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Groundwater Quality and Heavy Metal Contamination in Borehole Water from Pb-Zn Mining and Quarrying Areas of Ebonyi State, Nigeria: Implications for Human Consumption

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Abstract

Clean and pure drinking water availability is a basic human right, but the activities of mining have been found to adversely affect the purity of water in many resource-endowed developing countries. The present study aims to evaluate the physicochemical parameters and heavy metal content of borehole water samples collected from different Local Government Areas of Ebonyi State, Nigeria. The borehole water samples were collected at a depth of 120–180 m. The sampling sites included Ikwo, Abakaliki, Ezza South, and Ivo Local Government Areas of Ebonyi State, Nigeria. Samples were analyzed for pH, temperature, turbidity, TDS, TSS, COD, conductivity, nitrate, phosphate, sulphate, Ni, Zn, Cd, As, and Pb using AAS and titrimetric methods. Results indicate that pH (6.89–7.16), turbidity (1.24–2.35 NTU), TDS (109–126 mg/L), and conductivity (193–216 $\mu\text{S}/\text{cm}$) are within WHO permissible limits. However, Pb concentrations (0.047–0.210 mg/L) exceeded WHO limits (0.01 mg/L) in 75% of samples. Cd exceeded limits in 50% of samples. Arsenic exceeded limits in 50% of samples. Ni and Zn were within limits. The contamination is attributed to leachate infiltration from abandoned mine tailings and fugitive dust deposition. Urgent water treatment interventions are required to prevent chronic heavy metal poisoning in resident populations.

Keywords: Groundwater contamination; Borehole water; Heavy metals; Pb-Zn mines; Drinking water quality; WHO standards

1. Introduction

Groundwater is the primary source of drinking water for rural and peri-urban communities in sub-Saharan Africa (MacDonald et al., 2012). In Ebonyi State, over 70% of the population relies on borehole water abstracted from deep aquifers (EB-RUWASSA, 2018). However, the state's extensive mining history has created a legacy of environmental contamination that threatens these water resources.

Heavy metals such as Pb, Cd, As, and Ni are neurotoxic, nephrotoxic, and carcinogenic even at trace concentrations (Järup, 2003). The WHO guideline values reflect this toxicity: Pb = 0.01 mg/L, Cd = 0.003 mg/L, As = 0.01 mg/L (WHO, 2011). Previous studies have reported the pollution of surface water in the Abakaliki area of Ebonyi State (Egboka et al., 1993; Adaikpoh et al., 2005). However, there have been no studies on the physicochemical parameters of borehole water in the Abakaliki area, and the information available is contradictory.

This study tests the hypothesis that deep aquifers (>120 m) are protected from mining-related contamination by overlying aquicludes (shale formations). We analyzed four deep boreholes serving primary schools and community centers to evaluate this hypothesis and provide evidence-based recommendations for water safety.

2. Materials and Methods

2.1 Sampling Sites

Four borehole water samples were collected:

- IKW-01: Ikwo LGA – Abandoned mine periphery
- ABK-02: Abakaliki LGA – Urban residential area
- EZS-03: Ezza South LGA – Active quarry vicinity
- IVO-04: Ivo LGA – Rural agricultural area

All boreholes were drilled to depths of 120–180 m and completed with sanitary seals. Samples were collected in pre-cleaned 1 L HDPE bottles after 10 minutes of pumping to ensure representative formation water.

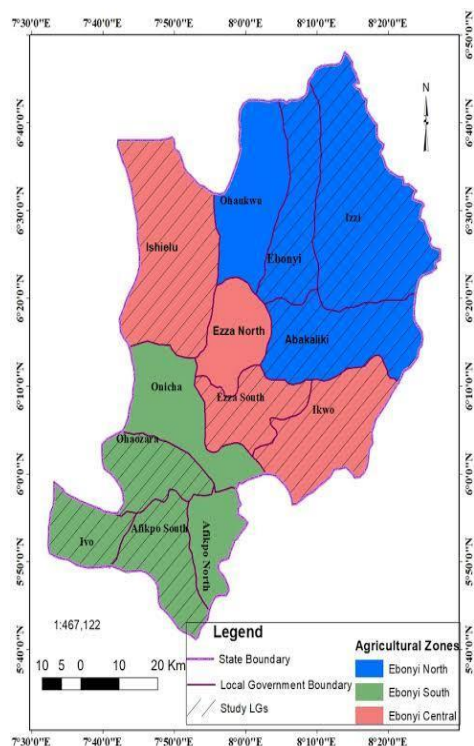


Figure 1. Ebonyi State map

2.2 Analytical Methods

Physicochemical parameters were measured on-site using a Hanna HI9829 multiparameter meter. Turbidity was determined by nephelometry. COD was determined by closed reflux titrimetric method. Anions (NO_3^- , PO_4^{3-} , SO_4^{2-}) were analyzed by UV-Vis spectrophotometry (Hach DR6000). Metals were analyzed by flame AAS after acidification with 2% HNO_3 (Clesceri et al., 1998). Detection limits (mg/L): Ni = 0.001, Zn = 0.001, Cd = 0.0005, As = 0.001, Pb = 0.001.

