



ASSESSMENT OF PHYSICOCHEMICAL QUALITY AND MICROBIAL CONTAMINATION IN BOREHOLE WATER IN BENIN CITY, SOUTHERN NIGERIA

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ABSTRACT

*This study evaluated the physicochemical quality, microbial contamination and possible health risks of borehole water samples taken from 12 locations in Benin metropolis, Nigeria. Physicochemical parameters, microbial indicators, and some heavy metals were analyzed in the water samples, and a questionnaire survey was conducted to assess the public perception of water-quality risks. The mean pH of all samples was 5.50 ± 0.36 , which was all acidic and 67% of boreholes had total coliforms present, while all physicochemical parameters met World Health Organization (WHO) and Standards Organization of Nigeria (SON) guidelines. The Occurrence of sporadic *Escherichia coli* suggested faecal contamination. Two general patterns were indicated by exploratory multivariate analysis: mineralization-related and a microbial-turbidity pattern. Heavy metals were found to have low risk of non-carcinogenic and carcinogenic effects, while microbial contamination still poses a public health risk. A validated public awareness questionnaire (Cronbach's $\alpha = 0.780$, $n = 20$) demonstrated societal relevance. Routine monitoring, adjusted pH, enhanced disinfection and public awareness are recommended.*

KEY WORDS: Borehole water; Groundwater quality; Microbial contamination; Public health; Benin City

1.0 INTRODUCTION

In sub-Saharan Africa, groundwater is a significant domestic water supply for the urban and peri-urban population, and is relatively accessible, affordable and less likely to be contaminated than surface water (WHO & UNICEF, 2019). The challenge of rapid urbanization, population growth and poor water management systems in urban areas, has contributed to the increased reliance on privately dug boreholes especially in the medium size cities of Nigeria like Benin City (Ogbeifun, Archibong, Chiedu, & Ikpe, 2019; Bassey & Archibong, 2022). In spite of this dependence, the urban aquifer is being increasingly disturbed by lack of sanitation, indiscriminate disposal of waste and substandard water-supply infrastructure (Musa

et al., 2023; Okhuebor & Izevbuwa, 2020). The common trend in the Nigerian studies on groundwater is that although the groundwater is heavily contaminated in the microbiological field, the physicochemical field is acceptable (Foka, Yah & Agbortabot Bissong, 2018; Gbadebo *et al.*, 2026). Borehole water may require treatment even if the electrical conductivity, hardness and concentrations of trace metals are within the regulatory limits, since faecal indicator bacteria have been found in water from these boreholes (Archibong, Osagie & Agho, 2025; Odewade, Imam, Adesakin & Odewade, 2025). Lateritic and sandy aquifers in southern Nigeria also occur in acidic water with high mobility of metals and corrosiveness of water systems (Musa *et al.*, 2023; Raji, Amih & Obeta, 2019). In areas

where data are limited, multivariate techniques such as correlation analysis, principal component analysis, and hierarchical cluster analysis can be helpful to find probable contamination patterns (Sánchez Navarro *et al.*, 2026). These techniques should be used with caution, however, if samples are small and hydrogeological data is limited. There have been few studies that have integrated physicochemical assessment, microbiological analysis, multivariate statistics, health-risk estimation and public awareness assessment in a single study around groundwater in urban areas (Fatoyinbo *et al.*, 2024; Alichí & Akudinobi, 2023).

Hence, the aim of this study was to assess the physicochemical and bacteriological quality of borehole water, estimate the health risk of trace metals and evaluate the awareness of the

households and their treatment practices in Benin City.

2.0 MATERIALS AND METHODS

2.1 Study Area

The study was carried out in the commercial and residential parts of Benin City, Edo State, South of Nigeria. The city falls within the latitudinal range of 6°19'-6°23'N and longitudinal range of 5°36'-5°44'E, and is enveloped by humid tropical climate having wet and dry seasons. It is underlain predominantly by unconsolidated sands and gravels of the Benin Formation with minor clay lenses. The groundwater is found primarily in unconfined to semi-confined aquifers, and is extensively tapped using shallow to moderately deep boreholes. Figure 1 shows the map of the study area and coordinates of the sampling points in Table 1.



