Assessing the Effect of Distribution Systems on Drinking Water Quality in Kapsabet and Nandi Hills Towns, Kenya

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Abstract- Safe drinking water access is a fundamental human right and is necessary for good health. The ineffective water delivery system in Kenya makes it difficult for water utilities to constantly provide quality water to consumers. Water maybe contaminated due to a variety of circumstances depending on the nature of operations occurring within the pipelines. This study focused on assessing the effect of distribution systems on drinking water quality in Kapsabet and Nandi Hills Towns. 348 water samples were collected at randomly selected taps for six months from November 2022 to April 2023 and analysis done in the laboratory for various water quality parameters. Results showed that pH, electrical conductivity, zinc, nitrates, nitrites and residual chlorine were within limits set by WHO and KEBS. However, turbidity, iron, total and fecal coliforms; and *E. coli* exceeded the limits, hence the water was not safe for human consumption. This was attributed to frequent bursts, corrosion of the iron pipes and illegal connections. The study recommended rehabilitation of old pipelines in Kapsabet and Nandi Hills towns using HDPE pipes, regular tap water surveillance checks by public health officers and regular monitoring of water quality at consumer end points by the respective water service provider.

Index Terms- Drinking Water Quality, Parameters, Distribution System, Deterioration.

1. INTRODUCTION

A supply of potable water is not only important for the sustenance of a healthy nation and but also productive population. The United Nations [1], reported that substantial progress has been made in increasing access to clean drinking water and sanitation, billions of people — especially those in rural areas — still have no access to these basic services. In the Sustainable Development Goals Report, it was found out that 2.2 billion people worldwide, including 785 million without access to basic drinking water, still lack access to safely managed drinking water. The report further highlights that, progress on Goal 6 (clean water and sanitation) is alarmingly off track citing that one in three people do not have access to safe drinking water, two out of five people do not have a basic hand-washing facility with soap and water, and that more than 673 million people still practice open defecation. Additionally, lack of safe drinking water is much more of a problem in urban environments especially in developing countries[2].

Many countries in Africa have made considerable efforts to improve access to clean water through establishment of water treatment infrastructure [3]. However, according to a study in Kabarnet water supply [4], some of the infrastructure such as the distribution systems become worn out with time and hence affect the quality of the water despite being good for consumption at the treatment plant. Studies have reported that contamination of treated water in reticulation systems is slowly becoming a growing concern especially to people living in urban areas[5].

According to UN World Water Development report [6], half of the people who drink water from unsafe sources lived in Africa. The study further highlighted that in Sub-Saharan Africa, only 24% of the population had access to safe drinking water, and 28% have basic sanitation facilities that are not shared with other households. From this report, it is evident that much efforts and measures need to be put in place by governments and other development partners to improve access to clean water and sanitation services in Africa. In a study on Africa's Water Quality [7], it was found out that developed water supply and sanitation services in the urban areas are concentrated in the upper and middle class areas and that the urban poor have the least access to these services hence pay the highest price for their water. Further, in the study, differentiation is made between urban centers with declining water distribution systems, due to inadequate, aging and overloaded networks and the situation of peri-urban dwellers. In the study, it was also mentioned that despite the development of distribution systems in Africa, there have been challenges of contamination of treated water during reticulation leading to outbreak of water borne diseases such as cholera and bilharzia.

In Kenya, drinking water quality can undergo dramatic changes in distribution systems owned by water service providers [8]. Because of this, many new regulations focus on monitoring water quality within the distribution system, causing utilities to face new challenges in maintaining high quality water delivered to the consumer's tap. Access to clean drinking water and basic sanitation, including toilets, waste water treatment and recycling, greatly affect the country's developmental progress in terms of human health, education and gender equality. The provision of sustainable drinking water and sanitation are inadequate across many parts of Kenya and, where available, water supply and sanitation services are differentiated according to urban, rural or informal settlements[9]. Previous studies in Kenya [4] indicated that the pipe network distribution system can cause deterioration of water quality although it may have been treated effectively by the treatment system in Kabarnet Water Supply, Baringo County, Kenya. In the study, it was established that the distribution system contributed to the significant variation in the water quality parameters. The study further highlights that the parameters that increased significantly in the distribution system were lead, copper and nitrates. It further found out that the causes of water deterioration in the distribution system included corrosion of the iron pipes, illegal connections, leakages and bursts, water stagnation at dead-ends, over-sized storage reservoirs, and low flow rates. In another study in South Africa [10], it was found out that the challenges facing the water utilities is the deterioration of the quality of water during supply to consumers and that the design and operation of distribution systems provide chances for water quality deterioration after treatment.

