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Assessment of Heavy Metals Concentration in Ground Water in Gboko, Nigeria

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ABSTRACT
Access to clean water is fundamental for public health, yet in many regions, including Gboko, Nigeria, water sources are increasingly compromised by the presence of arsenic and toxic heavy metals due to growing industrial activities and automobile workshops. This study assessed the concentration of heavy metals in groundwater sources in Gboko, Benue State, Nigeria, to evaluate their suitability for human consumption with the aim was to determine the levels of heavy metals, such as lead (Pb), cadmium (Cd), chromium (Cr), Mn and zinc (Zn), and compare them against WHO standards. Specific objectives included sampling borehole and well water from five strategic locations, conducting laboratory analysis, and identifying potential health risks associated with elevated metal concentrations. A total of ten groundwater samples (five each from boreholes and wells) were collected and analysed using Atomic Absorption Spectrophotometry (AAS). The results revealed varying concentrations of the targeted metals across different locations. Notably, lead and cadmium levels in several samples exceeded WHO permissible limits, raising health concerns due to their toxicity and bioaccumulation potential. Zinc and copper remained within safe limits, while iron and chromium exhibited slightly elevated levels in select areas. The findings suggest that anthropogenic activities such as industrial waste disposal, agricultural runoff, and poor sanitation practices contribute significantly to groundwater contamination in Gboko. The discussion emphasises the urgent need for improved waste management and regular monitoring to prevent long-term public health risks. In conclusion, while some groundwater sources in Gboko remain safe, others pose serious health threats due to high heavy metal concentrations. It is recommended that local authorities enforce stricter environmental regulations and promote public awareness to ensure access to safe drinking water.

Keywords:
Groundwater,
Heavy metals,
Arsenic,
Contamination,
Public health,
Environmental monitoring,
Water quality.

INTRODUCTION

Access to clean water is fundamental for public health, yet in many regions, including Gboko, Nigeria, water sources are increasingly compromised by the presence of arsenic and toxic heavy metals (Tukura., 2014). The growing industrial activities, such as automobile workshops and nearby Industrial facilities, have been linked to these contaminants, raising concerns about their direct impact on groundwater and surface water quality (Egbinola & Amanambu, 2014). For instance, studies have shown that heavy metal concentrations often exceed World Health Organization guidelines, with research indicating that groundwater near automobile repair sites exhibited significantly high levels of toxic elements such as lead and cadmium, which have severe health implications for local communities (Agaku et al., 2024). Furthermore, the studies as mentioned earlier, highlight alarming findings, where over 83% of groundwater samples in affected areas fell into 'poor' water quality categories, thus underscoring the urgency for comprehensive assessments and timely interventions to address this public health crisis (Oliveira et al., 2021) and (Emerenini & Joseph, 2020).

Water pollution is a critical public health issue worldwide, with developing countries particularly vulnerable (WHO, 2020). Arsenic and toxic heavy metals in groundwater can originate from natural sources, industrial activities, and agricultural runoff (Pal et al., 2009). In Nigeria, groundwater sources such as boreholes and wells serve as primary drinking water sources, yet concerns persist regarding their safety due to contamination risks (Adeyemo et al., 2021). Heavy metal exposure has been linked to various adverse health effects, including neurological disorders, organ damage, and cancer (Agaku et al., 2024). The increasing industrialization and urbanization in Gboko pose potential threats to groundwater quality, necessitating a thorough assessment of arsenic and heavy metal concentrations in these sources.

In Gboko, the primary sources of water include boreholes and hand-dug wells, which are crucial for the local population's daily needs, especially in agricultural communities. The reliance on these water sources necessitates a thorough assessment of their quality to ensure safety and sustainability (Chidi et al., 2019). Assessing water quality is essential not only to prevent waterborne diseases but also to monitor the presence of contaminants such as arsenic and toxic heavy metals, which can have devastating health implications. Studies, such as those conducted in similar contexts, indicate that borehole water often exhibits elevated electrical conductivity (EC) and total dissolved solids (TDS) levels, suggesting potential pollution sources (Akudinobi et al., 2019). Furthermore, advanced analytical techniques reveal both the geogenic and anthropogenic influences on water quality, reinforcing the importance of regular monitoring to safeguard public health (Alaanyi et al., 2021). Thus, understanding water sources and their quality is pivotal for the well-being of Gboko residents.

The presence of arsenic in borehole and well water poses a significant public health risk, especially in areas like Gboko, Nigeria, where reliance on these water sources is prevalent (Sharma et al., 2017). Studies indicate that arsenic contamination may stem from both natural geological sources and anthropogenic activities, leading to heightened levels in drinking water (Allen et al., 2015). Previous studies have indicated elevated levels of heavy metals in Nigerian water sources (Peterside et al., 2022). However, limited research has been conducted specifically in Gboko, a region with extensive groundwater use. Contaminated water sources can lead to severe health risks such as arsenicosis, kidney disease, and cognitive impairments (Kumar et al., 2018). Given the reliance of the local population on borehole and well water for drinking, cooking, and sanitation, understanding the extent of contamination is crucial for public health protection and policy formulation. This study aims to fill this knowledge gap by systematically analyzing water samples from various locations within Gboko to determine the levels of arsenic and toxic heavy metals.

