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Fecal contamination of drinking water in Kericho District, Western Kenya: role of source and household water handling and hygiene practices

Johana Kiplagat Too, Willy Kipkemboi Sang, Zipporah Ng'ang'a and Musa Otieno Ngayo

ABSTRACT

Inadequate protection of water sources, and poor household hygienic and handling practices have exacerbated fecal water contamination in Kenya. This study evaluated the rate and correlates of thermotolerant coliform (TTC) household water contamination in Kericho District, Western Kenya. Culture and multiplex polymerase chain reaction (PCR) techniques were used to characterize TTCs. The disk diffusion method was used for antibiotic susceptibility profiling of pathogenic *Escherichia coli*. Out of the 103 households surveyed, 48 (46.6%) had TTC contaminated drinking water (TTC levels of >10 cfu/100 mL). Five of these households were contaminated with pathogenic *E. coli*, including 40% enteroaggregative *E. coli*, 40% enterotoxigenic *E. coli*, and 20% enteropathogenic *E. coli*. All these pathogenic *E. coli* strains were multidrug resistant to sulfamethoxazole/trimethoprim, ampicillin, tetracycline and ampicillin/sulbactam. Rural household locality, drinking water hand contact, water storage container cleaning practice, hand washing before water withdrawal, water source total coliforms <10 cfu/100 mL, temperature, and free chlorine levels were associated with TTC contamination of household drinking water. Significant proportions of household drinking water in Kericho District are contaminated with TTCs including with pathogenic multidrug-resistant *E. coli*. Source and household hygiene and practices contribute significantly to drinking water contamination.

Key words | correlates, household drinking water, Kericho District Kenya, pathogenic *Escherichia coli*, susceptibility profiles, thermotolerant coliforms

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INTRODUCTION

The importance of water to human health is encapsulated in the Human Right to Water and Sanitation, which entitles everyone to 'sufficient, safe, physically accessible and affordable water for personal and domestic uses' (Committee on Economic, Social and Cultural Rights 2002; United Nations 2010). Unfortunately, over 275 million people in sub-Saharan Africa rely on unsafe drinking water sources from lakes, rivers, and open wells (WHO/UNICEF 2010). Consequently, in this region, many waterborne-related diarrheal diseases are responsible for significant morbidity and mortality among children, the elderly, and immunosuppressed individuals (Kariuki *et al.* 2006; WWAP 2006). The most common health problems associated with unsafe drinking water in Kenya include typhoid fever, cholera, diarrhea, dysentery, worms, and bilharzias (WWAP 2006).

The World Health Organization (WHO) guidelines for drinking water quality include criteria for assessing health risks and setting targets for improving water safety (WHO 2011). The guidelines recommend using either thermotolerant coliforms (TTCs) or *Escherichia coli* in assessing fecal contamination of drinking water (WHO/UNICEF 2010; WHO 2011). A 100 mL water sample with <1 indicator organisms is

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considered 'very low risk'; 1–10, 'low risk'; 10–100, 'medium risk'; >100, 'high risk' or 'very high risk' (WHO 1997).

Studies have given varied total and fecal (*E. coli*) coliform contamination of water samples in different settings. Over a quarter of samples from improved water sources in China, the United Kingdom, France, Portugal and in selected low and middle income countries were shown to contain fecal contamination (Bain *et al.* 2014). About 95% of water sources (dams, rivers, springs, and wells) in the informal settlements of Kisumu, Kenya had significant *E. coli* contamination (Opisa *et al.* 2012). In another informal settlement in Nairobi, Kenya, Chemuliti *et al.* (2002) identified 35% of standpipes and 95% of in-house storage containers as being contaminated with *E. coli* coliforms. Water source, storage practices, locality, poverty, hygiene, sanitary and environmental factors have been cited as sources for fecal water contamination (Gundry *et al.* 2006).

Currently, data are skewed on the quality of drinking water in Kericho District, Western Kenya. This district is faced with high population density and a growth rate of 3.6%, while the majority of urban and rural populations lack clean and safe piped water supply (Kenya Census 2010).

