

# Trace Elements Determination and Health Risk Assessment of Groundwater Quality in Southern Kaduna, Kaduna State, Nigeria

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**Abstract:** Groundwater contamination is a growing concern for water quality. This study examined the concentration of trace elements in groundwater and their implications to human health in Southern Kaduna, Nigeria. A stratified random sampling technique was adopted in stratifying the twelve (12) local government areas into four strata, while the sampling locations were selected using a purposive sampling technique. Fourty groundwater samples were collected, that is, twenty (20) samples from hand-dug wells and twenty (20) samples from boreholes. Furthermore, the concentrations of lead (Pb), chromium (Cr), manganese (Mn), iron (Fe), and zinc (Zn) were determined by direct aspiration into an air-acetylene flame using a Buck Scientific 235 atomic absorption spectrometer (AAS) and compared with the national drinking water quality standards (NDWQS). On the other hand, the human health risk assessment model was utilised to evaluate the health implications. The results of the analysis reveals that most of the trace elements (measured in mg/l) were within permissible limits, except for Chikun Borehole 2 (0.062), Chikun Well 5 (0.080), Sanga Well 5 (0.080), Zango Kataf Well 4 (0.062), Jaba Well 1 (0.054), and Jaba Well 5 (0.120) for Mn and Chikun Borehole 2 (2.7), Zango Kataf Borehole 2 (0.450), Zango Kataf Borehole 5 (0.400), Jaba Borehole 3 (0.300), Jaba Well 3 (0.250) for Fe. Additionally, the human health risk assessment for Cr indicates a very low likelihood of 0.0002 for cancer development due to oral exposure. Lastly, the study recommends continuous monitoring of groundwater quality and mapping contamination hotspots for targeted intervention.

**Keywords:** Groundwater, Contamination, Trace Elements, Human Health Risk, Southern Kaduna

## I. Introduction

Globally, groundwater (GW) serves as a vital freshwater source that supports various anthropogenic activities such as domestic consumption, industrial activities, agriculture, unrestricted mineral exploration amongst others. According to Li et al. (2021), GW used for domestic activities accounts for approximately one-third of the global population dependency. However, the quality of this water source is threatened by contamination. GW contamination, which refers to the addition of undesirable substances into GW, is caused by both natural and anthropogenic activities such as weathering, improper waste disposal, mining, agriculture, and can be grouped into three, namely, biological, chemical, and radioactive contamination (Government of Canada, 2017). While the consumption of GW increases annually, approximately twenty-five thousand people die daily as a result of water-related diseases, as well as a continuous dwindling in the world's water resources due to improper environmental management practices, especially in developing countries (Yohanna et al., 2021).

For example, in Nigeria, the demand for GW due to deteriorating water infrastructure is increasing as more than half of the Nigerian population relies on GW for domestic purposes, irrigation, and industrial production, among others (Adekunle et al., 2013; Omole, 2013; Yohanna et al., 2021). Similarly, GW quality presents a significant challenge in Southern Kaduna, due to its intricate lithological and hydrogeological characteristics accelerated by anthropogenic activities (Huang *et al.*, 2024). Although quite some studies (Ijah et al., 2020; Ugya et al., 2015; Wali et al., 2020) have been conducted concerning water quality in Kaduna State, the rate of water pollution (accelerated by anthropogenic activities) and its associated hazards to human health call for a more extensive assessment of water quality, especially for domestic purposes (Tong et al., 2021). The proliferation of GW within the Southern Kaduna increases this concern, as Obada & Oladejo (2013) highlighted that most rural communities in the Southern parts of Kaduna State depend largely on GW extracted from wells and boreholes for their water needs, as most surface sources are more susceptible to pollution.

It is against this backdrop that this study aims to examine the uses and sources of GW contamination, the concentration of trace elements in groundwater sources, and their effects on human health in Southern Kaduna, Nigeria. Although required in micro quantities to maintain certain physiological needs in the human body, excessive concentration of these elements can be very detrimental to human health. Hence, this study investigates the concentration of five trace elements, namely, Lead (Pb), Chromium (Cr), Iron (Fe), Manganese (Mn), and Zinc (Zn). This is very crucial as man has continually been exposed to these elements through the food and water we consume as well as the air we inhale. This study bridges a gap in knowledge by providing valuable information for water resource planning and management in Southern Kaduna and the state at large. It also provides useful information which when implemented can optimise decision making, especially in creating community awareness and environmental campaigns on water quality, hygiene and sanitation.

