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Physico-Chemical Quality of Selected Drinking Water Sources in Mbarara Municipality, Uganda

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Abstract

The study assessed the physico-chemical quality of selected drinking water sources (springs, boreholes, shallow wells and rainfall) in Mbarara municipality with respect to World Health Organization (WHO) drinking water guidelines and other guidelines in light of the increased anthropogenic activities in the municipality. A total of 70 water samples were collected from purposively selected boreholes, springs, wells and rainwater in Nyamitanga, Kamukuzi and Kakoba divisions of Mbarara municipality with various human activities. The samples were analysed for physico-chemical parameters: Temperature, pH, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS), Electrical Conductivity (EC) and Total hardness using American Public Health Association (APHA) standard methods. The mean temperature and pH ranged between 18.07˚C - 23.45˚C and 5.74 - 7.54, respectively. The mean DO values were found to be between 4.84 and 12.86 mg/l; whereas mean BOD was within the range of 1.83 - 7.71 mg/l. The mean TDS and EC of the water samples ranged, between 33.40 - 569.20 mg/l and 29.30 - 1139.90 µS/cm respectively. Furthermore, the lowest and highest mean total hardness were 70.00 and 264.00 mg/l, respectively. The recorded mean water temperatures for each of the water sources were above the WHO threshold temperature (15˚C) which makes drinking water palatable. Boreholes in Nyamitanga and Shuhaddea Secondary Schools, spring in Kiswahili, well in Kisenyi and rainwater in Mbarara University of Science and Technology (MUST) had mean pH below the WHO minimum guideline value (6.5) hence acidic. Borehole in Nyamitanga secondary school, spring in Kisenyi, shallow well in Nyamitanga and the rainwater in MUST had mean DO values below the WHO range (10 - 12 mg/l). Borehole in Shuhaddea Secondary School and the well in Kisenyi had average BOD values above the range of European Union guideline values (3 - 6 mg/l). TDS and EC of all the water sources were below the WHO maximum guideline limits of 1000 mg/l and 1500 µs/cm respectively. Total hardness was also below the WHO harmless limit of 1000 mg/l. However rainwater in MUST was moderately soft while the other drinking water sources exhibited moderate to full total hardness. The physico-chemical parameters of some of the selected water sources in Mbarara municipality have been compromised mainly by the increased human activities especially croplands, latrines, landfills, transportation, animal and municipal wastes at the vicinity of the water sources. Mbarara municipal council should therefore ensure proper sanitation and water safety plans for these drinking water sources to avoid further contamination from the human activities.

Keywords

Drinking Water Sources, Mbarara Municipality, Physico-Chemical Parameters

1. Introduction

Water is a natural resource which forms an essential component of life [1]. However, the suitability of water for various uses depends on the biological, physico-chemical and radiological properties of water [2]. Over 1 billion people lack access to safe drinking water worldwide [3]. The situation is worse in developing countries like Uganda where many people especially the poor have opted to using the underground drinking water sources like boreholes, springs, shallow wells as a source of drinking water and for other domestic use [4]. Particularly in Mbarara municipality, National water and sewerage cooperation supplies water to only 47.5% of the total population which can afford the piped water with the rest of the 52.5% of the population using the unprotected drinking water sources (boreholes, springs, wells) and rainwater to access drinking water [5]. However these natural drinking water sources are at a high risk of contamination from many sources of contaminants like pit latrines, agricultural pesticides and fertilizers, domestic and industrial wastes, leakages from landfills [6]. Unfortunately the public due to the less sensitization and limited knowledge about the quality of these water sources in Mbarara municipality has continued to use them for drinking and cooking purposes. The study therefore aimed at ascertaining the quality of selected drinking water sources (boreholes, springs, wells, rainwater) in Nyamitanga, Kamukuzi and Kakoba divisions of Mbarara municipality with various human activities.

2. Materials and Methods

2.1. Location of Study Area

The study was conducted in Mbarara municipality located in Mbarara District, South Western Uganda, 290 km from Kampala (capital city of Uganda) on Kampala-Kabale road at longitude 30.6582˚ and latitude 0.6132˚ [7] [8]. The municipality with a total area of 51.47 km^2 is situated on hilly areas (1432 m above sea level) separated by short, small and shallow valleys and is underlain mainly by precambium parent rock system consisting of gneisses, granitoid rocks, phyllites, shales and mud stones [9].