Figure 1. Benin City Showing Borehole Water Sampling Locations
Source: Fieldwork using Global Navigation Satellite System receiver

Table 1: Geographic Coordinates of Borehole Water Sampling Location

S/No	Location	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)	Elevation (Meters)
1	Ugbowo	6.41127	5.615673	113
2	Ikpoba Hill	6.347374	5.674824	82
3	Ikpoba Slope	6.347684	5.640513	56
4	Agbor Park	6.346158	5.688617	88
5	Akpakpava	6.340143	5.631682	87
6	Upper Sakponba	6.328653	5.628489	83
7	Airport Road	6.327742	5.618456	82
8	Ekenwan Road	6.337798	5.614851	84
9	Mission Road	6.347481	5.630286	90
10	Sapele Road	6.317742	5.627781	81
11	Oregbeni Quarters	6.343924	5.669063	67
12	Uselu	6.370072	5.617757	94

Source: Fieldwork using Global Positioning Systems (GPS, 2025)

2.2 Borehole Selection and Sample Collection

Twelve boreholes were purposively selected to represent the different land use and population densities. Selection was done based on accessibility, domestic use frequency and nearness to possible contamination sources like septic tanks, refuse dumps, and drainage channels. The sampling was done in November 2025 in the dry season, to minimize the effect of runoff dilution. To collect the samples, boreholes were purged for 5–10 minutes. Physicochemical samples were collected in pre cleaned high density polyethylene bottles, while bacteriological samples were taken in sterile glass bottles. Samples were kept in ice-packed coolers at around 4°C and analyzed following standard procedures within 6 h (American Public Health Association [APHA], 2017).

2.3 Physicochemical Analysis

In situ measurements of temperature, pH, electrical conductivity and total dissolved solids were taken with hand-held instruments

and turbidity was measured using a nephelometric turbidity meter. Standard water and wastewater methods were used to analyze alkalinity, total hardness, chloride, nitrate, sulphate, major cations in the laboratory (Ogbeifun *et al.*, 2019; APHA, 2017). Quality control involved duplicate analyses and reagent blanks, and instrument calibration.

2.4 Microbiological Analysis

The membrane filtration method was used for the determination of total coliforms and *Escherichia coli* and the pour-plate method were used for the determination of total heterotrophic bacteria. Reported results were in terms of colony-forming units per millilitre (CFU/mL). Quality control measures included sterile blanks and replicate analyses.

2.5 Heavy Metal Determination

Samples for heavy metal analysis were acidified to pH<2 with analytical grade nitric acid and analyzed by atomic absorption spectrophotometry (AAS) for Fe, Cu, Zn, Pb and Cr. Method detection limits were established by the standard detection method,

and recoveries were checked by recovery tests and standard reference material analysis, with recoveries between $\pm 10\%$ (Ogbeifun *et al.*, 2019).

2.6 Public Awareness Survey

Twenty households using the sampled boreholes were selected for filling a structured questionnaire to assess their regular use of the wells. They were selected purposively to make sure they were knowledgeable about local water-use practices. The survey covered aspects of awareness of the risk of groundwater contamination, home water treatment practices, and perceptions of drinking-water safety. The instrument was pre tested and internal consistency was found to be acceptable (Cronbach's alpha = 0.78).

2.7 Analysis of Data

The physicochemical and microbiological data were summarized and compared with the WHO and SON guidelines for drinking water using descriptive statistics. The 12 borehole observations were analyzed with Pearson correlation and exploratory principal component analysis (PCA) with varimax rotation and hierarchical cluster analysis (HCA) with Ward's linkage were used to determine patterns. Due to the small sample size, and the relative lack of variation in concentrations of lead, results from the correlation were viewed as exploratory. Significance was considered $p < 0.05$.

2.8 Health Risk Assessment

Health risks due to ingestion of heavy metals were estimated as non-carcinogenic and carcinogenic risk to adults and children based on United States Environmental Protection Agency (USEPA) assumptions. Chronic daily intake (CDI), hazard quotient (HQ), hazard index (HI) and lifetime cancer risk (ILCR) were obtained according to the method developed by Ibrahim, Mustapha & Muhammad (2020).

3.0 RESULTS AND DISCUSSION

The descriptive statistics for the physicochemical and microbial parameters are shown in Table 2.

