

Bacterial Analysis of Selected Drinking Water Sources in Mbarara Municipality, Uganda

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How to cite this paper: Lukubye, B. and Andama, M. (2017) Bacterial Analysis of Selected Drinking Water Sources in Mbarara Municipality, Uganda. *Journal of Water Resource and Protection*, 9, 999-1013.

<https://doi.org/10.4236/jwarp.2017.98066>

Received: June 11, 2017

Accepted: July 8, 2017

Published: July 11, 2017

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Abstract

Surveillance of water quality to ensure microbiological safety is a vital public health function to prevent water borne diseases. Bacterial total coliform and *Escherichia coli* (*E. coli*) examination provide indication of the hygienic condition of drinking water and are major tools in the assessment of the health risk borne by pathogen in water. Unfortunately, there is insufficient information on the total coliform and *E. coli* amounts in the common drinking water sources in Mbarara Municipality, Uganda despite the eminent anthropogenic sources of contamination. Hence the study established the sanitary risk and quantified the total coliform and *E. coli* load in selected drinking water sources in Mbarara Municipality, Uganda. A total of 70 water samples were collected from selected boreholes, springs, wells and rainwater in Nyamitanga, Kamukuzi and Kakoba divisions of Mbarara municipality. The water samples were analysed for total coliform and *E. coli* abundance using the American Public Health Association (APHA) standard method. The total coliform and *Escherichia coli* counts were compared with the World Health Organization (WHO) drinking water standard guidelines. The findings indicate that all the studied groundwater sources (boreholes, springs and wells) in Mbarara Municipality were not compliant to either both or one of the WHO total coliform (<10 CFU/100 ml) and *E. coli* (0 CFU/100 ml) criteria for drinking water hence they are unsuitable for drinking without treatment e.g. boiling etc. Only rainwater collected from Mbarara University of Science and Technology met the WHO total coliform and *E. coli* criteria for drinking water thus is suitable for drinking without any treatment. There is a strong linkage between bacterial (total coliforms and *E. coli*) water quality and water source sanitation, as well as the proximity of latrines, animal farms and landfills around the water sources. Mbarara municipal council should therefore ensure effective and regular operation and maintenance of the drinking water sources through the adoption and promotion of appropriate water safety plans.

Keywords

Drinking Water Sources, *Escherichia coli*, Mbarara Municipality, Total Coliforms

1. Introduction

Water is an essential element of life on planet Earth and about 75% of the earth's surface is covered by it [1] [2]. Water is indispensable for human health and well-being as it constitutes 60% of the human body and is also important for achieving sustainable development [1] [3]. However, of the available water, only 1% is drinkable [2] and hence much of the world's population lacks access to sufficient and safe water supplies [4]. As a result, most of people especially in the developing countries including Uganda get water from the unsafe water sources. Unfortunately unsafe water is an effective carrier of pathogens (bacteria, viruses, protozoans and some helminthes), capable of transmitting waterborne diseases to a large number of the population with devastating effects [5] [6]. These diseases result from the ingestion of water contaminated with the microbial pathogens from human or animal waste [3].

Waterborne diseases and death continue to be a worldwide burden in both developed and developing countries, the heaviest being diarrhoeal diseases. In Uganda, waterborne diseases have been found to be among the major public health problems [3]. A number of them such as diarrhoeal illness, cholera and typhoid etc. are known to cause health effects [5]. An estimated 30,000 persons die from diarrheal disease every year in Uganda and an annual average of 3000 cases of cholera are reported [7] [8].

The prevalence of waterborne diseases in Uganda is also attributed to poor hygiene and environmental sanitation including inadequate supply of safe water [9]. Only 33% of the urban population in Uganda had access to adequate sanitation in 2012, a 1% rise since 1990 while 2% still practiced open defecation [10]. Furthermore, [8] reported that a population of 13.8 million Ugandans use unsanitary or shared latrines while 3.2 million have no latrine at all and defecate in the open. [11] indicated that pit latrine coverage in Mbarara is at 74 percent. Yet the majority of the rural populations in Uganda get their water supplies from unprotected water, underground water, streams, spring wells, ponds and lakes [12].