The fairly densely populated Mbarara municipality of about 194,973 people [10] and growth rate of 2.9% is divided into Nyamitanga, Kamukuzi and Kakoba divisions. With limited access to piped water sources, the dense population greatly exerts pressure on drinking water sources (boreholes, springs, wells) especially those found in densely populated slum areas of Kakoba and Kiswahili [5]. Hence seven drinking water sources were purposively selected from the three divisions in Mbarara municipality viz. 1 spring *i.e.* Spring (Kise) at geographical coordinates 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), 2 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) located in Kamukuzi division as shown in Figure 1. The study was conducted from January, 2016 to May, 2016.

2.2. Survey Data Collection

A 200 m radius was measured from the water sampling point using a tape measure and selected anthropogenic activities with great influence on water quality within a 200 m radius circumference along established line transects were ob-

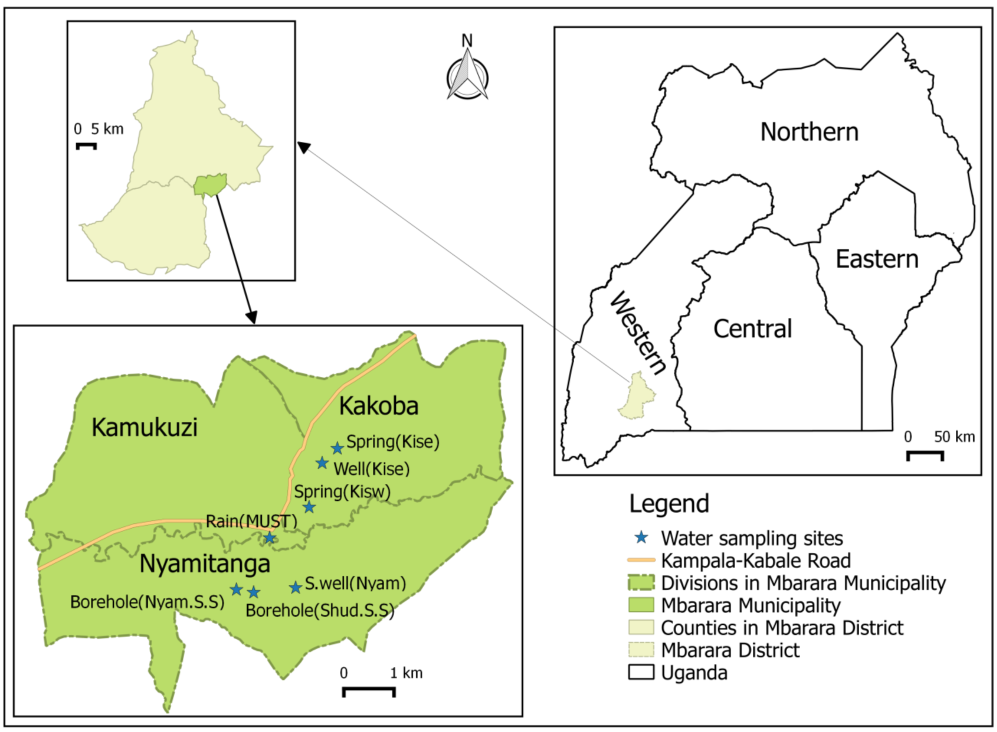

Figure 1. Map of Mbarara municipality showing the location of drinking water sources.

served and noted. A 200 m radius from the sampling points of drinking water sources was chosen because it is the maximum distance for protection of a lake [11] which is a static water body just like the drinking water sources. The proximity, distance (m) from the water sampling point to the first identified anthropogenic activity along the line transects were measured as well as the area (m^2) covered by each activity. The total coverage (m^2) of all the identified activities at each of the sampling sites was obtained by summing up the individual areas (m^2) of each activity.

2.3. Collection of Water Samples

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 plastic bottles which were immediately analysed for most of the physico-chemical parameters.

2.4. Analysis of Physico-Chemical Parameters in the Water Samples

The water samples were analysed for physico-chemical parameters; Temperature, pH, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS), Electrical Conductivity (EC) and Total hardness using standard methods [12]. A multi-purpose digital meter was used to determine the TDS, pH, temperature and EC of the water samples. Similarly the DO meter was used to determine the Dissolved Oxygen concentration in the water samples. Total hardness strips were used to determine the total hardness of the water. The water samples were immediately analysed for pH, Temperature, DO, EC, TDS, Total hardness after collection but not BOD.

