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ORIGINAL ARTICLE

Seasonal quality of water sources indicated by *Escherichia coli*: a case of *Elobied*, North Kordofan state, Sudan

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Abstract

Sudan is rich of water resources; however, the seasonal quality of water sources is largely unknown particularly in North Kordofan region. This study was designed to test the seasonal (winter, summer and autumn) quality of water sources in *El Obied*, North *Kordofan* State, Sudan. A number of 261 water samples (87 samples per season) were collected from *Hafirs (excavated either by hand or machine and used for storage of surface water), Gerab (big water containers made from plastic and used to store water at homes),* hand pumps, distribution network, households' containers and elevated water tanks in 2014/2015. Membrane filtration technique was used to investigate water samples. *Escherichia* coli or *E. coli* count was performed according to WHO and Sudanese Standards and Measurement Operation. The results illustrated that all samples collected showed positive results of *E. coli* which indicate poor water quality in the region. Proportion of contamination was highest in *Hafirs, Gerabs* and household containers across seasons. Hafirs samples were 100% contaminated across seasons. In autumn, Gerab and household containers samples showed 60% and 58% contaminated samples. In the summer season, the results showed 54% of Gerab, and 50% of the households' containers were contaminated. In winter season, prevalence of *E. coli* revealed that 67% of households' containers and 58% of Gerabs samples were contaminated. Greater contamination (60%) of the water sources was indicated in autumn followed by (55%) in winter and (51%) in summer season. Results showed significant contamination of water sources across seasons. Results indicated that elevated water tanks and hand pumps (groundwater sources) were safe compared with surface water source. The study recommended regular test to water sources across seasons to protect human and animal life.

Keywords Seasonality · Water quality · Water storage · *E. coli* · Sudan

Introduction

Poor water quality, sanitation and hygiene constitute serious problems in developing countries. A large proportion of the world's people do not have access to improved or microbiologically safe sources of water (WHO/UNICEF, 2014; World Health Organization 2002a) and approximately 2.1 billion people lack safe drinking water at home (WHO 2019). Two and a half billion people have no access to improved sanitation, and more than 1.5 million children die each year from diarrheal diseases (Fenwick 2006). For several decades, about a billion people in developing countries have not had a safe water supply (Hunter et al. 2010). A round 4 million people suffer from water borne diseases and 2.2 million people die from these diseases every year (WHO (2016), Clasen & Bastable (2003), and Simonovic, (2000). The problem is more severe in developing countries where generally the drinking water is untreated (Park 2007). USAID (2009) reported that access to water and sanitation are extremely low in rural areas in Sudan. Safe quality of water supplied to communities has an important consideration in the protection of human health and well-being. Therefore, Bashier et al. (2015) recommended frequent and routine qualitative analysis to water sources.

One of the pathogens that can be spread through drinking water and cause waterborne disease is bacteria. Bacteria particularly *E. coli* are one of the major contaminants of water

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(Suthar et al. 2009). *E. coli* have been reported to persist even in the extreme environmental conditions (Sigee 2005). *E. coli* is used as a water quality indicator because large numbers of the bacteria are always present in the feces of humans and other warm-blooded animals, but are not naturally found in water (CDC 2009). *E. coli* is a member of the fecal coliform group and is a more specific indicator of fecal contamination than other fecal coliform species (Khan 2020). Water may become unsafe at any point between collection and use (Gundry et al. 2006). Tadesse et al. (2010 and Adane et al. (2017) concluded that even if water was collected from a good microbial quality source, it may become contaminated during household's storage.

Literature recommends consideration of seasonal variation in water quality analysis, because seasonal variations in climate elements and surface runoff influence streams discharge and making pollutions in water ponds and *Hafirs*. Barakat et al. (2016) found that there were spatial and seasonal changes in surface water quality, which are usually indicators of contamination with rainfalls. Ward et al. (2020) found that in the dry season of Malawi, 18% of hand-pumped boreholes showed contamination, which increase to 21% in the wet season. Eregno et al. (2018) concluded that microbial contamination of recreational beaches is often at its worst after heavy rainfall events due to storm floods that carry fecal matter and other pollutants from the watershed.