3.1 The Physicochemical Characteristics

Most physicochemical parameters (Table 2) were within WHO and SON drinking-water standards, indicating generally low mineralization and salinity in the sampled boreholes. Electrical conductivity ranged from 18.7 to 398 $\mu\text{S}/\text{cm}$, and total dissolved solids ranged from 10.26 to 218.9 mg/L, both below guideline limits. Total hardness ranged from 0.29 to 19.33 mg/L as CaCO_3 , indicating very soft water with low carbonate buffering capacity. In contrast, pH values ranged from 5.03 to 6.27, with a mean of 5.50 ± 0.36 , showing that all sampled boreholes were acidic and outside the recommended drinking-water range of 6.5–8.5 (Takem *et al.*, 2015). Low alkalinity further suggests weak buffering capacity, which may increase the potential for metal mobilization and pipe corrosion (Roy *et al.*, 2025).

Table 2: Descriptive Statistics Showing the Mean, Range, and Compliance Rates for Each Parameter.

Parameter	Unit	Mean	Min	Max	Count	SON/WHO STANDARD
pH@25°C	–	5.50±0.36	5.03	6.27	12	6.50 - 8.50
Turbidity	NTU	0.39±0.43	0.00	1.05	12	5.0
Electrical Conductivity	$\mu\text{S}/\text{cm}$	143.67±124.97	18.70	398.00	12	900 – 1200
Total Dissolved Solids	mg/L	78.98±68.67	10.26	218.90	12	500 – 1500

Parameter	Unit	Mean	Min	Max	Count	SON/WHO STANDARD
Total Suspended Solids	mg/L	12.02±0.18	11.57	12.45	12	-
Total Solids	mg/L	91.00±68.73	22.26	230.90	12	-
Total Alkalinity	mg/L	49.67±12.91	24.00	72.00	12	100
Total Hardness	mg/L	7.96±6.08	0.29	19.33	12	100 – 250
Chloride	mg/L	3.71±1.85	1.10	7.00	12	10.00 - 50.00
Nitrate	mg/L	0.38±0.05	0.28	0.46	12	45.00-50.00
Bicarbonate	mg/L	0.51±0.14	0.24	0.72	12	-
Zinc	mg/L	0.07±0.09	0.01	0.34	12	100 – 500
Iron	mg/L	0.06±0.03	0.01	0.13	12	0.3 - 3.0
Copper	mg/L	0.02±0.01	0.01	0.04	7	0.00 - 2.00
Chromium	mg/L	0.03±0.01	0.01	0.05	10	0.00 - 0.05
Sulphate	mg/L	3.96±1.19	2.27	6.16	12	0.00 – 100
Lead	mg/L	0.01±0.00	0.01	0.01	7	0.00 - 0.01
Sodium	mg/L	13.79±9.50	0.80	33.43	12	10.00 - 25.00
Potassium	mg/L	32.34±29.14	0.97	74.67	12	NS
Calcium	mg/L	2.11±2.27	0.10	7.00	12	NS
Magnesium	mg/L	2.15±5.55	0.02	20.50	12	0.00 - 20.00
E. coli Count	CFU/mL	0.08±0.28	0.00	1.00	12	0
Coliform Count	CFU/mL	0.75±0.72	0.00	2.00	12	0
Yeast Count	CFU/mL	0.00±0.00	0.00	0.00	12	0
Bacteria Count	CFU/mL	2.17±1.28	1.00	5.00	12	0

NOTE- NS: calcium and potassium levels are more focused on aesthetic qualities and potential health impacts at higher concentrations

3.2 Microbial Quality and Public Health Implications

Microbiological analysis (Table 2) revealed that acceptable physicochemical quality did not correspond to microbiological safety. Total coliforms were detected in 67% of samples, with counts ranging from non-detectable to 2.0 CFU/mL, which is inconsistent with zero-tolerance drinking-water standards (Bakare-Abidola, Olaoye & Adams, 2025). *Escherichia coli* was detected in two samples, indicating possible faecal contamination and a direct public-health concern (Nwaiwu, Aduba, & Oni, 2020). Total heterotrophic bacterial counts were relatively low (1–5 CFU/mL) but still indicated the presence of microbial activity in

the water (Eyankware Ulakpa, Uchenna & Ulakpa, 2025). Likely contamination pathways include proximity to septic tanks, soak-away pits, inadequate sanitary protection, and surface infiltration (Chukwuemeka Ogbuleka, Aleruchi & Kueniode, 2024).

