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**Beneath the Surface: Uncovering Heavy Metal Contamination in Public  
Drinking Well Water and the Public Health Implications in Kaduna  
South LGA, Nigeria**

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**ABSTRACT**

Unsafe drinking water has emerged as a critical global public and environmental health concern, particularly in underdeveloped nations. Evidence indicates that unsafe water sources are responsible for approximately 1.2 million deaths annually, most of which are the result of heavy metal (HM) contamination, which poses a severe threat to public health. This study explored selected HM contamination and the likely non-carcinogenic and carcinogenic health risks to the consumers of public drinking well water sources in Kaduna South LGA, Nigeria. Atomic absorption Spectroscopy was adopted for HM analysis, and potential health risks were evaluated using the established Human Health Risk Exposure Assessment Indices. The findings indicated an unsafe quantity of HMs, with the mean concentration above the recommended limit prescribed by the Standard Organization of Nigeria (2007) and the World Health Organization (2011) for most HMs in the order; Zn (33.523) > Mn (2.805) > Pb (0.793) > Cr (0.05), as well as a substantial non-carcinogenic and carcinogenic health risk for adults and children with the Hazard Index and Cancer Risk values above the recommended standards. The findings will prove useful to public health authorities in developing evidence-based monitoring and active interventions to facilitate the delivery of safe drinking water to the local population.

**Keywords:** Cancer risk, Heavy metal, Hazard quotient, Health risk, Public health, Water quality

**1.0 INTRODUCTION**

Worldwide, especially in developing nations, unsafe drinking water poses significant environmental and public health concerns. For instance, reports show that unsafe water sources are responsible for approximately 1.2 million deaths annually (Ritchie & Roser, 2021), which, according to the same authors, is equal to the annual global deaths from road traffic accidents. Regrettably, most unsafe water sources are often polluted with heavy metals (HM), representing a grave risk to human health. Some HMs, such as chromium (Cr), zinc (Zn), copper (Cu), and manganese (Mn), are essential components of human nutrition with biochemical and physiological benefits (Prashanth *et al.*, 2015). However, consuming water containing excessive amounts of these essential or harmful metals, such as lead (Pb) and cadmium (Cd), may pose adverse health effects (Shah *et al.*, 2020). For example, Pb is highly toxic and may cause chronic health issues, including damage to

the liver, kidneys, and nervous and reproductive systems (Fu & Wang, 2011; Muhammad *et al.*, 2014). In addition, Cd is known to have grave effects on the liver and kidneys and is responsible for bone deformation (Fu & Wang, 2011; Dabai *et al.*, 2013; Muhammad *et al.*, 2014). Similarly, Cr, even with its benefit in the bio-synthesis of glucose tolerance factor (Prashanth *et al.*, 2015), is a known carcinogen that has been linked to damage to the liver, kidney, and blood cells (Fu & Wang, 2011; Dabai *et al.*, 2013; Muhammad *et al.*, 2014). Others have linked Mn to neurological disorders, including Cu with gastrointestinal disorders (Standard Organization of Nigeria, SON (2007), whereas Zn has been associated with diarrhoea, muscle cramps, and renal damage (Izah *et al.*, 2016). Therefore, prescribing permissible standards for HMs in drinking water is an effective strategy to safeguard the public from the risk of HM contamination; hence, the World Health Organization's (WHO) international guidelines at the global level (WHO,

2011) and Nigeria's Drinking Water Quality Standard at the national level (SON, 2007) provide measures to mitigate and control the risks associated with drinking water safety to improve public health.

Despite this, there are increasing concerns about the quality and availability of water supply in Nigeria, much like in most undeveloped nations, and understandably so, due to the rising demand and potential public health concerns of inadequate safe water supply occasioned by the increasing population growth, which is anticipated to reach 264 million, with a growth rate of about 2.57% annually (World Population Review, 2022). For example, the Federal Ministry of Water Resources (FMWR), in its 2022 report of findings on water sanitation and hygiene, documented that almost 87% (179 million) of Nigerians lack access to a clean water supply, with the north mainly affected (FMWR, NBS, UNICEF, 2022). Similarly, a recent study investigating the progress of drinking water quality in northern Nigeria found that more than half (55.74%) of the water sources were unfit for consumption (Imam *et al.*, 2023). Therefore, the need for regular monitoring of water quality, driven by empirical evidence on the water quality, particularly HM content, considering the numerous evidence of its potential chronic health impacts on consumers.

