

Assessment of the Physicochemical and Microbiological Quality of Borehole Water in Kananga, Democratic Republic of the Congo

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ABSTRACT

Introduction

Access to safe drinking water remains a major public health challenge in the Democratic Republic of the Congo (DRC), particularly in peri-urban and rural areas. In Kananga and its surrounding areas, the limited coverage of public water supply has forced many households to rely on boreholes and untreated groundwater. Rapid urban expansion, inadequate sanitation infrastructure, and permeable sandy-lateritic soils increase groundwater vulnerability to surface contamination, exposing populations to chemical and microbiological health risks.

Purpose

This study evaluated the physicochemical and microbiological quality of borehole water consumed in Kananga and its surrounding areas.

Methods

Five representative borehole water samples (F1–F5) were collected during the rainy season. Physicochemical parameters, nutrient levels, and microbiological indicators were determined at the National Institute for Biomedical Research (INRB) using standard protocols. Trace metals were quantified via energy-dispersive X-ray fluorescence (ED-XRF) spectrometry. Data were evaluated against World Health Organization (WHO) drinking water guidelines. Statistical analyses, including Pearson correlation and Water Quality Index (WQI) determinations, were performed using Stata software.

Results

Most physicochemical parameters met WHO guidelines. Low electrical conductivity, total dissolved solids, and suspended solids reflected weak mineralization, while low biochemical oxygen demand, chemical oxygen demand, nutrients, and trace metals (Cu, Mn, Hg, Fe, Pb, As, Cd) indicated minimal organic and chemical pollution. However, all boreholes exhibited acidic conditions (pH range: 4.00–5.50), falling below the WHO recommended range (6.5–8.5). Significant negative correlations were observed between pH and lead ($r = -0.92$, $p = 0.03$), as well as arsenic ($r = -0.90$, $p = 0.04$), indicating that acidic conditions enhance metal mobility. The physicochemical WQI rated F4 and F5 as "Excellent" (17.98 and 24.60), F1 and F2 as "Good" (41.60 and 35.29), and F3 as "Poor" (53.44). Crucially, microbiological analyses revealed contamination across all boreholes by total coliforms (148–250 CFU/100 mL), enterococci (5–12 CFU/100 mL), and *Escherichia coli* (4–15 CFU/100 mL).

Conclusion

Although the groundwater exhibits acceptable physicochemical properties (aside from low pH), widespread microbiological contamination renders the water unfit for direct human consumption. Corrective measures—including pH neutralization (liming), disinfection (chlorination or UV irradiation), regular hydrochemical monitoring, and sanitary protection zones—are required before consumption.

INTRODUCTION

Access to safe drinking water is a fundamental human right and a major global public health challenge. Approximately 2.2 billion people worldwide lack access to safely managed drinking water services (WHO/UNICEF, 2019). This gap is especially pronounced in sub-Saharan Africa, where rapid demographic growth, unplanned urbanization, and inadequate water supply infrastructure exacerbate water quality degradation and scarcity (Ngangu et al., 2026; UN-Water, 2021).

Drinking water must be free from pathogenic microorganisms and toxic chemical substances at concentrations harmful to human health (Tangou, 2017; World Health Organization [WHO], 2017, 2022). Microbiological indicator organisms—such as total coliforms, *Escherichia coli* (*E. coli*), and enterococci—serve as critical markers of fecal contamination. Concurrently, physicochemical parameters including pH, electrical conductivity (EC), nutrient loads (nitrates, nitrites, and phosphates), and trace metals influence water potability and long-term chemical toxicity (Appelo & Postma, 2005; Rodier et al., 2009).

In the Democratic Republic of the Congo (DRC), studies have documented systemic deterioration of drinking water quality. Microalgal and microbiological contamination, along with physicochemical anomalies, have been reported in groundwater across Kinshasa and adjacent regions (Bashige et al., 2026; Kapembo et al., 2019; Kyowire et al., 2024; Ngangu et al., 2026; Nienie et al., 2017; Nsiala et al., 2025). Similarly, Tchoumou et al. (2023) demonstrated that unmanaged well water in Brazzaville exhibited low mineralization, acidic pH, and severe fecal contamination.

