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Temporal Variations in Physico-Chemical Parameters of Ground Water in Kibujjo Village, Namayumba Sub-County, Wakiso District, Uganda

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Abstract

Water is one of the essential life's basic needs. However, the purity and quality of water from groundwater sources in developing countries are still in doubt due to contamination by different anthropogenic activities. This study assessed the temporal variations in physico-chemical parameters of water sources in Kibujjo Village, Wakiso District, Uganda. Water samples were collected from four water sources: two (2) wells and two (2) boreholes. The levels of both physical and chemical parameters were assessed using APHA standard analytical methods. The results indicated that most of the measured water quality variables did not exceed the UNBS and WHO standards for drinking water, and the majority of the water parameters positively correlated. Borehole waters had a better quality than well waters. The highest levels of most of the variables were recorded during the wet season. There was a significant statistical difference ($p < 0.05$) among the water sources in both seasons for about 67% of the assessed parameters. However, pH, temperature, Cl^-, and SO_4^{2-} showed a significant difference in the dry season amongst the water sources but no significant difference during the wet season ($p > 0.05$). Therefore, water from wells is not recommended for drinking before treatment, most especially during the wet season.

Keywords

Ground Water, Physico-Chemical Parameters, Temporal Variation

1. Introduction

Water is an essential component of human livelihood because of its use in both domestic and commercial activities [1]. However, most people in developing countries have no access to safe water for their domestic services [2]. This is because water sources in such countries have been affected directly and/or indirectly by anthropogenic activities such as the application of fertilizers, manure and pesticides, animal husbandry activities, industrial effluents, domestic sewage, etc. [3]. This has raised a number of water-related diseases like diarrhea, dysentery, campylobacteriosis and trachoma [4].

In Uganda, the situation is even worse because most people have no access to clean water from National Water and Sewerage Cooperation (NWSC) due to high poverty levels among the nationals [5]. They therefore opt to use cheap alternative water sources such as boreholes, springs, rainwater and wells for both drinking and domestic use [6]. Such sources usually contain dissolved inorganic substances like chlorides, fluorides, sulphates, carbonates, sodium, potassium, calcium, and magnesium as well as toxic heavy metals such as mercury, cadmium, chromium, zinc, copper, and lead [7] and organic substances like volatile organic compounds, trichloroethylene, etc. [8]. The consumption of water containing such substances by humans may lead to increased health complications [9]. Among others, the complications include blood pressure, fertility problems, nerve disorders, muscle and joint pain, irritability, memory impairments, gastrointestinal mucosal ulcerations and central-nervous-system (CNS) manifestations including headache, dizziness and convulsions [9].

To mitigate the prevalence of these complications, World Health Organization (WHO) recommends periodic testing of water for use. This is aimed at verifying the quality and suitability of water for a particular use by testing it against the recommended standards. These recommendations provide a framework for safe drinking water. This is done through the implementation of health-based targets, the creation of water safety plans, and the maintenance of water surveillance [10]. However, in developing countries like Uganda, regular monitoring of ground water quality is still difficult because of inadequate financial and technical resources. This has hindered the dream of achieving sustainable development goal 6 of clean water and sanitation; and goal 14 of life below water.

Ultimately, the local folks in Uganda's villages like Kibujjo have become vulnerable to unmonitored water sources, as no studies have been conducted to comprehensively appraise the temporal changes in the water quality and to ascertain the variable potential sources of water contamination. This study therefore aimed at determining the temporal variations in the quality of ground water sources in Kibujjo village, Wakiso district. This was done by determining the physico-chemical parameters of water from four different water sources. The results were compared with WHO [2] and the Ministry of Water and Environment (MWE)'s standards as recommended by UNBS [11] in order to determine its suitability for human consumption.

2. Materials and Methods

2.1. Study Area

Kibujjo Village is located between 0˚33'44"N and 32˚29'24"E in Namayumba Sub-County, Wakiso District, Uganda. It is positioned 40 km away from Kampala capital city. The area is warm and wet with relatively high humidity. It is characterized by a bimodal rainfall distribution, with the long rainy season occurring between October to November and short rains experienced in December, while January to February is the driest. The mean annual rainfall ranges 1320 mm. The livelihood activities of the people in the area largely depend on subsistence agriculture.

2.2. Sample Collection and Analysis

Water samples were collected in triplicates from four ground water sources: two boreholes (B1 and B2) and two wells (W1—for unprotected well and W2—for spring well). Samples were collected every second week of each month within the dry and wet seasons at 1000 hours, 1300 hours and 1600 hours for a period of four months (November 2019-February, 2020).

