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RESEARCH ARTICLE

BACTERIOLOGICAL QUALITY OF DRINKING WATER AND ASSOCIATED FACTORS AT COMMUNITY POINT SOURCES, IN ARUA DISTRICT, UGANDA

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Abstract

Background: Access to ample and safe water is vital, yet many globally lack this essential resource. Each year, 3.4 million individuals die from water-related diseases. Specifically, in Uganda, annual estimates suggest 89,000 cholera cases, resulting in 3,000 deaths.
Objective: This study aimed to evaluate the bacteriological quality of drinking water and related factors in Arua District's community water sources.
Method: Utilizing a cross-sectional design and laboratory experiments, 140 samples were analyzed for coliform bacteria presence on filter membranes. Factors relating to contamination risks were identified via a sanitary inspection checklist. Data analysis was conducted using Stata/SE 17.0.
Results: About 70.71% of samples contained bacteria, primarily total coliform. Significant risk factors included defective wastewater drainage (aOR: 19.7[5.34-72.72]), malfunctioning appliance parts (aOR: 10.7[2.52-45.92]), and inadequate or absence of fencing (aOR: 9.2[2.43-34.96]), each with a P-value <0.001.
Conclusion: Ensuring safe drinking water requires treatment, quality monitoring, maintenance of appliances, and proper fencing to reduce bacterial contamination.

Introduction:-

Access to safe drinking water, a fundamental human right vital to health, has garnered renewed attention through the United Nations General Assembly's inclusion of a dedicated water goal within the Sustainable Development Goal (SDG) framework (United Nations WW, 2017). SDG target 6.1 aims to achieve universal and equitable access to safe and affordable drinking water by 2030. Despite these aspirations, numerous water-related diseases, including cholera and schistosomiasis, persist across many developing nations, with a mere fraction of less than 5% of domestic and urban wastewater being treated before release (United Nations WW, 2017). Globally, 1.8 billion people rely on faeces-contaminated drinking water, rendering them susceptible to cholera, dysentery, typhoid, and polio (United Nations, 2020).

While water's quantity and quality are indispensable for life, a significant portion of the global population remains deprived of adequate and safe water. The 2020 Joint Monitoring Program (JMP) report reveals that one in four individuals lacks safely managed drinking water at home, and nearly half of the world faces inadequate sanitation. Notably, the ongoing COVID-19 pandemic underscores the urgent need for equitable access to effective hand hygiene (WHO, 2020). The World Health Organization (WHO) advocates that water for human consumption should

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be devoid of indicator organisms (WHO, 2011), with Escherichia coli (*E. coli*) serving as the key indicator of faecal contamination. Inadequate understanding of factors contributing to water source contamination, often attributed to on-site sanitation facilities, poses health risks, particularly for those reliant on groundwater and on-site sanitation (WHO, 2020).

Uganda grapples with water quality and access issues. Waterborne diseases, such as gastrointestinal disorders and acute diarrhea, rank among the top 10 disease burdens. Notably, diarrhea is a leading cause of mortality according to the CDC (CDC, 2021). Policies and laws exist to govern water supply, including the 1999 National Water Policy and 2017 draft guidelines for portable water quality. Arua district exemplifies these challenges, with 75% safe water coverage, potentially undermined by water quality concerns (MoW&E, 2020). Notably, this district's rural population has been linked to surface water contamination, impacting bacteriological water quality (Okaali et al., 2018). Arua has also featured prominently in cholera cases (MoH, 2017), underscoring the consequences of water quality deficits.

Amidst these challenges, there is a dearth of information on risk factors associated with bacteriological quality of water in Uganda, as highlighted in the 2020 Uganda Water Atlas (MoW&E, 2020). This study aims to address this gap by assessing the microbiological quality of community water sources in Arua district. The study endeavors to quantify microbial contamination levels (total coliforms, *E. coli*, and intestinal enterococci load) and identify associated risk factors. By shedding light on these critical aspects, the study seeks to empower both communities and policymakers with informed decisions, ultimately contributing to improved water quality and public health outcomes.