In Kananga, the public water distribution network operated by REGIDESO lacks capacity and operational reach (UNICEF, 2017; World Bank, 2018). Aging infrastructure, unreliable electricity, and insufficient maintenance result in frequent supply interruptions (World Bank, 2018), driving widespread dependence on groundwater boreholes and shallow wells (Kande, 2024).

Consuming contaminated water poses severe epidemiological risks, facilitating the transmission of diseases such as diarrheal illness, cholera, typhoid fever,

dysentery, and hepatitis A (Montgomery & Elimelech, 2007; WHO, 2011, 2022). Furthermore, groundwater acidity in tropical aquifers can accelerate the dissolution and bioavailability of toxic heavy metals from surrounding geology (Appelo & Postma, 2005; Mutileni et al., 2023).

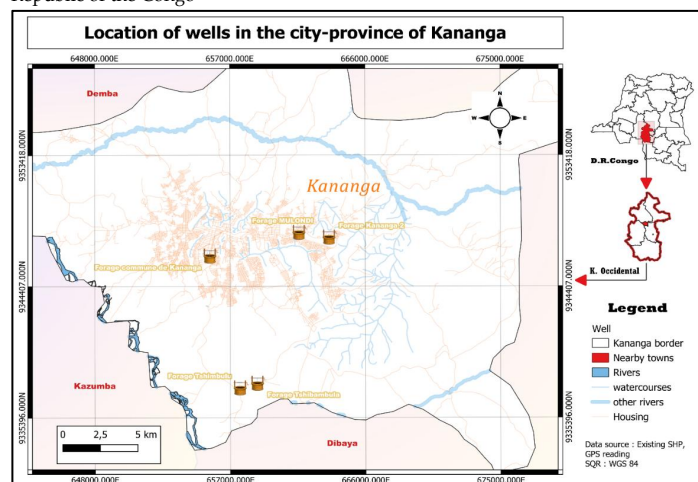
This study evaluated the physicochemical and microbiological quality of borehole water consumed in Kananga and its surrounding areas, testing the hypothesis that groundwater acidity significantly enhances the mobility and concentration of trace metals.

METHODS

Study Area

This cross-sectional pilot study was conducted in Kananga and its peri-urban surroundings, located in Kasai-Central Province, DRC (Figure 1). Kananga has an estimated population of approximately 2,000,000, with an annual growth rate of 3.3% driven primarily by rural-to-urban migration (PURUK, 2024). Most residents lack access to piped water systems and rely on untreated boreholes situated near unlined pit latrines and informal waste sites.

Figure 1: Geographic Location of the Sampling Borehole Sites in Kananga, Democratic Republic of the Congo



Sampling Procedure

Sampling was conducted during a single representative campaign during the rainy season. Water samples were collected from five purposively selected boreholes (F1–F5) that serve as primary drinking water points for the local population:

- a) **F1:** Forage commune de Kananga
- b) **F2:** Forage Mulondi
- c) **F3:** Forage Kananga 2
- d) **F4:** Forage Tshimbulu
- e) **F5:** Forage Tshibambula

Water samples were collected using sterile 700-mL polyethylene bottles. Prior to collection, the taps or pumps were purged for 3–5 minutes. Bottles were washed with tap water, rinsed with distilled water, and double-rinsed with the target borehole water in the field. Samples for physicochemical and microbiological analyses were collected in separate containers to eliminate cross-contamination. Collected samples were labeled, stored in dark coolers at 4 °C, and transported to the laboratory within 6 hours.

Laboratory Analyses

In Situ Measurements

Field measurements were performed immediately after sample extraction using a pre-calibrated multi-parameter probe (calibrated daily with standard buffer solutions). Parameters recorded *in situ* included temperature (°C), pH, electrical conductivity (µS/cm), salinity, and total dissolved solids (TDS, mg/L).

