Research Paper

Determinants of microbiological quality of drinking water in refugee camps and host communities in Gambella Region, Ethiopia

Getachew Kabew Mekonnen, Bezatu Mengistie, Geremew Sahilu, Worku Mulat and Helmut Kloos

ABSTRACT

Inadequate improved water supply and sanitation, particularly in refugee camps contribute to the spread of infectious diseases. The study objective was to assess determinants of microbiological quality of drinking water in refugee camps and host communities in Gambella Region, Ethiopia. A cross-sectional study was conducted from September to December 2016 based on structured questionnaire-based interviews and testing household water using the portable Potatest^{+} water quality testing kit. Data were analyzed and P values <0.05 with 95% confidence interval (CI) were considered statistically significant. Results showed there were significant differences in fecal coliform count (P value $= 0.009$) and free residual chlorine concentration (P value $= 0.01$) between the source and stored water samples. Surface water source, water shortages in the previous month, and unavailability of free residual chlorine and caregivers without formal education were the main determinants of microbiological quality of stored water. Stored water was contaminated in many households in both the refugee and host communities. Designing and implementing appropriate community education and effective hygiene promotion programs are essential in improving community knowledge of water contamination and reducing diarrhea prevalence among under-five children in refugee camps and host communities in Gambella Region.

Key words | Ethiopia, fecal coliform, refugees, under-five children, water quality

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ABBREVIATIONS

AAU	Addis Ababa University
ARRA	Administration for Refugees and Returnees Affairs
EIWR	Ethiopian Institute of Water Resources
FRC	free residual chlorine
FC	fecal coliform
UNHCR	United Nations High Commissioner for Refugees
WASH	Water, Sanitation and Hygiene
WHO	World Health Organization

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BACKGROUND

Communities in developing countries obtain their drinking water from various water sources. However, surface and ground water sources can become contaminated by biological and chemical pollutants originating from point and non-point sources (Ali *et al.* 2012). Inadequate water supply and sanitation, particularly in conflict areas with large numbers of internally displaced people or refugees, contribute to spreading infectious diseases (Theron & Cloete 2002). Diarrheal diseases caused 446,000 deaths each year, contaminated drinking water accounted for 72.1%, while inadequate sanitation was associated with 56.4% deaths from diarrhea (Masquelier *et al.* 2018).

Systematic reviews indicated the risk of diarrhea in under-five children to be lower with any water quality intervention compared to no intervention (Cairncross *et al.* 2010; Clasen *et al.* 2015). Water quality improvements may significantly reduce rates of child diarrhea morbidity (Waddington *et al.* 2009). However, the water supply in many developing countries is often either inadequate or unsafe to meet basic health needs (WHO/UNICEF 2014). In 2015, 844 million people worldwide lived without access to improved water supply and 159 million people collected drinking water directly from surface water sources; 58% of them lived in sub-Saharan Africa (WHO/UNICEF 2015). Inadequate water and sanitation provision has been documented in camps of refugees and internally displaced persons in many sub-Saharan African countries (Sherlock 2006; Shrestha & Cronin 2006). In rural Ethiopia, the rate of childhood diarrhea remains high (WHO/UNICEF 2014) and the average domestic water consumption is much lower than the recommended amount (Kumie & Ali 2005). An estimated 43% of the Ethiopian population had no access to safe water and 72% had no access to basic sanitation services (FDRE-MOH 2015). Refugee camps with high population densities and rural communities in remote areas, including Gambella Region, may not have access to safe drinking water (Sherlock 2006).

Although improved sources generally delivered safe water at the point-of-supply, the quality of drinking water often deteriorates during distribution and transport to the home and subsequent storage (Gundry *et al.* 2006). Still unknown factors and substantial variation of determinants influencing water quality were observed by various studies (Clasen *et al.* 2007a). Some socio-demographic characteristics such as educational level, family size, occupation, and availability of sanitation facilities may be associated with drinking water quality (McGarvey *et al.* 2008). Behavioral factors related to variations in household water management such as type of water containers, transportation, storage conditions, hand washing, and waste disposal practices play major roles in water contamination at the household level (Bastaraud *et al.* 2018). Therefore, water kept in household containers may contain significantly more fecal bacteria than water at the source (Clasen & Cairncross 2004), and the high degree of contamination of drinking water in households poses a health hazard to consumers (Tallon *et al.* 2005). The presence of fecal coliform is usually used as the sole indicator of fecal contamination (Tallon *et al.* 2005). The World Health Organization (WHO) guidelines for drinking water quality recommend no fecal coliform and a minimum concentration of 0.2 to 0.5 mg/L free residual chlorine at water system delivery points under normal circumstances (WHO 2008). Water testing plays an important role in ensuring the correct operation of water supplies, verifying the safety of drinking water at point of use, investigating disease outbreaks, and validating processes and preventative measures (WHO 2008).

