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Assessment of Heavy Metals in Shallow Aquifer Boreholes and Possible Links to Chronic Kidney Disease (CKD) In Maiduguri and Environs, Borno State, Nigeria

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ABSTRACT

Groundwater contamination by heavy metals is a global environmental and public health concern. In Maiduguri and environs, northeastern Nigeria, groundwater from the shallow unconfined aquifer is the principal source of drinking water and is highly vulnerable to pollution due to poor sanitation and waste disposal practices in the area. This study assessed heavy metal concentrations in groundwater from 300 shallow aquifer boreholes to evaluate potential health risks, particularly in relation to Chronic Kidney Disease (CKD). Water samples were collected during a 2022 field campaign and analysed for Mercury (Hg), Copper (Cu), Arsenic (As), Cadmium (Cd), Lead (Pb), and Chromium (Cr) using Atomic Absorption Spectrophotometry (AAS, Buck Scientific 210 VGP) following APHA standard methods. Results show that Hg concentrations were below both World Health Organization (WHO) and Nigerian Standards for Drinking Water Quality (NSDWQ) guideline values in all the borehole samples. Cu concentrations exceeded the WHO and NSDWQ in only one borehole sample. Thus, the level of Hg and Cu concentrations in the borehole samples do not appear to pose health concern. However, the concentrations of As, Cd, Pb and Cr in the borehole samples show variable percentages above the WHO/NSDWQ guideline from As-18%; Cd-23%; Pb-48%; and Cr-56%. These indicate significant health risks from exposure to these metals, because Pb and Cd are known nephrotoxicants, while As and Cr (particularly hexavalent chromium) have been reported to have links to kidney diseases. Therefore, consumption of water from these boreholes with elevated As, Cd, Pb and Cr may contribute to long-term adverse health outcomes, including increased CKD risk. Mitigation measures may include: implementing appropriate water treatment technologies on the affected boreholes; use of alternative treated surface water; and drilling to deeper aquifers free from these contaminants. In addition, there is the need to strengthen waste management practices, continuous groundwater monitoring and public education campaigns, which can reduce exposure to these risks and safeguard community health.

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Introduction

Groundwater is the primary source of drinking water for much of the world's population and is generally valued for its reliability and quality [1]. However, contamination of groundwater by heavy metals has become a major global environmental and public health concern [2]. At trace concentrations, certain metals such as copper (Cu) and chromium (Cr) are essential micronutrients, but excessive levels can result in severe toxicological effects. Arsenic (As), cadmium (Cd), lead (Pb), and hexavalent chromium [Cr(VI)] are of particular concern, as chronic exposure is strongly associated with nephrotoxicity and other systemic effects, and has been linked to an increased risk of chronic kidney disease (CKD) [3,4].

In northeastern Nigeria, particularly Maiduguri and its environs, groundwater from the shallow unconfined aquifer of the Chad Formation constitutes the principal source of domestic water supply. Although a central water supply system exists, it is unable to meet the rapidly increasing demand driven by high population growth, urban expansion, and the massive influx of displaced persons caused by the protracted insurgency in the region. As a result, households increasingly depend on self-supplied tube wells and wash bores that tap the shallow aquifer. These facilities are cheap to construct and easy to maintain, but the aquifer's shallow depth, unconfined nature, and the prevalence of poor sanitation and indiscriminate solid waste disposal practices render it highly vulnerable to contamination. Thousands of such boreholes now serve as direct sources of drinking water, raising concern about possible health risks associated with long-term exposure to contaminants.

Previous hydrogeological investigations in the Nigerian sector of the Chad Basin have highlighted the vulnerability of the Upper Aquifer (Unit A) due to its permeable overburden lithologies and

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rapid recharge dynamics [5,6]. However, systematic and city-wide assessments of heavy metal contamination in Maiduguri's shallow aquifer, especially those integrating human health risk considerations, are limited. Given increasing reports of kidney-related illnesses in the region, a focused evaluation of heavy metal concentrations in shallow groundwater and their implications for public health is urgently required.