Ex Situ Physicochemical and Nutrient Analyses

Laboratory analyses were performed at the National Institute for Biomedical Research (INRB) in collaboration with Golden Consulting. Analyzed parameters included turbidity (NTU), total suspended solids (TSS, mg/L), dissolved oxygen (O₂, mg/L), five-day biochemical oxygen demand (BOD₅, mg O₂/L), chemical oxygen demand (COD, mg O₂/L), nitrates (NO₃⁻), nitrites (NO₂⁻), and phosphates (PO₄³⁻), following standard water examination protocols (Rodier et al., 2009).

Trace Metal Quantification by ED-XRF

Trace elements—including copper (Cu), manganese (Mn), mercury (Hg), iron (Fe), lead (Pb), arsenic (As), and cadmium (Cd)—were quantified using a SPECTRO XEPOS III energy-dispersive X-ray fluorescence (ED-XRF) spectrometer. Method calibration was achieved using synthetic matrix-matched standards with external calibration, and peak intensity normalization was applied

relative to coherent and incoherent scattering peaks. Results were evaluated within 95% confidence intervals using Student's *t*-test.

Microbiological Enumeration

Microbiological parameters—including total coliforms, enterococci, and *Escherichia coli*—were quantified via membrane filtration and culture techniques following standard ISO protocols (ISO 6222:1988; ISO 9308-1:2014). Glassware was sterilized in a hot-air oven at 180 °C for 20 minutes, and culture media were autoclaved at 121 °C (2 bar) for 15 minutes. Plates were incubated at 37 °C for 24–48 hours, and results were recorded as colony-forming units per 100 mL (CFU/100 mL).

Statistical Analysis and Water Quality Index Calculation

Statistical processing was conducted using Stata software. Descriptive statistics (mean, standard deviation, minimum, and maximum) were calculated for all measured parameters. Relationships between pH, water temperature, organic indicators, and trace metal concentrations were assessed using Pearson correlation coefficients (*r*) and associated *p*-values, with statistical significance established at $\alpha = 0.05$.

The integrated physicochemical quality was determined using the Water Quality Index (WQI) based on WHO guidelines (WHO, 2017). The WQI was computed through four steps:

1. **Weight Assignment (*w_i*):** Each parameter was assigned a weight reflecting its health significance (e.g., *w_i* = 5 for toxic heavy metals and nitrates; lower values for aesthetic parameters).

2. **Relative Weight Calculation (*w_i*):**

$$W_i = w_i / \sum w_i$$

Where: *W_i* = Relative weight of parameter *i* *w_i* = Weight assigned to parameter *i* $\sum w_i$ = Sum of weights of all parameters

3. **Quality Sub-Index Calculation (*q_i*):** For general parameters:

$$Q_i = (C_i / S_i) * 100$$

Where: *Q_i* = Quality sub-index of parameter *i* *C_i* = Measured concentration of parameter *i* *S_i* = WHO guideline value for parameter *i*

For pH and dissolved oxygen, which have ideal baseline values:

$$Q_i = 100 * |(V_0 - V_i) / (V_n - V_i)|$$

Where: Q_i = Quality sub-index of parameter i V_0 = Observed value V_i = Ideal value (7.0 for pH, 8.0 mg/L for dissolved oxygen) V_n = Permissible limit / WHO guideline value

4. Sub-Index of Parameter i (SI_i):

$$SI_i = W_i * Q_i$$

5. Overall Water Quality Index (WQI)

$$WQI = \sum SI_i$$

WQI values were categorized according to standard classifications (Brown et al., 1970; Shigut et al., 2017) as outlined in Table 1.