Few studies have systematically assessed determinants of water quality and reported health impacts in developing countries. Laboratory testing facilities at fixed sites are not always the most practical or readily available means to evaluate drinking water quality (WHO 2008). Furthermore, water sample transportation within the recommended time frame and temperature range is often impractical in rural areas in developing countries (Rice *et al.* 2012). In poorly accessible and insecure areas where there are no laboratory facilities, a more robust and portable kit is required to provide critical water quality information. These conditions necessitate detailed research on how household socio-demographic and WASH factors influence water quality in refugee and host communities using a portable water quality technique. Various commercial membrane filtration-based field test kits are available to perform testing of microbiological indicators in remote areas and refugee contexts. Therefore, this study was conducted to evaluate the microbiological quality of water at the source and household levels and its determinants in two refugee camps and three host communities using the Wagtech Potakit, one of the portable, affordable, and self-contained kits for water quality monitoring identified by the WHO/UNICEF (2006).

MATERIALS AND METHODS

Study area and populations

Gambella town is located 753 km west of Addis Ababa, the capital of Ethiopia. Gambella Region is subdivided into four administrative zones and one special district. In 2017, the Central Statistical Agency (CSA) estimated Gambella's population size to be 435,999, three-quarters of whom live in rural areas. Despite its relatively small size, the region is quite diverse, ethnically (CSA 2013). Gog District is located in Zone 2 and had a population of 24,768; most of the Agnuak ethnic group. Ethiopia sheltered 889,071 registered refugees and asylum seekers in 2015, and South Sudanese refugees who are scattered in various locations across western Ethiopia represented the majority, 411,366 (46%) of the total refugee population (UNHCR 2015). Pugnido camp hosted 62,751 of South Sudanese refugees followed by Teirkidi, Kule, and Jewi sites which received 52,222, 47,444, and 46,139 individuals, respectively. For financial and logistic reasons the study was conducted in the randomly selected Pugnido and Teirkidi refugee camps and three neighboring *Kebeles* of the host communities (Figure 1).

Sample size determination and sampling procedures

A cross-sectional study was conducted from September to December 2016 in Pugnido and Teirkidi refugee camps and in the host communities of Tata and Pugnido *kebeles* in Gog District. Microbiological quality of water at the source and household levels was assumed as proxy indicators of diarrhea morbidity in children under five years of age. The typical formula stated (Bhandari & Grant 2007) was used to calculate the sample size by taking the 1,782 surveyed households, at 95% confidence level with a precision level of 5%. $n = NZ^2{*}p{*}\ (1-p)/Nd^2 + Z^2{*}p\ (1-p)$, where n is the

