Original Research Article

ASSESSMENT OF PHYSICO-CHEMICAL AND BACTERIOLOGICAL QUALITY OF DRINKING WATER SOURCES IN KAKAMEGA COUNTY, KENYA.

Abstract

Water-borne diseases still present a major health burden in Africa. Large segments of the rural population here have no access to potable water. This study has been designed to assess the physico-chemical and bacteriological quality of drinking water sources in the study area. The study was conducted in Kakamega county covering the twelve sub-counties of Likuyani, Lugari, Malava, Navakholo, Lurambi, Ikolomani, Shinyalu, Mumias East, Mumias West, Matungu, Butere and Khwisero. Socio-demographic characteristics of the study populations were captured using a structured pre-tested questionnaire. The Most Probable Number (MPN) method was used to determine the abundance of Total coliforms and Escherichia coli (E. coli) in the water samples collected. Physico-chemical analyses (Temperature, pH, Electrical conductivity, Total dissolved solids and Dissolved oxygen) were carried out. Free residual chlorine was determined by colorimetric method with DPD chlorine tablets. The analyses were conducted following guidelines of American Public Health Association and WHO. Only 17% (68/400) of the study population had access to piped water in the study area. Waste management practices of the localities was found poor as more than 62 % (248/400) of the respondents dispose waste materials in open fields. All drinking water sources investigated were contaminated with Total coliforms. There was a wide variation in Total coliforms and E. coli. Total coliform counts ranged from 0.0 - 3652.5 cfu/100 ml whereas E. coli ranged from 0.0 - 33.0 cfu/100 ml. Both Rivers/streams and unprotected dug wells recorded the highest number of Total coliforms and E. coli. Piped water, Rainwater collection and Boreholes recorded the lowest number of Total coliforms and E. coli. E. coli counts in most drinking water sources investigated exceeded the maximum permissible limits set by WHO/KEBS, implying that they are not safe for household applications without prior treatment. The results indicate that protected drinking water sources (piped water, boreholes, protected dug wells and protected springs) are subjected to a high level of fecal contamination in the study area. One of the possible reasons might be constructional defects on casing, concrete covers, fences, diversion ditches, and protection of eye of springs and other plumbing accessories. Lack of regular supervision, disinfection and proper maintenance might also be the reasons for contaminating protected water sources. The high level of E. coli can also be explained by poor sanitation habits, low level of hygiene education, poor supervision and maintenance and irregular disinfection of water points. The recorded temperature and pH ranged between 19.9–27.2 °C and 4.8 - 9.1, respectively. Turbidity and Electric conductivity of the water samples ranged, respectively, between 0.43–467.02 NTU and 18.7–510.7 µS/cm. Residual chlorine in piped water showed a range of 0.06-1.2 ppm. In addition, Total dissolved solids were found to be between 20.1 and 639.2 mg/l; whereas Dissolved oxygen ranged from 2.2- 15.4 mg/l. The present study has revealed that some of the bacteriological data and physico-chemical parameters of the different water sources had values beyond the maximum tolerable limits recommended by WHO/KEBS. Thus, it calls for appropriate intervention, including awareness development work and improving the existing infrastructure in order to minimize the potential health risks.

Keywords – Kakamega county, Physico-chemical and Bacteriological analysis, Drinking water sources.

1.0 Introduction

If diseases brought on by consuming contaminated water and using poor hygiene habits are to be avoided, safe drinking water is required. In many regions of the world, water borne diseases continue to be a significant health burden and are thought to be responsible for over 842,000 deaths from diarrheal disease each year [1]. 1.1 billion people worldwide rely on contaminated lakes, rivers, and open wells for their drinking water. Asia (20%) and sub-Saharan Africa (42%) account for the majority of them. Additionally, inadequate sanitation is a problem for 2.4 billion people worldwide [2]. Water that complies with WHO standards for microbiological, chemical, and physical qualities is considered safe to drink [3]. In Kenya, about 50% of diseases relate to water, sanitation and hygiene [4]. The main drinking water sources in Kakamega county are piped water, boreholes, protected dug wells, protected springs, rainwater collection, unprotected dug wells, unprotected springs and surface water-rivers/streams. Acute and long-term impacts can result from microbial and chemical pollutants in drinking water sources [5]. Regarding drinking water, bacterial contamination poses a serious health risk [6]. The source, distribution, transportation, or domestic handling, hygiene, and sanitation practices could all contribute to this contamination [7]. A sign of pathogenic/fecal contamination is the presence of bacteria, particularly E. coli [8]. Establishing water quality at drinking water sources is of critical importance to ascertain its safety. Several studies have been conducted in Kakamega county concerning water quality from different sources; but very few have been published to show water quality at drinking water sources. There is limited information on physico-chemical and bacteriological quality of drinking water sources in Kakamega county and many residents are unsure of the safety of their drinking water sources. The present study goes a long way in filling this gap.

2.0 Materials and methods

2.1 Study area

The study was conducted in Kakamega county. Kakamega County is located in the Western part of Kenya and borders the counties of Vihiga to the South, Siaya to the West, Bungoma and Trans Nzoia to the North and Nandi and Uasin Gishu to the East. (Figure-

1).

