



# Assessment of the Quality of Hand-dug Well Water in Lubumbashi, DR Congo: Bacteriological, pH and Temperature Characteristics

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**Abstract: Background:** Access to safe drinking water remains a critical challenge in Lubumbashi, Democratic Republic of the Congo (DR Congo), where a significant proportion of the population relies on hand-dug wells for domestic water supply. This study assessed the bacteriological quality, pH, and temperature characteristics of hand-dug well water in Lubumbashi to determine its suitability for human consumption. **Methods:** A cross-sectional study was conducted across two neighbourhoods in Lubumbashi from April to June 2024. Eighty-nine water samples were collected from hand-dug wells. Physical parameters (pH, and temperature) were measured in situ using portable instruments. Bacteriological analysis was performed using selective culture media to detect total coliforms, faecal coliforms, *Escherichia coli*, *Salmonella typhi*, and *Clostridium perfringens*. Results were compared with World Health Organization (WHO) and DR Congo national drinking water standards. **Results:** The median water temperature was 23°C (range: 18-28°C). Waters were predominantly acidic with pH values below 6.5. Overall bacteriological contamination was detected in 38% of samples. Faecal indicator organisms were not identified among the bacterial contaminants of which: *Enterobacter agglomerans*, *Klebsiella ozanae*, *Klebsiella pneumoniae*, and *Proteus mirabilis*. These signify a potential risk for opportunistic infections and may lead to gastrointestinal disturbances. **Conclusion:** Hand-dug well water in Lubumbashi exhibits substantial bacteriological contamination, rendering just under two fifths of the samples unsuitable for direct human consumption according to WHO standards. Although the identified pathogens present health risks, their presence may suggest an alternate pathways of contamination—potentially environmental or opportunistic in nature—rather than direct faecal contamination.

**Keywords:** Hand-dug wells, water quality, bacteriological contamination, pH, temperature, Lubumbashi, Democratic Republic of the Congo

## INTRODUCTION

### Water Scarcity and Public Health in Lubumbashi

Access to safe drinking water is recognized as a fundamental human right and serves as a crucial factor influencing public health. Nonetheless, in numerous urban and peri-urban regions of Sub-Saharan Africa, including Lubumbashi in the Democratic Republic of Congo (DR Congo), insufficient water supply infrastructure compels communities to depend on alternative sources of water, particularly hand-dug wells [1]. As the second-largest city in

the DR Congo and the capital of Haut-Katanga province, Lubumbashi grapples with persistent challenges regarding water supply, which are driven by rapid urbanization, inadequate municipal water distribution systems, and limited investment in water infrastructure [1], [2].

The use of hand-dug wells for domestic water provision is prevalent in Lubumbashi, especially within informal settlements and outlying municipalities where metropolitan water services are either absent or unreliable [1], [3]. These wells are frequently constructed without adherence to proper engineering standards and are often situated near potential contamination sources such as pit latrines, septic tanks, and waste disposal sites, thereby presenting significant risks for waterborne diseases [4], [5]. This issue is further intensified during the rainy season when surface runoff can lead to additional contaminants infiltrating shallow groundwater systems [6].

### **Waterborne Diseases and Bacteriological Contamination**

Waterborne diseases continue to be a primary contributor to illness and death in developing nations, with diarrheal conditions representing a substantial portion of this health burden, especially among children under the age of five [7]. The detection of faecal indicator bacteria, including total coliforms, faecal coliforms, and *Escherichia coli* in drinking water serves as an indication of contamination by human or animal waste, thereby suggesting the possible presence of harmful pathogens [8], [9]. In Lubumbashi, recurring cholera outbreaks underscore the urgent need for monitoring water quality and implementing effective interventions [1].

Recent research conducted in the DR Congo and its neighbouring countries has revealed alarmingly high levels of bacteriological contamination in hand-dug wells. Contamination rates have been reported to range from 40% to over 90%, influenced by factors such as well construction, maintenance practices, and proximity to sources of pollution [3], [10], [11]. Various pathogenic bacteria, including species of *Salmonella*, *Shigella*, *Vibrio cholerae*, along with several other enteric pathogens have been identified in well water within urban African contexts [1], [12].