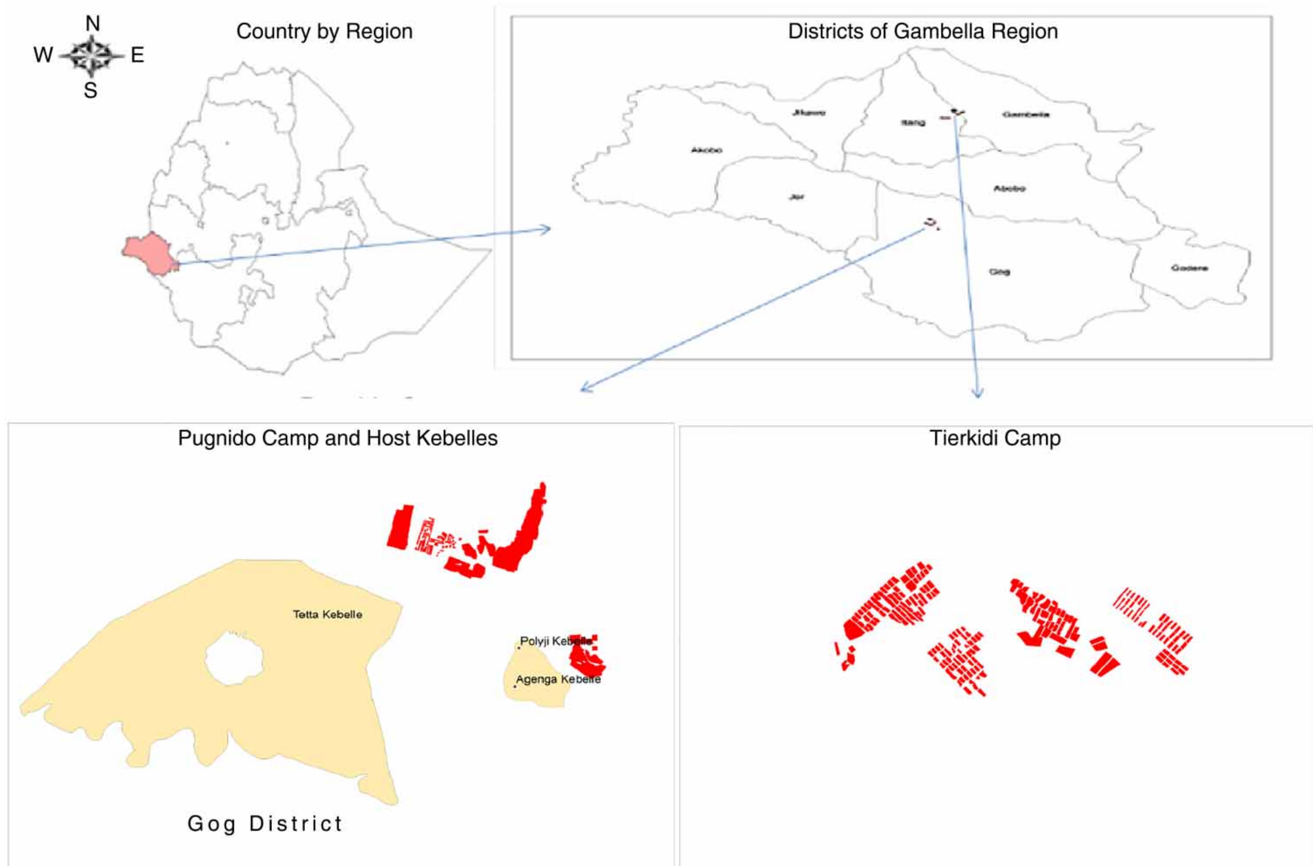

Figure 1 | Map of the study area.

sample size, N the total number of surveyed households, Z at 95% CI = 1.96, p the estimated population proportion of 0.5 which maximizes the sample size and d the error limit of 5% which is equal to 0.05. The computed 314 household (157 from each community) samples, 18% of the surveyed population was adequate to evaluate the microbiological quality of drinking water and identify its determining factors.

Data collection

A diarrhea survey was conducted randomly in 1,782 households with at least one under-five child prior to this study. The systematic random sampling technique was employed to select the 314 samples from these surveyed households. Samples were distributed over the study sites proportional to the target households. We used a questionnaire to collect information on socio-demographic characteristics and certain WASH factors which may influence water quality and child diarrheic status. The questionnaire was developed in the English language and then translated into the local Nuer and Agnuwak languages for better communication with the study subjects. Persons responsible for handling water in the household, usually the mothers or eldest daughters, were interviewed. The interviews were conducted by trained data collectors who had completed at least their secondary education and were able to write, read, and understand English. A 100 mL water sample was collected from the 306 selected households and from 51 (34%) of the direct water sources. Water samples were analyzed by the principal investigator to determine the level of fecal contamination of drinking water at the source and household levels.

Microbiological water quality test

The comprehensive Wagtech portable water testing kit allows tests to be carried out in remote areas following WHO guidelines. We used the portable water quality testing kit (WAG-WE10030 – Wagtech Potatest$^+$ Kit) to measure fecal coliform counts and free residual chlorine (WHO 2004). Samples were collected using serving cups from the same containers households routinely used to collect water for drinking and by pouring the water into 100 mL uncontaminated plastic bottles. We tightly covered the bottles with the stoppers and adhered to aseptic techniques. Each bottle was labeled with an identification number, and we recorded the time of sampling. All samples were stored in a small cold box with ice packs immediately after collection until tested within 6 hours of collection. We filtered 100 mL water samples using 0.45 mm pore size, 47 mm diameter filter membrane and incubated the loaded petri-dish rack at 44 °C for 14 hours following 1 to 4 hours resuscitation at 35 °C. Then, we inspected the plates for growth of fecal coliforms systematically, column by column in the grid. We counted all the yellow colonies irrespective of colony size using a hand lens within a few minutes, as the colors are likely to change on cooling and standing. The values are recorded as number of fecal (thermo-tolerant) coliforms or CFU per 100 mL of water.