This research provides valuable insights into water quality in Gboko, helping policymakers and health authorities design effective interventions. Findings will inform residents about potential health risks and encourage the adoption of safer water purification methods. Additionally, the study contributes to the global discourse on groundwater contamination, providing localized data that can be compared with findings from other regions experiencing similar environmental challenges. The study focuses on borehole and well water samples collected from different locations in Gboko. It analyzes arsenic, lead, cadmium, mercury, and chromium concentrations and compares them with established safety standards. Additionally, the study examines the sources of contamination, human exposure pathways, and mitigation strategies. The research integrates field surveys, laboratory analysis, statistical methods, and policy evaluation to provide a holistic understanding of the issue.

Theoretical Framework

The theoretical framework is structured around the principles of environmental toxicology, environmental monitoring, and exposure pathways. Heavy metals and radionuclides are the primary contaminants of concern in this study. Heavy metals, such as lead, cadmium, and arsenic, are toxic even at low concentrations and persist in the environment due to their non-biodegradable nature. The solubility of heavy metals in water is influenced by their chemical forms, called speciation.

Toxicology and Dose-Response Theory

The harmful effects of heavy metals and physicochemical parameters on living organisms are studied using toxicological principles. The dose-response relationship describes how the severity of the toxic effect (response) increases with the concentration or dose of the contaminant (Sokpuwu 2017).

Linear No-Threshold (LNT) Theory for Radiation Exposure

The Linear No-Threshold (LNT) model is commonly used to estimate the risk of cancer from exposure to ionizing radiation. The LNT theory posits that even the smallest dose of radiation has the potential to cause cancer, and the risk increases linearly with the dose. There is no "safe" threshold, meaning any amount of radiation could potentially lead to health effects, particularly cancer. This model is widely used for low-dose radiation exposure, such as that which might occur from radionuclides in contaminated water (Kortei et al., 2020).

Toxicology and Dose-Response Relationship for Heavy Metals

The toxicology of heavy metals in water contamination is commonly assessed using the dose-response relationship, which examines how the severity of a toxic effect (such as cancer) increases with exposure to a contaminant (Rahman et al., 2018; Rasool et al., 2016). This relationship is often used to estimate the reference dose (RfD) or the maximum acceptable dose that an individual can be exposed to without experiencing adverse effects. For heavy metals, a commonly used model for estimating cancer risk is the cancer slope factor (CSF), which quantifies the risk of cancer per unit of exposure to a carcinogen. The CSF is derived from epidemiological studies and animal models.

Diffusion Equation of contaminants in Environment

The diffusion equation describing the spread of contaminants in the environment is generally given by the equation or Fick's second law

$$\frac{\partial c}{\partial x} = D\nabla^2 C \qquad (1)$$

Where:

C (x.t) is the concentration of the contaminant at position x and time t. D is the diffusion coefficient, which represents how fast the contaminant spreads in the environment. ∇^2 is the Laplacian operator, which represents the spatial variation of the concentration (in multiple dimensions), this equation simplifies to:

$$\frac{\partial c(x,t)}{\partial t} = D\,\frac{\partial^2 c(x,t)}{\partial x^2} \qquad (2)$$

This equation assumes that the contaminant is diffusing through a medium (e.g. soil or water) and the diffusion is isotropic (the same in all directions). Boundary and initial conditions need to be specified to solve the equation for example, the initial distribution of contaminants at t = 0 and Boundary conditions to represent physical constraints like fixed concentrations at boundaries, no-flux conditions representing the absence of contaminant flow across boundaries, for example, $\frac{\partial c}{\partial x} = 0$ at the boundaries for no flux in D.

Toxicity Model

The toxicity of heavy metals typically increases with concentration. A simple model might be based on a dose-response relationship where the effect of toxicity is a function of the heavy metal present in the organism common form of this dose-response relationship is the Hills equation or the sigmoidal function (Chidi et al., 2019; Ekanem et al., 2020).

$$T(c) = \frac{T\,max.\,C^n}{EC^n_{50} + C^n} \qquad (3)$$

Where:

T (c) is the toxicity or the effect of heavy metal at concentration c, T max is the maximum possible toxic effect and EC_{50} is the concentration at which half of the maximum effect is observed (the effective concentration for 50% toxicity). n is the Hill efficient, which represent the steadiness of the curve.

Linking toxicity with mass and volume, recall that C = M/V, we can substitute this into the toxicity equation to have.

$$T(M) = \frac{Tmax\,(^M/_V)^n}{EC^n_{50} + (^M/_V)^n} \qquad (4)$$

This equation relates the toxicity of the heavy metal to the M of the metal in the organism and the volume V of the compartment. The toxicity over time, If the concentration or mass of the heavy metal changes over time (due to uptake accumulation and elimination) can be used to model the mass of metal over time using a dynamic equation.

$$T_{(t)} = \frac{T_{max}\left(\frac{M_{(t)}}{V}\right)n}{E\,C^n_{50} + \left\{\frac{M_{(t)}}{V}\right\}^n} \qquad (5)$$

Where M(t) is the mass of the heavy metal in the organism at time t, which can be modelled using bioaccumulation equations like the one described earlier. The mass M(t) changes over time due to the processes of uptake and elimination. General toxicity Equation: The relationship between bioaccumulation mass, volume and concentration could be written as

$$T_{(t)} = \frac{T_{max}\,(ku\,C_{ext}\,^V/_V)^n}{EC^n_{50} + (ku\,C_{ext}\,^V/_V)^n} \qquad (6)$$

Where ku is the uptake rate and constant Cert is the external concentration of the heavy metal, and V is the volume of the organism or the compartment. Using the Threshold model, where (toxicity Vs concentration) for a simpler approach, called threshold concentration ($C_{threshold}$), toxicity can only occur if the concentration exceeds a certain value. Hence, the toxicity equation can be written as:

$$T(c) \begin{cases} O, \text{ if } C < C_{threshold} \\ T_{max}, \text{ if } C \geq C_{threshold} \end{cases} \qquad (7)$$

Note, $C_{threshold}$ is the concentration of the metal above which toxicity begins to have an effect.

