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. Construction flaws on casing, concrete covers, fences, diversion ditches, and protection of springs' eyes and other plumbing accessories could be one of the causes. Protected water sources may become contaminated for other reasons, such as a lack of frequent surveillance, disinfection, and correct maintenance. Poor sanitation practices, a lack of hygiene education, poor supervision and maintenance, and inconsistent water point disinfection can all be blamed for the high levels of E. coli. 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 results of the current investigation showed that some bacteriological and physico-chemical parameters of the various water sources had values above the maximum permissible limits advised by WHO/KEBS. The Water sector stakeholders in the area should put in place proper intervention measures which include raising public awareness on the water quality of drinking water sources and enhancing the current infrastructure in order to reduce any potential health hazards.

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

Kakamega county is the second most populous county with the largest rural population in Kenya after Nairobi. It is situated 288 kilometers (179 miles) northeast of Nairobi, Kenya's capital (Figure-1).

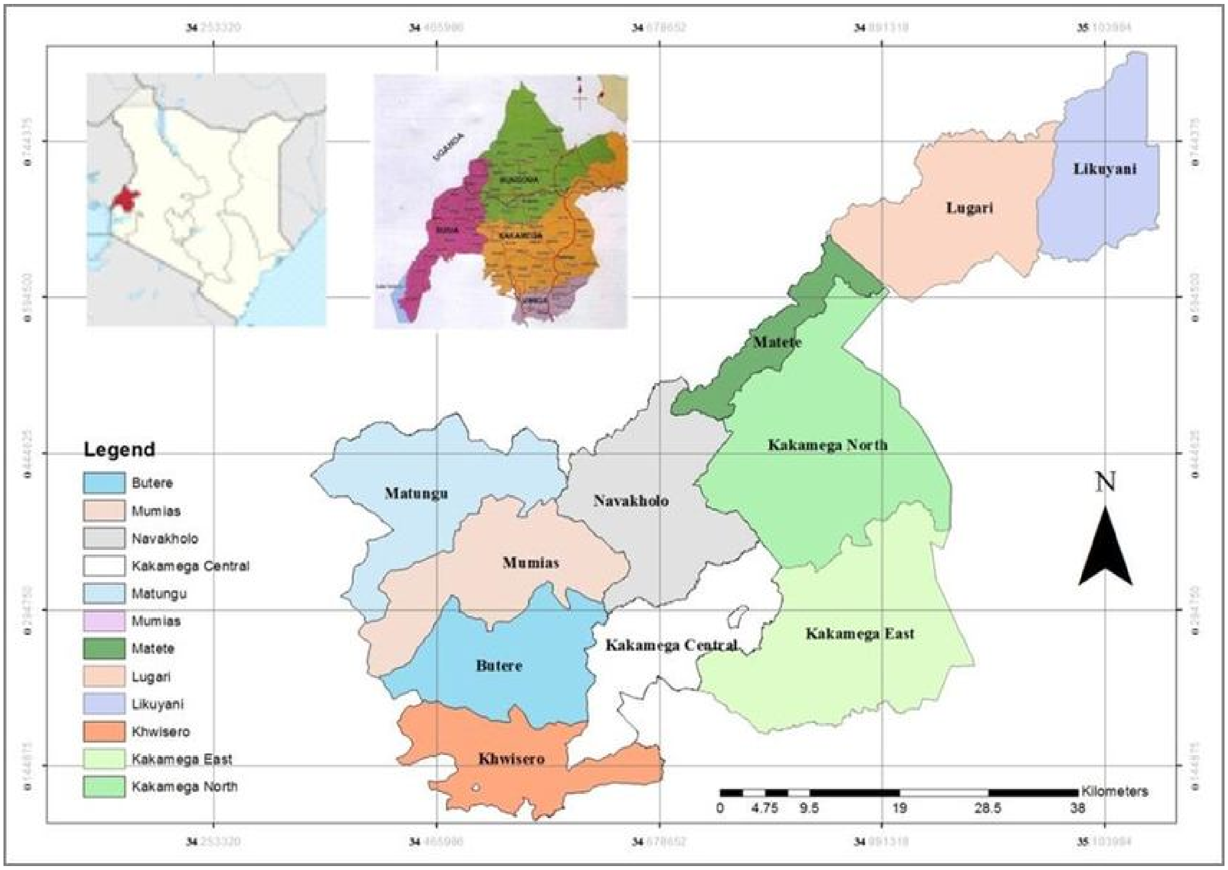

Figure 1: Map of the Study Sites, Kakamega County, Kenya

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Twelve sub-counties make up the county, which has a total size of 3,033.8 km^2 and a population of about 1,867,579 [9]. The county can be found between latitude 0°16'60.00" N and longitude 34°45'0.00" E. It has an altitude ranging from 1,240 m to 2,000 m above sea level. The county's southern region is steep and made of granite, elevating it 1950 m above sea level. A notable landmark on the county's eastern boundary is the Nandi escarpment, which has jagged cliffs ranging from 1700 m to 2000 m. Throughout the year, rainfall is evenly distributed, with March and July receiving the most and December and February the least. The annual rainfall varies between 1280.1 mm and 2214.1 mm. The hottest months are January, February, and March, while the coldest months are July and August. The temperature ranges from 18 °C to 29 °C.