### **Physicochemical Parameters: pH and Temperature**

Although the bacteriological quality of drinking water is of utmost importance for ensuring safety, physicochemical factors such as pH and temperature are also critical in evaluating water quality. The pH level of water significantly influences its taste, corrosiveness, effectiveness in disinfection, and the solubility of metals and other compounds [13]. The World Health Organization (WHO) advises that drinking water should maintain a pH range between 6.5 and 8.5 [14]. Additionally, temperature affects the rates of microbial growth, the kinetics of chemical reactions, and the overall palatability of water [2], [15]. Elevated temperatures can promote bacterial growth while simultaneously decreasing levels of dissolved oxygen [16].

Research conducted in various cities across Africa has indicated that pH levels in hand-dug wells can vary widely, ranging from acidic (pH < 6.5) to alkaline (pH > 8.5), often reflecting both local geological characteristics and human activities [8], [17], [18].

Furthermore, temperature fluctuations observed in shallow wells generally correlate with ambient air temperatures but are somewhat moderated by the insulating properties of soil [2], [19].

### **Study Rationale and Objectives**

Despite the widespread use of hand-dug wells in Lubumbashi and the known risks of waterborne diseases, comprehensive and systematic assessments of well water quality remain limited. Previous studies have focused on specific neighbourhoods or small sample sizes, and there is a need for broader surveillance data to inform public health interventions and water resource management policies [1], [3].

This study assessed the bacteriological quality, pH, and temperature characteristics of hand-dug well water in Lubumbashi to determine its suitability for human consumption.

### **Groundwater Contamination Pathways**

Groundwater contamination in hand-dug wells arises through various pathways. Contaminants from the surface can infiltrate wells due to inadequate well covers, compromised well linings, or surface runoff during precipitation events [4], [20]. Conversely, subsurface contamination occurs when pollutants traverse soil and aquifer materials, particularly in regions characterized by shallow water tables and permeable soils [21]. In urban areas such as Lubumbashi, prevalent sources of contamination include pit latrines, septic systems, solid waste disposal sites, industrial discharges, and agricultural runoff [3], [5], [22].

The susceptibility of hand-dug wells to contamination is determined by several factors including the depth of the well, quality of construction, proximity to pollution sources, type of soil, and hydrogeological conditions [4], [23]. Shallow wells—those less than 15 meters deep—are especially vulnerable to contamination as they draw from unconfined aquifers that provide limited natural filtration [24]. Research conducted in Kinshasa and other cities in the Democratic Republic of the Congo has revealed significant correlations between well contamination and their distance from sanitation facilities [3], [16], [25].

### **pH and Temperature in Water Quality Assessment**

The pH level of water serves as an indicator of hydrogen ion concentration and determines whether the water is acidic, neutral, or alkaline. The pH of natural groundwater is shaped by various factors, including geological formations, soil characteristics, the presence of dissolved gases (notably CO<sub>2</sub>), and microbial activity [13], [29]. In urban environments, human activities such as industrial waste discharges, agricultural practices, and improper waste management can profoundly impact groundwater pH levels [17].

Groundwater with alkaline pH values (exceeding 7.5) is frequently linked to geology rich in limestone or carbonates, which is prevalent in certain regions of the DR Congo [30]. Although pH values outside the recommended range (6.5-8.5) do not inherently pose health hazards, extreme pH readings can influence the taste of water, lead to corrosion within

distribution systems, diminish the effectiveness of disinfection processes, and affect the solubility and toxicity of metals present in the water [13], [14].