In Mbarara district, most rural people get water mainly from borehole (95%), protected spring (98%), rainwater (96%) and less from tap water (19%) while only 47.5% of the total population in Mbarara Municipality can afford piped water. The remaining 52.5% of the population in the municipality use unprotected groundwater water sources like boreholes, springs, wells and rainwater etc to access drinking water [11] [13]. Generally, safe water coverage in Mbarara district was estimated at 64.8% with hygiene and sanitation remaining very big problems. As such dirty water and water borne diseases have taken a heavy toll

on the people of Mbarara [11].

The Water borne diseases could be prevented by adopting water safety plans which include locating latrines and other point sources of potential faecal contamination sufficiently far (beyond 30 metres) from groundwater sources used for drinking purposes to ensure that the risk of pathogen survival is very low. Demarcating protection zones clearly and restricting anthropogenic activities (e.g., dumping of toxic waste, the discharge of undesirable effluents and the use of agricultural fertilizers and pesticides) that may affect water quality [14]. Unfortunately most of the people in Mbarara district and Uganda at large don't adhere to some of these water safety plans [15].

Bacterial total coliform and *Escherichia coli* (*E. coli*) examination provide indication of the hygienic condition of drinking water and are major tools in the assessment of the health risk borne by pathogen in water. Unfortunately, there is insufficient information on the total coliform and *E. coli* amounts in the common drinking water sources in Mbarara Municipality, Uganda despite the eminent sources of contamination. Hence the study established the sanitary risk and quantified the total coliform and *E. coli* load in selected drinking water sources in Mbarara Municipality, Uganda.

2. Materials and Methods

2.1. Location of Study Area

Mbarara municipality is densely populated with population of 194,973 people [16] and growth rate of 2.9%. The municipality is divided into Nyamitanga, Kamukuzi and Kakoba divisions. There is a great pressure exerted on drinking water sources (boreholes, springs, wells) especially those found in densely populated slum areas of Kakoba and Kiswahili [13]. Hence seven drinking water sources were purposively selected from the three divisions (Nyamitanga, Kamukuzi and Kakoba) of Mbarara municipality which included; 1 spring *i.e.* Spring (Kise) (0.6004°S, 30.6682°E) and 1 well *i.e.* Well (Kise) (0.6030°S, 30.6655°E) in Kisenyi village (Kakoba), 1 spring *i.e.* Spring (Kisw) (0.6109°S, 30.6631°E) in Kiswahili village (Kakoba). Two boreholes in Nyamitanga village at Nyamitanga Secondary School *i.e.* Borehole (Nyam. S.S) (0.6257°S, 30.6501°E) and Shuhaddea Secondary School *i.e.* Borehole (Shud. S.S) (0.6262°S, 30.6532°E) (Nyamitanga). One shallow well *i.e.* S. well (Nyam) (0.6254°S, 30.6607°E) in Kitebero village (Nyamitanga) and rainwater *i.e.* Rain (MUST) (0.6164°S, 30.6561°E) at Mbarara University of Science and Technology (MUST). The map of the study area and the selected water sources is shown in **Figure 1**. The details of the study area, Mbarara Municipality including the selected water sources are fully described in [17].