In the study area, the quality of the drinking water at the consumer end point greatly depends on the condition of the distribution network. Kapsabet is located at 0°12'14"N 35°6'18"E while Nandi Hills is located at 0°06'01.0"N, 35°10'35.0"E. The two are the major towns in Nandi County and are both experiencing rapid population growth due to rural to urban migration which has result into increased demand for drinking water. Both towns have two rainy seasons throughout the equinoxes, with temperatures ranging between 18 and 24 °C and this climate, along with the region's rich volcanic soils, make it excellent for growing tea. The study area is generally characterized by a rugged terrain consisting of rolling hilly ground creating valleys with steep slopes. Both towns have a centralized water supply system with Nandi Hills water treatment plant and distribution network being the oldest having been constructed in 1948 hence far much older than the one at Kapsabet – which was constructed in 2012. In Kapsabet, weekly water quality surveillance was done previously and majority on the physical chemical water quality parameters were found to be within the acceptable levels while a few cases of variations had been reported. In Nandi Hills, the treatment plant and distribution lines are old and the water quality monitoring is not often being done to ascertain the levels of the physico-chemical parameters. In both towns, none, if not a few, microbiological tests have been done by the water service provider to confirm presence of microorganisms (total, fecal coliforms and Escherichia coli) in the water at the consumer taps.

Additionally, the distribution system in the two towns is characterized by frequent bursts and leakages, which are the most likely avenues through which the water is contaminated during supply to customers. Kapsabet town has an old sewer system with 410 connections against a population of 43,000 people. Nandi Hills town, on the other hand, also has an old waste water disposal system – connected to only 25 households – and most people rely on pit latrines, toilets, and a few septic tanks. In terms of piped water connectivity, Kapsabet town has 5,075 connections while Nandi Hills town has 925 connections. In this situation, coupled with the rampant bursts and leakages in the pipelines, it is necessary to examine the quality of water at the consumer end taps. It is on this backdrop that the need to assess the effect of the distribution systems on water quality – in Kapsabet and Nandi Hills towns – is anchored.

The specific objectives of this study were to analyze the physical (pH, electrical conductivity and turbidity), chemical (nitrate, nitrite, iron, zinc, and residual chlorine) and bacteriological (total and fecal coliforms) parameters at treatment plant and consumer end taps of both Kapsabet and Nandi Hills towns; to compare the results between selected consumer end taps in the two towns and examine if the distribution system affects the water quality; to compare the results with the limits set by World Health Organization (WHO) and Kenya Bureau of Standards (KEBS); and to make recommendations to the Government of Kenya, local county government, to the water service provider as well as countries of the world on management of drinking water quality in distribution networks.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

2.1.1 Water Sources

River Kabutie is the main water source for Kapsabet town and is located approximately 5 kilometres Northwards from Namgoi Junction along the Eldoret-Kapsabet road. During the rainfall seasons, the river water contains a lot of clay and silts and looks red. In terms of the topology, the lowest elevation is 1,894 m above sea level at the Kabutie River at coordinates 0°13'08" N and 35°07'08" E rising steeply to 2,030 m at Kapsabet Town. Nandi Hills town sources its water from Taito Dam located 1.5km north of the town central business district.

2.1.2 Population, Weather and Economic Activities

Kapsabet town had 91,997 people while Nandi Hills had 8,032 people as per the Kenya National Population Census 2019. In terms of access to piped water connectivity, Kapsabet and Nandi Hills towns had 3,700 and 650 active connections respectively. Kapsabet and Nandi Hills towns have a cool and wet climate with two rain seasons during the equinoxes with temperatures vary between 18 °C and 24 °C. Tea farming is the dominant agricultural activity carried out in the study area – majorly attributed to the favorable conditions in the study area for the growing of tea. The study area is generally characterized by a rugged terrain consisting of rolling hilly ground creating valleys with steep slopes.

2.1.3 Geographical Location

Nandi County is in North Rift of Kenya, occupying an area of 2,884.4 square kilometres. Kapsabet and Nandi Hills towns are the two major towns in the County. Kapsabet is located at 0°11' 60 " N 35° 05' 60" E while Nandi Hills is located at 0° 6' 11.0628" N, 35°10'35.0"E.