The objective of this study is to assess the concentration of selected heavy metals (Hg, Cu, As, Cd, Pb, Cr) in shallow aquifer boreholes across Maiduguri and its environs, compare the results with both World Health Organization (WHO) and Nigerian Standards for Drinking Water Quality (NSDWQ) guideline values, and evaluate potential health risks using exposure-based indices. The findings are intended to provide evidence-based insights into groundwater safety and inform policy interventions aimed at reducing long-term health risks, including the potential burden of CKD, among communities in the study area.

Study Area

The study was conducted in Maiduguri and its environs, Borno State, northeastern Nigeria. The area is located between latitude 11.802273°N and 11.805671°N and longitude 13.177060°E and 13.224816°E, in a semi-arid region (Figure 1). Maiduguri and environs experience mean annual rainfall of about 600 mm, concentrated between June and September, with high evapotranspiration exceeding 2000 mm per annum [6]. Maiduguri is the most densely populated city in the region, with rapid urban growth and a substantial increase in water demand resulting from the influx of displaced persons due to the insurgency. Groundwater from the shallow aquifer represents the main source of domestic water supply in the city.

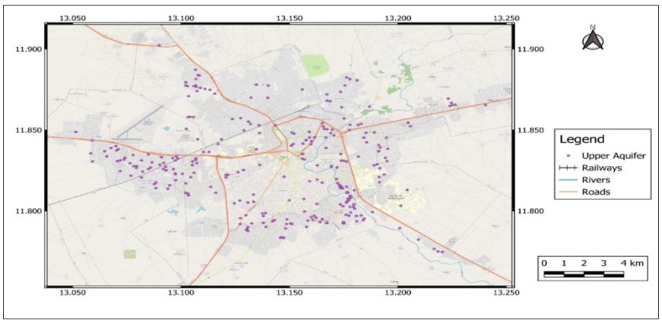

Figure 1: Map of Study area Showing Wards and Sample Locations. Inset is map of Nigeria with the location of Maiduguri in the Northeast

Hydrogeological Setting

The study area is underlain by the Plio-Pleistocene sediments of the Chad Formation, which represents the principal aquifer system in northeastern Nigeria. The formation consists of alternating sands, clays, silts, and occasional gravels, deposited under fluvio-lacustrine conditions [5,7]. Groundwater occurs under water table, semi- confined, and confined conditions within this sequence. Three main aquifer horizons are recognized and are collectively referred to as the Upper, Middle, and Lower aquifers (Figure 2) [8].

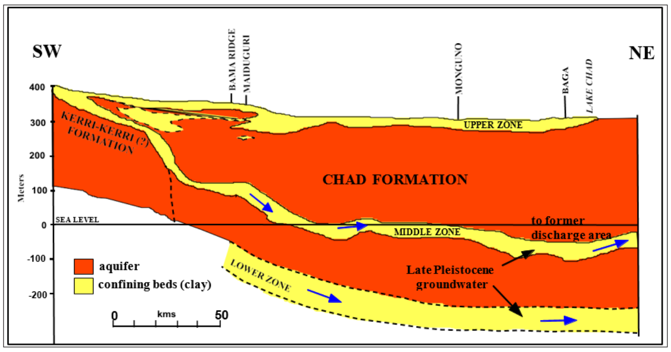

Figure 2: Geological Cross Section of Aquifers in the Chad Formation [8].

In Maiduguri and environs, water supply is derived predominantly from the Upper Aquifer, which is the most extensively exploited unit. This aquifer is not homogeneous but is further subdivided into three hydraulic sub-units: A, B, and C (Figure 3) [9].