2.2. Sanitary Inspection of the Water Sources

A cross-sectional sanitary assessment was carried out in each of the selected drinking water sources to identify the risks for contamination with faecal bacterial organisms similar to what [18] did for springs in Katwe and Kisenyi pari-

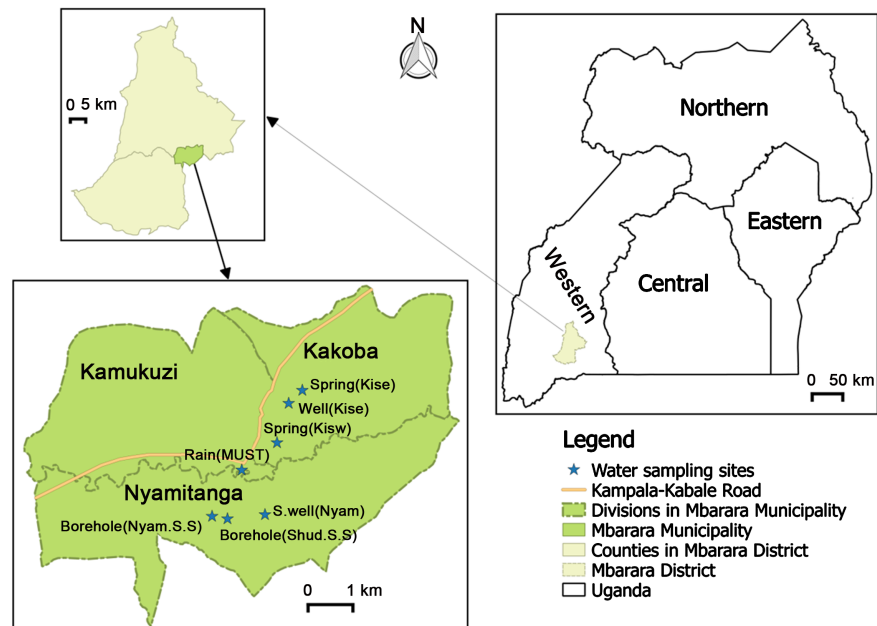


Figure 1. Map of Mbarara municipality showing the location of drinking water sources. Adopted from [17].

shes, Kampala city, Uganda. The assessment adapted the standardised procedure which involved completing a ten-point standardised data form with a set of questions having a yes and no options for designated risks [18] [19]. For each “yes” answer (risk observed), a score of one point was awarded while zero point was given for each “no” answer (no risk observed). A final risk score was obtained by summing all “yes” scores thus giving the overall assessment of the risk profile of each water source. The total sanitary risk score was converted to a percentage. The aggregate risk score was graded as very high (81% to 100%), high (51% to 80%), medium (31% to 50%), low (1% to 30%) and nil (0%).

2.3. Collection of Water Samples

Water samples were collected from the selected water sources from January, 2016 to May, 2016. All water samples were collected and preserved following the Standard methods for Examination of water and wastewater [20] and the [21] guidelines for drinking water sampling. A total of 70 water samples were collected from the seven drinking water sources (2 boreholes, 2 springs, 2 wells (shallow well, deep well) and rainwater) with ten samples from each water source. The ten rainwater samples were collected directly from a rainfall after an hour of downpour in an open space to be used as a control. The water samples were collected in 300 ml sterile glass bottles and immediately placed in an ice box containing ice blocks so as to maintain a low temperature of about 4°C so as to prevent multiplication of the microorganisms. The samples were then transported to the microbiology laboratory for bacteriological analysis. The bacteriological parameters analysed included total coliforms and *E. coli*. The physico-chemical parameters of the same drinking water sources in Mbarara Municipality are found in [17].

2.4. Water Sample Preservation

Water samples that were not immediately analysed for bacteriological parameters (total coliforms, *Escherichia coli*), were preserved in a refrigerator at temperatures below 4°C to slow down the chemical reactions in the water [22] until they were analysed in the microbiology laboratory, Mbarara University of Science and Technology.

2.5. Determination of Bacteriological Parameters (Total Coliforms and *E. coli*)

The Most Probable Number (MPN) method [20] was used to determine the abundance of total coliforms and *E. coli* in the water samples.