Chronic Daily intake (CDI) (mg/kg-day)

$$CDI = \frac{W_w \times IR \times EF \times ED}{BW \times AT} \qquad (8)$$

Where

CDI: Chronic Daily Intake (mg/kg-day), W_w: Contaminant Concentration in Water (mg/L), IR: Ingestion Rate(L/day) (2 L/day for adult, 1 L/day for children), EF: Exposure Frequency (days/year) (e.g., 365 days/year), ED: Exposure Duration (years) (e.g. 30 years for adults, 6 years for children), BW: Body Weight (kg) (70 kg for adults, 15kg for children) and AT: Averaging Time (days) (ED x 365 days)

Hazard Quotient (HQ) for Non-Carcinogenic Risk

$$HQ = \frac{CDI}{RfD} \qquad (9)$$

Where:

HQ = Hazard Quotient, RfD = Reference Dose (mg/kg-day) (fro EPA/WHO for each contaminant)

Cancer risk (CR) for carcinogenic contaminants

$$CR = CDI \times SF \qquad (10)$$

Where:
CR = cancer risk probability (unitless), SF = Slope factor for carcinogenic substances (mg/kg-day^{-1}).

MATERIALS AND METHODS

Study Area

This study was carried out in Gboko, Benue State of Nigeria, covering five major locations. There are, Gboko Central, Gboko North, Gboko South, Gboko East and Gboko West. Gboko, Gboko is a local government area in Benue State, North Central Nigeria. It's headquartered is Gboko town with a land mass of 2 264sq km. Having a population of 358 936 according to 2006 census. It is the largest of the twenty-three local governments by population in Benue State. It lies between latitude 7º 19' 30.00" N and longitude 9º 00' 18.00" E. The vegetation type in Gboko is Guinea Savannah with annual rainfall between 150- 180mm and temperature of 26ºC - 40ºC (Agaku et al., 2024). Figure 1 below shows the Map of Gboko, showing the five locations where samples were collected

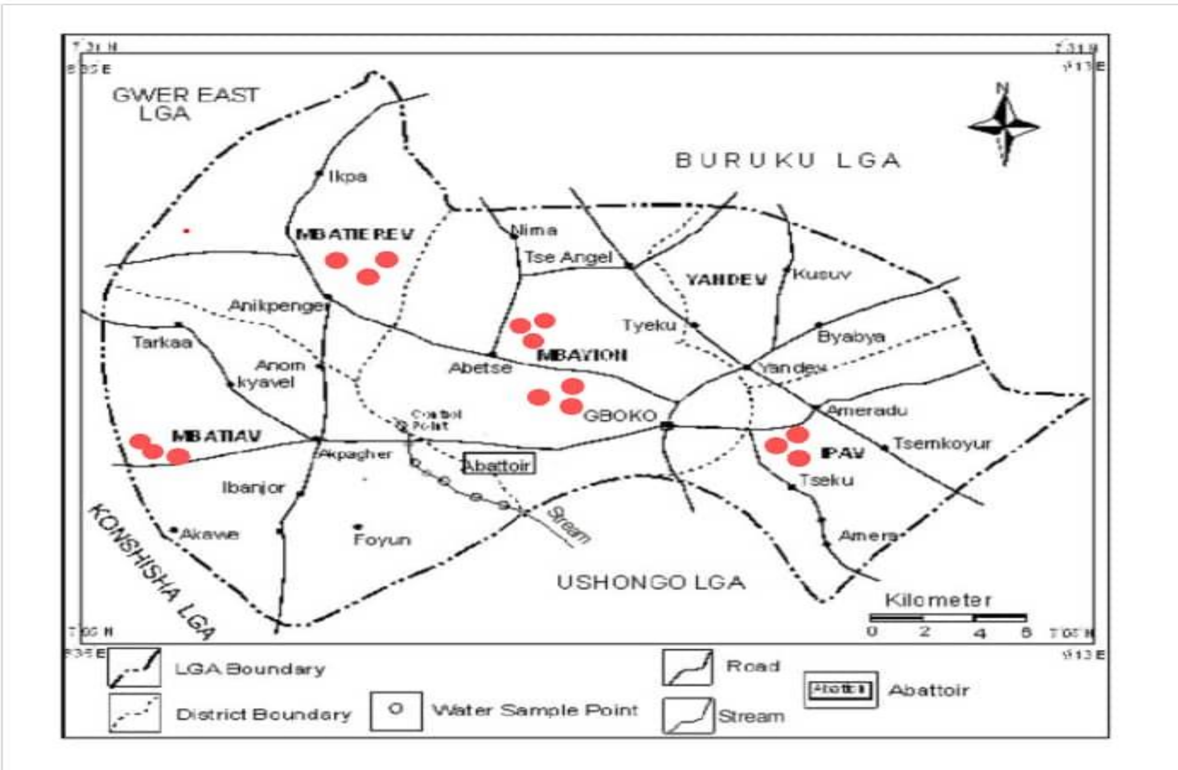

Figure 1: Below shows the Map of Gboko, showing the five locations

Method/Procedure

Sterilized 1-litre capacity plastic bottles were used to collect water samples from boreholes and wells in the Gboko Area, Benue State, with four samples collected per location, tagged, and submitted to Shaba Laboratory, Abuja, for the determination of Arsenic and Toxic Heavy Metal analysis, iodine solution using potassium iodide weighing 2g and iodine dissolved into a 100 mL distilled water, 1 gram starch solution was dissolved in a soluble starch in about 5 mL of cold deionized water by slowly adding the starch suspension to 95 mL of boiling water, boil until the solution clears and cool to room temperature. standardization of iodine solution through titration with As2O3 dissolved in NaOH and acidified with HCl, and titration of unknown arsenic where dried and weighed samples were dissolved in NaOH, acidified, buffered with sodium bicarbonate, and titrated with standardized iodine solution using starch as an indicator to determine the percentage of arsenic oxide (As2O3) based on the calculated molarity of the titrant using the equation to show the chemical reactions involved in this step given as Normality of Iodine Solution (if standardizing)