Samples were collected in polyethylene bottles (1.5 liter capacity) which had been prior cleaned using concentrated nitric acid and then rinsed with double distilled water [12].

The samples were subjected to physico-chemical analyses using standard APHA analytical procedures as described by Rice *et al.* (2012) [12]. However, Dissolved Oxygen and temperature were measured at the sampling sites using a Multimeter (Mettler Toledo SG78).

2.3. Data Analysis

Descriptive statistics were employed to determine the mean level and standard deviation of each of the parameters in triplicate analysis. SPSS was used to perform One-way ANOVA at 5% significance level following the recommendations by Anderson and Darling (1952) [13]. A correlation matrix was designed using Pearson correlation. The results of the analysis were compared with recommended values from WHO and UNBS.

3. Results and Discussion

Results in **Table 1** present an overview of the levels of physico-chemical parameters in each of the water sources during the two weather seasons, while results of analysis of variance between the two weather seasons and among the four water sources are presented in **Table 2** & **Table 3** respectively.

Seasonal variations in water quality amongst the water sources can be attributed to the changes in precipitation levels and temperature during the different seasons of the year which led to differential loading of contaminants into the water sources [14]. Within the wet season, all values showed significant differences amongst the different water sources possibly because of the differences in

Table 1. Mean levels of the different physico-chemical parameters in different water sources.

Parameters	Season	Water Source			
		W1	W2	B1	B2
Electrolytic conductivity (μS·cm^{-1})	Wet	167.7 ± 0.94	128.3 ± 0.16	222.7 ± 0.31	189.2 ± 0.54
	Dry	149 ± 0.816	126.6 ± 0.17	226 ± 0.816	197.7 ± 0.294
pH	Wet	6.08 ± 0.008	6.02 ± 0.05	6.12 ± 0.005	5.94 ± 0.005
	Dry	6.07 ± 0.047	6.05 ± 0.009	6.1 ± 0.069	5.94 ± 0.005
Temperature (˚C)	Wet	23 ± 0.082	22.4 ± 0.125	24.3 ± 0.163	25.2 ± 0.163
	Dry	22.4 ± 0.163	22.9 ± 0.047	24.6 ± 0.163	24.2 ± 0.082
Turbidity (NTU)	Wet	14.13 ± 0.021	3.737 ± 0.031	0.23 ± 0.024	0.833 ± 0.021
	Dry	9.58 ± 0.0008	3.02 ± 0.012	0.28 ± 0.009	0.71 ± 0.012
Dissolved Oxygen (mg·L^{-1})	Wet	3.32 ± 0.026	5.35 ± 0.016	7.02 ± 0.012	6.05 ± 0.008
	Dry	3.05 ± 0.008	5.79 ± 0.008	6.84 ± 0.008	5.95 ± 0.009
Total alkalinity (mg·L^{-1})	Wet	38.6 ± 0.262	42.4 ± 0.163	85.8 ± 0.163	63 ± 0.163
	Dry	40 ± 3.266	44 ± 3.266	88.3 ± 1.247	66 ± 1.414
Total hardness (mg·L^{-1})	Wet	48.7 ± 0.205	38.6 ± 0.5809	79.7 ± 0.082	62.2 ± 0.163
	Dry	50 ± 1.633	40 ± 1.633	86.33 ± 0.499	71.53 ± 0772
Calcium Hardness (mg·L^{-1})	Wet	19.2 ± 0.163	15.1 ± 0.082	27.8 ± 1.485	25.77 ± 0.125
	Dry	13.2 ± 0.163	14.2 ± 0.163	2.173 ± 0.249	21.67 ± 0.094
Magnesium Hardness (mg·L^{-1})	Wet	29.2 ± 0.163	23.8 ± 0.163	52.6 ± 0.432	36.2 ± 0.163
	Dry	38 ± 0.816	27 ± 0.816	66 ± 0.816	49.7 ± 0.943
Chloride (mg·L^{-1})	Wet	10.74 ± 0.043	8.23 ± 0.125	5.57 ± 0.125	5.2 ± 0.163
	Dry	4.767 ± 0.094	5.5 ± 0.082	4.533 ± 0.0944	4.333 ± 0.236
Total Dissolved Solids (mg·L^{-1})	Wet	117.6 ± 0.283	89.77 ± 0.125	156.2 ± 0.125	132.1 ± 0.205
	Dry	105 ± 1.633	88 ± 0.816	160 ± 1.633	139.3 ± 0.943
Fluoride (mg·L^{-1})	Wet	0.217 ± 0.017	0.14 ± 0.029	0.313 ± 0.012	0.22 ± 0.016
	Dry	0.22 ± 0.016	0.15 0.008	0.32 ± 0.009	0.27 ± 0.012
Nitrates (mg·L^{-1})	Wet	3.924 ± 0.003	196.2 ± 0.002	4.166 ± 0.002	5.212 ± 0.00
	Dry	1.0 ± 0.002	1.05 ± 0.025	1.51 ± 0.002	1.69 ± 0.001
Orthophosphates (mg·L^{-1})	Wet	0.06 ± 0.00	0.076 ± 0.004	0.035 ± 0.004	0.182 ± 0.002
	Dry	0.304 ± 0.001	0.266 ± 0.001	0.342 ± 0.048	0.295 ± 0.004
Sulphates (mg·L^{-1})	Wet	17.7 ± 0.624	6.8 ± 0.141	13.5 ± 0.216	18.6 ± 0.163
	Dry	12.2 ± 0.163	7.925 ± 0.125	12.4 ± 0.163	18.6 ± 0.327