Although several studies on water quality have been conducted in northern Nigeria, many have assessed the microbial and physicochemical quality of water (Amoo *et al.*, 2018; Bisiriyu *et al.*, 2020; Yohanna *et al.*, 2021), whereas others have only focused on the HM concentration in drinking water sources (Oyatayo *et al.*, 2015; Okegye & Gajere, 2015). However, comparisons with acceptable standards are inadequate for quantitatively measuring the likely health exposure risk of HMs in drinking water. Hence, the health risk evaluation of HMs in drinking water sources remains largely unexplored. The impact of HM pollutants in drinking water and the associated health risks are critical to consider when estimating drinking water quality (Onyele & Anyanwu, 2018; Saira *et al.*, 2019). The human health risk assessment examines the possibility of adverse health effects of HM in water or other environmental media on people who

may be exposed. Many studies have used this approach to analyze the likely health hazards of HM exposure in polluted water (Tay *et al.*, 2019; Nyambura *et al.*, 2020; Emmanuel *et al.*, 2022; Ogbonna, 2022). Thus, our study addresses this knowledge gap by exploring the human health risks of oral consumption of selected HMs in public drinking well water sources in Kaduna South Local Government Area (KSLGA), Nigeria.

Given the foregoing, the primary objectives of this study were to (1) determine the concentration of selected HMs in public drinking well water sources in KSLGA and (2) assess the potential carcinogenic and non-carcinogenic health risks of the aforementioned HMs on both children and adult populations by exploring the corresponding Incremental Lifetime Cancer Risk (ILCR) and the Hazard Quotient (HQ). Thus, this study makes significant contributions by providing valuable insight into the HM status of drinking water sources and the potential health risks to local consumers and highlights the relevance of monitoring water quality to safeguard public health. Furthermore, the findings will prove useful as a critical policy signpost for prioritizing long-term water quality regulations and monitoring programs at local and national levels.

The remaining parts of this paper are organized as follows: Section 2 summarizes the approaches and data used in the analysis. The empirical findings and discussions are provided in Section 4, and the last section presents the conclusions and valuable policy recommendations.

## 2.0 MATERIALS AND METHODS

### 2.1 Study Area

The assessment of HM concentrations in public drinking water sources was conducted in KSLGA, which is located in the north-central region of Kaduna State (see Figure 1), with a land area of 59 km<sup>2</sup> and geographic coordinates of approximately 10°27'43"N and 7°25'38"E. According to the 2006 census, the population of KSLGA was 402,731 (National Bureau of Statistics, 2007). However, this figure is projected to be approximately 595,000 as of 2022, indicating an annual population growth rate of 2.5 % (City Population, 2023). It is home to

many industries, including carpets, textiles toiletries amongst others.

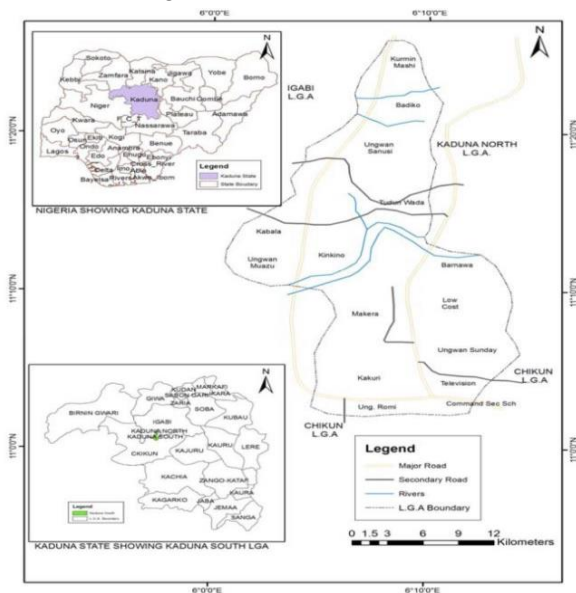


Figure 1. Study Area Map (Ezeamaka *et al.*, 2019)

