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Physico-chemical and bacteriological quality of water sources in rural settings, a case study of Kenya, Africa

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ABSTRACT

Water sources namely, rivers, dams, furrows, springs, wells, boreholes and rainwater were analyzed for selected physicochemical properties that included: pH, total alkalinity, dissolved oxygen (DO), turbidity, color, electrical conductivity (EC) and salinity, and screened for pathogenic bacteria (*Total coliforms, E. coli, Shigella, Salmonella, V. cholerae, Klebsiella, S. faecalis, C. perfringens*) to ascertain if the water met the required healthy standards. The physico-chemical characteristics investigated and bacterial load obtained were examined, equated and validated as per Kenya Bureau of Standards (KEBS) and the adopted World Health Organization (WHO) maximum guideline limits for potable water. Results revealed that parameter levels of mean turbidity (0.78 and 0.65 NTU) and color (0.0 mg pt L^{-1}) in borehole and rainwater did not exceed the maximum permissible level. The results analysis of color, temperature and conductivity found no significant differences ($P > 0.05$) while there was a significant difference in mean values of salinity, alkalinity, DO, turbidity, among water sources ($P < 0.05$). Presence of total coliforms (mean range, 10–23,830 CFU/ 100 mL), *Escherichia coli* (mean range, 10–3480 CFU/100 mL), *Vibrio cholera, Shigella* sp., *Salmonella* sp., *Klebsiella* sp., *Streptococcus faecalis* and *Clostridium perfringens* were detected in the water sources. The pathogenic bacteria screened were all detected in Athi and Kauthulini Rivers; hence these were the most polluted water sources. *Shigella* was found to be the most dominant pathogen occurring in all sampling sites except in borehole and rainwater. Borehole and rainwater was found to be the safest in terms of physicochemical properties and bacteriological quality. The study concludes that most water sources in tropics do not meet the potable water standards according to KEBS and WHO; hence they can be potential sources of waterborne diseases.

Introduction

More than one sixth of the world's population lack access to safe drinking water sources [1]. Climate change (floods and draughts) have affected water availability and surface water quality [2,3]. It is estimated that 1.8 billion people (28% of the world's population) use unsafe water in 2010 and that additional 1.2 billion (18% of the world's population) use water from water sources with significant sanitary risks [4,5].

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Two-fifth of Africans lack improved water supply, 60.2% have access to improved drinking water source, and 36% have access to improved sanitation facilities [6]. The lack of safe water creates a remarkable burden of diarrheal disease and other debilitating, life-threatening illnesses for people in the developing world [7]. Pathogenic microbes from human and animal wastes in the water that have been obtain from different studies includes: bacteria namely, *Campylobacter jejuni, C. coli*, Enteropathogenic *Escherichia coli, Salmonella typhi, Salmonella paratyphi*, other *Salmonella, Shigella spp., Vibrio cholerae, Yersinia enterocolitica, Pseudomonas aeruginosa, Aeromonas spp*., *Legionella pneumophila* and related bacteria, *Leptospira spp*., various mycobacterium and opportunistic bacteria; Viruses such as *Adenoviruses, Enteroviruses*, Polio viruses, *Coxsackie* viruses A, Hepatitis A, Enterically transmitted non-A, non-B hepatitis virus, hepatitis E, Echo viruses, Norwalk virus, Rotaviruses, Small round viruses; Protozoa namely *Entamoeba histolytica, Naegleria fowleri, Acanthamoeba castellani, Balantidium coli*, Giardia intestinalis, *Giardia lamblia, Cryptosporidium homonis*, Cryptosporidium parvum; and Helminthes such as *Dracunculus medinensi* and *Ascaris lumbricoides* [8,9].

Across the world, requirement for freshwater will continue to increase significantly over the coming decades to meet the needs of ever-increasing populations, growing economies, changing lifestyles and evolving consumption patterns [10]. This will greatly amplify the pressure on limited natural resources and ecosystems [10]. Of late, fresh water has become a scarce basic commodity as a result of over utilization coupled with water pollution [11]. Also, the emerging pathogens in drinking water have become increasingly important. These include newly-recognized pathogens from fecal sources such as *Cryptosporidium parvum, Campylobacter* spp., and rotavirus, as well as pathogens that are able to grow in water distribution systems, like *Legionella* spp., mycobacteria, and aeromonads [12]. The potential consequences of a drinking water source becoming contaminated with pathogenic microorganisms make prevention of such an occurrence critical [13]. Most of these infectious diarrheal diseases affect children in developing countries. The major enteric pathogens in these children include: rotavirus, *Campylobacter jejuni*, enterotoxigenic *E. coli, Shigella* spp. and *V. cholerae* O1, and possibly enteropathogenic *E. coli, Aeromonas* spp. *V. cholerae* O139, enterotoxigenic *Bacteroides fragilis, Clostridium difficile* and *Cryptosporidium parvum* [8]. Furthermore, almost all enteric pathogens and opportunistic pathogens that are transmissible by the fecal-oral route can be transmitted through water [14].

Natural water sources are at risk of contamination from numerous sources of contaminants [15] e.g., extensive agricultural industrial activities and urbanization results into the contamination of aquifer [16]. Other sources of these contaminants include agricultural fertilizers and pesticides, industrial and domestic wastes, leakages from landfills and pit latrines [17]. Furthermore, there are many pollutants in groundwater due to seepage of organic substances and inorganic chemicals, heavy metals [18], and pathogenic microbes from human and animal wastes.

Water intended for consumption, preparation of food and drinks or for personal hygiene should not contain agents pathogenic for humans [19]. However, varieties of microorganisms continue living in water including bacteria, fungi, protozoa, algae, and viruses, where they form a complex ecosystem whose dynamics are usually difficult to understand [20]. Those varieties of microbes play an essential role for contamination of water and results in a variety of outbreaks of diseases and death [20]. The presence of fecal coliforms in water is a hint of a potential presence of pathogenic microorganisms, which might cause water borne diseases [21].

The most notorious waterborne pathogens of recent times are protozoan such as *Giardia, Cryptosporidium Schistosoma* sp. and *Entamoeba hystolytica*; bacteria such as *Campylobacter, Shigella, Salmonella, V. cholerae, Clostridium perfringens, Mycobacterium* and *E. coli* (*E. coli*); and viruses such as polio virus and hepatitis A (*Picornavirus)*. The most common waterborne disease is diarrhea, which results from the use of contaminated water. Diarrheal disease is one of the primary causes of morbidity and mortality among children in the developing countries [22]. Hygiene practices are an important complement to improved water and sanitation in reducing diarrhea morbidity [23]. Therefore, if clean water (free from pathogens and physicochemical contaminants) can be adequately supplied to the growing populations and hygiene practices improved, the mortality and morbidity rates resulting from these water borne diseases would be greatly reduced, especially in children mostly younger than five years.

