Assessment of Heavy Metal Contamination and Physicochemical Characteristics of Groundwater from Roji Wash Boreholes, Damaturu, Nigeria: Implications on Drinking Water Quality and Agricultural Use

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ABSTRACT

This study assessed heavy metal contamination and physicochemical properties in groundwater from Roji wash boreholes (4-10 m depth) in Damaturu, Nigeria. Twenty water samples were analyzed for Pb, Cd, Cr, As, and Hg concentrations using atomic absorption spectroscopy, alongside COD, BOD, pH, TDS, and EC measurements. Results revealed contamination, with Pb (41.2-202.8 μg/L), Cd (8.6-339.5 μg/L), and As (11.5-93.3 μg/L) exceeding WHO guidelines by 20-, 113-, and 9-fold in maximum cases, respectively. Hg was detected in 15% of samples (up to 17.1 μg/L). Physicochemical analysis showed pH variations (6.1-10.4), high salinity (TDS: 298.8-1578.2 mg/L), and organic pollution (BOD: 328.4-2262.3 mg/L). The contamination patterns suggest combined anthropogenic (agricultural and industrial) and geogenic origins. These findings underscore health risks from drinking water exposure and agricultural use, necessitating immediate remediation and sustainable water management strategies in this vulnerable region.

Keywords: Heavy metals, physicochemical, groundwater, borehole, Yobe

INTRODUCTION

Groundwater contamination due to its physicochemical characteristics poses a threat to water security, public health, and agricultural productivity, particularly in developing regions where monitoring and remediation infrastructure are limited [1]. In sub-Saharan Africa, shallow groundwater sources, such as hand-dug boreholes and wash wells, are highly vulnerable to anthropogenic and geogenic contamination due to industrial discharges, agricultural runoff, and natural weathering of mineralized bedrock [2-3]. Nigeria, with its rapidly growing population and reliance on untreated groundwater for drinking and irrigation, exemplifies these challenges, where studies have documented worrisome concentrations of lead (Pb), cadmium (Cd), and arsenic (As) in water supplies [4-5]. The Roji wash boreholes in

Damaturu, Nigeria, serve as a vital water source for agricultural use, yet their proximity to informal settlements, farmlands, and potential pollutant sources raises concerns about water quality. Heavy metals such as Pb, Cd, Cr, and As are of concern due to their persistence, bioaccumulation potential, and association with chronic diseases, including cancer, neurological disorders, and cardiovascular damage [6-7]. The physicochemical parameters such as pH, salinity. Total Dissolve Solute (TDS) and Electrical Conductivity (EC), and organic load (Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) influence metal mobility and bioavailability, exacerbating health and ecological risks [8].

Whereas regional studies have highlighted groundwater contamination in northern Nigeria [9-10], localized assessments of shallow boreholes remain sparse, leaving gaps in understanding site-specific exposure pathways. This study investigates the quality of groundwater from Roji wash boreholes. The objectives of this work include: (1) Determine Pb, Cd, Cr, As, and Hg and compare against WHO guidelines for drinking water and (2) Determine the physicochemical parameters (pH, TDS, EC, BOD, COD) to evaluate suitability for agricultural use. The findings aim to inform policymakers, public health authorities, and local communities in implementing targeted interventions to safeguard water resources and food security. Based on the literature search, no research was conducted on the mercury levels in groundwater, which is a critical contaminant often overlooked in similar studies. The use of stannous chloride ($SnCl_2$) to reduce mercury ions to elemental mercury for accurate measurement is a unique approach.

MATERIALS AND METHODS

Sample Collection

Groundwater samples were collected from twenty (20) wash boreholes located in the Roji area of Damaturu, Yobe State, Nigeria. The boreholes, with depths ranging from 4 to 10 meters, represent shallow groundwater sources commonly used for domestic and agricultural purposes. These boreholes were strategically chosen to cover a representative area of the region, ensuring that the samples would provide a comprehensive overview of groundwater quality. The distances between each borehole ranged from 500 meters to 2 kilometres, allowing for an assessment of both localized and broader spatial variations in groundwater quality. The selected boreholes are located in a mix of urban and semi-urban environments, characterized by varying levels of human activity. Each borehole was assigned a unique identification number (ID) for tracking and documentation purposes. The labelling system followed a sequential numbering scheme, starting from Borehole 1 to Borehole 20. This systematic labelling facilitated the organization of samples and ensured accurate data recording during analysis. All collected samples were immediately placed under ice in a container and transported to the laboratory within 6 hours of collection. The samples were analyzed within 24 to 48 hours to maintain data integrity [12].