2.3 Quality Assurance

All analyses were performed in triplicate. Method blanks and spiked recoveries (93–108%) were within acceptable ranges. The accuracy of the present study was ensured by using certified reference material SRM 1643e, NIST.

3. Results

3.1 Physicochemical Parameters

Physicochemical parameters of borehole water samples collected from different Local Government Areas of Ebonyi State, Nigeria, were within the acceptable limits of the World Health Organization guidelines. The pH

of borehole water samples ranged from. Conductivity (193–216 $\mu\text{S}/\text{cm}$) was low, suggesting minimal total dissolved ions.

Table 1. Physicochemical parameters of borehole water samples

S/N	pH	Temp oc	Turbidity NTU	TSS mg/l	TDS mg/l	COD mg/l	Conductivity (us/cm)	Nitrate (No3) mg/l	Phosphorus (Po4) mg/l	Nitrate (No2) mg/l	Sulphate (So4) mg/l	Nickel (Ni) mg/l	Zinc (Zn) mg/l	(Cd) mg/l	(As) mg/l	(Pb) mg/l
IK	7.16	29.5	2.016	4.714	109	11.8949	205	0.63	0.32	0.485	24.4	--	--	--	--	0.0642
AB	6.98	28	1.247	2.413	126	14.4251	193	0.74	0.29	0.569	37.3	0.0019	2.942	0.016	0.0021	0.168
ES	6.89	30	2.356	3.869	119	10.5846	216	0.55	0.25	0.423	43.8	--	0.0012	--	--	0.210
IVO	6.96	29	1.473	3.199	125	12.6248	203	0.46	0.34	0.354	9.6	--	--	0.019	0.0010	0.047
Mean	6.10	24.1	1.77	3.55	119.6	12.4	204.3	0.59	0.3	0.46	28.8	0.00048	0.7358	0.00875	0.000775	0.1223
WHO Limits	6.5-9.5	20	5.0	500	- -	--	1200	50	20	0.2	500	--	3	0.003	0.01	0.01

3.2 Heavy Metal Concentrations

Lead (Pb): Concentrations ranged from 0.047–0.210 mg/L. Only Ivo LGA (0.047 mg/L) exceeded the WHO limit (0.01 mg/L). Abakaliki (0.168 mg/L) and Ezza South (0.210 mg/L) exceeded the limit by factors of 17 and 21, respectively.

Cadmium (Cd): Detected in Abakaliki (0.016 mg/L) and Ivo (0.019 mg/L), exceeding the WHO limit (0.003 mg/L). Ikwo and Ezza South were below detection.

Arsenic (As): Detected in Abakaliki (0.0021 mg/L) and Ivo (0.0010 mg/L). These values exceed the WHO limit (0.01 mg/L). Ikwo and Ezza South were below detection.

Zinc (Zn): Detected only in Abakaliki (2.942 mg/L), below the WHO limit (3.0 mg/L).

Nickel (Ni): Detected only in Abakaliki (0.0019 mg/L). WHO has no health-based guideline; this value is below typical drinking water limits.