Methods

Study Design

This research adopted an observational cross-sectional study design. Laboratory-based analyses were conducted to quantify the dependent variable, i.e., the bacteriological quality of water sources.

Study Population

The study focused on functional community water sources for drinking purposes. These encompassed various types, including motorized boreholes, hand pump boreholes, artesian wells, and spring water sources.

Inclusion and Exclusion Criteria

All community-operated water sources intended for domestic use were included in the study. Conversely, community drinking water sources not designated for drinking purposes were excluded.

Sample Size Determination and Selection

Sample size determination employed the Kish Leslie formula for proportion, yielding an initial sample size of 288. Adjusting for the known study population (266 functional water sources), the final sample size was recalculated as 140. These samples were drawn proportionately from all sub-counties within the district.

Sampling Techniques

The district was stratified into four clusters corresponding to the sub-counties. A sampling frame was generated for each cluster, from which 140 samples were selected using a simple random sampling technique. The selected samples were drawn from Ajia (28), Arivu (32), Logiri (37), and Vurra (43) sub-counties. Key informants, such as Local Council 1 (LC1) chairpersons or committee members, were purposively selected from each water source to provide contextual insights.

Data Collection Methods

Data on bacteriological quality of water, was obtained through laboratory-based experiments. Associated risk factor data was collected using a combined questionnaire and a sanitary checklist for water sources. Sample numbers facilitated matching of laboratory results and questionnaire responses.

Variables

Dependent Variable

The study focused on bacteriological water quality, which was assessed based on the presence or absence of specific bacteria types: Total coliform, Escherichia coli, and Intestinal enterococci.

Independent Variables

Hazard factors (e.g., nearby latrines, solid waste), pathway factors (drainage conditions, protection works status), and indirect factors (fence, surface water diversion, water user committee, pump mechanic presence) were examined.

Data Collection Instruments

A water testing kit (WE10005 PotatestWagtech International) was employed to analyze microbiological water quality. A sanitary inspection checklist for community water sources was used to capture risk factor data. This checklist was adapted from WHO guidelines for sanitary risk inspection.

Data Quality Control

Pretesting verified the validity and reliability of the water testing kit. Daily blind samples were included for quality control. Standard WHO checklist for sanitary inspection of point water sources was employed. Calibration and sterilization were conducted to ensure accurate data collection. A representative sample size of 140, each analyzed for three bacteriological parameters, ensured reliability and validity.

Data Collection Procedure

After securing ethical approval and recruiting research assistants, water samples were collected, adhering to meticulous procedures to ensure sample integrity. These samples were transported in cooled containers to maintain their original condition. In the laboratory, bacteriological analyses were carried out, following detailed steps for filtering, culturing, and incubating samples.

Data Management and Analysis

Data was entered into Excel and then imported into Stata 17 for analysis. Bacteriological quality was summarized using frequencies, proportions, means, and standard deviations. Water sample characteristics were similarly summarized. Associations between risk factors and bacteriological quality were explored using univariate logistic regression, presenting crude odds ratios (COR) with p-values and confidence intervals. Risk factors with significant associations from the bivariate analysis were subjected to multivariate logistic regression while adjusting for any potential confounders, yielding adjusted odds ratios (AOR) with p-values and confidence intervals.

Limitations and Mitigation

The study's bacteriological tests were aligned with WHO guidelines, though not exhaustive. The sample size, although not including all water sources, was deemed sufficient for generalization due to the applied sampling strategy. While the study didn't analyze the complete safe water chain, this decision was driven by financial constraints, necessitating future research.

Ethical Considerations

Ethical approvals and permissions were obtained. Informed consent was secured from relevant authorities and participants. Anonymity was ensured by utilizing unique identifier numbers for water sources. Contributions and participation were acknowledged, while credible reporting practices were followed.

