Faecal pollution and solar purification of community water sources within Lake Naivasha basin, Kenya

Donde O. Omondi, Muia A. Wairimu, Wanga L. Aketch, Shivoga A. William, Charles G. Trick and Irena F. Creed

ABSTRACT

As in other parts of Africa, and in other developing nations, the rise in the human population and anthropogenic activities within the Lake Naivasha basin is causing an increase in human health risks due to faecal contamination of domestic water sources. This study investigated faecal pollution of community water sources within the Lake Naivasha basin by measuring the densities of total coliforms, *Escherichia coli*, intestinal enterococci, *Clostridium perfringens* and heterotrophic bacteria in Lake Naivasha, the Malewa and Gilgil Rivers, and boreholes using membrane filtration techniques and heterotrophic plate count procedures. Selected physico-chemical parameters were also measured *in situ* from all the water sources sampled. Lakes and rivers had significantly higher microbial abundances than boreholes. Unlike boreholes, surface sources (rivers and lake) showed significant variation with respect to sampling sites for all the microbiological parameters ($P < 0.05$). The use of solar radiation in water disinfection with temperatures of 75 °C after 30 minutes from pasteurization point (time zero) fully eradicated *E. coli* and total coliforms from all the water sources. In conclusion, there is faecal pollution in water sources used by communities within the Lake Naivasha basin. The use of solar radiation is therefore recommended for water purification to reduce likely incidences of waterborne diseases.

Key words | coliforms, disinfection, microbial, pasteurization, pollution

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INTRODUCTION

Water is an essential commodity whose quantity and quality needs to be secured for easier accessibility at the household level (Boniface & John 2002). Within Kenya, the problem of faecal contamination of water is common in many areas with informal settlements, where tap water, proper sanitation facilities and sewage treatment plants are still inadequate (JICA 2003). Faecal pollution of water sources is one of the major water contaminants, with a great impact on public health (McLean 2001). The World Health Organization (WHO) has estimated that 80% of diarrhoeal diseases are related to poor water and sanitation. About 1.7 million annual deaths are attributed to unsafe water supplies, with most of these being due to diarrhoeal diseases. The majority of these cases are due to bacterial pathogens and are associated with water contamination (World Health Organization 2002; Mireri 2005). Major domestic water sources (lakes, rivers and boreholes) within Naivasha receive large contaminant loads from anthropogenic activities in its heavily populated catchment (Harper & Mavuti 2004). The contamination of these sources is worsened by inadequate sanitation, as most communities within the area utilize bushes and poorly constructed pit latrines for sewage disposal. In addition, the majority of the population in this area still do their laundry and bathing using the available rivers and lake (Mireri 2005; Onyango & Rieck 2010; Donde *et al.* 2013).

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The detection of indicator organisms is used to assess the likelihood of the presence of pathogens. The principal coliform bacterial indicators include total coliforms, faecal coliforms and *Escherichia coli*. Various agencies, including the World Health Organization (WHO), the National Environmental Management Authority of Kenya (NEMA-Kenya), the United States Environmental Protection Agency (US-EPA) and the European Framework, have laid out standards for drinking water provisions (Table 1). Water quality can be improved through boiling and physical and chemical treatments to achieve these standards. However, some of these methods can be expensive, cause environmental damage and require skilled personnel (Acher *et al.* 1997). Solar energy is a renewable resource that can be used in water purification and may be helpful to communities where other methods are not feasible (Lawand *et al.* 1997). This study examined the quality of water used by the communities within the Lake Naivasha basin by measuring physico-chemical parameters and abundances of faecal contamination indicator organisms from different water sources. The potential of using solar energy to improve water quality was also explored by treating water from different sources using solar cookers and measuring the abundances of indicator microorganisms.

METHODS

Study area

Lake Naivasha basin is a freshwater lake and a Ramsar site in the Rift Valley Province of Kenya (Figure 1). Its watershed is served by two perennial rivers that enter the lake from the north, the Malewa and Gilgil Rivers. The lake is also drained by other seasonal rivers and streams, including the Kerati River to the north (Mireri 2005). The Naivasha community is large and rapidly increasing, with a current estimated total population of 54,000 people, distributed in blocks. Karagita and Mirera are two of these blocks. Karagita is a densely populated slum with a population of about 27,000 people; Mirera has a population slightly less than Karagita. The area is continuing to be built up, and using conservative growth rates, the population is expected to grow to almost 100,000 people by 2017 and to 173,000 people by 2027 (Government of Kenya 2009).