## 2.2 Sample Collection and Preparation

A purposive sample of four public hand-dug wells was selected to analyze the HM concentration of water in the area of study based on the accessibility and representation of the water sources for the local population. The laboratory glassware and sampling bottles were washed and rinsed with 10% nitric acid, deionized and double-distilled water, and finally, with sample water before sample collection. After collection, the samples were made acidic by adding pure nitric acid ( $\text{HNO}_3$ ) to achieve a pH below 2.0 and measured using a Metrohm E-744 model pH meter. This helped to prevent metal precipitation and preserve the samples until analysis. The collected samples were labelled accordingly to eliminate mix-ups, stored in sampling kits maintained at  $4^\circ\text{C}$ , and then transported to a laboratory for examination.

## 2.3 Sample Analysis

An acidic digestion technique used to produce the HMs in the water samples was adopted from previous studies (Ogbonna, 2022). The preparation of the samples involved mixing 100 ml of each sample with 2 ml of concentrated  $\text{HNO}_3$  and 1 ml of concentrated HCL and heating the mixture until the volume decreased to about 20 ml (Nyambura *et al.*, 2020). The characteristic colour of the mixture indicated that the samples had been fully digested.

To enhance the removal of organic contaminants from samples, avoid interference with the analysis, and boost the sensitivity of metal detection by atomic absorption spectrophotometry (AAS), the samples were digested in a 250 ml conical flask with 10 ml of strong nitric acid and 50 ml of water. Using a 0.45-mm Whatman pore membrane, the mixture was filtered after being digested on a hot plate and then allowed to cooled (Alidadi *et al.*, 2019). Preceding the analysis, the digested samples were kept in plastic bottles at  $4^\circ\text{C}$ . Samples of the acidified water were examined for the presence of Zn, Cu, Mn, Cd, Pb, and Cr using AAS (Varian AA-932), which uses an air-acetylene flame (Emmanuel *et al.*, 2022). The acidified samples were examined in duplicate, and the calibration curve was used to infer the average metal content present, which was compared with the minimum permissible limits of the Nigerian Drinking Water Quality Standard by SON (2007) and international standards by the WHO (2011).

## 2.4 Data Analysis

The resulting concentration values for the chosen HMs were descriptively analyzed with SPSS version 23.0, and the outcomes were graphically displayed with the help of Microsoft Excel.

## 2.5 Human Health Risk Assessment

### 2.5.1. Exposure Assessment

To evaluate non-cancer and cancer risks for adults and children, the chronic daily intake (CDI) of HMs in drinking water for adults and children was estimated during the exposure period (mg/kg/day) (Yu *et al.*, 2014) via ingestion pathway as the primary route for population exposure (Paul *et al.*, 2019; Egbueri & Mgbenu, 2020). The CDI of the HMs via oral pathway was calculated using Eq. 1 (Yu *et al.*, 2014):

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

Where CDI is the chronic daily intake (mg/kg/day), IR is the ingestion rate per unit time, C is the HM concentration in a water sample (mg/L), EF is the exposure frequency, ED is the exposure duration, AT is the exposure time, and BW is body weight. Table 1 lists the values used to calculate human risk, and the oral reference dose (RfD) for each of the different HMs used to evaluate toxicity reactions is shown in Table 2.

### 2.5.2 Non-Cancer Risk Assessment

According to Yu et al. (2014) and Bamuwamye et al. (2015), the non-cancer hazard quotient was used to calculate the non-cancer hazards resulting from the non-carcinogenic impacts of HMs in drinking water:

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

where HQ is the non-cancer hazard quotient, RfD is the chronic oral reference dose, and CDI is the chronic daily intake (mg metal/kg/day), which roughly corresponds to the average daily oral exposure amount in the human population (Yu et al., 2014; Bamuwamye et al., 2015).