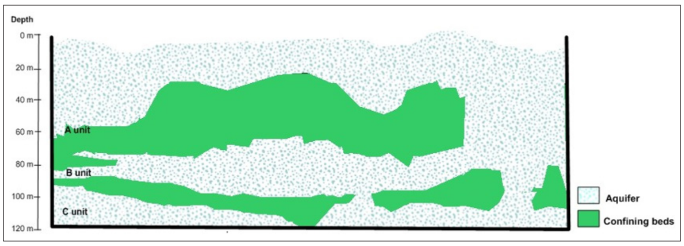

Figure 3: Conceptual cross Section of the Upper Aquifer System [9].

• Unit A represents a shallow, water-table aquifer that occurs at depths of up to 60 m. It is largely developed within recent alluvial and aeolian sands overlying the Chad Formation, but also includes interbedded sandy horizons within the upper part of the formation. Recharge occurs annually through direct infiltration of rainfall and seepage from the Ngadda River. The coarse sandy lithology and shallow unconfined conditions make Unit A highly productive but also extremely vulnerable to contamination from surface activities [6] .
• Unit B is encountered at depths of approximately 70–90 m and typically occurs under semi- confined to leaky artesian conditions. It is separated from Unit A by discontinuous clayey horizons. While less vulnerable than Unit A, it may still be impacted by downward leakage of contaminants, depending on the continuity and thickness of the intervening clay layers [5].
• Unit C occurs at depths of 90-120 m and is generally artesian, with negligible leakage under natural conditions. This sub-unit is considered more protected from contamination but is less frequently developed because of the higher drilling costs and the technical capacity required.

The reliance of households in Maiduguri on Unit A is driven by the ease of manual drilling and lower construction costs for domestic use. However, the hydrostratigraphic characteristics of this unit: shallow depth, permeable vadose zone, and rapid recharge, renders it susceptible to pollution from poorly managed sanitation facilities and refuse dumps. This vulnerability provides a hydrogeological basis for assessing heavy metal contamination in shallow boreholes across Maiduguri and environs.

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Methodology

Sampling Strategy

A total of 300 groundwater samples (Figure. 1) were collected from boreholes tapping the shallow aquifer across Maiduguri and surrounding communities during a single sampling campaign in 2022. Boreholes were selected to provide wide spatial coverage across residential, peri-urban, and community areas. The exact depths of the wells could not be ascertained, as such information was not available from borehole owners or local records. At each sampling location, a handheld Garmin Global Positioning System (GPS) unit was used to record the coordinates and elevation.

Sample Collection

Water samples were collected in accordance with standard field protocols (APHA, 2005). At each site, boreholes were pumped for several minutes before sampling to ensure representative groundwater was obtained. Three replicate water samples were collected at each site using pre- cleaned 100 mL High-Density Polyethylene (HDPE) bottles. Prior to collection, bottles were rinsed three times with the source water to minimize cross-contamination. Samples were labeled with unique codes, date, location, and GPS coordinates, then stored in an ice-cooled box during fieldwork and immediately transported to the laboratory for analysis.

Laboratory Analysis

All samples were analysed at the Chemistry Laboratory, Yobe State University, for six target heavy metals: Mercury (Hg), Copper (Cu), Arsenic (As), Cadmium (Cd), Lead (Pb), and Chromium (Cr). Concentrations were determined using Atomic Absorption Spectrophotometry (AAS). Instrument calibration was carried out using certified standard solutions, and quality control included the use of blanks and replicate analyses. The detection limits of the instrument were adequate for quantifying the metals of interest within drinking water guideline ranges.

Data Treatment

Results were compared against the guideline values of the World Health Organization (WHO, 2011) [1] and the Nigerian Standards for Drinking Water Quality (NSDWQ). Exceedances were calculated as percentages of total borehole samples above the permissible limits for each metal to establish concentration levels relative to standards.

Results

Groundwater Physical Parameters

The measured in situ physical parameters included Temperature (T), pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and redox potential.

Temperature (T): Groundwater temperatures in the shallow aquifer ranged from 26°C to 38°C, consistent with ambient subsurface conditions in semi-arid environments. pH values are variable across the study area, with most samples near neutral (6.5-7.5). A few boreholes showed slightly acidic (<6.5) or slightly alkaline (>8.0) conditions (Figure 4).