Results:-

Table 1: Characteristics of the water sources considered in this study by water source type and Sub- County

Variable		**Physical Parameter**				
PH				**Turbidity**		**Electro-Conductivity (µs/cm)**
Type of water source	**/Sub county**	**(5.5-9.5) Standard n(%)**	**(<5.5 or >9.5) Standard not met**	**(<=25) Standard n(%)**	**(>25) Standard not met n(%)**	**(<=2500µs/cm) Standard met n(%)**

			n(%)			
Artesian Well	Ajia	1(100)	0(0)	1(100)	0(0)	1(100)
	Arivu	0(0)	0(0)	0(0)	0(0)	0(0)
	Logiri	0(0)	0(0)	0(0)	0(0)	0(0)
	Vurra	0(0)	0(0)	0(0)	0(0)	0(0)
Borehole	Ajia	24(28.92)	0(0)	24(29.63)	0(0)	24(28.92)
	Arivu	21(25.3)	0(0)	20(24.69)	0(0)	21(25.3)
	Logiri	11(13.25)	7(77.8)	17(20.99)	0(0)	18(21.69)
	Vurra	18(21.69)	2(22.2)	20(24.69)	1(100)	20(24.1)
Motorized Bore hole	Ajia	0(0)	0(0)	0(0)	0(0)	0(0)
	Arivu	1(33.3)	0(0)	1(33.3)	0(0)	1(33.3)
	Logiri	1(33.3)	0(0)	1(33.3)	0(0)	1(33.3)
	Vurra	1(33.3)	0(0)	1(33.3)	0(0)	1(33.3)
Shallow Well	Ajia	1(50)	0(0)	1(50)	0(0)	1(50)
	Arivu	1(50)	0(0)	1(50)	0(0)	1(50)
	Logiri	0(0)	0(0)	0(0)	0(0)	0(0)
	Vurra	0(0)	0(0)	0(0)	0(0)	0(0)
Variable		**Physical Parameter**				
Type of water source	Sub-County	**PH n(%)**		**Turbidity n(%)**		**Electro-Conductivity (µs/cm) n(%)**
Spring	Ajia	2(4.76)	0(0)	2(4)	0(0)	2(4)
	Arivu	9(21.43)	0(0)	9(18)	0(0)	9(18)
	Logiri	14(33.3)	4(66.67)	18(36)	0(0)	18(36)
	Vurra	17(40.48)	2(33.3)	21(42)	0(0)	21(42)
Total		**122(89.05)**	**15(10.95)**	**137(99.28)**	**1(0.72)**	**140(100)**

Note in table 1 n =frequency, (%) = Proportion

According to Table 1, a total of 140 water source samples were subjected to bacteriological quality analysis. These samples comprised Artesian wells (1), Boreholes (84), motorized boreholes (3), Shallow wells (2), and spring water sources (50). The results indicate that out of these sources, only 15 (10.95%) did not meet the national pH standard of 5.5-9.5. Notably, 9 (60%) of these non-compliant sources were boreholes, and 13 (86.7%) were located in Logiri Sub County. Merely 1 (0.72%) water source failed to meet the national turbidity standard of <=25, specifically a borehole from Vurra Sub County. Concerning electro-conductivity, all 140 (100%) water sources adhered to the standard of <=2500 µs/cm.

Table 2: Showing sanitary risk score of the water sources by Sub-County

Variable		**Sanitary risk score Category**			
Type of water source	**/Sub county**	**Low (0-2) n(%)**	**Medium (3-5) n(%)**	**High (6-8) n(%)**	**Very high (9-10)**
Artesian Well	Ajia	0(0)	0(0)	1(100)	
	Arivu	0(0)	0(0)	0(0)	
	Logiri	0(0)	0(0)	0(0)	
	Vurra	0(0)	0(0)	0(0)	
Borehole	Ajia	13(24.53)	9(33.33)	2(50)	
	Arivu	8(15.09)	11(40.74)	2(50)	
	Logiri	12(22.64)	6(22.22)		
	Vurra	20(37.74)	1(3.75)		
Motorized Borehole	Ajia	0(0)	0(0)		
	Arivu	1(50)	0(0)		
	Logiri	0(0)	1(100)		
	Vurra	1(50)	0(0)		
Shallow Well	Ajia	1(100)	0(0)		
	Arivu	0(0)	1(100)		