The hazard index (HI), which is the total of all the HQ values calculated for each HM, was used to evaluate the possible non-carcinogenic risk to public health (Liu et al., 2013). The HI, derived using Eq. 3 (Bamuwamye et al., 2015), assesses the overall non-carcinogenic risk effects of exposure to several HMs in drinking water.

$$HI = \sum HQ_{Pb} + HQ_{Cr} + HQ_{Cd} \quad (3)$$

Consequently, any HQ or HI value less than 1 denotes no substantial non-cancer risk; a value greater than 1 denotes considerable non-cancer risk, which rises with higher HQ or HI values (Wei et al., 2015).

**Table 1: HM Exposure Assessment Parameters Used for Estimating CDI In Drinking Water**

Exposure Variables	Symbols	Unit	value	
			Adult	Children
Ingestion rate	IR	L/day	2.2	1.8
Exposure frequency	EF	Day/year	350	350
Exposure duration	ED	years	70	6
Body weight	BW	kg	70	15
Average time	AT	years	25550	2190

Source: (Wongsasuluk et al., 2014)

### 2.5.3 Cancer Risk Assessment

The United States Environmental Protection Agency's (USEPA) human risk assessment approach was used to determine the cancer risk related to HM consumption (USEPA, 2012). By calculating the Incremental Lifetime Cancer Risk (ILCR) from Equation (4), "cancer risk" signifies the likelihood that any cancer would develop in a population as a result of exposure to carcinogens (Bamuwamye et al., 2015; Sultana et al., 2017).

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

Where ILCR is the incremental life cancer risk, CDI is chronic intake (mg/kg/Bw/day), and CSF is

the cancer slope factor (Table 2). The individual heavy metal increment risk (ILCR), computed using Eq. 5 (Liu et al., 2013), was thought to be equivalent to the aggregate of the cumulative cancer risk following exposure to numerous carcinogenic HMs owing to water intake.

$$\sum ILCR = ILCR_1 + ILCR_2 + ILCR_3 + \dots ILCR_n \quad (5)$$

Where n is the carcinogenicity of each HM in sampled water. For regulatory purposes, the USEPA considers a cancer risk to be within the range of  $1 \times 10^{-6}$  to  $1 \times 10^{-4}$  (Li et al., 2014).

**Table 2: The Oral Reference Dose (RfD) and CSF of various HMs were used to Determine the Toxicity Responses**

HM	RfD <sub>ing</sub> (mg/kg/day)	CSF <sub>ing</sub> (mg/kg/day)
Pb	3.5E-03	0.0085
Cr	3.0E-03	0.5
Cd	5.0E-04	0.38
Zn	3.0E-01	-
Cu	4.0E-03	-
Mn	1.4E-02	-

Source: Tay et al. (2019)

### 3.0 RESULTS

#### 3.1 HM Concentration in the Sampled Water Sources

To assess the level of HM in the water sample, we conducted a laboratory analysis using AAS and compared the results with the permissible standards set by SON (2007) and WHO (2011). The results obtained from the preliminary analysis of HMs in the sampled wells (Table 3) showed that the amount of Zn was significantly higher than the acceptable limit of 3.0 mg/L (SON, 2007; WHO, 2011) for all samples, with a range of 6.12–99.14 mg/L. Also, Mn concentrations in all four samples (ranging from 2.50 to 3.31 mg/L) are above the SON (2007)