2.5.1. Enumeration of Total Coliforms

Five tubes containing double strength MacConkey broth (10 ml) were each inoculated with a sub water sample (10 ml) from the same water sample. Using a sterile pipette, five tubes containing single strength MacConkey broth (5 ml) were each inoculated with a sub water sample (5 ml) from the same water sample. To other five tubes containing single strength MacConkey broth (5 ml), a sub water sample (1 ml) was inoculated into each tube using a sterile pipette. The tubes were closed and shook to distribute the sample uniformly throughout the medium and to ensure that the Durham tube inside had no air. The tubes were then incubated at 35°C for 24 hours. The above procedure was done to each of the water samples collected. After 24 hours the incubated tubes were examined for gas production and lactose fermentation. The tubes that showed production of gas and acid were isolated, recorded and considered positive for total coliforms. The MPN of total coliform was read off from the Standard MPN table.

2.5.2. Enumeration of *E. coli*

From each of the positive tubes for total coliforms, a sample (1 ml) was removed and inoculated into MacConkey broth single strength (5 ml) and incubated at 44.5°C for 48 hours. The tubes were examined for gas production and acid production. The positive tubes were isolated and were taken as positive for faecal coliforms. Using a sterile inoculating loop, cultures in the tubes positive for faecal coliforms were inoculated on MacConkey Agar and sub cultured at 37°C for 24 hours. The sub cultures were examined for the growth of *E. coli* colonies. The positive colonies were inoculated using a sterile loop into different tubes containing tryptone water and incubated at 37°C for 24 hours. To each tube of tryptone water Kovac's reagent (0.1 mL) were added and mixed gently. The presence of Indole was indicated by a red colour in the Kovacs reagent, forming a film over the aqueous phase of the medium. Presence of Indole, growth, and gas production showed the presence of *E. coli* which was later confirmed using the IMViC reactions.

The most probable number of *E. coli* in each samples was determined by recording down the tubes positive for *E. coli* in a sample with respect to the dif-

ferent amounts of the sub samples that were inoculated for total coliforms (10, 5 and 1 ml) and the MPN of *E. coli* was read off from the Standard MPN table.

2.6. Data Analysis

The descriptive statistics (range, mean, standard deviation, coefficient of variation) of the MPN total coliform and *E. coli* counts of the water samples were tabulated. The total coliform and *E. coli* counts in the water sources were compared with the WHO drinking water standards. Mean differences of the total coliform and *E. coli* counts between water sources were compared using one-way ANOVA (F) test. The relationship between bacterial counts with sanitary risk score, proximity of latrines and landfills and physico-chemical parameters [17] were established using Pearson's correlation coefficient (*r*). The inferential tests were performed at 5% level of significance. The data presentations and analyses were done by using Microsoft Excel 2007 and SPSS 20.0 statistical packages.

3. Results and Discussion

3.1. Sanitary Risk Assessment of the Drinking Water Sources

Sanitary inspection is a vital tool in assessing risks of the bacterial contamination of water sources including spring water [18] [19]. It is beneficial in identifying causes of contamination, risk of future contamination and overall assessment of operation and maintenance of water supplies [14] [18] [19]. The sanitary risk assessment of the selected groundwater sources (boreholes, springs, wells) in the study areas for bacterial contamination is shown in **Table 1**.

All the six groundwater sources studied faced some risk of contamination with bacterial faecal organisms. The qualitative aggregate risk scores ranged from medium to high. Three of the water sources had a medium risk score (31% - 50%) and three had a high risk score (51% - 80%) as shown in **Table 1**. There

Table 1. Risk assessment scores of selected groundwater sources in Mbarara Municipality, Uganda.