Physical characteristic of water such as temperature, taste, color and smell can indicate water quality; however, water may look drinkable but contain bacterial contamination, which is not visible to eye. Therefore, this study identified quality of water sources using *E. coli* indicator across seasons of autumn, summer and winter in Sudan.

Study area

El Obied is the capital of North *Kordofan* state in Sudan located in the semi-desert region between latitude 13°11′N and longitudes 30°13′E (Fig. 1). The seasons in the region are autumn, winter and summer as detailed in (Table 1). Annual precipitation ranges from 170 to 350 mm from June to October. Maximum temperature is generally high ranging from 39.5 °C in the summer to 32.2 °C. Minimum temperature is ranging from 22.8 °C in autumn to 16.1 °C in winter. The total population of El Obeid town is 408 thousand people, 26% of them urban, 64% rural and 10% nomadic population. There are surface and groundwater sources. The surface water feeds the town by 70% of the required drinking water. It is collected from four *Hafirs* (water harvesting) at *Khor Bagara*, *Wad Al Baga*, *Al Aen* and *Bano,* where water stands for six months from June to November. This surface water pumped from the treatment plant to the town. Groundwater is collected from 18 wells in *Bara* Basin and *Elsidr* field. Agriculture and animal grazing constitute the major economic activities for the community. Scarcity of water slow development of the city as water is mainly pumped from Bara basin. *Elobied* is the center of the gum Arabic trade, which is one of Sudan's important exports.

Fig. 1 North *Kordofan* state, Sudan

Sample size and methods of data collection

A number of 261 water samples were collected from different water sources including *Hafirs, Gerab* (plastic cover container used to store water), hand pumps, distribution network, water distribution network, household containers and elevated water tanks (Table 2). This number of samples collected for three seasons of autumn, summer and winter (87 samples per each season were taken from the same sources) (Table 2). The samples of 100 ml each were examined across seasons from November 2014 to December 2015. Samples were retentive in cold container and analyzed in the North *Kordofan* public health laboratory within a maximum of six hours from the time of collection. Samples were incubated at 44 °C for 24 h. The study used membrane filtration technique (MFT) to detect and count *E. coli* which considered an evidence of fecal contamination and presence of pathogens. Scheutz and Strockbine (2005) stated that *E. coli* is uses as an indicator of microbiological water quality since the end of the nineteenth century. MFT was used to count *E. coli*. Then, samples were classified to positive/contaminated (MPN greater than 0.0 EC/100 ml) and negative/acceptable (MPN less than 0.0 EC/100 ml). Samples were statistically analyzed to test contamination across seasons. Observations were made on household water storage practices. This includes type of water storage containers, sanitary status, how was these facilities managed.

Table 1 Seasons in Sudan

Season	Length	Description	Temperatures (°C)	Precipitation	Average evaporation (mm/day)	Wind speed (Km/day)
Autumn	From June to October	Wet or rainy season	Minimum 22.8 maximum 35.10	Ranges from 170 to 350 mm	07	292
Winter	From November to March	The coldest season	Minimum 16.1 °C.to maximum 32.4 °C	No precipitation	7.2	318
Summer	April, May	Dry season	Minimum 23.4 °C to maximum 39.5 °C	No precipitation	8.5	294