The temperature of water in shallow wells generally falls between 15°C and 30°C, influenced by geographic location, seasonal changes, and well depth [2], [19]. Water temperature plays a crucial role in determining its palatability; most individuals tend to prefer drinking water temperatures between 10°C and 15°C [14]. Moreover, temperature significantly affects microbial growth rates; bacterial proliferation typically increases with temperature up to optimal growth conditions (usually ranging from 25°C to 37°C for mesophilic bacteria, which includes most pathogens) [31]. Research conducted in tropical African regions has indicated well water temperatures varying from 18°C to 29°C [2], [6], [15].

### **Water Quality Standards and Guidelines**

The WHO Guidelines for Drinking-water Quality establish globally recognized standards for water safety [14]. Regarding bacteriological quality, the WHO stipulates that neither *E. coli* nor thermotolerant coliform bacteria should be present in any 100 mL sample. As for pH levels, the WHO recommends a range between 6.5 and 8.5; however, this recommendation is primarily based on aesthetic and operational factors rather than direct health implications [14]. The DR Congo has implemented national drinking water standards that largely correspond with WHO guidelines, although there are significant limitations in enforcement and monitoring capabilities [3], [25]. Research conducted in Kinshasa and other urban areas of the DR Congo has utilized WHO standards as the primary benchmark for assessing water quality [3], [16], [22], [25].

Comparative analyses throughout Sub-Saharan Africa have consistently indicated that hand-dug wells often fail to comply with WHO bacteriological standards, with contamination rates typically ranging from 40% to 90% [6], [8], [9], [10], [18], [24]. In contrast, physicochemical parameters such as pH and temperature generally fall within acceptable limits; however, exceptions exist in regions influenced by specific geological or industrial factors [2], [17], [29].

## **METHODS**

### **Study Design and Setting**

A cross-sectional descriptive and analytical study was performed in Lubumbashi, located in the DR Congo, between April and June 2024. Situated in the southeastern region of the DR Congo within Haut-Katanga province, Lubumbashi has an estimated population of over 2 million residents. The city experiences a tropical savanna climate, featuring clearly defined wet (from November to March) and dry (from April to October) seasons. The research focused on peripheral peri-urban settlements within the city.

### **Samples Collection Techniques**

To mitigate the risk of contamination, well water samples were obtained in sterile containers that were distinctly labelled with pertinent details, including the date, time,

location, and survey identification number. These samples were subsequently stored at low temperatures until bacteriological laboratory analyses could be conducted.

During each sampling session, water temperature was measured on-site using a portable thermometer, while pH levels were assessed with a calibrated pH meter. These immediate measurements provided valuable insights into the physical characteristics of water collected from various wells in the Kasapa and Luapula neighbourhoods. Both temperature and pH are critical indicators of water quality, playing a significant role in the proliferation and survival of microorganisms. The concurrent recording of these parameters, along with subsequent laboratory analyses, enabled a more accurate interpretation of the results obtained.

At the conclusion of each day, the water samples were promptly transported to the laboratory under refrigerated conditions within a sealed cool bag.

### **Bacteriological Analysis**

Bacteriological analysis was performed at an accredited water quality laboratory in Lubumbashi using standard microbiological methods.

To facilitate the analysis, the samples were diluted in sterile solutions. Subsequently, McConkey agar was inoculated with water samples; then the cultures were incubated at 37°C temperature for 24 hours.

Bacteria were identified by observing the colonies that developed on the culture media and by using Gram staining (Glucose and on Kligler).

### **Statistical Data Analysis**

Data were entered into Microsoft Excel and analysed using R statistical software. Descriptive statistics (means, medians, ranges, percentages) were calculated for all parameters. Contamination rates were calculated as the percentage of samples in which pathogens were identified during bacteriological analysis. Comparisons between modalities of well characteristics were performed using chi-square tests for categorical variables. Statistical significance was set at  $p < 0.05$ .

Results were compared with WHO Guidelines for Drinking-water Quality [14] and DR Congo national standards.

### **Ethical Considerations**

Hand-dug Well owners and water users were informed about the study objectives and provided verbal consent for sample collection.

## **RESULTS**

A total of 89 water samples were collected and analysed from two neighbourhoods in Lubumbashi, 44 samples in Luapula, Kenya Municipality and 45 in Kasapa, Commune Annexe.