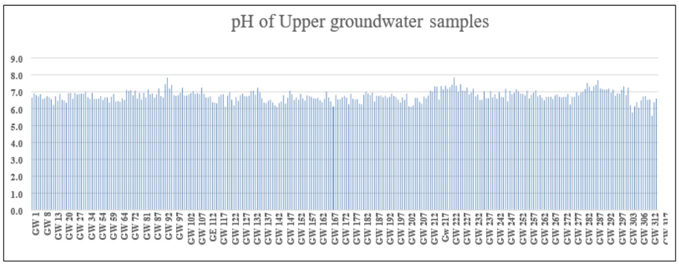

Figure 4: Results of pH in Boreholes of Upper Aquifer Groundwater Samples

Electrical Conductivity (EC) and TDS: EC values ranged from 50 µS/cm to over 3,000 µS/cm, with corresponding TDS values showing a strong linear correlation ($R^2 > 0.95$; Figure 5).

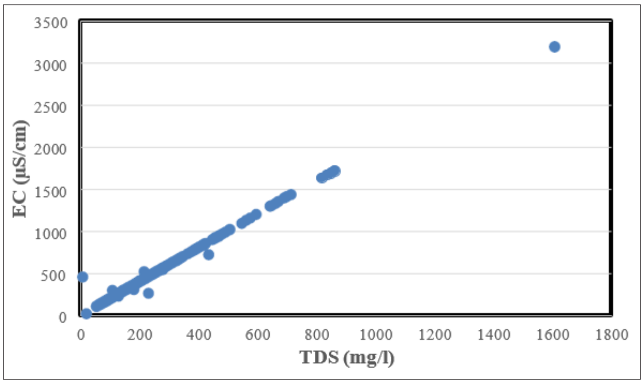

Figure 5: Results of TDS against EC of Water Samples Showing Linear Relationship

This indicates that ionic concentrations are the principal contributors to water salinity in the shallow aquifer. Spatial variability was observed, with some boreholes showing elevated EC and /TDS, suggestive of localized contamination or evaporative concentration effects (Figures. 6-7).

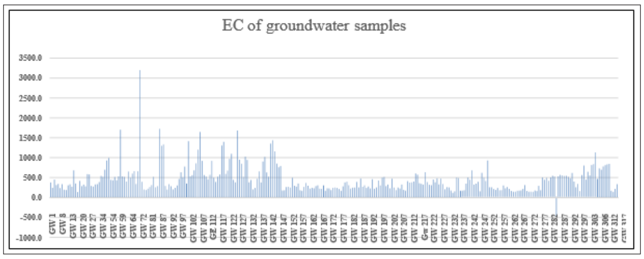

Figure 6: Results of EC (µS/cm) in Boreholes of Upper Aquifer Groundwater Samples

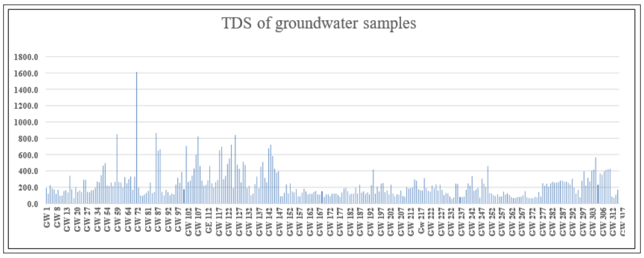

Figure 7: Results of TDS (mg/l) in Boreholes of Upper Aquifer Groundwater Samples

Overall, the physical parameters indicate that while most groundwater samples fall within acceptable limits for drinking water, localized areas show elevated salinity that may affect potability.

Heavy Metals Concentrations

Mercury (Hg)

All 300 samples had Hg concentrations below the WHO (0.006 mg/L) and NSDWQ (0.001 mg/L) guideline values (Figure 8). This indicates that mercury is not a significant contaminant in the shallow aquifer of Maiduguri and environs.