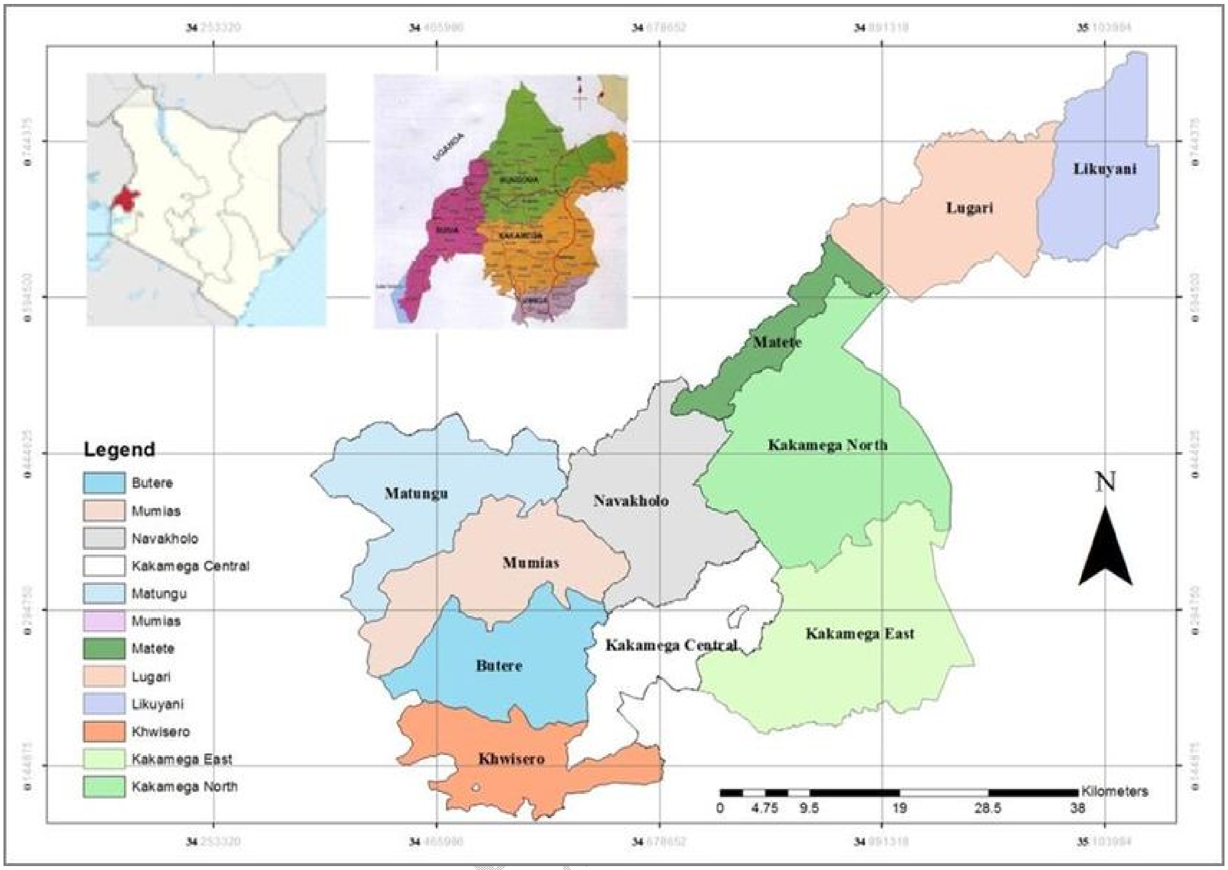

Figure 1: Map of the Study Sites, Kakamega County, Kenya

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Kakamega county is located about 288 kilometers (179 miles) North-east of Nairobi, the capital city of Kenya. Geographically, the county is located between latitude 0°16'60.00" N and longitude 34°45'0.00" E. The altitude ranges from 1,240 m to 2,000 m above sea level. The County covers an area of 3,051.3 KM^2 and is the second populous county after Nairobi with the largest rural population in Kenya. As per 2019 census Kakamega county had a total population of 1,867,579 people, of which 897,133 are males, 970,406 being females and 40 intersex persons [9]. There are 433,207 households with an average size of 4.3 persons per household and a population density of 618 people per square kilometer. The annual rainfall ranges from 1280.1mm to 2214.1 mm per year. The rainfall pattern is evenly distributed all year round with March and July receiving heavy rains while December and February receives light rains. The temperatures range from 18°C to 29°C. January, February and March are the hottest months with other months having relatively similar temperatures except for July and August which have relatively cold spells. The county has an average humidity of 67 percent. Since the early 1960s both minimum (night) and maximum (day) temperatures have been on a warming trend throughout Kenya. Current projections indicate increases in temperature. Recent trends show a marked increase in inter-annual variability and distribution of rains, with an increase in the number of consecutive dry days and shorter but more intense periods of rainfall resulting in an increase in frequency of floods. Future climate change may lead to a change in the frequency or severity of such extreme weather events, potentially worsening impacts. Increased average temperatures and changes in annual and seasonal rainfall will affect the availability (quantity) and quality of drinking water resources.

2.2 Description of sampled water sources

Sampled water sources in the study area included: Improved drinking water sources (piped water/tap, boreholes, protected dug wells, protected springs, rainwater collection) and Unimproved drinking water sources (unprotected dug wells, unprotected springs, surface water-rivers/streams). Improved water source is a type of water source which as a result of a construction or intervention programs, is protected from external sources of contamination, whereas Unimproved water sources are those that are not protected in any way from external contaminants like fecal matter.

Piped water/tap

This covers water sources from piped water supply schemes within the study area. The schemes sampled under this study were those with full treatment works. For piped water systems, samples were drawn from household taps or communal water points.

Boreholes

Boreholes are machine-drilled wells with a tiny diameter (less than 300 mm) that are typically 30–250 m deep. Installing a well screen and vertical pipe (casing) to prevent the borehole from caving completes them. Additionally, this protects any installed pump from being filled with sand and sediment by preventing surface impurities from entering the borehole. They are installed with motorized or hand pumps, have drainage aprons, and a sanitary seal. Samples were taken straight from the pump head for hand pumps and drawl taps for motorized systems.

Protected springs

A spring source can be used to supply a gravity system or to create a single, continuously running outlet that is high enough to accommodate a bucket or other container beneath it. Natural springs that are protected by one or more of the following structures include those with concrete spring boxes, head walls, drainage channels, fences, and cut-off ditches. Many different methods exist for getting the clear spring water from its source into the bucket or pipeline. For protected springs, samples were taken from the same tap or open pipe as the users.

Unprotected springs

Surface springs occur where groundwater emerges at the surface because an impervious layer of rock prevents seepage downwards or where the water table is high enough to intersect a depression in the local topography. Unprotected springs normally lack the construction works to prevent water from contamination. For unprotected springs samples were drawn from points where consumers draw their water for domestic use.

Rain water collection

Rainwater harvesting is the collection and storage of rain, rather than allowing it to run off. Rainwater harvesting is one of the simplest and oldest methods of self-supply of water for households, having been used in India and other countries for many thousands of years. Installations can be designed for different scales including households, neighborhoods and communities and can also be designed to serve institutions such as schools, hospitals and other public facilities. In the study area this includes both formal (i.e. with guttering, downpipe, covered storage and tap) and informal (i.e. open container under roof or gutter) systems for the collection of rainwater. For rainwater collection systems samples were taken from the taps if available or otherwise from the pouring jug usually used to draw water from storage containers.

Protected dug wells

Dug wells are holes in the ground dug by shovel or backhoe; excavated below the groundwater table until incoming water exceeded the digger's bailing rate. Protected wells are lined with stones, brick, culverts, or other materials to prevent collapse and covered with a concrete slab. Since it is so difficult to dig beneath the ground water table, dug wells are not very deep. Typically, they are only 10 to 40 m deep. Being so shallow, dug wells have the highest risk of becoming contaminated. To minimize the likelihood of contamination, your dug well should have certain features. These features help to prevent contaminants from traveling along the outside of the casing or through the casing into the well. The well should be cased with a watertight material (for example, tongue-and-groove precast concrete) and a cement grout or bentonite clay sealant poured along the outside of the casing to the top of the well. The well should be covered by a concrete curb and cap that stands about a foot above the ground. Protected wells are normally installed with motorized or hand pumps. For hand pumps samples were collected directly from the pump head, and for motorized systems drawl taps.

Unprotected dug wells

Unprotected dug wells are common in the study area. They are unlined, uncapped and without pumps, and very few may have aprons. They are typically built within household compounds. Some wells have part of the shaft sealed with brickwork, and some have a headwall. They lack most of the features for protected wells listed above. From unprotected wells samples were taken by pouring water into the bottle from the bucket used to extract water.

Surface water-rivers/streams

These are points along rivers/streams where communities draw water for domestic use. Samples were drawn directly from the points where consumers draw their water.