Water source	Risk observed	Percent risk score	Qualitative risk profile
Borehole (Nyam. S. S)	3, 5, 6, 9, 10	50	Medium
Borehole (Shud. S. S)	3, 4, 5, 6, 9, 10	60	High
Spring (Kisw)	3, 5, 6, 7, 10	50	Medium
Spring (Kise)	3, 5, 7, 9, 10	50	Medium
Well (Kise)	3, 5, 6, 7, 9, 10	60	High
S. well (Nyam)	3, 4, 5, 6, 7, 9, 10	70	High

Nyam. S. S: Nyamitanga Secondary School; Shud. S. S: Shuhaddea Secondary School; Kisw: Kiswahili; Kise: Kisenyi; S. well: Shallow well; Nyam: Nyamitanga. Key to risks observed: 1 = Water source unprotected; 2 = Masonry protecting water source faulty; 3 = Backfill area eroded; 4 = Spilt water floods collection area; 5 = Perimeter fence absent; 6 = Animals have access within radius 10 m of water source; 7 = Pit-latrines uphill and/or within 30 m of water source; 8 = Surface water collects upstream of water source; 9 = Diversion ditch above water source absent/non-functional; 10 = Other pollution sources uphill of water source e.g., solid waste dumps, faeces, stagnant water, and drainage channels.

was no water source with a very high (81% to 100%) or no (0%) risk score. The common risks identified were access by animals within a radius 10 m of water source, presence of pit latrines within a radius of 30 metres from the water source, eroded backfill area, existence of pollution sources e.g. as solid wastes, lack of protective measures like fencing of the water source, and having diversion ditches. The risk assessment was not done for direct rainfall water which is not a groundwater source and thus it was assumed to have no eminent bacterial contamination source hence used as a control.

Sanitary risk assessment of the drinking water sources showed that shallow well at Nyamitanga and well in Kisenyi both had high bacterial contamination risk while springs at Kiswahili and Kisenyi had medium contamination risk. [15] reported that shallow wells in Budaka District, Uganda were very vulnerable to pollution. They further found out that shallow well sanitation was significant to *E. coli* pollution of the water sources in Budaka District, Uganda. Both springs in Kiswahili and Kisenyi, Mbarara Municipality posed medium risk of bacterial contamination similar to the contamination risk for Kasule, Maama Betty and Bwanika I springs in Katwe and Kisenyi parishes, Kampala city, Uganda reported by [18].

3.2. Total Coliforms and *Escherichia coli* in the Selected Drinking Water Sources

Total coliforms include bacteria which are found in the soil, water and animal or human wastes [23]. The coliform bacterium which is the primary bacterial indicator for faecal pollution in water [24] [25] was present in all the selected drinking water sources. The ranges of the MPN of total coliform and *E. coli* per 100 ml in the water samples are shown in **Table 2**. There were wide variations in the mean counts of the total coliforms and *E. coli* ($CV > 10\%$) within samples of the water sources (**Table 2**).

Mean total coliforms and *E. coli* counts significantly ($p < 0.05$) varied among the selected water sources.

The highest mean total coliform and *E. coli* counts were recorded in the shallow well at Nyamitanga *i.e.* S. well (Nyam.) followed by the well in Kisenyi *i.e.*, Well (Kise). The spring in Kisenyi *i.e.* Spring (Kise) had the third highest *E. coli* counts while borehole in Nyamitanga secondary school *i.e.* Borehole (Nyam. S. S) recorded the third highest mean total coliform counts as detailed in **Table 2**.

Boreholes in Nyamitanga and Shuhaddea secondary schools, well in Kisenyi and shallow well in Nyamitanga had mean total coliform bacterial count beyond the World Health Organization [17] [26] and Canadian [27] [28] recommended guideline level for drinking water of 10 total coliforms per 100 ml. The two studied spring waters in Kiswahili and Kisenyi all recorded total coliforms. [17] reported 90% detection of the same microbial groups from protected springs in Katwe and Kisenyi parishes, Kampala city, Uganda. Microbial studies of spring water in Natete, Kampala found faecal contamination of the spring water [29], a phenomenon similar to spring (Kise) and spring (Kisw) in the present study.

Table 2. Bacterial counts of selected drinking water sources and the proximity of the water sources to some anthropogenic activities in Mbarara Municipality.

