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ASSESSMENT OF HEAVY METAL CONTAMINATION AND HEALTH RISK ASSOCIATED WITH SELECTED BOREHOLE WATER PROXIMAL TO A DUMPSITE IN GIWO, BAUCHI STATE

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ABSTRACT

Water quality is a critical concern for human well-being and ecological stability, particularly as groundwater serves as a vital source of freshwater globally, sustaining various societal sectors. Human activities have increasingly polluted groundwater with contaminants, notably heavy metals, presenting potential health hazards to communities reliant on these water sources. This study investigates heavy metal contamination in borehole water samples from four distinct locations within Giwo, Bauchi State, Nigeria, and evaluates the associated long-term health risks of consuming this water. Analysis of the water samples identified iron to have the highest concentration (1.140 mg/L) while lead recorded the lowest concentration (0.0003 mg/L), the concentrations of zinc and copper across all the four locations were within the Nigerian Standard for Drinking Water Quality (NSDWQ) established by the Nigerian Industrial Standard (NIS) of 3.0 mg/L and 1.0 mg/L. The Average Daily Intake (ADI) from water consumption for, zinc, iron, copper, cadmium, and manganese were consistently below their corresponding Reference Doses (RfDs) of 0.3 mg/kg/day, 0.7 mg/kg/day, 0.04 mg/kg/day, 0.0005 mg/kg/day, and 0.14 mg/kg/day, respectively for all water samples analyzed while the remaining heavy metals exhibited ADIs exceeding their established RfDs. Hazard Quotient (HQ) values for most metals were below the threshold of 1, suggesting a relatively low risk of adverse health effects. However, prolonged consumption of this water may heighten cumulative health risks associated with specific heavy metals, warranting continuous monitoring and remedial actions.

Keywords: Groundwater Contamination, Heavy Metals, Health Risk Assessment, Giwo

INTRODUCTION

Water is essential for the sustained survival of every life form on earth, it exhibiting unique properties that make it indispensable (Awoyemi *et al.*, 2021). The accessibility of safe water, both in terms of its quality and quantity to the human population is paramount for ensuring public health, environmental sustainability, and overall survival (Nduka *et al.*, 2023). According to Ferreira *et al*. (2023), groundwater is the world's primary freshwater reserve, constituting 97% of the Earth's freshwater, groundwater is the primary water resource for domestic, industrial, and agricultural sectors in numerous counties, around one-third of the global populace relies on groundwater as their primary drinking water source (Vasanthavigar *et al.*, 2012). The naturally occurring filtering process in groundwater makes it to be pure and of high quality (Myers *et al*., 2023). Human-induced activities stemming from urban development, industrial activities, and agricultural practices have imposed significant strain on sources of water which include both surface and groundwater (Joseph *et al*., 2022), these activities generate pollutants, including heavy metals and fecal matter which are introduced into groundwater via processes such as eluviation, leaching, and osmosis (Osei-Owusu *et al.*, 2023).

Heavy metals represent sources of pollution in domestic water systems, leading to the deterioration of water standards (Adeyemi & Ojekunle, 2021). These metals possess metallic characteristics, featuring atomic numbers surpassing 20, atomic weights ranging from 63.5 to 200.6 g/mol^{-1}, and densities exceeding 5 g/cm^3 (Joseph *et al.*, 2024). Heavy metals exhibit characteristics such as non-biodegradability, persistence, accumulation, and toxicity, prominent heavy metals include nickel (Ni), lead (Pb), chromium (Cr), manganese (Mn), iron (Fe), copper (Cu), cadmium (Cd), and various others (Yahaya *et al*., 2024). Once heavy metals are ingested into the body, they have the potential to induce diverse health complications, including neurological damage, developmental abnormalities, kidney damage, and cancer (Sudharshan & Sunitha, 2023). This study aims to investigate the concentration of heavy metals in borehole water from Giwo District, Bauchi State and subsequently assess the potential health risks associated with exposure to these contaminants.