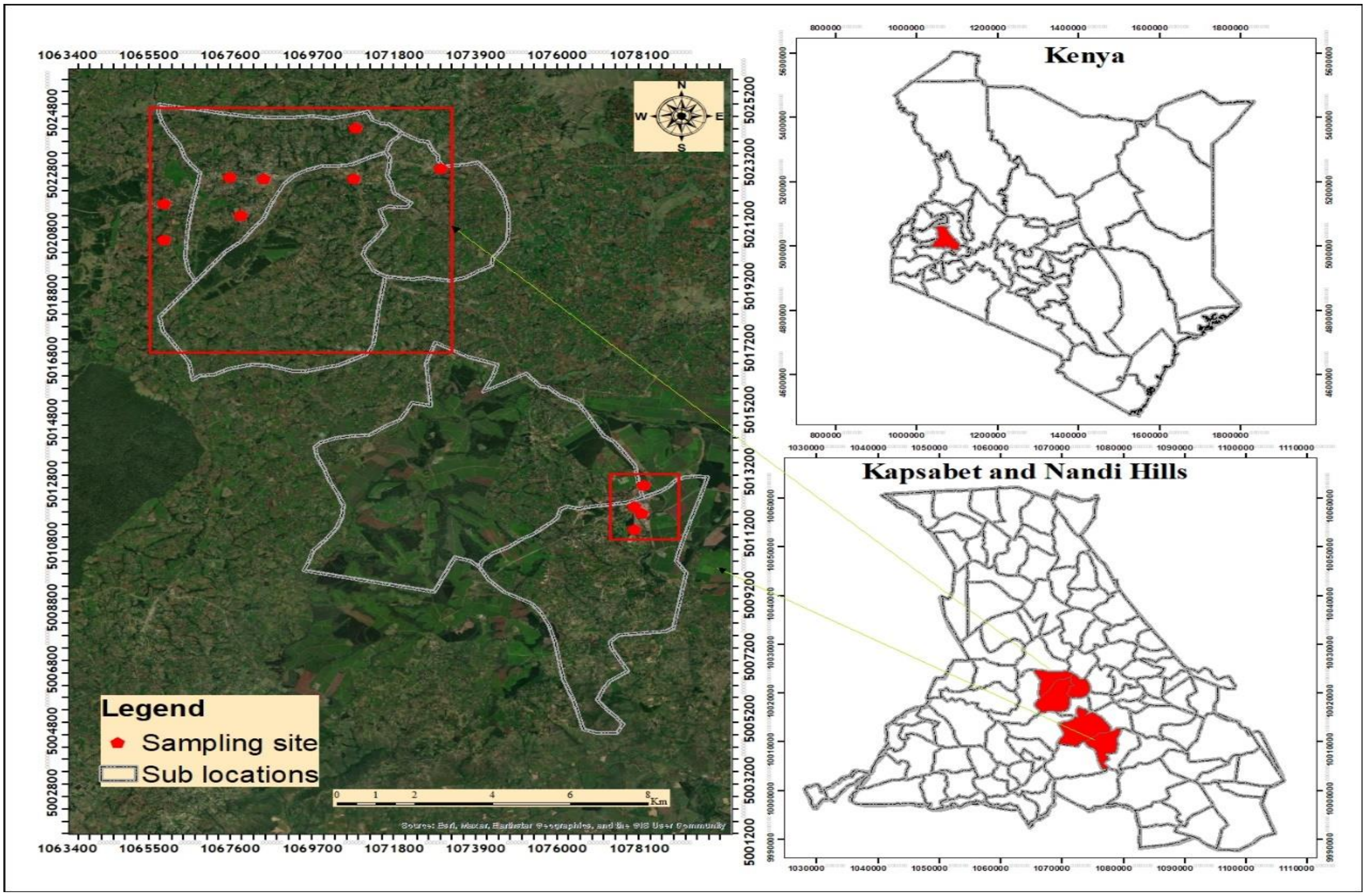

Figure 1 Map of Kenya the study area showing the sampling sites

2.2 Research Design

A cross sectional research design was used in this study which principally involved the collection of water samples at randomly selected consumer end taps for a period of six months from November 2022. This study was an experimental type of research and it purposely aimed at suitably determining the effect of the distribution system on the physicochemical and bacteriological water quality parameters in Kapsabet and Nandi Hills towns. Kapsabet town is supplied with clean water from Kabutie Water Treatment Plant while Nandi Hills town is supplied with water from Taito Dam Treatment Plant. The water is treated to the recommended standards in Kapsabet while in Nandi Hills the treatment plant is old and partial treatment is done.

However, in both towns, it is possible that the water supply distribution network could affect the water quality from source to consumer end. Therefore, the quality of water was determined in samples collected from the treatment stations and consumer end taps. These two towns were chosen as study sites due to their vicinity and contrasting water service conditions as well as age differences in their water supply distribution infrastructure.

