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Research Paper

Physicochemical Characterization and Heavy Metalassessment of Water Sources in Some Parts of Maiduguri Metropolitan Council, Borno State

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Abstract
Safe and potable water provision has been one of the greatest challenges in fast growing urban cities in sub-Saharan Africa such as Maiduguri Metropolis in northeastern Nigeria, where groundwater is one of the major sources of domestic water supply. In this paper, physicochemical properties and heavy-metal content of groundwater in the selected boreholes in the Maiduguri Metropolis were determined and the appropriateness of the groundwater to the domestic was evaluated. Ten groundwater samples were taken at various positions and in situ determination of the pH, electrical conductivity (EC) and total dissolved solids (TDS) were conducted with the mercury (Hg) and cadmium (Cd) being analyzed using Atomic Absorption Spectrophotometry (AAS). It was revealed that the pH values were in the range of 6.70 to 7.26, which is close to neutral values and corresponds to the guidelines that are provided by World Health Organization (WHO) and Nigerian Industrial Standard (NIS). The values of TDS (123-551 mg/L) and EC (247-600 uS/cm) indicated low to moderate mineralization, which implied the generally satisfactory quality of groundwater. The analysis of heavy-metals showed low levels of Fe and Zn, and Pb + Hg were not found in any sample, which means a minimum level of the industrial pollution. But in some of them, cadmium was found in amounts that are above the WHO guideline thresholds, and it is question whether there are long-term health effects. In general, the quality of groundwater in Maiduguri Metropolis is mostly appropriate to be used in the home environment, but the local cadmium distribution increases the necessity to monitor its levels and to take the necessary treatment measures to protect the health of the population.

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I. Introduction

The availability of safe and potable water is a key determinant of both socio-economic development and the population well-being of most rapidly urbanizing cities of sub-Saharan Africa, yet the water resources in these urban areas are susceptible to both natural and artificial water contamination (WHO, 2022). In Nigeria, a considerable percentage of the population uses groundwater and surface-water sources for domestic purposes and in most cases, these sources are not properly treated or monitored, thus exposing them to physicochemical contaminants and toxic heavy metals (NIS, 2007; WHO, 2022). Maiduguri Metropolis is a big city and administrative centre in Borno State, with a high and increasing population that relies on boreholes, hand-dug wells, and surface-water reserves, including the Alau Dam, to drink, cook, and irrigate its residents (Mshelia et al., 2023; Sanda et al., 2023).

The factors that have been found to cause water-quality declines in Maiduguri and its surroundings include urbanization, population pressure, lack of good waste-management practices, and industrial and domestic effluents (Charles, 2025; Mshelia et al., 2023). Recent investigations of borehole and dam-water samples in Maiduguri have indicated that there are high concentrations of some of the heavy metals such as copper (Cu), lead (Pb), iron (Fe), chromium (Cr), and cadmium (Cd) in some areas, and the concentration of some of the said metals in the water is sometimes higher than maximum recommended levels indicated by WHO and the Nigerian Industrial Standard (NIS) of drinking water (Charles, 2025; Sanda et al., 2023; Mshelia et al These results suggest that there is a possible danger of chronic exposure, especially in vulnerable populations, including children or pregnant women, as the negative health effects of heavy-metal ingestion are reported, including neurotoxicity, kidney dysfunctions, and carcinogenicity (Jaishankar et al., 2014; WHO, 2022).

The physicochemical parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), as well as specific ions (e.g., Ca2+, Mg2+, Cl-, NO3-), offer important baseline data on the quality of water and assist in finding out the possible source of pollution and required treatment (APHA, 2017; Mshelia et al., 2023). Previous studies have indicated that although certain borehole water samples in Maiduguri pass the WHO and NIS limits regarding most of the physicochemical indicators, others have high hardness, chloride, iron, and nitrate levels, which may be due to localized contamination by septic leachate, agricultural runoffs, and urban effluents (Mshelia et al., 2022; Charles, 2025). But such studies tend to be either narrow in location or the metals under analysis, creating critical gaps in the knowledge of the entire contamination picture in the city in terms of the types of the water sources.

It is against this background that the current paper aims at physicochemical characterization and heavy-metal measurements of sampled water sources in certain portions of Maiduguri, Borno State.