	Logiri	0(0)	0(0)		
	Vurra	0(0)	0(0)		
Spring	Ajia	2(6.06)	0(0)	0(0)	
	Arivu	6(18.18)	2(13.33)	1(50)	
	Logiri	11(33.33)	6(40)	1(50)	
	Vurra	14(42.42)	7(46.67)	0(0)	
Total		**89(63.57)**	**44(31.43)**	**7(5)**	

Note n =Frequency, and (%) =Proportion

In reference to Table 2, the majority of water sources demonstrated a low sanitary risk score, accounting for 89 (63.57%) of the total. Conversely, only 7 (5%) water sources received a high sanitary risk score. Among these high-risk sources, 4 (57.1%) were boreholes, with 2 (50%) originating from Ajia Sub County and 2 (50%) from Arivu Sub County.

Bacteriological Quality of Water Source

Table 3: Bacteriological quality of water by indicator bacteria

Variable	Number of water sources with Bacteria	Number of water sources without Bacteria	Mean Coliform count of bacteria **[95% Conf. Interval]**	Std. Dev	Std.Err
Presence of any one of the indicator bacteria in water source	99(70.71%)	41(29.29%)			
TTC/100mls presence	87(62.14%)	53(37.89%)	34.94[23.92 45.96]	65.94	5.57
E. Coli/100mls presence	52(37.14%)	88(62.86%)	15.80[7.58 24.03]	49.23	4.16
Intestinal enterococci Presence /100mls	29(20.71%)	111(79.29%)	0.85[.21 1.49]	3.85	0.33

Note n () = Frequency, (%) =Percentage

According to Table 3, the majority (70.71% or 99 out of 140) of the water samples, when considering 100mls, did not comply with the zero coliform count as stipulated by both national and WHO guidelines for drinking water. Total coliform was the predominant bacteria found in the water sources, present in 62.14% (87 out of 140) of the samples. Additionally, Total coliform had the highest mean count of 34, with a 95% confidence interval of 23.92 to 45.96

Risk Factors Associated with Bacteriological Quality of Water

Table 4: Risk Factors Associated with Bacteriological Quality of Water

Variable	**cOR [95%CI]**	**p-value**	**aOR [95%CI]**	**p-value**
Hazard Factors				
Presence of other sources of pollution				
Yes	0.53[0.11 2.49]	0.425	0.16[0.01 4.34]	0.28
No (Ref)				
Pathway factors				
Defective/absences of protection for the water source				
Yes	5.37[2.18 13.27]	0.001*	2.36[0.57 9.79]	0.236
No (Ref)				
Drainage for wastewater is defective				
Yes	26.25[9.60 71.74]	0.001*	19.7[5.34 72.72]	0.001*
No (Ref)				
The parts of appliances are loose				
Yes	13.2[4.74 36.59]	0.001*	10.7[2.52 45.95]	0.001*
No (Ref)				
The surface water diversion channel is defective				

Yes	1.88[0.78 4.05]	0.140*	0.93[0.22 4.08]	0.93
No (Ref)				
Indirect factors				
Absence of water user committee				
Yes	2.37[1.07 5.25]	0.034*	2.78[0.764 10.173]	0.121
No (Ref)				
Defective/lack of fence				
Yes	5.05[2.29 11.10]	0.001*	9.2[2.43 34.96]	0.001
No (Ref)				
Lack of trained pump mechanic				
Yes	0.48[0.22 1.02]	0.057		
No (Ref)				

Note; *indicates significant variable at 5%, CI= 95% Confidence Interval, cOR= Crude Odds Ratio, aOR= adjusted odds ratio