Potable or drinking water refers to water that has acceptable quality (by WHO guidelines or national standards for drinking water quality) in terms of physical, chemical and microbiological characteristics so that it can be safely used for drinking and cooking [24]. Pathogen free water is attainable by selection of high-quality uncontaminated sources of water, by efficient treatment and disinfection of water known to be contaminated with human or animal feces [13,25,26]. Surveillance of water quality to guarantee microbiological safety is an essential public health function in prevention of water borne diseases [15], hence improved health, socio-economic development and poverty reduction.

Therefore the focus of this paper was to assess the hydrological and the bacterial quality of water in selected common water sources in Kithimani area, Yatta District in tropical Africa based on the key physicochemical and bacteriological properties in relation to KEBS and WHO water drinking standards. This is supported by the fact that several water borne disease cases have been reported in Kithimani dispensary and other hospitals. Also, information on the quality of water sources in Kithimani location is scanty.

Materials and methods

Site description

Kithimani region is found in Yatta District, approximately 100 km from Nairobi City along Thika - Garissa road and is located at a latitude of 1°03′S to 1°10′S and a longitute of 37°30′E to 37°50′E (Fig. 1).

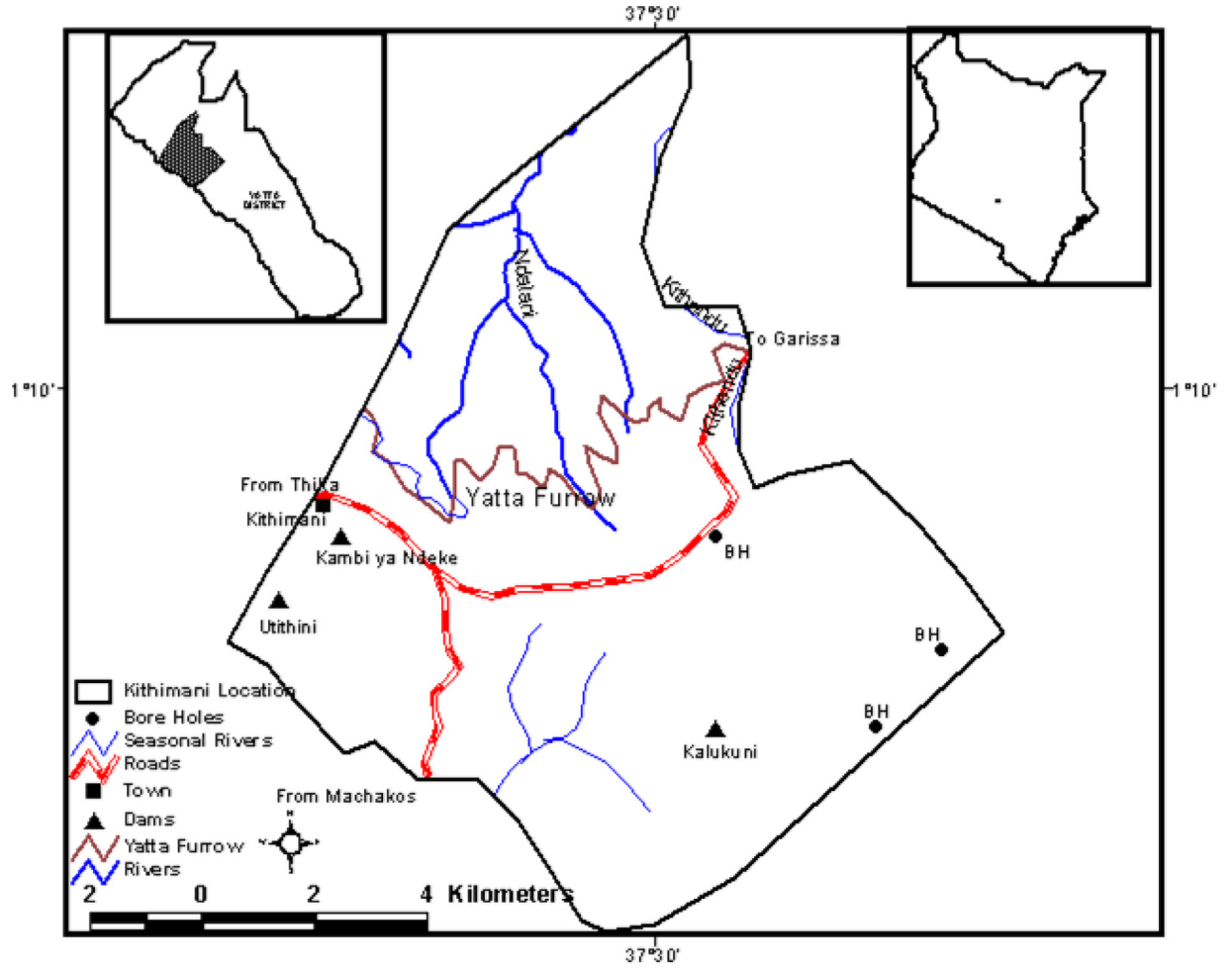

Fig. 1. Map of Kithimani area showing some sampling sites (Source: modified from Survey of Kenya, Machakos district map, 1999).

More than 70% of the location lies on the Yatta Plateau. The mean monthly temperature ranges from 29 °C in the coldest months to 36 °C in the hottest months [27]. It is a semi-arid savannah grassland region with a mean annual precipitation of 754 mm [28]. The region is served with water mainly by three rivers, namely Thika, Athi, and Tana. The main water sources are Yatta canal (furrow) and River Athi [28], which supply water for household, livestock and irrigation use. Its soils are well drained moderately deep to very reddish brown loamy soils. Its vegetation varies with altitude, although most of it has been depleted as a result of human activities like charcoal making [27]. The ground water (subterranean springs and deep wells) potential is also varied with some areas having a high potential while others are moderate. It experiences bimodal rain pattern which starts from March to May for long rains and from October to December in the short rain season [29]. Its altitude ranges from 790 to 1524 m above sea level. This location was chosen for the study because the water quality of most sources had not been determined, yet diarrheal diseases (a social relevance problem) had been reported in the region. Sources of non-point pollution in the water sources include cultivation, fertilizer, animal feed lots, pasture and dairy farming while Point sources of pollution include direct access to the water sources like people washing, livestock drinking and water fetching for household use [30].