II. Study Area and Methodology

2.1 Study Area

Maiduguri Metropolis is the capital and largest city in Borno State, North-Eastern Nigeria (Figure 1) and is the second largest State in Nigeria after Niger State. Borno State is bounded in North-East by Chad, East by Cameroon, North by Niger, West by Yobe State and South by Gombe and Adamawa States. It is located between latitudes 11°N and 13°N and longitudes 10°E and 14°E. Spanning 65,868 square kilometers (Shettima, et al 2025).The region's climate is characterized by three distinct seasons, as reported by Hess et al. (1996): a cold dry season from October to March, a hot dry season from April to June, and a rainy season from July to September. Relative humidity varies significantly, ranging from 13% in the dry season to 65% in the rainy season, making the area extremely vulnerable to drought. The state experiences year-round high temperatures, with the hot season reaching between 39°C and 40°C in the shade; the southern regions of the state frequently experience cooler weather.The terrain in Maiduguri is predominantly flat, with elevations ranging from under 600 meters to over 600 meters above sea level in the southern and southeastern highlands of Borno State. These plains play a crucial role in the area's drainage system, facilitating groundwater recharge during the rainy season, primarily between August and October (Hollis et al., 1993). Notably, groundwater is mainly recharged from floodplains rather than rivers, highlighting the importance of local hydrological systems in groundwater replenishment.

The region Is drained by two major river systems: one that flows southward into the Benue River and another that drains toward Lake Chad. Seasonal rivers reach their peak during the rainy season (July to August), with major rivers such as the Hawul River draining the Biu Plateau and the Yedzeram River draining the southeastern and eastern regions toward Lake Chad. However, drought and upstream water abstraction have significantly reduced the volume of water reaching Lake Chad, contributing to the lake's shrinking size in recent decades.