METHODS

Study design and setting

Kimani-Murage & Ngindu (2007) showed that 13% of the households in Kenya had their drinking water contaminated with thermotolerant *E. coli*. Applying the formula for estimating the population proportion with specified relative precision described by Lemeshow *et al.* (1990), setting the α at 0.05, and a detection rate of 20%, a total of 103 households were recruited to achieve 0.90 power. A two-stage sampling method was then used to select these households. First, a complete list of all the households in the 17 locations/villages in Kericho District was generated based on the Kenya Census of 2010. A total of 12 locations were then selected based on probability proportionate to size. Second, a systematic sampling method was then used to select every fifth household in each pre-selected location. The number of households per location varied based on their total household size.

Participants

Consent was gained from the heads of these households, who were interviewed using a structured questionnaire to gather information relating to the quality of drinking water. Further, two different water samples were collected from these households: one from source (tap, rivers, or wells) and the second from household drinking water storage vessels. This study was done between 2013 and 2014 and was approved by the Ethical Review Committee of Kenya Medical Research Institute (SSC No. 2579 on 18 July, 2013). This research has adhered to the STROBE guidelines for observational studies as outlined at: http://www.strobe-statement.org.

Interviews

Structured questionnaires adopted from the WHO/UNICEF Joint Monitoring Programme (http://www.wssinfo.org/fileadmin/user_upload/resources/1268174016-JMP_Core_Questions.pdf) were used to gather information related to water-extraction patterns, type of water transport, water-treatment methods, hygiene and sanitation related issues.

Water sample collection

Water samples were collected aseptically using sterile sampling containers. About 100 mL of the water sample was collected and immediately analyzed for bacteriological qualities and physical chemical properties (pH, temperature, turbidity, and free chlorine) on site using a DelAgua water testing kit. The cultured plates were then transported to the Micro Hub Kericho Walter Reed Project (WRP) of Kenya Medical Research Institute for further bacteriological analysis. Water source sampling (rivers, streams, or other surface waters in the district where enrolled households collect their waters) involved drawing water from 30 cm below the surface. Sampling from wells and boreholes involved drawing water using a bucket and taking 100 mL into a sterile container. This was considered to be more representative of what is actually being consumed by the household. Sampling water from taps was done directly into collecting containers (WHO 1998). Household water sampling was done by requesting the household head to draw water from their storage reservoir.

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Total coliforms and TTC isolation

Water samples were filtered through a 0.45 μm pore size membrane filter, which was then incubated on lauryl sulphate agar for 18–24 hours at 35 ± 0.5 °C or 37 ± 0.5 °C for total coliforms and 18–24 hours at 44 ± 0.25 °C or 44.5 ± 0.25 °C for TTCs. To confirm TTCs and *E. coli*, membranes were then incubated at 35, 37 or 44 °C, and each colony (or a representative number of colonies) was sub-cultured into a tube of lactose peptone water and a tube of tryptone water. Tubes were incubated at 44 °C for 24 hr. Growth with the production of gas in the lactose peptone water confirmed the presence of TTCs. Confirmation of *E. coli* was made by the addition of 0.2–0.3 mL of Kovac's reagent to each tryptone water culture. Production of a red color indicated the synthesis of indole from tryptophan, which confirmed the presence of *E. coli*. Figure 1 shows the isolation and identification of TTCs using culture and API strips.

E. coli pathotype identification

The *E. coli* pathotypes were determined using multiplex polymerase chain reaction (PCR) as described by Gomez-Duarte (2009). The first PCR of this multiplex contained M1 primers for amplification of *eae*, *bfpA*, VT, and *aggR* genes for identification of shiga toxin-producing *E. coli* (STEC), enteropathogenic *E. coli* (EPEC), and enteroaggregative *E. coli* (EAEC) pathotypes. The second PCR contained M2 primers for amplification of LT, ST, *daaE*, *ipaH*, and *virF* gene targets for identification of enterotoxigenic *E. coli* (ETEC), diarrheagenic *E. coli* (DAEC), and enteroinvasive *E. coli* (EIEC) pathotypes. About 1 μL of genomic DNA was mixed with 24 μL of a premade mix containing primers at a 0.2 μM final concentration and Platinum Blue PCR SuperMix polymerase (Invitrogen, Carlsbad, CA, USA). The PCR amplification consisted of 2 min at 94 °C denaturing temperature, followed by 40 cycles of 30 sec at 92 °C denaturing temperature, 30 sec at 59 °C annealing temperature, and 30 sec at 72 °C extension temperature. The PCR products were visualized and recorded under ultraviolet light using a 2% agarose ethidium bromide-stained gel. The verotoxin of STEC isolates were analyzed using PCR specific for shiga-like toxin 1 (VT1) (Vidal *et al.* 2005) and shiga-like toxin 2 (VT2) (Nguyen *et al.* 2005).