2.3 Collection of water samples

A cross sectional study was conducted in Kakamega county from May, 2017 to September, 2017. Ninety six water samples were randomly selected from the twelve sub-counties of Likuyani, Lugari, Malava, Navakholo, Lurambi, Ikolomani, Shinyalu, Mumias East, Mumias West, Matungu, Butere and Khwisero. Bacteriological and physico-chemical quality of the drinking water sources were analyzed in three rounds. Both improved and unimproved drinking water sources were sampled. Sampling was done as follows: Improved drinking water sources [piped water (n=12), boreholes (n=12), protected dug wells (n=12), protected springs (n=12), rainwater collection (n=12)] and Unimproved drinking water sources [unprotected dug wells (n=12), unprotected springs (n=12), surface water-rivers/streams (n=12)]. During sample collection, handling, preservation and analysis, standard procedures recommended by the American Public Health Association APHA [10] were followed to ensure data quality and consistency. Analysis of physico-chemical parameters was done on site based on APHA [10] protocol. Bacteriological analysis of water samples for Total Coliforms and E. coli was done in the laboratory using the Most Probable Number (MPN) method APHA [10]. For laboratory analyses, four samples of water were collected from each sampling site using 500 ml plastic bottles which were pre-cleaned with non-ionic detergents and rinsed with deionized water. The bottle samples were then labeled according to the sampling sites and preserved in a cooler box containing ice blocks at 4°C so as to maintain a low temperature to prevent multiplication of the micro-organisms. The samples were then transported to Kakamega County Water and Sanitation Company (KCWASC) and Eldoret Water and Sanitation Company (ELDOWAS) laboratories for bacteriological analysis. Water samples that were not immediately analyzed at the laboratory were preserved in a refrigerator at temperatures below 4˚C to slow down the chemical reactions in the water [11]. After analyses, the obtained results for physico-chemical and bacteriological parameters were compared with water standards specified by WHO [12] and KEBS [13].

2.4 Physico-chemical analysis

Analysis of physico-chemical parameters was done on site based on APHA [14] protocol. Temperature (ºC) and Dissolved oxygen concentration (mgl-1) were measured using an Oxygen meter model YSI 15B; Turbidity (NTU) was measured using a Turbidimeter model Hach 2100P; Electrical conductivity (EC) and Total dissolved solids (TDS) were measured using EC/TDS meter model H1 99300; pH was measured using a Digital Mini Model 49- pH meter. For a pH measurement, the equipment was first standardized with a buffer solution of pH ranging from 4 to 9. Free residual chlorine was determined by colorimetric method whereby DPD chlorine tablets are used. All tests were performed in triplicates and the averages are reported herein.

2.5 Bacteriological analysis of water samples for Total Coliforms and E. coli

The Most Probable Number (MPN) method, APHA [10], was used to determine the abundance of Total coliforms and Escherichia coli (E. coli) in the water samples collected from piped water/taps, boreholes, protected dug wells, protected springs, rainwater collection systems, unprotected dug wells, unprotected springs and surface water-rivers/streams.

2.5.1 Enumeration of Total Coliforms

Five tubes containing double strength MacConkey broth (10 ml) were each inoculated with a sub water sample (10 ml) from the same water sample. Using a sterile pipette, five tubes containing single strength MacConkey broth (5 ml) were each inoculated with a sub water sample (5 ml) from the same water sample. To other five tubes containing single strength MacConkey broth (5 ml), a sub water sample (1 ml) was inoculated into each tube using a sterile pipette. The tubes were closed and shook to distribute the sample uniformly throughout the medium and to ensure that the Durham tube inside had no air. The tubes were then incubated at 35˚C for 24 hours. The above procedure was done to each of the water samples collected. After 24 hours the incubated tubes were examined for gas production and lactose fermentation. The tubes that showed production of gas and acid were isolated, recorded and considered positive for total coliforms. The MPN of total coliform was read off from the Standard MPN table.

2.5.2 Enumeration of E. coli

From each of the positive tubes for total coliforms, a sample (1 ml) was removed and inoculated into MacConkey broth single strength (5 ml) and incubated at 44.5˚C for 48 hours. The tubes were examined for gas production and acid production. The positive tubes were isolated and were taken as positive for faecal coliforms. Using a sterile inoculating loop, cultures in the tubes positive for faecal coliforms were inoculated on MacConkey Agar and sub cultured at 37˚C for 24 hours. The sub cultures were examined for the growth of E. coli colonies. The positive colonies were inoculated using a sterile loop into different tubes containing tryptone water and incubated at 37˚C for 24 hours. To each tube of tryptone water Kovac's reagent (0.1 ml) were added and mixed gently. The presence of Indole was indicated by a red colour in the Kovacs reagent, forming a film over the aqueous phase of the medium. Presence of Indole, growth, and gas production showed the presence of E. coli which was later confirmed using the IMViC reactions. The most probable number of E. coli in each samples was determined by recording down the tubes positive for E. coli in a sample with respect to the different amounts of the sub samples that were inoculated for total coliforms (10, 5 and 1 ml) and the MPN of E. coli was read off from the Standard MPN table.

2.6 Data analysis

Data were analyzed using SPSS statistical software version 20. Results of physico-chemical analysis and mean microbial counts of the investigated water samples were compared with the set standards WHO [12] and KEBS [13] and interpreted as acceptable or unacceptable. The significances of differences within samples were determined based on calculated coefficient of variation (% CV). Mean separation between samples categories were computed using one-way ANOVA. The parameters were correlated against each other to determine their relationship using Pearson's correlation. Variables were compared using Chi square test (χ^2). Chi square test was used to establish relationship between physico-chemical and bacteriological parameters. In all cases, significance was considered at 95% confidence interval. Risk analysis was performed according to the obtained range of E. coli.

3.0 Results and discussion.

3.1 Socio-demographic characteristics of the study population

The socio-demographic characteristics of the study population reveals that of the 400 (100%) respondents, the majority 21% (84) use protected springs, followed by 18% (72) protected dug wells, 17% (68) piped water (water piped into compound, yard or plot; public tap/standpipe; piped water into dwellings); 13% (52) unprotected springs, 12%

(48) unprotected dug wells, 9% (36) boreholes, 5% (20) surface water (river, dam, lake, pond, canal), 4% (16) rainwater collection, and 1% (4) others (tanker/truck/cart with small tank; vendors; bottled water). For the point of use water treatment technologies, the majority of the respondents 54% (216) used boiling to make household drinking water safe; followed by 29% (116) chlorination with safe storage, 12% (48) ceramic filtration candles, 2% (8) combined coagulation/chlorine disinfection systems, 2% (8) solar water disinfection, and 1% (4) bio-sand filtration (concrete). Plastic pots are the most favored 79% (316) material for water storage, making the heat treatment of facilities unlikely. About 54 % (216) of the water sources were found at a distance of less than 20 meters from latrine and 33 % (132) of them were located in lower elevation with respect to the nearby toilet rooms. Waste management practices of the localities was found poor as more than 62 % (248) of the respondents dispose waste materials in open fields.

3.2 Physico-chemical properties of drinking water sources in Kakamega county.

The results of physico-chemical analysis of drinking water sources sampled in the study area are shown in Table-1. The physico-chemical parameters that were tested include temperature, pH, turbidity, residual chlorine, electrical conductivity, total dissolved solids and dissolved oxygen. The obtained results were compared with water standards specified by WHO [12] and KEBS [13].