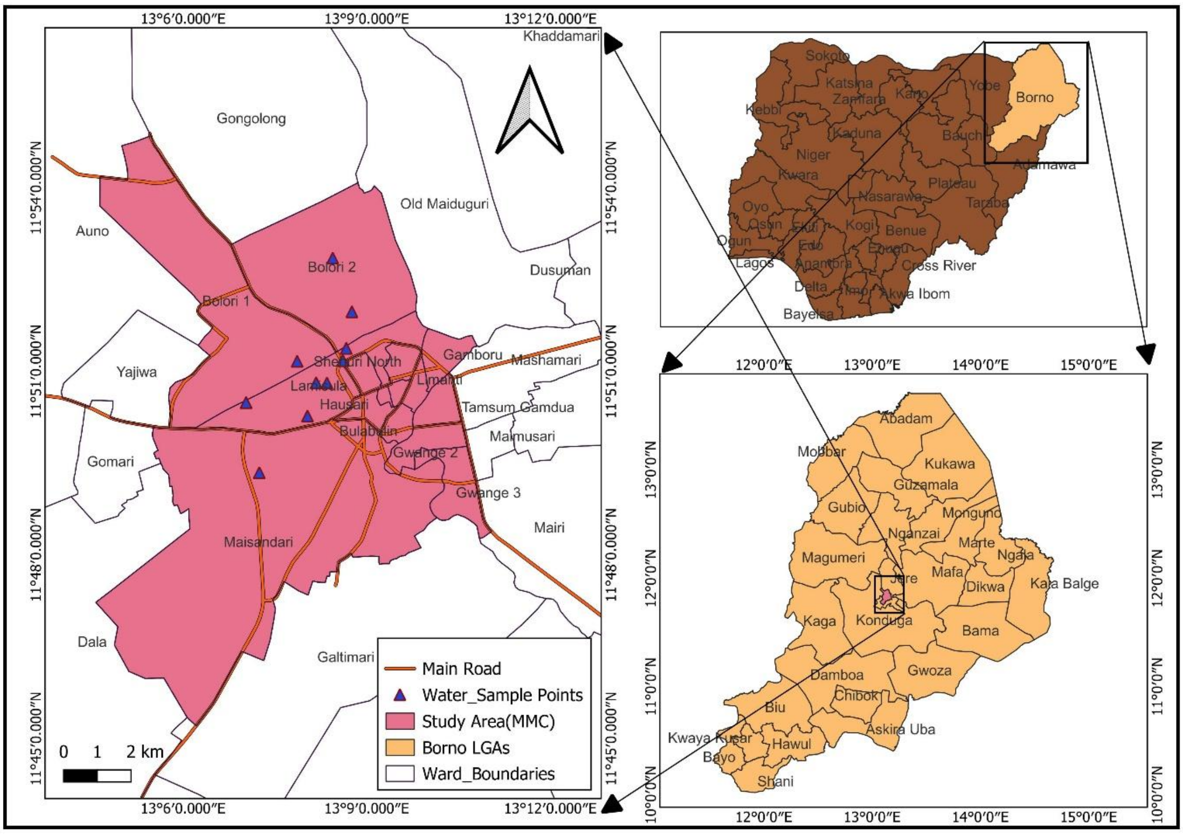

Fig.1: Map of Borno state showing Maiduguri

2.2 Materials And Methods

1. Global Positioning System (GPS) device
2. Sample bottles (acid-washed polyethylene, 500 ml)
3. Portable pH and EC meters
4. Atomic Absorption Spectrophotometer (AAS) for heavy metal analysis
5. Masking tape and marker pens for labeling
6. Field notebook and pen

A GPS device (Fig.2) was used to record the precise location of outcrops, sampling points, traverses, and structural features, ensuring accuracy in mapping and data correlation. A field notebook used to record observations, sketches, measurements, and interpretations directly from the field and sample bottle is used to preserve the sample in the field for analysis. The bottle is used in other the prevent the sample from contamination(Fig.3).

Fig.2: GPS Device

Fig.3: Sample Bottle

Portable pH Meter: A handheld device used to measure the acidity or alkalinity (pH) of a liquid sample in the field or laboratory. It provides quick and accurate readings, making it suitable for environmental, agricultural, and industrial monitoring(Fig.:4).
Portable EC (Electrical Conductivity) Meter: A handheld device used to measure the electrical conductivity of a solution, which reflects the concentration of dissolved ions (salts, minerals, or impurities). It is commonly used in water quality assessment, agriculture, and hydrochemistry studies.

Fig.:4: pH meter

Masking tape is a type of pressure-sensitive adhesive tape made of thin, easy-to-tear paper and a light adhesive. In laboratory or fieldwork, it is commonly used for labeling samples, sealing containers, and temporary fastening, since it can be removed cleanly without leaving sticky residues.

2.21.Laboratory Materials

An Atomic Absorption Spectrophotometer (AAS) is an analytical instrument used to determine the concentration of heavy metals (e.g., lead, cadmium, arsenic, zinc, copper) in liquid samples. It works by measuring the absorption of light at specific wavelengths by atoms in a gaseous state, providing highly sensitive and precise quantitative analysis of trace metals.

Fig.:5 :Flammen AAS

2.2.2Procedure

A total of 10 water samples were collected from boreholes across Maiduguri Metropolis. Each sample was collected in clean 500 ml bottles. Bottles were pre-rinsed with the respective sample water. Physical parameters were determined in situ to avoid alteration during transportation. Heavy metal samples were preserved by acidifying with concentrated nitric acid (HNO_3).

2.2.3 Laboratory Analysis

The laboratory analysis was conducted at National Geoscience research laboratory (NGRL). The concentrations of chromium (Cr), cadmium (Cd), lead (Pb), mercury (Hg), and zinc (Zn) in the water samples were determined using standard analytical procedures. The samples were first collected in clean, acid-washed plastic bottles and immediately preserved with a few drops of concentrated nitric acid to prevent adsorption of metals onto the container walls. Before analysis, each sample was digested with concentrated nitric acid to break down organic matter and release the metals into solution. After digestion, the samples were filtered and diluted to a known volume with deionized water.

Chromium, cadmium, lead, and zinc were determined using the Atomic Absorption Spectrophotometer (AAS). The AAS instrument was calibrated with standard metal solutions of known concentrations to ensure accuracy. Each of the elements absorbed light at its specific wavelength, and the amount of light absorbed.

Mercury, on the other hand, was determined using the Cold Vapor Atomic Absorption Spectrophotometric (CV-AAS) method because of its volatile nature. In this method, mercury ions in the sample were reduced to elemental mercury using stannous chloride ($SnCl2$). The vapor formed was passed through an absorption cell, and the absorbance was measured at a wavelength of 253.7 nm. This method provided a very high sensitivity for mercury detection even at very low concentrations.