## II. Materials and Methods

### Study Area

#### Location, Position and Size

Southern Kaduna is situated in the Northwestern part of Nigeria. The region occupies an estimated landmass of 24,500 square kilometres and lies between latitudes 9° 00' - 10° 45' N of the Equator and longitudes 7° 10' - 8° 45' E of the Greenwich Meridian. It is bounded by Niger State, Federal Capital Territory (FCT) and Plateau State in the West, South and southeast, respectively (Obada & Oladejo, 2013). The region also comprises twelve (12) local government areas, namely, Chikun, Jaba, Jema'a, Kachia, Kaduna South, Kagarko, Kajuru, Kaura, Kuru, Lere, Sanga and Zangon Kataf (as shown in figure 2.1).

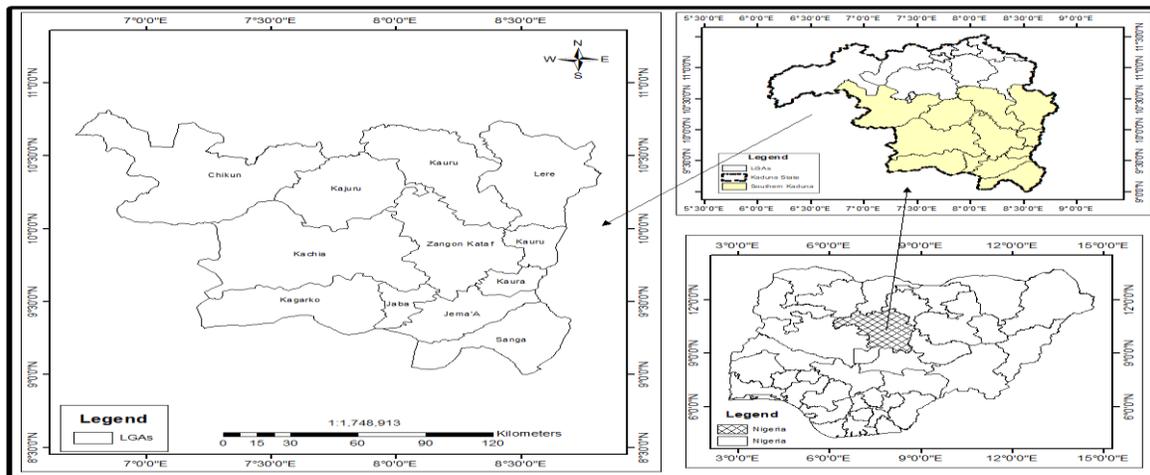


Figure 2.1: Map of Nigeria showing the study area.

Source: Author's Work (2025).

### Geology and Hydrogeology

Southern Kaduna is underlain by crystalline basement rocks, which are dominated by a migmatite and gneiss complex (Nigerian Geological Survey Agency, 2020). GW occurrence in this region is categorized into three, namely:

- (a) The Weathered/Fractured Basement Complex
- (b) The Newer Basalts
- (c) The River Alluvium

The weathered granular sandy zone, which is composed of coarse-grained sands, forms a level below the loose clayey laterite. The granular sands consist of sands or gravels derived from the disintegration of the crystalline rock. The Newer Basalts occur in the vicinity of Kafanchan and Manchok along the western edge of the Jos Plateau. The Basalts erupted after the Plateau had achieved almost its present-day topography and are themselves little affected by erosion. Thus, they often overlie alluvial deposits. Zones of weathering and beds of alluvium also occur between individual basalt flows. The dry season flow of this spring is about 11,000 m<sup>3</sup>/day. It forms the headwater of a tributary of the Kaduna River.

### Socio-Economic Activities

The people of Southern Kaduna are predominantly farmers and traders. However, the region is increasingly becoming urbanised because of infrastructural development, growing population and aesthetic endowments such as the Mastriga waterfall, Nok settlement and rich cultural diversity. Southern Kaduna serves as home for many educational institutions such as, Kaduna State University, Kafanchan Campus, Kaduna State College of Education, and College of Nursing, amongst others.

## III. Methodology

### Research Design

A mixed research design was implored for this study. This research design is complex and allows the use of both qualitative and quantitative elements in achieving the research questions. Most importantly, this research design makes the most of the strengths of each data type while neutralising their weaknesses.

