the other hand, represents chronic daily intake measured in milligrams per kilogram of body weight per day. Additionally, CSF denotes the cancer slope factor as outlined in Table 2.

$$\Sigma ILCR = (ILCR1 + ILCR2 + ILCR3 + \cdots ILCRn) \quad (5)$$

n denotes carcinogenicity of individual heavy metal in analysed water samples. According to Li *et al*. (2014), the USEPA sets the range for cancer risk within 1×10^{-6} and 1×10^{-4} for regulation purposes.

Table 3: Cancer slope factor and Oral reference doses employed to compute the toxicity of HMs from the sampled water

Heavy Metals	RfDing (mg/kg/day)	CSFing (mg/kg/day)
Chromium	3.0E-03	0.5
Lead	3.5E-03	0.0085
Cadmium	5.0E-04	0.38
Manganes	1.4E-02	-
Zinc	3.0E-01	-
Copper	4.0E-03	-

Source: Tay *et al*. (2019)

RESULTS AND DISCUSSION

Concentration of HM in the sampled water

Table 1 and Fig. 2 compares the HM mean concentration values in the analyzed sampled water with WHO (2011) and SON (2007) recommended acceptable limit for drinking water. It indicated that the average HM levels of Cr, Pb, Cu and Zn in all the sampled water exceeded both the WHO (2011) and SON (2007) permissible limit standards except Mn that was within the WHO limit but exceeded the SON limit. Cr levels found from this research is lower than in 5.08 mg/l in a study by Mohammadi *et al*. (2019) but higher than 0.078 mg/l as reported by Opasola and Otto (2023). The concentration of Pb as found in this research is however lower than the value of 0.179 mg/l reported in previous studies by El-Sayed and Salem (2015) and 0.35 mg/l reported by Mkude (2015). However, the range of Mn concentration as found in this research exceeds the value of 0.057- 0.175 mg/l as reported by Abdullahi *et al*. (2016) in a Nigerian study. However, Cu average concentration level was below and meet the recommended limits of the two monitoring bodies. Cu concentration from this research exceeds those of previous studies (El-Sayed and Salem,2015; Bamuwamye *et al*.,2017). Cr levels in WS4, WS2 and WS1 and were below and within the SON and WHO limits while WS3 had values that exceeded both regulatory bodies. The concentration of Cr as found in this research is above the value reported by Afiukwa (2013) in Ebonyi State. The levels of Pb in WS3, WS2 and WS1 exceeded both SON and WHO recommended standard except for WS4 that was below and within the SON and WHO limits. Cd concentration in all the sampled water WS1, WS2, WS3 and WS4 exceeded both SON and WHO permissible limits. The level of Cd in this research exceeds the value of 0.001 mg/l as reported by Opasola and Otto (2023) who examined heavy metals status of well water in Kaduna State. However, Cd concentration from this research is lower than the value of 0.008 mg/l reported by Afiukwa (2013) in a study on heavy metal analysis of ground water samples. The concentration of Mn in WS1 and WS3 exceeded the SON limit but within the WHO limit. However, WS2 exceeded both SON and WHO limit apart from WS4 that as below and within both SON and WHO permissible limit. The concentration of Mn from this research is below the value of 1.095 mg/l in a study by El-Sayed and Salem (2015) and 2.805 mg/l reported by Opasola and Otto (2023). The concentration of Zn in WS1 and WS2 were within the SON and WHO permissible limits except WS3 and WS4 that exceeded both regulatory bodies. Zn concentration from this work exceeds those from previous studies (Nigatu *et al*.,2015; Mkude,2015). Cu levels in the analysed samples- WS1, WS2, WS3 and WS4 were below and within the SON and WHO permissible limits. Cu levels from this research exceeds the values reported by earlier studies (El-Sayed and Salem,2015;Bamuwamye *et al*.,2017).The increasing order of the HMs concentration in the water samples (Table 1) shows the following pattern: Cd(0.006) < Pb(0.081) < Cu (0.108) < Cr (0.138) < Mn (0.368) < Zn (4.363).Cd had the lowest mean concentration followed by Pb and the highest mean concentration was found in Zn.