Temperature

In the study area, temperature ranges from 14.3 – 27.2 °C with a mean value of 23.5°C. Two (2.1%) of the samples were within WHO acceptable temperature range for drinking water which should not exceed 15°C; which makes drinking water palatable [15,16]. Majority (97.9%) of the drinking water sources had temperatures above WHO recommended values. This agrees with Ondieki, et al, [17], who observed under tap water in Kisii 3.8% of the samples being within WHO acceptable temperature ranges of 15°C and below. The high temperatures might be attributed to global warming, microbial activities and geographical location of study area (tropical temperatures).Water temperature is a physical property expressing how hot or cold water is. Water temperatures can be affected by turbidity. For instance, increased turbidity will also increase water temperature. Since turbidity is the amount of suspended solids in water, these suspended particles absorb heat from solar radiation more efficiently than water. The heat is then transferred from the particles to water molecules, increasing the temperature of the surrounding water [18]. Water temperature as a physical property depends on seasons, geographical location and meteorological conditions such as rainfall, humidity, cloud cover, wind velocity and turbidity. The growth rate of micro-organisms increases by increasing the temperature as high temperature accelerates the chemical and biological processes in the water resulting in reduction of its ability to hold the essential dissolved gases like oxygen. High temperature level reduces dissolved oxygen and hence put micro-organisms under stress. Variation in temperature levels in both dry and wet season could be due to higher rainfall with intense cloud covers which reduced intensity of sunrays hence leading to low temperature levels.

pH

The pH of analyzed water samples had a range of 4.8 - 9.1 with a mean of 6.6. This agrees with Ondieki, et al, [17], who reported pH of piped water samples from Kisii municipality ranging from 5.0–8.9 with a mean of 6.7; and Ogendi et al, [19] who observed in Nyanchwa–Riana river flowing through Kisii town in South west Kenya a range and mean pH of 5.1–9.0 and 6.76 respectively. pH is a term used universally to express the intensity of the acidic or alkaline condition of a solution. It is measured on a scale from 0 -14. pH of 7 is neutral, pH of less than 7 is acidic and pH greater than 7 is basic. Samples from boreholes, protected dug wells and unprotected dug wells showed 100% compliance to WHO/KEBS recommended pH of 6.5–8.5. Highest non-compliant samples 37% were observed under unprotected and protected springs (< 6.5- 37% and >8.5 -0%) followed by piped water 30% (< 6.5- 28% and >8.5 -2%); rainwater collection 20% (< 6.5- 20% and >8.5 -0%) and surface water –streams/rivers 16% (< 6.5- 5% and >8.5 -11%). Long┐ term exposure to pH beyond the permissible limit affects the mucous membrane of cells [20]. pH values observed in the study area <6.5 and >8.5 could be attributed to anthropogenic activities such as sewage disposal and use of fertilizers in agricultural lands. The pH of most raw water normally ranges from 6.5 - 8.5. At pH levels of less than 7.0, corrosion of water pipes may occur, releasing metals into the drinking water. This is undesirable and can cause other concerns if concentrations of such metals exceed recommended limits [21]. The water from boreholes in some parts of the county has been found to corrode metal water pipes due to the acidic nature of the water. Damaged metal pipes due to acidic pH values can also lead to esthetic problems, causing water to have a metallic or sour taste [22]. Some of the highest pH values were noted in stream/river waters. Change in pH within the stream/river might be due to the nature of open water bodies, which are exposed to various pollutants that can influence the variation of pH [23]. The use of alkaline detergents in the nearby streams and discharge of alkaline waste water from the households into the stream can also result in increase in pH. This observation is also supported by Napacho and Manyele [23] who reported pH values in stream that ranged from 7.8 - 8.0.

Table 1. Physico-Chemical Quality of Drinking Water Sources in Kakamega County, Kenya
N (96)

Parameters	**Improved Drinking Water Sources**						**Unimproved Drinking Water Sources**			**WHO (2011)/KEBS (2010) Standards**
	Results	Piped water	Boreholes	Protected dug wells	Protected springs	Rainwater collection	Unprotected dug wells	Unprotected springs	Surface water (Rivers/Streams)	
Temperature **(°C)**	Range	20.5-26.2	14.3.1-27.2	19.9-27.2	20.5-26.2	20.5-26.2	19.9-27.2	20.5-26.2	20.3.-26.9	WHO, 1996; WHO, 2003) <15 ºC
	Mean	23.6	24.3	22.7	23.6	23.6	22.7	23.6	24.1	
	% Compliant	0%	0%	0%	0%	0%	0%	0%	0%	
	% Non-Compliant	100%	100%	100%	100%	100%	100%	100%	100%	
pH (pH scale)	Range	5.0.-8.9	6.4-7.6	6.4-7.6	4.8-7.1	5.5-6.9	6.4-7.6	4.8-7.1	5.6-9.1	WHO (2011) 6.5–8.5 KEBS (2010) 6.5–8.5
	Mean	6.7	6.8	6.8	6.2	6.1	6.5	6.2	7.5	
	% Compliant	70	100	100	63	80	100	63	84	
	% Non-Compliant	30	0	0	37	20	0	37	16	
Turbidity (NTU)	Range	1- 3.7	0.43-2.9	0.9-3.7	2.9-44.6	2.9-44.6	0.9-4.1	1.3- 22.4	9.87- 467.02	WHO (2011) KEBS (2010) 1-5 NTU
	Mean	2.98	0.9	1.1	4.7	4.7	1.8	4.0	60.5	
	% Compliant	96%	100%	100%	84%	84%	100%	82%	0%	
	% Non-Compliant	4%	0%	0%	16%	16%	0%	18%	100%	
Residual chlorine (ppm)	Range	0.06-1.2	-	-	-	-	-	-	-	WHO (2011) KEBS (2010) 0.2-0.5 ppm
	Mean	0.8	-	-	-	-	-	-	-	
	% Compliant	11%	-	-	-	-	-	-	-	
	% Non-Compliant	89%	-	-	-	-	-	-	-	
Electrical conductivity (μS cm−1)	Range	30-151	59.9-315.7	72.1-509.5	111.9-463.6	18.7-48.4	72.1-509.5	111.9-463.6	120.3-510.7	WHO (2011) < 1500 μS/ cm KEBS (2010) < 2500 μS /cm
	Mean	60.2	145.4	201.43	194.7	35.1	201.43	194.7	191.8	
	% Compliant	100%	100%	100%	100%	100%	100%	100%	100%	
	% Non-Compliant	0%	0%	0%	0%	0%	0%	0%	0%	
Total Dissolved Solids (TDS mg/l)	Range	20.1-85.3	28.6-435.3	70.5-344.7	66.2-398.3	40.4-207.2	60.4-639.2	66.2-398.3	176.4-443.1	WHO (2011) < 1000 ppm KEBS (2010) < 1500 ppm
	Mean	44.6	132.1	140.1	100.7	99.7	200.9	100.7	237.8	
	% Compliant	100%	100%	100%	100%	100%	100%	100%	100%	
	% Non-Compliant	0%	0%	0%	0%	0%	0%	0%	0%	
Dissolved Oxygen (DO mg/l)	Range	2.3-4.5	3.4-8.7	4.0-7.7	2.2-9.8	7.4-13.5	3.8-15.4	3.7-11.5	4.2-10.1	WHO (2011) < 5 KEBS (2010)
	Mean	2.9	6.0	6.6	4.1	8.0	7.5	5.3	6.8	
	% Compliant	100%	73%	69%	71%	100%	67%	62%	31%	