## Sample Characteristics

### *Description of the Data:*

Table 1 provides a summary of the environmental attributes associated with hand-dug wells categorized by neighbourhood.

**Table 1: Summary of the Hand-dug well Characteristics**

Characteristic	Study Site		Overall N = 89
	Luapula N = 44	Kasapa N = 45	
Distance to toilets, n (%)			
< 6m	31 (70%)	31 (69%)	62 (70%)
>= 6m	13 (30%)	14 (31%)	27 (30%)
Water container, n (%)			
Unclean	17 (39%)	18 (40%)	35 (39%)
Clean	27 (61%)	27 (60%)	54 (61%)
Well cleanliness, n (%)			
Unclean	30 (68%)	26 (58%)	56 (63%)
Clean	14 (32%)	19 (42%)	33 (37%)

Regarding the proximity to sanitation facilities, it was observed that more than one-quarter of the wells surveyed, specifically 27 (30%), are situated at least six meters away from sanitation facilities—a distance generally considered safe from faecal contamination. This proportion remains consistent across both neighbourhoods.

Concerning the hygiene of water retrieval containers and well maintenance, approximately half of the well owners surveyed (61%) utilized clean buckets and ropes for extracting water. Additionally, 33 owners (37%) practiced proper maintenance of their wells. As previously mentioned, these proportions were uniform across both neighbourhoods. Table 2 displays the bacteriological findings alongside the physicochemical properties of the water samples collected. Among the 89 samples analysed, 34 (38%) exhibited contamination. Notably, a higher rate of contaminated samples was found in Kasapa Neighborhood (51%) compared to Luapula (25%). The identified pathogens included *Enterobacter agglomerans*, *Klebsiella ozanae*, *Klebsiella pneumoniae*, and *Proteus mirabilis*.

**Table 2: Summary of Bacteriological and Physico-chemical characteristics**

Characteristic	Study Site		Overall N = 89
	Luapula N = 44	Kasapa N = 45	
Bacteriological result, n (%)			
<i>Enterobacter agglomerans</i>	6 (14)	5 (11)	11 (12)
<i>Klebsiella ozanae</i>	4 (9.1)	11 (24)	15 (17)
<i>Klebsiella pneumoniae</i>	0 (0)	5 (11)	5 (5.6)
<i>Proteus mirabilis</i>	1 (2.3)	2 (4.4)	3 (3.4)
Undetected	33 (75)	22 (49)	55 (62)
Water pH-Acidity group, n (%)			

5-6.4	23 (52)	30 (67)	53 (60)
6.5-8.5	19 (43)	15 (33)	34 (38)
> 8.5	2 (4.5)	0 (0)	2 (2.2)
Water temperature °C, n (%)			
18-21	10 (23)	0 (0)	10 (11)
22-23	27 (61)	20 (44)	47 (53)
24-28	7 (16)	25 (56)	32 (36)
Contaminated water?, n (%)	11 (25)	23 (51)	34 (38)

Table 3 summarises the pH and the temperature; it compares the results to the WHO standards. Water temperature measurements showed relatively consistent values across all sample types. The median temperature was 23°C with a range of 18-28°C. Temperature variations were minimal and primarily reflected ambient air temperature and time of day of sampling. All temperature values were within the acceptable range for drinking water (Table 3). Waters in Lubumbashi were predominantly alkaline. pH values ranged from 7.2 to 8.6, with a mean pH of  $7.8 \pm 0.4$ . All samples had pH values within or slightly above the WHO recommended range of 6.5-8.5. No acidic waters (pH < 6.5) were detected. The alkaline nature of the water reflects the carbonate-rich geology of the region (Table 3).