$$NI_2 = \frac{mmol\ of\ \mathrm{As2O3}}{Volume\ of\ I_2\ used\ (L)\ ^{x}\ Equivalent\ factor} \quad (11)$$

Percentage of As2O3 in unknown

$$\%\ \mathrm{As2O3} = \frac{(VI_2\ X\ VI_2\ X\ NI_2\ X\ MW_{\mathrm{As2O3}}\ X\ 100)}{(Mass\ of\ sample\ (g) X\ 4000)} \quad (12)$$

Where
VI_2 = Volume of iodine used (L), NI_2 = Normality of iodine solution, MW_{As2O3} = Molecular weight of As_2O_3

(197.84 g/mol) and Stoichiometric factor (1 mol As_2O_3 reacts with 2 mol I_2)

3.3 Bicarbonate Buffering

Sodium bicarbonate ($NaHCO_3$) was added in small portions while swirling until no more dissolves (indicating saturation), 3 g excess $NaHCO_3$ was added to ensure sufficient buffering capacity. If bicarbonate dissolves before titration completion, more of $NaHCO_3$ will be added to maintain excess.

3.4 Titration with Standard Iodine Solution

Immediately add 3 mL of starch indicator (forms a deep blue complex with iodine). Titrate rapidly with the standard iodine solution from the burette while swirling continuously. The endpoint will be appearing first permanent pale blue colour (indicating excess iodine), and the value was recorded.

RESULTS AND DISCUSSION

Results

Table 1: Results of Concentration of Heavy Metals

Sample Location	Sample ID	As(mg/L)	pH	Ni(mg/l)	Cd(mg/l)	Cr(mg/l)	Pb(mg/l)	Mn(mg/l)	Zn(mg/l)
Gboko Central									
Location 1	Borehole	0.075921	6.86	0.0329	1.3679	-1.0381	1.2911	0.3654	0.1317
Location 2	Borehole	0.1138815	6.42	-0.0590	1.2807	-0.6583	-3.2154	0.0474	0.2437
Location 3	Well Water	0.075921	6.69	-0.1411	0.4572	-2.8649	-3.5776	-0.2220	0.0351
Location 4	Well Water	0.151842	6.42	-0.0966	0.3950	-2.4073	0.2187	-0.3075	0.0806
Gboko North									
Location 1	Borehole	0.075921	6.69	0.0817	0.2654	-1.5866	-2.8957	0.1833	0.1334
Location 2	Borehole	0.075921	6.64	-0.0773	0.3546	-2.7699	3.2457	0.1035	0.0432
Location 3	Well Water	0.1138815	6.71	-0.2431	0.2205	0.9646	-4.8399	0.1069	0.0388
Location 4	Well Water	0.1138815	6.17	0.0626	0.1371	-0.4827	-1.9283	0.0724	0.0840
Gboko South									
Location 1	Borehole	0.1138815	6.91	-0.0041	0.2863	-0.6262	4.4852	0.0118	0.0281
Location 2	Borehole	0.1138815	6.75	-0.1855	0.2083	0.1628	0.4244	0.0243	0.0774
Location 3	Well Water	0.1138815	6.75	-0.0111	0.3752	2.2561	0.8925	-0.0408	0.0188
Location 4	Well Water	0.1138815	6.91	-0.1029	0.2295	-0.1240	5.2033	-0.1570	0.0462
Gboko East									
Location 1	Borehole	0.13286175	6.70	-0.1192	0.2853	0.5071	-1.5494	-0.0959	0.0445
Location 2	Borehole	0.13286175	6.58	-0.0946	0.3644	2.6846	7.2076	-0.0297	0.0273
Location 3	Well Water	0.09490125	7.06	-0.1818	0.1693	3.5209	0.4300	-0.0677	0.0210
Location 4	Well Water	0.1138815	6.65	-0.0816	0.2542	0.1016	-2.4231	0.0956	0.0288
Gboko West									
Location 1	Borehole	0.1138815	6.31	-0.1910	0.1422	-0.1153	4.6625	0.1355	0.0890
Location 2	Borehole	0.075921	7.03	-0.2021	0.1824	2.5690	0.7721	0.1925	0.0617
Location 3	Well Water	0.1138815	6.72	-0.1604	0.1153	0.2807	3.5167	0.0922	0.0271
Location 4	Well Water	0.1138815	6.62	-0.1205	0.1917	0.8657	-1.7297	0.0897	0.0345