Results and discussion

Physical characteristics of the water samples

Physical measurements of pH, turbidity and total dissolved solids (TDS) were carried out to detect changes in physical water quality. These measurements have the potential to be utilized more efficiently as early warning tools to check water quality. pH test is important because biological contamination can change a waters pH, which in turn can harm animals and plants living in the water. SSMO and WHO set maximum acceptable limit for TDS of 1000 mg/l; however, Alam et al. (2007) stated that the US Environmental Protection Agency 1976 set a guideline limit of 500 mg/l for the TDS. Turbidity indicates suspended sediment in water. It has been found that both turbidity and TDS were with the acceptable levels a cross season because water was stored in these sources for a longer period of time. The results indicated that pH average values were 7.5, in both autumn and winter and 6.9 for summer. The values were within the range of SSMO and WHO. It is within the optimum pH of water as confirmed by (Abdel-Magid 1997). TDS registered values were 353.5 mg/l, 385.7 mg/l and 378.3 mg/l in autumn, winter and summer, respectively. These values of TDS were below SSMO and WHO standards and within the acceptable limits (Table 3). Turbidity recorded 2.2NTU, 2.4NTU and 2.9NTU in autumn, winter and summer, respectively. The results found that turbidity was below the SSMO and WHO standards. The results showed that turbidity was less than 5 NTU which is acceptable to consumers. There are some water treatment plants, most of which are now aging, but contributed to reduce the turbidity to acceptable levels. In all investigated water sources, water was stored for a longer period of time to reduce turbidity. It is recommended that turbidity be kept as low as possible to drinkable water.

Seasonal contamination of water

Water quality during different seasons is variable because of different temperatures, increased storage times, different levels of airborne particulates (dust storms), floods and human practices. Surface water sources such *Hafirs* and ponds are much used in many populated areas; however, reports indicated that surface water sources are almost always polluted. Therefore, it should only be used if there are no other safe sources of water available (World Health Organization 2002b). Groundwater is cheap and usable for rural areas; however, groundwater is very rare and not available because the study area (*Elobied* city) lies in basement rock area. According to the WHO (2011) guidelines, *E. coli* should not be detectable in any water intended for drinking; however, all samples collected in the study area showed positive results of *E. coli* which indicate poor water quality in the region. The results showed that contamination of water sources varied from season to season with the highest level in autumn followed by winter and summer season (Fig. 2). During autumn, the heavy rainfall accumulated and runs off to *Hafirs* carrying a lot of pollutants and bacteria. Tolouei et al. (2019) confirmed that concentration of *E. coli* was positively correlated with waste water flow rate. The contamination of water may occur immediately following rainfalls because of the runoff. Summer season is the driest and hottest season in Sudan of high consumption rates of water. Generally, water scarcity occurs at summer season every year because of high water consumption rate and high evaporation from surface water sources. Winter season is the season of lowest consumption of water because of cold weather condition.

Quality of water sources versus seasons

During autumn season, the results showed that all (100%) of *Hafirs* water was contaminated with E coli across the seasons (Table 4). This is because *Hafirs* were open all the time and exposed to pollution. It has been observed that *Hafirs* were unprotected and impacted by open defecation practices of people in the tributaries. This result is in agreement with Amara, & Saad (2014), who found that biological quality of all studied *Hafirs* was very poor with very high levels of E coli in most seasons with peaks in June and minimum in

Table 2 Water sources, description and number of samples collected per season

Water sources	Source photo	Description	Number of samples per season (taken from same sources)
Hafir (surface water source)		"Hafir" is an Arabic word derived from Hafir, "to dig" it is excavated either by hand or machine and used for storage of surface water. It is capacity ranges from 500 to 10,000 m^3	05
Gerab (surface water source)		This is big water containers made from plastic and used to store water at homes in Elobied. It is big container difficult to keep it clean from inside	48
Hand pump (groundwater source)		Hand pumps is used to pump water from wells	07
Public elevated water tank (groundwater source)		Reservoirs used to store water. From these tanks, water is distributed directly to the consumers through pipelines network. The tanks used to store water either at home or public for a group of people	04
Basin landslide (both surface and groundwater source)		Big basin designed at home to store water. The tap at home normally leaves open to fill this basin because of unknown time when water will come	12

Table 2 (continued)

Water sources	Source photo	Description	Number of samples per season (taken from same sources)
Distribution network (both surface and groundwater source)		Pipelines used to distribute water from source to homes	11

December**.** The results illustrated that 65% of *Gerab* and 58% of household containers were highly contaminated during autumn. A 55% of the distribution network was also contaminated during autumn because the rain comes and runs off and then entered the network through leakages in the pipelines. Heavy rains may transport organisms from the soil to the groundwater and fecal contaminants from human excreta may also find their way to the wells' waters. In *Elobied* the *E. coli* may be washed into streams, *Hafirs,* or groundwater during rainfalls. The results indicated that surface water sources in *El Obied* region were contaminated with *E. coli* during rainy season. This result leads to possible hazardous presence of highly pathogenic bacteria of *E. coli* in water and potential high prevalence of diarrheal cases among the community. It was observed that water was stored in poor environment, poor personal hygiene and unsanitary practices such as leaving containers open exposed to children, insects and animals.