For BOD, four 300 ml glass stoppered BOD bottles were used to determine the Biological Oxygen Demand in the water samples. To two of the bottles, water sample (10 ml) was added and filled to the mark with dilution water while the other two were filled to the mark only with dilution water to act as blank solutions. All bottles were immediately stoppered and labelled. One bottle with blank solution and another with the water sample were placed in the incubator and kept for 5 days at 21˚C. The other two bottles (one with a blank solution and the other with the water sample solution) were immediately analysed for dissolved oxygen (DO) and their values noted down as B_0 and D_0 respectively. After 5 days the blank solution and water sample solution were removed from the incubator and analysed for dissolved oxygen (DO) with their DO values noted as B_5 and D_5 respectively.

The BOD was then calculated using the formular, $BOD = ((D_O - B_O) - (D_5 - B_5))/P$ where B_0 is dissolved oxygen for blank solution on first day; D_0 is dissolved oxygen for sample solution on first day; D_5 is dissolved oxygen for sample solution on fifth day; B_5 is dissolved oxygen for blank solution on fifth day; P is decimal volumetric fraction sample used..

2.5. Data Analysis

The results of the proximity (m) and coverage (m^2) of the anthropogenic activities as well as the minimum, maximum, standard deviation, mean, standard error of the mean and coefficient of variation values of the measured physico-chemical parameters were tabulated. The physico-chemical parameters were compared with set standards, WHO and European Union guidelines for drinking water. Mean differences of the parameters between water sources were determined using one-way ANOVA (F) test and relationships between the physico-chemical parameters established using Pearson product-moment correlation coefficient (r) at 5% level of significance. The data presentations and analysis were done by using Microsoft Excel 2007 and SPSS 20.0 Statistical packages.

3. Results and Discussion

This section presents the findings of the study and discussion beginning with the anthropogenic activities in the vicinity of the drinking water sources followed by the physico-chemical quality of the water sources.

3.1. Anthropogenic Activities in the Vicinity of the Drinking Water Sources in Mbarara Municipality

The identified anthropogenic activities within the vicinity of the drinking water sources with great impact on the quality of the water sources are presented in Table 1. The nearest croplands covering 3096 m^2 area were located 1 m from the

Table 1. Proximity (m) and coverage (m^2) of the selected anthropogenic activities in the vicinity of the drinking water sources.

Activities		Borehole (Nyam. S.S)	Borehole (Shud. S.S.)	Spring (Kisw)	Spring (Kise)	Well (Kise)	S. well (Nyam)
Croplands	Proximity	24	35	12	-	-	1
	Coverage	2589	3970	207	-	-	3096
Animal farms	Proximity	-	23	-	-	2	-
	Coverage	-	8	-	-	27	-
Latrine	Proximity	37	53	17	4	20	2
	Coverage	148	185	370	370	222	256
Settlements	Proximity	16	54	17	8	16	3
	Coverage	-	-	-	-	-	-
Land fills	Proximity	12	33	58	11	12	7
	Coverage	149	67	387	442	211	158
Brick laying	Proximity	-	-	-	-	-	10
	Coverage	-	-	-	-	-	9
Washing sites	Proximity	-	-	-	-	10	-
	Coverage	-	-	-	-	21	-
Municipal waste	Proximity	-	-	4	-	26	-
	Total coverage	2886	4230	964	812	481	3519

Nyam. S.S: Nyamitanga Secondary School; Shud. S.S: Shuhaddea Secondary School; Kisw: Kiswahili; Kise: Kisenyi; Nyam: Nyamitanga; S. well: Shallow well; -: represents no anthropogenic activity.

shallow well in Nyamitanga while the furthest was situated 35 m from the borehole in Shuhaddea Secondary School though it had the highest coverage (3970 m^2) as shown in **Table 1**. Animal farms were only observed around the well in Kisenyi, a distance of 2 m and a coverage of 27 m^2 and borehole in Shuhaddea Secondary School at a distance of 23 m and covering 8 m^2 area. Latrines were found around all the drinking water sources with the closest located 2 m from the shallow well (Nyamitanga) followed by Spring (Kise) and the furthest situated 53 m from borehole (Shuhaddea Secondary School) greatly coinciding with the human settlements (**Table 1**). The closest landfills were also to the shallow well in Nyamitanga (7 m) with a coverage of 158 m^2 followed by Spring (Kisenyi) recording an overall highest coverage of 442 m^2. The furthest land fills were located 58 m from Spring (Kiswahili) with 387 m^2 area coverage. Brick laying and cloth washing sites were only observed around S. well (Nyam) and Well (Kise) respectively both at a proximity of 10 m from the water sources with each covering 9 m^2 and 21 m^2 in that order. Municipal waste drainage channels were found only around the spring in Kiswahili and well in Kisenyi at distances of 4 m and 26 m respectively.