3.3 Heavy Metals and Trace Elements

Heavy metal concentrations were generally within SON/WHO limits (Table 2). Iron, copper, zinc, and chromium were low, reflecting weakly mineralized groundwater. Chromium concentrations ranged from 0.01 to 0.05 mg/L and approached guideline limits in some samples, while lead was recorded at 0.01 mg/L, near the regulatory threshold. Although these values do not indicate acute chemical

contamination, acidic conditions may increase metal mobility and bioavailability (Agada, Agada, Bilikisu & Bright, 2024). Lead values showed limited variability and were close to the detection limit, so any interpretation involving lead should remain preliminary.

3.4 Pathways of contamination Analysis and Correlation

Pearson correlation analysis (Figure 2) suggested associations among acidity, turbidity, microbial indicators, and some metals. Lower pH appeared to be associated with higher lead concentrations, which is consistent with the known behaviour of lead under acidic

conditions (Nayak *et al.* 2024). Turbidity showed a positive relationship with coliform occurrence, suggesting that suspended particles may support microbial persistence by providing attachment surfaces. Because lead concentrations varied little and were near the analytical detection limit, relationships involving lead should be interpreted cautiously. Overall, the correlation results were in support of the descriptive findings and multivariate patterns, but they should not be interpreted as causal evidence (Ibe, Chukwu, Ibe, Ahmad & Chinedu, 2025).

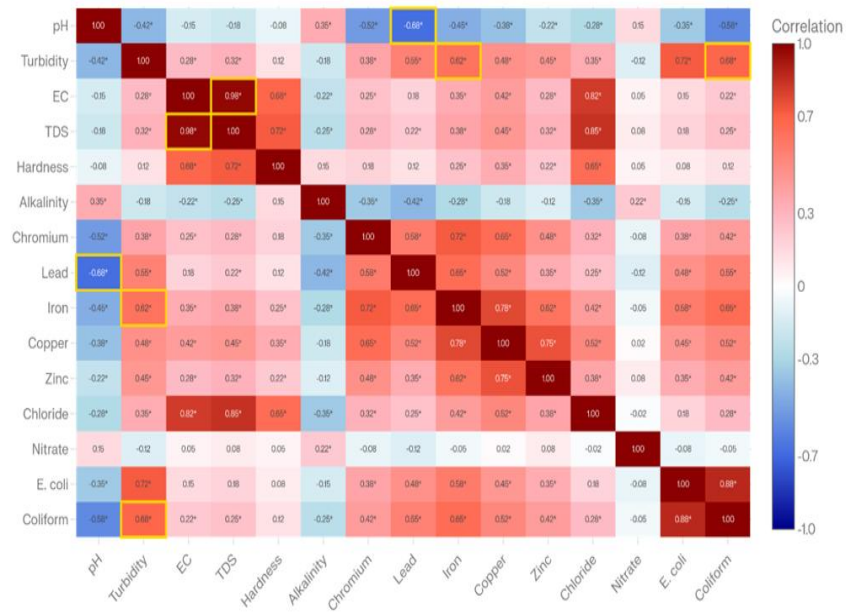
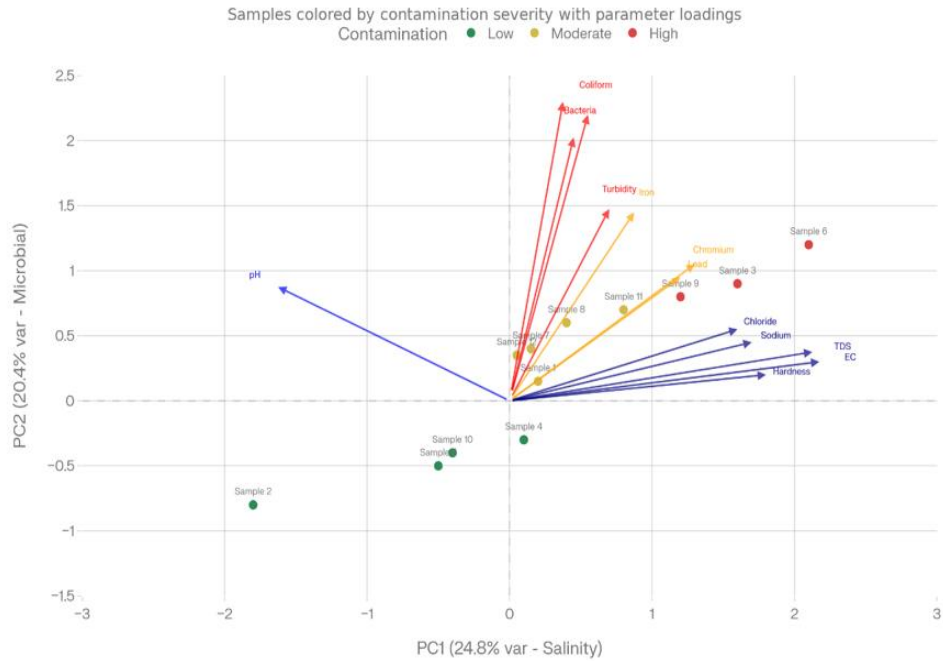