Water source (n = 10)		Borehole, Nyam. S. S	Borehole, Shud. S. S	Spring (Kisw)	Spring (Kise)	Well (Kise)	S. well (Nyam)	Rain, MUST	p-value (F test)	WHO (1993) standard
Total coliforms (CFU/100 ml)	Range	109 - 177	25 - 63	0 - 12	0 - 20	130 - 920	240 - 1600	0 - 5		
	Mean	145.00	44.60	4.00	9.50	320.20	807.40	1.30	0.00	10
	SD	23.71	11.29	4.32	6.74	239.56	579.23	1.64		
	% CV	16.35	25.31	108.00	70.95	74.82	71.74	126.15		
<i>E. coli</i> (CFU/100 ml)	Range	0 - 0	0 - 6	0 - 7	0 - 12	2 - 25	11 - 43	0 - 0		
	Mean	0.00	2.40	1.20	3.40	11.60	20.90	0.00	0.00	0
	SD	0.00	2.41	2.57	4.20	6.28	10.62	0.00		
Proximity (m)*	% CV	0.00	100.42	214.20	123.53	54.14	50.81	0.00		
	Animal farms	-	23	-	-	2	-			
	Latrine	37	53	17	4	20	2			
	Landfills	12	33	58	11	12	7			
Municipal waste	-	-	4	-	26	-				

SD: standard deviation; % CV: percent of coefficient of variation; Nyam. S. S: Nyamitanga Secondary School; Shud. S. S: Shuhaddea Secondary School; Kisw: Kiswahili; Kise: Kisenyi; Nyam: Nyamitanga; S. well: Shallow well; MUST: Mbarara University of Science and Technology; - : represents no anthropogenic activity; * [17].

However, total coliform in the springs in Kiswahili and Kisenyi and the rainwater in Mbarara University of Science and Technology were below 10 CFU/100 ml. [15] found out that the water quality compliance to Uganda National Bureau of Standards (UNBS) guidelines for biological quality as 97%, 73% and 63% for boreholes, protected springs and shallow wells respectively signifying that shallow wells are most contaminated followed by springs and boreholes. But the studied boreholes had more total coliform than spring waters contrary to the water quality compliance reported by [15]. However, the total coliform content in all the selected water sources from Mbarara Municipality were within the Directorate of water resource management Uganda (DWRMU) guideline for untreated supplies of water in the rural of <50 cfu/100 ml [3].

Borehole in Shuhaddea Secondary School springs in Kiswahili and Kisenyi, Shallow well in Nyamitanga and well in Kisenyi had *E. coli* beyond the World Health Organization [26] guideline value of 0 while the borehole in Nyamitanga secondary school and the rainwater at MUST did not have *E. coli*. According to WHO guidelines, *E. coli* should not be detectable in any water intended for drinking [14] [30] i.e. it should be 0 CFU/100ml. [15] also found higher *E. coli* amounts in shallow wells in Budaka District, Uganda than the WHO water quality guideline (0 *E. coli*/1000 ml).

Overall mean *E. coli* was the highest in Shallow well in Nyamitanga followed by well in Kisenyi (Table 2), spring waters (2.3 CFU/100 ml) and boreholes (1.2 CFU/100 ml). The trend of *E. coli* in these water sources is in agreement with the compliance of shallow wells, protected springs and boreholes to Uganda Na-

tional Bureau of Standards (UNBS) water quality guidelines of 63%, 73% and 97% respectively [15].

The variations of the total coliforms and *E. coli* counts among the selected water sources are related to the bacterial contamination risks posed to the various water sources. Pearson correlation coefficient ($n = 6$) showed significant ($p < 0.05$) strong positive correlations between the sanitary risk scores for the groundwater sources and the mean total coliform and *E. coli* counts ($r = 0.862$, and $r = 0.888$, respectively). This significant strong positive correlation proved the reliability of the use of sanitary scores for preliminary risk assessment of contamination of water sources with faecal bacterial organisms. [18] also obtained positive strong correlation of total coliform counts with the sanitary score for springs in Katwe and Kisenyi parishes, Kampala city, Uganda. An earlier study by [31] reported a related correlation in several developing countries.