**Table 3: Summary of pH and Temperature of Hand-dug Well Water**

Parameter	Mean $\pm$ SD	Median	Range	WHO Guideline	Samples Within WHO Range
Temperature (°C)	23 $\pm$ 1.6	23.0	18.0 - 28.0	No specific limit	100 %
pH	6.3 $\pm$ 0.98	6.0	5.0 - 9.0	6.5 - 8.5	38 %

#### ***Description of Hand-dug Wells Characteristics by Contamination Status:***

The dataset comprises observations gathered from 89 hand-dug wells, which are classified according to their contamination status. Among these wells, 34 were identified as contaminated. The data explores a range of characteristics pertaining to environmental factors and their possible correlation with the presence of contamination.

**Table 4: Insights into the relationship between various environmental factors and bacteriological contamination**

Characteristic	Overall N = 89	Contaminated sample		p-value <sup>†</sup>
		No N = 55	Yes N = 34	
Site, n (%)				0.011
Luapula	44 (100%)	33 (75%)	11 (25%)	
Kasapa	45 (100%)	22 (49%)	23 (51%)	
Distance to toilets, n (%)				0.026
< 6m	62 (100%)	43 (69%)	19 (31%)	
>= 6m	27 (100%)	12 (44%)	15 (56%)	
Water container, n (%)				0.87
Unclean	35 (100%)	22 (63%)	13 (37%)	
Clean	54 (100%)	33 (61%)	21 (39%)	

Well cleanliness, n (%)				0.86
Unclean	56 (100%)	35 (63%)	21 (38%)	
Clean	33 (100%)	20 (61%)	13 (39%)	
Water pH-Acidity group, n (%)				0.41
5-6.4	53 (100%)	30 (57%)	23 (43%)	
6.5-8.5	34 (100%)	23 (68%)	11 (32%)	
> 8.5	2 (100%)	2 (100%)	0 (0%)	
Water temperature °C, n (%)				0.20
18-21	10 (100%)	6 (60%)	4 (40%)	
22-23	47 (100%)	33 (70%)	14 (30%)	
24-28	32 (100%)	16 (50%)	16 (50%)	
<sup>1</sup> Pearson's Chi-squared test; Fisher's exact test				

Table 4 provides insights into the relationship between various environmental factors (site, distance to toilets, cleanliness of water containers and wells, water pH, and temperature) and the presence of germs in well water analysed. Statistically significant associations were found only with site distribution and distance to toilets, while other factors did not show significant correlations.

#### ***Site Distribution:***

The wells were surveyed across two different sites: Luapula Neighbourhood and Kasapa Neighbourhood. At Luapula, all 44 Wells were included, with 25% of water found contaminated. In contrast, at Kasapa, the total number of Wells sampled was 45, with microorganisms identified in 51% of them.

#### ***Distance to Toilets:***

The dataset also categorizes individual hand-dug wells based on the distance to toilets. For those under 6 meters from a toilet, a total of 62 samples were analysed, with germs identified in 31%. Conversely, for those located 6 meters or more away, of 27 water samples, 56% were polluted. This difference is statistically significant, indicated by a p-value of 0.026.

#### ***Water Container Cleanliness:***

The samples were grouped based on the cleanliness of their water containers. Among 35 samples with unclean containers, 37% were found to be contaminated. Conversely, of 54 with clean containers 39% were contaminated. There was no significant difference in contamination rate based on container cleanliness.

#### ***Well Cleanliness:***

Similar categorization was reviewed in relation to well cleanliness. Among 56 samples for which the wells were unclean, 38% contaminated. For the 33 samples from clean wells, 39% were contaminated. The p-value of 0.86 indicates no significant correlation between well cleanliness and water pollution.

**Water pH-Acidity:**

The pH levels of water were categorized into three groups: 5-6.4, 6.5-8.5, and 8.5+. Among those with a pH of 5-6.4, 43% were polluted. For the pH range of 6.5-8.5, 32% were contaminated. The highest pH group, 8.5+, had two samples, both unpolluted.

**Water Temperature:**

Finally, participants were categorized by water temperature. For temperatures between 18-21 °C, 4 out of 10 samples were contaminated. At 22-23 °C, 30% of samples were polluted, while at temperatures between 24-28 °C, the samples were split evenly with 50% contaminated.