Discussion

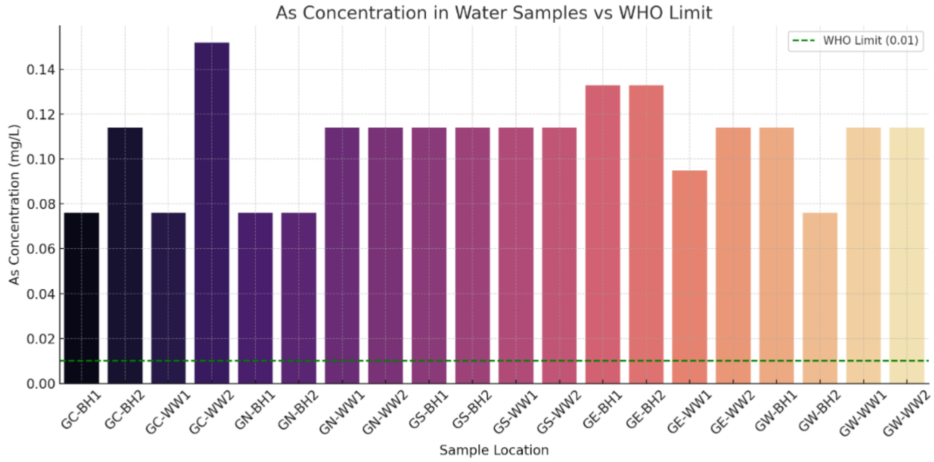

Figure 2: Shows a bar chart visualizing the concentration of arsenic (As) in milligrams per liter (mg/L) for different sample Sites

Figure 2 shows Arsenic (As) concentrations in borehole and well water samples collected from various locations within Gboko, Benue State, and compares them against the World Health Organization (WHO) guideline limit of 0.010 mg/L for safe drinking water. Each bar represents a specific sampling site, with boreholes and hand-dug wells analysed USEPA (2019) separately. A dashed red line indicates the WHO permissible limit, providing a clear benchmark for evaluating contamination levels. All sampled water sources, both boreholes and wells, exhibit Arsenic levels significantly higher than the WHO recommended limit of 0.010 mg/L. Values range from 0.075 mg/L to 0.151 mg/L, which are 7.5 to over 15 times higher than the safety threshold. This widespread exceedance suggests a systemic issue of arsenic contamination in groundwater sources across Gboko.

The highest concentration (0.151 mg/L) was observed at Gboko Central (Location 4 – Well Water), indicating a hotspot of arsenic contamination. Other high concentrations (≥0.13 mg/L) were seen in Gboko East (boreholes) and Gboko South (both well and borehole sources). This geographic spread indicates that arsenic presence is not localised, but potentially driven by regional geological, agricultural, or anthropogenic factors. Both borehole and well water sources are affected, while there's no consistent trend showing one type to be more contaminated than the other, some well water samples (e.g., Gboko Central and East) appear slightly more elevated. This suggests that arsenic contamination may originate below shallow surface levels, affecting both deep and shallow groundwater systems. Possible Causes of Contamination: Arsenic naturally occurs in certain rock and soil formations and can leach into groundwater.

The geology of Gboko, rich in minerals, may contribute to elevated As levels. Anthropogenic Activities, use of agrochemicals (fertilisers and pesticides) in farming. Improper disposal of industrial or domestic waste may also introduce arsenic into aquifers. USEPA (2019) stated that chronic exposure to arsenic through drinking water can cause Skin lesions, cancer (especially skin, lung, and bladder), cardiovascular diseases, and neurological effects. Children and pregnant women are particularly vulnerable. Given that all samples exceed the safe limit, there is a critical public health risk for communities relying on these water sources.

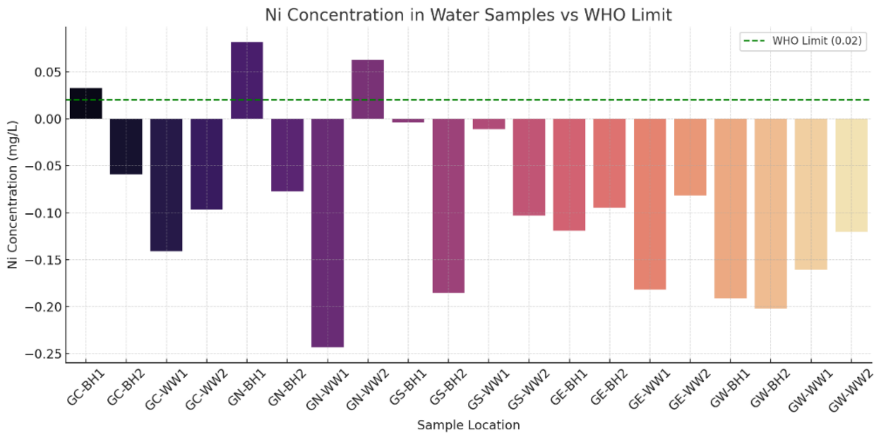

Figure 3: Presents the concentration of Nickel (Ni) in milligrams per liter (mg/L) for various sample Sites

Figure 3. presents the concentration of Nickel (Ni) which varies significantly across the sample locations, with some values negative, likely due to instrument calibration error, zero-point drift, or data preprocessing issues (these should ideally be treated as "below detection limit"). Several positive values exceed the WHO guideline of 0.020 mg/L: Gboko Central Location 1: 0.0329 mg/L, Gboko North Location 1: 0.0817 mg/L, Gboko South Location 4: 0.0626 mg/L

The highest value recorded is 0.0817 mg/L, which is over 4 times the WHO limit. Several readings fall just below or close to the threshold, but even these still raise concerns due to potential cumulative exposure. Nickel, at elevated concentrations, is associated with Dermatitis, Respiratory issues, Kidney and cardiovascular toxicity, Chronic ingestion can lead to carcinogenic effects, especially when combined with exposure to other heavy metals (Kurwadkar, 2019). The presence of Ni in groundwater may be linked to Industrial runoff or corrosion of plumbing, Natural leaching from ultramafic rocks or minerals in the local geology. Higher levels in Gboko Central and North suggest regional variations, possibly tied to geological formations or specific anthropogenic activities. Boreholes and wells are both affected, implying widespread aquifer contamination. Negative values need to be flagged and reviewed; they may indicate non-detects or instrumental noise, and should be either corrected or reported as "< LOD" (limit of detection).