### Data Collection and Sampling Technique

GW samples were retrieved from hand-dug wells and boreholes for analysis. To achieve this, a stratified sampling technique was implored to stratify the twelve LGAs in Southern Kaduna State into four strata, giving a total of three (3) LGAs in each stratum

(as shown in table 2.1). While purposive sampling, adopted from (Ijah et al., 2020), was used in selecting sampling locations. Ten (10) samples were obtained from each LGA, that is, five (5) samples from boreholes and five (5) samples from hand-dug wells, making a total of forty (40) GW samples altogether (as appendix for coordinates of each sample location).

Table 2.1: Sampling Collection Procedures.

LGAs in Southern Kaduna	Stratify sampling of LGAs in Southern Kaduna	Sample LGAs
Chikun	Chikun	Chikun
Kaduna South	Kaduna South	
Kajuru	Kajuru	
Kauru	Kauru	Zangon-Kataf
Lere	Lere	
Zangon-Kataf	Zangon-Kataf	
Kachia	Kachia	Jaba
Kagarko	Kagarko	
Jaba	Jaba	
Jema`a	Jema`a	Sanga
Sanga	Sanga	
Kaura	Kaura	

Source: Author’s Work (2025).

**Sampling Procedures and Quality Assurance**

The sampling procedure used was adopted and modified from (Opasola & Otto, 2024; Riaz et al., 2022). Forty (40) pieces of 250ml propylene containers were used to store the GW samples. The propylene containers were properly cleaned and rinsed using deionised water before retrieving and storing the GW samples. Each sampling container was well labelled to avoid errors. The trace elements, i.e Lead (Pb), Iron (Fe), Zinc (Zn), Manganese (Mn) and Chromium (Cr) were preserved for analysis by adding 2–3 drops of concentrated nitric acid (HNO<sub>3</sub>) to dissolve metal ions and reduce their precipitation. All collected samples were stored in an insulated cooler containing ice at 4 °C and transported to the National Water Resources Institute (NWRI), Mando, Kaduna, for water quality analysis.

**Data Analysis – Trace Element Concentration and Human Health Risk Assessment**

The concentration of trace elements, i.e Lead (Pb), Iron (Fe), Zinc (Zn), Manganese (Mn) and Chromium (Cr), were determined by direct aspiration into an air-acetylene flame using a Buck Scientific 235 atomic absorption spectrometer (as shown in plate 2.1a and b). The concentration of each metal in a sample was determined at a specific wavelength by using an appropriate hollow cathode lamp and a freshly prepared standard calibration solution using APHA (2017).

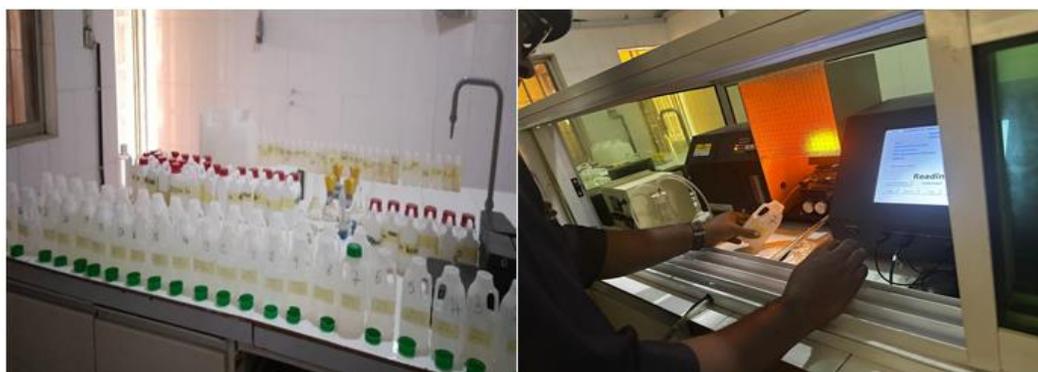


Plate 2.1: Laboratory Assessment of Trace Element Concentration in GW samples.

Source: Author’s Work (2025).