Sample collection

Two 500 mL water samples were collected weekly from April to July 2011 from three categories of water sources (Figure 1). Category one included river and lake water comprising four sampling sites (Lake Naivasha at Kamere beach, the Malewa River, the Gilgil River downstream and Gilgil River upstream). Category two included Borehole Direct (BH Direct) sources. These were water sources where water samples were obtained directly from under ground during pumping. The water was not pumped to the reservoir as is usually the norm. This category had four sampling sites: three at Karagita village (BH I Direct, BH III Direct and BH IV Direct) and one at Naivasha Water and Sanitation Company (NAWASCO) situated at the Denmark Company of Kenya (DCK) markets centre (DCK BH Direct). Category three included five boreholes from public Points of Access (POAs) within Karagita village (BH I POA, BH II POA, BH III POA, BH IV POA and BH V POA). For this category, water was sampled in the same way same as the community accessed their water, which was from reservoirs storing water that had been pumped from the boreholes. The sampling followed the procedures in the American Public Health Association (2005) and Donde *et al.* (2013). Water temperature, dissolved oxygen concentration and pH were measured *in situ*, using a WTW_O microprocessor meter. The meter was calibrated for a pH value of 4 and 7, using standard buffer solutions according to the manufacturer's instructions (WTW; Vienna, Austria). The meter electrode was rinsed with distilled water between samples. The electrical conductivity was also measured *in situ* using a WTW microprocessor conductivity meter calibrated at 25 °C.

Solar pasteurization

Solar pasteurization was conducted using a pasteurization kit, which consisted of an aluminium saucepan with a lid, painted black on the outside and fixed with a water pasteurization indicator and a thermometer. The saucepan was placed onto a $0.5 \times 0.5 \times 0.2$ m reflector panel made of

Table 1 | Drinking water quality guidelines by different agencies

Parameters	Units	WHO	NEMA-Kenya	US-EPA	EU-Framework
Physico-chemical					
pH	pH units	6.5–8.5	–	6.5–8.5	6.5–9.5
Conductivity	μs/cm at 20 °C	–	–	–	2,500
Microbial					
Total viable counts at 37 °C/mL	CFU	–	100	500	20/mL
Total coliforms	CFU	Undetectable/100 mL	Absent	<1/100 mL	0/100 mL
E. coli	CFU	Undetectable/100 mL	Absent	<1/100 mL	0/100 mL
Enterococci	CFU	Undetectable/100 mL	Absent		0/100 mL
Sulphite-reducing anaerobes	CFU	Undetectable/100 mL	Absent		0/100 mL

Source: Donde *et al.* (2013).

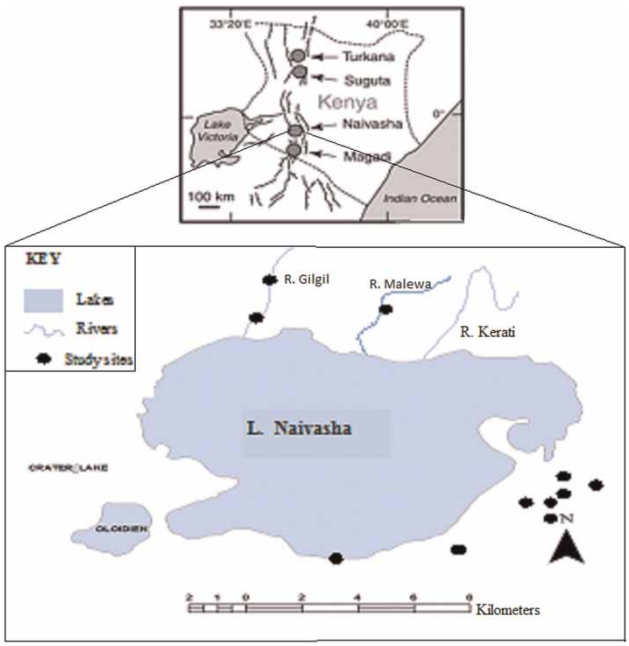

Figure 1 | Map of Lake Naivasha basin showing study sites.