The increased anthropogenic activities (croplands, animal farms, latrine, settlements, landfills, brick laying, washing sites and municipal waste) within the vicinity (200 m) of the different drinking water sources could be attributed to the increased population as a result of urbanisation. This is in line with [10] which reported that Mbarara municipality is fairly densely populated. Urbanisation is associated with activities such as settlements, landfills, education, infrastructure development, slum development, urban traffic of cars, and transport among others [13].

3.2. Physico-Chemical Quality of the Drinking Water Sources in Mbarara Municipality

The descriptive statistics of the physico-chemical parameters of the selected drinking water sources and the comparisons among the water sources are summarized in **Table 2**.

3.2.1. Temperature

There were significant temperature variations ($p < 0.05$) in the water sources with low variability within the samples (CV = 1.38% - 4.84%). The highest mean temperature was recorded in spring (Kisenyi) and lowest in rainwater (MUST). Temperature is among the physico-chemical parameters useful in evaluating the quality of drinking water as it influences the overall quality of water (physico-chemical and biological characteristics) including the rate of chemical reactions in the water body, decrease in the solubility of gases and improving the tastes and colours of water [14] [15]. The temperature range of boreholes in Nyamitanga and Shuhaddea secondary schools were within the temperature range (23˚C - 25.90˚C) of boreholes in Lira district, Uganda obtained by [16] while that of springs in Kiswahili (21.3˚C - 23.0˚C) and Kisenyi (22.6˚C - 24.9˚C) were close to the temperate range (23.6˚C - 26.4˚C) of Katwe and Kisenyi springs in Kampala

Table 2. Physico-chemical parameters in the drinking water sources in Mbarara Municipality.

Parameter (n = 10)	Water source	Min.	Max.	SD	Mean ± SE	CV (%)	p-value for F test	Guideline value
Temperature (°C)	Borehole (Nyam. S.S)	22.30	23.50	0.57	**22.98 ± 0.29**	2.50	0.00	15˚C*
	Borehole (Shud. S.S)	21.60	22.90	0.41	**22.34 ± 0.13**	1.84		
	Spring (Kisw)	21.30	23.00	0.52	**22.38 ± 0.16**	2.32		
	Spring (Kise)	22.60	24.90	0.72	**23.45 ± 0.23**	3.07		
	Well (Kise)	18.50	21.70	1.01	**20.79 ± 0.32**	4.84		
	Shallow well (Nyam)	21.70	22.60	0.31	**22.17 ± 0.10**	1.38		
	Rainwater	17.20	18.80	0.54	**18.07 ± 0.17**	2.98		
pH	Borehole (Nyam. S.S)	6.19	6.77	0.22	**6.37 ± 0.07**	3.42	0.00	6.5 - 9.5*
	Borehole (Shud. S.S)	5.50	6.53	0.29	**5.74 ± 0.09**	5.06		
	Spring (Kisw)	6.17	6.29	0.03	**6.21 ± 0.01**	0.56		
	Spring (Kise)	6.65	7.02	0.14	6.77 ± 0.04	2.08		
	Well (Kise)	4.49	6.70	0.64	**6.31 ± 0.20**	10.18		
	Shallow well (Nyam)	7.23	7.70	0.13	7.54 ± 0.04	1.71		
	Rainwater	5.80	6.70	0.32	**6.21 ± 0.10**	5.16		
Dissolved Oxygen (mg/L)	Borehole (Nyam. S.S)	5.30	8.60	1.08	**7.42 ± 0.34**	14.57	0.00	10 - 12 mg/l*
	Borehole (Shud. S.S)	5.10	14.20	2.83	10.41 ± 0.90	27.22		
	Spring (Kisw)	8.00	15.60	3.15	10.28 ± 10	30.61		
	Spring (Kise)	1.90	6.30	1.20	**4.84 ± 0.38**	24.76		
	Well (Kise)	9.00	18.10	3.01	12.86 ± 0.95	23.37		
	Shallow well (Nyam)	3.20	6.30	1.01	**5.07 ± 0.32**	19.86		
	Rainwater	9.30	10.00	0.22	**9.54 ± 0.07**	2.33		
BOD (mg/L)	Borehole (Nyam. S.S)	4.00	7.00	1.10	5.59 ± 0.35	19.60	0.00	3 - 6 mg/l***
	Borehole (Shud. S.S)	3.10	12.00	3.33	**7.71 ± 1.05**	43.19		
	Spring (Kisw)	4.00	9.10	1.69	5.98 ± 0.54	28.34		
	Spring (Kise)	0.50	3.10	0.86	2.16 ± 0.27	39.72		
	Well (Kise)	3.20	8.90	2.09	**6.72 ± 0.66**	31.10		
	Shallow well (Nyam)	1.80	5.40	1.10	4.14 ± 0.35	26.59		
	Rainwater	1.30	2.50	0.36	1.83 ± 0.11	19.79		
Total Dissolved Solids (mg/L)	Borehole (Nyam. S.S)	256.00	380.00	32.74	297.70 ± 10.35	11.00	0.00	1000 mg/l*
	Borehole (Shud. S.S)	272.00	348.00	22.51	298.40 ± 7.12	7.54		
	Spring (Kisw)	345.00	357.00	3.63	350.10 ± 1.15	1.04		
	Spring (Kise)	557.00	579.00	6.61	569.20 ± 2.09	1.16		
	Well (Kise)	347.00	370.00	6.03	357.90 ± 1.91	1.68		
	Shallow well (Nyam)	250.00	268.00	5.53	257.80 ± 1.75	2.15		
	Rainwater	12.00	55.00	13.28	33.40 ± 4.20	39.78		