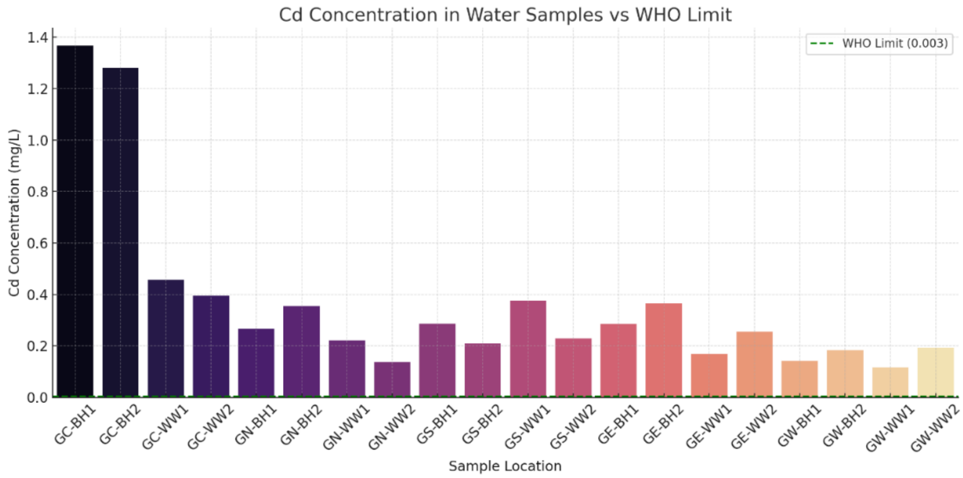

Figure 4: Presents the concentration of Cadmium (Cd) in milligrams per liter (mg/L) for various sample Sites

All sampled locations (Figure 4) exceed the WHO guideline value of 0.0030 mg/L, with concentrations ranging from 0.1153 mg/L to as high as 1.3679 mg/L. Gboko Central Location 1 (Borehole) has the highest cadmium concentration: 1.3679 mg/L, which is over 455 times the WHO limit. Consistently high values are observed across all locations and water types (both borehole and well). Even the lowest positive values (e.g., 0.1153 mg/L) are still almost 40 times above the acceptable threshold. Cadmium is a highly toxic metal, even in trace amounts. Chronic exposure through drinking water is associated with: Notably, long-term

cadmium accumulation in the body is irreversible, making this an extremely serious public health concern.
The uniformly high cadmium levels suggest widespread contamination, which may be from: Improper disposal of batteries and electronics. Industrial activities such as metal smelting, paint manufacturing, or plastic stabilizers. Fertilizer runoff (especially phosphate-based fertilizers contain cadmium as a contaminant). Natural weathering of cadmium-bearing rocks in the region. Both borehole and hand-dug wells are equally contaminated (Ejigboye, 2021). This suggests contamination is not superficial, but possibly affects deeper aquifers. The contamination trend appears to be systemic across Gboko, not isolated to specific zones.

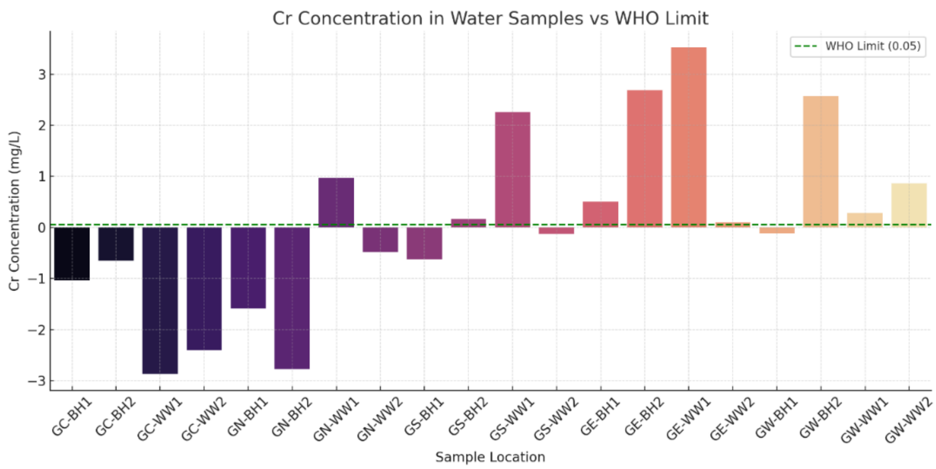

Figure 5: Presents the concentration of Chromium (Cr) in milligrams per litre (mg/L) for various sample Sites

Chromium concentrations in the dataset display significant variability, ranging from -2.8649 mg/L to +3.5209 mg/L; the highest value recorded is 3.5209 mg/L (Gboko East, Location 3 –Well Water), which is over 70 times the WHO limit. Several other locations also exhibit high concentrations, including, Gboko East Location 2 (2.6846 mg/L), Gboko West Location 2 (2.5690 mg/L), and Gboko South Location 3 (2.2561 mg/L) (Figure 5). Some values are negative, which, as with other metals, are below the detection limit or instrumental artifacts and handled appropriately.
The main concern in water is Hexavalent Chromium (Cr^{6+}), a known carcinogen. The health risks associated with long-term exposure include: Liver and kidney damage, Dermatitis and skin ulcers, Lung and stomach cancers, DNA damage due to oxidative stress mechanisms [30]. Importantly, even short-term exposure to high concentrations can lead to acute toxicity. Elevated chromium levels are often linked to: Industrial discharges, especially from tanneries, metal plating, and dye production, Improper disposal of paints, pigments, and anti-corrosion products, Natural sources like ultramafic rocks, though less likely to contribute to such extreme levels. Highest contamination is observed in Gboko East and South, suggesting a localized source of contamination. Both well and borehole sources are affected, indicating possible aquifer-wide infiltration.