Due to the sharing of water sources (both surface and sub surface) with domestic and wild animals, sanitation standards are low and wanting in Kithimani. The region is also in dire need of potable water due to its continuous shortage resulting from droughts and inadequate rainfall. However, to assure the quality and availability of safe water to the users as well as avoiding water resources contamination, the county government had adopted several strategies including fencing and cementing some water sources to protect domestic and wild animals from entering into the sources, promoting cooperation between academicians (me included during my M.Sc. degree studies) and politicians to work together to develop ideas and innovative technologies to provide sustainable solutions, sensitization of the families by NGOs to act responsibly with household chemicals and their disposal as well as recycling materials whose production creates water pollution. The Government had also put stern measures in reduction of harmful land erosion caused by agricultural irrigation as well as

Table 1
Recommended drinking water standards by WHO (WHO, 2006) as per Thika Water & Sewerage Company Ltd, Kenya water analysis manual.

Property of water	Highest desirable levels	Maximum permissible level
Turbidity	5 NTU	10 NTU
Color (units on platinum)	5	25
Chlorine (residual level)	0.20 mg L^{-1}	1.0 mg L^{-1}
pH	7.0–8.0	9.2
Salinity	500 mg L^{-1}	1000 mg L^{-1}
Chlorides	200 mg L^{-1}	600 mg L^{-1}
Sulphates	200 mg L^{-1}	400 mg L^{-1}
Nitrates	45 mg L^{-1}	45 mg L^{-1}
Fluorides	1.0 mg L^{-1}	1.0 mg L^{-1}
Calcium	75 mg L^{-1}	200 mg L^{-1}
Zinc	5.0 mg L^{-1}	15 mg L^{-1}
Copper	0.05 mg L^{-1}	1.5 mg L^{-1}
Lead	0.1 mg L^{-1}	0.1 mg L^{-1}
Type of micro-organism	**Per ml max.**	
E. coli or thermotolerant coliform	Must not be detectable in any 100-mL sample	
Total coliform bacteria	Must not be detectable in any 100-mL sample	
Streptococcus faecalis	Must not be detectable in any 100-mL sample	
Shigella	Must not be detectable in any 100-mL sample	
Salmonella	Must not be detectable in any 100-mL sample	

regulation on use of pesticides and fertilizers to ensure no overuse of pesticides and fertilizers. There were also efforts of chlorinating some water sources at regular intervals to help in keeping the water safe from getting contaminated.

Water sampling and field work

Water sources considered to be representative of available water sources in tropical Africa were selected from Kithimani area, Yatta district, Kenya (Fig. 1). At each water source, one sampling station was established based on accessibility. Each sampling station was sampled fourteen times during the study period that lasted for one year (from January to December 2009).

Water samples for laboratory analyses of physico-chemical properties were collected mid-stream at depths of 20–50 cm directly into clean one-liter borosil glass containers. The containers were first rinsed using the water from the source being sampled, then the water sample collected and tightly sealed and labeled in the field. For collection of samples from dams and boreholes, a sample bottle neck was tied with a string of appropriate length and the bottle with open mouth thrown in to the water source to collect the water sample after which the screw cap was immediately fixed aseptically. The Electrical conductivity (µS cm^{-1}) was determined at sampling site. The pH was determined in situ at the sampling site where possible, or immediately after the samples were collected. The chemical fixation of the oxygen in water samples meant for determining DO by Titration (Winkler) method in the laboratory were done immediately by adding the necessary reagents. The sample bottles were air-tight corked and protected from sunlight until the determination of the DO was done. Since pH and DO is temperature dependent, the water temperatures were also measured at the time of sampling in order to determine accurately the pH and DO.

Samples for microbial analyses were collected following same procedures for water physicochemical properties analysis, but using a thoroughly washed and heat-sterilized glass bottles with a capacity of 250 ml. All the collected samples were carried in an ice-packed cooler to the laboratory where they were immediately preserved in refrigerator maintained at four degrees Celsius until they were analyzed. Water samples for microbial analysis were filtered using 0.45 µm disposable membrane filters. The filter pad was incubated in appropriate media and temperature. Water physicochemical properties and bacteriological load samples results obtained were each evaluated in accordance with the recommended Kenya Bureau Standards and World Health Organization drinking water quality monitoring guidelines (Tables 1 and 2) to ascertain if each particular water source meets the regulatory standards for drinking water.

Laboratory analysis of the samples

The water temperatures and pH were measured using Whitman PHA 260 pH-meter. The total alkalinity, salinity, color, turbidity, dissolved oxygen (DO) and Electrical conductivity was measured following the standard methods as outlined in APHA [31]. The load of total coliform bacteria and *E. coli* contamination was determined and enumerated by Millipore filtration method as outlined in APHA [32] and as per the procedure by Krishnan et al [33]. Fecal coliform in water samples were analyzed at elevated incubation temperature of 44.5 ± 0.2 °C using mEndo agar while coliforms (a group of Gram-negative, facultative anaerobic rod-shaped bacteria that ferments lactose to produce acid and gas within 48 h at 35 °C) were analyzed at 35 ± 1.0 °C using endo agar. Their presence in water samples was used as an indicator of sanitary quality of water sources.

Table 2
Recommended drinking water standards according to the Kenya Bureau of Standards (Source: Adopted from KS 05–459: Part 1:1996) as per Thika Water and Sewerage Company Ltd, Kenya water analysis manual.

PARAMETER	UNIT	KS 05–459 REQUIREMENT
pH	pH Scale	6.5–8.56
Color	mg pt L^{-1}	15
Turbidity	NTU	5 Max
Conductivity	µS cm^{-1}	2500
Calcium	mg L^{-1}	100 Max
Total alkalinity	mg $CaCO_3$ L^{-1}	500
Chloride	mg L^{-1}	250 Max
Fluoride	mg L^{-1}	1.5 Max
Nitrate nitrogen	mg L^{-1}	10 Max
Sulphate	mg L^{-1}	400
Copper	mg L^{-1}	0.1
Zinc	mg L^{-1}	5
Lead	mg L^{-1}	0.05
Nitrates	mg L^{-1}	10
Type of micro-organism	**Per ml max.**	**Method of Test**
Total viable counts at 37 °C per ml	100	KS 05 – 200
Coliforms in 250 mL	Shall be absent	KS 05 – 200
E. coli in 250ml	Shall be absent	KS 05 – 200
Streptococcus faecalis in 250 ml	Shall be absent	KS 05 – 200
Shigella in 250ml	Shall be absent	KS 05 – 200
Salmonella in 250ml	Shall be absent	KS 05 – 200

For total coliforms m-FC agar plates were used while for E. coli MLG agar plates were used. Colonies of interest on the surface of the filter membranes (blue and yellow colonies on m-FC agar as total coliforms and green colonies on MLG agar as E. coli were observed, counted and recorded as colony forming units (cfu) per 100 ml [34].

