Environmental Challenges 10 (2023) 100667

Contents lists available at ScienceDirect

Environmental Challenges

journal homepage: www.elsevier.com/locate/envc

Assessment of suitability of drinking water from the springs in Urban slums of Kampala

Moses Kiwanuka[a,b,d], Hosea Eridadi Mutanda[a,b,c,*], John Bosco Niyomukiza[b,d,e], Erinah Nakasagga[d]

[a] Department of Civil and Building Service Engineering, Mbarara University of Science and Technology, P.O. Box, 1410, Mbarara, Uganda
[b] Department of Civil Engineering, Ndejje University, P.O. Box,7088, Kampala, Uganda
[c] Africa Centre of Excellence for Water Management, Addis Ababa University, P.O. Box 1176, Addis Ababa, Ethiopia
[d] Department of Civil Engineering, International University of East Africa, P.O.Box 35502, Kampala, Uganda
[e] Department of Civil Engineering and Technology, Sirindhorn International Institute of Technology, Thammsat University, Pathum Than, 12120, Thailand

A R T I C L E I N F O

Keywords:
Springs
Faecal contamination
Water parameters
Water quality index

A B S T R A C T

Any water source used for domestic purposes should meet World Health Organization water quality standards. In most slums of developing nations, water sources such as springs are critical to the residents. Although spring water is often considered fit for domestic use, poor sanitation practices in slums lead to faecal contamination of spring. The objectives of this study were to assess the faecal contamination risk factors and the water quality from the identified springs in Bwaise, Kampala in the dry and rainy seasons. Parameters that were considered in this study were: pH, Electrical conductivity, apparent colour, turbidity, hardness, Chloride, Nitrate, total coliform and E-coli. The cross-sectional sanitary risk assessment for all springs revealed faecal contamination risks. The physiochemical parameters were within the allowable limits of World Health Organization standards for drinking water in all seasons. E-coli values were between 1.35 -13.75Cfu/ 100ml in all seasons. Both total coliform and E-coli were above the permissible limit of o Cfu/100ml in all seasons. When the water samples were analyzed basing WQI, the indices revealed excellent water during the dry season and good water during the wet season. The index values were between 40.09 to 49.34 in the dry season and 54.24 to 74.17 in the wet season. Therefore, treatment or boiling before drinking should be encouraged in the community. Also, proper solid waste management and pit latrine construction strategies should be used in the area

1. Introduction

Globally, 30.1% of the freshwater on earth is groundwater that is under intense pressure from anthropogenic contamination caused by climate change effects and other man's activities (Twinomucunguzi et al., 2021). Due to the scarcity of fresh surface water across the world, groundwater abstraction is becoming a major water source for domestic, agricultural, and industrial purposes in urban and rural areas. This kind of water is stored underground in the aquifers (unconfined or confined aquifers) that are beneath the surface. The quality of groundwater (physiochemical and biological characteristics) is largely dependent on the geological formation of the area, however, there is also an effect due to anthropogenic activities in the locality. The water quality is as vital as the quantity depending on the different purposes of the user. The groundwater quality globally is declining due to various factors namely, agriculture, mining, industrialization, waste disposal, and urbanization rendering it unsafe for human consumption (Kazakis & Voudouris, 2015; Moldovan et al., 2020).

With the increased movement of humans from villages to town centres, the formation of informal, unplanned, and peri-urban settlements is inevitable specifically in developing countries like Uganda. In Kampala, these communities have increased and are characterized by poor sanitation practices and substandard solid waste disposal management (Twinomucunguzi et al., 2020). The predominant water source in these slum areas is from springs because of their affordability compared to piped water. Spring water is considered economically friendly; however, its quality is based on certain physiochemical parameters that need to be assessed before its consumption (Ameen, 2019). In urban slums, water from springs is mainly stressed by on-sanitation practices that render to its contamination. Therefore, residents who consume such water are vulnerable to water-borne diseases namely cholera typhoid, etc. According to World Health Organization, 80% of illnesses across the globe are

* Corresponding author.
E-mail address: hmutanda@must.ac.ug (H.E. Mutanda).

https://doi.org/10.1016/j.envc.2022.100667
Received 9 November 2022; Received in revised form 30 November 2022; Accepted 16 December 2022

Table 1
Geographical Location of springs.

Spring	Village	Description	Easting m E	Northing m N
Nabukalu	Nabukalu zone	Unprotected	451213	39593
Bishop Mukwaya	Kakajo zone	Unprotected	451868	39155
Kiggundu	Kiggundu	Unprotected	451510	38704
Jace school	Kawaala	Unprotected	449861	38199

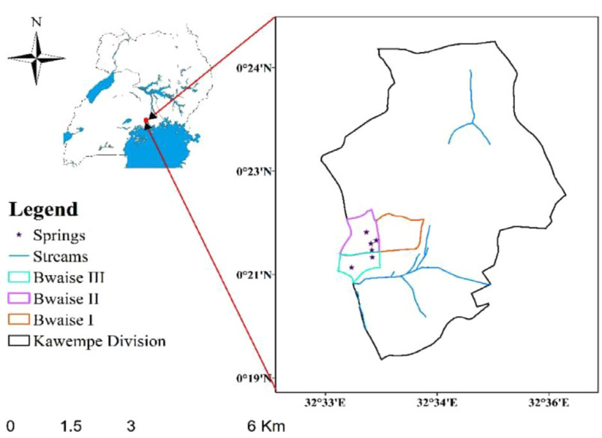
caused by poor sanitation, which includes polluted water or poor access to drinking water (World Health Organization, 2018).