On the other hand, the United States Environmental Protection Agency’s (US-EPA) human health risk assessment model Equations (1) and (3) were applied to calculate human health risk associated with consumption of chromium-contaminated water

(adopted from Riaz et al., 2022). The parameters used in the health risk assessment are presented in Table 2.2. This approach allows for individual human health risk assessment via initial calculation of the average daily dose (ADD) of Cr due to ingestion of Cr contaminated drinking water via equation (1):

$$\text{Average daily dose (ADD)} = ED \times C \times IR \times EF / AT \times BW \dots\dots\dots \text{Eqn (1)}$$

where;

ED represents exposure duration (assumed to be 10 and 18 years for children and adolescents, respectively, and 67 years each for males and females, which is comparable with other studies).

C represents Cr concentration in water (µg/L),

IR represents the ingestion rate of water (L day<sup>-1</sup>),

EF represents exposure frequency (365 days per year),

AT represents average lifetime (days) and

BW represents body weight (10 for children, 18 for adolescents, 67 for males and 67 for females in kgs).

**Cancer Risk**

The cancer risk (CR) was also calculated using the following equation.

$$\text{Cancer risk} = \text{ADD} / \text{CSF} \dots\dots\dots \text{Eqn (3)}$$

where the cancer slope factor (CSF) for Cr is 0.5 (mg/kg/day) for oral exposure according to US-EPA.

Table 2.2: Parameters used for Health Risk Assessment

Age Group	IR (L/Day)	BW (kg)	EF (Days)	ED (Years)	AT (Days)
Children	1	13	365	10	3650
Adolescents	1.6	28	365	18	6570
Adult male	2	72	365	67	24,455
Adult female	2	53	365	67	24,455

Source: Author’s Work (2025).

**IV. Results and Discussions**

The findings of this study are presented according to the study objectives. These are:

**GW Uses and Sources of Contamination**

The study reveals that GW extracted from hand-dug wells and boreholes in Southern Kaduna are used for domestic consumption (such as drinking, cooking, washing and bathing), agriculture, mineral exploration, and business; these findings aligns with the study of (Adekunle et al., 2013; Ocheri et al., 2014). The study also highlights improper waste disposal, mining activities, unprecedented urbanisation, application of pesticides and herbicides, sewage from septic tanks as well as run-off as the major sources of GW contamination in Southern Kaduna (see plate. 3.1a and b). Increase in GW contamination from these sources if not monitored can pose threat to human health as well as used the viability of businesses and other related activities. The result of this analysis correlates with the works of (Yohanna et al., 2021).



Plate 3.1: Sources of Groundwater Contamination in Southern Kaduna.

Source: Author's Work (2025).

### Trace Elements Concentration

As earlier mentioned, the concentration of five trace elements, namely: Manganese (Mn), Iron (Fe), Zinc (Zn), Lead (Pb), and Chromium (Cr), were investigated and compared with the national drinking water quality standards (NDWQS) to ascertain their suitability for domestic consumption. Figure 3.1 shows the sampling location points.

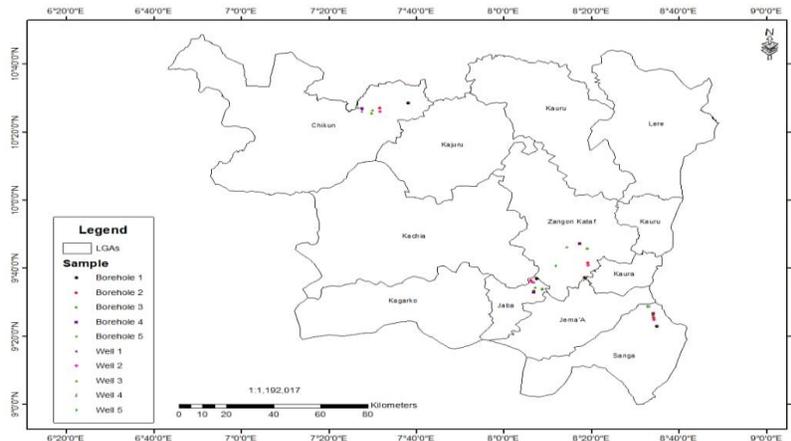


Figure 3.1: Map showing the sampling location points

The results of the analysis are as follows:

### Manganese (Mn)

More than half of the samples from Chikum, Sanga, Jaba, and Zangon-Kataf LGA (as shown in fig 3.2) were below the permissible limit (0.05mg/l). Exceedances were Chikum Borehole 2 (0.062), Chikum Well 5 (0.080), Sanga Well 5 (0.080), Zango Kataf Well 4 (0.062), Jaba Well 1 (0.054), and Jaba Well 5 (0.120). The exceedances are largely driven by agricultural activities (such as maize cultivation, rice, millet, amongst others) as well as improper waste disposal taking place within the sampling areas. It is worth noting that high concentrations of Mn can cause discolouration, metallic taste, and long-term neurological effects if consumed at elevated levels. The result of this study correlates with the works of Andrew E. (2021), which reveals a high concentration of Mn in GW when compared with surface water.