The incubated tubes with water samples were examined for gas production and lactose fermentation. Gram stain was performed on all cultures. All those cultures that appeared as Gram-negative, short rods were tested for the IMViC reactions. For confirmatory test, a loopful of broth was streaked for isolation on a L-EMB agar plate and incubate for 18–24 h at 35 °C ± 0.5 °C. The plates were examined for suspicious *E. coli* colonies (dark centered and flat, with or without metallic sheen). For Indole production test, tube of tryptone broth was inoculated and incubated at 24 ± 2 h at 35 °C ± 0.5 °C. The test for indole was performed by adding 0.2–0.3 mL of Kovacs' reagent. Positive test was confirmed by observing if distinct red color in upper layer appears. All those cultures that were found to ferment lactose with gas production within 48 h at 35 °C, appear as Gram-negative non-spore forming rods and give IMViC patterns of + + – (biotype 1) or - + – (biotype 2) were considered to be of *E. coli*. The bacteriological analysis for the presence of *Shigella, Salmonella, V. cholerae, faecal Streptococci* and *Clostridium perfringens* were carried out as described earlier by Nzung' a et al [35].

For the screening of *Salmonella* and *Shigella*, a 1.0 mL water sample from each water source was enriched with selenite 'f' broth and incubated at 37 °C for 18–24 h. A loopful of the broth was then carefully streaked onto a Petri-dish containing salmonella-shigella agar (SSA) and incubated at 37 °C for 18–24 h. Presence of *Salmonella* and *Shigella* were confirmed by transferring the suspected colonies onto triple sugar iron (TSI) agar. Further confirmatory tests were conducted by inoculating the colonies onto motility indole urease agar test and incubated at 37 °C for 18–24 h. *Salmonella* are motile, urease positive, hydrogen sulphide producing microorganisms while *Shigella are* non-motile, urease negative and non-hydrogen sulphide producing microorganisms [61].

For the screening of *V. cholerae*, 0.1 mL of each water sample was enriched in different tubes containing alkaline peptone water broth and incubated for 6–8 h at 35 °C. A loopful of enriched broth was then streaked onto Thiosulphate Citrate Bile Salts-sucrose (TCBS) agar plate and incubated at 35 °C for 18–24 h. A drop of overnight pure bacterial peptone culture was transferred onto the surface of oxidase discs. Positive results were indicated by immediate change of the disk from white to purple color [63]. The colonies were gram stained to confirm the presence of *V. cholerae. V. cholerae* is characteristically Gram negative and comma or curve-shaped rods [62]. To screen for *faecal Streptococci,* subcultures were made from colonies obtained in EMB agar into a tube containing 5.0 mL glucose azide broth and incubated for 18 h at 37 °C. Positive results of *Enterococcus faecalis* were indicated by production of acid in the medium [61]. For the screening of *Clostridium perfringens*, colonies formed in EMB agar were inoculated in litmus milk medium and incubated at 37 °C for 5 days. Positive results of *Clostridium perfringens*, which are pathogenic Gram-positive bacteria, were indicated by a typical stormy clot reaction together with acid formation [61].

Statistical analysis

The obtained data was analyzed with SPSS 19.0 statistical package. The data in the results were described as averages of each variable. The physicochemical properties data of the water sources were subjected to ANOVA and correlated with bacterial quantity properties at the 0.05 significant levels.

Table 3a
Physico-chemical properties of water sources sampled during the study.

Water Source	N	EC (*μS/ cm*)	SD	pH	SD	Color (*mg Pt L^{-1}*)	SD	Temp(°C)	SD	Salinity (mgL^{-1})	SD
Athi R.	**14**	804.60	107.7	7.31	0.14	668.60	31.59	23.58	3.13	0.20	0.30
Borehole	**14**	679.80	196.1	7.42	0.29	0.00	0.0	24.24	2.49	0.08	0.03
Ianguni R.	**14**	732.70	346.7	7.72	0.13	112.30	64.4	23.60	2.95	0.15	0.19
Kambi Ndeke	**14**	345.10	255.3	7.56	0.21	658.40	44.23	24.17	3.05	0.02	0.00
Kauthulini R.	**14**	816.20	53.8	7.80	0.16	99.60	48.8	23.96	2.50	0.14	0.06
Kwa Kitoo	**14**	487.80	72.9	6.32	0.21	47.70	33.3	23.64	2.52	0.01	0.03
Kwa maengo	**14**	530.70	152.9	6.40	0.09	0.00	0.00	24.06	2.37	0.04	0.00
Rain water	**14**	43.90	15.56	7.02	0.12	14.90	14.1	23.64	2.70	0.01	0.00
Utithini Dam	**10**	1020.40	228.9	7.68	0.36	5317.70	343.48	23.99	2.92	0.00	0.00
Yatta Furrow	**11**	628.30	191.1	7.74	0.29	154.30	20.61	23.96	2.75	0.01	0.00

N: number of repetition; **SD**: standard deviation.

Table 3b
Physico-chemical properties of water sources sampled during the study.

Water source	N	Turbidity (NTU)	SD	DO (mgL^{-1})	SD	Alkalinity (*mg $CaCO_3$ L^{-1}*)	SD
Athi River.	**12**	32.20	8.0	6.00	0.68	149.00	16.62
Borehole	**12**	0.80	0.8	5.82	0.29	130.03	5.24
Ianguni River	**12**	10.90	2.5	8.48	0.49	128.63	14.30
Kambi ya Ndeke Dam	**12**	91.20	71.4	8.75	0.71	109.17	16.36
Kauthulini River	**9**	9.20	1.5	6.67	0.67	138.48	7.34
Kwa Kitoo spring	**12**	21.40	4.7	5.86	0.48	94.57	18.04
Kwa Maengo well	**12**	9.10	1.6	5.12	0.25	97.67	12.15
Rain water	**12**	0.60	0.6	9.35	0.39	11.00	4.07
Utithini Dam	**8**	1235.60	374	8.92	0.69	193.09	3.27
Yatta Furrow	**9**	19.50	16.9	7.85	0.44	124.50	18.55

N: number of repetition; SD: standard deviation.

Results and discussion

Water physicochemical properties

The results of the physico-chemical *properties* of the water sources sampled during the study period are summarized in Table 3a and b, respectively.

Water pH

Water pH in the study sites ranged between 6.0 and 8.3. The pH variation in different months according to various groups of water sources were as shown in Fig. 2.