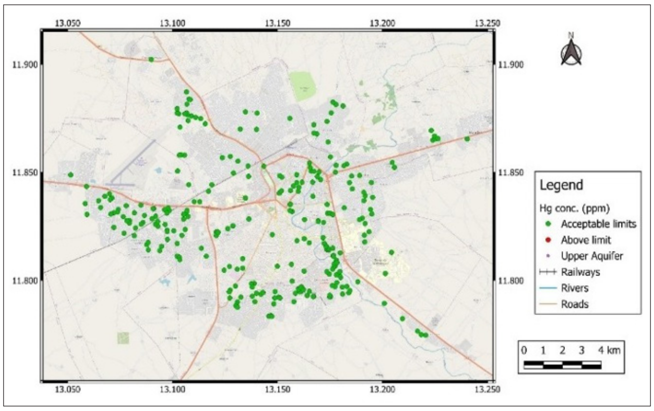

Figure 8: Showing spatial distribution of Hg Concentrations in the Upper Aquifer Boreholes in Maiduguri and Environs

Copper (Cu)

Cu concentrations in groundwater samples were generally low, with only one sample (0.3% of total) exceeding the WHO permissible limit of 2.0 mg/L (Figure 9). Most samples fell within both WHO and NSDWQ thresholds, suggesting that copper contamination is not widespread in the area.

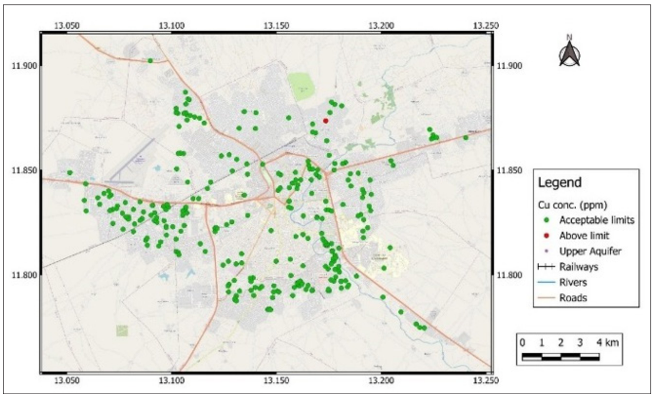

Figure 9: Showing Spatial Distribution of Cu Concentrations in the Upper Aquifer boreholes in Maiduguri and environs

Arsenic (As)

Arsenic concentrations varied spatially, with approximately 18% of borehole samples exceeding the WHO and NSDWQ guideline value of 0.01 mg/L (Fig. 10). The distribution of exceedances suggests localized hotspots of contamination.

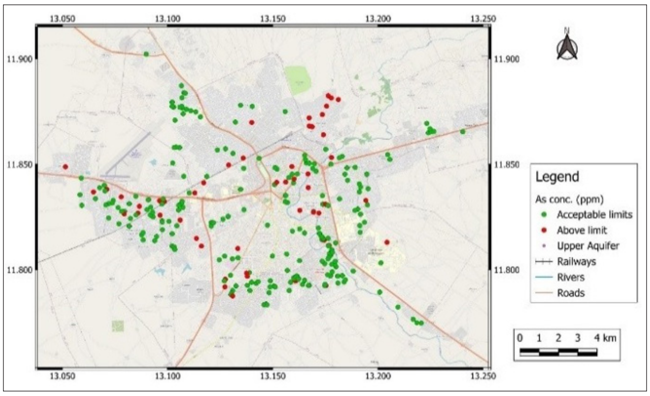

Figure 10: Showing spatial Distribution of Arsenic Concentrations in the Upper Aquifer Boreholes in Maiduguri and Environs

Cadmium (Cd)

Cd concentrations exceeded the WHO and NSDWQ limit of 0.003 mg/L in 23% of the borehole samples (Figure 11). The widespread but scattered distribution of elevated Cd levels suggests leaching from waste disposal sites and sewage sludge as possible sources.