In the summer season, the results showed all *Hafirs*, 50% of the households' containers, 55% of the distribution network and 54% of Gerab were contaminated (Table 5). Elevated water tanks registered lower level of bacteria and hand pumps showed bacteria free. Low contamination in elevated water tanks and hand pumps was due to continuous and high consumption rate of water from these sources. In winter season, prevalence of *E. coli* revealed that *Hafirs* were risky source of water followed by 67% of households' containers and more than 58% of *Gerab*s (Table 5). This may be due to the act of wind blowing in winter which carries pathogens to uncovered storage containers (*Hafirs* and Basin landslide).

Total bacterial count was significantly associated with the *Hafirs* which account the highest total bacterial among all others sources followed by *Gerab,* household containers and distribution network. These results suggest contamination of water in households after collection as several studies confirmed contamination of water after being stored in households. Hand pumps water was the safest source of water across seasons. The result also showed the same picture of prevalence of bacteria with lower percentage (25%) in the elevated water tanks across seasons.

Results indicated that the pumped water and that stored in elevated water tanks were found to be safe sources. Groundwater is still and will continue to be the main source of safe and reliable drinking water, especially in rural areas in Sudan. Contamination of elevated water tank might be indirectly due to climate conditions and unsanitary practices (dirty containers that use to bring water) and poor personal hygiene. Groundwater is relatively free from pathogenic agents, and therefore, it is generally preferred as source for municipal water supplies (Park 2007). Poor sanitary practices a round water sources that are also one of the causes of contamination as confirmed by Cosgrove, (2000). It has

Table 3 Physical characteristics of water samples

Parameters	SSMO (2008)	World Bank (1993)	Autumn	Winter	Summer
pH	6.6—8.5	Less than 8	7.5	7.5	6.9
TDS (mg/l)	1000	1000	353.5	385.7	378.3
Turbidity (NTU)	5	5	2.2	2.4	1.9