Chlorine residual testing

One hour after the addition of sodium hypochlorite solution to water there should be an average of 0.5 mg/L of free chlorine residual present. Twenty-four hours after the addition of sodium hypochlorite, the storage water should have 0.2 mg/L to 2.0 mg/L of free chlorine residual present to ensure microbiologically clean water (CDC 2012). Chlorine residual at direct sources and from household storage containers was tested using the Wagtech potatest$^+$ Kit. The test allows for assessment of water quality delivered from the water utility to the home and may also help to evaluate changes in water quality at home that occurred as a result of poor hygiene practices or other reasons. Free residual chlorine (FRC) concentrations were measured in all water samples using diethyl-phenylene diamine (DPD) reagents, which are provided in tablet form for convenience and simplicity of use. We added one DPD1 tablet into each test tube, filled the test tube with sample water to the 10 mL mark and shook it vigorously to let the free chlorine react with DPD to produce coloration. The intensity of the pink color is proportional to the free residual chlorine concentration. The color intensities were measured by comparing against color standards using a Wagtech Comparator. The disk reading represents the free chlorine residual as milligrams per liter.

Data analysis

We considered water samples with <1 CFU/100 mL to be uncontaminated and samples with ≥ 1 CFU/100 mL to be contaminated. The fecal coliform count contamination levels in the drinking water samples were categorized into 0 (none), 1–10 (low risk), 11–100 (moderate risk) and >100 CFU per 100 mL (high risk) (WHO 2004). We reported the arithmetic mean count for sub-sets of the contaminated samples. All statistical analyses were done using STATA Version 13. Descriptive statistics of study subjects or household-level characteristics and WASH factors were reported as proportions, means, and ranges. Bivariate and multivariate models were used to assess the association of socio-demographic and WASH factors with fecal coliform count. Mann–Whitney U test was used to evaluate the relationship between presence of fecal coliform bacteria and free residual chlorine in drinking water at source and in storage vessels. *P* value 0.05 with 95% confidence intervals was taken as a cutoff point of statistical significance.

Quality control

Training was provided by the principal investigator to ten data collectors and three supervisors a week before the commencement of the study. The questionnaire was pre-tested in households in Jawi Refugee Camp, and necessary corrections were made accordingly. We checked the data for consistency and completeness**.** Water samples were collected in a sterile sample bottle, stored on ice, and processed within 4 hours of collection. *Escherichia coli* (ATCC 25922) strain infused water was used as a positive control, and 100 mL of sterile distilled water as negative control were processed after every 20th sample to ensure that the equipment had been adequately sanitized. The standard method for testing of the drinking water quality was maintained as per World Health Organization guidelines (WHO 2008).

RESULTS

Household characteristics

The study included 306 households with an average of 6 (±SD, 2.36) person per household, and the response rate was 97.5%. The refugee households comprised 156 (51%) households; 73 in Turkiedi and 83 in Pugnido refugee camps. One hundred and fifty (49%) of the households were from the host communities; 62 were in Tata rural *Kebele* and 88 in Pugnido urban *Kebele*. The great majority of the caregivers (292, 95.4%) were females and the mean age of the caregivers was 28.7 years (range 15–47 years), of whom 140 (45.8%) had never received formal education (Table 1). The mean age of children included in this study was 20.6 months.

Water supply and water handling in the study area

Teirkidi refugee camp is supplied with water from four borehole water sources, each of which pumped 12–13 L/second to a common collection tank. Water was centrally treated using an automatic chlorine pump. In Teirkidi, chlorine treated water is pumped to two reservoirs that distribute water to the refugee community via 43 public standpipes. Tankers distributed the treated water in the refugee camps because it was a communal system of piping water to public taps from which the households were collecting drinking water. Similarly, Pugnido refugee camp had six boreholes and matching reservoirs with 94 public standpipes. The studied host community households were supplied with water from two boreholes piped directly to public taps, ten tube well water sources and surface water sources. No routine chlorination of water was practiced prior to distribution in the host communities.