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). Unimproved water sources are those that are not in any manner protected from external impurities like feces. Improved water sources are those that are protected from external sources of contamination as a consequence of construction or intervention programs.

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. There are numerous ways to transport the crystal-clear spring water from its source to the bucket or pipeline. Samples were obtained from the same tap or open pipe as the users for protected springs.

Unprotected springs

Where the water table is high enough to cross a depression in the local terrain or where seepage downward is prevented by an impermeable layer of rock, surface springs can be found. 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

The act of collecting and storing rainwater as opposed to letting it run off is known as rainwater harvesting. One of the earliest and most straightforward ways to provide water for homes on your own is through rainwater collection, which has been used for thousands of years in India and other nations. Installations can be made to serve institutions like schools, hospitals, and other public facilities as well as scales as diverse as households, neighborhoods, and communities. This covers both formal (i.e., downpipes, covered storage, and taps) and informal (i.e., open containers under roofs or gutters) systems for collecting rainwater. For rainwater collection systems, samples were drawn from the pouring jug typically used to draw water from storage containers, or from the taps if they were available.

Protected dug wells

Excavated below the groundwater table until the incoming water surpassed the digger's bailing rate, dug wells are holes in the ground dug by a shovel or backhoe. Dug wells are not particularly deep because it is so difficult to penetrate below water table. They are typically only 10 to 40 meters deep. Due to their extreme shallowness, dug wells are most susceptible to contamination. Your dug well should have particular characteristics to reduce the possibility of contamination. These characteristics aid in preventing impurities from entering the well through the casing or along its outside. A watertight material (such as tongue-and-groove precast concrete) should be used to case the well, and then cement grout or bentonite clay sealant should be put around the exterior of the casing all the way to the top. A concrete curb and cap that is about a foot above the ground should be used to cover the well. 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. Few, if any, may have aprons; they are unlined, uncapped, and without pumps. They are often constructed within residential complexes. Some wells have a headwall, while others have a portion of the shaft shut off with brickwork. 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”. [56]

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". [56]

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 could be ascribed to microbial activity, global warming, and the study area's geographic position (tropical temperatures). A physical characteristic that describes how hot or cold water is is its temperature. Turbidity can have an impact on water temperature. For instance, rising turbidity will likewise raise the temperature of the water. The amount of suspended solids in water, or turbidity, is what determines how well water absorbs heat from solar radiation. The temperature of the surrounding water subsequently rises as the heat is transmitted from the particles to the water molecules [18]. Seasons, geographic location, and climatic factors including precipitation, humidity, cloud cover, wind speed, and turbidity all affect water temperature as a physical characteristic. By raising the temperature, which speeds up the water's chemical and biological processes and reduces the capacity of the water to hold important dissolved gases like oxygen, microorganisms proliferate more quickly. Reduced dissolved oxygen due to a high temperature stresses microorganisms. An increase in rainfall and thick cloud cover during the dry and wet seasons may have lowered the intensity of the sun's rays, resulting in lower temperatures.

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%). The mucous membrane of cells can be impacted by prolonged exposure to pH levels beyond the permitted limit [20]. Anthropogenic activities like the dumping of sewage and the application of fertilizers to agricultural lands can be blamed for the pH values that were found in the research area of pH <6.5 and pH >8.5. 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. If the amounts of these metals surpass the recommended limits, this is undesirable and may lead to other problems [21]. Due to the water's acidic composition, it has been discovered that borehole water in some areas of the county corrodes metal water pipes. A metallic or sour taste to the water might result from damaged metal pipes caused by acidic pH levels [22]. Stream and river waters were found to have some of the highest pH values. Because open water bodies are subject to numerous pollutants that might affect pH, there may be a change in pH within the stream or river [23]. Increased pH may also be caused by the usage of alkaline detergents in surrounding streams and the discharge of alkaline household waste water into those streams.