Water sources with good quality that meets WHO standards or Nation's Standards are essential for improving human health in the community. The informal settlements in Kampala largely depend on water from springs for domestic purposes (Omara et al., 2019). Therefore, this paper aimed at assessing water quality from the springs in Bwaise, peri-urban areas of Kampala during the Country's predominant seasons. The study utilized three assessment methods: sanitary inspection around the springs, the physiochemical and bacteriological parameters of water samples from springs, and the quantification of the Water Quality Index.

2. Materials and methods

2.1. Study area

The study was conducted in Bwaise, Kawempe Division, Kampala city. The area is roughly about 5km from the Central Business District (CBD). It lies on geographical coordinates of 00 21 00N, 32 33 40E. Bwaise shares boundaries with Kawempe in the North, Kyebando in the East, Mulago in the Southeast, Makerere in the South, and Kasubi in the Southwest.



2.2. Sanitary inspection of springs in Bwaise

Four springs (Nabukalu, Bishop Mukwaya, Kiggundu, and Jace School) were identified in the study area with the assistance of community leaders. There were denoted as NAB for Nabukalu, BM for Bishop Mukwaya, KIG for Kiggundu, and JS for Jace School. The geographical location of the identified spring is presented in Table 1.

To examine the identified springs for faecal bacterial contamination risk, a cross-sectional sanitary assessment was utilized. A standardized Howard's method previously applied in other studies was followed in the assessment (Omara et al., 2019). The assessment involved the completion of ten questions on sanitary inspection forms of Yes (Y) and No (N) format per designated risk as in Table 2.

A question answered with Yes (Y) was awarded one point and it indicated that risk was observed within the area. However, the question answered with No (N) suggested that no risk was observed in the vicinity and zero point was awarded. The final sanitary risk score for each spring was obtained by aggregating all the yes. It was then computed into percentages by applying the formula as in Eq. 1.

Table 2
Risk assessment questions of the springs.

Questions	Risks
1. Is the spring unprotected?	Y/N
2. Is the masonry protecting the spring faulty?	Y/N
3. Is the backfill area behind the retaining wall or spring box eroded?	Y/N
4. Does spilt water flood the collection area?	Y/N
5. Is the fence absent or faulty?	Y/N
6. Do animals have access within 10m of the spring?	Y/N
7. Is there a latrine within 30m and uphill of the spring?	Y/N
8. Does surface water collect uphill of the spring?	Y/N
9. Is the diversion ditch absent or non-functional?	Y/N
10. Are there any other sources of pollution in the spring (e.g., solid waste)	Y/N

$$Risk\ \% = \frac{No\ of\ answered\ Yes\ risk\ questions}{Total\ No\ of\ risk\ questions} * 100 \quad (1)$$

The study adopted the risk scorecard from the previous researchers, where 81-100% indicated a very high risk, 51-80% high risk, 31-50% medium risk, 1-30% low risk, and 0% no risk (Lukubye & Andama, 2017; Omara et al., 2019).

2.3. Water representative sampling and analysis

The water samples from Nabukalu (NAB), Kiggundu (KIG), Bishop Mukwaya (BM), and Jace School (JS) springs were systematically collected in April (Wet season) and June (dry season) in the year 2022. The collection followed strict sampling guidelines according to ISO 5667-3. The representative water samples were fetched in pre-cleaned plastic bottles of one little capacity for physical parameter analysis. The bacteriological samples were collected using pre-cleaned 500ml glass bottles. Finally, the refrigerator box was used to transport the samples to the Laboratory, WRDC, Ndejje for analysis

The samples were examined for domestic purposes. the considered parameters in the study were pH, Electrical conductivity, colour turbidity, hardness, Chloride, Nitrate, total coliform, and Escherichia Coli. The APHA, 1998 the methods for water analysis were followed for each parameter. The pH was measured utilizing a Mettle Toledo 320 model pH meter. The calibrated conductivity meter of the AD310 model was used to measure electrical conductivity. Colour and Turbidity were measured using DR2010 Spectrophotometer and DR2010 Turbid meter respectively. The titrimetric method was used to examine the samples for Total hardness and Alkalinity. The chloride was determined by a potentiometric titration method with a silver nitrate solution. The cadmium reduction spectrophotometric method was used to measure the Nitrate. Total coliform and E-coli were measured by classical membrane filtration technique.

2.4. Data analysis

The statistical analysis of water sample results was computed using Microsoft Excel 2019 and Statistical Package for Social Science, IBM SPSS statistics 2020. The measured parameters of each spring for each season (dry and wet) were analyzed as the average (mean) and standard deviation for comparison with WHO drinking water quality standards.

Table 3
Description of water source using WQI (source (Bashir et al., 2020).

WQI Range	Water type
<50	Excellent
50-100	Good water
100-200	Poor water
200-300	Very poor water
>300	Unfit for use

Table 4
Risk assessment scorecard for the springs.

Name of spring	Risk answered 'Yes' questions	% Risk score
Nabukalu	1,2,4,5,6,7,8, 9,10	90%
Bishop Mukwaya	1,2,3,4,5,6,7,10	80%
Kiggundu	1,2,3,4,5,6,7,8,10	90
Jace School	1,2,3,4,6,8,9	70%

Comparison between the dry and wet seasons results for each spring was analyzed by the independent t-test, where the null hypothesis rejection revealed a significant difference and a non-rejection indicated that there was no significant difference between the parameters at 0.05, that is 95% level of significance.