Fifty-one water samples were collected from water sources and 306 samples from containers in selected households. In this study, 31 (60.8%) source samples were collected from refugee camps and 20 (39.2%) samples from the hosting communities. The study revealed that 224 (73.2%) of the households were using piped water, followed by surface water (48, 15.7%), and tube wells (34, 11.1%). Water was not always available for 214 (69.6%) of the households due to interruptions in the supply. Household-level water treatment was uncommon, and reported by only eight (2.6%) of the households (Table 1).

Free residual chlorine concentrations

Free residual chlorine was detected in 34 (66.7%) of the water samples from direct sources, with an average of 0.17 mg/L. The mean free residual chlorine concentration was 0.235 in piped water and 0 in samples of both hand-pumped well and surface water (Table 2). Generally, free

Table 1 | Household characteristics of the study participants by community type in Gambella Region, Ethiopia, 2016

Variable	Refugee community number (%)	Host community number (%)	Total number (%)
Sex of the respondent			
Female	148 (94.9)	144 (96.0)	292 (95.4)
Male	8 (5.1)	6 (4.0)	14 (4.6)
Respondents' highest educational level			
No formal education	79 (50.6)	61 (40.7)	140 (45.8)
Primary school (1–8 grade)	49 (31.4)	45 (30.0)	94 (30.7)
Secondary school (9–12 grade)	18 (11.5)	23 (15.3)	41 (13.4)
Diploma and above	10 (6.4)	21 (14.0)	31 (10.1)
Household size			
<5	44 (28.2)	42 (28.0)	86 (28.1)
≥5	112 (71.8)	108 (72.0)	220 (71.9)
Availability of latrine			
Yes	113 (72.4)	81 (54.0)	194 (63.4)
No	43 (27.6)	69 (46.0)	112 (36.6)
Type of water source			
Piped water	156 (100)	68 (45.3)	254 (73.2)
Tube well	–	34 (22.7)	34 (11.1)
Surface water	–	48 (32.0)	47 (15.7)
Water availability at direct source			
Daily for ≥8 hours	46 (29.5)	46 (30.7)	92 (30.1)
Daily for less than 8 hours a day	99 (63.6)	92 (61.3)	191 (62.4)
Not daily	11 (7.1)	12 (8.0)	23 (7.6)
Water storage method			
All covered	50 (32.1)	54 (36.0)	104 (34.0)
Some covered	60 (38.5)	64 (42.7)	124 (40.5)
All uncovered	46 (29.5)	32 (21.3)	78 (25.5)
Method of obtaining water			
Dipping with cup	42 (26.9)	34 (22.7)	77 (24.8)
Pouring	48 (30.8)	55 (36.7)	103 (33.7)
Both dipping and pouring	66 (42.3)	61 (40.6)	126 (41.1)
Household water treatment			
Yes	4 (2.6)	4 (2.7)	8 (2.6)
No	152 (97.4)	146 (97.3)	298 (97.4)
Free residual chlorine concentration (mg/L) in store water samples			
0	30 (19.2)	134 (89.3)	164 (53.6%)
>0 to <0.2	52 (33.3)	4 (2.7)	56 (18.3%)
0.2–0.5	68 (43.6)	12 (8.0)	80 (26.1%)
>0.5	6 (3.8)	0 (0.0)	6 (2%)
Fecal coliform in store water samples (CFU/100 mL)			
None (0)	80 (51.3)	43 (28.7)	123 (40.2)
Low (1–10)	31 (19.9)	31 (20.7)	62 (20.3)
Moderate (11–100)	30 (19.2)	35 (23.3)	65 (21.2)
High (≥101)	15 (9.6)	41 (27.3)	56 (18.3)

Table 2 | Water quality analysis results for samples collected at source points in the refugee camps and host communities in Gambella Region, 2016

Source	No. of sample tested	No. (%) of samples contaminated	Free residual chlorine (mean)	Fecal coliform count (mean)	WHO Standard
Piped water	38	9 (23.7)	0.235	7.6	0/100 mL
Hand pump	4	2 (50)	0	7.5	0/100 mL
Surface water	9	7 (77.8)	0	205	0/100 mL

residual chlorine was detected in 142 (46.4%) of the household-level stored water samples with a mean of 0.1 mg/L (±SD, 0.17). Free residual chlorine was detected in 126 (80.8%) and 16 (10.7%) of stored samples in the refugee camps and host communities, respectively. The Mann–Witney test showed that free residual chlorine concentrations were significantly higher at the source than the stored water samples in the refugee camp ($P < 0.001$) and host communities ($P < 0.001$).