Table 1:

Water Quality Index (WQI) Classification and Quality Ratings

WQI Range	Quality Class	Interpretation
0–25	Excellent	Excellent water quality
26–50	Good	Good water quality
51–75	Poor	Poor water quality
76–100	Very Poor	Very poor water quality
> 100	Unfit	Unfit for drinking / consumption

RESULTS

General Physicochemical Parameters

General physicochemical parameter values were within WHO guidelines, with the exception of pH (Table 2). Water temperature ranged from 24.8 to 26.0 °C. Electrical conductivity (31–120 µS/cm), TSS (0.001–22 mg/L), and TDS (16–102 mg/L) showed weak groundwater mineralization. Turbidity complied with the 5 NTU limit across most boreholes, except for F1 (5.80 NTU). All boreholes exhibited marked acidity, with pH values ranging from 4.00 to 5.50, consistently failing to meet the WHO range of 6.5–8.5.

Table 2:

General Physicochemical Parameters of Borehole Water Samples in Kananga

Borehole Code	Temperature (°C)	pH	EC (µS/cm)	Turbidity (NTU)	TSS (mg/L)	TDS (mg/L)
F1	25.20	4.00	111.00	5.80	11.00	102.00
F2	24.80	4.30	39.00	4.00	15.00	19.00
F3	25.50	4.40	31.00	5.00	22.00	16.00
F4	26.00	5.50	120.00	0.75	0.00	60.00
F5	25.50	5.48	38.00	0.01	0.00	74.00
WHO Standard	25.00	6.50–8.50	1000.00	≤ 5.00	≤ 25.00	1000.00

Note. EC = Electrical Conductivity; TSS = Total Suspended Solids; TDS = Total Dissolved Solids.

Organic Indicators and Nutrient Concentrations

Organic pollution parameters and nutrient loads remained well within acceptable WHO guideline limits (Table 3). Values for BOD₅ (0.003–0.30 mg O₂ L) and COD (0.60–4.50 mg O₂/L) indicated minimal organic loading. Dissolved oxygen concentrations (6.00–8.18 mg/L) reflected well-oxygenated conditions. Nutrient levels—including nitrites (0.01–0.60 mg/L), nitrates (1.00–33.00 mg/L), and phosphates (0.007–0.200 mg/L)—remained below WHO upper thresholds across all sites.

Table 3:

Organic Matter and Nutrient Concentrations in Borehole Water Samples

Borehole Code	BOD ₅ (mg O ₂ /L)	COD (mg O ₂ /L)	Dissolved O ₂ (mg/L)	Nitrites (mg/L)	Nitrates (mg/L)	Phosphates (mg/L)
F1	0.300	0.70	7.80	0.01	2.00	0.020
F2	0.100	0.60	8.14	0.03	4.00	0.030
F3	0.100	0.80	6.00	0.60	33.00	0.007
F4	0.003	2.00	8.14	0.10	1.00	0.010
F5	0.003	4.50	8.18	0.02	3.00	0.200
WHO Standard	≤ 2.00	≤ 5.00	5.00–8.00	≤ 3.00	≤ 50.00	0.05–0.50

Note. BOD₅ = Biochemical Oxygen Demand (5-day); COD = Chemical Oxygen Demand.

Trace Metal Concentrations

Trace metal concentrations across all five boreholes complied with maximum WHO permissible limits (Table 4). Concentrations were consistently low for copper (≤ 1.90 µg/L), manganese (≤ 0.06 mg/L), mercury (≤ 2.10 µg/L), iron (≤ 1.30 mg/L), lead (≤ 0.004 µg/L), arsenic (≤ 0.008 µg/L), and cadmium (≤ 0.80 µg/L).