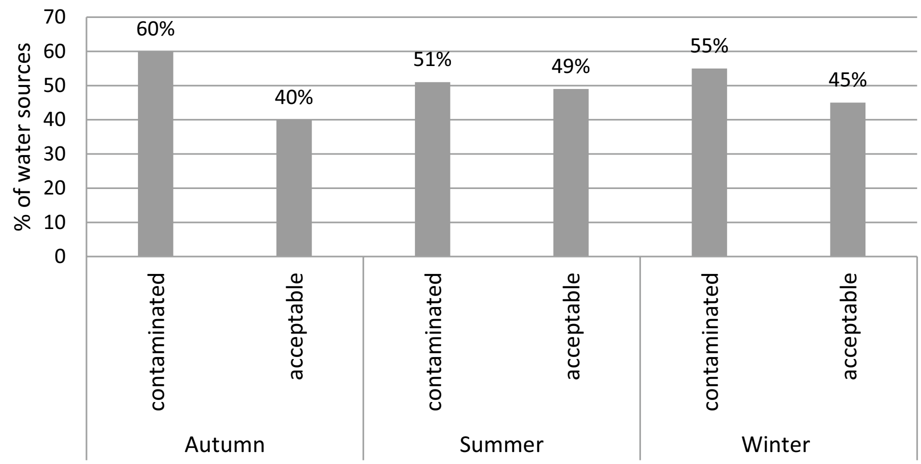

Fig. 2 Seasonal quality of water sources

Table 4 Percent of seasonal *E. coli* in different water sources

Water source	Number of samples per each season	Contaminated samples (87 samples per each season)		
		Autumn	Summer	Winter
Gerab	48 (55.17)	31 (35.6)	26 (29.9)	28 (32.2)
Hafirs	5 (5.75)	5 (5.75)	5 (5.75)	5 (5.75)
Hand pumps	7 (8.01)	2 (2.29)	0 (0.0)	0 (0.0)
Elevated tanks	4 (4.59)	1 (1.14)	1 (1.14)	1 (1.14)
Distribution network	11 (12.64)	6 (6.89)	6 (6.89)	5 (5.75)
Household containers	12 (13.79)	7 (8.01)	6 (6.89)	8 (9.19)
Total	87 (100)	52 (59.8)	44 (50.5)	48 (55.2)

been observed that there were many animals left free to contaminate water with their fecal matters when washed away with water runs off. Statistical analysis, one-sample t test, showed significant contamination (p 0.000) of water sources across seasons (Table 5). Elevated water tanks which filled from groundwater wells showed significant contamination (p 0.006).

Conclusion

The study found that the water sources in *Elobied* region were significantly contaminated across seasons. Contamination of water sources varied from season to season with the highest level in autumn followed by winter and summer. Highest contamination in water sources was found in *Hafirs* followed by *Gerab,* household containers and distribution network. Information in this study suggests treatment of water before use particularly *Hafirs* water as main sources of water to a greater number of rural communities in North *Kordofan* state. The community should be advised to keep water free of contamination at storage containers in homes. The study provides information on seasonal water quality and polluted sources which will help to sustainably manage and use water sources toward healthy human and animal life.

Table 5 One-Sample Test

Seasonal water sources	t	df	Sig. (2-tailed)	Mean difference	95% Confidence interval of the difference	
					Lower	Upper
Gerab autumn	19.411	47	.000*	1.35417	1.2138	1.4945
Gerab summer	20.065	47	.000*	1.45833	1.3121	1.6045
Gerab winter	19.700	47	.000*	1.41667	1.2720	1.5613
Hand pumps autumn	9.295	6	.000*	1.71429	1.2630	2.1656
Elevated tanks autumn	7.000	3	.006*	1.75000	.9544	2.5456
Elevated tanks summer	7.000	3	.006*	1.75000	.9544	2.5456
Elevated tanks winter	7.000	3	.006*	1.75000	.9544	2.5456
Distribution network autumn	9.238	10	.000*	1.45455	1.1037	1.8054
Distribution network summer	9.238	10	.000*	1.45455	1.1037	1.8054
Distribution network winter	9.815	10	.000*	1.54545	1.1946	1.8963
Households autumn	10.652	11	.000*	1.58333	1.2562	1.9105
Households summer	9.950	11	.000*	1.50000	1.1682	1.8318
Households winter	9.381	11	.000*	1.33333	1.0205	1.6462

*Significant at 95% confidence level

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Declarations

Conflict of interest There is no conflict of interest.