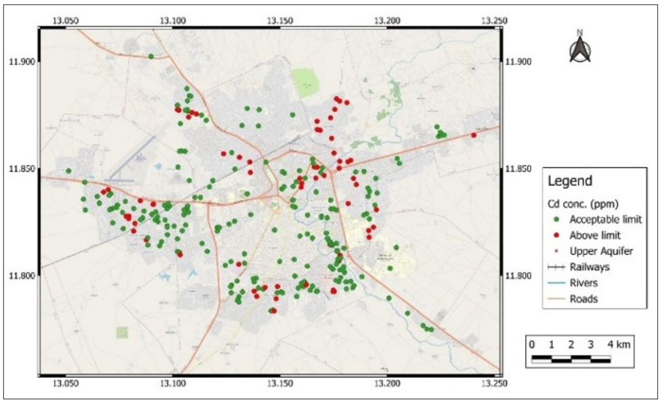

Figure 11: Showing Spatial Distribution of Cd Concentrations in the Upper Aquifer Boreholes in Maiduguri and Environs.

Lead (Pb)

Pb was one of the most concerning contaminants, with nearly half of the borehole samples (48%) exceeding the WHO and NSDWQ limit of 0.01 mg/L (Fig. 12). The widespread distribution of Pb contamination across the study area indicates diffuse pollution sources, possibly related to waste disposal and surface activities.

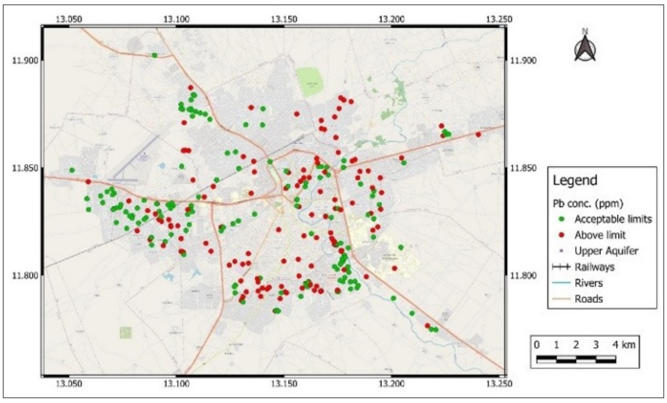

Figure 12: Showing Spatial Distribution of Pb Concentrations in the Upper Aquifer Boreholes in Maiduguri and Environs.

Chromium (Cr)
Chromium concentrations were the highest among the contaminants, with 56% of borehole samples exceeding the WHO and NSDWQ permissible limit of 0.05 mg/L (Fig. 13). Given that hexavalent chromium [Cr(VI)] is highly toxic, this represents a significant water quality concern in the shallow aquifer.

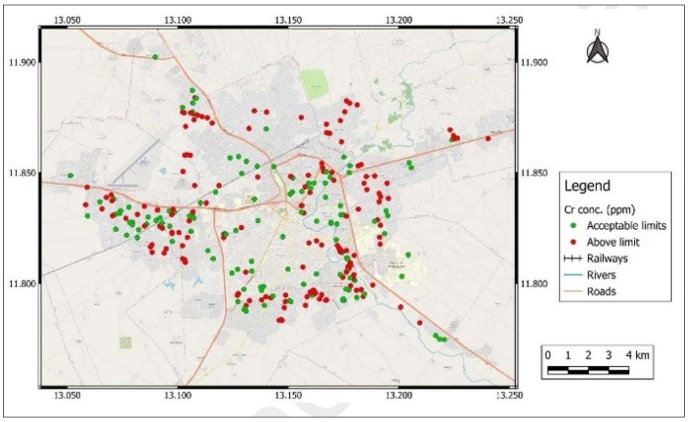

Figure 13: Showing Spatial Distribution of Cr Concentrations in the Upper Aquifer Boreholes in Maiduguri and Environs

These results demonstrate that while Hg and Cu are not of concern, groundwater from the shallow aquifer in Maiduguri is significantly affected by Pb and Cr contamination, with notable contributions from As and Cd.