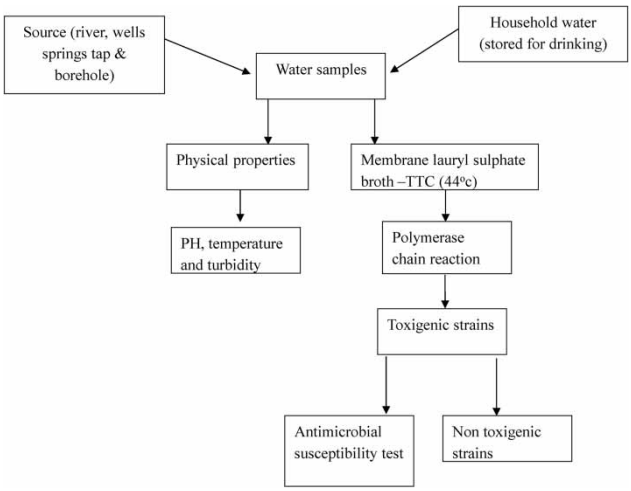

Figure 1 | Water sample collection and laboratory testing chart.

Antimicrobial susceptibility testing

Antimicrobial susceptibility patterns of *E. coli* pathotypes were undertaken using the disk diffusion technique of Kirby-Bauer. The susceptibility was checked against the following antibiotics: ampicillin, nalidixic acid, chloramphenicol, tetracycline, cefotaxime, cotrimoxazole, ceftazidime, and ciprofloxacin. The zones' inhibition was interpreted using standards for antimicrobial susceptibility testing (CLSI 2010).

Data analysis

Frequency (%), mean, standard deviation, and medium (interquartile ranges at 25% and 27%) were used to describe the qualitative and laboratory parameters. Chi-square or Fisher's exact test were used to test for significance where applicable. In bivariate analyses, odds ratios (OR) and 95% confidence intervals (CI) for the association between pathogenic thermotolerant *E. coli* contaminating water and socio-demographic, hygienic and environmental characteristics were calculated using Poisson regression. In multivariate analyses, a manual backward elimination approach was used to reach the most parsimonious model, including factors that were associated with contamination with pathogenic thermotolerant *E. coli* at the significance level of $P \leq 0.05$. All statistical analyses were performed using STATA v 13 (StataCorp LP, College Station, TX, USA).

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RESULTS

Characteristics of study population

Table 1 shows the summary of characteristics of households recruited in this study. The mean age of the 103 household heads was 21.59 years (range 18–29 years) with slightly under a quarter (42.7%) aged 21–30 years. About 68.9% of households were located in rural areas, with 95.1% of them being female headed. About 57.3% had primary level education, 27.2% were farmers, while 54.4% had children below 5 years of age. Close to 36.9% of the households sourced their drinking water from rivers. Nearly all of them (91.3%) did not treat their drinking water, with 81.6% stating that their drinking water was clean regardless of the source. Most of the households (64.1%) stored the drinking water for more than 2 days, with the majority (83.5%) of them drawing drinking water by dipping the cup into the water storage container. Nearly half of the households reported having contact with drinking water during drawing. Some 60.2% used clay pots for water storage, with 64.1% of them never washing these storage containers.

Nearly half of the households (49.5%) used pit latrines or open pits for their toilet facility. About 32% of these toilets were moderately clean, with flies but no visible fecal matter. About 31.1% of households disposed of their children's fecal waste in the pit latrine. Slightly over half of them (59.2%) did not wash their hands before drawing water. The majority (96.1%) often rinsed water drawing utensils. About 88.3% were aware of waterborne diseases while only 30% had suffered from diarrhea, vomiting, and fever in the past 3 months.