For effective evaluation of water pollution levels for each spring, Water Quality Index (WQI) analysis was computed using the measured physicochemical parameters. The weighted arithmetic mean method was employed in this study. From several studies, these WQI calculations entail three main steps: Firstly, a weight (w_i) was fixed to every parameter following its relative importance in WHO drinking standards. The relative weight (W_{ri}) was estimated from Eq. 2;

$$W_{ri} = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (2)$$

Where W_{ri} was the relative weight of every parameter; w_i was the fixed weight for every parameter, and n was the aggregated number of parameters. Secondly, the quality rating q_n was estimated by utilizing Eq. 3;

$$q_n = \frac{C_n}{S_n} * 100, \quad (3)$$

q_n was quality rating; C_n was the measured mean concentration of each parameter in standard units; S_n was the recommended WHO standard for every parameter.

The third step was computing the sub-index of individual parameters by applying Eq. 4

$$SI_i = W_{ri} * q_n \quad (4)$$

By summing up all the sub-index, the WQI for each spring was obtained. The water point source (spring) was described according to the WQI categories from the previous studies as in Table 3 (Bashir et al., 2020; Singh & Hussian, 2016; Solihu & Bilewu, 2022).

3. Results and discussions

3.1. Sanitary risk examination

The risk assessment score for each spring was reported in Table 4. The four springs were at faecal contamination risk. From the scorecard, the aggregated values ranged between high and very high. Nabukalu and Kiggundu springs had a score between 81-100% indicating very high risk while Bishop Mukwaya and Jace School had a score between 51-80% signifying high risk. There was a spring that attained a score from medium to nil. It was observed the springs' vicinity had two common risks: pit latrine location from the spring was less than 30 meters which is recommended by the Ministry of Water and Environment (MoWE), and solid waste dumping sites. A similar study done by Haruna et al in Kisenyi and Katwe parishes in Kampala reported risk scores between high and medium (Haruna et al., 2005). Similarly, the study on Kyambogo springs revealed that the risk score was between high and medium (Omara et al., 2019). These results are in agreement with those two studies done in other slums in the Greater Kampala Metropolitan area.

3.2. Water quality parameters

The results obtained for each spring are represented in Tables 5 and 6. These are the average and standard deviation for the individual parameter of every spring. Table 5 is for the dry season while Table 6 is for the wet season. These were discussed following the WHO standards for drinking water. Table 7 reveals the statistically independent t-test comparison of the results for two seasons for every spring.

Human activities such as industrialization, improper management of solid wastes, and agricultural chemicals have highly contributed to water quality deterioration (Bashir et al., 2020; Shirani et al., 2018; Solihu & Bilewu, 2022). Therefore, any water source must meet WHO standards or the country's standards to serve intended purposes such as domestic use.

Warm water is not palatable for domestic purposes. Therefore, temperature measurement of any source is for acceptability reasons rather than health. The growth of microorganisms that affect colour, odour, taste, and corrosion happens at high temperatures. The mean temperature for the springs ranged from 27.67 to 22.33°C, Table 5 during the dry season, and between 18.43 to 14.69°C, Table 6 during the wet season. Nabukalu spring had the highest temperature of 27.67°C and Kiggundu reported the lowest at 22.33°C in the dry season. The 18.43°C was the highest reported at Kiggundu spring and 14.69°C was the lowest, reported at Jace School spring in the wet season. There was no statistical significance at a 95% confidence interval between temperature measurements in the dry and wet seasons for each spring as in Table 6. These results were within the acceptable value of WHO standards. Similar results were reported in the study within Greater Kampala (Omara et al., 2019). Globally, these results were similar to the studies conducted in Western Nepal and Southwestern Basin, Jordan on spring water (Al-Khashman et al., 2017; Gurung et al., 2019).

Compounds that dissolve in water are responsible for colour in water. The colour can be anthropocentric or natural. The water samples from the springs revealed that the average colour measurements were within the WHO limits for drinking of ≤ 15 Pt-Co in all seasons as in Tables 5 and 6. The highest colour was recorded at Kiggundu spring during the rainy season and the lowest was Nabukalu spring also during the same season. The high/low colour measurements are not perfect indicators of drinkable water; however, colour affects the aesthetic or cosmetics of the water more than human health concerns. According to Table 7, the results were statistically insignificant between the two seasons at a 95% confidence interval.

The solid matter in the suspended condition determines the turbidity of either groundwater or surface water. Turbidity evaluates water clarity properties and the measurement is applied to designate the waste quality discharge in the water regarding the colloidal matter (Ilori et al., 2019; Meride & Ayenew, 2016). Turbidity measurements from all the springs were very low during the dry season ranging between 0.66 to 0.58 NTU, within the permissible limits of WHO standards. The study by Haruna et al found similar results during the dry season (Omara et al., 2019). It was attributed to the reduction in precipitations which aid runoff leading to the dissolution and infiltration of suspended solids in the dry period (Ngabirano et al., 2016). The water sample measurements carried out during the wet season yielded slightly higher turbidity above the WHO acceptable level ranging between 8.86 to 5.50 NTU. Statistically, results were insignificant between the seasons. Turbidity $> 5\ NTU$ reveals bacteria, pathogen and viruses presence in water (Omara et al., 2019). Consequently, consumption of water with high turbidity is attributed to diseases and symptoms such as diarrhoea, cramps, and nausea (Chaudhary & Satheeshkumar, 2018; Memon et al., 2016).

Table 5
Parameters' statistical average and standard deviation during the dry season.

