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

Wesal Edam1 · Eltigani E. Abdelgalil2

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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...
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.

**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. Schertz 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.
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 water's 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 within acceptable levels across 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
| 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 m³ | 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                                                    |
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 Gerabs (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 2 (continued) |
|---------------------|
| **Water sources**   |
| **Description**     |
| Source photo        |
| Number of samples per season (taken from same sources) | 11 |
| Distribution network (both surface and groundwater source) |
| Pipelines used to distribute water from source to homes |

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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 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

| Water source | Number of samples per each season | Contaminated samples (87 samples per each season) |
|--------------|-----------------------------------|--------------------------------------------------|
|              | Autumn | Summer | Winter | Autumn | Summer | Winter |
| Gerab        | 48 (55.17) | 31 (35.6) | 26 (29.9) | 28 (32.2) | 24 (27.3) | 27 (30.1) |
| Hafirs       | 5 (5.75) | 5 (5.75) | 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) | 0 (0.0) | 0 (0.0) |
| Elevated tanks | 4 (4.59) | 1 (1.14) | 1 (1.14) | 1 (1.14) | 1 (1.14) | 1 (1.14) |
| Distribution network | 11 (12.64) | 6 (6.89) | 6 (6.89) | 5 (5.75) | 5 (5.75) | 5 (5.75) |
| Household containers | 12 (13.79) | 7 (8.01) | 6 (6.89) | 8 (9.19) | 8 (9.19) | 8 (9.19) |
| Total        | 87 (100) | 52 (59.8) | 44 (50.5) | 48 (55.2) | 48 (55.2) | 48 (55.2) |

### 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 | Autumn | Summer | Winter |
| Gerab        | 48 (55.17) | 31 (35.6) | 26 (29.9) | 28 (32.2) | 24 (27.3) | 27 (30.1) |
| Hafirs       | 5 (5.75) | 5 (5.75) | 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) | 0 (0.0) | 0 (0.0) |
| Elevated tanks | 4 (4.59) | 1 (1.14) | 1 (1.14) | 1 (1.14) | 1 (1.14) | 1 (1.14) |
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| Household containers | 12 (13.79) | 7 (8.01) | 6 (6.89) | 8 (9.19) | 8 (9.19) | 8 (9.19) |
| Total        | 87 (100) | 52 (59.8) | 44 (50.5) | 48 (55.2) | 48 (55.2) | 48 (55.2) |
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Declarations

Conflict of interest  There is no conflict of interest.

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Table 5  One-Sample Test

| Seasonal water sources     | t    | df  | Sig. (2-tailed) | Mean difference | 95% Confidence interval of the difference |
|----------------------------|------|-----|----------------|-----------------|------------------------------------------|
| 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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