Discussion
The analysis of groundwater samples from the shallow aquifer of Maiduguri and environs provides critical insight into heavy metal contamination relative to World Health Organization [1]. and Nigerian Standards for Drinking Water Quality (NSDWQ) guidelines. The findings show that while mercury (Hg) and copper (Cu) concentrations are consistently within safe limits, Arsenic (As), Cadmium (Cd), Lead (Pb), and Chromium (Cr) have significant number of boreholes exceeding the permissible thresholds, raising concern about groundwater safety and public health.

The absence of mercury above guideline values is consistent with the hydrogeological and anthropogenic conditions of the area, where there are no major mercury-based industries or activities that could significantly pollute groundwater [5]. Similarly, copper concentrations show that groundwater in the area is within the safe limits except for one borehole sample that exceeds the limits. The source of Cu has been largely attributed to piping materials [1]. in this case groundwater samples were collected directly from boreholes with minimal interaction with plumbing systems, which could explain the low Cu concentrations in these samples.

In contrast, arsenic, cadmium, lead, and chromium present serious concerns. Arsenic exceeded permissible limits in about 18% of borehole samples. Chronic exposure to arsenic has been associated with kidney damage, cardiovascular disorders, and cancers, even at low concentrations [3,4]. Cadmium, which was above safe levels in 23% of borehole samples, is a well-known nephrotoxicant that accumulates in the kidney and has been identified as a contributor to Chronic Kidney Disease (CKD) in exposed populations [2]. Its presence in the Maiduguri aquifer is likely due to leaching from solid waste and sewage sludge, a common feature of poor waste management systems in the region [6] .

Lead was among the most concerning contaminants, with 48% of samples exceeding safe limits. Lead exposure is known to cause renal impairment, hypertension, and neurological damage, and its widespread distribution in Maiduguri suggests diffuse pollution pathways, possibly from waste dumping, vehicle emissions, and corrosion of residual lead-based materials [1]. Chromium, particularly hexavalent chromium [Cr (VI)], was above guideline values in 56% of samples. This form of chromium is highly toxic and has been linked to kidney and liver damage as well as carcinogenic effects in humans [2].

The vulnerability of the shallow aquifer explains the contamination patterns observed. Unit A of the Upper Aquifer is shallow, unconfined, and recharged annually by rainfall and river seepage,

with sandy lithologies that allow rapid infiltration [5,6]. These characteristics make the aquifer highly susceptible to pollutants from indiscriminate waste disposal, poor sanitation, and agricultural runoff. This is consistent with observations in other parts of the Chad Basin, where shallow aquifers are more exposed to contamination than deeper, semi- confined aquifers [5].

Although this study did not include a formal quantitative health risk assessment, the comparison of measured concentrations with WHO and NSDWQ guideline values provides a qualitative indication of health risks. The exceedances of As, Cd, Pb, and Cr are particularly concerning, as all four are nephrotoxic and have been linked to kidney dysfunction and CKD in various contexts [2,3]. The fact that nearly half of the boreholes sampled contained Pb and Cr above safe levels indicates that long-term reliance on shallow aquifer water may contribute to the reported rising CKD cases in Maiduguri. Although, confirming a direct causal relationship will require further epidemiological studies and dose-response modelling.

Conclusions
This study assessed the concentrations of six heavy metals (Hg, Cu, As, Cd, Pb, and Cr) in 300 groundwater samples from shallow aquifer boreholes in Maiduguri and environs. The results show that Mercury (Hg) and Copper (Cu) were within the permissible limits set by WHO (2011) and NSDWQ for all the borehole samples, indicating no immediate health concern from these metals. In contrast, Arsenic (As), Cadmium (Cd), Lead (Pb), and Chromium (Cr) were found at concentrations exceeding guideline values in 18%, 23%, 48%, and 56% of the borehole samples respectively [1].