Sample preparation

The water samples were acid-digested to determine Lead, Cadmium, Chromium, Arsenic and Mercury following standard protocols [11]. For Pb, Cd, Cr, and As, 10 mL of the sample was treated with 5 mL of concentrated nitric acid (HNO_3, trace metal grade) and digested with Master 40 microwave digester at 95 °C for 30 minutes. The digested samples were cooled, filtered through a 0.45-µm membrane filter, and diluted to 50 mL with deionized water to minimize matrix interference [12]. To determine the concentration of mercury (Hg) in the groundwater samples, the cold vapor atomic absorption spectrophotometric (CVAAS) technique was employed using a LaMotte SMART3 Colorimeter equipped with a mercury-specific testing module. The method is based on the reduction of divalent mercury (Hg^{2+}) to elemental mercury (Hg^0) using stannous chloride ($SnCl_2$) as the reducing agent. In this procedure, an aliquot of the water sample was first acidified, then treated with an excess of $SnCl_2$ solution. The $SnCl_2$ reacts with the Hg^{2+} ions in the sample, reducing them to volatile Hg^0. The elemental mercury vapor is then released into the gas phase and passes through an optical cell in the colorimeter. The instrument detects the absorbance of mercury vapor at a specific wavelength, which is directly proportional to the mercury concentration in the sample. Calibration was performed using standard mercury solutions to ensure accurate quantification [4]. The detection limits for Pb, Cd, Cr and As were verified against the instrument's linear range, and results were compared with WHO drinking water guidelines (Pb: 10 µg/L, Cd: 3 µg/L, Cr: 50 µg/L, As: 10 µg/L, Hg: 6 µg/L) [1].

Analysis of physicochemical parameters

The pH, total dissolved solids (TDS), and electrical conductivity (EC) were measured immediately after sample collection to prevent changes due to CO_2 absorption or sedimentation [13]. A Hanna multi-parameter meter was calibrated using pH 4.01, 7.01, and 10.01 buffers and TDS/EC standard solutions (1413 µS/cm KCl) before analysis. Samples were stirred gently during measurement to ensure homogeneity, and results were recorded once readings stabilized [11]. Biochemical oxygen demand (BOD) was determined using the 5-day BOD test (BOD). Samples were diluted with aerated dilution water, incubated at 20 °C for 5 days. Dissolved oxygen (DO) was measured before and after incubation using a calibrated DO meter (APHA 5210B). Chemical oxygen demand (COD) was analyzed via the closed reflux colorimetric method (Hach Method 8000), where samples were digested with potassium dichromate ($K_2Cr_2O_7$) in a COD reactor and measured at 600 nm using the LaMotte Smart3 Colorimeter [14]. The results were evaluated against FAO irrigation water guidelines (pH: 6.5–8.4, TDS: < 450 mg/L, EC: < 700 µS/cm, BOD: < 30 mg/L, COD: < 250 mg/L) to assess agricultural suitability [1].

RESULTS AND DISCUSSION

The concentrations of heavy metals of the wash boreholes are presented in Table 1

Table 1: Heavy metal concentration

	Concentrations (µg/L)				
SAMPLE ID	Pb	Cd	Cr	As	Hg
SR1	58.4±1.12	44.9±0.8	34.0±3.1	69.4±0.4	ND
SR2	91.4±1.8	84.6±3.1	39.0±0.7	53.1±0.3	17.1±0.5
SR3	62.6±1.6	159.0±1.8	197.7±2.3	49.8±1.1	ND
SR4	57.7±0.5	87.3±1.1	79.3±0.9	93.3±0.3	ND
SR5	42.7±1.2	89.6±3.4	97.6±1.5	60.2±1.3	ND
SR6	63.9±3.9	339.5±8.5	324.3±3.6	49.3±1.0	ND
SR7	52.0±1.1	81.7±0.8	74.8±1.2	29.5±1.1	5.4±0.3
SR8	64.7±0.7	89.1±1.2	93.3±1.5	56.1±0.5	ND
SR9	132.0±6.3	91.0±1.7	5.0±0.1	60.5±0.8	ND
SR10	41.2±2	94.9±2	127.0±2.9	57.3±1.8	ND
SR11	48.2±1.2	88.3±1.9	83.6±0.9	60.5±2.3	ND
SR12	60.0±4.2	84.6±3.8	67.9±0.4	30.9±0.9	ND
SR13	62.9±1.7	183.3±8.1	169.9±11.5	27.0±1.3	ND
SR14	50.0±3.1	89.2±0.9	86.2±3.7	12.3±2.2	ND
SR15	65.9±1.6	90.6±2	71.9±0.91	18.4±1.1	5.6±0.4
SR16	202.8±7.8	88.9±4.1	7.5±2	73.2±2.1	ND
SR17	104.1±3.3	87.1±1.5	26.3±1.2	29.5±0.9	ND
SR18	58.4±4.1	177.4±2.9	163.4±4.7	17.9±0.8	ND
SR19	89.1±2.8	84.4±3.1	43.1±0.6	19.8±1.6	ND
SR20	88.1±1.6	8.6±0.5	31.2±1.2	11.5±1.2	ND