Figure 2. Correlation Matrix showing Parameter Relationship between Variables

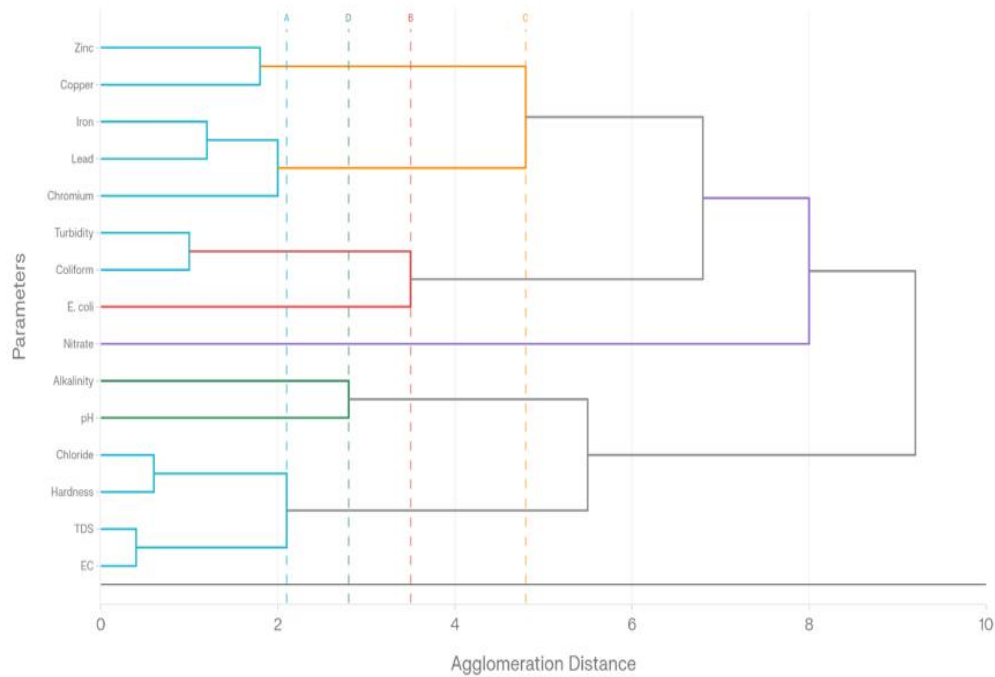
3.5 Multivariate Statistical Evaluation

The results indicated that there were two exploratory factors (Figure 3a) suggested by PCA (Srivastava & Malik, 2026). The first factor was related principally with electrical conductivity, total dissolved solids, chloride and major ions indicating mineralization related influences. Sanitary and particulate influences were associated with the second

factor, which was related to turbidity, microbial indicators and some metals (Iannone *et al.*, 2025; Zair *et al.*, 2025). Groupings were broadly similar from the HCA (Figure 3b), which divided the variables into salinity related and microbial and trace-metal related groups (Dange Arumugam & Vijayaraghavalu, 2025; Kacha *et al.*, 2025). Due to limited sample size these results are descriptive and not conclusive.



(a)



(b)

Figures 3a & 3b. PCA Biplot and HCA Dendrogram presenting Water Quality Variables

The non-carcinogenic risk indices (Figure 4) were below concern levels for the metals measured for both adults and children under

3.6 Health Risk Implications

current exposure conditions in the health-risk assessment. The estimated HI values for the 2-6 year old children and adults aged 21-78 years were both lower than the HI value of 1.0, at 0.0264 and 0.0132, respectively. The HI was dominated by chromium (73%), followed by lead (23%) and metals in general (<5%). The estimated carcinogenic risk from chromium exposure ($\approx 7.05 \times 10^{-5}$) was in the range of the common acceptance (10^{-6} to 10^{-4} , Balogun,

Sympa, Maigari, Mohammed & Abubakar, 2023), but this is a conservative estimation and does not adequately consider the increased bioavailability of the metals under acidic conditions (Oni *et al.*, 2022). In contrast, the presence of faecal indicator bacteria is a current drinking-water danger because microbial contamination is in breach of zero-tolerance standards (Belina *et al.*, 2023; Waseem, Akhtar & Nawaz, 2025).