Table 2. ANOVA between two seasons.

			Sum of Squares	df	F	Sig.
Electrolytic Conductivity * Season	Between Groups	(Combined)	27.735	1	0.019	0.892
	Within Groups		32502.783	22		
	Total		32530.518	23		
pH * Season	Between Groups	(Combined)	0.000	1	0.004	0.949
	Within Groups		0.124	22		
	Total		0.124	23		
Temperature * Season	Between Groups	(Combined)	0.282	1	0.254	0.620
	Within Groups		24.443	22		
	Total		24.725	23		
Turbidity * Season	Between Groups	(Combined)	10.693	1	0.436	0.516
	Within Groups		540.101	22		
	Total		550.794	23		
Dissolved Oxygen * Season	Between Groups	(Combined)	0.005	1	0.002	0.962
	Within Groups		46.184	22		
	Total		46.189	23		
Total alkalinity * Season	Between Groups	(Combined)	27.520	1	0.069	0.796
	Within Groups		8810.186	22		
	Total		8837.706	23		
Total Hardness * Season	Between Groups	(Combined)	130.200	1	0.421	0.523
	Within Groups		6799.316	22		
	Total		6929.516	23		
Ca Hardness * Season	Between Groups	(Combined)	109.227	1	4.707	0.041
	Within Groups		510.467	22		
	Total		619.693	23		
Mg Hardness * Season	Between Groups	(Combined)	0.000	1	0.000	1.000
	Within Groups		2818.420	22		
	Total		2818.420	23		
Chloride Content * Season	Between Groups	(Combined)	42.188	1	14.757	0.001
	Within Groups		62.894	22		
	Total		105.082	23		
Total Dissolved Salts * Season	Between Groups	(Combined)	4.167	1	0.006	0.941
	Within Groups		16516.473	22		
	Total		16520.640	23		

Continued

Fluoride * Season	Between Groups	(Combined)	0.002	1	0.341	0.565
	Within Groups		0.097	22		
	Total		0.098	23		
Nitrate * Season	Between Groups	(Combined)	37.557	1	46.899	0.000
	Within Groups		17.618	22		
	Total		55.174	23		
Orthophosphate * Season	Between Groups	(Combined)	0.274	1	112.438	0.000
	Within Groups		0.054	22		
	Total		0.328	23		
Sulphates * Season	Between Groups	(Combined)	15.520	1	0.720	0.405
	Within Groups		474.046	22		
	Total		489.566	23		

Table 3. ANOVA amongst the four water sources.

			Sum of Squares	df	F	Sig.
Electrolytic Conductivity * Water Source	Between Groups	(Combined)	7354.897	3	0.331	0.803
	Within Groups		148071.223	20		
	Total		155426.120	23		
pH * Water Source	Between Groups	(Combined)	83.876	3	4.510	0.014
	Within Groups		123.992	20		
	Total		207.868	23		
Temperature * Water Source	Between Groups	(Combined)	27.623	3	0.091	0.964
	Within Groups		2026.046	20		
	Total		2053.668	23		
Turbidity * Water Source	Between Groups	(Combined)	1459.450	3	0.452	0.719
	Within Groups		21523.860	20		
	Total		22983.310	23		
Dissolved Oxygen * Water Source	Between Groups	(Combined)	2192.187	3	0.697	0.565
	Within Groups		20956.338	20		
	Total		23148.525	23		
Total alkalinity * Water Source	Between Groups	(Combined)	3045.195	3	1.866	0.168
	Within Groups		10878.355	20		
	Total		13923.550	23		