Parameters/D	NAB	BM	KIG	JS	WHO (2017)
Temp (°C)	25.67± 1.26	24.96 ± 2.17	22.33±0.75	27.51 ±0.98	20 –30
Colour (PtCo)	7.21± 3.79	8.47 ± 2.07	8.31 ± 0.88	7.52 ±0.29	≤15
Turbidity (NTU)	0.61± 0.14	0.66 ± 0.12	0.65 ± 0.02	0.58 ± 0.03	5
TDS (mg/l)	252.69± 24.13	261.67 ± 20.97	207.93 ±4.73	125.53 ±2.90	≤ 1000
pH	5.70± 0.48	6.27 ± 0.60	6.21 ± 0.15	5.95 ± 0.16	6.5 –– 8.5
EC	512.76± 39.26	516.13 ±41.82	349.13 ±6.37	382.87±5.58	≤400
Hardness(mg/l)	90 ±	134.50 ± 0.43	125.5±2.45	178.24±2.32	≤500
Ca (mg/l)	22.12± 1.87	23.80 ± 3.51	18.62±1.05	15.65 ±0.89	≤150
Mg (mg/l)	12.93± 1.62	18.07 ± 4.86	22.87 ±2.88	23.27 ±2.55	≤30
Na (mg/l)	61.93± 1.62	66.40 ± 5.50	126.80 ± 8.10	133.67 ±4.29	≤250
Cl (mg/l)	65.69± 22.74	59.53 ± 23.59	14.07±2.19	15.71 ±1.39	≤ 250
NO_3^{-1} (mg/l)	35.55± 9.03	43.13 ±12.12	16.67±2.85	29.77 ±1.52	≤ 50
TC (Cfu/100ml)	11.76± 1.15	10.33 ± 4.50	8.92 ±1.56	8.92 ±1.56	0
E-coli (Cfu/100ml)	1.35± 0.43	1.55±0.90	2.21±0.39	0.77 ± 0.12	0

Table 6
Parameters' statistical average and standard deviation during the wet season.

Parameters/D	NAB	BM	KIG	JS	WHO (2017)
Temp (°C)	17.54± 0.61	16.49 ± 0.27	18.43±0.30	14.69 ±0.50	20 –30
Colour (PtCo)	4.45± 0.32	13.59 ± 0.46	14.79 ± 0.30	7.52 ±0.29	≤15
Turbidity (NTU)	7.29± 0.25	8.86 ± 0.14	6.35 ± 0.46	5.50 ± 0.07	5
TDS (mg/l)	205.0 ± 4.28	294.07 ± 2.25	249.73 ± 3.77	221.20 ± 9.14	≤ 1000
pH	5.17± 0.05	5.73 ± 0.13	5.22 ± 0.10	5.49 ± 0.30	6.5 –– 8.5
EC	417.87± 2.90	937.60 ±27.36	619.00 ± 5.84	470.93± 5.57	≤400
Hardness(mg/l)	156.33 ± 3.37	189.30 ± 2.97	412.67± 5.85	154.20± 11.33	≤500
Ca (mg/l)	56.27± 3.37	22.32 ± 1.11	120.33± 6.14	46.33 ± 4.08	≤150
Mg (mg/l)	15.37± 0.97	13.09 ± 1.23	24.69 ± 1.49	27.60 ± 1.92	≤30
Na (mg/l)	143.33± 2.99	166.47 ± 5.57	136.87 ± 8.57	222.69 ±9.35	≤250
Cl (mg/l)	42.53± 1.90	148.80 ± 28.55	13.49±0.93	29.67 ± 3.87	≤ 250
NO_3^{-1} (mg/l)	19.32± 0.19	28.45 ± 0.77	18.69± 0.31	13.69± 0.83	≤ 50
TC (Cfu/100ml)	31.13± 2.88	17.67 ± 2.50	25.33 ± 3.44	8.92 ±0.56	0
E-coli (Cfu/100ml)	12.69± 0.46	2.36±0.34	13.75 ±0.66	5.80 ± 0.01	0

Table 7
Independent t-test between parameters during the dry and wet seasons for each spring.

Parameters	n	df	P-Values			
			NAB	BM	KIG	JS
Temp (°C)	15	28	0.000	0.000	0.000	0.000
Colour (PtCo)	15	28	0.013	0.000	0.000	0.028
Turbidity (NTU)	15	28	0.000	0.000	0.000	0.000
TDS (mg/l)	15	28	0.000	0.000	0.000	0.000
pH	15	28	0.001	0.002	0.000	0.000
EC	15	28	0.000	0.000	0.000	0.000
Hardness(mg/l)	15	28	0.000	0.000	0.000	0.000
Ca (mg/l)	15	28	0.000	0.129	0.000	0.000
Mg (mg/l)	15	28	0.000	0.001	0.038	0.000
Na (mg/l)	15	28	0.000	0.000	0.003	0.000
Cl (mg/l)	15	28	0.045	0.000	0.354	0.000
NO_3^{-1} (mg/l)	15	28	0.000	0.000	0.011	0.000
TC (Cfu/100ml)	15	28	0.000	0.000	0.000	0.049
E-coli (Cfu/100ml)	15	28	0.000	0.003	0.000	0.000

**95% confidence interval.

Total dissolved solids show the ability of water to break down inorganic and organic salts or minerals for instance sulphates, chlorides, calcium, potassium, sodium bicarbonates, magnesium, and others (Ilori et al., 2019; Meride & Ayenew, 2016). These substances create an undesirable colour appearance and taste (Ibrahim, 2019). There is severe harm in the consumption of drinking water with high TDS concentrations (Ilori et al., 2019). However, some studies report constipation or laxative effects, and the suffering of people with heart or kidney disease (Ilori et al., 2019; Sasikaran et al., 2012). TDS values during the dry period ranged between 100 and 300 mg/l and for the wet season ranged between 214 and 452mg/l. There was a slight increment in TDS values for water samples from all the springs. All the TDS values were within the desirable level (<500mg/l) for drinking water (Chaudhary & Satheeshkumar, 2018; WHO, 2017). However, there results between seasons were statistically insignificant.