hard, shiny cardboard, which concentrated the solar radiation to the saucepan. Water samples (1, 2.5 and 5 L) from the lake, river and borehole were treated. The kit was set up and exposed to direct sunlight on a clear day and left to stand until the wax in the indicator melted, indicating the pasteurization point. Water samples (100 mL each) were collected at 0, 15 and 30 minutes after pasteurization point and then analysed together with the untreated sample using the methods outlined in the section 'Sample analyses' below to determine the densities of total coliforms and *E. coli*. A thermometer was used to measure the temperature of water prior to treatment and after every treatment stage.

Sample analyses

Samples were aseptically analysed within 6–24 hours of sampling time. For total coliforms and *E. coli* counts, filters were placed onto chromocult agar (Merck) plates and incubated at 37 °C for 24 hours. Typical colonies appearing pink and dark blue were counted as total coliforms and *E. coli*, respectively. For intestinal enterococci counts, filters were placed onto enterococci agar (Merck) plates and incubated at 44 °C for 24–48 hours. Typical colonies appearing pink were counted as intestinal enterococci. For *C. perfringens* counts, filters were placed onto Tryptose Sulphite Cycloserine agar (Merck) plates. The filters were then placed in an anaerobic jar containing Anaerocult strips and incubated at 44 °C for 18–24 hours. Black fluorescent counts of *C. perfringens* were made under 360 nm UV light. For heterotrophic plate counts (HPCs), 1 mL of each sample or its dilution was placed onto 80 mm diameter plates with plate count agar and incubated at 37 °C for 48 hours. Colony forming units (CFUs) were expressed as the number of colonies counted per 1 mL. Analysis followed the guidelines outlined in Lawand *et al.* (1997), Scott *et al.* (2002) the American Public Health Association (2005) and Donde *et al.* (2013).

Data analysis

Data were analysed using Sigmaplot® analysis software version 12, with $\alpha = 0.05$. Since most of the data were neither normally distributed nor had equal variances, they are reported as medians with 25th and 75th percentiles, and non-parametric tests were used to test for significant differences.

RESULTS

Physical and chemical parameters

There was significant variation in all five measured physical and chemical parameters among the three different water source types (Figure 2). Water temperature was warmer in the two borehole water sources (22.8 °C for direct and 22.7 °C for POA) than the surface waters (21.6 °C). For both dissolved oxygen and % saturation of dissolved oxygen, the surface waters were highest (6.5 mg/L and 95.0%, respectively), followed by the borehole POAs (5.1 mg/L and 71.5%, respectively), and then the boreholes directly (3.6 mg/L and 52.8%, respectively). The pH of the borehole POAs (8.3) was slightly higher than both for the direct borehole sources (8.1) and surface waters (8.2), and the conductivity was much lower in surface waters (228.0 μs/cm) than both borehole sources (1224.0 μs/cm for direct and 1240.5 μs/cm for POAs). Looking within the different types of water sources, there were significant differences among sites for all physical and chemical parameters except for pH in the borehole POAs and the surface waters (Table 2) and there were no consistent patterns regarding which sites had the highest or lowest parameters. All the median values of physical and chemical parameters for all the water source types were within the recommended values of the NEMA-Kenya, WHO, US-EPA and the European Framework for drinking water (Table 1).

Microbiological parameters

The densities of all five microbial parameters measured from the three different water sources were significantly different