	% Non-Compliant	0%	27%	31%	29%	0%	33%	38%	69%	< 5

Table 2. Bacteriological Quality of Drinking Water Sources in Kakamega County, Kenya N (96)

Parameters	**Improved Drinking Water Sources**						**Unimproved Drinking Water Sources**			**WHO (2011)/KEBS (2010) Standards**
	Results	Piped water (N=12)	Boreholes (N=12)	Protected dug wells (N=12)	Protected springs (N=12)	Rainwater collection (N=12)	Unprotected dug wells (N=12)	Unprotected springs (N=12)	Surface water (Rivers/Streams) (N=12)	
Total Coliforms cfu/100ml	Range	0-10.7	13.5-86.8	31.0 – 1430.7	0-30.0	0-11.2	115.0 – 1890.3	6.3-80.6	30.5 – 3652.0	WHO (2011) 0 CFU/100mL KEBS (2010) 0 CFU/100mL
	Mean	3.0	29.6	70.6	11.5	3.8	400.5	22.1	550.0	
	% Compliant 0 cfu/100ml	(8.04) 67%	(4.92) 41%	() %	(3.48) 29%	(8.88) 74%	() %	(2.04) 17%	0%	
	% Non-Compliant 0< cfu/100ml	(3.96) 33%	(7.08) 59%	(12.0) 100%	(8.52) 71%	(3.12) 26%	(12.0) 100%	(9.96) 82%	(12.0) 100%	
Escherichia coli (E. coli) cfu/100 ml	Range	0 -6.7	0-4.00	0-33.8	0-15.3	0-0	0-39.4	0-17.8	8.2 – 26.4	WHO (2011) 0 CFU/100mL KEBS (2010) 0 CFU/100mL
	Mean	2.1	3.00	2.5	3.7	0	13.3	4.5	12.8	
	% Compliant 0 cfu/100ml	(2.42) 61%	(3.96) 56%	(6.72) 56%	(3.85) 45%	(3.12)100%	(3.48) 33%	(2.67) 27%	(0) 0%	
	% Non-Compliant 0< cfu/100ml	(1.54) 39%	(3.12) 44%	(5.28) 44%	(4.67) 55%	(0) 0%	(8.52) 71%	(7.27) 73%	(12.0) 100%	

Table 3. Risk levels of Drinking Water Sources with reference to Bacterial contamination in Kakamega County, Kenya N (96)

Parameters	**Risk Level**		**Improved Drinking Water Sources**					**Unimproved Drinking Water Sources**		
			Piped water (N=12)	Boreholes (N=12)	Protected dug wells (N=12)	Protected springs (N=12)	Rainwater collection (N=12)	Unprotected dug wells (N=12)	Unprotected springs (N=12)	Surface water (Rivers/Streams) (N=12)
Escherichia coli (E. coli) cfu/100 ml	Conformity	0 cfu/100ml	(2.42) 61%	(3.96) 56%	(6.72) 56%	(3.85) 45%	(3.12)100%	(3.48) 33%	(2.67) 27%	(0) 0%
	Low	1-10 cfu/100ml	(0.36) 9%	(0.99) 14 %	(2.04) 17 %	(1.54) 18 %	(0.31) 10 %	(2.64) 25 %	(2.77) 28 %	(6.24) 52%
	Intermediate	11-100 cfu/100ml	(0.20) 5%	(0.71) 10 %	(1.32) 11 %	(0.77) 9 %	(0.22) 7 %	(1.16) 11 %	(1.48) 15%	(3.60) 30%
	High	101-1000 cfu/100ml	0	0	0	0	0	(0.84) 8 %	(0.89) 9 %	(2.16) 18%
	Very High	>1000 cfu/100ml	0	0	0	0	0	0	0	0

They suggested that the high pH obtained could be attributed to different activities done near the stream, such as washing clothes and cars. A similar observation was also reported by Chang [24] who observed increased pH in stream water was mainly associated with increased use of alkaline detergents and alkaline material from waste water from the household. Although the tolerance of individual species varies, pH values between 6.5 and 8.5 usually indicate good water quality and this range is typical of most major drainage basins of the world. The pH is classified as a secondary drinking water contaminant whose impact is considered an aesthetic concern. Low pH has the potential to cause the erosion of tooth enamel in extreme cases, although this is more of an issue with the pH values encountered in soft drinks than in drinking water. Corrosion effects may become significant below pH 6.5, and the frequency of incrustation and scaling further pointed out that exposure to extreme pH values results in irritation to the eyes, skin and mucous membranes; and that eye irritation and exacerbation of skin disorders have been associated with pH values greater than 11. In addition, the study stated that solutions of pH 10 - 12.5 have been reported to cause hair fibres to swell; while in sensitive individuals, gastrointestinal irritation may also occur. Exposure to low pH values can also result in similar effects. Below pH 4, redness and irritation of the eyes have been reported, the severity of which increases with decreasing pH below pH 2.5, damage to the epithelium is irreversible and extensive. In addition, because pH can affect the degree of corrosion of metals as well as disinfection efficiency, it may have an indirect effect on health.

The pH of rainwater recorded in this study ranging from 5.5-6.9 with a mean of 6.1 compares well with the results of Lukubye & Andama [25], showing a pH range of 5.80 - 6.70. This also agrees with Bridge and Demicco [26], who recorded freshly fallen rainwater pH range of 5.5 - 6.0. The slightly acidic nature of rainwater is mainly attributable to sulfuric and nitric acids formed from increased SO_2 and NO_x emissions into the atmosphere as a result of combustion of fossil fuels from transportation vehicles as mentioned by Dincer & Rosen [27]. According to them, the SO_2 and NO_x (which are transferable from one place to another) react with water and oxygen in the atmosphere to produce sulfuric and nitric acids which form acid rain. One of the impacts of acid precipitation is acidification of surface and ground waters [27]. Furthermore, the ground water sources (boreholes, wells and springs) in the study area had slightly acidic pH values consistent with the findings of Deas & Orlob [28], that show that ground water is acidic. Byamukama, et al, [29] and Haruna, etal, [30] associated the low pH values in most wells and springs to carbon dioxide saturation in the groundwater. The physico-chemical nature of the soil of the sampling sites partly dictates the final pH of the water samples. The deposition of sediments and organic materials into the water causes a change in the carbonate-bicarbonate equilibrium in surface water causing a relatively higher pH beyond neutral [31].