The acidity or basicity conditions of the water are evaluated based on the pH logarithmic scale. The scale has a range of 0 - 14, water is neutral at a pH of 7, pH< 7 designates acidic, and pH >7 for alkaline status. In this study, the average measurements of the pH were between 6.40 to 5.13 in both seasons, indicating that the values were slightly below the World Health Organization standards for drinking water (WHO, 2017). When a comparison was made with other research, these were similar to the study in other slums in Kampala (Omara et al., 2019). The water samples were moderately acidic. Organic matter decomposition probably led to the acidity of water as in the study in Lukaya town, Uganda (Nayebare et al., 2020). Several studies have disclosed minimal health concerns with human consumption of water with low pHs such as acidosis, skin and eye irritation, and mucous membrane cell injury (Popoola et al., 2019). However, a few more studies have also reported problems of metal corrosion for household apparatus and others as a major concern for low pH (Adnan et al., 2020).

The Electrical Conductivity water parameter measurement indicates the conductor or insulator properties of the water. Generally, pure water should be a good insulator of electric current rather than a good conductor (Meride & Ayenew, 2016), but such water does not exist in reality. EC in water is mainly determined by the concentration of the inorganic ions such as magnesium, sodium, and calcium chloride in the aquifers (Al-Khashman et al., 2017; Meride & Ayenew, 2016). The results in Table 5 revealed that Electrical Conductivity ranged between 345-400 μS/cm in the dry season, within the acceptable limit of drinking water by the WHO standards (WHO, 2017). The dry season values were in agreement with the range obtained by Omara et al on Kyambogo springs (Omara et al., 2019). On the contrary, the aver-

Table 8
WQI of springs during the dry season.

Parameters	WHO	w_i	W_{ri}	SI_{iNAB}	SI_{iBM}	SI_{iKIG}	SI_{iJS}
Turbidity (NTU)	**5**	**3**	**0.08**	1.08	1.10	1.08	0.96
TDS (mg/l)	**600**	**5**	**0.14**	5.76	6.06	4.81	2.91
pH	**8.5**	**4**	**0.11**	7.47	8.20	8.11	7.77
EC	**400**	**2**	**0.06**	7.10	7.17	4.85	5.32
Hardness(mg/l)	**500**	**2**	**0.06**	0.99	1.49	1.39	1.98
Ca (mg/l)	**150**	**3**	**0.08**	1.21	1.32	1.03	0.87
Mg (mg/l)	**30**	**3**	**0.08**	3.46	5.02	6.35	6.46
Na (mg/l)	**200**	**4**	**0.11**	3.45	3.69	7.04	7.43
Cl (mg/l)	**250**	**5**	**0.14**	2.98	3.31	0.78	0.87
NO_3^{-1} (mg/l)	**50**	**5**	**0.14**	9.76	11.98	4.63	8.27
		36	**WQI =**	43.27	49.34	40.09	42.84

Table 9
WQI of the springs during the wet season.

Parameters	WHO	w_i	W_{ri}	SI_{iNAB}	SI_{iBM}	SI_{iKIG}	SI_{iJS}
Turbidity (NTU)	**5**	**3**	**0.08**	12.16	14.46	10.58	9.17
TDS (mg/l)	**600**	**5**	**0.14**	4.75	6.81	5.78	18.78
pH	**8.5**	**4**	**0.11**	6.76	7.49	6.82	7.17
EC	**400**	**2**	**0.06**	5.80	13.02	8.60	6.54
Hardness(mg/l)	**500**	**2**	**0.06**	1.74	2.10	4.59	1.71
Ca (mg/l)	**150**	**3**	**0.08**	3.13	1.24	6.69	2.57
Mg (mg/l)	**30**	**3**	**0.08**	4.27	3.64	6.86	7.67
Na (mg/l)	**200**	**4**	**0.11**	7.96	9.25	7.60	12.37
Cl (mg/l)	**250**	**5**	**0.14**	2.36	8.27	0.75	1.65
NO_3^{-1} (mg/l)	**50**	**5**	**0.14**	5.37	7.90	5.19	3.80
		36	**WQI =**	54.29	74.17	63.45	71.44

age Electrical Conductivity (EC) of the springs during the wet season ranges between 414-947 μS/cm. Bishop Mukwaya spring reported the highest EC and Nabukalu spring recorded the lowest. These were above the WHO standards for drinking water (WHO, 2017). And there was no relationship between the dry and wet seasons values. Most scientific papers associate high EC predominantly with geochemical processes such as reverse exchange, silicate weathering, oxidation, ion exchange, sulphate reduction, evaporation, and rock-water interaction processes (Annapoorna & Janardhana, 2015; Kangpe et al., 2014). However, the major attribute in this study is the seasonal rains which influence the nearby soil conditions causing high leachate infiltration into groundwater (Sorensen et al., 2015). Annapoorna & Janardhana divulged that human gastrointestinal irritation can also be caused by higher Electrical Conductivity (Annapoorna & Janardhana, 2015).