Napacho and Manyele [23], who observed pH levels in streams that ranged from 7.8 to 8.0, provide additional support for this observation. They proposed that several activities performed close to the stream, such as washing automobiles and clothes, may be responsible for the elevated pH that was achieved. Chang [24] made a similar finding that higher pH in stream water was primarily related to increased usage of alkaline detergents and alkaline materials from domestic waste water. Although each species has a different tolerance range, pH readings between 6.5 and 8.5 typically indicate good water quality and are typical of the majority of the world's main drainage basins. The pH is categorized as a secondary drinking water contaminant, and its effects are seen to be aesthetically objectionable. Although this is more of a problem with the pH levels seen in soft drinks than in drinking water, low pH has the ability to seriously damage tooth enamel. Corrosion effects may become noticeable below pH 6.5, and the frequency of incrustation and scaling further highlighted that exposure to extreme pH values causes irritation to the skin, mucous membranes, and eyes. pH values higher than 11 have also been linked to eye irritation and the exacerbation of skin disorders.

The study also noted that hair fibers have been documented to swell in solutions with a pH range of 10 to 12.5; additionally, gastrointestinal upset may also happen in sensitive people. Similar effects can also be brought on by low pH exposure. Eye redness and irritation have been observed below pH 4, and their severity worsens when pH falls below pH 2.5, where significant and irreversible epithelial damage occurs.

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

Additionally, pH may indirectly affect health since it can influence how much metals corrode and how well water disinfection occurs. 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. According to Dincer & Rosen [27], increased SO_2 and NOx emissions into the atmosphere as a result of the combustion of fossil fuels by transportation vehicles are primarily responsible for the slightly acidic quality of rainwater. They contend that acid rain is created when the transferring gases SO_2 and NOx combine with water and oxygen in the atmosphere to produce sulfuric and nitric acids. Acidification of surface and ground water is one of the effects of acid precipitation [27]. Additionally, Deas & Orlob's [28] results that ground water is acidic are supported by the pH values of the research area's ground water sources (boreholes, wells, and springs). The low pH values in the majority of wells and springs were attributed by Byamukama, et al. [29] and Haruna, etal. [30] to carbon dioxide saturation in the groundwater. The ultimate pH of the water samples is somewhat determined by the physico-chemical makeup of the soil at the sampling locations. Surface water experiences a change in the carbonate-bicarbonate balance as a result of the deposition of sediments and organic compounds, which raises the pH above neutral [31].

Turbidity

The water samples' turbidity ranged from 0.45 to 467.02, with a mean of 10.1 NTU. The majority of the samples, 79 (82.3%), showed turbidity levels that were within the WHO-recommended range of 5NTU. One of the crucial physical indicators of water quality is turbidity, which refers to the amount of suspended matter that gives a body of water a muddy or turbid appearance [32]. Clay, silt, finely divided inorganic and organic materials, algae, soluble colored organic compounds, plankton, and other microscopic organisms are among the substances that make water turbid. It is occasionally essential to remove particles or suspended particulates by filtration, screening, or flocculation during water treatment to obtain low levels of turbidity. Pathogens may find food and refuge in turbidity. In the current study region, it was discovered that the turbidity varied across drinking water sources such as boreholes, protected dug wells and protected springs, rainwater collection, unprotected dug wells and unprotected springs, and surface water (rivers and 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. The cost of treatment may rise as a result of excessive turbidity in water interfering with water purification procedures like flocculation and filtration. The high turbidity suggests that inorganic particle debris and non-soluble metal oxides may be present. Consuming water that is highly turbid poses a health risk because it can shield harmful microorganisms from the 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 disinfecting drinking water by introducing chlorine to eradicate viruses, bacteria, and parasites. To get drinking water with safe levels of chlorine, various techniques can be utilized. Small levels of chlorine in water do not have negative health effects and offer defense against the spread of waterborne diseases.

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 general tendency in conductivity was that higher conductivity levels were attained during months with little rainfall while lower conductivity values were attained during months with high rainfall. Water's ability to conduct electricity is measured by its electrical conductivity (EC). It demonstrates the electric current the solution carries. Total dissolved solids (TDS) are measured by EC, which means that it is influenced by the ionic strength of the solution. The ionic strength of the solution increases as the concentration of dissolved solids increases. 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]. The amount of gaseous oxygen dissolved in an aqueous solution is measured by dissolved oxygen analysis. Dissolved oxygen is a crucial factor in determining the quality of the water since it provides insight into the physical and biological processes that are present. The levels of pollution in water bodies are indicated by the DO readings. All aquatic species that engage in aerobic respiration depend on the dissolved oxygen parameter, which is a crucial component of their metabolism. Direct diffusion from the air and autotrophic plants' photosynthetic activities may be to blame for the presence of DO in water. Oxygen can be quickly removed from the water by releasing wastes that require oxygen. Increased neighborhood organic material decomposition can be blamed for the decreased DO in the shallow wells. The slightly elevated temperature values in these water sources can also be linked to the low DO values found in springs, boreholes, and shallow wells. The amount of oxygen that can be dissolved in water depends on the temperature; the higher the solubility of oxygen in water, the lower the temperature, 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 somewhat low DO in rainwater that was observed may have resulted from chemical processes that formed acid rain using some of the oxygen in the atmosphere. This is also consistent with the finding that acid rain is produced when SO2 and NOx emissions from cars interact with atmospheric water vapor and oxygen to form sulfuric and nitric acids. The results of this study concur with those from [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.