2.3 Data Collection

Water samples were collected from the two treatment plants as well as at the randomly selected consumer end taps – a total of 10 water samples for per week were collected from consumer end taps and at treatment plants in Kapsabet and Nandi Hills towns from November 2022 to April 2023 while water samples for bacteriological tests were collected once in a month in all the sampling stations. Samples of treated water were analyzed to ascertain the efficiency of the treatment works. Supply zones were taken as sampling sections and sampling points were chosen randomly. The sampling points Chebarbar, Namgoi, Kapsabet Town Centre, Surungai, Kamobo, Cheber,

Showground (for Kapsabet town) and Nandi Hills Town Centre, Kipriria and Junction (for Nandi Hills town). The sampling points were chosen in these zones since they were populous and easy to access hence served as the representative points in the distribution network. The physical and chemical parameters of the water samples were analyzed at the site while bacteriological analysis was done at the Kapsabet Nandi Water and Sanitation Company laboratory. Standard sampling procedures for each parameter were followed and the parameters were analyzed using standard methods of testing water [11]. Sampling frequency was determined in accordance with section 1.3.3 of the guidelines on drinking water quality and effluent monitoring [12]. The number of samples for each parameter were determined using this guideline. According to the guideline, based on the water production at both treatment plants of 1,212,867 m3, at least 23 samples for bacteriological, 57 samples for residual chlorine, 14 samples of pH and turbidity; and 6 samples of fecal indicator per 5,000 head of population were required to be tested since the study period The guideline, however, recommends testing of more samples in order to be able to adequately establish the trends in quality of water supplied to customers.
The sampling dates were chosen after a thorough scrutiny of the weekly water supply rationing programme in both Kapsabet and Nandi Hills towns – in order to ensure water was available at the consumer end points. Kapsabet and Nandi Hills Towns have a total of 6,000 registered consumers out of which 4,500 were active connections. During the study, sampling was done at least 4 times in a month and at least once a month for bacteriological tests for six months from November 2022. A total of 348 water samples were collected and analyzed during the study period with reference to guidelines in APHA, 1998 [13] out of which 1,920 tests were done for physicochemical parameters and 180 tests for total coliforms, fecal coliforms and E. coli.

2.4 Water Sample Analysis

Water samples were collected from the consumer end taps using 500ml beaker after rinsing using the tap water for 1 minute. Immediately the sample was collected pH, turbidity, residual chlorine, nitrates, nitrites, zinc and iron were measured onsite using a DR900 Multiparameter Portable Colorimeter from HACH. Electrical Conductivity was measured using Microprocessor Turbidity Meter (Model HI 93703). Samples for bacteriological analysis were collected using 500ml plastic bottles (PET), capped and put in a cooler box for further analysis in the laboratory. The plastic bottles were used as they are unreactive with the water sample and are not as fragile as glass. All the parameters were measured following the standard methods as outlined in APHA [11].
It is worth to note that during the individual sample testing using the DR900 Multiparameter Portable Colorimeter, the instrument cap was installed on the cell holder before zero was pushed. In order to ensure best results, the reagent blank value was measured before measuring the values of the sample. The appropriate reagents were applied for pH (phenolphthalein), residual chlorine (DPD tablets), nitrates, nitrites, zinc and iron in each case for every parameter. The data for each parameter was recorded in a raw data sheet and later transferred to a master data sheet in Microsoft Excel.

2.5 Standards for Parameters in Drinking Water

Globally, World Health Organization has prescribed limits of water quality parameters that inform whether or not water is suitable for human consumption. These limits have been customized by countries of the world with a view to reducing on water-related diseases among citizens. In Kenya, KEBS is an institution mandated to ensuring quality standards are adhere to in all goods and services consumed by the people of Kenya. The Government of Kenya has also established WASREB to further oversee the water service providers to ensure good quality water is supplied to citizens. Table 1 shows the limits set by KEBS for the parameters assessed during the study period.

Table 1 WHO and KEBS standards on drinking water quality.

Parameter	Units	WHO	KEBS
pH	pH scale	<8	6.5 – 8.5
Turbidity	NTUs	<5	<5
Electrical Conductivity	μScm^{-1}	-	<1500
Iron (Fe)	mgl^{-1}	<0.3	<0.3
Zinc (Zn)	mgl^{-1}	<3	<5
Nitrates (NO_3^-)	mgl^{-1}	<50	<50
Nitrites (NO_2^-)	mgl^{-1}	<10	<3
Residual Chlorine	mgl^{-1}	0.6 – 1.0	0.2 – 0.5
Total Coliforms	CFU/100ml	nil	nil
Fecal Coliforms	CFU/100ml	nil	nil
E. coli	CFU/100ml	nil	nil

2.6 Data Analysis and Presentation

The data was analyzed where means, standard deviations and one way ANOVA and Pearson Correlation were computed at 0.05 significance level. The significance of the differences between the characteristics of the treated water at treatment plant and those in the distribution system was assessed using an ANOVA of the means. The KEBS's guidelines served as the reference values for the water quality parameters. [12]. Bar charts, graphs, and tables were then used to illustrate the analyzed data in order to highlight various comparisons between the test variables in the data obtained.