In the majority of the water sources sampled, pH was within the acceptable range for drinking water as per KEBS and WHO standards (Tables 1 and 2). However, both the spring and Manual dug well water sources recorded pH levels that were below the acceptable lower limits for the two standards in June (pH 6.0) and September (pH 6.3) months, respectively (Fig. 2). The pH range (6.0–8.3) of all water sources were within the acceptable range for fresh waters, which usually ranges between pH 6.5 and 8.2 [36]. According to Boone and Xun [37], a pH value greater than 7.0 is vital for growth and reproduction for the majority of mesophilic pathogenic bacteria involved in the biodegradation of organic matter dissolved in water.

The annual means for the respective water sources were as depicted in Fig. 3. Research has shown that *V. cholerae* can thrive well in slightly acidic to alkaline media (pH 6 and above) but not in strong acidic media (pH below 5) as found in intestinal tract of humans. Therefore the mean range of pH 6.32 to 7.81 offered a viable environment for the survival of the *V. cholerae* detected in Athi and Kauthulini Rivers, respectively (Table 5).

Total alkalinity (mg $CaCO_3$ L^{-1})

Total alkalinity ranged from 59 to 196.3 mg $CaCO_3{}^{-}$L. Total alkalinity in most sampling sites depicted values that fell within the acceptable limit for potable water as per the two standards (Tables 1 and 2). The total alkalinity range (59.0–196.3 mg $CaCO_3$ L^{-1}) recorded at the study sites is typical of freshwater bodies [36]. Because total alkalinity is an estimate of the ability of water to resist change in pH when acid is added to it, such water sources meant that they had stable pH. Since the alkalinity of water is caused primarily by CO_3, HCO_3 and OH ions, it is evidence that such ions were less in these rivers and the other water sources.

Dissolved oxygen (DO)

Dissolved oxygen of the sampled water ranged from 4.9 to 10.3 mg/l. However, this concentration was higher than the minimum concentration of 3.0 mg/l (at 25 °C) necessary for aquatic life protection [38,39,40]. Of all the water sources sam-

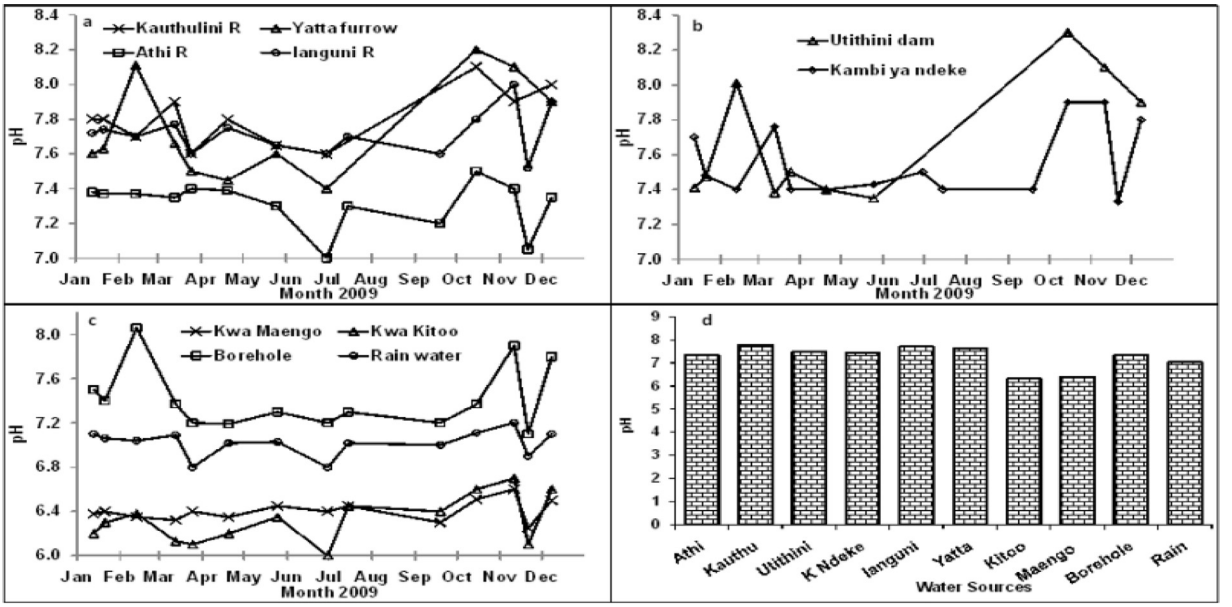

Fig. 2. Temporal changes in pH in the year 2009 (a–c) and median pH values for each study site (d).

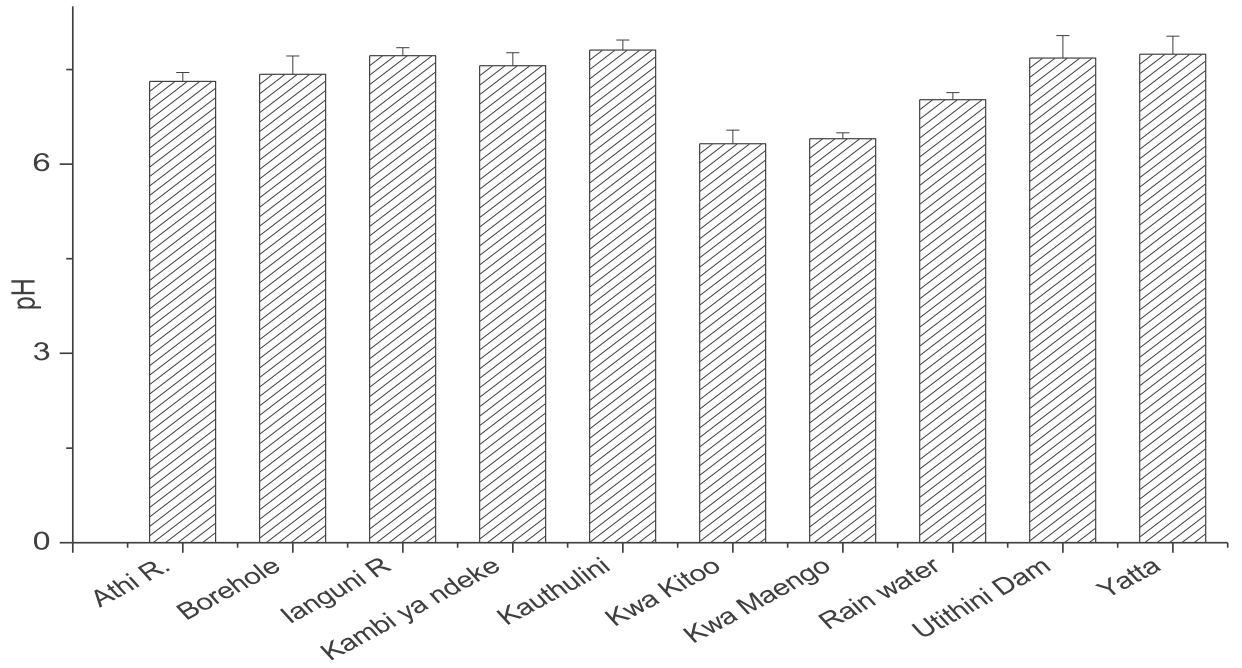

Fig. 3. Annual mean for each water source during the study period. Error bars represent the standard deviation (SD) of each mean.

pled, rainwater recorded the highest amount of DO (10.3 mg L^{-1}). The DO concentration range for the three rivers, Athi, Ianguni and Kauthulini (5.0–7.3 mg/l, 5.9–7.9 mg/l and 7.1– 8.8 mg/l, respectively), were almost within the same range. Thus, the level of nutrient load and rate of oxygen consumption by oxidisable matter in these rivers were more less the same. The DO concentration recorded in the water sources studied is within the expected range for excellent quality potable water for domestic supply and for recreational purposes.