The widespread exceedances of As, Cd, Pb, and Cr highlight the vulnerability of the shallow unconfined aquifer (Unit A) of the Chad Formation, which is annually recharged by rainfall and surface water seepage, with potential for contaminants leachate into the shallow groundwater. Poor waste management, sanitation practices, and the permeable sandy lithology of the aquifer contribute to the contamination risks. Although this study did not include a formal health risk assessment, the presence of these metals above permissible limits is concerning, given their well-documented nephrotoxic effects and potential contribution to the growing burden of Chronic Kidney Disease (CKD) in Maiduguri and environs.

Addressing the challenges of using the shallow pollution prone groundwater requires a multi- faceted approach. These measures may include: implementing appropriate water treatment technologies such as ion exchange, reverse osmosis, or activated alumina adsorption in affected the boreholes; surface water treated;

and drilling to deeper aquifers. There is also the need to strengthen waste management practices, continuous groundwater monitoring and public education campaigns, which are critical to reducing exposure to risks and safeguard community health [10].

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Data Availability
Datasets generated during the current study are available from the corresponding author on reasonable request.

Ethical Responsibilities of Authors
All authors have read, understood, and agreed with the content of the manuscript.

Statements & Declarations Funding
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Competing Interests
The authors have no relevant financial or non-financial interests to disclose.

Authors' Contributions
All authors contributed to the conception, design, data collection, analysis, and writing of the manuscript. The first draft was prepared collectively, and all authors reviewed, revised, and approved the final version for submission.

Availability of Data and Materials
The datasets used and/or analyzed during the current study are available from the corresponding author on request.

Ethical Approval
This article does not contain any studies with human participants or animals performed by any of the authors.

Consent to Participate
Not applicable.

Consent for Publication
All authors consent to the publication of this article in Water Resources Management.

References

1. World Health Organization (WHO) (2011) Guidelines for drinking-water quality (4th ed.). Geneva: WHO Press. https://www.who.int/publications/i/item/9789241549950.
2. Tchounwou PB, Yedjou CG, Patlolla AK, Sutton DJ (2014) Heavy metal toxicity and the environment. EXS 101: 133-164.
3. Maria AM, Oliveira LM, Costa LM (2023) Health effects of arsenic exposure: A systematic review. Environmental Research 228: 115908.
4. Raja P, Prasad MNV, Kumar A (2021) Arsenic toxicity in groundwater and its health effects. Environmental Science and Pollution Research 28: 25465-25478.
5. Adelana SMA, Abiye TA, Nkhuwa DCW, Tindimugaya C, Oga MS (2008) Urban groundwater management and protection in Sub-Saharan Africa. UNESCO IHP Series on Groundwater 14: 1-14.
6. Goni IB, Edmunds WM, Fellman E (2004) Rainfall, recharge and groundwater quality: The case of Maiduguri, northeastern Nigeria. Hydrological Sciences Journal 49: 277-297.
7. Barber W, Jones DC (1960) The geology and hydrology of Maiduguri, Borno Province. Geological Survey of Nigeria Bulletin 30: 138.
8. Miller RE, Barber W, Jones DC (1968) Groundwater hydrology of the Chad Basin in Borno and Dikwa Emirates, Northeastern Nigeria. Geological Survey of Nigeria Bulletin 42: 138.
9. Beacon Services Ltd. & Consulint International (1979) Hydrogeological investigation of the had Basin, Borno State, Nigeria. Lagos: Federal Ministry of Water Resources.
10. Nigerian Standards for Drinking Water Quality (NSDWQ) (2007) Nigerian standard for drinking water quality. Abuja: Nigerian Industrial Standards, NIS 554: 2007. https://africacheck.org/sites/default/files/Nigerian-Standard-for-Drinking-Water-Quality-NIS-554-2015.pdf.