Continued

Total Hardness * Water Source	Between Groups	(Combined)	4105.171	3	9.066	0.001
	Within Groups		3018.568	20		
	Total		7123.740	23		
Ca Hardness * Water Source	Between Groups	(Combined)	131.948	3	0.449	0.721
	Within Groups		1958.817	20		
	Total		2090.765	23		
Mg Hardness * Water Source	Between Groups	(Combined)	8982.480	3	1.246	0.320
	Within Groups		48079.253	20		
	Total		57061.733	23		
Chloride Content * Water Source	Between Groups	(Combined)	29.070	3	0.567	0.643
	Within Groups		342.047	20		
	Total		371.117	23		
Total Dissolved Salts * Water Source	Between Groups	(Combined)	3533.111	3	0.252	0.859
	Within Groups		93597.867	20		
	Total		97130.978	23		
Fluoride * Water Source	Between Groups	(Combined)	0.047	3	5.524	0.006
	Within Groups		0.057	20		
	Total		0.104	23		
Nitrate * Water Source	Between Groups	(Combined)	178.478	3	2.362	0.102
	Within Groups		503.821	20		
	Total		682.299	23		
Orthophosphate * Water Source	Between Groups	(Combined)	0.016	3	0.345	0.793
	Within Groups		0.312	20		
	Total		0.328	23		
Sulphates * Water Source	Between Groups	(Combined)	448.575	3	72.954	0.000
	Within Groups		40.992	20		
	Total		489.566	23		

the levels of protection of the different water sources from different anthropogenic contamination like sewage, surface and agricultural runoff and wastes from different domestic activities [14].

The mean water temperature ranged from 22.4˚C ± 0.125˚C to 25.2˚C ± 0.163˚C in wet season and 22.4˚C ± 0.163˚C to 24.6˚C ± 0.163˚C in dry season. The highest average temperature was 25.2˚C ± 0.163˚C obtained from water source B2 while the lowest average temperature was obtained from water sources W1 and W2. The results are in agreement but lower than the findings of Mustapha *et* *al.* (2012) [15] which showed that the temperature of Jakara River, north-western Nigeria varied between 27˚C to 32˚C in the course of dry and wet seasons respectively. There was a significant difference ($p < 0.05$) in mean temperature among the water sources and between most of the pairs of the different water sources during wet season. However, there was no significant difference ($p > 0.05$) during dry season. Except for B2, the mean temperature values of all the sites were within the acceptable temperature WHO (2015) and UNBS (2014) standard temperature of 25˚C.

In this study, the average DO contents varied from 3.32 ± 0.026 $mg \cdot L^{-1}$ to 7.02 ± 0.012 $mg \cdot L^{-1}$ in wet season and 3.05 ± 0.008 $mg \cdot L^{-1}$ to 6.84 ± 0.008 $mg \cdot L^{-1}$ in dry season. The highest DO content was in B1 and the lowest was in W1. Dissolved oxygen (DO) is the most significant water quality parameter and imitates the physical and biological processes prevalent in water [16] [17]. The decrease in DO in the dry season could be attributed to the high rate of organic matter decomposition [17]. There was a significant difference in the average total hardness among the four sites ($p < 0.05$) in both wet season and dry season.

The mean value of pH in this study varied from 5.94 ± 0.005 to 6.12 ± 0.005 and 5.94 ± 0.005 to 6.1 ± 0.069 in wet season and dry season respectively. The pH is a vital water quality parameter as it affects organisms inhabiting the water as well as humans [18]. The pH was slightly acidic in all the water sources, which could be a result of the natural purification processes taking place within water. All the values showed a significant difference among the different water sources during wet season ($p < 0.05$) and showed no significant difference among the different water sources during dry season ($p > 0.05$). However, the results were within UNBS' permissible limits of 5.5 - 9.5 for natural potable water.

The mean EC values ranged from 222.7 ± 0.31 $\mu S \cdot cm^{-1}$ to 128.3 ± 0.16 $\mu S \cdot cm^{-1}$ in wet season and 226 ± 0.816 $\mu S \cdot cm^{-1}$ to 126.6 ± 0.17 $\mu S \cdot cm^{-1}$. The highest EC values were recorded for B1 and the lowest EC values were for W2. Electrical conductivity (EC) describes the concentration of cations which has weighty influence on the quality of water, and may rise from natural weathering of sedimentary rocks, or might be anthropogenic sources such as industrial and sewage waste [19]. Conductivity values of the water sources were below the WHO (2015) and UNBS (2014) standard maximum values of 1500 and 2500 $\mu S \cdot cm^{-1}$ respectively. There was a significant difference in the electrical conductivity among the four sources ($p < 0.05$).