According to WHO [41], water meant for domestic and recreational purposes (e.g. recreational activities like bathing, swimming, boating and fishing) should not have DO concentration below 3.0 mg L^{-1}. The high concentration of dissolved oxygen in the three river waters of Kithimani location can be attributed to the mixing and ventilation by wind action under conditions of limited organic matter loading as well as photosynthetic activities of aquatic plants and surrounding plant

species [42]. With the dissolved oxygen levels in open water sources being well above the 5.0 mg L^{-1} concentrations, this suggests that all these sources have the potential of supporting fish life and other forms of aerobic organisms [43]. The DO concentration ranges (5.01 and 8.79 mg L^{-1}) in the rivers sampled were within a range close to that of other rivers in Africa e.g. River Densu (6.6–7.16 mg L^{-1}) in Ghana obtained by Karikari and Ansa-Asare [44]. However, Eastern Region Rivers of Kenya had comparatively higher DO concentrations than western region of Kenya e.g., Kasat River (0.38 mg L^{-1}) in Kisumu obtained by Ochieng [45], though sampled at different times.

Turbidity (NTU)

Turbidity levels ranged from below limit of detection (0.0 NTU) to 1477 NTU, with the highest levels being recorded in the month of May (1477 NTU). Rainwater and borehole water had the lowest turbidity (0.0 NTU). In most of the water sources investigated, turbidity levels were above the acceptable maximum limit for drinking water as per the two standards (Tables 1 and 2). Of the entire sources sampled, only manual pump well, rainwater and borehole had turbidity values that were within the acceptable range for both KEBS and WHO in most of the months sampled. The other water sources had turbidity values that were above the acceptable range (5.0–10.0 NTU) for drinking water as per the two standards (Tables 1 and 2).

Water with high turbidity is normally considered to have a high chance of pathogenic microorganism contaminants, since elevated turbidity levels may make the water difficult to be disinfected appropriately [46]. Mean turbidity values for the dams (1235.62 and 91.21 NTU) recorded in Kenya were very high compared to some of other tropical countries e.g., Weija Intake (20 NTU), Machigani (18 NTU) and Galilea (16 NTU) reservoir stations in Ghana, respectively, according to results obtained by Asante et al. [42]. The high turbidity values in Kithimani region, Kenya can be owed to soil erosion and runoff, which is remarkably high during the high rainfall months. This is because the heavy rain causes floods, thus carrying nutrients, silt and household wastes into the water bodies, thus altering the turbidity.

Water color (mg pt L^{-1})

Water color of the sources during the study period ranged from below detection limit (0.0 mg Pt L^{-1}) to 7460 mg Pt L^{-1}. Dams had the highest water color of 1256 and 7460 mg Pt L^{-1} in the months of March and May, respectively. Most of the water sources investigated had water color above the acceptable limit for drinking water (Tables 1 and 2). However, manual pump well, borehole and rainwater color was within the acceptable range (Tables 1 and 2). The variation in water color of the water bodies investigated can be attributed to variation in the amount of dissolved and colloidal humic substances. The high water color in the sources is very significant in that, it increases the cost of water treatment.

Electrical conductivity (µS/ cm)

Electrical conductivities (EC) of the sampled sources varied from 32 to 7455 µS cm^{-1}. The trend in overall conductivity was that higher values of conductivity were obtained during low rainfall months while low conductivity values were obtained during the high rainfall months. In most of the water sources investigated, conductivity values fell within the acceptable range for drinking water as per KEBS water drinking standards (2500 µS cm^{-1}). Dams recorded conductivity value that was above the acceptable limit set by KEBS in the month of April (7455 µS cm^{-1}).

Electrical conductivity determines the capability of water to allow electrical current to pass through. Since the electric current is conducted through the movement of ions in solution form, EC also gives a clue of ion concentrations or total dissolved salts (TDS) in the water being tested for EC. The water conductivity ranges (32–7455 µS cm^{-1}) in Kithimani, Kenya were more variable than that obtained in other African countries e.g. at Densu basin water sources (237 - 402 µS cm^{-1}) in Ghana as per results by Karikari and Ansa-Asare [44]. The mean conductivity for the three rivers was 804.57, 816.18 and 732.71 µS cm^{-1}, respectively.

The low conductivity values during high rainfall months (range, 110–1419 µS cm^{-1}) compared to high values (range, 592–1428 µS cm^{-1}) recorded in the low rainfall months can be attributed to an increased discharge of more dilute water. Thus, the dilution of water sources by rainwater leads to low number of conductive ions, hence low conductivity during high rainfall months. The electrical conductivity range (110 to 1053 µS cm^{-1}) recorded in the rivers was greater than that of Thome river (range, 160–496 µS cm^{-1}) in Kenya obtained by Karanja [47]. In a river catchment, electrical conductivity is usually low in the upper reaches but increases downstream as the river water picks up ions from soil biota and other debris [48]. The mean EC value of standard uncontaminated water of a river roughly is 350 µScm^{-1} [49]. Thus, pollution related increase in the electrical conductivities of rivers is a cause for alarm since it makes the river water unsuitable for household use before the water is treated. The mean electrical conductivity for dams was 345.11 µS cm^{-1} which is slightly lower than the average EC (350 µS cm^{-1}) for a typical unpolluted river or dam. However, Utithini dam recorded comparatively high EC (1020.35 µS cm^{-1}), which is an indication of pollution.

Water salinity

Water salinity during the study period was found to vary from below detection limit to 1.2 mg/L^{-1}. Any water salinity readings of 500 mg/l and below are normally presumed to be excellent for drinking according to WHO [50]. However, water with salinity concentrations above maximum permissible level may perhaps have several direct and indirect health effects on those consuming it untreated e.g. the water may be unpalatable, and if consumed can cause raised blood pressure. High

Table 4
Mean total coliforms and *E.coli* recorded in the water sources during the study.