The proximity of the water sources to human and animal faecal sources as well as landfills [17] also played a significant role in total coliform and *E. coli* contamination of the water sources (Table 2). Pearson's correlation coefficient ($n = 6$) showed moderate negative correlation between mean total coliforms and *E. coli* counts with proximity of latrines ($r = -0.446$, and $r = -0.551$, respectively) and proximity of landfills ($r = -0.535$, and $r = -0.502$, respectively) though statistically insignificant ($p > 0.05$). The moderate negative correlation between mean total coliforms and *E. coli* counts with proximity of latrines and landfills showed the effect of the proximity of pit latrines and landfills to bacterial contamination of the water sources. Thus the nearer the pit latrines and landfills are to the water sources, the higher the level of bacterial contamination and vice versa.

The location of a latrine uphill within 10 m showed the greatest positive association with contamination in Mbale, Uganda [32]. Moreover, the latrines in the present study were located 2 m and 4 m to the shallow well in Nyamitanga and spring in Kisenyi respectively hence contributing significantly to the bacterial contamination of the shallow well and spring. According to [15], latrine proximity to shallow wells was significant to *E. coli* pollution of the water sources in Budaka District, Uganda. Furthermore, proximity of some boreholes to solid waste dumpsites and animal droppings being littered around them are also potential contaminants of the quality of groundwater [33] [34]. Hence the location of the well in Kisenyi 2 m to animal farms and position of S. well (Nyam), Spring (Kise), Well (Kise) and Borehole (Nyam. S. S) at 7, 11, 12 and 12 m respectively to landfills [17] contributed a lot to the bacterial contamination of the water sources in the present study. Therefore the presence of coliform bacteria in water sources close to the latrines, animal farms and landfills signifies that the source waters are polluted with coliform bacteria from faecal material of humans or other animals originating from the above mentioned sources rather than from soil. Pit latrines are sources of bacteria to groundwater and the presence of coliform bacteria in water is a sign that the source water is polluted with coliform bacteria from faecal material of humans or other animals [1] [35] [36]. [18] also

attributed the microbial (bacterial) load into springs in Katwe and Kisenyi parishes, Kampala city, Uganda to sub-surface leaching from pit latrines.

Furthermore, sampling of the water in the present study was done between January to May 2016 which coincided with the rain season of Mbarara district and this could have accounted for the high total coliform and *E. coli* counts in some of the water sources. According to [16], Mbarara records bi-annual rainfall pattern, one of which is in the months of February-May. The high total coliform counts could probably have been as a result of sub-surface infiltration during heavy rainfall. In Uganda, subsurface infiltration has been demonstrated to coincide with heavy rainfall [37] [38]. Different studies have associated rainfall events to high counts of *E. coli* [29] [39]. According to [3] heavy rainfall causes contamination of water sources. Floods from rainfall transport faecal matter from the ground or sewers and contaminate wells, boreholes and surface waters [40]. [18] also attributed the microbial (bacterial) load into springs in Katwe and Kisenyi parishes, Kampala city, Uganda to direct washing of faecal material. Unfortunately some of the urban population of Mbarara use uncovered pit latrine (13%) and bush (3%) as toilet facilities [11] and this could have exacerbated the bacterial contamination during the heavy rainfall periods.

The relatively high mean total coliforms and *E. coli* in well at Kisenyi could also be attributed to the poor sanitation in Kisenyi due to its slum nature [13] and to the high population density. Overcrowding in slums reduces the adequate distance between wells and pit latrines causing contamination of the wells. The findings of a study by [41] in Langas slum, Kenya with 40% of the pit latrines situated in a distance less than 15m from wells showed that fecal matter heavily contaminated the water sources especially the shallow wells. However the well in Kisenyi (a slum area) was situated 20 m from the latrine but still less than the 30 m distance recommended by world health organization [15] hence the high bacterial contamination levels. In addition, the high human densities in the slum areas are associated with microbial contamination of water as a result of human faeces and animal waste disposal [39] [42].