Total and TTCs

Table 2 shows a summary of total and TTC levels in source and household drinking water. The mean total coliform count in water sources was 1,029.7 (SD 1,574.1 cfu/100 mL) and a range of 5,595 (80–5,675 cfu/100 mL). Close to half (50; 48.5%) of the water sources were contaminated (had total coliforms above >10 cfu/100 mL) ($P = 0.768$).

The mean household drinking water total coliform count was 529.1 (SD 857.5 cfu/100 mL) with a range of 5,462 (98–5,560 cfu/100 mL). The majority (85; 83.5%) of household drinking waters were contaminated, with total coliforms above >10 cfu/100 mL ($P < 0.001$).

The mean TTC count in the water sources was 798.6 (SD 1,302.6 cfu/100 mL) and a range of 3,539 (1–3,540 cfu/100 mL). Only 23 of the 103 (22.3%) water sources were contaminated with TTC (>10 cfu/100 mL) ($P < 0.001$).

The mean TTC count in households' drinking water was 321.2 (SD 761.5 cfu/100 mL) with a range of 3,799 (1–3,800 cfu/100 mL). Slightly below half (48) of the 103 (46.6%) households' drinking water was contaminated with TTC levels of >10 cfu/100 mL ($P < 0.001$).

Household drinking water contamination with thermotolerant *E. coli* and other coliforms

In all 48 (46.6%) households with TTC, each had thermotolerant *E. coli* as well. Among the 48 thermotolerant *E. coli*, 5 (10.4%) were pathogenic *E. coli*: 2/5 (40%) EAEC, 2/5 (40%) ETEC, and 1/5 (20%) EPEC. There were 35 other types of TTCs isolated from household drinking water. These included 8/35 (22.8%) Serratia, 7/35 (20%) Enterobacter, 5/35 (14.3%) Klebsiella, 5/35 (14.3%) Moraxella, 4/35 (11.4%) Pseudomonas, 2/35 (5.7%) Shigella, 2/35 (5.7%) Acinetobacter, 1/35 (2.9%) Aeronomonas, and 1/35 (2.9%) Yersinia.

All the five pathogenic *E. coli* were multidrug resistant to four commonly prescribed antibiotics in Kenya, including sulfamethoxazole/trimethoprim, ampicillin, tetracycline and ampicillin/sulbactam.

Factors associated with TTC contamination of household drinking water

Table 3 summarizes the factors associated with TTC contamination (>10 cfu/100 mL) of household drinking water. In the bivariate analyses, drinking water of households located in the rural set-up were more likely to have TTC contamination than households located in the urban areas (OR 2.01, 95% CI 1.09–4.12). Households with a piped water supply or water from a municipal source were less likely to have TTC contamination than those households whose source of water was from a river/spring (OR 0.38, 95% CI 0.16–0.91). Households which reported hand contact with drinking water during withdrawal were more likely to be contaminated with TTC compared to households which had no hand contact during water withdrawal (OR 1.11, 95% CI 1.11–3.39). Households that washed their water storage containers regularly were less likely to be

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Table 1 | Characteristics of the study population

Household characteristics	Unit	Frequency	Percentage
Locality	Rural	71	68.9
	Urban	32	31.1
Gender	Female	98	95.1
	Male	5	4.9
Age group	<20	8	7.8
	21–30	44	42.7
	31–40	25	24.3
	41–50	10	9.7
	>51	16	15.5
Education level	Primary	59	57.3
	Secondary	25	24.3
	Tertiary	11	10.7
	Non-formal	8	7.8
Occupation	Business	18	17.5
	Employee/Laborer	17	16.5
	Farmer	28	27.2
	Housewife	25	24.3
	Student/Unemployed	15	14.6
Have children below 5 years	Yes	56	54.4
	No	47	45.6
Consider drinking water source safe	Yes	95	92.2
	No	1	1.0
	Do not know	7	6.8
Treatment of water	Boil	3	2.9
	Filtration	4	3.9
	Water guard	2	1.9
	Do not treat	94	91.3
Reasons for not treating water	Lack of knowledge	6	5.8
	Water is clean	84	81.6
	Time consuming and costly	2	1.9
	Not applicable	11	10.7
Water storage period	1 day	21	20.4
	2 days	16	15.5
	More than 2 days	66	64.1
Method for drawing drinking water	Dip into container	86	83.5
	Pour directly from container/use tap	17	16.5
Hand contact with drinking water	Yes	44	42.7
	No	59	57.3
Water storage container	Clay pot	62	60.2
	Plastic	41	39.8
Wash hands before drawing water	Yes	42	40.8
	No	61	59.2
Rinse water drawing utensils	Yes	99	96.1
	No	4	3.9
Type of toilet facility	Piped sewer system/septic tank/pit latrine	6	5.8
	Pit latrine without slab/open pit	51	49.5
	Ventilated improved pit latrine	6	5.8
	Bush/field	15	14.6
	Shared facility	25	24.3
Toilet cleanliness	Clean (no flies nor visible fecal matter)	16	15.5
	Moderately clean(flies but no visible fecal matter)	33	32
	Dirty(flies and visible fecal matter)	14	13.6
	Not applicable	40	38.8
Disposal of children's feces	Put in the latrine	32	31.1
	Put/rinsed into drain or ditch	19	18.4
	Thrown into garbage	4	3.9
	Not applicable	48	46.6