Water Source	N	T. Coliforms	SD	E. Coli	SD
Athi River.	**14**	238.29	51.08	34.79	10.75
Borehole	**14**	0.86	1.35	0.14	0.36
Ianguni River	**14**	176.29	36.47	11.57	11.61
Kambi ya Ndeke Dam	**14**	167.64	82.78	15.0	13.74
Kauthulini River	**11**	233.91	49.95	31.18	8.61
Kwa Kitoo spring	**14**	90.36	47.94	3.29	3.91
Kwa Maengo well	**14**	20.93	9.61	3.14	2.54
Rain water	**14**	0.07	0.27	0.0	0.00
Utithini Dam	**11**	212.27	47.62	27.36	11.12
Yatta Furrow	**11**	146.0	47.40	12.36	9.65

Table 5
Percentage frequency occurrence of pathogenic bacteria in water samples from different sources over the period of January – December 2009.

Site (100 mL of water sample)	Shigella.	Salmonella.	V. cholerae	Klebsiella	S. faecalis	C. perfringens
Athi R. (%)	43	71	21	7	45	54
Kauthulini R. (%)	64	64	36	36	38	50
Utithini dam (%)	50	50	0	30	57	71
Kambi ya Ndeke dam (%)	43	50	0	0	45	45
Ianguni R. (%)	43	0	0	21	27	36
Yatta Furrow (%)	36	45	0	0	0	50
Kwa Kitoo spring (%)	43	14	0	29	0	0
K. Maengo well (%)	29	0	0	36	0	0
Borehole (%)	0	0	0	0	0	0
Rain water (%)	0	0	0	0	0	0

saline levels in ground water and rivers may be due to increased upstream withdrawal, reduced river flows, dry season and sea-level rise [51,52].

Mean salinities of Athi, Ianguni and Kauthulini Rivers were 0.23 mg L^{-1} (range 0.1- 0.3 mg/L^{-1}), 0.13 mg/l (range 0.1–0.2 mgL^{-1}) and 0.16 mg/L^{-1} (range 0.1–0.5 mg/L^{-1}), respectively. These salinity levels are well within the desirable limits for KEBS and WHO outlined standards. The salinity level of all the sampling sites studied in Kithimani region was comparatively lower than the WHO maximum permissible concentration level of 600 mg/l, thus does not pose any risk to users. However, the salinity levels in Rivers were slightly higher compared to the other sources. These differences in salinity can be because of ground water flowing in from areas affected by dry land salinity, evaporation and leakage from ground water systems feeding the river [53].

Microbial water quality

The mean total coliforms and *E.coli* in water sources sampled during the study were as summarized in Table 4. The other pathogenic microorganisms (*Shigella, Salmonella spp, V. cholerae, Klebsiella spp, Streptococcus faecalis and Clostridium perfringens*) in the water sources were as discussed in the following sub-headings and as summarized in Table 5.

Total coliforms

Total coliform (TC) counts in the water sources investigated varied from 0.0 to 3.43×10^4 colony forming units (CFU) per 100 mL. The highest TC load was recorded in Athi and Kauthulini Rivers with TC counts of 3.43×10^4 and 2.94×10^4 CFU per 100 mL in the months of December and November respectively. Total coliforms were detected in all the water sources with the lowest counts being recorded in borehole and rainwater, where TC counts of 100.0 CFU per 100 mL were recorded in the months of March and April. The mean total coliforms and *E.coli* per 100 ml recorded in the water sources during the study are as per Table 4. A positive correlation between TC counts and a number of physico-chemical properties was noted during the study period. A positive correlation with pH ($r = 0.596$, $P = 0.006$) and conductivity ($r = 0.494$, $P = 0.03$) to that of TC counts were noted. Increase in water pH resulted in an increase in total coliform counts. It was further noted that an increase in water conductivity appeared to have contributed to an increase in TC counts in the water ($r = 0.494$, $P = 0.027$). Water turbidity in the area was however not significantly related to the TC counts in this area ($r = 0.293$, $P > 0.05$). Salinity in the water sources in Kithimani was found not to be significantly related to the TC counts in the water sources ($r = 0.406$, $P > 0.05$).

In most of the sampling sites investigated, the results suggest that the quality of water were unacceptable owing to the presence of coliforms. Total coliform counts, expressed as colony forming units (CFU varied widely with a range from below detection limit in some samples obtained from borehole and rainwater to 2.38×10^4 CFU 100 mL^{-1} recorded at River Athi. Hence, most of the water sources sampled are not safe for household applications without prior treatment to

reduce both the total and faecal coliforms to zero CFU 100 mL^{-1} as per KEBS and WHO stipulation for drinking water. Total coliforms mean range ($1.0–2.38 \times 10^4$ CFU 100 mL^{-1}) recorded in the water sources was above the WHO [50] and KEBS [54] recommendations that total coliforms of drinking water should not exceed 1.0 CFU 100 mL^{-1}. The range ($1.0–2.38 \times 10^4$ CFU 100 mL^{-1}) of total coliforms was lower than that recorded in Thome river, Nairobi ($0.0–3.5 \times 10^5$ CFU 100 mL^{-1}) by Karanja [47]. The mean total coliforms for Athi, Kauthulini and Ianguni rivers were 2.38×10^4, 2.34×10^4 and 1.76×10^4 CFU 100 mL^{-1}), respectively.

The total coliform range (1.0–4.0 CFU 100 mL^{-1}) for borehole water recorded in the present study is slightly lower than the range in some of African countries' boreholes e.g., 7.0 – 11.0 CFU 100 mL^{-1} recorded in Victory lodge and Doggy hostel borehole waters in Uli, Anambra state, Nigeria [55]. The difference in total coliforms could be due to water contamination by the sewerage system, which is in the proximity of water sources in the Nigerian lodges unlike in Kithimani where there were no sewerage systems near boreholes.

E. coli *counts per 100 mL*

Total *E. coli* counts in the water sources investigated were found to be between 0.0 and 5.9×10^3 CFU 100 mL^{-1}. Both Athi and Kauthulini Rivers recorded the highest number of total *E. coli* of 5.9×10^3 and 4.7×10^3 CFU 100 mL^{-1}, respectively in the months of December. Rainwater and Borehole recorded the lowest number of total *E. coli* range of 0.0 to 1.0 CFU 100 mL^{-1} in most of the samples collected. Results analysis using a one way ANOVA test revealed a significant difference in *E. coli* counts among the water sources investigated ($F = 30.2$, $P = < 0.05$).