E. coli presence in springs in Kiswahili and Kisenyi and the borehole in Shuhaddea secondary school agrees with the findings of [43] that showed presence of *E. coli* in springs and boreholes in Mbarara Municipality. However the present study registered an increase in *E. coli* in springs (0 - 12 CFU/100 ml) and boreholes (0 - 6 CFU/100 ml) compared to the previous findings of [44] which recorded *E. coli* in springs and boreholes ranging between 0 and 3 counts per 100 ml of water.

Rainwater from Mbarara University of Science and Technology which was collected from direct rainfall after an hour of downpour recorded no *E. coli* counts. This could mainly be attributed to improved hygiene in the university environment and hence no *E. coli* ended into surrounding atmosphere of the university with either soil or particulate matter. Additionally, the toilet facilities at the university are improved with no spills of faecal materials into the environment. Furthermore there were also no animal farms in the university com-

pound. However the minute abundance of total coliforms in the rainwater could have emanated from windblown soil particles into the atmosphere. According to [23] total coliforms include bacteria which are also found in the soil but not only in water, animal or human wastes.

3.3. Effect of the Physico-Chemical Parameters on the Abundance of *E. coli* in the Selected Potable Water Sources

The correlation analysis ($n = 70$) indicated that total coliform and *E. coli* were significantly ($p < 0.05$) positively correlated with pH ($r = 0.483$, and $r = 0.525$, respectively), and negatively correlated with dissolved oxygen (DO) ($r = -0.267$, and $r = -0.247$, respectively). There was insignificant ($p > 0.05$) correlation of total coliform and *E. coli* with other physico-chemical parameters (temperature, biological oxygen demand, total hardness, electrical conductivity and total dissolved solids). Early studies have reported *E. coli* growth and replication to be influenced by physico-chemical parameters like pH and many others [44].

The significant positive correlation between *E. coli* abundance and pH is most likely due to the fact that *E. coli* survives well in environments with pH ranging between 5.5 and 8.5. Within this range increase in pH causes an increase in growth and replication of *E. coli* hence the positive correlation. [45] reported that *E. coli* counts increase with increase in pH and decrease when pH is beyond 9. This supports the positive correlation since the pH of the water sources was generally below 9. [46] reported that decrease in pH beyond 5 causes a decrease in the viability of the *E. coli* populations. On the other hand, the significant negative correlation between *E. coli* and dissolved oxygen could be attributed to *E. coli* being a facultative anaerobe which enables it to survive and replicate even in oxygen depleted environments hence the increase in abundance of *E. coli* as oxygen decreases [47]. This concurs with [48] who found out that some strains of *E. coli* prefer surviving better under anaerobic conditions than aerobic conditions.

4. Conclusions

The sanitary risk assessment score is a reliable tool for predicting the possible levels of bacterial contamination of drinking water sources in Mbarara municipality.

The results indicated that there is a strong linkage between microbiological (total coliforms and *E. coli*) water quality and water source sanitation, as well as the proximity of latrines, animal farms and landfills around the water sources.

All the studied groundwater sources (boreholes, springs and wells) in Mbarara Municipality were not compliant to either both or one of the WHO total coliform and *E. coli* criteria for drinking water hence they are unsuitable for drinking without treatment e.g. boiling etc.

Only rainwater collected from Mbarara University of Science and Technology met the WHO total coliform and *E. coli* criteria for drinking water thus is suitable for drinking without any treatment.

Mbarara municipal council should therefore ensure that pit latrines and animal farms are not located within WHO recommended minimum proximity of 30 m to the groundwater sources (boreholes, springs and wells).

Mbarara municipal council should also ensure effective and regular operation and maintenance of the drinking water sources through the adoption and promotion of appropriate Water Safety Plans.

Acknowledgements

The authors wish to thank the entire Department of Biology of Mbarara University of Science and Technology for the support and guidance they offered during the entire research and preparation of the paper.

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