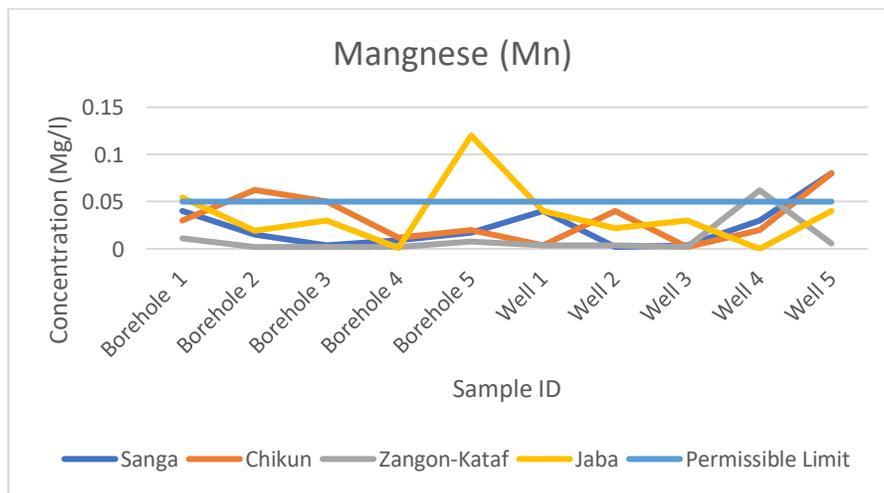


Figure 3.2: Concentration of Mn in Groundwater, Southern Kaduna, Nigeria.

### Iron (Fe)

Similarly, quite a number of GW samples obtained from boreholes and hand-dug wells (as shown in table 3.1) exceeded the permissible limit of 0.3mg/l (e.g., Chikum Borehole 2 at 2.7 mg/L, Zango Kataf Borehole 2 at 0.450 mg/L, Zango Kataf Borehole 5 at 0.400 mg/L, Jaba Borehole 3 at 0.300 mg/L, Jaba Well 3 at 0.250 mg/L) for Fe. This is largely attributed to weathering activities taking place within the basement complex and is of concern as excessive concentration of Fe causes reddish-brown staining, unpleasant taste, and can harbour iron bacteria, though it is not acutely toxic. Findings from this analysis correlate with the works of (Yohanna et al., 2021). This is because both studies are situated in the same region and are underlaid by the same geology.

Table 3.1: Concentration of Iron (Fe)

	Borehole1	Borehole2	Borehole3	Borehole4	Borehole5	Well 1	Well 2	Well 3	Well 4	Well 5
Sanga	0.05	0.2	0.5	0.15	0.15	0.15	0.1	0.2	0.15	0.15
Chikun	0.25	2.7	0	0.25	0.15	0.15	0.25	0.3	0.02	0.02
Zangon-Kataf	0.3	0.45	0.2	0.2	0.4	0.15	0.05	0.1	0.2	0.4
Jaba	0.25	0	0.25	0.1	0.15	0.25	0.1	0.3	0.05	0.25
Permissible Limit	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

Source: Author’s Work (2025).

**Zinc (Zn)**

This is an essential element in drinking water. The result of the analysis (as shown in table 3.2) reveals that the concentration of Zn in all GW samples obtained from both hand-dug wells and boreholes in Southern Kaduna were within the permissible limit (the highest is 0.370 mg/L at Zango Kataf Borehole 5) – largely due to the intensive agricultural activities taking place within the sample collection point. However, the result of the analysis is at variance with the findings of (Ocheri et al., 2014).