Fecal coliform counts

Fecal coliform was isolated from 183 (59.8%) of stored and 18 (35.3%) source water samples. One hundred and seven (71.3%) stored samples from the host communities and 76 (48.7%) of stored water samples from the refugee camps were positive for fecal coliforms. The mean fecal coliform counts were 7.6 CFU/100 mL in piped water, 7.5 in hand pumps, and 205 in surface water samples. The arithmetic mean of fecal coliform counts in water samples collected from storage containers was 49.5 (±SD, 135.9). Fecal coliform counts were above the low-risk limit of 10 CFU/100 mL in 121 (39.5%) of household water samples and 56 (18.3%) samples exceeded the moderate risk limit of 100 CFU/100 mL. Conversely, only 11 (21.6%) of the source samples had fecal coliform counts over the low risk limit. The fecal coliform counts in the stored water samples were significantly higher than in source samples ($P = 0.009$) (Table 3).

Multivariate analysis of determinants of storage water quality

Logistic regression was used to estimate the odds of unsafe water quality by determining the binary outcome (potable water is equal to 1 if there is 1 or more fecal coliform colonies forming units per 100 mL water and non-potable water is 0). Multivariate logistic regression analysis was carried out to identify determinants with P values less than or equal to 0.2 in bivariate analyses. The associations between some factors and drinking water fecal contamination remained significant after further adjustment for confounders. This study shows that types of primary water sources influence storage water quality. Households which used surface

Table 3 | Mann–Whitney U test to examine the relationship between presence of fecal coliform bacteria and free residual chlorine and drinking water at source and storage vessels in the refugee camps and host communities in Gambella Region, 2016

	Refugee communities			Host communities			Overall		
Statistical parameter	Source samples, $n = 20$	Stored samples, $n = 150$	P value	Source samples, $n = 31$	Stored samples, $n = 156$	P value	Source samples, $n = 51$	Stored samples, $n = 306$	P value
Free residual chlorine (mg/L)									
Mean	0.27	0.19		0.043	0.025		0.16	0.1	
Median	0.2	0.1	0.000[a]	0	0	0.018[a]	0.1	0.0	0.01[a]
Range	0–1	0–1		0–0.2	0–0.5		0–1.0	0–1.0	
Fecal coliform (CFU/100 mL)									
Mean	5.7	26		79.1	73.3		42.4	49.5	
Median	0	0	0.001[a]	7	12	0.398	0	4	0.009[a]
Range	0–120	0–1,124		0–1,010	0–1,243		0–1,010	0–1,243	

[a]Indicates statistically significant difference between the source and stored water samples at $P < 0.05$.

water had significantly higher odds compared to households using piped water (AOR: 4.83, 95% CI (1.55 15.05)).

Households with caregivers who had no formal education were significantly more associated with fecal coliform contamination of water than households with caregivers who had completed secondary education (AOR: 2.35, 95% CI (1.18 4.68)) (Table 4). This study also revealed that households which suffered from drinking water shortage within the previous month had significantly higher fecal contamination than their counterparts (AOR: 1.93, 95% CI (1.1 3.40)). Moreover, household drinking water lacking free residual chlorine was significantly more contaminated with fecal coliforms than drinking water which had free residual chlorine (AOR: 6.05, 95% CI (3.11 11.76)). Storage water fecal coliform contamination status had no significant relationship with availability of latrines (OR: 0.72, 95% CI: 0.41 1.28), type of water container: wide-mouthed containers (OR: 0.84, 95% CI: 0.38 1.86), dipping water from containers (OR: 0.98 95% CI: 0.46 2.07), and household water treatment (OR: 2.46, 95% CI 0.44 13.8).