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Table 2 | Total and TTCs in source and household drinking water

Total/TTC (cfu/100 mL)		Frequency	%	*P* value
Water source total coliforms				
Mean (± SD)	1,029.7 (1,574.1)			
Median	320			
Range	5,595 (80–5,675)			
10–100		50	48.5	
100–1,000		41	39.8	0.768
> 1,001		12	11.7	
Water source TTCs				
Mean (± SD)	798.6 (1,302.6)			
Median	30			
Range	3,539 (1–3,540)			
10–100		80	77.7	
100–1,000		9	8.7	0.001
> 1,001		14	13.6	
Household total coliforms				
Mean (± SD)	529.1 (857.5)			
Median	289			
Range	5,462 (98–5,560)			
10–100		17	16.5	
100–1,000		78	75.7	0.001
> 1,001		8	7.8	
Household TTCs				
Mean (± SD)	321.23 (761.5)			
Median	40			
Range	3,799 (1–3,800)			
10–100		55	53.4	
100–1,000		33	32.0	0.001
> 1,001		15	14.6	

%, percentage; SD, standard deviation; TTC, thermotolerant coliforms.

contaminated with TTC than those households who did not wash the water storage container (OR 0.58, 95% CI 0.31–0.99). Households who practiced hand washing before drawing drinking water were less likely to have TTC contamination than those households that did not wash hands (OR 0.33, 95% CI 0.15–0.67). Households whose total coliform count was less than 10 cfu/100 mL were less likely to have TTC drinking water contamination than those households with more than 10 cfu/100 mL (OR 0.45, 95% CI 0.26–0.81). Further, households whose main water source temperatures were between 15 and 20 °C were less likely to have TTC drinking water contamination than those households with water source temperatures greater than 25.1 °C (OR 0.39, 95% CI 0.16–0.96). Lastly, households whose main water source had a free chlorine concentration of less than 1 mg/L were less likely to have their drinking water contaminated with TTC compared to households with a water source free chlorine concentration of above 1 mg/L (OR 0.41, 95% CI 0.24–0.71).

The following variables, which have been linked with drinking water contamination, were included in the multivariate model: socio-demographic characteristics (e.g., household locality, household headship, gender, age, educational level, and occupation), attitude and knowledge, water handling (e.g., water collection, treatment, storage, and handling practices) and sanitation (e.g., waste disposal and pollution alongside water source). None was found to be independently associated with TTC contamination of household drinking water.

DISCUSSION

Kenya has experienced recurrent cases of waterborne diseases like cholera (TDN 2007; Wambua 2008). In the last 10 years, the morbidity patterns ranked diarrhea as the fourth priority disease (HSSR 2005). Western Kenya and part of Rift Valley Province, notably the districts of Bungoma, Busia, Kakamega, and Kericho are among the most affected regions (Onyango & Angienda 2010). This study was a build up of the limited data in Kericho District, evaluating the quality of household drinking water and highlighting the role of source and household water handling and hygiene practices in the contamination of drinking water with TTC. Invariably, the extent of safe water handling was determined by the local people's knowledge and attitudes towards water safety and sanitation (Özdemir *et al.* 2011).