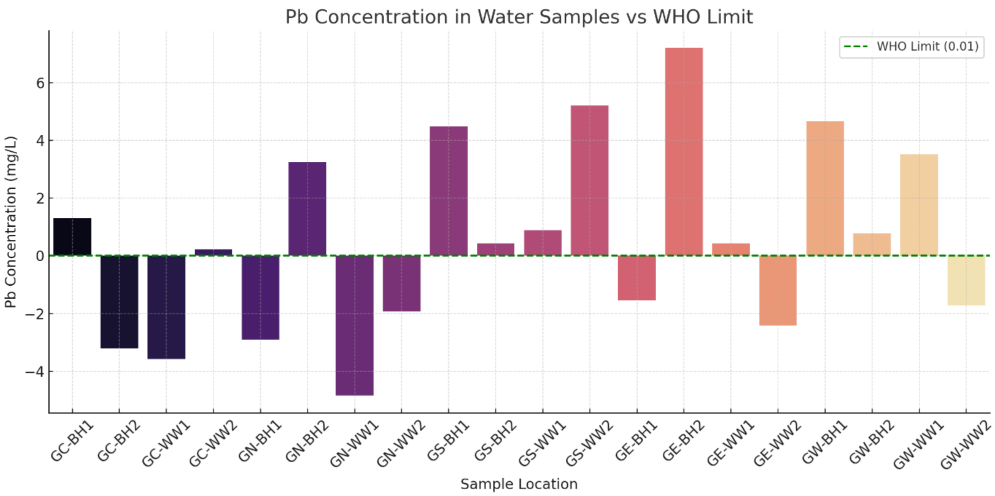

Figure 6: Presents the concentration of Lead (Pb) in milligrams per litre (mg/L) for various sample Sites

Lead concentrations in the samples show extreme variations, with values ranging from -4.8399 mg/L to +7.2076 mg/L (Figure 6). Several locations show drastically elevated lead levels, notably: Gboko East, Location 2 (Borehole) – 7.2076 mg/L, Gboko South, Location 4 (Well Water) – 5.2033 mg/L, Gboko West, Location 1 (Borehole) – 4.6625 mg/L and Gboko South, Location 1 (Borehole) – 4.4852 mg/L. These values are hundreds of times above the WHO threshold (0.010 mg/L), indicating critical contamination, with previous metals, negative values (e.g., -4.8399 mg/L) should be flagged for quality control. Lead is highly toxic, with no known safe exposure level, especially for vulnerable populations like infants and pregnant women.

The health effects include Neurodevelopmental delays in children, reduced IQ and attention span, Renal failure and hypertension in adults, Miscarriage and premature birth. Lead accumulates in bones and soft tissues, and chronic exposure leads to irreversible damage. The extremely high values suggest significant anthropogenic input, possibly from: Lead pipes and plumbing fixtures, Battery disposal, Industrial waste and emissions, Use of leaded gasoline residues in soil (legacy contamination), Some natural leaching is possible, but not typically at these magnitudes. Contamination appears to be widespread and indiscriminate of source type, affecting both boreholes and wells. Some borehole sites, which tap deeper aquifers, show even higher Pb levels than shallow wells, suggesting possible deep contamination or poorly lined boreholes.

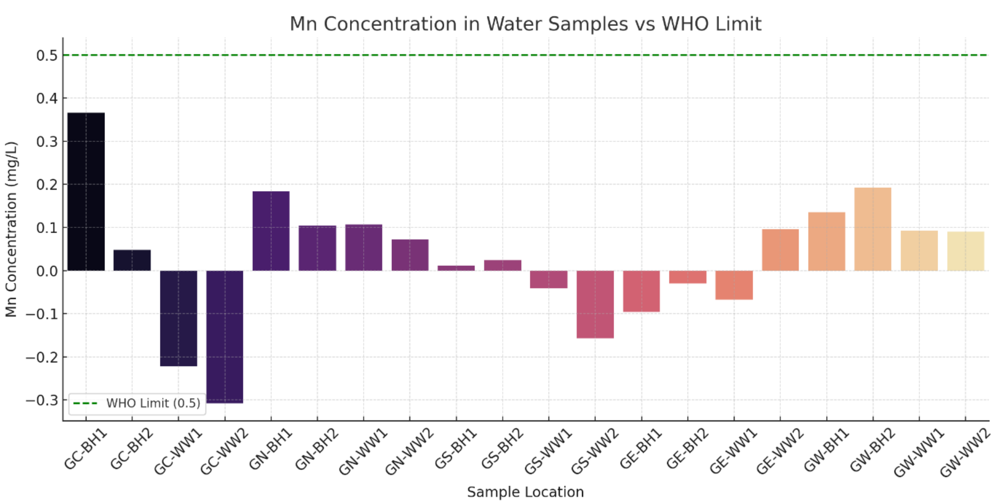

Figure 7: Presents the concentration of Manganese (Mn) in milligrams per liter (mg/L) for various sample Sites

Figure 7 illustrates the concentration of Manganese (Mn) across the different sampled locations. The results show a relatively consistent distribution of Manganese Mn, with slight variations among the sites. This consistency

suggests that Manganese contamination or enrichment in the area may be influenced by natural geological formations rather than anthropogenic sources. However, some elevated values observed in specific locations might be attributed to leaching from fertilizers or agricultural runoff, considering the known use of manganese-containing agrochemicals.
The concentrations recorded remain within permissible limits set by the WHO and other relevant environmental standards, indicating no immediate threat to public health. The presence of Mn at moderate levels can be beneficial, as it is an essential mineral for both plants and animals. Nonetheless, long-term monitoring is advisable to ensure that levels remain stable and do not trend toward excess due to increased agricultural or industrial activities.