MATERIALS AND METHODS

Study Area

Giwo, situated near Ningi LGA in Bauchi State, it covers a land area of 5,250km^2 and has a population of 501,912 as per the 2006 census. Located on the northern fringe of the Jos Plateau at an elevation of 616m above sea level, it lies between Latitude 10° 22' 17" N and Longitude 9° 50' 11" E. The town's emergence was influenced by migration from Bauchi and Plateau states due to various factors such as search for arable land, security, basic amenities etc. With an annual growth rate of 2.8%, Giwo is experiencing rapid expansion, as indicated by a household survey conducted by Glawe in 2014.

Climate

The cold in season spans between December to January with an average daily temperature below 30 °C while the coldest month of the year in Giwo District of Bauchi is January (Mailafiya, 2011). Humidity varies throughout the year in Giwo, reaching approximately 12% in February and peaking at around 68% in August, rainy season spans from May to September, with humidity levels ranging from 37% to 68%. Monthly rainfall in Giwo varies widely, from 0.0mm in December and January to approximately 343 mm in July. Rainfall typically begins in April and ends by October. The Mean daily maximum temperatures range from 27 °C to 29 °C in July and August, reaching a high of 38 °C in March and April. Conversely, mean daily minimum temperatures range from 22 °C in December and January to about 25 °C in April and May (Sylvester & Abdulquadir, 2015)