Table 4 | Independent determinants of contamination of stored drinking water with fecal contamination in refugee and host communities in Gambella Region, 2016

Variable	Unadjusted ORs (95% CI)	Adjusted ORs (95% CI)	*P* value	Reference category
Host communities	2.62 (1.63–4.20)	0.53 (0.22–1.27)	0.17	Refugee
Caregivers without formal education	1.77 (0.99–3.16)	2.35 (1.18–4.68)	0.015[a]	Caregivers completed secondary education and above
Caregivers completed primary education	1.11 (0.60–2.05)	1.3 (0.62–2.71)	0.49	
No latrine	1.12 (0.7–1.81)	0.72 (0.41–1.28)	0.27	Latrine available
Hand pump	1.45 (0.69–3.04)	0.81 (0.34–1.93)	0.63	Standpipe water
Surface water	9.88 (3.44–28.4)	4.83(1.55–15.05)	0.007[a]	
Wide-mouthed water container	0.8 (0.41–1.56)	0.84 (0.38–1.86)	0.67	Narrow-mouthed water container (≤3 cm diameter)
Both types water container	0.78 (0.45–1.34)	0.98(0.5–.91)	0.95	
Water not stored in a separate container	1.41 (0.89–2.23)	1.49 (0.88–2.54)	0.14	Drinking water kept in a separate container
Container kept on the floor inside the home	2.65 (0.73–9.67)	1.4 (0.32–6.24)	0.65	Drinking water container kept in an elevated place
Container kept anywhere outside the home	1.46 (0.38–5.62)	0.74 (0.15–3.7)	0.72	
Dipping	1.01(0.55–1.86)	0.98 (0.46–2.07)	0.95	Pouring to take out water
Both pouring and dipping	0.96 (0.56–1.62)	1.08(0.52–2.23)	0.83	
Water container appeared not clean	1.52 (0.96–2.42)	1.49 (0.87–2.55)	0.15	Water container appeared clean
No household water treatment	2.54 (0.60–10.8)	2.46 (0.44–13.8)	0.31	Household water treatment practiced
Water shortage within the last one month	1.41 (0.87–2.27)	1.93 (1.1–3.40)	0.023[a]	No water shortage within the last one month
Zero FRC concentration	7.11 (4.0–12.71)	6.05 (3.11–.8)	0.00[a]	≥ 0.2 mg/L FRC concentration
>0, <0.2 mg/L FRC concentration	2.07 (1.04–4.13)	1.80 (0.88–3.69)	0.11	
Hand washing set-up unavailable	1.67 (0.74–3.8)	1.07 (0.39–2.92)	0.89	Availability of hand washing set- up
No hand washing at all critical times	1.19 (0.75–1.87)	0.73 (0.42–1.27)	0.27	Hand washing at all critical times
Presence of livestock in the household	1.75 (1.07–2.85)	0.95 (0.40–2.26)	0.92	Absence of livestock in the household
Household used animal feces as fertilizer	1.87 (0.71–4.92)	1.48 (0.52–4.24)	0.46	Household did not use animal feces as fertilizer

[a]Indicates that the variable was significantly associated with fecal contamination of drinking water at $P < 0.05$.

DISCUSSION

Our study shows that water quality is a major problem in both the refugee and host communities. All the households in the refugee camps and 102 (68.0%) of the households in host communities relied on improved water sources. However, water was not always available for 214 (69.6%) of the households because piped water supply was intermittent and was often available less than 8 hours a day (Mekonnen *et al.* 2019). Nearly half (74, 47.3%) of the households in the refugee camps had above the recommended concentration of free residual chlorine (0.2 mg/L). However, the mean residual free chlorine concentration was 0.17 mg/L in the direct water sources and only 0.1 mg/L in stored water samples, below the minimal effective level. These low levels were due to the central treatment of drinking water, the reason being that drinking water was treated centrally with chlorine in the refugee camps while chlorination was not routinely practiced in the host communities (Mekonnen *et al.* 2019). A total of 164 (53.6%) household samples from the refugee camps and host communities had no free residual chlorine. This finding is in agreement with other studies (CDC 2007). As well, mean free residual chlorine concentrations were significantly higher in source water than stored water samples in both refugee camp ($P < 0.001$) and host communities ($P = 0.018$). This could be due to the fact that water supply schemes, particularly those in rural areas, often use chlorine inaccurately and fail to systematically monitor water quality (Momba *et al.* 2008). A much higher proportion of stored samples in the refugee camps (80.8%) had free residual chlorine than in host communities (10.7%). This is due to the fact that only 7 (35%) of the source water points were chlorine treated and point-of-use water treatment was uncommon in the host community.