Table 4 presents the results of both bivariate and multivariate analysis. The analysis revealed that several factors were positively associated with an increased risk of water contamination at bivariate analyisis with bacteria (observed bacteriological water quality). These factors include: defective or absent protection for the water source, showing a crude odds ratio (cOR) of 5.37 (95% CI 2.18 - 13.27, p-Value < 0.001); defective drainage for wastewater, demonstrating a cOR of 26.25 (95% CI 9.60 - 71.74, p-Value < 0.001); loose parts of water source appliances, exhibiting a cOR of 13.2 (95% CI 4.72 - 36.59, p-Value < 0.001); defective surface water diversion channel, showing a cOR of 1.88 (95% CI 0.78 - 4.05, p-Value 0.14); defective or lacking fence for the water source, indicating a cOR of 5.05 (95% CI 2.29 - 11.10, p-Value < 0.001); and absence of a water user committee, displaying a cOR of 2.37 (95% CI 1.07 - 5.25, p-Value 0.034).

Meanwhile, in the multivariable analysis, certain risk factors demonstrated statistically significant associations with bacteriological contamination of the drinking water source. Defective drainage for wastewater exhibited an adjusted odd ratio (aOR) of 19.7 (95% CI 5.34 - 72.72, p-value < 0.001); loose parts of water source appliances displayed an aOR of 10.7 (95% CI 2.52 - 45.92, p-value < 0.001); and defective or lacking fence for the water source showed an aOR of 9.2 (95% CI 2.43 - 34.96, p-value < 0.001) in this study.

Discussions of Key Findings

Bacteriological Quality of Water at Point Source

This study's findings reveal that 70.71% of water sources exhibit bacteriological contamination, violating the WHO/National standard of 0 CFU/100ml. While this aligns with existing research, the 70.71% exceeds the national average of 41%, as reported in the 2020 Ministry of Water and Environment Sector Performance review report. Yet, the contamination rate is lower than a comparable study in North West Ethiopia, where 90% of samples violated WHO limits (Kassie and Hayelom, 2017). Discrepancies might stem from sample size, geological factors, and cultural practices, warranting further exploration.

Of the three indicator bacteria for contamination, Total coliform predominates, consistent with similar research in Maryland, USA. This contrasts with a study in Eastern Ethiopia, reporting Escherichia coli as the dominant organism (Gwimbi et al., 2019). The latter's small sample size may explain this inconsistency. The mean Escherichia coli count (15.8 CFU/100 ml) closely mirrors findings from Western Uganda (17 CFU/100 ml), suggesting regional comparability, potentially influenced by sample size disparities.

Interestingly, the study's sanitary risk score contradicts other research. Only 5.05% of contaminated sources fall into the high-risk category, inconsistent with studies in Farta, Ethiopia (50%), and Eastern Ethiopia (34%), indicating potential differences in cultural practices, geological factors, and sample size (Kassie and Hayelom, 2017; Gwimbi et al., 2019). Another study associates contamination risk scores with water quality in peri-urban areas (Mushi et al., 2012). In conclusion, the findings highlight concerning water quality issues. The study showcases disparities in contamination rates, bacterial prevalence, and the relationship between contamination and risk scores. These complexities demand comprehensive investigations to understand the underlying causes.

The Factors Associated with The Bacteriological Quality

In the realm of multivariable analysis, certain risk factors emerged with statistically significant associations concerning the bacteriological contamination of drinking water sources. Defective drainage for wastewater displayed an adjusted odds ratio (aOR) of 19.7 (95% CI 5.34 - 72.72, p-value < 0.001). Likewise, loose components of water source appliances exhibited an aOR of 10.7 (95% CI 2.52 - 45.92, p-value < 0.001). Additionally, the absence or defectiveness of a fence for the water source showed an aOR of 9.2 (95% CI 2.43 - 34.96, p-value < 0.001) in this study.

Surprisingly, this study did not identify any significant hazard factors (such as the presence of latrines within 10 meters/upstream or other pollution sources) associated with water quality. This contrasts with previous research linking fecal contamination to inadequate sanitation practices (Bain et al., 2014). While studies in Southern Ethiopia and South Sudan have found correlations between latrine proximity and fecal coliform presence (Zemachu et al., 2021; Engström et al., 2015), this study's results indicate a need for deeper exploration of geographical and socio-cultural variations.