III. Results And Discussion

3.1 Physical And Chemical Parameters

The physical and chemical parameters of the water samples that were analyzed include; potential of hydrogen (pH), Electrical conductivity (EC) and Total dissolved solids (TDS) as shown in table 1.The obtained results of groundwater quality demonstrate that the pH values (6.70-7.26) at all the points of sampling belong to the permissible drinking-water interval of 6.5-8.5, which means that the groundwater can be considered in near-neutral conditions that are not potentially corrosive or harmful to health (WHO, 2017; BIS, 2012). The Total Dissolved Solids (TDS) fall between 123 and 551 mg/L with the majority of samples falling below the desirable range of 500 mg/L and is an indicator of good palatability and low mineralization and yet has a low tolerance to other sources (WHO, 2017). The EC values are low (247 to 600 uS/cm) which suggests the presence of low to moderate ionic concentration and the EC increase is usually consistent with the increase in TSS in the groundwater systems, which supports the close correlation between dissolved ions and conductivity (Hem, 1985; WHO, 2017). In general, the findings indicate that the ground water can be considered of acceptable quality to be used in domestic purposes with some localized enhancements in mineral content which may be due to the sub-surface geology and interaction between the ground water and rocks than the extreme anthropogenic contamination.

Table1: Physical Parameters

S_N	Sample_ID	Longitude_DD	Latitude_DD	pH	TDS	EC
1	L1	13.146	11.86628	6.84	185	345
2	L2	13.14078	11.8809	7.1	182	356
3	L3	13.14447	11.85633	6.7	276	349
4	L4	13.1311	11.8528	6.77	298	600
5	L5	13.14353	11.853	7.03	136	272
6	L6	13.13625	11.84695	7.05	146	296
7	L7	13.1339	11.8379	7.26	551	304
8	L8	13.1392	11.8469	7.21	123	247
9	L9	13.11718	11.84157	6.97	226	452
10	L10	13.12078	11.82247	6.79	164	325

3.2 Heavy MetalsAnalysis

The heavy-metal analysis shows that the groundwater has relatively low and moderate concentrations of the heavy-metals, and most of the parameters are within the international drinking-water limits (Fig 6-10). Iron (Fe) was observed in part of the samples (0.066-0.488 mg/L), of which sample L1 (0.4879 mg/L) (Fig.6) is close to the WHO guideline value (0.3 mg/L), implying that it had aesthetic problems (taste, staining, or turbidity) but not a significant health risk, probably due to natural geologic sources and interaction of groundwater and rock (WHO, 2017). The zinc (Zn) levels (0.0022-0.0802 mg/L) are much less than the guideline value of 3.0 mg/L(Fig.7) which implies no health issue, and a small amount of anthropogenic activity (WHO, 2017). All samples did not have lead (Pb) and mercury (Hg) and it is noteworthy as they are very toxic at low levels meaning that there was no industrial or severe anthropogenic contamination in the study area (WHO, 2017). No samples, however, contained no cadmium (Cd) (0.0011-0.0365 mg/L), (Fig.8) with a number of them exceeding the WHO guideline limit of 0.003 mg/L, which points to a possible health risk with long-term consumption, and some of their concentrations could lead to contributions by geogenic sources or diffuse anthropogenic sources such as waste disposal or farm inputs (WHO, 2017; Alloway, 2013). In general, the groundwater is not very dangerous in terms of Fe, Zn, Pb, and Hg, but the high level of Cd in certain areas should be regularly monitored and potentially treated before long time domestic consumption.