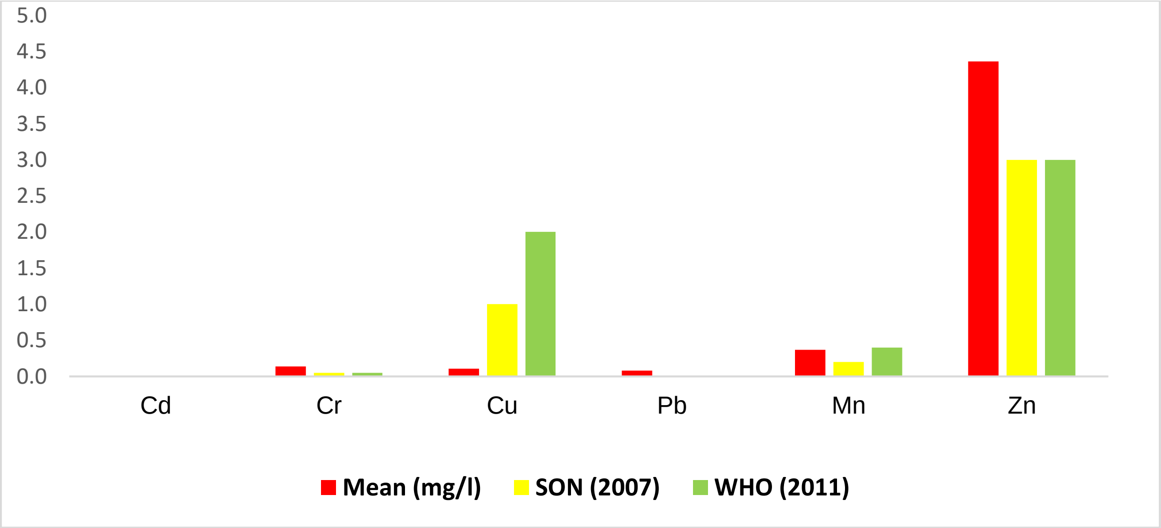

Figure 2: HM mean concentration comparison with WHO (2011) and SON (2007) drinking water permissible limits

Assessment of Non-Cancer Risk

To estimate the non-carcinogenic effect of exposing to HM in water, Hazard Quotient (HQ) of various HMs in the water sample as adopted by Yu *et al*.(2014) and Bamuwamye *et al*. (2015) was adopted (see Equation 2).In addition, Equation 3 was utilized to calculate the HI by total addition of all individual HQs of the HM in the water samples consumed by the users - vulnerable groups (adult and children) this was adopted from earlier work by Bamuwamye *et al*. (2015) and Opasola and Otto (2023).

The HQ of the HM for both groups of consumers i.e. children and adults. The Children had both HQ values for Cr and Mn exceeded one i.e. HQ>1; Cr (5.26E+00); Mn (3.021E+01) and adults Cr (1.38E+00) ; Mn (7.92E+00), suggesting there is possibility of non-cancer risk after consuming such water by the adult and the children and adult from the sampling location (see Table 4). The HQ for Pb (6.97E-01), Cd (3.62E-01), Zn (4.3E-01) and Cu (8.12E-01) was less than one (HQ<1) for adult, representing no non-carcinogenic risk linked with Pb, Cd, Zn and Cu contents of the sampled water among the adult consumers via oral intake. However, the values of HQ of the analysed HMs include; Cr (5.26E+00),Pb (2.66E+00), Cd (1.38E+00), Zn (1.67E+00) and Cu (3.1E+00) all exceeded one (HQ>1) for children. This indicates that the non-cancer risk effects of consuming the water that is contaminated by the HMs is significant for children. The Hazard Index (Table 4) indicates higher values for both adults (1.16E+01) and children (4.42E+01) which exceeded the WHO recommended limits. This implies a significant risk to the children and the adults while children is likely to have the most non-carcinogenic risk. The increasing order of non-cancer risk arising from consuming the HM from the sampled water from the location is Cd > Zn > Pb > Cu > Cr > Mn for the adults and the children.

In addition, the computed HIs for children (4.42E+01) and adults (1.16E+01) were above the allowable thresholds (HI >1), meaning both consumers (children and adults) are greatly at risk of having non-cancer effects from consuming the water (Opasola and Otto,2023; Wagh *et al*., 2018). The result of this research supports earlier studies on health effects of HM contamination in groundwater which identifies non-carcinogenic risks effects associated to HI values that exceed the permissible thresholds (HQ > 1) (Opasola and Otto.,2023; Ganiyu *et al*., 2021).