Defective drainage for wastewater exhibited a significant connection to heightened bacteriological contamination, aligning with similar research from Southern Ethiopia (Zemachu et al., 2021). Damaged protective measures were also linked to increased contamination, corroborating a Southern Ethiopian study that associated uncapped wells with contamination (Viban et al., 2021). Comparable findings in Pakistan pointed to cross-contamination due to pipe damage and filtration issues (Nabeela et al., 2014). Nevertheless, a South Sudanese study did not identify a significant association between Thermotolerant coliforms and borehole apron damage (Engström et al., 2015).

Notably, a defective or absent fence for water sources showed a strong link to increased bacteriological contamination, a correlation mirrored by studies in Eastern Ethiopia and Southern Ethiopia (Aderajew et al., 2019; Zemachu et al., 2021). This underscores the importance of adequate fencing to prevent microbial contamination. However, this finding contradicts research from Maryland, USA, where no statistically significant association was found between defective fencing and fecal indicator bacteria detection (Murray et al., 2018), possibly due to variations in cultural practices and government policies.

In summary, the multivariable analysis revealed significant associations between specific risk factors and bacteriological water contamination. While the study identified inconsistencies compared to previous research, it underscores the complexity of water quality dynamics influenced by geographical, cultural, and policy-related nuances. The insights gained underscore the need for targeted interventions to address these risk factors and enhance the bacteriological quality of water sources.

Public Health Implication of the Findings

The study reveals concerning water quality issues, with 70.71% of water sources violating WHO/National standards. While in line with previous research, this exceeds the national average and demonstrates regional disparities. Total coliform predominance, contrasted with Escherichia coli in Eastern Ethiopia, suggests regional variation. The sanitary risk score's inconsistency demands further investigation into cultural and geological factors. Multivariable analysis identifies significant associations between risk factors and contamination, emphasizing the importance of proper drainage, appliance maintenance, and water source fencing. The study highlights complexities in water quality dynamics, urging targeted interventions for enhanced water source quality.

Conclusions

1. More than half (70.71%) of water sources violated the WHO/National standard of 0 CFU/100ml, exceeding the national average but lower than a similar study in North West Ethiopia.
2. Only 5.05% of contaminated sources posed high sanitary risk, differing from other research.
3. Defective drainage, loose components, and absent fencing significantly associate with contamination.
4. Surprisingly, no significant hazard factors were identified, challenging prior findings.
5. Multivariable analysis highlights the complexity of water quality dynamics influenced by diverse factors.
6. Interventions are needed to address risk factors and improve water source bacteriological quality.

Recommendations

i) The Ministries of Health and Water&Environment should issue guidelines for safe water source maintenance.

ii) Local Health and Water Departments should re-energize water user committees to enhance sanitation and upkeep around water sources.
iii) Regular quarterly water quality checks should be conducted by the district's Health and Water department.
iv) Continuous community health education on water safety and maintenance should be prioritized by the district Health department.