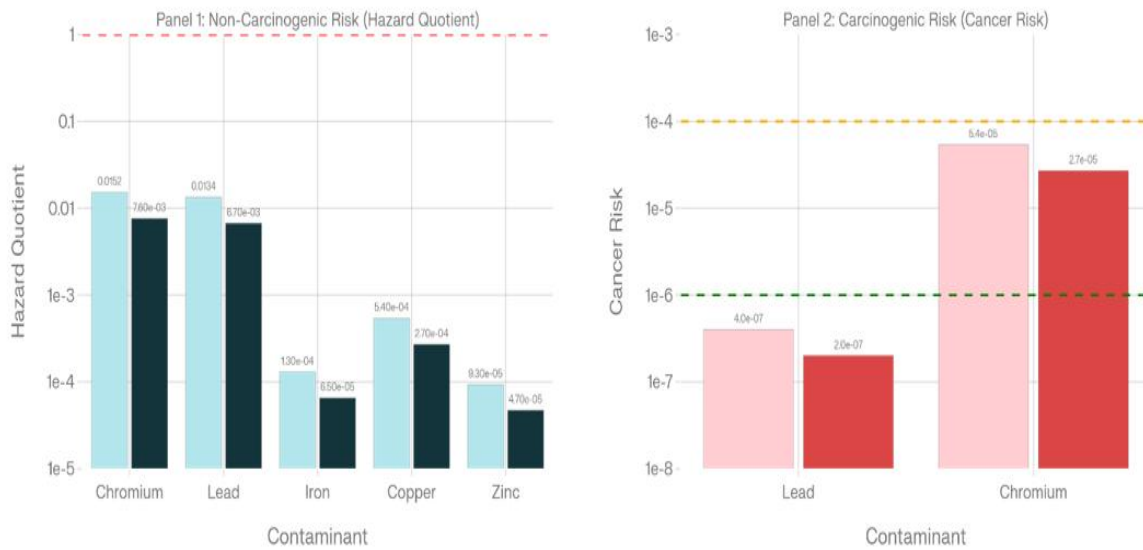


Figure 4. Health Risk below Thresholds for All Contaminants

3.7 Public Awareness and Risk Perception

Table 3. Internal Consistency of the Public Awareness Questionnaire

Reliability

Scale: ALL VARIABLES

The public awareness survey (Table 3) was found to have a good internal consistency and also a medium awareness of groundwater contamination risks (Ahmad, Alias, Hamat & Mohamed, 2024). However, the application of

household water-treatment methods was not consistent, indicating that behavioural factors may pose a greater constraint to risk reduction than technical factors (Okhuebor & Izevbuwa, 2020; Umar *et al.*, 2020). The majority of the respondents reported that they were willing to use low-cost treatment options, further suggesting the importance of community education as well as technical interventions.

Case Processing Summary

Cases	Valid	N	%
	Excluded ^a	20	100.0
	Total	0	0
		20	100.0

a. Listwise detection based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
780	20

3.8 Synthesis and Implications

Overall, the results indicated that there were low mineralization levels in the boreholes, low heavy-metal risk, and evidence of microbiological contamination, but that pH levels were acidic. Therefore, routine pH correction, disinfecting and sanitizing boreholes, as well as educating the public and regular monitoring, are important. The study is limited due to the small sample size, single-season sampling, and absence of chromium speciation data. Future work should consist of further increases in sample size, multi-season monitoring, and hydrogeological characterization to provide support for causal interpretation.

Conclusion

The result of this study indicated that the borehole water samples from selected borehole sites in Benin City generally met the physicochemical standards as well as the standard for heavy metals, but had acidic pH and microbiological contamination. Estimated health risks from high concentrations of the heavy metals were low, however, the presence of coliforms and *Escherichia coli* shows that a number of boreholes are not suitable for direct use without treatment. The exploratory multivariate analyses showed that mineralization, turbidity and sanitary conditions are potential factors affecting water-

quality variation, but should be viewed with caution due to the small sample size. To enhance groundwater safety, regular monitoring, sanitation around boreholes, pH correction, disinfection and raising awareness amongst the communities are suggested.

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