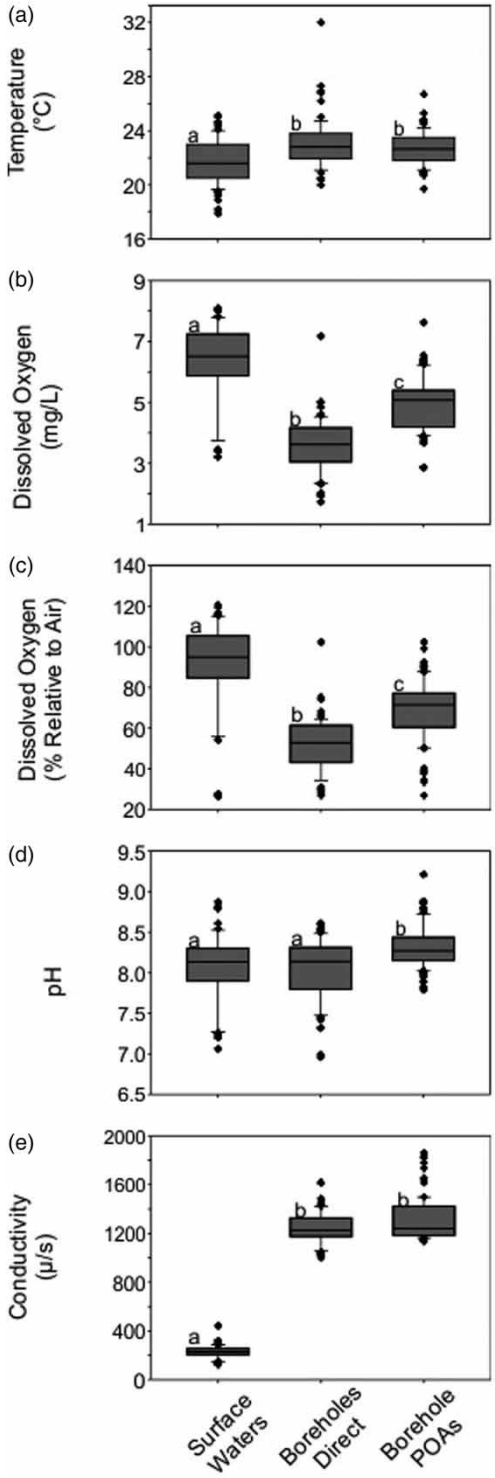

Figure 2 | Box and whisker plots of median (25%, 75% interval) water quality parameters within sites: (a) temperature, (b) dissolved oxygen (DO), (c) % DO, (d) pH and (e) electrical conductivity. Where analysis of variance (ANOVA) on ranks was significant ($P < 0.05$), Tukey tests were performed to determine sites that were significantly different (indicated with different letters).

Table 2 | Median (25%, 75% interval) water quality parameters (temperature, DO, % DO, pH and electrical conductivity) within sites

Sources	N	Temperature	DO	% DO	PH	Conductivity
Kamere Beach	16	22.8 (21.6, 23.4)A	4.4 (3.4, 7.2)B	75.1 (34.3, 110.5)B	8.0 (7.4, 8.8)	266.0 (253.000, 291.750)A
River Malewa	16	21.8 (20.2, 23.0)AB	6.7 (6.2, 7.0)AB	95.0 (86.5, 100.5)AB	8.3 (7.8, 8.4)	222.0 (192.3, 239.5)B
River Gilgil-Up	16	22.0 (20.7, 23.3)A	6.9 (6.3, 7.9)A	100.2 (95.5, 113.5)A	8.1 (8.1, 8.2)	217.5 (165.0, 228.8)B
River Gilgil-Dwn	16	20.9 (20.0, 21.2)B	6.4 (5.6, 7.1)AB	90.6 (83.2, 98.2)B	8.1 (8.0, 8.2)	218.5 (188.750, 229.500)B
P		0.001	0.021	0.012	0.791	0.001
BH I – Direct	16	22.4 (21.7, 22.7)B	4.2 (93.8, 4.385)A	59.6 (53.8, 62.7)A	8.1 (8.0, 8.4)A	1254.0 (1224.0, 1415.0)A
BH III – Direct	16	23.3 (22.9, 23.9)A	3.0 (2.3, 3.8)B	37.2 (31.7, 50.5)B	8.2 (8.0, 8.2)A	1211.0 (1187.0, 1306.5)AB
BH IV – Direct	16	21.9 (21.1, 23.9)AB	3.2 (3.0, 3.8)B	52.3 (44.9, 58.4)AB	8.3 (8.2, 8.5)A	1236.0 (1177.3, 1343.0)AB
DCKBH – Direct	16	23.5 (22.5, 26.7)A	3.8 (3.2, 4.2)AB	55.4 (42.6, 61.6)AB	7.5 (7.4, 7.7)B	1093.0 (1039.3, 1255.5)B
P		0.003	0.01	0.002	0.001	0.004
BH I – POA	16	22.3 (21.2, 22.8)B	5.5 (5.2, 6.4)A	79.4 (76.4, 88.6)A	8.4 (8.2, 8.7)	1230.0 (1210.0, 1397.0)B
BH II – POA	16	22.7 (21.3, 23.2)AB	5.1 (4.2, 5.8)AB	74.7 (61.2, 78.8)B	8.4 (8.3, 8.5)	1184.0 (1175.0, 1364.0)B
BH III – POA	16	22.5 (21.9, 23.8)AB	4.9 (3.9, 5.1)B	72.2 (53.4, 74.8)B	8.2 (8.1, 8.3)	1189.5 (1162.8, 1288.0)B
BH IV – POA	16	23.5 (22.7, 24.2)A	5.1 (4.7, 5.5)AB	75.4 (65.2, 80.2)AB	8.3 (8.2, 8.7)	1231.0 (1180.5, 1362.3)B
BH V – POA	16	22.7 (22.5, 23.5)AB	4.3 (4.2, 4.8)B	65.9 (64.7, 72.3)B	8.2 (8.1, 8.4)	1494.0 (1437.0, 1766.0)A
P		0.019	0.001	0.001	0.054	0.001