Water hardness and alkalinity are governed by the existence of alkaline for example calcium and magnesium in bicarbonate forms. Therefore, the higher number of Total hardness and alkalinity reveal the existence of hydroxide, carbonate, and bicarbonate in the water (Kangpe et al., 2014). The hardness of water bodies is classified into four grounds, 75 mg/l is regarded as soft; 75-150 mg/l is considered moderately hard; 150-300 mg/l is reviewed as hard and above 300 mg/l is considered as very hard (Al-Khashman et al., 2017). The results in Tables 5 and 6 indicate that the hardness of all the representative samples for all seasons was within the acceptable values of the WHO. Total hardness has no health effect; however, it leads to deficient lather formation during washing and scales in water distribution pipers and boilers (Ackah et al., 2011; Ezeribe et al., 2012). Also, Calcium and Magnesium measurements in both seasons were within permissible levels for domestic water.

Chloride is largely acquired through hydrochloric salts' dissolution such as sodium chloride and sodium Carbonate (Meride & Ayenew, 2016). Groundwater sources frequently have more concentrations of chlorides than surface water sources. Chloride has a fundamental function in the human body during the metabolism process. A high concentration of chloride destroys structures and metallic pipes and it is also an indicator of pollution (Meride & Ayenew, 2016; Mkadmi et al., 2018). All the measurements for chloride in both seasons ranged between 148.8 mg/l and 14.07 mg/l. These were slightly above those reported by Omara et al (Omara et al., 2019) on Kyambogo spring during the dry season. However, values in both studies do not exceed the maximum acceptable limit figure of 250 mg/l for domestic water (WHO, 2017).

Nitrate can happen naturally through the nitrogen cycle but also occurs as a result of human-made sources for instance nitrogenous fertilizers, industrial waste, etc (Mkadmi et al., 2018; Popoola et al., 2019). It is one of the most parameters that cause diseases such as methemoglobinemia (blue baby syndrome) in babies, neural tube defects, miscarriage, colorectal cancer, birth defects, leukaemia, and thyroid (Meride & Ayenew, 2016; Ward et al., 2018). The World Health Organization standards allow the topmost value of 50mg/l for nitrate tested as Nitrogen in drinking water (Al-Khashman et al., 2017; WHO, 2017). The water samples from the springs in all seasons were within WHO standards. Nitrate values were statistically insignificant at a 95% confidence level for the springs in all seasons. These were in agreement with the results obtained by Omara et al (2019). Permissible values were also obtained from the spring in Bihar, India (Gupta et al., 2017) however the source was located in a rural area.

Total coliform and Escherichia Coli are bacteria that inhabit the lower intestine of warm-blooded animals. The detection of Escherichia Coli is a great indicator of pathogen existence (disease-causing organisms i.e., bacteria, protozoa, and viruses) in water for drinking (Ibrahim, 2019; Meride & Ayenew, 2016). The diseases that can be caused by those pathogens are dysentery, cholera, diarrhoea, viral hepatitis A, and typhoid (Adebayo et al., 2015). Therefore, it is a requirement by WHO standards to have an absence of total coliform and Escherichia Coli in domestic water (Meride & Ayenew, 2016). Obtained results reveal faecal contamination for springs in all seasons. Omara et al (2019) also reported faecal contamination in a study done in Kyambogo slums. Similarly, in the study conducted in Mbarara city, Uganda, total coliform and Escherichia Coli contamination were found in the springs in the city (Lukubye & Andama, 2017). However, the results in this study were statistically insignificant for each spring in all seasons except for Jace School's reported p-value of 0.625 for total coliform. Generally, the contamination was from infiltrations of animal or human faeces into the ground as in other studies (Aboagye & Zume, 2019; Layton et al., 2010).

3.3. Water quality index

As indicated in Tables 7 and 8 were Water Quality indices for each spring in all seasons (the dry and wet seasons) using the WHO standards for drinking. The WQI is the most constructive method of disseminating water quality information from any source due to the aggregation of studied parameters (Toma et al., 2013). A list of ten parameters was selected for this analysis. When these results were compared with the WQIs ranges (Bashir et al., 2020; Singh & Hussian, 2016; Solihu & Bilewu, 2022), during the dry season values ranged between 40.09 to 49.34 suggesting that water was excellent for domestic purposes. In the wet season values ranged from 54.29 to 74.17 suggesting water was good for domestic use with some treatment. The WQIs for spring water quality from the study in Barwari Bala, Duhok, Kurdistan Region, Iraq was excellent and good water during the dry and wet seasons respectively as in the study (Ameen, 2019). Also, Taloor et al revealed that 95% of springs fell under the excellent and good categories (Taloor et al., 2020). However, due to the anthropogenic activities observed in areas such as nearby pit latrines and improper disposal of wastes, water from springs needs prior treatment before drinking. Table 9.

4. Conclusions

A cross-sectional sanitary risk examination revealed that all springs in Bwaise were at risk of faecal contamination due to pit latrines and improper disposal of solid wastes. Results further reported that physiochemical parameters (PH, Electrical conductivity, colour, turbidity, hardness, Chloride, Nitrate) were within the permissible WHO limits. However, there was a statistically insignificant between the results during the dry and wet seasons for each spring. The total coliform and Escherichia Coli were above the standards in all seasons. The WQI indices showed excellent water during the dry season and good water during the wet season. The study recommends boiling water for drinking purposes, proper pit latrine construction, and solid waste management in the community.

Author contributions

All authors contributed to the conceptualization and design of the study. MK, HEM and JBN, EN collected the samples, performed the experiments, and analyzed the data. MK and HEM wrote the draft manuscript, and all authors commented on previous versions of the manuscript. All authors reviewed and approved the final manuscript.

Funding

No external funding was received for this research, authorship, and publication

Conflict of interest

There is no conflict of interest in this work because there was no external funding for this research.

Conflicts of Interest: The authors declare no conflict of interest.