Table 4:

Trace Metal Concentrations in Borehole Water Samples

Borehole Code	Cu (µg/L)	Mn (mg/L)	Hg (µg/L)	Fe (mg/L)	Pb (µg/L)	As (µg/L)	Cd (µg/L)
F1	1.900	0.050	1.20	1.14	0.004	0.006	0.20
F2	0.070	0.060	2.10	1.30	0.002	0.008	0.80
F3	0.900	0.040	2.10	1.00	0.004	0.007	0.00
F4	0.000	0.030	0.00	0.01	0.000	0.002	0.00
F5	0.001	0.002	0.00	0.20	0.000	0.000	0.00
WHO Standard	2000.00	0.400	6.00	0.30	10.000	10.000	3.00

Microbiological Quality

Microbiological profiling revealed non-compliance with health standards across all sampled boreholes (Table 5). Total coliform counts ranged from 148 to 250 CFU/100 mL (WHO standard: 0–10 CFU/100 mL). Fecal indicators *E. coli* (4–15 CFU/100 mL) and enterococci (5–12 CFU/100 mL) were detected in all samples, violating the zero-tolerance WHO standard (0 CFU/100 mL).

Table 5:
Microbiological Indicator Counts in Borehole Water Samples

Parameter (CFU/100 mL)	F1	F2	F3	F4	F5	WHO Standard
<i>Escherichia coli</i>	7	4	7	12	15	0
Total Coliforms	150	165	250	200	148	0–10
Enterococci	5	5	12	6	5	0

Statistical Correlations and Spatial Variations

Descriptive statistics for pH and selected trace metal concentrations across the five boreholes are summarized in Table 6. Mean pH was 4.74 ± 0.70 (range: 4.00–5.50).

Table 6:
Descriptive Statistics for pH and Trace Metals Across Borehole Samples (N = 5)

Variable	Mean	Standard Deviation	Minimum	Maximum
pH	4.736	0.704	4.000	5.500
Hg (µg/L)	1.080	1.052	0.000	2.100
Cd (µg/L)	0.200	0.346	0.000	0.800
Pb (µg/L)	0.002	0.002	0.000	0.004
Cu (µg/L)	0.574	0.833	0.000	1.900
As (µg/L)	0.005	0.003	0.000	0.008

Pearson correlation analysis demonstrated negative associations between groundwater pH and trace metal concentrations. Statistically significant inverse correlations were confirmed between pH and lead ($r = -0.92$, $p = 0.029$), as well as between pH and arsenic ($r = -0.90$, $p = 0.036$). Negative correlations were also observed for mercury ($r = -0.78$, $p = 0.118$), copper ($r = -0.65$, $p = 0.235$), and cadmium ($r = -0.52$, $p = 0.369$).

Figure 2:
Microbiological Trends (*E. coli*, Enterococci, and Total Coliforms) Across Boreholes Relative to WHO Drinking Water Guidelines

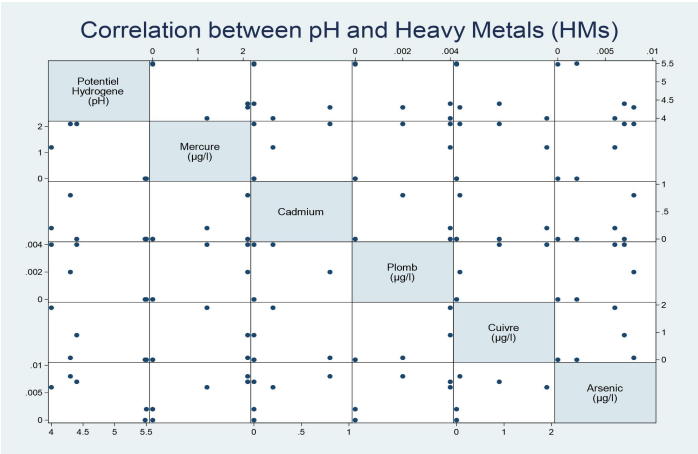
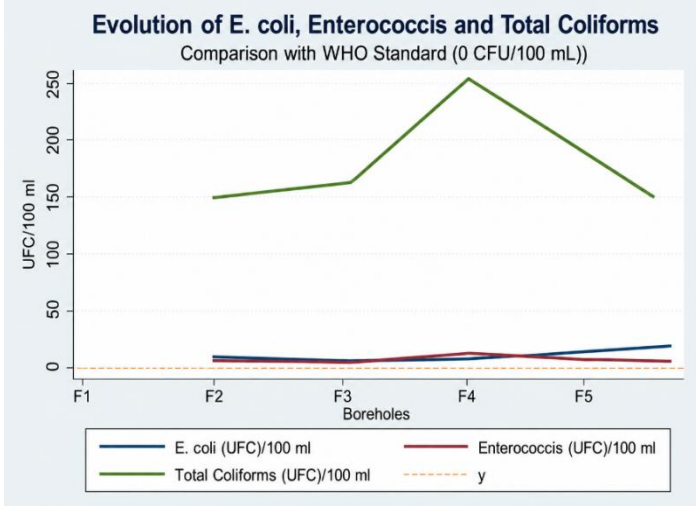