Turbidity

Turbidity of the water samples ranged between 0.45-467.02 with a mean of 10.1 NTU. Most of the samples, that is, 79 (82.3%) had turbidity within the WHO recommended standards of 5NTU. Turbidity is one of the important physical parameters for water quality, defining the presence of suspended solids in water that causes the muddy or turbid appearance of water body [32]. Material that causes water to be turbid include clay, silt, finely divided inorganic and organic matter, algae, soluble colored organic compounds, and plankton and other microscopic organisms. To reach low levels of turbidity during water treatment, it is sometimes necessary to remove particles or suspended particulates by filtration, screening, or flocculation. Turbidity can provide food and shelter for pathogens. In the present study area, the turbidity was found varied between the drinking water sources of piped water, boreholes, protected dug wells, protected springs, rainwater collection, unprotected dug wells, unprotected springs and surface water (rivers/streams) as shown in Figure.1. The highest turbidity was recorded in surface water-streams/rivers, followed by groundwater boreholes and dug wells, then springs, rainwater collection and piped water supply. Excessive turbidity in water interferes with water purification processes such as flocculation and filtration, which may increase treatment cost. The high turbidity indicates that there may be the presence of inorganic particulate matter and non-soluble metal oxides. The consumption of high turbid water may cause a health risk, as excessive turbidity can protect pathogenic micro-organisms from effects of disinfectants [33,34].

Piped water in the study area had turbidity ranging between 1- 3.7 with a mean of 2.98 NTU. 96 % of the samples under piped water had turbidity within the WHO and KEBS recommended standards of 5NTU. 4% of the samples had values above 5 NTU. This result concurs with the findings of Ondieki, et al, [17]. Surface water-rivers/streams had turbidity levels ranging from 9.8- 467.2 with a mean of 60.5 NTU. 100 % of the samples had turbidity values above WHO [12] and KEBS [13] recommended standards of 1-5NTU. The high turbidity values observed in surface water-rivers/streams are as a result of 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 surface water-rivers/streams, thus altering the turbidity. Keya [35] in his study on Microbial and physico-chemical parameters of River Kuywa, Bungoma, Kenya found turbidity levels ranging from 10.03- 13.42 NTU. Otieno [36] in his study on physico-chemical and bacteriological quality of water from five rural catchment areas of Lake Victoria Basin, Kenya recorded turbidity levels ranging from 279-554 NTU). These studies attributed high turbidity levels to increased human/anthropogenic activities along the river.

Boreholes, protected wells and unprotected wells showed turbidities ranging from 0.43-2.9; 0.9-3.7; 0.9-4.1 with mean values of 0.9; 1.1; 1.8 respectively. 100 % of the samples were within WHO [12] and KEBS [13] recommended standards of 1-5NTU. These results are consistent with [37,38]. Protected and unprotected springs showed turbidities ranging from 2.9-14.6 with mean values of 4.7. 84 % of the samples were within WHO and KEBS recommended standards of 1-5NTU. These results are consistent with [39,37,40]. Rainwater collection system had turbidity ranging from 1.3-22.8 with mean values of 4.0. 88 % of the samples were within WHO [12] and KEBS [13] recommended standards of 1-5NTU. These results are consistent with Sila [39].

Residual chlorine

Chlorine residue was tested from 12 samples obtained from taps served by piped water supply. It ranged from 0.06-1.2. 11% of the samples were compliant to WHO and KEBS standards of residual chlorine. WHO [12] recommends chlorine residues of between 0.2-0.5ppm especially for piped/tap water. 50% of the samples were less than 0.2 ppm and 39% were above 0.5 ppm. These results concur with Ondieki, et al, [17]. Chlorination is the process of adding chlorine to drinking water to kill parasites, bacteria, and viruses. Different processes can be used to achieve safe levels of chlorine in drinking water. Using or drinking water with small amounts of chlorine does not cause harmful health effects and provides protection against waterborne disease outbreaks.

Electric conductivity (EC)

Electrical conductivity ranged from 30-510.7 µS cm^{-1} with a mean of 60.2 µS cm^{-1} .All the water samples were within the acceptable range for drinking water as per WHO [12], 1500 µS cm−1 and KEBS [13], 2500 µS cm−1). This concurs with observations made on EC values in other parts of the country [36,35,39,41]. 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. Electrical conductivity (EC) denotes the conducting capacity of water. It shows electric current that solution carries. EC is a measure of total dissolved solids (TDS) i.e., it depends upon the ionic strength of the solution. Increase in the concentration of dissolved solids increases the ionic strength of the solution. It is measured with the help of EC meter which measures the resistance offered by the water between two platinized electrodes. The instrument is standardized with known values of conductance observed with a standard KCl solution.

Total dissolved solids (TDS)

In the study area, TDS values varied from 20.1 – 639.2 mg/L; with a mean of 132.1 ppm.

All the samples analyzed were found within the standard permissible, WHO [12] less than 1000 ppm and KEBS [13] less than 1500 ppm. This concurs with observations made on TDS values in other parts of the country [36,17,37]. TDS affects the palatability of drinking water. Total dissolved solids are the total amount of mobile charged ions, including minerals, salts or metal dissolved in a given volume of water in mg/L. TDS is directly related to the purity of water and the quality of water purification system and affects everything that consumes, lives in, or uses water, whether organic or inorganic, whether for better or for worse. Common inorganic salts that can be found in water include calcium, magnesium, potassium and sodium, which are cations and carbonates, nitrates, bicarbonates, chlorides and sulphates which are anions.

Dissolved oxygen (DO mg/l)

DO values ranged from 2.2 – 15.4 mg/L; with a mean of 5.9 mg/L. The recommended permissible standard, WHO [12] less than 5 mg/L and KEBS [13] less than 5 mg/L. Piped tap water showed DO values in the range of 2.3-4.5 with a mean of 2.9. This is consistent with the findings of Yasin, et al [42]. Dissolved oxygen analysis measures the amount of gaseous oxygen dissolved in an aqueous solution. Dissolved oxygen is important parameter in water quality assessment and reflects the physical and biological processes prevailing in the water. The DO values indicate the degree of pollution in water bodies. Dissolved Oxygen is an important parameter which is essential to the metabolism of all aquatic organisms that poses aerobic respiration. Presence of DO in water may be due to direct diffusion from air and photosynthetic activity of autotrophs. Oxygen can be rapidly removed from the waters by discharge of oxygen demanding wastes. The low DO in the shallow wells can be attributed to increased decomposition of organic material from the neighborhood. The low DO values in springs, boreholes and shallow wells can also be associated with the slightly elevated temperature values in these water sources. Solubility of oxygen in water is a function of its temperature viz. the lower the temperature, the greater the solubility of oxygen in the water and vice versa. High photosynthetic rates in the water which reduce the available carbon dioxide (increasing the pH) would liberate oxygen leading to positive correlation between DO and pH. The slightly low DO in rainwater recorded could be due to use of some of the atmospheric oxygen in chemical reactions forming acid rain. This is also in agreement with the observation that SO_2 and NO_x emissions from vehicles react with water and oxygen in the atmosphere to produce sulfuric and nitric acids which form acid rain. The findings in this study agree with [42,25,19,43].