Table 3.2: Concentration of Iron (Zn)

	Borehole1	Borehole2	Borehole3	Borehole4	Borehole5	Well 1	Well2	Well3	Well4	Well5
Sanga	0.014	0	0.024	0.007	0.008	0.023	0.016	0.046	0.044	0.061
Chikun	0.043	0.006	0.023	0.006	0.011	0.033	0.015	0.019	0.178	0.031
Zangon-Kataf	0.027	0.057	0.043	0.048	0.37	0.05	0.055	0.061	0.087	0.077
Jaba	0	0.027	0.002	0.002	0.023	0.015	0.024	0.035	0.034	0.05
Permissible Limit	3	3	3	3	3	3	3	3	3	3

Source: Author’s Work (2025).

**Lead (Pb)**

Several groundwater samples from wells exceeded the permissible limit of Pb concentration for domestic use, as shown in fig 3.3. For example, Sanga Well 1 had 0.028, Sanga Well 2 had 0.032, Sanga Well 3 had 0.032, Sanga Well 4 had 0.047, Sanga Well 5 had 0.060, while Zango Kataf Wells 1–5 ranged from 0.042 to 0.068, and Jaba Wells 2–5 ranged from 0.025 to 0.046. This is of critical concern, as high or very low Pb concentrations can cause developmental delays in children, kidney damage, and in severe cases, cancer and neurological problems. The analysis results also align with the findings of

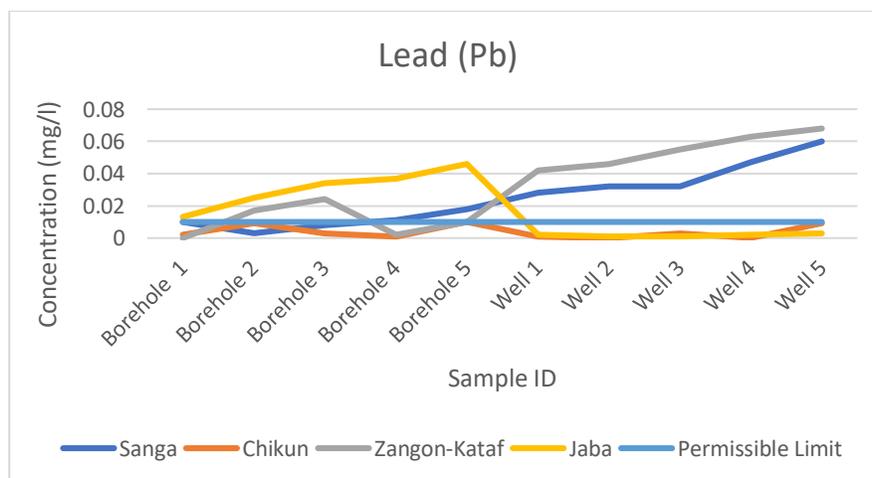


Figure 3.3: Concentration of Pb in Groundwater, Southern Kaduna, Nigeria.

**Chromium (Cr)**

Similar to the findings on the concentration of Zn, the result of the analysis (as shown in fig 3.4) reveals that the concentration of zinc for all GW samples obtained from both hand-dug wells and boreholes within Southern Kaduna were below the permissible limit (0.05mg/l) except Jaba Well 3 (0.038, still below but notable). Although the concentration of this element is safe for domestic consumption, there is a need for continuous monitoring.

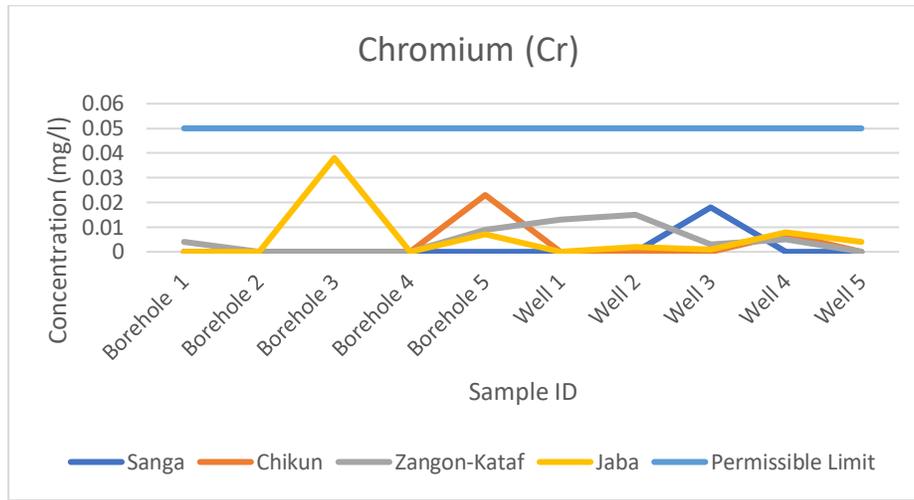


Figure 3.4: Concentration of Pb in Groundwater, Southern Kaduna, Nigeria.