Where ANOVA on ranks was significant ($P < 0.05$), Tukey tests were performed to determine sites that were significantly different (indicated with different letters).

(Figure 3). For all parameters, there were at least 20 times as many CFUs in the samples from surface waters than in samples from either borehole sources. Comparing the direct borehole sources and the POAs, there were significantly fewer total coliforms in the direct sources (15.0 CFUs) than the POAs (23.0 CFUs). Even though the median values for *E. coli* (1.0 and 0.0 CFUs for direct and POAs, respectively) and intestinal enterococci (0.0 and 0.0 CFUs for direct and POAs, respectively) were similar, there were statistically significant differences. There were no significant differences between the CFUs of *C. perfringens* and HPCs of samples collected from direct boreholes and POAs. Within the different water sources, there were some significant differences among the different sites (Table 3). For the surface water sources, there were significant differences for four of the five parameters (all except *C. perfringens*). No site was consistently the highest or lowest, although the River Gilgil downstream site had the highest total coliforms, *E. coli* and HPCs, and the second highest median intestinal enterococci values, and the River Malewa and River Gilgil upstream samples tended to be lower than the other samples for most parameters. Within the borehole sites, there were fewer significant differences. Only total coliforms within the POA sites and the HPC within both the direct borehole and POA sites were significantly different. On a general note, surface water sources had the highest percentage contamination followed by borehole POA while borehole direct had the lowest (Figure 4). Based on drinking water quality standards set by various agencies (Table 1), the samples collected from the direct borehole sites had *E. coli*, intestinal enterococci and *C. perfringens* values that were within the recommended water quality standards while total coliforms and HPC values were above the recommended standards. Within the borehole POA sources, all the microbiological parameters were above the recommended drinking water quality standards and the microbiological parameters of samples collected from the surface sources were much higher than the recommended drinking water quality standards.

Solar disinfection

It took 50 minutes for the water samples to reach 65 °C, the temperature of pasteurization. The water source and volume of water treated influenced the amount of time it took to pasteurize the water samples (Table 4). After 50 minutes the