The average TDS contents were found to be in the range of 89.77 ± 0.125 $mg \cdot L^{-1}$ to 156.2 ± 0.125 $mg \cdot L^{-1}$ in wet season and 88 ± 0.816 $mg \cdot L^{-1}$ to 160 ± 1.633 $mg \cdot L^{-1}$ in dry season. The highest TDS values were recorded in B1 while the lowest in W2. The total dissolved solids (TDS) represent the total amount of dissolved solids such as metal cations, and anions present in water [20]. Higher contents of TDS could be attributed to the dissolution of salts from agricultural surfeit and industrial discharge because of anthropogenic activities alongside the river [21]. The TDS values were lower than the WHO (2015) standard of 500 $mg \cdot L^{-1}$ (maximum) and that of UNBS (2014) standard of 1500 $mg \cdot L^{-1}$ (maximum) in both wet and dry seasons. There was a significant difference ($p < 0.05$) in the average TDS value in all water sources as well as between pairs of water sources in all seasons.

In this study, the mean Total Alkalinity (TA) ranged from 38.6 ± 0.262 $mg \cdot L^{-1}$ to 85.8 ± 0.163 $mg \cdot L^{-1}$ in wet season and 40 ± 3.266 $mg \cdot L^{-1}$ to 88.3 ± 1.247 $mg \cdot L^{-1}$ in dry season. The highest mean content was in B1 and the lowest was in W1. Total alkalinity (TA) is the measure of the competence of an aqueous solution to neutralize an acid. TA is detectable because of the numerous carbonates, bicarbonates and hydroxide ions present in water [22]. There was a significant difference in the mean values of alkalinity among and between pairs of the different portable water sources in all seasons ($p < 0.05$). All the mean alkalinity values were in the acceptable range of WHO (2015) and UNBS (2014) guide values.

The detected mean levels of total hardness ranged from 38.6 ± 0.5809 $mg \cdot L^{-1}$ to 79.7 ± 0.082 $mg \cdot L^{-1}$ and 40 ± 1.633 $mg \cdot L^{-1}$ to 86.33 ± 0.499 $mg \cdot L^{-1}$ for the wet season and dry season respectively. The highest was in B1 and the lowest in W2. The total hardness (TH) in water is detected owing to the presence of cations (calcium and magnesium) and anions (carbonate, bicarbonate, chloride, and sulfate) [23]. Total hardness values of water sources were below the UNBS (2014) standard maximum value of 600 $mg \cdot L^{-1}$ and below the WHO (2015) maximum standard range of 100 - 300 $mg \cdot L^{-1}$. Total hardness measures the mineral content of water in the form of dissolved calcium and magnesium. From the results, it can be concluded that the water sources contained some detectable levels of non-hazardous mineral content. There was a significant difference in the average total hardness among the four sites ($p < 0.05$).

The highest average magnesium hardness values (52.6 ± 0.432 and 66.0 ± 0.816 $mg \cdot L^{-1}$) were both recorded in borehole (B1) samples during wet and dry season respectively. The lowest average magnesium values (23.8 ± 0.163 and 27.0 ± 0.816 $mg \cdot L^{-1}$) were recorded in spring well (W2) in wet and dry season respectively. There was a significant difference in the average magnesium hardness among the four water sources for both wet and dry season ($p < 0.05$). However, all the values were in the acceptable range of WHO (2015) and UNBS (2014) guideline range.

The highest mean calcium values (27.8 ± 1.485 and 21.73 ± 0.249 $mg \cdot L^{-1}$) were recorded in borehole (B1) in wet and dry season respectively. The lowest mean values (15.1 ± 0.082 and 13.2 ± 0.163 $mg \cdot L^{-1}$) were recorded in spring well (W2) during wet season and (13.20 ± 0.49 $mg \cdot L^{-1}$) in unprotected well during the dry season. There was a significant difference in the average calcium hardness values in all water sources as well as between pairs of water sources in both dry and wet season ($p < 0.05$). The average values were within the acceptable WHO (2015) and UNBS (2014) range guidelines of 0 - 70 $mg \cdot L^{-1}$ and 0 - 75 $mg \cdot L^{-1}$ respectively.