E. coli counts in most water sources investigated exceeded the maximum permissible limits set by WHO and KEBS for drinking, irrigation and recreational purposes on most occasions indicating that the water is unsuitable for such uses. For all the water directly intended for drinking, *E. coli* or thermotolerant coliform bacteria should be undetectable in any 100 ml water sample [39,56]. This also applies to treated water entering a water supply system. The set limit for irrigation of crops eaten raw is 77 CFU 100 mL^{-1} of water [57]. The *E. coli* range (0.0–1.0 CFU 100 mL^{-1}) for borehole water obtained in this study is lower than the range obtained in other tropical countries e.g. 3–7 CFU 100 mL^{-1} recorded for victory lodge and Doggy hostel borehole waters in Uli, Anambra state, Nigeria [55].

Shigella, salmonella spp, V. cholerae, klebsiella spp, streptococcus faecalis and clostridium perfringens in the water sources

Over the study period, spatial-temporal variation of potentially pathogenic bacteria in water samples from various sources was experienced (Table 5).

Salmonella spp was most frequent in Athi River where it occurred in 71% of the samples collected. *Salmonella* spp was absent in Kwa Maengo manual pump well, Borehole, Ianguni River and rainwater samples. *Shigella* spp. was most frequent in Kauthulini River samples where it occurred in 64% of the samples collected while *Shigella* levels below detection limit were recorded in borehole and rainwater Table 5. *V. cholerae* were actually absent in most of the water sources analyzed except in Kauthulini and Athi Rivers. The frequency of occurrence for the *V. cholerae* was highest in River Athi (36%). The highest *Klebsiella spp* occurrence frequency (36%) was detected in Kwamaengo manual pump well and Kauthulini River. Yatta furrow, borehole, Kambi ya ndeke dam and rainwater water sources recorded *Klebsiella* sp. levels below detection limits. A few water sources were detected with *Streptococcus faecalis* with most sources recording levels below detection limit. Utithini dam had the highest occurrence frequency (57%) for the *Streptococcus faecalis* (Table 5). Since the recommended maximum limit for *Fecal streptococcus* in raw drinking water is 0 to 20 CFU 100 mL^{-1} for recreational and irrigation of crops eaten raw [58], the water sources did not meet these standards. Nearly half of the water sources sampled had some *Clostridium perfringens* with Utithini dam recording the highest percentage (70%) (Table 5). Most of the water sources therefore had an appreciable amount of pathogenic bacteria, hence was not within the expected potable KEBS and WHO drinking standards of zero colony forming units per 100 ml. Only Mosque borehole and rainwater sources fell within the expected potable water standards as per KEBS and WHO standards.

The low occurrence frequency of both *Shigella* and *S. typhi* at Kwa Maengo hand pump well (29% and 0%, respectively) suggests that the site is less frequently contaminated with fecal wastes containing these bacteria. Furthermore, the well had concrete slab and often the aperture was tightly covered with a lockable lid all the time we visited the well to collect the water, hence possible reasons why there was little or no contamination. The lower occurrence frequency can also be attributed to a limited exposure of underground water to surface pollutants. Absence of *V. cholerae* in most of the water samples from the water sources is a suggestion that there is a low incidence of the disease caused by this pathogenic microorganism among the people living around Kithimani.

High occurrence frequency of *Shigella* in Utithini dam (50%) and Kauthulini River (64%), *Salmonella* in Athi (71%) and Kauthulini (64%) Rivers, *Streptococcus faecalis* in Utithini dam (57%), *Clostridium perfringens* in Athi River (54%) and Utithini dam (71%) suggests that these water sources are highly contaminated with fecal matter of homoeothermic origin. Detection of *V. cholerae* in Kauthulini (36%) and Athi (21%) rivers could be due to high prevalence of cholera in the population, thus contributing to the pollution of the upstream sampling site of the two rivers.

Both animal and human excreta are the principal sources of pathogenic contaminants in water. Bacteria can also enter a water supply through surface runoff or by inundation or infiltration by floodwaters. Floodwaters usually contain high levels of bacteria [59]. Small depressions filled with floodwater provide a viable breeding ground for bacteria [60]. The main sources of pollution of the water sources in Kithimani are domestic and agricultural activities. Domestic pollution can be as a result of leakage from faulty septic tanks and discharge from pit latrines. When the distance between the wells and

the pit latrines is generally short, there is high probability of pathogenic microorganisms migrating from the pit latrines through seepage to the wells. Agricultural pollution is from irrigation water and precipitation runoffs that transport residual herbicides, insecticides, fertilizers and fecal material that enters water sources. According to WHO guideline on construction of pit latrines, the distance between the underground water sources and the pit latrine should be adequate enough not to allow the migration of pathogenic microorganisms from fecal contents into the water sources (boreholes and wells) i.e. not less than 30 m from the pit latrine and at least 2 m above the water table while the septic tank should be 15–17 m away from underground water sources. However, the research established that some households had their manual dug wells and rainwater catchments tanks positioned within less than the recommended 30 m and 15 m distance from pit latrines and septic tanks, respectively, hence this could be one of the possible contamination sources.

Implications of the microbial quality of the water sources

Results analysis obtained have shown that most of the water sources in Kithimani area do not conform to the KEBS and WHO standards for potable water. This being a representative of part of Sub-Saharan Africa is evidence that there is lack of safe and sanitary water supply, hence the reason why Sub-Saharan Africa's (SSA's) population suffers markedly from water-borne infections. This is supported by the fact that water-borne diseases are as a result of consumption of polluted water containing pathogenic microorganisms whose origin may be from human and animal feces. It is therefore highly recommended that the water from these sources be treated or boiled before it is used for domestic purposes. With access to improved potable water sources or supply and water treatment services, improved basic sanitation facilities like access to excreta disposal facilities, this can drastically reduce biological contamination of drinking water, hence prevention of water borne diseases, thus leading to better health, lessening poverty, and more so improved social and economic growth. Nevertheless, SSA has many setbacks that prevent her from achieving these goals, for example natural disasters, chronic political conflicts, disparities in urban-rural settings and rapid population growth.

Conclusions

The results have shown that some of the physicochemical properties of the water sources investigated do not meet the adopted WHO and national guideline values for potable water qualities. Of all the pathogenic bacteria screened, *Shigella spp* was the most abundant in the sampling sites. Rivers were found to be the most contaminated sources in terms of bacteriological quality. With the exception of borehole and rainwater sources, the bacteriological quality of all other sampled sites was not within the outlined water quality standards according to KEBS and WHO. Therefore the study concludes that there is a potential risk of contracting waterborne diseases and other ailments by those using the untreated water.

Conflict of interest statement

The author declares that there is no conflict of interest whatsoever.

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Supplementary material

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