Declaration of Competinng Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

The authors wish to acknowledge Ndejje University and Mbarara University of Science and Technology for making this study possible. Many thanks go to the Water Research and Development Centre of Ndejje University for allowing authors to use the laboratory.

References

Aboagye, D., Zume, J.T., 2019. Assessing groundwater quality in peri-urban localities of Kumasi, Ghana. Afr. Geogr. Rev. 4, 390–405. doi:10.1080/19376812.2018.1484781.

Ackah, M., Agyemang, O., Anim, A.K., Osei, J., Bentil, N.O., Kpattah, L., Gyamfi, E.T., 2011. Assessment of groundwater quality for drinking and irrigation : the case study of Teiman-Oyarifa Community. Ga East Municipality, Ghana, pp. 186–194.

Adebayo, A.S., Ariyibi, E.A., Awoyemi, M.O., Onyedim, G.C., 2015. Delineation of contamination plumes at Olubonku Dumpsite using geophysical and geochemical approach at Ede Town, Southwestern Nigeria. Geosciences 1, 39–45. doi:10.5923/j.geo.20150501.05, 2015.

Adnan, K., Syed, R.A., Afrida, F., Syed, W.H., 2020. Assessment of groundwater quality in coastal region a case study of Qayyumabad, Karachi, Pakistan. Asian Rev. Environ. Earth Sci. 1, 9–17. doi:10.20448/journal.506.2020.71.9.17.

Al-Khashman, O.A., Alnawafleh, H.M., Jrai, A.M.A., Al-Muhtaseb, A.H., 2017. Monitoring and assessing of spring water quality in Southwestern Basin of Jordan. Open J. Mod. Hydrol. 04, 331–349. doi:10.4236/ojmh.2017.74019.

Ameen, H.A., 2019. Spring water quality assessment using water quality index in villages of Barwari Bala, Duhok, Kurdistan Region, Iraq. Appl. Water Sci. 8. doi:10.1007/s13201-019-1080-z.

Annapoorna, H., Janardhana, M.R., 2015. Assessment of groundwater quality for drinking purpose in rural areas surrounding a defunct copper mine. *Aquatic Procedia, Icwrcoe* 685–692. doi:10.1016/j.aqpro.2015.02.088.

Bashir, N., Saeed, R., Afzaal, M., Ahmad, A., Muhammad, N., Iqbal, J., Khan, A., Maqbool, Y., Hameed, S., 2020. Water quality assessment of lower Jhelum canal in Pakistan by using geographic information system (GIS). Groundw. Sustain. Dev., 100357 doi:10.1016/j.gsd.2020.100357.

Chaudhary, V., Satheeshkumar, S., 2018. Assessment of groundwater quality for drinking and irrigation purposes in arid areas of Rajasthan, India. Appl. Water Sci. 8, 1–17. doi:10.1007/s13201-018-0865-9.

Ezeribe, A.I., Oshieke, K., & Jauro, A. (2012). *Physico-chemical properties of well water samples from some villages in nigeria with cases of stained and mottle teeth. ISSN 1597-6343*, 1–3. www.scienceworldjournal.or

Gupta, B.K., Prakash, P., Ahmad, F., 2017. The study of physico-chemical parameters and bacteriological examination of Rishikund hot water. Natl. J. Multidiscip. Res. Dev. 3, 353–357.

Gurung, A., Adhikari, S., Chauhan, R., Thakuri, S., Nakarmi, S., Rijal, D., Dongol, B.S., 2019. Assessment of spring water quality in the rural watersheds of Western Nepal. J. Geosci. Environ. Protect. 07 (11), 39–53. doi:10.4236/gep.2019.711004.

Haruna, R., Ejobi, F., Kabagambe, E.K., 2005. The quality of water from protected springs in Katwe and Kisenyi parishes, Kampala city, Uganda. Afr. Health Sci. 1, 14–20.

Ibrahim, M.N., 2019. Assessing groundwater quality for drinking purpose in Jordan: Application of water quality index. J. Ecol. Eng. 3, 101–111. doi:10.12911/22998993/99740.

Ilori, B., Adewumi, J., Lasisi, K., Ajibade, F., 2019. Qualitative assessment of some available water resources in Efon-Alaaye, Ekiti State Nigeria. J. Appl. Sci. Environ. Manage. 2 (1119–8362), 35–40. https://www.ajol.info/index.php/jasem.

Kangpe, N.S., Egga, E.S., Mafuyai, G.M., 2014. Physico-chemical and microbial assessmentof s ome well water from Mista-Ali Town, Bassa LGA, Plateau State- Nigeria. Asian Rev. Environ. Earth Sci. 1 (2), 39–42.

Kazakis, N., Voudouris, K.S., 2015. Groundwater vulnerability and pollution risk assessment of porous aquifers to nitrate: modifying the DRASTIC method using quantitative parameters. J. Hydrol. 13–25. doi:10.1016/j.jhydrol.2015.03.035.

Layton, B.A., Walters, S.P., Lam, L.H., Boehm, A.B., 2010. Enterococcus species distribution among human and animal hosts using multiplex PCR. J. Appl. Microbiol. 109 (2), 539–547. doi:10.1111/j.1365-2672.2010.04675.x.

Lukubye, B., Andama, M., 2017. Bacterial analysis of selected drinking water sources in Mbarara Municipality, Uganda. J. Water Resour. Prot. 08, 999–1013. doi:10.4236/jwarp.2017.98066.

Memon, A.H., Ghanghro, A.B., Jahangir, T.M., Lund, G.M., 2016. Arsenic contamination in drinking water of district Jamshoro, Sindh,pakistan. Biomed. Lett. 1, 31–37.