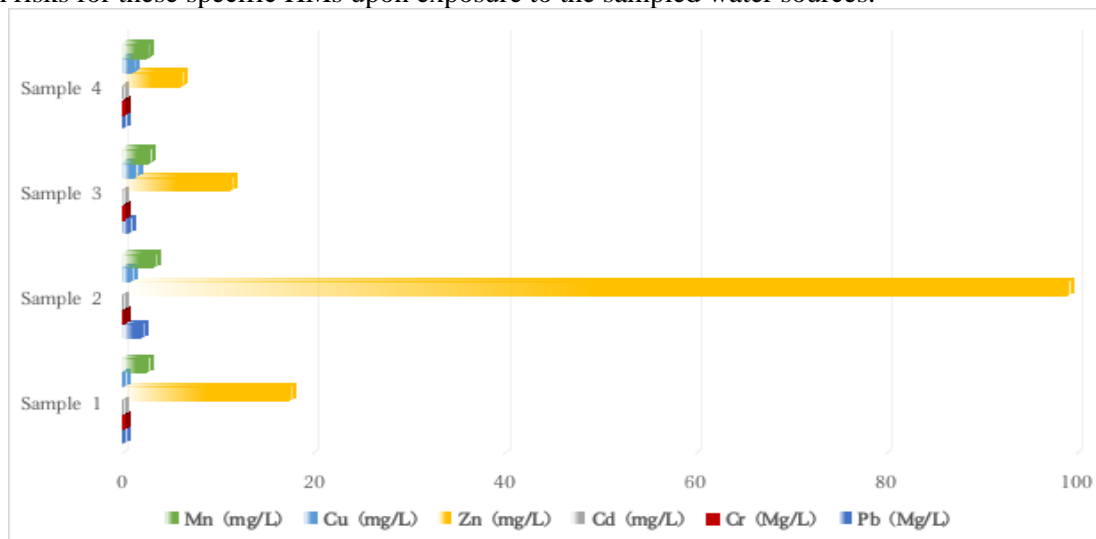
and WHO (2011) standards of 0.2 and 0.4 mg/L, respectively. Similarly, the concentration of Pb ranges between 0.20 and 2.0 mg/L and is slightly above the safe limit of 0.01 mg/L (SON, 2007; WHO, 2011) in samples. The results further show that the concentration level of Mn in all four samples (ranging from 2.50 to 3.31 mg/L) is above the SON (2007) and WHO (2011) standards of 0.2 and 0.4 mg/L, respectively. These results suggest the possible adverse health consequences following the ingestion of sampled water at the HMs concentration level, particularly with prolonged exposure.

**Table 3: Concentrations (mg/L) of the selected HMs in Sampled Water Sources**

HM (mg/l)	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	S <sub>4</sub>	Range	Mean (mg/L)	Std. Dev.	SON 2007	WHO 2011
Pb	0.20	2.0	0.76	0.21	0.200 - 2.000	0.793	0.85	0.01	0.01
Cr	0.03	0.01	0.1	0.17	0.010 - 0.170	0.078	0.07	0.05	0.05
Cd	0.001	0.001	nd	0.001	0.000 - 0.001	0.001	0.001	0.003	0.003
Zn	17.5	99.14	11.33	6.12	6.120 - 99.14	33.523	43.99	3.0	3.0
Cu	0.19	0.90	1.36	1.01	0.190 - 1.360	0.865	0.49	1.0	2.0
Mn	2.61	3.31	2.81	2.50	2.500 - 3.310	2.805	0.361	0.2	0.4

nd = not detected

Interestingly, as indicated in Table 1, the level of Cr and Cd in all four water samples were below the SON (2007) and WHO (2011) standards of 0.05 and 0.003 mg/L, respectively. Similarly, the level of Cu in all four samples (ranging from 0.19 to 1.36 mg/L) was less than the WHO value of 2.0 mg/L in all samples but higher than the national standard of 1.0 mg/L in samples 3 and 4, indicating the absence of potential health risks for these specific HMs upon exposure to the sampled water sources.



**Figure 2. Mean HM Concentration across the various Water Samples**

Overall, it is apparent from Table 1 that most HMs had a mean concentration in the following order: Zn (33.523) > Mn (2.805) > Pb (0.793) > Cr (0.05) above the admissible limits prescribed by both regulatory agencies, except for Cd (0.001) and Cu (0.865), with a mean concentration within the acceptable limit for both regulatory standards (Figure 2).