Figure 3:
Microbiological Evolution of *Escherichia coli*, Enterococci and total coliforms



Water Quality Index (WQI) and Compliance Summary

Physicochemical WQI calculations rated boreholes F4 (WQI = 17.98) and F5 (WQI = 24.60) as "Excellent", boreholes F1 (WQI = 41.60) and F2 (WQI = 35.29) as "Good", and borehole F3 (WQI = 53.44) as "Poor" (Table 7). However, despite acceptable physicochemical ratings for most sites, all boreholes were classified as unsuitable for direct human consumption without prior treatment due to mandatory microbiological non-compliance.

Table 7:
Physicochemical Water Quality Index (WQI) Values, Classifications, and Potability Status

Borehole Code	Physicochemical WQI	Physicochemical Rating	Microbiological Compliance	Overall Potability Status
F1	41.60	Good	Non-compliant (<i>E. coli</i> , enterococci) treatment	Unfit without treatment
F2	35.29	Good	Non-compliant (<i>E. coli</i> , enterococci) treatment	Unfit without treatment
F3	53.44	Poor	Non-compliant (<i>E. coli</i> , enterococci) treatment	Unfit without treatment
F4	17.98	Excellent	Non-compliant (<i>E. coli</i> , enterococci) treatment	Unfit without treatment
F5	24.60	Excellent	Non-compliant (<i>E. coli</i> , enterococci) treatment	Unfit without treatment

DISCUSSION

Physicochemical Status and Aquifer Geochemistry

The general physicochemical properties of the analyzed groundwater reflect low overall mineralization and turbidity, consistent with findings from similar sub-Saharan African hydrogeological settings (Christine et al., 2018; Ngangu et al., 2026; Shigut et al., 2017; Tchoumou et al., 2023). However, marked acidity (pH 4.00–5.50) represents a persistent anomaly. Groundwater

acidification in this region is primarily driven by the weathering of acidic sandy-lateritic parent soils, low buffering capacity, and organic carbon degradation in shallow soil zones (Appelo & Postma, 2005; Nsiala et al., 2025).

The statistically significant inverse correlations between pH and lead ($r = -0.92$) as well as arsenic ($r = -0.90$) confirm the study hypothesis: lower pH enhances the dissolution and mobility of trace elements within tropical aquifers (Appelo & Postma, 2005; Mutileni et al., 2023). Although trace metal concentrations currently comply with WHO thresholds, sustained acidic conditions could accelerate metal leaching from surrounding soil and geological strata over time, potentially escalating toxicity risks (ATSDR, 2020; WHO, 2022).

Organic and Nutrient Pollution

Low levels of BOD₅, COD, nitrites, nitrates, and phosphates demonstrate limited contamination from deep industrial organic waste or agricultural runoff, aligning with observations from suburban Kinshasa (Kapembo et al., 2019). Elevated dissolved oxygen levels (6.00–8.18 mg/L) further confirm open atmospheric recharge and active aquifer aeration (Rodier et al., 2009).