References

Abdel-Magid H. M. (1997), Assessment of drinking water quality in Al-Gassim region of Saudi Arabia, Environ Int, l23, 247–251
Adane M, Mengistie B, Medhin G, Kloos H, Mulat W (2017) Piped water supply interruptions and acute diarrhea among under-five children in Addis Ababa slums, Ethiopia: a matched case-control study. PLoS ONE 12(7):e0181516
Alam B, Islam R, Muyen Z, Mamun M, Islam S (2007) Water quality parameters along rivers. Int J Environ Sci Tech 4(1):159–167
Amara, H. M., & Saad, S. A. (2014). Seasonal variation of Hafirs water quality in north Kordufan state, Sudan. Int J Sci Toxicol Res
Barakat A, El Baghdadi M, Rais J, Aghezzaf B, Slassi M (2016) Assessment of spatial and seasonal water quality variation of Oum Er Rbia River (Morocco) using multivariate statistical techniques. Int Soil Water Conser Res 4(4):284–292
Bashier EE, Bashir NH, Mohamadani A, Elamin SO, Abdelrahman SH (2015) A challenge of sustaining water supply and sanitation under growing population: a case of the Gezira state. Int J Water Resour Environ Eng, Sudan. https://doi.org/10.5897/IJWREE2015
CDC (2009). E. coli from Source to tap Canadian council of the environment. Canadian Drinking Water Policy. pp 301–320.
Clasen TF, Bastable A (2003) Fecal contamination of drinking water during collection and household storage: the need to extend protection to the point of use. J Water Health 1(3):109–115
Cosgrove WJ, Rijsberman FR (2000) Challenge for the 21st century: making water everybody’s business. Sustain Dev Int 2:149–156
Eregno FE, Tryland I, Tjomsland T, Kempa M, Heistad A (2018) Hydrodynamic modelling of recreational water quality using Escherichia coli as an indicator of microbial contamination. J Hydrol 561:179–186
Fenwick A (2006) Waterborne infectious diseases: could they be consigned to history? Science 313(5790):1077–1081
Gundry, S. W., Wright, J. A., Conroy, R., Du Preez, M., Genthe, B., Moyo, S., & Potgieter, N. (2006). Contamination of drinking water between source and point-of-use in rural households of South Africa and Zimbabwe: implications for monitoring the Millennium Development Goal for water. Water Pract Technol, 1(2).
Hunter PR, MacDonald AM, Carter RC (2010) Water supply and health. PLoS Med 7(11):1350
Khan, F. M. (2020). *Escherichia coli* (*E. coli*) as an indicator of fecal contamination in water: a review.
Park, JE (2007).'Text book of preventive and social medicine'. Nineteen edition. Jabalpur 482001, India, 107–130.
Sigee DC (2005) Freshwater Microbiology: biodiversity and dynamic interactions of microorganisms in the aquatic environments. John Wiley & Sons Ltd. Chi Chester, West Sussex, England. pp. 287–336.
Simonovic SP (2000) One view of the future. Water Int 25(1):76–88
SSMO, Sudanese standards and Metrology organization (2008) Drinking water guidelines bulletin, Sudan

Suthar S, Chhimpa V, Singh S (2009) Bacterial contamination in drinking water: a case study in rural areas of northern Rajasthan India. Environ Monit Assess 159(1–4):43

Tadesse D, Desta A, Geyid A et al, (2010) Rapid assessment of drinking water quality in the federal democratic Republic of Ethiopia: country report of the pilot project implementation in 2004–2005. Geneva: WHO UNICEF

Tolouei S, Burnet JB, Autixier L, Taghipour M, Bonsteel J, Duy SV, Dorner S (2019) Temporal variability of parasites, bacterial indicators, and wastewater micropollutants in a water resource recovery facility under various weather conditions. Water Res 148:446–458

USAID, (2009), Sudan water and sanitation profile. http://www.usaid.gov/pdf.docs/PNADO 924.pdf

Ward JS, Lapworth DJ, Read DS, Pedley S, Banda SC, Monjerezi M, MacDonald AM (2020) Large-scale survey of seasonal drinking water quality in Malawi, using in situ tryptophan-like fluorescence and conventional water quality indicators. Sci Total Environ 744:140674

World Bank (1993) World development report 1993: investing in health, vol 1. The World Bank

World Health Organization (2011) Guidelines for drinking-water quality, 4th edn. WHO, Geneva, Switzerland

WHO/UNICEF Joint Water Supply, & Sanitation Monitoring Programme (2014) Progress on drinking water and sanitation: 2014 update. World Health Organization

World Health Organization (2002a) Message from, Dr Hussein A. Gezairy, regional director, WHO eastern mediterranean region, to the informal consultation on healthy environments for children in the Eastern Mediterranean Region, Amman, Jordan, 3–4 November 2002.

World Health Organization (2002b) The world health report 2002: reducing risks, promoting healthy life. World Health Organization

World Health Organization. (2016). United nations children's fund joint monitoring programme for water supply and sanitation, (JMP). Progress on drinking water and sanitation: special focus on sanitation [Internet]. UNICEF, New York and WHO, Geneva; 2008.

World Health Organization, (2019). Progress on household drinking water, sanitation and hygiene 2000–2017: special focus on inequalities. World Health Organization