Continued

Electrical Conductivity (μs/cm)	Borehole (Nyam. S.S)	565.00	615.00	14.81	585.60 ± 4.68	2.53	0.00	1500 μs/cm*
	Borehole (Shud. S.S)	580.00	630.00	15.49	601.40 ± 4.90	2.58		
	Spring (Kisw)	685.00	715.00	9.92	698.90 ± 3.14	1.42		
	Spring (Kise)	1113.00	1152.00	10.89	1139.90 ± 3.44	0.96		
	Well (Kise)	708.00	730.00	7.98	717.80 ± 2.52	1.11		
	Shallow well (Nyam)	409.00	553.00	37.17	508.70 ± 11.75	7.31		
	Rainwater	16.00	47.00	10.09	29.30 ± 3.19	34.43		
Total Hardness (mg/L)	Borehole (Nyam. S.S)	215.00	285.00	33.81	264.00 ± 10.69	12.81	0.00	1000 mg/l**
	Borehole (Shud. S.S)	140.00	215.00	38.73	185.00 ± 12.25	20.94		
	Spring (Kisw)	215.00	285.00	33.81	236.00 ± 10.69	14.33		
	Spring (Kise)	140.00	215.00	39.53	177.50 ± 12.50	22.27		
	Well (Kise)	140.00	215.00	31.62	200.00 ± 10.00	15.81		
	Shallow well (Nyam)	140.00	140.00	0.00	140.00 ± 0.00	0.00		
	Rainwater	70.00	70.00	0.00	70.00 ± 0.00	0.00		

Min.: Minimum; Max.: Maximum; SD: Standard deviation; SE: Standard error of the mean; CV: coefficient of variation; *: [18]; **: [22]; ***: European Union guideline as cited in [23].

City, Uganda [17]. However all the recorded water temperatures of the drinking water sources were above the WHO recommended value (<15˚C), the threshold temperature which makes drinking water palatable [18] [19]. The high temperatures could be associated with global warming. According to [20], the global land mean surface temperature increase is 0.85˚C over the period from 1850-2012 and Uganda's National Adaptation Program of Action, reported an average temperature increase of 0.28˚C per decade between 1960 and 2010 [21].