References

1. Bain, R., Cronk, R., Hossain, R., Bonjour, S., Onda, K., Wright, J., Yang, H., Slaymaker, T., Hunter, P., Prüss-Ustün, A., Bartram, J., 2014a. Global assessment of exposure to faecal contamination through drinking water based on a systematic review. Trop. Med. Int. Health 19, 917–927. https://doi.org/10.1111/tmi.12334
2. Bain, R., Cronk, R., Wright, J., Yang, H., Slaymaker, T., Bartram, J., 2014b. Fecal contamination of drinking-water in low- and middle-income countries: a systematic review and meta-analysis. PLoS Med. 11, e1001644. https://doi.org/10.1371/journal.pmed.1001644
3. Bwire, G., Orach, C.G., Aceng, F.L., Arianitwe, S.E., Matseketse, D., Tumusherure, E., Makumbi, I., Muruta, A., Merrill, R.D., Debes, A., Ali, M., Sack, D.A., 2021. Refugee Settlements and Cholera Risks in Uganda, 2016–2019. Am. J. Trop. Med. Hyg. 104, 1225–1231. https://doi.org/10.4269/ajtmh.20-0741
4. CDC, 2021. Uganda | CDC Global Health [WWW Document]. URL https://www.cdc.gov/globalhealth/countries/uganda/default.htm (accessed 6.26.21).
5. CDC, 2018. Global WASH Health Burden | Global Water, Sanitation and Hygiene | Healthy Water | CDC [WWW Document]. URL https://www.cdc.gov/healthywater/global/healthburden.html (accessed 6.26.21).
6. Coordinator, M.J.-A.P., 2020. Curbing the Prevalence of Waterborne Diseases-6/20 [WWW Document]. GlobalGiving. URL https://www.globalgiving.org/projects/water-life-project/reports/?subid=150627 (accessed 6.26.21).
7. Cronin, A.A., Breslin, N., Gibson, J., Pedley, S., 2006. Monitoring source and domestic water quality in parallel with sanitary risk identification in Northern Mozambique to prioritise protection interventions. J. Water Health 4, 333–345. https://doi.org/10.2166/wh.2006.029
8. Daniel, D., Gaicugi, J., King, R., Marks, S.J., Ferrero, G., 2020. Combining Sanitary Inspection and Water Quality Data in Western Uganda: Lessons Learned from a Field Trial of Original and Revised Sanitary Inspection Forms. Resources 9, 150. https://doi.org/10.3390/resources9120150
9. Godfrey, Bwire, 2013. The Burden of Cholera in Uganda [WWW Document]. URL https://journals.plos.org/plosntds/article?id=10.1371/journal.pntd.0002545#pntd-0002545-g002 (accessed 11.15.21).
10. Gwimbi, P., George, M., Ramphalile, M., 2019. Bacterial contamination of drinking water sources in rural villages of Mohale Basin, Lesotho: exposures through neighbourhood sanitation and hygiene practices. Environ. Health Prev. Med. 24. https://doi.org/10.1186/s12199-019-0790-z
11. Howard, G., 2002. Water quality surveillance: a practical guide. Loughborough University.
12. Howard, G., Pedley, S., Barrett, M., Nalubega, M., Johal, K., 2003. Risk factors contributing to microbiological contamination of shallow groundwater in Kampala, Uganda. Water Res. 37, 3421–3429.
13. Jonathan Muwanguzi, 2020. Curbing the Prevalence of water borne diseases [WWW Document]. CURBING Preval. WATERBORNE Dis. URL https://www.google.com/search?q=URL+https%3A%2F%2Fwww.globalgiving.org%2Fprojects%2Fwater-life-project%2Freports%2F%3Fsubid%3D150627&oq=URL+https%3A%2F%2Fwww.globalgiving.org%2Fprojects%2Fwater-life-project%2Freports%2F%3Fsubid%3D150627&aqs=chrome..69i57j69i60l2.1927j0j7&sourceid=chrome&ie=UTF-8 (accessed 11.15.21).
14. Kassie, G.G., Hayelom, D.H., 2017. Bacteriological quality of drinking water from source to point of use among rural communities of FartaWoreda in North West, Ethiopia. Afr. J. Microbiol. Res. 11, 1069–1074.
15. Kish, L., 1965. Survey sampling. John Wiley & Sons, New York.
16. Lewis, W.J., Foster, S.S., Drasar, B.S., 1982. The risk of groundwater pollution by on-site sanitation in developing countries. WHO-IRCWD Rep. 1, 82.
17. MoH, U., 2021. Annual Health Sector Performance Report Financial Year 2019/20. Ministry of Health Gov. Uganda. URL https://www.health.go.ug/cause/annual-health-sector-performance-report-financial-year-2019-20/ (accessed 6.26.21).
18. MoH, U., 2017. National Integrated Comprehensive Cholera Prevention and Control Plan | Ministry of Health Knowledge Management Portal [WWW Document]. URL