The current study detected significantly high (46.6%) numbers of household drinking water contaminated with TTC. The fecal contamination of water sources and a further deterioration between the collection points and homes has been observed in other studies. In Kibera, Nairobi, Chemuliti *et al.* (2002) observed higher contamination levels of fecal coliforms (95%) in in-house sources and (35%) of outdoor sources. In Western Kenya, Muruka *et al.* (2012) observed a lower (2%) source water fecal coliform contamination. In Masaba, Kisii, Nyagwencha *et al.* (2012) observed that 16% of the households accessed unsuitable water for

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Table 3 | Factors associated with household drinking water TTC contamination

Socio-demographic characteristic	Sample size	Drinking water TTC contamination		Bivariate OR (95% CI)	Multivariate OR (95% CI)
		No.	%		
Locality					
Rural	71	39	54.9	2.01 (1.09–4.12)	1.13 (0.12–10.37)
Urban	32	9	28.2	Referent	Referent
Education level					
Primary	59	29	49.2	0.99 (0.54–1.82)	1.23 (0.52–2.91)
Secondary	25	11	44	0.96 (0.49–1.84)	1.13 (0.44–2.91)
Tertiary	11	4	36.4	0.91 (0.42–1.94)	1.33 (0.44–4.06)
Non-formal	8	4	50	Referent	Referent
Stay with child below 5 years					
Yes	56	20	35.7	0.85 (0.62–1.17)	NS
No	47	28	59.5	Referent	Referent
Main drinking water source water					
Piped supply/municipal	34	9	26.5	0.38 (0.16–0.91)	0.78 (0.33–1.87)
Rain water/roof catchment	12	6	50	0.73 (0.52–1.92)	0.89 (0.39–2.02)
River	38	21	55.3	0.81 (0.41–1.61)	0.98 (0.58–1.63)
Spring	19	12	63.2	Referent	Referent
How do you treat drinking water					
Boil	3	2	66.7	1.04 (0.34–3.18)	0.95 (0.22–4.1)
Filtration	4	2	66.7	0.62 (0.07–4.99)	0.61 (0.07–5.09)
Water guard	2	0	0	0.91 (0.44–1.85)	1.11 (0.32–3.92)
Do not treat	94	43	45.7	Referent	Referent
Water storage period					
1 day	21	8	38.1	0.92 (0.54–1.58)	0.88 (0.48–1.61)
2 days	16	8	50.0	1.01 (0.65–1.57)	0.99 (0.59–1.67)
More than 2 days	66	32	48.4	Referent	Referent
Hand contact with drinking water					
Yes	36	24	66.7	1.11 (1.11–3.39)	1.19 (0.77–1.83)
No	67	24	35.8	Referent	Referent
Type of water storage container					
Clay pot	62	31	50	1.06 (0.76–1.47)	NS
Plastic	41	17	41.6	Referent	
Washing of water storage container					
Yes	37	12	32.4	0.58 (0.31–0.99)	NS
No	66	36	54.6	Referent	
Household kind of toilet facility					
Piped sewer system/septic tank/pit latrine	6	2	33.3	0.92 (0.43–1.99)	
Pit latrine without slab/open pit	51	22	43.1	0.99 (0.66–1.48)	NS
Ventilated improved pit latrine	6	2	33.3	0.92 (0.43–1.99)	
Bush/field	15	11	73.3	1.2 (0.72–1.99)	
Shared facility	25	11	44	Referent	

(*continued*)

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Table 3 | continued

Socio-demographic characteristic	Sample size	Drinking water TTC contamination		Bivariate OR (95% CI)	Multivariate OR (95% CI)
		No.	%		
Wash hands before drawing water					
Yes	42	9	21.4	0.33 (0.15–0.67)	NS
No	61	39	63.9	Referent	
Household total coliforms (cfu/100 mL)					
≤ 10 cfu/100 mL	17	0	0	0.45 (0.26–0.81)	NS
> 10 cfu/100 mL	86	48	55.8	Referent	
Water source temperature (°C)					
15–20	47	12	25.5	0.39 (0.16–0.96)	
20.1–25	41	20	48.8	0.67 (0.29–1.52)	NS
> 25.1	9	9	100	Referent	
Water source pH					
5–7	24	14	58.3	1.1 (0.76–1.59)	NS
> 7.1	79	34	43	Referent	
Water source free chlorine (mg/L)					
≤ 1	80	33	41.3	0.41 (0.24–0.71)	NS
> 1.1	23	23	100	Referent	