3.2.2. pH

Statistically significant mean pH variations were observed among the seven water sources ($p < 0.05$) although there were low differences within samples for six water sources (CV < 10%) apart from the well in Kisenyi (CV = 10.18%). The highest mean pH was recorded in shallow well (Nyam) and the least in Borehole (Shud. S.S). The pH of water is a useful parameter as most biological activities take place only within a narrow range. As a result, any pH variations beyond an acceptable limit could be fatal to a particular organism [24]. The mean pH values of spring (kise) and shallow well (nyam) drinking water sources were within the pH range for drinking water sources (6.5 - 9.5) by [18] while the rest of the water sources had mean pH values below the minimum guide line value (6.5). Apart from the shallow well in Nyamitanga with a pH value above 7 (slightly alkaline), the other water sources were a little acidic (pH below 7). The pH range of rainwater (5.80 - 6.70) was close to that given by [25] of freshly fallen rainwater (5.5 - 6.0). The slightly acidic nature of rainwater is mainly attributable to sulfuric and nitric acids formed from increased SO_2 and NO_x emissions into the atmosphere as a result of combustion of fossil fuels from transportation vehicles as mentioned by [26]. According to them, the SO_2 and NO_x (which are transferable from one place to another) react with water and oxygen in the atmosphere to produce sulfuric and nitric acids which form acid rain. Additionally, the rainwater sampling site, Mbarara University of Science and Technology borders the main Kampala-Kabale road (**Figure 1**) that experiences dense traffic flow of vehicles, a common global problem in the recent decades [26] which produce a lot of SO_2 and NO_x emissions.

Acid rains in Mbarara municipality resulting from SO_2 and NO_x emissions from urban traffic of cars [13] could have contributed to the slightly acidic pH of most of the drinking water sources in addition to other causes. One of the impacts of acid precipitation is acidification of surface and ground waters [26]. Furthermore, the ground water sources (boreholes, springs) including the well in Kisenyi in the present study also had slightly acidic pH values consistent with the findings of [27] that show that ground water is acidic. [28] and [17] associated the low pH values in most wells and springs to carbon dioxide saturation in the groundwater. The physico-chemical nature of the soil of the sampling sites partly dictates the final pH of the water samples as it was the case for the water samples collected and analyzed from Katanga, North of Kampala city [29] [30]. The mean pH of springs in Kiswahili (6.21) and Kisenyi (6.77) were close to the pH range (4.4 - 6.7) of Katwe and Kisenyi springs in Kampala City [17].

However, the slightly higher mean pH value (7.54) in the shallow well in Nyamitanga (a surface water source) than other drinking water sources can be attributed to organic material and sediment runoff from the closely located surrounding croplands (1 m from the water source) as opposed to croplands around other water sources. The deposition of sediments and organic materials into the water causes a change in the carbonate-bicarbonate equilibrium in surface water causing a relatively higher pH beyond neutral [31].

3.2.3. Dissolved Oxygen (DO)

DO concentrations showed significant variations ($p < 0.05$) among the water sources with highly variable values within samples for most of the water sources (CV > 10%) except for rainwater at MUST (CV = 2.33%). The highest and lowest mean DO concentrations were recorded in the well and spring at Kisenyi respectively. Dissolved oxygen (DO) is a very important parameter of water quality and an index of physical and biological process going on in water which favors solubility of oxygen [32]. The DO of some of the water sources *i.e.* Borehole (Shud. S.S) and spring (Kisw) lie within the acceptable standards for dissolved oxygen in fresh water (10 - 12 mg/l) by [18]. Only one drinking water source *i.e.* well (Kise) had mean DO value above WHO range. On the other hand, over 50% of the drinking water sources *i.e.* Borehole (Nyam. S.S), spring (Kise), Shallow well (Nyam) and rainwater had DO values below the WHO range. Similar results were obtained by [33] for drinking water in Bahir Dar, Ethiopia, where the mean DO concentration of the water samples were between 0.45 and 5.27 mg/l.

The low DO in the shallow well in Nyamitanga can be attributed to increased decomposition of organic material from the closely situated surrounding croplands (1 m from the water source) though on the contrary, BOD does not reflect it despite the significant overall positive correlation with DO ($r = 0.683$, $p < 0.05$, $n = 70$). The low DO values in spring (Kise.), Borehole (Nyam. S.S) and Shallow well (Nyam) can be associated with the slightly elevated temperature values in these water sources. This is further supported by the overall significant negative correlation of temperature with DO ($r = -0.454$, $p < 0.05$, $n = 70$). Low DO values in drinking water samples have been attributed to the high temperature of the water [29]. Furthermore, [34] and [33] asserted that the solubility of oxygen in water is a function of its temperature viz. the lower the temperature, the greater the solubility of oxygen in the water and vice versa. Thus the slightly high dissolved oxygen (DO) in Well (Kise) is attributable to the slightly low temperature of the well but not due to increased productivity (photosynthesis) in the well. High photosynthetic rates in the water which reduce the available carbon dioxide (increasing the pH) would liberate oxygen leading to positive correlation between DO and pH. According to [35] photosynthesis of aquatic plants releases oxygen into the water and in low-velocity or still waters with plants, an increase in pH can be expected during the growing season. However there was an overall significant negative correlation between pH and DO ($r = -0.444$, $p < 0.05$, $n = 70$). The slightly low DO in rainwater (MUST) despite the low mean temperature recorded could be due to use of some of the atmospheric oxygen in chemical reactions forming acid rain. This is in agreement with [26] who reported that SO_2 and NO_x emissions from vehicles react with water and oxygen in the atmosphere to produce sulfuric and nitric acids which form acid rain.