The highest mean fluoride values (0.313 ± 0.012 and 0.32 ± 0.009 $mg \cdot L^{-1}$) were both recorded in borehole (B1) for wet and dry season respectively and the lowest mean fluoride values (0.14 ± 0.029 and 0.15 ± 0.008 $mg \cdot L^{-1}$) were both recorded in spring well in both seasons. The fluoride levels of all water sources were within the acceptable range in both wet and dry seasons. There was a significant difference in the mean fluoride values in all water sources and between the pairs of water sources.

The unprotected well (W1) had the highest mean chloride (10.74 ± 0.043 $mg \cdot L^{-1}$) in wet season and spring well (W2) with the highest (5.5 ± 0.082 $mg \cdot L^{-1}$) during dry season. The lowest mean chloride values (5.2 ± 0.163 and 4.333 ± 0.236 $mg \cdot L^{-1}$) were recorded in borehole 2 (B2) and borehole 1 (B1) in wet and dry season respectively. There was a significant difference in the mean values of chloride among and between pairs of the different portable water sources during wet season ($p < 0.05$). However, there was no significant difference in the mean values of chloride among and between pairs of the different portable water sources during dry season ($p > 0.05$). All the mean chloride values were within the acceptable range of WHO (2015) and UNBS (2014) standards. The high chloride concentration for unprotected well during the wet season could be as a result of inflows from domestic and agricultural effluent sources when it rains.

The highest nitrate levels of the water sources ranged from 5.212 ± 0.00 to 1.69 ± 0.001 $mg \cdot L^{-1}$ and the lowest was recorded in unprotected well (W1) in the range of 3.924 ± 0.003 to 1.0 ± 0.002 $mg \cdot L^{-1}$. The nitrate levels of all water sources were lower than the WHO (2015) and UNBS (2014) standard range of 20.0 $mg \cdot L^{-1}$ and 50.0 $mg \cdot L^{-1}$ respectively. There was a significant difference in the average nitrates among the water sources as well as in the pairs of water sources ($p < 0.05$) for both wet and dry seasons. Nitrate levels for all water sources were below the WHO (2015) and UNBS standard values of 10.0 - 50.0 $mg \cdot L^{-1}$ and 45.0 $mg \cdot L^{-1}$ respectively. Nitrates are contained in most fertilizers and are also a constituent of human and animal wastes. Due to their high solubility in water, nitrates are highly leachable and readily move through the soil profile [17]. This therefore, means that entry of such wastes into water sources through surface runoffs and infiltration elevates the level of nitrates in water. The levels of nitrates in drinking water in Kibujjo area are low and therefore individuals may not be at risk of the effects of oral nitrate exposure.

Borehole (B2) showed the highest mean orthophosphate value (0.182 ± 0.002 $mg \cdot L^{-1}$) of all water sources during wet season and borehole (B1) (0.342 ± 0.048 $mg \cdot L^{-1}$) during dry season. The lowest mean orthophosphate value (0.035 ± 0.004 $mg \cdot L^{-1}$) was recorded in borehole (B1) during wet season and (0.266 ± 0.001 $mg \cdot L^{-1}$) in spring well (W2) during dry season. All values showed a significant difference among the different water sources and between pairs of water sources during wet season ($p < 0.05$). However, all values showed no significant difference among the different water sources during dry season ($p > 0.05$). All mean values were in the acceptable range of UNBS (2014) and WHO (2015). This could be because the little phosphates added in the form of fertilizers and pesticides adsorbs on top of the soil and underground sediments and thus not readily transported into underground water [24].

The sulphate levels ranged from 6.8 ± 0.141 $mg \cdot L^{-1}$ to 18.6 ± 0.163 $mg \cdot L^{-1}$ in wet season. In dry season, the sulphate levels ranged from 7.925 ± 0.125 $mg \cdot L^{-1}$ to 18.6 ± 0.327 $mg \cdot L^{-1}$. The spring well (W2) had the lowest value and borehole 2 (B2) had the highest in both seasons. The mean sulphate value in both wet and dry season was lower than the WHO (2015) and UNBS (2014) standard value of 250 $mg \cdot L^{-1}$. These results indicated that some soils and rocks like gypsum which contain sulphate minerals that dissolved in water sources were not yet a threat. The presence of sulphate could be a result of upland agricultural runoffs and the use of synthetic detergents [25]. There was a significant difference ($p < 0.05$) in the mean values of sulphates among the different water sources and between pairs of natural potable water sources.

The results in **Table 4** & **Table 5** present the correlation matrix of the fifteen parameters in wet season and dry season respectively.