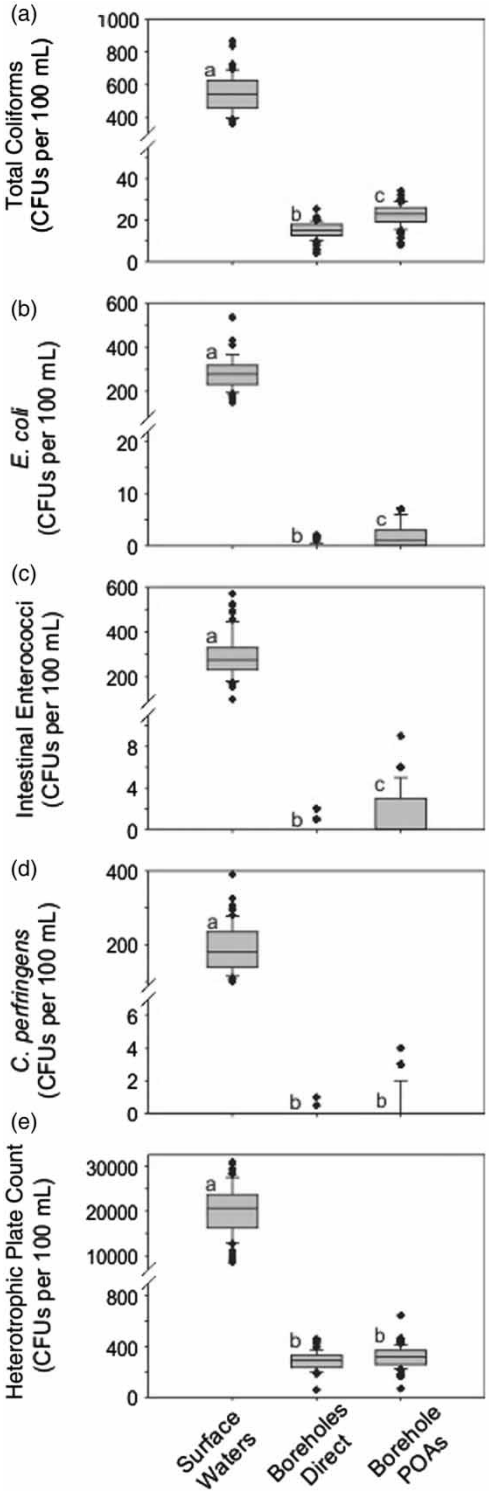

Figure 3 | Box and whisker plots of median (25%, 75% interval) water quality parameters within sites: (a) temperature, (b) DO, (c) % saturation of DO, (d) pH and (e) conductivity. Where ANOVA on ranks was significant ($P < 0.05$), Dunn tests were performed to determine sites that were significantly different (indicated with different letters).

borehole waters were disinfected of *E. coli* and total coliforms. It took an additional 30 minutes to completely disinfect the river and lake water samples, at which point the water temperature reached 75 °C.

DISCUSSION

Higher levels of electrical conductivity were recorded from borehole water than from surface water sources, and this can be attributed to the high levels of dissolved minerals such as fluoride that have been recorded in borehole waters within this Rift Valley province of Kenya (Opinya *et al.* 1987; Matofali 2006). The high values of dissolved oxygen in rivers and borehole waters at POA could have been due to the aeration process. The lack of significant variation in the physico-chemical parameters of the borehole direct (DIR) and borehole POA data showed that the entire borehole water was from a common aquifer.

Water sampled from the lake and rivers had significantly higher levels of indicator organisms than water from borehole DIR and borehole POA. Depending on the densities of microbiological parameters, the three water source types (borehole DIR, borehole POA and surface sources) can be categorized into classes I, II and III, respectively, based on the reference adapted from Kavka *et al.* (2006). This indicates that water from borehole POA and surface sources are not safe for human consumption unless efficiently treated. The microbiological quality of lake, river and borehole POA were above the recommended standards, while borehole DIR sources were within the standards. River Gilgil, downstream had higher values of microbiological abundances than its upstream point. This is an indication of an increase in faecal pollution loading, as the river cuts across the animal grazing fields, residential sites and flower farms. This result was comparable to a study that showed that there was a gradual increase in the bacterial counts from El-Qanater to Damietta on the River Nile as a result of domestic, sewage and agricultural effluents discharge by Damietta Ranch (Shawky & Saleh 2007; Hala 2007). The deteriorating quality from upstream to downstream was also comparable to studies on the River Njoro, Kenya (Mokaya *et al.* 2004; Yillia *et al.* 2009).