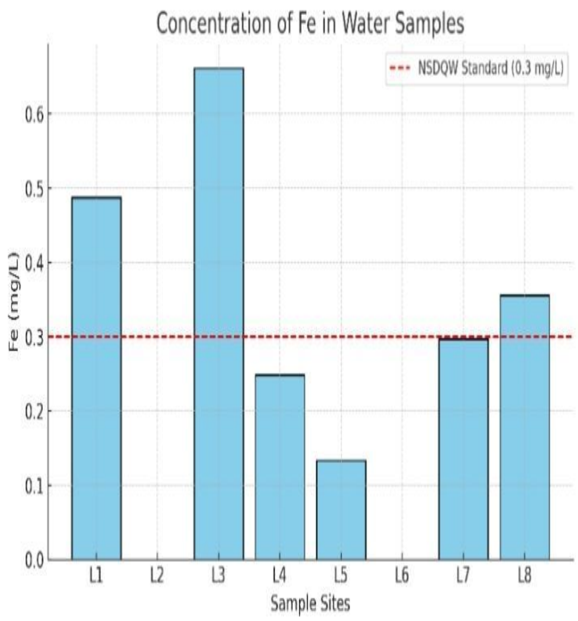

Fig6 :Fe concentration

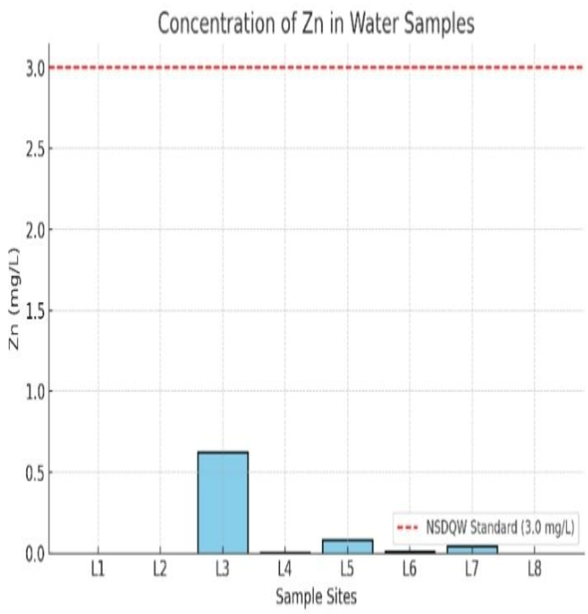

Fig 7 : Zinc concentration

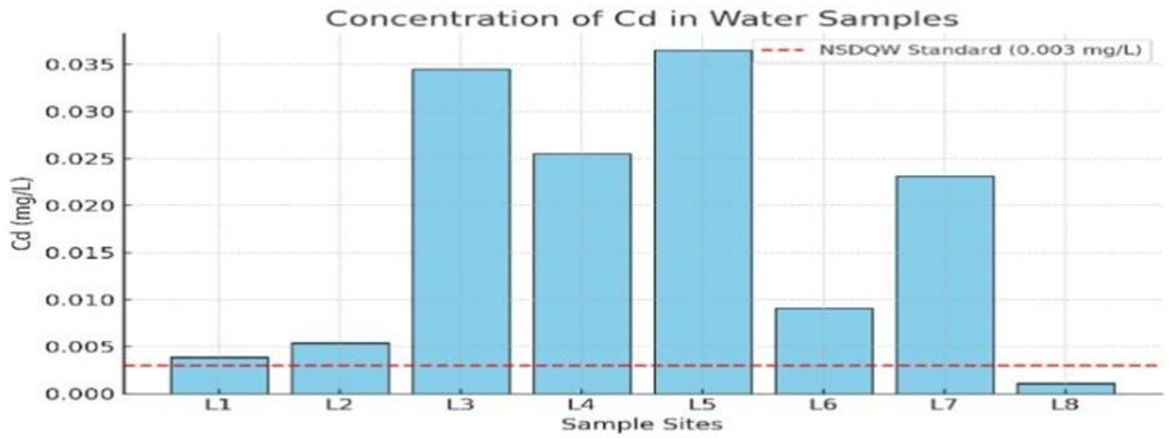

Fig8 The concentration of cadmium in the water samples

IV. Conclusion

The paper has measured the physicochemical characteristics and heavy metals contents of groundwater in selected boreholes in Maiduguri Metropolis to establish its viability as a domestic water source. The findings show that the groundwater is usually of good physicochemical quality with pH values acceptable and TDS and EC values indicating low to medium mineralization with low palatability and few salinity issues. The majority of the analyzed heavy metals (iron, zinc, etc.) appeared in concentrations below the limits of the international guidelines, whereas no lead or mercury was detected in all samples, indicating no major industrial and point-source pollution. Nonetheless, some of these locations contain cadmium which is in excess of the values of WHO guidelines and is potentially hazardous especially when taken over a long period of time and could be due to geogenic processes or diffuse anthropogenic processes like waste disposal and agricultural activities. The majority of the groundwater can be used as drinking and other household water, but due to the high cadmium content in some locations, constant water-quality control, community education, and, in some cases, treatment programs can ensure the long-term water safety and protection of human health in the Maiduguri Metropolis.

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