**Human Health Risk Assessment**

Using the US-EPA human health risk assessment model equations (1) and (3), adopted from (Riaz et al., 2022). The human health risk assessment for average daily dose (ADD) of Cr due to ingestion of Cr contaminated drinking water was investigated as follows:

$$\text{Average daily dose (ADD)} = \text{ED} \times \text{C} \times \text{IR} \times \text{EF} / \text{AT} \times \text{BW} \dots\dots\dots \text{Eqn (1)}$$

- a. For children:  $\text{ADD} = 10 \times 0.004 \times 1 \times 365 / 3650 \times 13$   
**ADD = 0.00031**
- b. Adolescents:  $\text{ADD} = 18 \times 0.004 \times 1.6 \times 365 / 6570 \times 28$   
**ADD = 0.00023**
- c. Adult male:  $\text{ADD} = 67 \times 0.004 \times 2 \times 365 / 24,455 \times 72$   
**ADD = 0.0001**
- d. Adult female:  $\text{ADD} = 67 \times 0.004 \times 2 \times 365 / 24,455 \times 53$   
**ADD = 0.00015**

**Cancer Risk**

The cancer risk (CR) was also calculated using the following equation.

$$\text{Cancer risk} = \text{ADD} / \text{CSF} \dots\dots\dots \text{Eqn (3)}$$

where the cancer slope factor (CSF) for Cr is 0.5 (mg/kg/day) for oral exposure according to US-EPA.

- a. For children:  $\text{Cancer risk} = 0.00031 \times 0.5$   
**Cancer risk = 0.00062**
- b. Adolescents:  $\text{Cancer risk} = 0.00023 \times 0.5$   
**Cancer risk = 0.00046**
- c. Adult male:  $\text{Cancer risk} = 0.0001 \times 0.5$   
**Cancer risk = 0.0002**
- d. Adult female:  $\text{Cancer risk} = 0.00015 \times 0.5$

**Cancer risk = 0.0003**

The result of the human health risk assessment reveals 0.00062, 0.00046, 0.0002, and 0.0003 for children, adolescents, adult males, and adult females, respectively. This shows that the probability of contracting cancer through oral ingestion of GW extracted from hand-dug wells and boreholes in Southern Kaduna is grossly insignificant. However, the likelihood of contraction increases with increased exposure to Cr. A very similar result to our study was reported by Riaz et al. (2022).

**V. Conclusion**

In conclusion, the growing population, unprecedented urbanization, and increasing agricultural and mining activities taking place within Southern Kaduna are accelerating the threat to GW quality and human health. This calls for continuous monitoring, especially for Cr, which is cancerogenic.

**Recommendations**

Given the results of the analysis, the study deems it fit to recommend the following.

**a. Immediate Actions:**

- I. Hand-dug wells with high concentrations of Pb (especially in Sanga, Zango Kataf, and Jaba) should not be used for domestic consumption (particularly drinking and cooking) except it has been treated.
- II. Also, alternative and safe water sources (e.g., tanker supply, rainwater harvesting, or treated borehole water) should be provided within the Pb-contaminated regions.

**b. Treatment Solutions:**

- I. Lead removal: use point-of-use filters with activated carbon, reverse osmosis, or ion-exchange systems.
- II. Iron and manganese removal: apply aeration, oxidation (chlorine or potassium permanganate), and sand filtration.
- III. Well rehabilitation: seal leaking walls and replace corroded pumps or pipes that may leach metals.

**c. Policy & Community Measures:**

- I. Regular monitoring of groundwater quality (quarterly testing).
- II. Launch community awareness campaigns on the dangers of lead and safe water handling.
- III. Government/NGOs should invest in centralised water treatment plants or small-scale packaged treatment for high-risk communities.

**d. Long-Term Actions:**

- i. Extensively investigate sources of GW contamination (geological vs. anthropogenic). For instance, Pb contamination may be from old pipes, batteries, or nearby mining/industrial activities. In contrast, Fe and Mn are usually geological.
- ii. Map contamination hotspots for targeted interventions.

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