Meride, Y., Ayenew, B., 2016. Drinking water quality assessment and its effects on residents health in Wondo genet campus, Ethiopia. Environ. Syst. Res. 1, 1–7. doi:10.1186/s40068-016-0053-6.

Mkadmi, Y., Benabbi, O., Fekhaoui, M., Benakkam, R., Bjijou, W., Elazzouzi, M., Kadourri, M., Chetouani, A., 2018. Study of the impact of heavy metals and physico-chemical parameters on the quality of the wells and waters of the Holcim area (Oriental region of Morocco). J. Mater. Environ. Sci. 2, 672–679. doi:10.26872/jmes.2018.9.2.74.

Moldovan, A., Hoaghia, M.A., Kovacs, E., Mirea, I.C., Kenesz, M., Arghir, R.A., Petculescu, A., Levei, E.A., Moldovan, O.T., 2020. Quality and health risk assessment associated with water consumption—a case study on karstic springs. Water (Switzerland) 12. doi:10.3390/w12123510.

Nayebare, J.G., Owor, M.M., Kulabako, R., Campos, L.C., Fottrell, E., Taylor, R.G., 2020. WASH conditions in a small town in Uganda: How safe are on-site facilities? J. Water, Sanit. Hyg. Dev. 1, 96–110. doi:10.2166/washdev.2019.070.

Ngabirano, H., Byamugisha, D., Ntambi, E., 2016. Effects of seasonal variations in physical parameters on quality of gravity flow water in Kyanamira Sub-County, Kabale District, Uganda. J. Water Resour. Prot. 13, 1297–1309. doi:10.4236/jwarp.2016.813099.

Omara, T., Nassazi, W., Adokorach, M., Kagoya, S., 2019. Physicochemical and Microbiological Quality of Springs in Kyambogo University Propinquity. OALib 01, 1–13. doi:10.4236/oalib.1105100.

Popoola, L.T., Yusuff, A.S., Aderibigbe, T.A., 2019. Assessment of natural groundwater physico-chemical properties in major industrial and residential locations of Lagos metropolis. Appl. Water Sci. 8, 1–10. doi:10.1007/s13201-019-1073-y.

Sasikaran, S., Sritharan, K., Balakumar, S., Arasaratnam, V., 2012. Physical, chemical and microbial analysis of bottled drinking water. Ceylon Med. J. 3, 111–116. doi:10.4038/cmj.v57i3.4149.

Shirani, Z., Santhosh, C., Iqbal, J., Bhatnagar, A., 2018. Waste Moringa oleifera seed pods as green sorbent for e ffi cient removal of toxic aquatic pollutants. J. Environ. Manage. 95–106. doi:10.1016/j.jenvman.2018.08.077, *April*.

Singh, S., Hussian, A., 2016. Water quality index development for groundwater quality assessment of Greater Noida sub-basin, Water quality index development for groundwater quality assessment of Greater Noida sub-basin. Cogent Eng. 1. doi:10.1080/23311916.2016.1177155.

Solihu, H., Bilewu, S.O., 2022. Assessment of anthropogenic activities impacts on the water quality of Asa river: a case study of Amilengbe area, Ilorin, Kwara state, Nigeria. Environ. Challenges, 100473 doi:10.1016/j.envc.2022.100473.

Sorensen, J.P.R., Lapworth, D.J., Nkhuwa, D.C.W., Stuart, M.E., Gooddy, D.C., Bell, R.A., Chirwa, M., Kabika, J., Liemisa, M., Chibesa, M., Pedley, S., 2015. Emerging contaminants in urban groundwater sources in Africa. Water Res. 72, 51–63. doi:10.1016/j.watres.2014.08.002.

Taloor, A.K., Pir, R.A., Adimalla, N., Ali, S., Manhas, D.S., Roy, S., Singh, A.K., 2020. Spring water quality and discharge assessment in the Basantar watershed of Jammu Himalaya using geographic information system (GIS) and water quality Index(WQI). Groundw. Sustain. Dev., 100364 doi:10.1016/j.gsd.2020.100364.

Toma, J.J., Ahmed, R.S., Abdulla, Z.K, 2013. Application of water quality index for assessment of Dokan Lake Ecosystem, Kurdistan Region, Iraq. J. Adv. Lab. Res. Biol. 4, 128–134.

Twinomucunguzi, F.R.B., Nyenje, P.M., Kulabako, R.N., Semiyaga, S., Foppen, J.W., Kansiime, F., 2020. Reducing groundwater contamination from on-site sanitation in peri-urban sub-saharan Africa: Reviewing transition management attributes towards implementation ofwater safety plans. Sustainability (Switzerland) 10, 1–21. doi:10.3390/su12104210.

Twinomucunguzi, F.R.B., Nyenje, P.M., Kulabako, R.N., Semiyaga, S., Foppen, J.W., Kansiime, F., 2021. Emerging organic contaminants in shallow groundwater underlying two contrasting peri-urban areas in Uganda. Environ. Monit. Assess. 4. doi:10.1007/s10661-021-08975-6.

Ward, M.H., Jones, R.R., Brender, J.D., de Kok, T.M., Weyer, P.J., Nolan, B.T., Villanueva, C.M., van Breda, S.G., 2018. Drinking water nitrate and human health: an updated review. Int. J. Environ. Res. Public Health 7, 1–31. doi:10.3390/ijerph15071557.

WHO, 2017. Guidelines for Drinking-water Quality, (FOURTH EDI) WHO.

World Health Organization, 2018. Guidelines on sanitation and health. World Health Organization.