3.2.4. Biological Oxygen Demand (BOD)

BOD showed significant variations ($p < 0.05$) among the water sources and were very variable within samples for all the water sources (CV > 10%). The borehole at Shuhaddea Secondary School had the highest mean BOD and the least was in rainwater at Mbarara University of Science and Technology. BOD is the measure of the amount of dissolved oxygen required for the decomposition of organic compounds [36]. The mean BOD after 5 days (BOD5) for most of the water sources *i.e.* Borehole (Nyam. S.S), Spring (Kisw), Spring (Kise), Shallow well (Nyam) and Rainwater (MUST) fall within the European Union guideline range for fisheries and aquatic life of 3 - 6 mg/l [23]. This guideline was used to assess the water sources due to lack of set guideline for maximum tolerable limit of BOD in drinking water [29]. On the other hand, the water sources *i.e.* Borehole (Shud. S.S) and Well (Kise) had BOD values above the European Union guideline value attributable to increased organic matter in these water sources as previously reported by [29] in their drinking water sources. The borehole in Shuhaddea secondary school is located in a swampy area with probably organic matter rich underlying soil. Swamps are characterized by high amounts of dissolved organic matter [37]. Due to the swampy nature of the area where Shuhaddea borehole is located, it probably has a lot of micro-organisms which could have resulted into increased microbial activity hence a high BOD. [38] earlier on found out that swamp soils are usually rich in organic matter content and have high numbers of aerobic and anaerobic microorganism that decompose the organic matter. For the case of the well in Kisenyi, the close proximity (2 m) of the animal farms which expose the well to animal wastes (organic matter) can be blamed for the high BOD. According to [39], the proximity of boreholes to animal droppings being littered around them contaminates the quality of groundwater. Surface waters such as the well in Kisenyi are quite easily contaminated by these animal droppings which directly end up into them. According to [40], animal wastes greatly affect the quality of ground water in terms of BOD due to the direct disposal of the wastes on the land surface. These wastes could much easily affect surface waters like the well in Kisenyi than ground water.

3.2.5. Total Dissolved Solids (TDS)

Total dissolved solids showed significant variations ($p < 0.05$) among the water sources and were less variable within samples for most of the water sources (CV < 10%) except for rainwater at MUST and borehole in Nyamitanga (CV > 10%). The spring water in Kisenyi also recorded notably the highest total dissolved solids while rainwater (MUST) had the least. Total dissolved solids (TDS) including carbonate, bicarbonate, chloride, sulphate, phosphate, nitrate, calcium, magnesium, sodium, organic ions and other ions determine the general nature of water quality [14]. They affect the taste of drinking water if found at concentrations above the WHO recommended value. Consequently the TDS in all the water sources were below the WHO maximum allowable limit of 1000 mg/l [18], hence making these water sources suitable for drinking.

3.2.6. Electrical Conductivity (EC)

There was a statistically significant difference ($p < 0.05$) among mean electrical conductivities of the different water sources with spring (Kise) having the highest extreme value and the least value was in rainwater (MUST). The within sample variation of the conductivities for six water sources were small (CV < 10%) except for rainwater at MUST (CV = 34.43%). Electrical conductivity is the ability of any medium, water in this case, to carry an electric current. The presence of dissolved solids such as calcium, chloride, and magnesium in water samples carries the electric current through water [41]. All the mean EC values of the water sources were below the WHO maximum guideline limit of 1500 μs/cm. Similar results were obtained for water samples in Ethiopia by [29]. The mean conductivity of spring in Kiswahili (698.90 μS/cm) was within the range of conductivity (95 - 705 μS/cm) of Katwe and Kisenyi springs in Kampala City [17]. However the conductivity of the spring in Kisenyi (1139.90 μS/cm) was outside the ranges of Katwe and Kisenyi springs in Kampala. The extremely high conductivity in spring (Kise) compared to the other water sources could be associated with the corrosion of the metallic pipe of the spring that led to enrichment of metals in the water. High conductivity was recorded from tap water sources in Ethiopia attributable to the corrosion of metals leading to accumulation of heavy metals [29]. High concentration of charged ions resulting from leaching and run off into the drinking water sources particularly from latrines and landfills including the underlying rocks could have also contributed.