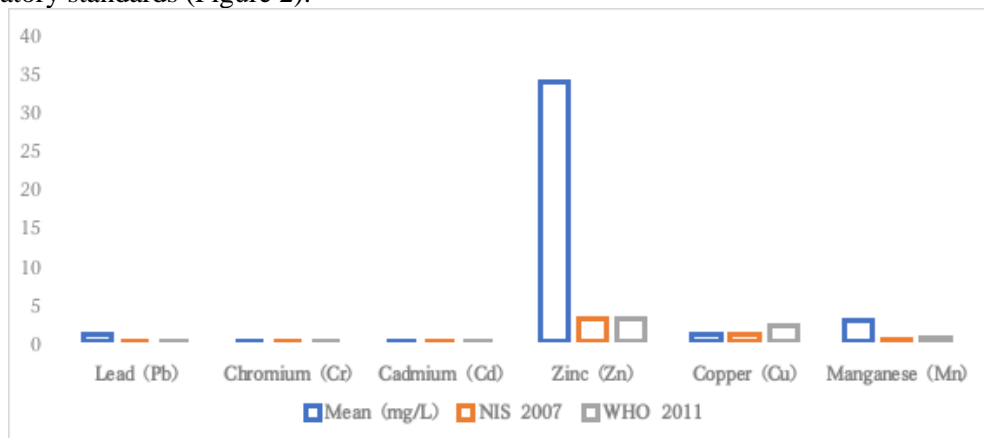


Figure 3. Comparison of the Mean Concentration of HMs with SON (2007) and WHO (2011) Standards

### 3.2 Non-cancer Risk Assessments

To assess the non-cancer risk of HM consumption in public water, we estimated the HQ of various elements using Eq. 2 (Yu *et al.*, 2014; Bamuwamye *et al.*, 2015), and the resulting data were summed to assess the HI using Eq. 3 (Liu *et al.*, 2013; Bamuwamye *et al.*, 2015). The HQ values (Table 4) for Pb, Cu, Mn, and Zn were greater than one (HQ>1) for adults and children, indicating the likelihood of non-cancer risks following the consumption of the sampled well waters. However, the HQ for Cd was less than one (HQ < 1) for adults

(0.0603) and children (0.23), whereas the HQ for Cr for adults (0.667) was less than one (HQ < 1), indicating the absence of health effects following exposure to both HMs. In addition, the HI (Table 4) for both adults (8.23 E+01) and children (1.59 E+03) was significantly above the recommended limits, indicating a significant adverse health outcome for both population groups. Further, the order of contributing ratios identified the likely non-carcinogenic risk of the HM content of the water in the study location as Zn > Cu > Pb > Mn > Cr > Cd for both children and adults.

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

Parameters	CDI (mg/kg/day)		HQ	
	Adult	Child	Adult	Child
Pb	2.39E-02	9.1E-02	6.83E-00	2.6E+01
Cr	2.0E-03	9.0E-03	6.67E-01	3.0E+00
Cd	3.014E-05	1.15E-04	6.03E-02	2.3E-01
Zn	1.01E +0	3.86E+00	3.43E+00	1.29E+03
Cu	2.61E-02	1.0E - 01	6.53E+01	2.50E+02
Mn	8.5E-02	3.23E - 01	6.07E+00	2.31E+01
<b>HI</b>			<b>8.23E+01</b>	<b>1.59E+03</b>

### 3.3 Cancer Risk Assessments

Using the calculated CDI (Table 5) and obtained CSF values (see Table 2), we adopted Eq. 4 (Bamuwamye *et al.*, 2015; Sultana *et al.*, 2017) to estimate the cancer risk (ILCR) of consuming the sampled water. The results revealed that the ILCR

values of all HMs analyzed for adults and children were above the permissible range of 10<sup>-6</sup> to 10<sup>-4</sup> (USEPA, 2012), demonstrating a significant risk of cancer for both groups of consumers (see Table 5). Similarly, the results showed that the  $\sum$ ILCR values for adults (1.21E-03) and children

(5.32E-03) were above the recommended standards, as indicated earlier, thus posing a carcinogenic effect on both groups of public water consumers in the study area (see Table 5). Furthermore, the potential carcinogenic risk of

HMs following exposure to water sources in adults and children was in the order of Cr > Pb > Cd. Overall, the results suggest significant CR for both groups of consumers, which is worrisome and calls for active intervention.