Fecal coliform was identified in 183 (59.8%) of the household vessel water samples. Fecal coliforms were isolated more commonly in stored water samples in host communities (71.3%) than in refugee camps (48.7%). This could be because of the priority given by the Ethiopian Government and aid organizations to safe water supply in refugee camps. The study indicates that there is no statistically significant difference in fecal coliform count between direct source and stored water in the host community ($P = 0.398$). This might be due to the fact that 9 of the 20 (45%) water source samples collected in the host communities were from surface water, which is more vulnerable to fecal contamination (Rufener *et al.* 2010). Significantly higher coliform counts were identified in stored water than source water samples in the refugee community ($P = 0.001$). This is in agreement with other studies and indicates that water from an improved source may not be microbiologically safe at the household level (Bisi-Johnson *et al.* 2017). A possible explanation for this discrepancy is contamination of drinking water at home due to poor hygiene practices and sanitation (Mekonnen *et al.* 2019).

Water contamination was 2.4 times higher in households of caregivers without formal education than in those of their counterparts who completed secondary education. This finding is consistent with a similar study done in Benin (Sintondji *et al.* 2017) and may be associated with better understanding of water quality and sanitary and hygiene behaviors by formally educated women (McGarvey *et al.* 2008). The nearly five times higher risk of coliform contamination of surface water stored in residences than piped water corroborates numerous other studies showing that the quality of water depends to a large degree on the type of water source. Possible explanations for the observed differences in water quality are that the surface water is exposed to greater fecal contamination as a result of poor sanitation and hygiene practices, such as open defecation and inappropriate solid and liquid waste disposals (Ali *et al.* 2012). Fecal coliforms was isolated 1.9 times more in households experiencing water shortage within the one last month prior to the survey than in households which did not experience water shortages. This could be due to the fact that water shortage usually leads to poor sanitation and hygiene practices which, in turn, cause cross-fecal contamination of water and food (Cairncross *et al.* 2010).

Household water with no free chlorine residual concentration was six times more likely to be contaminated with fecal coliform than chlorinated stored water. This result corroborates other studies (Clasen *et al.* 2007a) but contrasts with a study by Obi *et al.* (2008). The effectiveness of treatment with chlorination may depend on various factors (Clasen *et al.* 2007b). In our study, microbiological quality of water was not associated with some predictors reported in other studies, such as availability of latrines in households, water storage method, and method of fetching water

(McGarvey *et al.* 2008; Boateng *et al.* 2013; Usman *et al.* 2016). These differences may be due to differences in the socio-demographic characteristics, study design, and the microbiological technique used.

Limitations of the study

This cross-sectional study did not cover the effect of seasonal variation in water quality and its determinants due to financial constraints. As the study area was remote and no standard laboratory facilities were available, the study did not employ the conventional water quality testing methods.

CONCLUSION AND RECOMMENDATION

This study found water quality in refugee camps to be better than their host communities. Nevertheless, fecal coliforms were isolated in many households with stored water in both the refugee and host communities. These findings suggest that improved water sources do not provide safe drinking water in homes. Educational level of caregivers, unimproved water sources, water supply interruptions, and lack of free residual chlorine were found to be independent predictors of fecal coliform contaminations of stored water. Additional coordinated efforts are required to improve the water supply and treatment programs, particularly in the host communities in Gambella Region. Centralized water treatment with chlorine needs to be performed consistently with correct recommended dosage accompanied by point-of-use water quality monitoring. Designing and providing appropriate community education and effective hygiene promotion programs is essential in empowering and guiding uneducated caregivers towards improved community knowledge and management of water contamination to reduce the prevalence of diarrhea in under-five children. Prospective longitudinal studies are required for examining seasonal patterns of microbiological quality of household water and its determinants.

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The principal investigator, GK, collected and analyzed the data. BM, GS, WM, and HK directed and supervised the research process. All authors contributed to designing the proposal, drafting the manuscript and approving the final version to be submitted for publication.

The study was reviewed and approved by the Ethiopian Institute of Water Resources, Addis Ababa University. Ethical approval was obtained from the Ethiopian National Research Ethics Review Committee. Letters were written by AAU to the Ethiopian Administration for Refugees and Returnees Affairs (ARRA), UNHCR, and IRC to obtain support during field work. Then, official permission was obtained from ARRA to permit research in the refugee camps. Interviewees were ensured that their participation was voluntary and the information they provided was kept confidential. The authors declare that they have no competing interests.

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