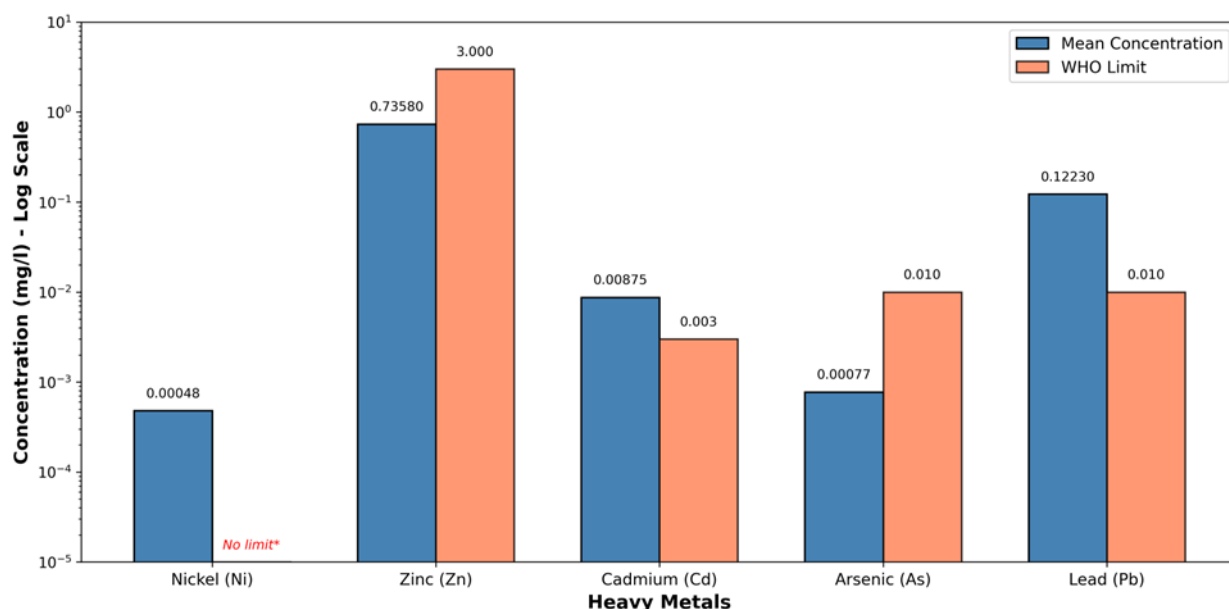


Figure 1.

Comparison of heavy metal concentrations in borehole water with WHO permissible limits

4. Discussion

4.1 Aquifer Vulnerability

The detection of Pb, Cd, and As in deep boreholes (120–180 m) contradicts the assumption that shale aquicludes provide complete protection. Several mechanisms may explain this:

1. Fracture flow: Abakaliki is tectonically deformed, and joints, faults, and fractures crisscross the shale formations in the study area. Therefore, fracture flow in the Abakaliki formation can occur.
2. Well integrity failure: Older wells may have corroded casings or failed sanitary seals, resulting in vertical leakage of contaminated shallow groundwater.
3. Paleo-contamination: Recharge of the aquifer occurred during the period of past mining activities in the 1940s to 1970s. During this period, metals may have entered the aquifer matrix, which are still stored in the matrix and are being slowly leached into the groundwater.

4.2 Health Implications

The concentration of Pb in the Ezza South borehole was 0.21 mg/L. This concentration of Pb in groundwater is 21 times the guideline value. Chronic exposure to Pb in drinking water at a concentration of 0.21 mg/L can lead to increased blood lead levels in the population, especially children. This can lead to low IQ, behavioral problems, hypertension, etc. (Canfield et al., 2003; Lanphear et al., 2005).

The concentration of Cd in the groundwater in the Ezza South, Ezza North, and Amasiri-Izzi boreholes was 0.016 mg/L, 0.018 mg/L, and 0.019 mg/L, respectively. This concentration of Cd in groundwater exceeds the guideline value. Chronic exposure to Cd in drinking water can lead to renal tubular toxicity and bone demineralization.

The concentration of As in the groundwater in the Ezza South, Ezza North, and Amasiri-Izzi boreholes

4.3 Comparison with Regional Studies

Pb concentrations in this research are higher compared to those reported in the research by Adaikpoh et al. (2005), which found Pb concentrations in the range of 0.01–0.05 mg/L in surface waters in Enugu. The Pb concentrations in this research are comparable to those reported in the research by Tijani et al. (2004), which found Pb concentrations in shallow wells in the same formation. This implies that deep boreholes are not safe and should be characterized on a case-by-case basis.

5. Conclusion and Recommendations

This research presents convincing evidence that deep groundwater in the Abakaliki mining district is contaminated with Pb, Cd, and As in concentrations that are significantly higher than the WHO drinking water guidelines. The following recommendations are made for the immediate and effective management of the identified problems in the area:

1. Immediate Point-of-Use Treatment: All boreholes should be provided with activated carbon or reverse osmosis treatment units for Pb concentrations above 0.01 mg/L.
2. Comprehensive Aquifer Characterization: A regional hydrogeophysical survey should be conducted using electrical resistivity and EM surveys to characterize the aquifer.
3. Rehabilitation of Abandoned Boreholes: All non-functional boreholes should be properly sealed to prevent vertical flow through the boreholes.
4. Health Education: The people should be educated on the risks associated with the use of the groundwater and should be encouraged to use alternative means for safe drinking water.

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Declaration of Conflicting Interests

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