3.3 Correlation of physico-chemical parameters of drinking water sources in Kakamega county

The interactions within and between the physico-chemical parameters of the different water sources were further verified by Pearson correlation. The Pearson's correlation (r) is used to find a correlation between at least two continuous variables. The value for a Pearson's correlation can fall between 0.00 (no correlation) and 1.00 (perfect correlation).More precisely, it can be said that parameters showing r = 0.7 are considered to be strongly correlated, whereas when r has a value between 0.5 and 0.7, a moderate correlation is shown to exist. The test revealed several significant interactions among the physico-chemical variables in the water samples of the study area. Many of the physico-chemical parameters showed strong correlations with each other. At $P< 0.01$, pH correlated negatively with EC (r = -897), TDS (r = -899) and Turbidity (r = -713). Turbidity correlated positively with EC (r = 726), and TDS (r = 693). EC correlated positively with TDS (r = 964). Since at $P< 0.01$ or $P< 0.05$ most of the physico-chemical parameters correlated with several other parameters, there were significant interactions between the physico-chemical parameters in water samples of the study area. This confirms that the presence of certain pollution indicators will influence the presence or increase of some other parameters. The increase of one physico-chemical parameter indicates the increase or decrease of another parameter. For example, a higher TDS means that there are more cations than anions in the water, and with more ions in the water the water's EC increases. By measuring the water's EC, we can indirectly determine its TDS concentration. At a high TDS concentration, water becomes saline.

3.4 Bacteriological quality of drinking water sources in Kakamega county.

Twelve water samples were collected for each one of the eight drinking water sources leading to equal sample sizes among the twelve sub-counties in the study area. The results obtained were then compared to the WHO [12] and KEBS [13] recommended levels for drinking water quality. Table 2 shows that all drinking water sources were contaminated with Total coliforms. There was a wide variation in Total coliforms and E. coli. The total coliform counts ranged from 0.0 to 3652.0 cfu/100 ml whereas the E. coli ranged from 0.0 to 39.4 cfu/100 ml. The highest Total coliforms load was recorded in rivers/streams, unprotected wells and protected wells. Lowest Total coliforms counts were recorded in piped water supply and rainwater collection; followed by protected springs, boreholes and unprotected springs. The distribution of E. coli also followed the same pattern as Total Coliforms. Thus, the highest E. coli load was recorded in rivers/streams, unprotected wells and protected wells; as the lowest E. coli counts were recorded in piped water supply and rainwater collection; followed by protected springs, boreholes and unprotected springs. E. coli counts in most drinking water sources investigated exceeded the maximum permissible limits set by WHO [12] and KEBS [13] for drinking purposes indicating that the water is unsuitable for such use. For all the water directly intended for drinking, E. coli or thermotolerant coliform bacteria should be undetectable in any 100 ml water sample. Thus, most of the drinking water sources sampled are not safe for household applications without prior treatment.

Piped water, for the 12 water samples analyzed showed that, 3.96 (33%) had total coliforms and 1.54 (39%) of these had E. coli. These findings agree with Ondieki, et.al [17]. For **Boreholes,** out of the 12 water samples analyzed, 7.08 (59%) had total coliforms and 3.12 (44%) of these had E. coli. These findings are in agreement with Lukubye, et.al [25]. **Rainwater collection** revealed out of the 12 water samples analyzed, 3.12 (26%) had total coliforms and 0 (0%) of these had E. coli. These findings are in agreement with Lukubye, et.al [25]. Rainwater collected from direct rainfall after an hour of downpour recorded no E. coli counts. This was mainly attributed to improved hygienic environment in the surroundings. The observed total coliforms in the rainwater could have emanated from windblown soil particles into the atmosphere as total coliforms include bacteria which are also found in the soil and not only in water, animal or human wastes. **Protected springs** showed out of the 12 water samples analyzed, 8.52 (71%) had total coliforms and 4.67 (55%) of these had E. coli. These findings are in agreement with [25, 39,40]. **Unprotected springs'** 12 water samples analyzed revealed that, 9.96 (82%) had total coliforms and 7.27 (73%) of these had E. coli. These findings are in agreement with [25, 39,40]. P**rotected dug wells'** 12 water samples analyzed indicated that, 12.0 (100%) had total coliforms and 5.28 (44%) of these had E. coli. These findings are in agreement with [25, 39]. Similarly, **Unprotected dug wells'** 12 water samples analyzed indicated that, 12.0 (100%) had total coliforms and 8.52 (71%) of these had E. coli. These findings are in agreement with [25, 39]. **Rivers/streams'** 12 water samples analyzed revealed that, 12.0 (100%) had total coliforms and 12.0 (100%) of these had E. coli. These findings are in agreement with [25, 39,44].

In Kakamega county, when we rank the drinking water sources from the lowest to the highest in terms of bacteriological contamination, piped water/tap is the least contaminated, followed by rainwater collection, boreholes, protected springs, protected dug wells, unprotected springs, unprotected dug wells and finally surface water-rivers/streams. This study agrees with other studies [45,46,47,48,49], which state that boreholes have the highest microbiological quality water, followed by open hand dug wells and protected springs which are of similar quality, with open water having the lowest quality. Very few studies have compared rainwater collection to other source types, but in this study it is rated as better than boreholes, protected springs, protected dug wells, unprotected springs, unprotected dug wells and surface water-rivers/streams. From a common man's point of view, improved drinking water sources are expected to provide safer water than unimproved sources, however, as per the results provided by this study, this is not always the case. Piped water/tap, rainwater collection and boreholes were the safest sources. Protected springs, protected dug wells and unprotected springs also provided water that could be used at the households fairly after subjecting it to household water treatment. Unprotected dug wells and surface water-rivers/streams were the worst drinking water sources in the study area in terms of bacteriological quality. It was noted during data collection that some people use these poor quality sources only for washing and agriculture, and choose to travel further to collect safe drinking water. Post collection contamination in the households often compromises water quality, hence in the study area, rainwater collection is advantageous in this regard as the storage is nearer to the home than most groundwater supplies and in tanks, hence reducing the opportunities for contamination during transport or storage.

Total coliforms include bacteria which are found in the soil, water and animal or human wastes [50]. The coliform bacterium which is the primary bacterial indicator for faecal pollution in water [51,52] was present in all sampled drinking water sources. The results indicate that protected drinking water sources (piped water, boreholes, protected dug wells and protected springs) are subjected to a high level of fecal contamination in the study area. One of the possible reasons might be constructional defects on casing, concrete covers, fences, diversion ditches, and protection of eye of springs and other plumbing accessories. Furthermore, lack of regular supervision, disinfection and proper maintenance might also be the reasons for contaminating protected water sources. The high level of E.coli can also be explained by poor sanitation habits, low level of hygiene education, poor supervision and maintenance and irregular disinfection of water points. The high total coliforms content of the protected and unprotected dug wells poses a health risk and renders the water unsuitable for human consumption. The presence of pathogenic organisms in the water could be attributed to pit latrine in the vicinity that extent their influence on these water qualities, since they are sited close to them. Ground water flow is either lateral or vertical. During lateral flow, filtration does not occur and could carry faecal pollution for much longer distance [53]. In a similar work done by Umar [54], in Asamankese in the Eastern Region of Ghana he found high microbial indicators in the wells. The study related the level of contamination of water to the lateral distance between pit latrine and wells. This corroborates the high counts of microbial loads obtained in protected and unprotected dug wells in the study area. Results confirm the important role of runoff in bacterial transport on soil surfaces. They show E. coli survive in semiarid areas for a long time and increases potential of contamination [55].