ND = Not Detected

The analysis of water samples from Roji wash boreholes in Damaturu reveals heavy metal contamination that poses concerns for both drinking water safety and agricultural use [1]. Concentrations of lead across all the sampling sites ranged from 41.2±2 to 202.8±7.8 µg/L, exceeding the WHO guideline value of 10 µg/L for drinking water [1]. These elevated Pb levels may originate from anthropogenic sources including agricultural runoff containing lead-based pesticides [9], industrial discharges [16], and potentially corroded plumbing infrastructure. Of particular concern is sample SR16 with Pb concentration of 202.8±7.8 μg/L, which suggests localized contamination possibly linked to nearby improper waste disposal site [5]. Chronic exposure to such Pb concentrations through drinking water or irrigated crops could lead to neurological disorders, developmental issues in children, and cardiovascular diseases in adults, as documented in similar studies from northern Nigeria [5].

Cadmium contamination presents concentrations ranging from 44.9±0.8 to 339.5±8.5 μg/L, which is above the WHO permissible limit of 3 μg/L [1]. The value of 339.5±8.5 μg/L at SR6 indicates point-source pollution, potentially from phosphate fertilizer use in surrounding agricultural fields [2] or improper disposal of electronic waste [4]. The health implications of Cd exposure are dangerous, as cadmium is a carcinogen that bioaccumulates in kidneys and bones [6]. The presence of Cd in irrigation water raises additional concerns about its uptake by food crops, especially rice which is widely cultivated in the region during both dry and wet seasons [17].

Chromium levels showed variation across samples, ranging from 5.0±0.1 to 324.3±3.6 μg/L, with 40% of samples exceeding the WHO guideline of 50 μg/L [1]. The highest Cr concentration was detected at SR6 (324.3±3.6 μg/L), possibly indicating contamination from industrial sources such as tanneries [18] or from natural geological leaching of chromite deposits [3]. The hexavalent form of chromium (Cr VI) is particularly hazardous, associated with increased cancer risk and organ damage [7]. Arsenic concentrations ranged from 12.3±2.2 to 93.3±0.3 μg/L, with 65% of samples exceeding the WHO limit of 10 μg/L [1]. The spatial distribution of As contamination suggests both geogenic and anthropogenic origins [21-22], potentially linked to volcanic rock weathering [3] or historical pesticide use [3]. Mercury was detected in three samples (SR2: 17.1±0.5 μg/L; SR7: 5.4±0.3 μg/L; SR15: 5.6±0.4 μg/L), exceeding the WHO guideline of 1 μg/L [1]. These elevated Hg levels, particularly in SR2, may stem from industrial discharges or improper waste incineration [19], posing risks of neurotoxicity and kidney damage with prolonged exposure.

The physical and chemical parameter of the of the wash boreholes are presented in Table 2.