Table 4: Non-Cancer Risk Assessment: Chronic Daily Intake (CDI), Hazard Index (HI) and Hazard Quotient (HQ)

Parameters	CDI (mg/kg/day)		HQ	
	Child	Adult	Child	Adult
Cr	1.58E-02	4.15E-03	5.26E+00	1.38E+00
Pb	9.32E-03	2.44E-03	2.66E+00	6.97E-01
Cd	6.90E-04	1.81E-04	1.38E+00	3.62E-01
Mn	4.23E-02	1.11E-02	3.021E+01	7.92E+00
Zn	5.02E-01	1.31E-01	1.67E+00	4.36E-01
Cu		3.25E-03	3.1E+00	8.12E-01
HI		1.24E-02	**4.42E+01**	**1.16E+01**

Assessment of Cancer Health Risk

Table 5: Cancer Risk Assessment: Incremental Life Cancer Risk (ILCR)

Parameters	ILCR	
	Child	Adult
Cr	7.9E-03	2.07E-03
Pb	7.92E-05	2.07E-05
Cd	2.62E-04	6.87E-05
ILCR	**8.24E-03**	**2.16E-03**

Of the six HMs that were analysed, only Cr, Pb, and Cd contributed significantly to the carcinogenic risk assessment, as indicated in Table 5. The reason for this was because CSF was not available for the other HMs. The ILCR cancer risk associated with ingesting the sampled water was calculated using Equation 4 (Sultana *et al*., 2017) by computing the CDI (Table 4) and obtaining Cancer Slope Factor (CSF) values (Table 3). Table 5 shows that there is a considerable carcinogenic risk effects to both adult and children users who consumes the sampled water, based on higher values of ILCR of all the analyzed HMs which were found to be above the USEPA permissible limit of 10^{-6} to 10^{-4}. Additionally, the result of our research indicated that ΣILCR sum for children (8.24E−03) and adults (2.16E−03) were above the USEPA-acceptable range of 10^{-6} to 10^{-4}, suggesting a carcinogenic effect on both adult and child users of the water in the research area (Table 5).However, given the high ILCR values among the children who consumes the water, the carcinogenic effect is perhaps greater in children than in adults. Moreover, adults and children exposed to well water that contains the analysed HMs tend to have a potentially cancer risk accordingly from low to high risk; Cd > Pb > Cr. This findings align with those of earlier research conducted by Ganiyu *et al*. (2021), Rajaei and Hesari (2012), and Opasola and Otto (2023), that independently found that the cancer risk associated with HM in groundwater exceeded allowable limits for both the adults and the children. In general, the findings indicate a notable cancer risk for all categories of consumers, which is unhealthy and necessitates proactive intervention.

This study contributes significantly by assessing the concentration of specific HMs from sampled groundwater taken from wells close to the Gosa dumpsite in the FCT, Abuja. Furthermore, the ten chemicals that the WHO has identified as posing serious health concerns to humans were part of the HMs that were assessed in this study. Therefore, it provides insightful data that will support evidence-based interventions for improving water quality and advance the achievement of SDG 6, which calls for the availability and accessibility of a sustainable and safe supply of water. However, the fact that the ingestion pathway was adopted to evaluate the exposure risk rather than considering other possible routes of exposure, such as the dermal pathway, limited the scope of our investigation. Further research into the health risks of HMs on human health through dermal exposure is suggested to improve the understanding of the well water quality in the area.

CONCLUSION

This work has evaluated the possible health risks and HMs in groundwater samples obtained from well water around the Gosa dumpsite. The results indicate a notable level of heavy metal contamination, with mean levels of most heavy metals exceeding the allowable thresholds established by WHO (2011) and SON (2007).The order of the HM contamination follows; Zn (4.363) > Mn (0.368) > Cr (0.138) > Cu (0.108) > Pb (0.081) > Cd (0.006). Potentially, the adults and children who consume the sampled well water are at risk of experiencing significant health risks, including carcinogenic and non-carcinogenic effects, with values of HI and ΣILCR that exceeded the allowable limits. In general, this investigation suggests that individuals residing in the area may face detrimental effects from HMs, including both carcinogenic and non-carcinogenic impacts. Notably, children are more at risk of carcinogenic health effects compared to adults, primarily due to exposure to Pb, Cr and Cd through oral pathways. The study recommends the need to monitor the quality of water while ensuring proactive action is taken by environmental agencies to tackle the looming threat.

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