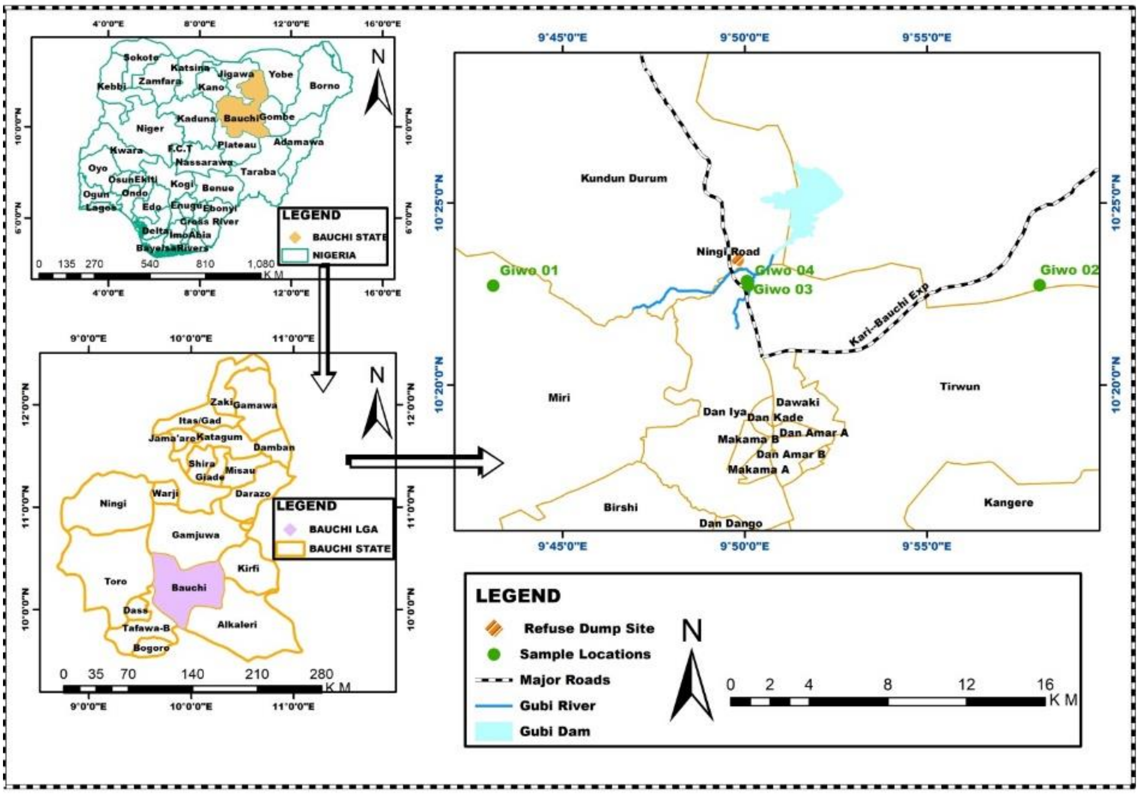

Figure 1: Giwo District, Bauchi LGA Depicting Borehole Water Sampling Locations

Collection of Water Sampling

Four boreholes, ranging in depth from 24 to 32 meters were selected for water sample collection, these boreholes are located near a dumpsite within Giwo District of Bauchi LGA. Water samples were collected in adherence to the established protocols outlined in the National Field Manual for the Collection of Water-Quality Data (USGS, 2006). Water samples were collected three times from each of the four borehole identified over the course of 3 weeks during the dry season. The water samples collected were labeled Giwo WS-01, Giwo WS-02, Giwo WS-03 and Giwo WS-04 respectively.

Determination of Heavy Metals in Borehole Water

The determination of heavy metal content followed the methodology described by Yahaya & Kalgo (2022). 100 mL of water sample, 5 mL of concentrated HNO_3, and then tightly sealed to avoid contamination. The mixture was heated slowly at 95 °C until it evaporated to about 21 mL. The solution was left to cool, after which it was poured into a 100 mL volumetric flask and filled up to the meniscus with distilled water. The digest was transferred to a plastic bottle and labelled ready for analysis using Angtrom Atomic Absorption Spectroscopy Model AA-320N.

Health Risk Assessment of the Water

Health hazards from borehole water ingestion were assessed for non-cancer-causing impacts of studied metals for adult. The toxicity variables evaluated are the Reference Dose (RfD) for non-cancer-causing risk. The Average Daily Ingestion (ADI) was calculated by the methodology reported by Adeyemi & Ojekunle, (2021) as shown in equation (1). It was evaluated to determine the extent, occurrence, and period of exposure to investigated metals.

$$ADI = \frac{C_x \times I_r \times E_f \times E_d}{B_{wt} \times A_t} \quad (1)$$

Where ADI is Average Daily Ingestion of heavy metals per kilogram of body weight; C_x is the concentration of heavy metals in water; I_r is the ingestion rate per unit time; E_f is the exposure frequency; E_d is the exposure duration; Bwt is the body weight; A_t is the average time (E_d x E_f)

According to Yahaya *et al*., (2020) the standard values for calculation daily ingestion for heavy metals are as follows: E_F = 365 days/years; I_r = 2L/day; E_d = 55 years; B_{wt} = 65 kg; A_t = 20075 days.

The Hazard Quotient (HQ) which is a measure use to evaluate the potential health risk associated with exposure to the heavy metals is calculated using equation (2)

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

Where RfD is the heavy metal oral reference dose. An HQ value higher than 1 suggest that the exposure to the heavy metal may pose a health risk, while HQ values less than 1 show that exposure to the heavy metal is likely to be safe (Myers *et al.*, 2023) . According to The United State Environmental Protection Agency (2024), the RfD of these heavy metals are listed in Table 1.

Table 1: Reference Dose (RfD) for Heavy Metals

Heavy Metals	RfD (mg/kg/day)
Zinc	0.3
Iron	0.7
Copper	0.04
Cadmium	0.0005
Chromium	0.0003
Lead	0.00035
Arsenic	0.0003
Manganese	0.14