Microbiological Risks and Public Health Vulnerability

The detection of *E. coli*, total coliforms, and enterococci across all sampled boreholes indicates widespread fecal contamination. These findings align with groundwater quality studies conducted in Kikwit (Nienie et al., 2017), Kinshasa (Bashige et al., 2026; Kyowire et al., 2024; Ngangu et al., 2026), Brazzaville (Tchoumou et al., 2023), Kenya (Christine et al., 2018), and Ethiopia (Shigut et al., 2017).

Fecal contamination in Kananga's boreholes is primarily driven by:

- a) High soil permeability associated with sandy-lateritic formations, which accelerates liquid waste percolation.
- b) Proximity of unlined pit latrines, soakaways, and surface runoff to water supply infrastructure (Howard & Bartram, 2003; Lapworth et al., 2017).
- c) Absence of protected sanitary perimeters around public borehole heads.

- d) Consuming untreated water from these sources exposes local populations to waterborne pathogens, increasing the incidence of diarrheal diseases, cholera, typhoid fever, and dysentery (Montgomery & Elimelech, 2007; WHO, 2022).

Study Limitations

This study served as a preliminary pilot evaluation and was subject to limitations:

- i. Sampling was restricted to five purposively selected boreholes during a single rainy season campaign, which did not capture seasonal hydrochemical fluctuations.
- ii. Microbiological assessments focused on bacterial indicator organisms (*E. coli*, total coliforms, enterococci) and did not quantify viral, protozoan, or helminthic pathogens.
- iii. Detailed health risk modeling (e.g., Hazard Quotient and Hazard Index calculations) was not conducted.
- iv. Despite these limitations, the dataset provides essential baseline evidence regarding groundwater contamination in Kananga.

CONCLUSION

This study demonstrates that borehole water consumed in Kananga and its surrounding areas is unfit for direct human consumption without prior treatment. Although most general physicochemical parameters and heavy metal concentrations currently meet WHO guidelines, the water is characterized by acidic pH levels (4.00–5.50) and widespread fecal contamination (*E. coli*, enterococci, and total coliforms).

To protect public health, local authorities and stakeholders should implement the following intervention strategies:

1. **Water Treatment:** Mandatory disinfection (point-of-use chlorination, boiling, or UV disinfection) combined with pH correction (e.g., lime treatment or calcite filtration).
2. **Infrastructure Protection:** Establishment of protected sanitary perimeters around all public

boreholes and relocation of unlined latrines away from groundwater sources.

3. **Surveillance:** Implementation of routine microbiological and chemical monitoring programs by public health agencies.
4. **Future Research:** Comprehensive multi-season longitudinal studies incorporating expanded spatial sampling, viral pathogen screening, and quantitative human health risk assessments.

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Authors' Contributions:

- i. **M. F. Babadi:** Conceptualization, methodology, field sampling, laboratory analysis, writing – original draft, review & editing.
- ii. **N. R. Bokombo:** Field sampling, data curation, statistical analysis, writing – review & editing.
- iii. **L. P. Iyeli:** Writing – review & editing, visualization.
- iv. **K. J. Mbuyi:** Writing – review & editing, validation.
- v. **M. H. Diesse:** Formal analysis, writing – review & editing.
- vi. **N. A. Kusonika:** Laboratory analysis, writing – review & editing.
- vii. **M. E. Biey:** Supervision, methodology, writing – review & editing.
- viii. **D. E. Musibono:** Conceptualization, project administration, supervision, writing – review & editing.

Data Availability Statement: The physicochemical, microbiological, trace metal, and Water Quality Index (WQI) datasets generated and analyzed during this study of borehole water quality in Kananga, Democratic Republic of the Congo, are available from the corresponding author upon reasonable academic request.

Ethical Approval: Ethical approval was not required for this study, as it did not involve human participants, clinical trials, or animal tissue. The research was limited to the collection and laboratory analysis of environmental water samples. Access to the borehole sites was granted by local municipal authorities and community leaders..

Informed Consent and anonymity: Written informed consent was obtained from all individual participants included in the study prior to blood sample collection and questionnaire administration.

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Conflicts of Interest: The authors declare that they have no conflicts of interest.

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