Table 3 | Median (25%, 75% interval) water quality parameters (*E. coli*, total coliforms, intestinal enterococci, *C. perfringens* and heterotrophic plate counts) within sites

Sources	N	*E. coli*	Total coliforms	Intestinal enterococci	*C. perfringens*	Heterotrophic plate counts
Kamere Beach	16	297.5 (238.8, 347.5) AB	532.5 (445.0, 558.8)A	415.00 (342.50, 492.50)A	197.5 (141.3, 243.8)A	23525.0 (18812.5, 25362.5)A
River Malewa	16	240.0 (211.3, 281.3) A	472.5 (396.3, 512.5)A	235.00 (187.50, 270.00)BC	175.0 (116.3, 195.0)A	19950.0 (14150.0, 21550.0)B
River Gilgil-Up	16	230.0 (190.0, 285.0) A	537.5 (428.8, 613.8)A	240.00 (201.25, 261.25)B	145.0 (125.0, 217.5)A	19650.0 (14762.5, 20325.0)B
River Gilgil-Dwn	16	325.0 (272.5, 358.8) B	652.5 (567.5, 670.0)B	297.50 (252.50, 326.25)C	197.5 (152.5, 277.5)A	24450.0 (18525.0, 27737.5)A
P		0.002	<0.001	<0.001	0.099	<0.001
BH I – Direct	16	0.0 (0.0, 0.0)A	15.0 (12.5, 17.8)A	0.00 (0.00, 0.00)A	0.0 (0.0, 0.0)A	245.0 (210.0, 305.0)A
BH III – Direct	16	0.0 (0.0, 0.0)A	15.5 (12.8, 18.4)A	0.00 (0.00, 0.00)A	0.0 (0.0, 0.0)A	290.0 (236.3, 342.5)AB
BH IV – Direct	16	0.0 (0.0, 0.0)A	16.0 (13.6, 16.5)A	0.00 (0.00, 0.00)A	0.0 (0.0, 0.0)A	292.5 (211.3, 322.5)AB
DCKBH – Direct	16	0.0 (0.0, 0.0)A	14.0 (11.3, 16.0)A	0.00 (0.00, 0.00)A	0.0 (0.0, 0.0)A	322.5 (276.3, 386.3)B
P		0.663	0.592	1.000	0.107	0.033
BH I – POA	16	1.5 (0.0, 3.8)A	20.3 (15.5, 23.4)A	0.00 (0.00, 3.00)A	0.0 (0.0, 0.0)A	250.0 (192.5, 322.5)A
BH II – POA	16	3.0 (0.0, 4.8)A	25.0 (20.3, 28.5)A	1.00 (0.00, 4.75)A	0.5 (0.0, 2.8)A	345.0 (297.5, 378.8)AB
BH III – POA	16	0.5 (0.0, 2.8)A	21.8 (20.0, 24.8)A	0.00 (0.00, 1.75)A	0.0 (0.0, 0.0)A	305.0 (235.0, 365.0)AB
BH IV – POA	16	0.0 (0.0, 2.0)A	20.3 (18.1, 25.4)A	0.00 (0.00, 1.75)A	0.0 (0.0, 0.8)A	302.5 (240.0, 381.3)AB
BH V – POA	16	2.0 (0.0, 5.8)A	25.8 (20.4, 26.9)A	0.50 (0.00, 5.00)A	0.0 (0.0, 1.0)A	350.0 (321.3, 396.3)B
P		0.248	0.021	0.420	0.201	0.018

Where ANOVAs on ranks were significant ($P < 0.05$), Tukey tests were performed to determine sites that were significantly different (indicated with different letters).

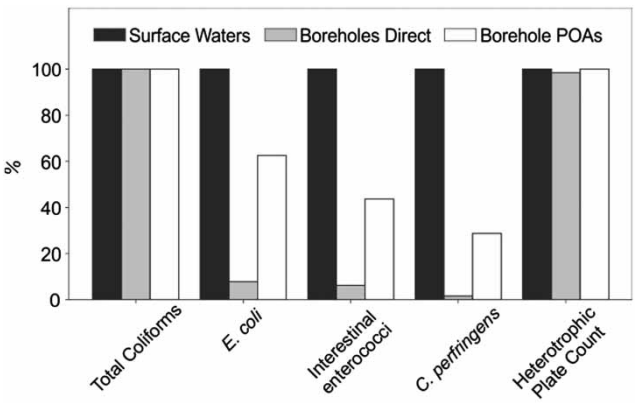

Figure 4 | The percentage of samples from different sources with microbiological densities above the recommended drinking water quality guidelines.