RESULT AND DISCUSSION

Table 2: Average Concentrations of Heavy Metal in Borehole Water from Giwo

Heavy Metals (mg/L)	Giwo WS-01 M±S.D	Giwo WS-02 M±S.D	Giwo WS- 03 M±S.D	Giwo WS- 04 M±S.D	NSDWQ
Zinc	0.551 ± 0.000	0.387 ± 0.008	0.663 ± 0.001	0.408 ± 0.060	3.0
Iron	0.287 ± 0.008	0.714 ± 0.000	1.140 ± 0.006	0.512 ± 0.010	0.3
Copper	0.106 ± 0.002	0.118 ± 0.010	0.167 ± 0.009	0.163 ± 0.001	1.0
Cadmium	0.008 ± 0.001	0.005 ± 0.001	0.010 ± 0.002	0.007 ± 0.001	0.003
Chromium	0.004 ± 0.001	0.057 ± 0.000	0.100 ± 0.004	0.097 ± 0.001	0.05
Lead	0.003 ± 0.000	0.018 ± 0.000	0.050 ± 0.001	0.004 ± 0.002	0.01
Arsenic	0.002 ± 0.001	0.003 ± 0.001	0.011 ± 0.001	0.005 ± 0.001	0.01
Manganese	0.221 ± 0.005	0.387 ± 0.005	0.113 ± 0.010	0.151 ± 0.006	0.2

Table 2 presents the concentrations of eight studied heavy metals in the four water samples (Giwo WS-01, Giwo WS-02, Giwo WS-03, Giwo WS-04) alongside the corresponding NSDWQ limit for comparative analysis. Iron exhibits the highest mean concentration at 1.140 mg/L, while lead shows the lowest mean concentration at 0.003 mg/L. Notably, the concentrations of zinc and copper across all four locations comply with the NSDWQ set at 3.0 mg/L and 1.0 mg/L, respectively, this result corresponds to the study carried out by Jagaba *et al.* (2020) and Umar *et al.* (2020). Myers *et al.* (2023) posit that the observed elevation in cadmium levels may be attributable, at least in part, to improper waste battery disposal. On the contrary, the concentrations of cadmium in all four locations surpass the established safety threshold of 0.003 mg/L, although remaining lower than the levels reported by Mahmoud and Hamza (2021). Conversely, the chromium concentrations documented by Mahmoud and Hamza (2021) were found to be within the stipulated NIS standards. Nonetheless, the chromium levels detected at three of the study sites exceeded the prescribed regulatory limit of 0.05 mg/L, as highlighted by this study. Giwo WS-01 consistently demonstrates the lowest heavy metal concentrations, except for cadmium (0.008 mg/L) and manganese, which surpasses the 0.2 mg/L NSDWQ standard, indicating it may be the least contaminated water source. Conversely, Giwo WS-02 and WS-04 exhibit concentrations above the standard limit for five heavy metals, while Giwo WS-03 is identified as the most contaminated, with six heavy metals exceeding the standard limit.

Table 3: Average Daily Intake (ADI) of Heavy Metals in Borehole Water from Giwo

Heavy Metals (mg/kg/day)	Locations			
	Giwo WS-01	Giwo WS-02	Giwo WS-03	Giwo WS-04
Zinc	0.01695	0.01191	0.02040	0.01255
Iron	0.00883	0.02197	0.03508	0.01575
Copper	0.00326	0.00363	0.00514	0.00502
Cadmium	0.00025	0.00015	0.00031	0.00022
Chromium	0.00012	0.00175	0.00308	0.00298
Lead	0.00009	0.00055	0.00154	0.00012
Arsenic	0.00006	0.00009	0.00034	0.00015
Manganese	0.00680	0.01191	0.00348	0.00465

Table 3 present the ADI of the eight investigated heavy metals across the four water samples collected from Giwo. These values are then compared to the established RfDs for each metal, as presented in Table 1. This comparative analysis provides valuable insights into potential health implications associated with long-term consumption of this water.
Based on the estimated daily intake from water consumption, zinc, iron, copper, cadmium and manganese remained below their respective RfDs of 0.3 mg/kg/day, 0.7 mg/kg/day, 0.04 mg/kg/day, 0.0005 mg/kg/day, and 0.14 mg/kg/day across all samples, this suggests a minimal health risk associated with exposure to these elements through water consumption. However, the result reveals potential concerns for lead, chromium, and arsenic in specific water samples. Lead concentrations exceeding the established RfD of 0.00035 mg/kg/day were observed in Giwo WS-02 and Giwo WS-03. These elevated levels have potential health consequences, including cancer, disruption of vitamin D metabolism, impaired mental development in infants, and central and peripheral nervous system toxicity (NIS, 2015). Additionally, chromium concentrations in Giwo WS-04, Giwo WS-03, and Giwo WS-02 exceeded the established RfD of 0.0003 mg/kg/day, highlighting a potential human health risk. Chronic exposure to chromium through contaminated