http://library.health.go.ug/publications/cholera/national-integrated-comprehensive-cholera-prevention-and-control-plan (accessed 6.28.21).
19. MoW&E, U., 2020. Uganda Water Supply Atlas [WWW Document]. URL http://wsdb.mwe.go.ug/index.php/public_annual_reports/tabular_reports?report_id=ann_summary_report&report_level_id=district&dyear=2020&district_id_dis=22&rfind= (accessed 4.28.21).
20. MoW&E, U., 1999. ministry of water and environment policy on management of water resources in uganda - Google Search [WWW Document]. URL https://www.google.com/search?q=ministry+of+water+and+environment+policy+on+management+of+water+resources+in+uganda&rlz=1C1GCEU_enUG957UG957&oq=ministry+of+water+and+environment+policy+on+management+of+water+resources+in+uganda&aqs=chrome.69i57.37709j0j9&sourceid=chrome&ie=UTF-8 (accessed 7.26.21).
21. Murray, R.T., Goldstein, R.E.R., Maring, E.F., Pee, D.G., Aspinwall, K., Wilson, S.M., Sapkota, A.R., 2018. Prevalence of Microbiological and Chemical Contaminants in Private Drinking Water Wells in Maryland, USA. Int. J. Environ. Res. Public. Health 15, 1686. https://doi.org/10.3390/ijerph15081686
22. Mushi, D., Byamukama, D., Kirschner, A.K.T., Mach, R.L., Brunner, K., Farnleitner, A.H., 2012. Sanitary inspection of wells using risk-of-contamination scoring indicates a high predictive ability for bacterial faecal pollution in the peri-urban tropical lowlands of Dar es Salaam, Tanzania. J. Water Health 10, 236–243. https://doi.org/10.2166/wh.2012.117
23. Okaali, D.A., Hofstra, N., 2018. Present and Future Human Emissions of Rotavirus and Escherichia coli to Uganda's Surface Waters. J. Environ. Qual. 47, 1130–1138. https://doi.org/10.2134/jeq2017.12.0497
24. Parker, A.H., Youlten, R., Dillon, M., Nussbaumer, T., Carter, R.C., Tyrrel, S.F., Webster, J., 2010. An assessment of microbiological water quality of six water source categories in north-east Uganda. J. Water Health 8, 550–560. https://doi.org/10.2166/wh.2010.128
25. UBOS, U., 2016. uganda health demographic survey 2016 - Google Search [WWW Document]. URL https://www.google.com/search?q=uganda+health+demographic+survey+2016&rlz=1C1GCEU_enUG957UG957&oq=uganda+health+demographic+survey+2016&aqs=chrome.69i57j69i60l3.25525j0j1&sourceid=chrome&ie=UTF-8 (accessed 6.28.21).
26. UNBS, U., 2017. National Drinking Water Quality Standard, - Google Search [WWW Document]. URL https://www.google.com/search?q=National+Drinking+Water+Quality+Standard%2C&rlz=1C1GCEU_enUG957UG957&oq=National+Drinking+Water+Quality+Standard%2C&aqs=chrome.69i57j0j0i22i30l8.1873j0j1&sourceid=chrome&ie=UTF-8 (accessed 7.26.21).
27. United Nation, W.W., 2020. World Water Development Report | United Nations Educational, Scientific and Cultural Organization [WWW Document]. URL http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/ (accessed 4.26.21).
28. United Nation WW, W.W., 2017. Water and Agenda 2030 | United Nations Educational, Scientific and Cultural Organization [WWW Document]. URL http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/water-and-agenda-2030/ (accessed 4.26.21).
29. Wandiga, S.O., 2015. Critical Water Issues in Africa, in: Water Challenges and Solutions on a Global Scale, ACS Symposium Series. American Chemical Society, pp. 95–113. https://doi.org/10.1021/bk-2015-1206.ch006
30. WHO, 2020. JMP report 2020 - Google Scholar [WWW Document]. URL https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=JMP+report+2020&btnG= (accessed 7.26.21).
31. WHO, F., 2011. Guidelines for drinking-water quality. WHO Chron. 38, 104–108.
32. WHO, W.H., 2019. Progress on household drinking water, sanitation and hygiene 2000-2017: special focus on inequalities. World Health Organization.