Boreholes are considered to be the cleanest water sources because deep aquifers are protected from pathogenic contamination, which are effectively removed by soil particles, die-off and predation (Dufour *et al.* 2003; Cronin *et al.* 2006). High densities of faecal indicators are therefore attributed to poor handling of water at the borehole POA where storage of water in the reservoir before it becomes available to consumers could be exposed to contamination. At the POA, water samples were obtained without sterilizing the pipes to give an exact indication of the microbial quality of water that is taken by the community from the sources. A similar approach was also applied in Zambia, where sterilization was not practised during sampling as this may often results in underestimation of the contamination status, especially in supply points where hose pipes are inserted onto the taps, as was the case in the Naivasha borehole water points (Wright *et al.* 2004). With that in mind, the most reliable means of preventing contamination of water sources is the protection of those sources (Figueras & Borrego 2010). On the other hand, the use of hosepipes that are held in dirty hands, and dragged on the muddy and filthy ground also contributes a great deal to water contamination at the POA.

Solar disinfection was able to eliminate *E. coli* and total coliforms from all the water sources (rivers, lake and

Table 4 | Response of total coliforms and *E. coli* to solar pasteurization for different times after pasteurization and for different water sources (borehole POA, lake and rivers) and volumes (1, 2.5 and 5 L)

			Total coliforms			*E. coli*		
Water source	**Treatments**	**Temperature °C**	**1 L**	**2.5 L**	**5.0 L**	**1 L**	**2.5 L**	**5.0 L**
Borehole – point of access	Raw	23.0	73	73	73	15	15	15
	0 minutes	50.9	0	3	7	0	0	2
	15 minutes	66.1	0	0	0	0	0	0
	30 minutes	74.2	0	0	0	0	0	0
Lake water	Raw	22.7	440	440	440	210	210	210
	0 minutes	50.5	26	42	30	14	20	25
	15 minutes	64.2	11	16	24	9	7	13
	30 minutes	74.7	0	0	0	0	0	0
River water	Raw	22.5	590	590	590	230	230	230
	0 minutes	50.1	7	20	24	3	13	19
	15 minutes	65.1	4	5	11	2	0	7
	30 minutes	75.0	0	0	0	0	0	0

borehole) and hence proved to be the most cost-effective method of purifying water for domestic consumption. Poor microbiological quality of drinking water has for a long time been associated with the incidence of gastrointestinal illnesses (World Health Organization 2002). This could therefore be the cause of the rampant diarrhoeal cases within Naivasha. Based on this, WHO guidelines that regulate water service providers to ensure they provide a consistent supply of safe drinking water are of great importance as far as the quality of water is concerned (Figueras & Borrego 2010). Owing to a variety of risk factors in the spread, transmission and acquisition of waterborne and water-related illnesses, interventions for their prevention not only enhance water quality but also try to improve the proper disposal of human faeces, as well as personal and environmental hygiene (Clansen 2002). Awareness creation of affordable, easy-to-use and locally available point-of-use/household water treatment approaches need to be available and emphasized, especially in rural and informal urban settlements (slums), as in the case of the Naivasha Lake basin.

CONCLUSIONS AND RECOMMENDATIONS

Borehole microbial water quality was better from the borehole direct sources than at the borehole POA. For the River Gilgil, the quality degraded as the water flowed downstream. Several boreholes were also noted to have been constructed close to pit latrines where flies could easily move from the pit latrines to the hose pipes used in delivering water to the consumers. General filth, the swampy nature and the use of hose pipes that were dragged on the filthy grounds were the most likely contamination routes. These could have contributed to the poor quality of the water sampled from the borehole POA.

The following recommendations are necessary to improve the quality of water available for human consumption and reduce the incidence of waterborne disease outbreaks: creation of awareness to the community of ways of maintaining good environmental sanitation; use of inexpensive and environmentally friendly methods, such as solar purification, to treat water before it is consumed; and putting in place proper waste disposal and treatment measures to reduce the amount of raw sewage finding its way into the water sources.

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