TDS exhibited a significant positive linear correlation with sulphate (1.00), temperature, total alkalinity, calcium hardness, total hardness and magnesium hardness. However, TDS showed strong negative correlation with F^-, Cl^-, and NO_3^-. This can be explained as the soil present in the study areas mainly constitute high concentration of domestic and animal waste and thus soil consists of high sulphate, calcium, and magnesium concentration. The Total TDS in the water sources is not influenced by the F^-, Cl^-, and NO_3^- concentrations.

Electrolytic conductivity showed a positive linear correlation with temperature, total alkalinity, calcium hardness, total hardness, magnesium hardness, F^-, NO_3^-.

Table 4. Pearson correlation matrix for parameters during wet season.

	TDS	EC	pH	Temp	Turbidity	DO	TA	Ca	TH	Mg	Cl	F	NO_3^-	PO_4^{3-}	SO_4^{2-}
TDS	1	1.000**	0.306	0.755**	−0.377	0.555	0.880**	0.953**	0.982**	0.956**	−0.588*	0.928**	0.756**	−0.063	0.562
EC	1.000**	1	0.298	0.760**	−0.382	0.558	0.881**	0.956**	0.982**	0.955**	−0.594*	0.927**	0.760**	−0.053	0.566
pH	0.306	0.298	1	−0.378	0.291	−0.066	0.219	0.058	0.290	0.403	0.327	0.446	−0.232	−0.936**	−0.197
Temp	0.755**	0.760**	−0.378	1	−0.568	0.584*	0.700*	0.883**	0.749**	0.646*	−0.796**	0.588*	0.891**	0.584*	0.677*
Turbidity	−0.377	−0.382	0.291	−0.568	1	−0.967**	−0.741**	−0.525	−0.528	−0.526	0.946**	−0.258	−0.158	−0.306	0.208
DO	0.555	0.558	−0.066	0.584*	−0.967**	1	0.876**	0.645*	0.696*	0.711**	−0.936**	0.461	0.211	0.116	−0.163
Total alkalinity	0.880**	0.881**	0.219	0.700*	−0.741**	0.876**	1	0.884**	0.953**	0.960**	−0.828**	0.805**	0.492	−0.060	0.174
Ca Hardness	0.953**	0.956**	0.058	0.883**	−0.525	0.645*	0.884**	1	0.952**	0.896**	−0.742**	0.832**	0.819**	0.182	0.588*
Total Hardness	0.982**	0.982**	0.290	0.749**	−0.528	0.696*	0.953**	0.952**	1	0.987**	−0.695*	0.904**	0.669*	−0.072	0.421
Mg Hardness	0.956**	0.955**	0.403	0.646*	−0.526	0.711**	0.960**	0.896**	0.987**	1	−0.655*	0.915**	0.549	−0.212	0.298
Chloride Content	−0.588*	−0.594*	0.327	−0.796**	0.946**	−0.936**	−0.828**	−0.742**	−0.695*	−0.655*	1	−0.432	−0.465	−0.427	−0.113
Fluoride	0.928**	0.927**	0.446	0.588*	−0.258	0.461	0.805**	0.832**	0.904**	0.915**	−0.432	1	0.596*	−0.279	0.456
Nitrate	0.756**	0.760**	−0.232	0.891**	−0.158	0.211	0.492	0.819**	0.669*	0.549	−0.465	0.596*	1	0.500	0.927**
Orthophosphate	−0.063	−0.053	−0.936**	0.584*	−0.306	0.116	−0.060	0.182	−0.072	−0.212	−0.427	−0.279	0.500	1	0.442
Sulphates	0.562	0.566	−0.197	0.677*	0.208	−0.163	0.174	0.588*	0.421	0.298	−0.113	0.456	0.927**	0.442	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Table 5. Pearson correlation matrix of parameters during dry season.