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

Parameters	ILCR	
	Adult	Child
Pb	2.03E-04	7.74E-04
Cr	1.0E-03	4.5E-03
Cd	1.15E-05	4.37E-05
$\Sigma$ ILCR	<b>1.214E-03</b>	<b>5.32E-03</b>

## 4.0 DISCUSSIONS

### 4.1 Levels of HMs in groundwater samples

This study evaluated HM contamination of public drinking water and likely non-cancer and cancer risks to local consumers. Findings indicate that more than two-thirds of the HMs in the sampled well water had mean concentrations above the safe limit prescribed by SON (2007) and WHO (2011), respectively, in the order; Zn (33.523) > Mn (2.805) > Pb (0.793) > Cr (0.05), which signifies potential deleterious effects on health, particularly following prolonged consumption by the local population. These findings align with a previous study, which showed high levels of these elements above the recommended limit (Okogbue & Ukpai, 2013). Encouragingly, the results for Cd (0.001) and Cu (0.865) revealed mean concentrations within the acceptable limits for both regulatory standards (see Figure 3), indicating the absence of potential risks to consumer health. This outcome aligns with a similar report by Sarvestani & Aghasi (2019), who concluded that the mean Cd concentrations and Cu in a similar study were less than all accepted benchmarks.

### 4.2 Non-cancer risk assessment

Analysis of the potential non-cancer risk (HQ) linked with exposure to HMs in sampled well water for adults and children revealed that the HQ values (see Table 3) for Pb, Zn, Cu, and Mn were greater than one (HQ>1) for both adults and children, indicating the likelihood of non-carcinogenic risks to health following the consumption of the sampled well waters. Additionally, the calculated HIs for

both adults (8.23 E+01) and children (1.59 E+03) exceeded the recommended standard (HI >1), indicating that both populations were at significant risk of non-carcinogenic health outcomes (Wagh *et al.*, 2018). Similar studies have also reported non-carcinogenic risks with HI values exceeding the safe limits (HQ > 1) in many health risk assessments of HM contamination in groundwater (Wagh *et al.*, 2018; Ganiyu *et al.*, 2021a), further corroborating the present results.

### 4.3 Carcinogenic health risk assessment

Regarding cancer risk analysis, as illustrated in Table 5, only Pb, Cr, and Cd out of the 6 HMs studied contributed considerably to the carcinogenic risk assessment. This was because of the unavailability of CSF for the remaining HMs. Nonetheless, the ILCR values of all the HMs analyzed (Pb, Cr, and Cd) for adults and children were within the acceptable range of 10<sup>-6</sup> to 10<sup>-4</sup> (USEPA, 2012). In addition, the  $\Sigma$ ILCR values for adults (1.21E-03) and children (5.32E-03) were above the recommended standards, posing carcinogenic health risks to both groups of consumers of the well waters in the study area. These results are consistent with those of previous studies by Rajaei & Hesari (2012), and Ganiyu *et al.* (2021a, 2021b), who in separate studies, reported that CR due to HMs in groundwater was outside the permissible limits for both children and adults.

The current study makes significant contributions by demonstrating the concentration levels of selected HMs in public drinking well water sources

in the KSLGA, most of which are among the ten chemicals listed as significant public health concerns by the WHO. Thus, it provides valuable information that will drive evidence-based water quality intervention and facilitate progress towards achieving SDG 6, ensuring the availability and accessibility of safe and sustainable water supply. Nonetheless, our study was limited because the health risk of exposure was assessed mainly through the ingestion pathway, excluding other potential routes of exposure, including inhalation and dermal routes. Therefore, further studies considering these variables are suggested to provide more in-depth insight and a robust conclusion on the overall public drinking water quality in Nigeria's Kaduna South local government area.

## 5.0 CONCLUSION

This study evaluated HM concentrations in public water sources and probable health risks. Findings demonstrate a high level of HM with a mean concentration above the safe limits prescribed by SON (2007) and WHO (2011) for most of the HMs: Zn (33.523) > Mn (2.805) > Pb (0.793) > Cr (0.05), as well as significant carcinogenic and non-carcinogenic health risks for both adults and children, with HI and  $\sum$ ILCR values above the recommended standards. Overall, our findings indicate a potential risk of exposure to the toxic effects (carcinogenic and non-carcinogenic) of the HMs, mainly Pb, Cr, and Cd, by the locals, thus suggesting the need for water quality monitoring and active intervention by relevant environmental and public health agencies to address the impending danger to public health.

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