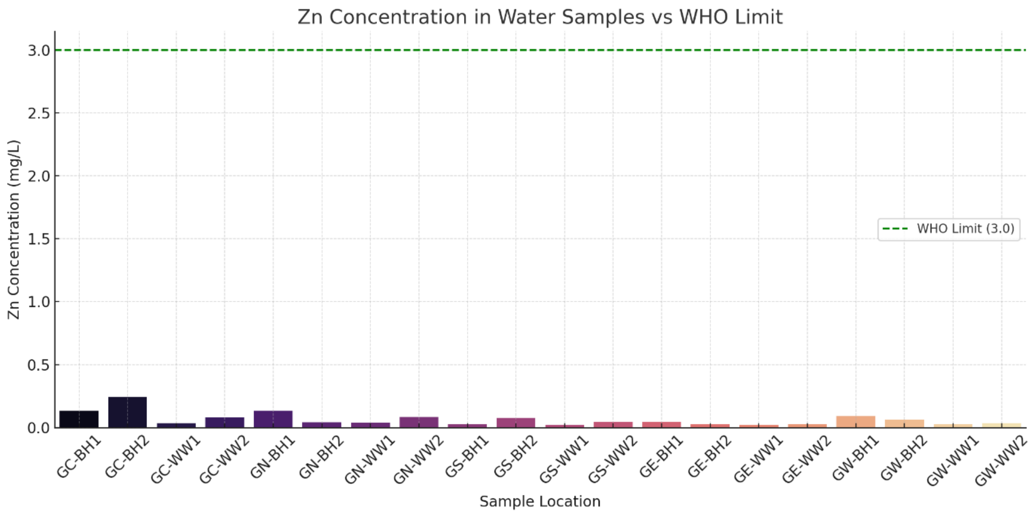

Figure 8: Presents the concentration of Zinc (Zn) in milligrams per liter (mg/L) for various sample Sites

Figure 8 displays the variation in Zinc (Zn) concentration across the study locations. Zinc levels showed more pronounced differences compared to magnesium, with some locations exhibiting significantly higher concentrations. This variability could point to localized sources of zinc input, such as industrial discharge, galvanized material corrosion, or application of zinc-based fertilizers and pesticides.
Although zinc is an essential micronutrient, elevated concentrations—especially those exceeding regulatory thresholds—could pose ecological risks or lead to bioaccumulation in aquatic organisms. The observed high levels in certain areas call for further investigation into potential anthropogenic sources and possible remediation strategies. Overall, the spatial distribution of zinc suggests a more direct influence of human activities compared to manganese, underscoring the need for targeted pollution control and community awareness in affected regions.

CONCLUSION

This study evaluated the concentrations of seven heavy metals Arsenic (As), Nickel (Ni), Cadmium (Cd), Chromium (Cr), Lead (Pb), Manganese (Mn), and Zinc (Zn) in borehole and hand-dug well water samples from various locations in Gboko, Benue State. The results were compared to World Health Organization (WHO) drinking water standards, revealing that all sampled water sources contained metal concentrations significantly above permissible limits, indicating extensive groundwater contamination. Arsenic levels (0.075–0.151 mg/L) surpassed the WHO limit of 0.010 mg/L in all samples, likely due to geological formations and agricultural practices. Nickel concentrations exceeded the 0.020 mg/L threshold in several areas, suggesting industrial runoff or leaching from rocks. Cadmium levels were especially alarming, reaching up to 1.3679 mg/L, more than 450 times the safe limit, possibly due to fertilizer use, electronic waste, or natural sources. Chromium was detected at levels as high as 3.5209 mg/L, pointing to potential industrial pollution and significant toxicity risk. Lead contamination was severe, with concentrations up to 7.2076 mg/L, vastly exceeding the 0.010 mg/L standard, likely due to anthropogenic activities. The presence of heavy metals in both shallow and deep-water sources suggests a regional-scale problem affecting all types of groundwater in Gboko. This widespread contamination poses a serious public health threat, particularly to vulnerable populations, and underscores the urgent need for remedial action. Recommended measures include immediate water treatment, stricter pollution control, environmental regulation enforcement, and community education. This research makes a vital contribution to the understanding of groundwater quality and environmental health in Gboko by providing a comprehensive analysis of heavy metal contamination in both boreholes and hand-dug wells. It establishes a baseline for future water quality monitoring and identifies contamination hotspots, particularly Gboko Central, East, and South using geographical distribution data. These insights are essential for targeted interventions and informed water safety planning. The study highlights the link between contaminated groundwater and chronic health risks such as cancer, kidney disease, and neurotoxicity. It emphasizes the need for local and state-level frameworks to monitor water quality, manage pollution sources, and implement emergency response strategies. By identifying key contamination contributors industrial discharge, agricultural runoff, and natural leaching the study also offers direction for future research into pollutant transport and remediation in the region.

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