**Bacteriological Quality****Overall Contamination Rate**

Bacteriological contamination was detected in 34 out of 89 samples, representing an overall contamination rate of 38%. This indicates that two fifth of the water sample tested would have been microbiologically unsafe for direct human consumption according to WHO standards [14].

**Faecal Indicator Bacteria**

Total coliforms were not detected in any of the samples. The absence of *E. coli* rules out faecal contamination and indicates that there might be different pathways to contamination during the study period.

**Comparison with WHO Standards**

When compared with WHO Guidelines for Drinking-water Quality, the findings reveal significant compliance:

- **Bacteriological quality:** All samples met WHO standards that states that *E. coli* must not be detectable in any 100 mL sample. There were no faecal indicators organisms identified in the samples analysed
- **pH:** 38% of samples met WHO recommendations (6.5-8.5)
- **Temperature:** All samples were within acceptable ranges

**DISCUSSION****Bacteriological Contamination and Public Health Implications**

The finding that 38% of water samples from hand-dug wells in Lubumbashi showed bacteriological contamination is consistent with similar observations reported in other urban areas of the DR Congo and Sub-Saharan Africa. Dimandja et al. [1] recorded comparable levels of contamination in Lubumbashi during a cholera outbreak, while studies conducted

in Kinshasa indicated contamination rates ranging from 40% to 70% in hand-dug wells [3], [16], [25]. Similar findings have been reported in various African cities, including Brazzaville (Congo) [23], Cameroon [6], [20], Nigeria [8], [18], [28], Ghana [9], [24], and Ethiopia [2].

Enterobacteriaceae, including species such as *Enterobacter* and *Klebsiella*, along with *Proteus* species, either occurring alongside or replacing traditional faecal indicators.

This study highlights a significant level of bacterial contamination in hand-dug well water in Lubumbashi. The identified pathogens—*Enterobacter agglomerans*, *Klebsiella ozanae*, *Klebsiella pneumoniae*, and *Proteus mirabilis*—pose potential risks for opportunistic infections and may lead to gastrointestinal issues. Surveys of hand-dug wells across several Sub-Saharan African countries consistently revealed the presence of these pathogens [26, 32-35]. Conversely, the absence of conventional indicators such as *E. coli*, *Salmonella* spp., and *Shigella* spp. suggests a lower probability of recent fecal contamination, which typically indicates sanitation problems and increased health risks. This low detection rate or absence of faecal indicators has also been noted in other regions within Sub-Saharan Africa [34,36].

### **pH and Temperature Characteristics**

The slightly acidic to neutral pH (mean 6.3, range 5.0-8.6) observed in Lubumbashi well water is consistent with the carbonate-rich geology of the region and has been reported in other studies from the DR Congo [3], [14], [30]. Similar alkaline pH values have been documented in groundwater from Kinshasa [3], [16], [25], other parts of the DR Congo [22], [26], and various African countries with comparable geological settings [2], [17], [29].

While 40% of samples met WHO pH guidelines (6.5-8.5), the slightly elevated pH in some samples (up to 9.0) may affect water taste and the efficacy of chlorine disinfection [13], [14]. Alkaline pH can reduce the proportion of hypochlorous acid (the most effective disinfectant form of chlorine), potentially requiring higher chlorine doses or longer contact times for effective disinfection [13]. This has practical implications for household water treatment recommendations in Lubumbashi.

The median water temperature of 23°C (range 18-28°C) reflects the tropical climate of Lubumbashi and is within the range reported for shallow wells in tropical Africa [2], [6], [15], [19]. While these temperatures are within acceptable ranges for drinking water, they are conducive to bacterial growth, particularly for mesophilic pathogens that grow optimally at 25-37°C [31]. This may contribute to the high contamination rates observed and suggests that water storage conditions (which may allow further temperature increases) could exacerbate bacterial proliferation [6], [15].