No., number; %, percentage; TTC, thermotolerant coliforms; OR, odds ratio; CI, confidence interval; NS, not significant.

human consumption. In Chinese, English, French, Portuguese, and Spanish populations over a quarter of samples from improved sources were shown to contain fecal contamination (Bain *et al.* 2014). In Peru, Gil *et al.* (2014) found TTCs in 48% of all water samples. In India, Boisson *et al.* (2013) found that 20% of the household drinking water had fecal contamination. Our study shows that a significant population in Kericho District, Kenya lacks safe clean drinking water according to the WHO guidelines.

The presence of TTCs in water indicates actual contamination with feces (human and non-human) and potential contamination by disease-causing pathogens of all kinds. In this study, pathogenic bacteria including *E. coli,* Serratia, Enterobacter, Klebsiella, Moraxella, Pseudomonas, Shigella, Acinetobacter, Aeromonas, and Yersinia were isolated. This is worrying given that these bacteria are associated with waterborne human diseases. Similar coliforms have been isolated by others from water sources (Kämpfer *et al.* 2008). All of the thermotolerant pathogenic *E. coli* were resistant to various important antibiotics including ampicillin, sulfamethoxazole/trimethoprim, and tetracycline. In Nigeria, resistance patterns of 80.9% ampicillin, 95.4% tetracycline, and 46.5% chloramphenicol were observed; while in Tanzania, resistance rates of 83.1% to ampicillin, 57% chloramphenicol, 87.7% tetracycline, and 90.8% co-trimoxazole were found (Vila *et al.* 2000). Of major concern with our findings is that antibiotics such as ciprofloxacin and cefotaxime, which are prescription antibiotics in Kenya, showed considerable resistance. This indicates misuse of these and other classes of antibiotics which would have major implications in the treatment of *E. coli* causing diarrhea in Kenya.

The rural locality of the household and the type of water source contributed significantly to TTC household drinking water contamination. These findings mirror those of Bain *et al.* (2014), who showed water sources in low-income countries and rural areas as being more likely to be contaminated. As expected, households located in rural areas are prone to poor waste disposal, poor household hygiene, lack of resources, and knowledge of water treatment. These factors were likely to contribute to the higher TTC drinking water contamination. This argument is supported by the study of Bain *et al.* (2014), who observed that a defective water delivery system and inadequate environmental sanitation are shown to be a potential source of contamination for household

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drinking water. The poor levels of environmental hygiene coupled with a dilapidated water delivery system are major contributors to TTC water contamination (Chemuliti *et al.* 2002).

Household hygiene, and practices such as hand washing, hand contact with drinking water during withdrawal, household water storage type, cleanliness, water treatment, and human waste disposal were important for TTC household drinking water contamination. Eshcol *et al.* (2009), in India, showed that fecal contamination occurs principally during storage due to poor water handling. In Zimbabwe, homes where traditional drinking water containers have been replaced with covered, narrow-mouthed pots with a tap outlet have significantly less contamination (Mazengia *et al.* 2002). A combination of special storage vessels with point-of-use treatment has been shown to be very effective (Rose *et al.* 2006). Hand washing initiatives and the introduction of point-of-use disinfection can reduce diarrheal incidence (Ejemot *et al.* 2008).

CONCLUSIONS

Other water quality surveys have shown natural ecosystems (geological, topographical, hydrological in the drainage basin), seasonal differences, weather conditions, water levels as well as other human hygiene and practices affect the quality of water. The cross-sectional nature of this study, relatively small sample size, inadequate assessment using the full WHO/JMP standardized questionnaires for household water handling and sanitation, could partly explain the observed lack of association between household drinking water TTC contaminations in our multivariate analyses.

Given these limitations, a reasonable conclusion that can be drawn from these data is that a significant number of household drinking waters in Kericho District are unsafe in line with WHO guidelines, and some are contaminated with pathogenic multidrug-resistant *E. coli*. Water source and household hygiene and practices contribute significantly to the quality of drinking water.

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