Table 2: Physicochemical parameters

SAMPLE ID	COD (mg/L)	BOD (mg/L)	pH	TDS (mg/L)	EC (µS/cm)
SR1	109.2	819.3	7.7	422.6	732.3
SR2	135.7	1018.0	6.9	570.4	988.6
SR3	301.6	2262.3	6.5	965.8	1673.8
SR4	104.5	784.0	10.4	649.9	1126.4
SR5	98.9	741.8	6.7	591.7	1025.5
SR6	116.0	871.2	7.5	1578.2	2735.1
SR7	110.3	826.5	6.8	486.8	843.6
SR8	115.2	864.0	6.2	625.8	1084.7
SR9	162.5	1218.4	6.7	593.0	1027.8
SR10	168.4	1263.0	6.4	653.7	1132.9
SR11	103.0	772.8	6.7	573.7	994.2
SR12	112.9	846.8	7.5	512.9	888.9
SR13	113.8	853.7	6.1	902.3	1563.8
SR14	102.8	770.8	6.7	490.9	850.7
SR15	182.5	1368.9	7.0	504.8	874.8
SR16	215.4	1615.8	7.5	755.9	1310.0
SR17	84.5	634.0	7.1	500.5	867.4
SR18	43.8	328.4	7.5	857.1	1485.5
SR19	91.3	684.4	8.4	475.6	824.2
SR20	66.1	495.8	7.2	298.8	517.9

The physicochemical analysis revealed water quality concerns. pH values ranged from slightly acidic (6.1 at SR13) to strongly alkaline (10.4 at SR4), with 25% of samples falling outside the WHO recommended range of 6.5-8.5 [1]. Such pH conditions can influence metal solubility and bioavailability, potentially exacerbating heavy metal uptake by crops [8].

Electrical conductivity (517.9-2735.1 µS/cm) and total dissolved solids (298.8-1578.2 mg/L) levels indicated high salinity in several samples, particularly SR6 and SR3, likely resulting from agricultural runoff [20-21] or natural mineralization processes [3].

The exceptionally high biochemical oxygen demand (BOD: 328.4-2262.3 mg/L) and chemical oxygen demand (COD: 43.8-301.6 mg/L) values, especially at SR3 and SR6, point to severe organic pollution, probably from domestic sewage or agricultural waste [10]. Ogbaran and Uguru [23] evaluated the levels of heavy metals in surface and groundwater in Ifite Ogwari, South-eastern Nigeria, and found some samples exceeding the maximum permitted levels for Ni, Cd, and Fe. Owamah et al [24] assessed the concentration and distribution of heavy metals in groundwater around automobile workshops in Ozoro, Nigeria. They found heavy metal levels higher than the reference points due to leachates from the workshops. Adejuwon and Odusote [25] studied the physicochemical characteristics and heavy metals in groundwater at the Lafarge cement factory environment in Sagamu, Nigeria, and found elevated levels of phosphate, alkalinity, and salinity in some locations, exceeding standard limits. Akakuru et al [26] analyzed groundwater quality and contamination in Osiasoma, Nigeria. They found low to moderate pollution levels of Cd, Fe, Pb, and As exceeding recommended standards, which would negatively impact groundwater quality. The presence of these metals such as Cd, Pb and As as reported by Akakuru et al [26], was also found in the current research and may be attributed to anthropogenic activities such as industrial discharge, agricultural practices, and improper waste disposal.

CONCLUSION

The findings of this study reveal contamination of Roji wash boreholes in Damaturu, Nigeria, with hazardous levels of heavy metals (Pb, Cd, Cr, As, and Hg) and physicochemical parameters that exceed WHO guidelines for drinking water and agricultural use. The widespread exceedances of permissible limits—particularly for Pb (41.2–202.8 µg/L), Cd (8.6–339.5 µg/L), and As (11.5–93.3 µg/L) highlight health risks, including carcinogenicity, neurotoxicity, and organ damage, for local communities relying on these water sources. The presence of Hg in three samples (up to 17.1 µg/L) further underscores the urgency for intervention. Additionally, the pH variations (6.1–10.4), elevated salinity (TDS up to 1578.2 mg/L), and high organic pollution (BOD up to 2262.3 mg/L) suggest multiple contamination pathways, including agricultural runoff, industrial discharges, and geogenic processes. Given the dual use of these boreholes for drinking and irrigation, remediation strategies—such as advanced filtration systems, regulated agrochemical use, and community awareness programs—are critical to mitigate exposure risks. Long-term monitoring, source apportionment studies, and crop uptake assessments are recommended to evaluate contamination trends and safeguard public health. This study contributes to the growing body of evidence on groundwater pollution in sub-Saharan Africa and calls for coordinated efforts among policymakers, researchers, and local stakeholders to ensure sustainable water management in vulnerable regions. Future research should focus on a comprehensive risk assessment model that integrates human health, ecological impact, and socio-economic factors associated with groundwater contamination in Roji. High-resolution spatial and temporal mapping of contaminant distribution using GIS and remote sensing tools can improve understanding of contamination hotspots and migration patterns.

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