Bacteria that can be found in soil, water, and animal or human waste are included in the total coliforms [50]. All of the drinking water sources that were analyzed contained the coliform bacterium, which is the main bacterial biomarker for faecal pollution in water [51,52]. The findings show that fecal contamination levels are significant in the study area for protected drinking water sources, including piped water, boreholes, protected dug wells, and protected springs. Construction flaws on casing, concrete covers, fences, diversion ditches, and protection of springs' eyes and other plumbing accessories could be one of the causes. Additionally, inadequate maintenance, regular oversight, and disinfection could all contribute to protected water sources becoming contaminated. Poor sanitation practices, a lack of hygiene education, inadequate supervision and maintenance, and inconsistent water point disinfection can all be blamed for the high levels of E. coli. The protected and unprotected dug wells' high total coliforms level puts human health at risk and renders the water unfit for consumption. Pit latrines nearby that have a significant impact on these water quality due to their proximity to them may be to blame for the presence of harmful organisms in the water. Either lateral or vertical flow exists in ground water. Filtration does not take place during lateral flow, which has the potential to carry feces for a significantly greater distance [53]. Umar [54] discovered significant microbiological indicators in the wells in Asamankese in the Eastern Region of Ghana in a similar study he conducted. The study correlated the lateral distance between pit latrines and wells with the degree of water contamination. This supports the high counts of microbial loads discovered in study area protected and unprotected dug wells. The findings support the crucial part runoff plays in bacterial translocation on soil surfaces. They demonstrate that E. coli can persist for a long time in semi-arid environments, which raises the risk of contamination [55].

Additional information on contamination levels may be provided by the design and depth of the protected and unprotected dug wells. The wells under study ranged in depth from 5 to 40 meters. Most of the wells in the research region were within a 15m radius of pit latrines, and several of them had poor inside linings. This makes the well water more likely to become contaminated by microorganisms. Therefore, the surrounding communities are likely to have more diarrheal episodes as a result of the higher concentration of total coliforms. Because of their low immunity, children, the elderly, and those who are immunosuppressed are particularly susceptible to diarrhea. The county's health facilities have reported a significant prevalence of unexplained diarrhea, which has been directly connected to ingesting water contaminated with pathogens. Consuming drinking water that has been polluted with microbes is one of the main causes of diarrheal illnesses. The immune system is weakened by these diarrheal illnesses, which increases the chance of contracting other illnesses that manifest as opportunistic infections. The bulk of the drinking water sources in Kakamega County are contaminated, according to the results of the microbiological quality test.

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.

Although other sources and modes of exposure may also be important, drinking water that has been contaminated with human and animal excreta poses the greatest risk to the public's health from bacteria. Waterborne epidemics have been linked to subpar distribution management of drinking water and subpar treatment of water sources. Such outbreaks, for instance, have been connected to cross-connections, contamination during storage, low water pressure, and inconsistent supply in distribution systems. If an integrated risk management framework based on a multiple-barrier approach from catchment to consumer is applied, waterborne epidemics can be avoided. Protection of water sources, the selection and use of drinking-water treatment methods, and adequate risk management within distribution networks are all part of implementing an integrated risk management framework to keep the water safe from contamination in 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. Only a very small number of the drinking water sources had acceptable water quality, and the rest were severely contaminated. Most drinking water sources exhibited bacteriological quality data and physico-chemical parameters that were beyond the maximum permissible levels advised by WHO/KEBS. As a result, given the current heavy reliance on alternative water sources other than tap water, it is necessary for the relevant authorities to implement protections and routine purification techniques in addition to raising awareness about the hygienic treatment of water points.

5.0 Ethical approval and consent

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.

Declarations

Author contribution statement

E.O. Odwori: Conceived and designed the experiments with Laboratory staff, performed the experiments with Laboratory staff; analyzed and interpreted the data; contributed reagents, materials, analysis tools and prepared the manuscript.

J.W. Wakhungu: Supervised the study, participated in project design, data analysis and preparation of the manuscript. All Authors read and approved the final manuscript.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

The data that has been used is confidential.

Declaration of interest statement

The Authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

I sincerely acknowledge support received from staff at Kakamega County Department of Water, Environment and Natural Resources, Kakamega County Water and Sanitation Company, Eldoret Water and Sanitation Company, Lake Victoria North Water Works Development Agency, Water Resources Management Agency, and a number of Water Sector NGOs operating in the region.

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