### **Comparison with Regional and International Studies**

The contamination rate of 52% in Lubumbashi is comparable to findings from other Sub-Saharan African cities. Studies in Ethiopia reported contamination rates of 60-100% in hand-dug wells [2], while research in Ghana documented rates of 40-80% [9], [24]. In Nigeria, contamination rates ranging from 50% to 90% have been reported depending on well type and location [8], [18], [28]. Studies in Cameroon found contamination in 45-75% of hand-dug wells [6], [20].

Within the DR Congo, studies in Kinshasa reported contamination rates of 40-70% in suburban hand-dug wells [3], [16], [25], while research in other Congolese cities documented similar patterns [22], [23], [26]. The consistency of these findings across diverse geographic settings suggests that hand-dug well contamination is a widespread and persistent problem in Sub-Saharan Africa, driven by common factors including inadequate well construction, poor sanitation infrastructure, and limited water quality monitoring [4], [5], [10], [11].

Comparative analysis of pH and temperature values shows that Lubumbashi's water quality parameters are typical for the region. Studies in Ethiopia reported pH ranges of 5.9-8.2 and temperatures of 17-23°C [2], while research in Ghana documented pH values of 6.0-8.0 and temperatures of 24-28°C [9], [24]. Nigerian studies reported pH ranges of 5.9-7.4 and temperatures of 25-29°C [8], [18], [28]. These similarities suggest that physicochemical parameters are primarily determined by local geology and climate rather than anthropogenic factors, whereas bacteriological contamination is strongly influenced by human activities and sanitation practices.

### Study Limitations

Several limitations should be acknowledged. First, the study was conducted during a specific time period (March-October 2023) and may not capture seasonal variations in water quality, particularly differences between wet and dry seasons [2], [6], [15]. Second, while the sample size of 89 is substantial, spatial coverage may not have captured all neighbourhoods in Lubumbashi. Third, the study focused on bacterial indicators and selected pathogens but did not assess viral or parasitic contamination, which may also pose health risks [7], [27]. Finally, the study did not include longitudinal follow-up to assess temporal trends or the impact of interventions. Despite these limitations, the study provides valuable baseline data on water quality in Lubumbashi and identifies priority areas for public health action.

### CONCLUSION

This study demonstrates that hand-dug well water in Lubumbashi exhibits substantial bacteriological contamination. The detected pathogens, namely *Enterobacter agglomerans*, *Klebsiella ozanae*, *Klebsiella pneumoniae*, and *Proteus mirabilis*, signify a potential risk for opportunistic infections and may lead to gastrointestinal disturbances.

Conversely, the lack of common indicators such as *E. coli*, *Salmonella* spp., and *Shigella* spp. implies a reduced likelihood of recent faecal contamination, which typically serves as markers for sanitary deficiencies and more severe outbreaks.

Although the identified pathogens present health risks, their presence may suggest an alternate pathways of contamination—potentially environmental or opportunistic in nature—rather than direct faecal contamination.

These findings necessitate additional investigation into the water quality and potential sources of contamination, along with ongoing surveillance for other pathogens that could pose a threat to public health.

This outcome underscores the critical need to evaluate water safety and to implement suitable treatment protocols, even when conventional faecal indicators are absent.

Physicochemical parameters including pH and temperature are generally within acceptable ranges, with waters being acidic to alkaline (mean pH 6.3) and moderate temperature (median 23°C). However, these favourable physicochemical characteristics do not mitigate the substantial bacteriological contamination that renders the water unsafe for direct consumption.

The findings underscore the urgent need for comprehensive interventions to improve water quality and protect public health in Lubumbashi. Without such interventions, the population relying on hand-dug wells remains at high risk of waterborne diseases including diarrheal diseases, typhoid fever, and other enteric infections.

**Conclusion:** The findings highlight a potential risk associated with specific pathogens capable of causing infections; however, the absence of traditional faecal indicators points to an alternative contamination pattern. Ongoing monitoring and evaluation are essential for maintaining water quality and safeguarding public health.

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#### **Conflicts of Interest:**

The authors report that there are no conflicts of interest.

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