	TDS	EC	pH	Temp	Turbidity	DO	TA	Ca	TH	Mg	Cl	F	NO_3^-	PO_4^{3-}	SO_4^{2-}
TDS	1	0.999**	−0.057	0.907**	−0.612*	0.567	0.941**	0.921**	0.998**	0.954**	−0.792**	0.964**	0.851**	0.650*	0.644*
EC	0.999**	1	−0.050	0.912**	−0.622*	0.577*	0.943**	0.925**	0.997**	0.953**	−0.788**	0.960**	0.856**	0.636*	0.644*
pH	−0.057	−0.050	1	−0.153	0.242	−0.082	0.029	−0.291	−0.033	0.197	0.288	−0.047	−0.436	−0.044	−0.539
Temp	0.907**	0.912**	−0.153	1	−0.869**	0.827**	0.951**	0.973**	0.914**	0.844**	−0.577*	0.797**	0.915**	0.402	0.532
Turbidity	−0.612*	−0.622*	0.242	−0.869**	1	−0.978**	−0.766**	−0.832**	−0.620*	−0.557	0.234	−0.430	−0.785**	−0.147	−0.244
DO	0.567	0.577*	−0.082	0.827**	−0.978**	1	0.767**	0.754**	0.581*	0.573	−0.109	0.386	0.667*	0.167	0.063
TA	0.941**	0.943**	0.029	0.951**	−0.766**	0.767**	1	0.906**	0.951**	0.949**	−0.573	0.863**	0.795**	0.572	0.407
Ca	0.921**	0.925**	−0.291	0.973**	−0.832**	0.754**	0.906**	1	0.916**	0.810**	−0.707*	0.822**	0.974**	0.445	0.669*
TH	0.998**	0.997**	−0.033	0.914**	−0.620*	0.581*	0.951**	0.916**	1	0.961**	−0.763**	0.961**	0.840**	0.648*	0.618*
Mg	0.954**	0.953**	0.197	0.844**	−0.557	0.573	0.949**	0.810**	0.961**	1	−0.642*	0.926**	0.681*	0.701*	0.403
Cl	−0.792**	−0.788**	0.288	−0.577*	0.234	−0.109	−0.573	−0.707*	−0.763**	−0.642*	1	−0.843**	−0.742**	−0.542	−0.874**
F	0.964**	0.960**	−0.047	0.797**	−0.430	0.386	0.863**	0.822**	0.961**	0.926**	−0.843**	1	0.752**	0.721**	0.656*
NO_3^-	0.851**	0.856**	−0.436	0.915**	−0.785**	0.667*	0.795**	0.974**	0.840**	0.681*	−0.742**	0.752**	1	0.336	0.783**
PO_4^{3-}	0.650*	0.636*	−0.044	0.402	−0.147	0.167	0.572	0.445	0.648*	0.701*	−0.542	0.721**	0.336	1	0.266
SO_4^{2-}	0.644*	0.644*	−0.539	0.532	−0.244	0.063	0.407	0.669*	0.618*	0.403	−0.874**	0.656*	0.783**	0.266	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

It however showed a negative correlation with Cl^-. This is probably as a result of surface run off of the rainwater, increasing soil erosion and leaching of mineral deposits in the water. The increase in mineral composition increased the electrolytic conductivity.

Temperature showed a positive correlation with dissolved oxygen, total alkalinity, calcium hardness, total hardness and magnesium hardness. Temperature, however, showed a negative correlation with Cl^-, F^-, NO_3^- and PO_4^{3-}. This is because temperature influences the rate of mineral and oxygen dissolution in water.

Turbidity showed a negative correlation with dissolved oxygen and total alkalinity. It indicated a positive correlation with Cl^-. This is because probably the soil contains a high concentration of chloride containing minerals which leach and dissolve in water hence causing a direct interrelationship between turbidity and chloride ions.

Dissolved oxygen showed a strong positive correlation with total alkalinity, calcium hardness, total hardness, and magnesium hardness. It showed a negative correlation with Cl^-.

Calcium hardness showed a positive correlation with total alkalinity, total hardness, magnesium hardness, but indicated a negative correlation with Cl^-. Sulphates and temperature showed a negative correlation while it showed a strong positive correlation with NO_3^-. NO_3^- showed a positive correlation with Ca, total hardness, fluoride and sulphates. Total hardness showed a positive correlation with dissolved oxygen, total alkalinity, calcium hardness, Mg hardness. However, it showed a negative correlation with Cl^-.

4. Conclusion

From the results, it can be concluded that borehole water was less contaminated than water from good sources. Borehole (B2) had the best water quality, followed by B1 while the water sample from an unprotected well was more contaminated. There was a significant difference ($p < 0.05$) among the water sources in both seasons for dissolved oxygen, electrolytic conductivity, TDS, total alkalinity, total hardness, Mg hardness, Ca hardness, F^-, NO_3^-, and PO_4^{3-}. However, pH, temperature, Cl^-, and SO_4^{2-} showed a significant difference in the dry season amongst the different water sources; but showed no significant difference during the wet season. We strongly recommend that to avoid further contamination, regulatory authorities should closely monitor wells/boreholes in Wakiso District, especially Kibujjo Village. Further studies to investigate in detail the point sources of contamination and the possible causes of high concentrations of contaminants in the water sources should be conducted.

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Conflicts of Interest

The authors declare no conflict of interest.

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