The notably higher mean conductivity in spring (Kise) than the other water sources corresponds to the high Total Dissolved Solids (TDS) in the spring water. This is further augmented by the overall significant positive correlation between conductivity and TDS ($r = 0.996$, $p < 0.05$, $n = 70$). This confirms that it is mainly the same ions that constitute TDS *i.e.* carbonate, bicarbonate, chloride, sulphate, phosphate, nitrate, calcium, magnesium, sodium, organic ions and other ions which lead to the conductivity of the water sources. The high temperature (23.45˚C) in spring (Kise) could have increased the dissolution of the ions leading to high TDS and conductivity as supported by the overall significant positive correlation ($p < 0.05$) of temperature with TDS ($r = 0.762$) and conductivity ($r = 0.764$).

3.2.7. Total Hardness

There were significant variations ($p < 0.05$) in total hardness of the 7 water sources with borehole (Nyam. S.S) registering the highest value while the least was for rainwater (MUST). Total hardness values were highly variable within samples for most of the water sources (CV > 10%) except for shallow well in Nyamitanga and rainwater at MUST (CV = 0.00%). Calcium and magnesium dissolved in water are the two most common minerals that make water "hard" [42] [43]. These were the same ions that also possibly contributed to the TDS and conductivity of the water sources as total hardness was significantly positively correlated ($p < 0.05$) with TDS ($r = 0.504$) and conductivity ($r = 0.513$). The total hardness of all the drinking water sources were below the harmless limit of 1000 mg/L [22]. Basing on the classification of total hardness of water by [44], rainwater was moderately soft; S. well (Nyam) and borehole (Shud. S.S) were moderately hard; Spring (Kisw.), Borehole (Nyam. S.S), spring (Kise.) and well (Kise.) waters were hard. Generally, all the other drinking water sources except rain were moderately hard to hard probably due to the presence of high concentration of calcium and magnesium ions in the water as a result of leaching and run off into the water sources especially from croplands, latrines, landfills, animal and municipal wastes within their vicinity as well as the underlying rocks. Calcium ions are usually common in water sources due to leaching of the rocks [45]. However rainwater was not soft as would be expected probably due to atmospheric particulates that had calcium ions. The dissolution of calcium and magnesium minerals which cause hardness of water was enhanced by the relatively high temperatures of the water sources. This is supported by the significant positive correlation of temperature with total hardness ($r = 0.645$, $p < 0.05$, $n = 70$) and the slightly elevated water temperatures of the drinking water sources.

4. Conclusions

A range of physico-chemical parameters in most of the selected drinking water sources (boreholes, springs, wells, rainwater) in Mbarara Municipality have been compromised by anthropogenic activities (croplands, latrines, landfills, transportation, animal and municipal wastes) situated within the vicinity of these water sources.

The temperature of the water sources were above the WHO threshold temperature for palatable water.

The pH of boreholes in Nyamitanga and Shuhaddea Secondary Schools, spring in Kiswahili, well in Kisenyi and rainwater in Mbarara University of Science and Technology were below the WHO minimum guideline value hence acidic.

The dissolved oxygen levels of borehole in Nyamitanga secondary school, spring in Kisenyi, shallow well in Nyamitanga and the rainwater in Mbarara University of Science and Technology were below the WHO range thus less suitable for other aerobic aquatic life.

BOD values of borehole in Shuhaddea secondary school and the well in Kisenyi were above the European Union guideline value signifying a lot of decomposition of organic matter in these water sources.

The selected water sources (boreholes, springs, and wells) were found to have moderately hard and hard water from the total hardness measure hence undesirable for domestic uses like washing and boiling etc.

Mbarara municipal council should therefore ensure proper sanitation and water safety plans for these drinking water sources to avoid further contamination from the human activities.

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