The construction and depth of the protected and unprotected dug wells could further explain contamination levels. The depth of the wells studied ranged from 5 to 40 m deep. The interior lining of some wells were defective and most of the wells in the study area were within a 15m or less radius from pit latrines. This predisposes the well water to bacterial contamination. Therefore the increased concentration of total coliforms is likely to result to increased diarrheal episodes among the local communities. The children, elderly and immunosuppressed people are most affected from diarrhea due to low immunity. The reports from the Health facilities within the county indicate a high prevalence of undiagnosed diarrhea which was closely linked to consumption of pathogen-polluted waters. One of the major causes of diarrheal diseases is consumption of microbe contaminated drinking water. These diarrheal diseases weakens the immune system leading to higher risk of other diseases which present themselves as opportunistic infections. The results obtained for microbial quality in Kakamega county indicate that majority of the drinking water sources are contaminated.

3.5 Risk levels of drinking water sources with reference to bacteriological contamination in Kakamega county.

According to WHO [12], risk levels in terms of E. coli are categorized as shown in Table 3. For the 12 **piped water samples** analyzed, (2.42) 61% were free of E. coli hence in conformity with safe drinking water requirements. (0.36) 9% were in low risk category and (0.20) 5% were in intermediate risk category. There were no high risk or very high risk categories in all investigated samples. **Boreholes** 12 water samples analyzed showed (3.96) 56% free of E.coli, hence in conformity with safe drinking water requirements, (0.99) 14 % were in low risk category and (0.71) 10 % were in intermediate risk category. There were no high risk or very high risk categories in all investigated borehole water samples. The 12 **Rainwater collection** samples analyzed showed all samples, (3.12)100% being free of E. coli hence in conformity with safe drinking water requirements. For the 12 **Protected springs** samples analyzed, (3.85) 45% of the samples were free of E. coli hence in conformity with safe drinking water requirements, (1.54) 18 % were in low risk category while (0.77) 9 % were in intermediate risk category. There were no high risk or very high risk categories in all investigated protected springs water samples. **Unprotected springs** 12 water samples analyzed revealed (2.67) 27% being free of E. coli hence in conformity with safe drinking water requirements, (2.77) 28 % were in low risk category while (1.48) 15% were in intermediate risk category and (0.89) 9 % high risk category. There were no very high risk category members in all investigated unprotected springs water samples. The 12 **Protected dug wells** samples analyzed had (6.72) 56% of the samples free of E. coli hence in conformity with safe drinking water requirements, (2.04) 17 % were in low risk category while (1.32) 11 % were in intermediate risk category. There were no high risk or very high risk categories in all investigated protected dug wells water samples. For the 12 **Unprotected dug wells** samples analyzed, (3.48) 33% of the samples were free of E. coli hence in conformity with safe drinking water requirements, (2.64) 25 % were in low risk category while (1.16) 11 % were in intermediate risk category and (0.84) 8 % high risk category. There were no very high risk category members in all investigated unprotected dug wells water samples. Rivers/streams 12 water samples analyzed revealed (0) 0%, none of the samples were free of E. coli hence not in conformity with safe drinking water requirements, (6.24) 52% were in low risk category while (3.60) 30% were in intermediate risk category and (2.16) 18% high risk category. There were no very high risk category members in all investigated Rivers/streams water samples.

The greatest risk to public health from microbes in water is associated with consumption of drinking-water that is contaminated with human and animal excreta, although other sources and routes of exposure may also be significant. Waterborne outbreaks have been associated with inadequate treatment of water supplies and unsatisfactory management of drinking water distribution. For example, in distribution systems, such outbreaks have been linked to cross-connections, contamination during storage, low water pressure and intermittent supply. Waterborne outbreaks are preventable if an integrated risk management framework based on a multiple-barrier approach from catchment to consumer is applied. Implementing an integrated risk management framework to keep the water safe from contamination in distribution systems includes the protection of water sources, the proper selection and operation of drinking-water treatment processes, and the correct management of risks within the distribution systems.

3.6 Relationship between physico-chemical properties of drinking water sources and presence of Total coliforms.

Total coliforms were positively correlated with Turbidity and DO ($r = 0.651$ and $r = 0.738$, respectively). Water with high turbidity was more likely to be contaminated with total coliforms as turbidity provides food and shelter for pathogens. The consumption of high turbid water may cause a health risk, as excessive turbidity can protect pathogenic microorganisms from effects of disinfectants. The DO values indicate the degree of pollution in water bodies, and is essential for the metabolism of all aquatic organisms that poses aerobic respiration. Solubility of oxygen in water is a function of its temperature, thus, the lower the temperature, the greater the solubility of oxygen in the water and vice versa.

Total coliforms had a positive correlation with temperature ($r = 0.733$, $p < 0.05$); as water with a temperature of more than 15°C is more likely to be contaminated with the total coliforms. The growth rate of micro-organisms increases with increasing temperature as high temperature accelerates the chemical and biological processes. Total coliforms had a positive correlation with Chlorine ($r = 0.688$, $p < 0.05$); as water without residual chlorine was more likely to be contaminated with total coliforms. Chlorination is the process of adding chlorine to drinking water to kill parasites, bacteria, and viruses. Total coliforms were negatively correlated with pH, EC and TDS ($p < 0.05$) ($r = -0.889$, $r = -0.899$ and $r = -0.847$, respectively). These findings are in agreement with [42, 17].

4.0 Conclusion

In this study, water samples from improved (piped water/tap, boreholes, protected dug wells, protected springs, rainwater collection) and unimproved (unprotected dug wells, unprotected springs, surface water-rivers/streams) drinking water sources from the twelve sub-counties of Kakamega county were analysed for bacteriological quality and some selected physico-chemical parameters (temperature, pH, EC, TDS and DO) to acertain the water quality status of Kakamega county. From the analysis of physico-chemical parameters, temperature and pH ranged between 19.9–27.2 °C and 4.8 - 9.1, respectively. Turbidity and EC were 0.43–467.02 NTU and 18.7–510.7 µS/cm. Residual chlorine in piped water showed a range of 0.06-1.2 ppm. TDS were found to be between 20.1 and 639.2 mg/l; whereas DO ranged from 2.2- 15.4 mg/l. On bacteriological analysis, all drinking water sources investigated were contaminated with Total coliforms. There was a wide variation in Total coliforms and E. coli. Total coliform counts ranged from 0.0 - 3652.5 cfu/100 ml whereas E. coli ranged from 0.0 - 33.0 cfu/100 ml. The drinking water sources were grossly contaminated and only very few of them had reasonable water quality. The bacteriological quality data and physico-chemical parameters of most drinking water sources had values beyond the maximum tolerable limits recommended by WHO/KEBS. Thus, with the current high dependence on alternative water sources other than tap water, it calls for awareness development on hygienic handling of water points besides designing protections and regular purification strategies by the concerned authorities.

5.0 Ethical approval

Ethical clearance was obtained from Masinde Muliro University of Science and Technology (MMUST). A Research permit was issued by the National Commission for Science, Technology and Innovation (NACOSTI). Permission was then granted by Kakamega County Commissioner and County Director of Education to conduct research in their areas of jurisdiction. Informed consent was sought from potential participants prior to the commencement of data collection process.

6.0 Limitation of the study

Water quality is a broad subject that involves several parameters. This study focused on some selected parameters that are considered key in the determination of drinking water quality in the county based on WHO/KEBS standards. The other parameters that were not assessed in this study are as well important such as heavy metal levels, etc.

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