drinking water has been associated with an increased risk of stomach and intestinal cancers, as reported in a study conducted in Liaoning Province, China (Myers *et al.*, 2023). Furthermore, Giwo WS-03 displayed an arsenic concentration exceeding the established RfD of 0.0003 mg/kg/day. The measured value of 0.00034 mg/kg/day suggests a potential health risk, particularly regarding carcinogenicity (NIS, 2015).

Table 4: Hazard Quotient (HQ) of Heavy Metals in Borehole Water from Giwo

Heavy Metals	Location			
	HQ Giwo WS-01	HQ Giwo WS-02	HQ Giwo WS-03	HQ Giwo WS-04
Zinc	0.057	0.040	0.068	0.042
Iron	0.013	0.031	0.050	0.023
Copper	0.082	0.091	0.128	0.125
Cadmium	0.492	0.308	0.615	0.431
Chromium	0.410	5.846	10.26	9.949
Lead	0.264	1.582	4.396	0.352
Arsenic	0.200	0.308	1.128	0.513
Manganese	0.049	0.085	0.085	0.033

Table 4 presents the HQ values for the investigated heavy metals in Giwo water samples. With the exception of chromium in Giwo WS-02 (5.846), Giwo WS-03 (10.26), and Giwo WS-04 (9.949), and lead in Giwo WS-02 (1.582) and Giwo WS-03 (4.396), and arsenic in Giwo WS-03 (1.128), the analysis of heavy metals in borehole water samples from the four locations in Giwo indicates that a majority of the metals possess HQ values below the established threshold of 1. The present study's findings regarding the HQ risk associated with chromium and lead differs from those reported by Yahaya *et al*. (2024) in a South-West Nigerian context. In contrast to our findings, Yahaya et al. (2024) concluded that these metals pose insignificant health risks. However, it is noteworthy that Yahaya et al. (2022) also reported a location within Southwest Nigeria with a chromium HQ value exceeding 3.0, highlighting potential geographical variations in heavy metal presence. The current study's findings suggest a relatively low potential for adverse health effects associated with chronic exposure over a 55-year timeframe in Giwo. However, for residents consuming this water for extended periods exceeding this duration, the cumulative health risks associated with certain heavy metals may become progressively more significant. Notably, the chromium concentrations in Giwo WS-02, Giwo WS-03, and Giwo WS-04, the lead concentrations in Giwo WS-02 and Giwo WS-03, and the arsenic concentration in Giwo WS-03 warrant particular attention.

CONCLUSION

The study conducted in Giwo assessed the concentrations of eight heavy metals across four water samples and compared them to NSDWQ to gauge compliance and potential health implications. Zinc exhibited the highest mean concentration, while lead showed the lowest. Notably, zinc and copper levels complied with NSDWQ, contrasting with elevated cadmium concentrations possibly linked to improper waste disposal. Chromium levels exceeded regulatory limits at three sites. Giwo 03 showing the highest heavy metal contamination. Analysis of ADI revealed minimal health risks for zinc, iron, copper, cadmium and manganese. However, lead, chromium, and arsenic levels in specific samples raised concerns, exceeding RfDs and potentially posing health risks, including cancer. HQ values indicated most metals posed low risks, although chromium and lead levels in some locations surpassed thresholds. Overall, while long-term exposure in Giwo may pose limited health risks, attention to specific contaminants is warranted for residents consuming water over extended periods.

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