3. RESULTS

3.1 Summary of physico-chemical and bacteriological parameters during the study period

In Kapsabet town, the results of the physico-chemical and bacteriological parameters ranged as follows; pH ranged from 6.10 – 7.90, turbidity (0.00 – 22.00 NTUs), electrical conductivity (60.00 – 145.00 µScm-1), Iron (0.06 – 1.68 mg/l), Zinc (0.00 – 0.28 mg/l), nitrates (6.20 – 24.60 mg/l), nitrites (0.025 – 0.134 mg/l), residual chlorine (0.04 – 0.63 mg/l), total coliforms (0.00 – 22.00 CFU/100ml), fecal coliforms (0.00 – 12 CFU/100ml) and *E. coli* (0.00 – 9.00 CFU/100ml). In Nandi Hills town, the results showed that pH ranged from 6.30 – 7.70, turbidity (5.00 – 29.00 NTUs), electrical conductivity (100.00 – 162.00 µScm-1), Iron (0.09 – 1.58 mg/l), Zinc (0.06 – 1.40 mg/l), nitrates (8.07 – 58.70 mg/l), nitrites (0.072 – 0.204 mg/l), residual chlorine (0.08 – 0.48 mg/l), total coliforms (0.00 – 21.00 CFU/100ml), fecal coliforms (0.00 – 9.0 CFU/100ml) and E.coli (0.00 – 6.00 CFU/100ml).

Table 2. Summary of physico-chemical and bacteriological parameters during the study period

Parameter	SS1	SS2	SS3	SS4	SS5	SS6	SS7	S11	S12	S13
pH	6.84 ±0.27	6.84 ±0.17	6.85 ±0.26	6.87 ±0.26	6.85 ±0.18	6.78 ±0.24	6.88 ±0.27	6.90 ±0.27	6.91 ±0.33	6.80 ±0.28
EC (µScm^{-1})	84.60 ±16.90	85.83 ±18.31	85.86 ±18.01	87.53 ±15.73	87.90 ±17.67	88.60 ±16.36	84.70 ±17.06	125.20 ±11.8	123.80 ±11.6	126.73 ±13.8
Turbidity (NTUs)	1.77 ±1.99	1.73 ±2.33	1.80 ±2.04	1.50 ±1.33	1.50 ±1.20	2.70 ±3.90	1.67 ±1.42	12.23 ±4.52	12.37 ±3.94	13.63 ±4.99
Nitrates (mg/l)	11.35 ±4.47	11.86 ±4.80	1.84 ±4.42	11.90 ±4.89	12.04 ±4.40	11.97 ±4.55	11.97 ±4.54	18.6 4±6.44	19.74 ±8.64	20.60 ±10.95
Nitrites (mg/l)	0.07 ±0.02	0.07 ±0.02	0.07 ±0.02	0.07 ±0.02	0.08 ±0.02	0.07 ±0.02	0.08 ±0.02	0.11 ±0.02	0.12 ±0.02	0.12 ±0.02
Iron (mg/l)	0.32 ±0.28	0.30 ±0.25	0.38 ±0.29	0.45 ±0.34	0.57 ±0.44	0.52 ±0.39	0.45 ±0.34	0.46 ±0.32	0.70 ±0.34	0.49 ±0.34
Zinc (mg/l)	0.09 ±0.06	0.10 ±0.08	0.10 ±0.07	0.09 ±0.06	0.12 ±0.07	0.11 ±0.06	0.10 ±0.07	0.71 ±0.31	0.75 ±0.25	0.82 ±0.27
Residual Chlorine (mg/l)	0.33 ±0.06	0.36 ±0.07	0.28 ±0.09	0.37 ±0.08	0.37 ±0.10	0.36 ±0.11	0.28 ±0.06	0.28 ±0.09	0.32 ±0.09	0.32 ±0.09
Total Coliforms (CFU/100ml)	0.00 ±0.00	0.00 ±0.00	8.29 ±8.73	0.00 ±0.00	2.86 ±5.75	0.86 ±2.45	0.00 ±0.00	10.26 ±9.51	1.14 ±3.27	0.00 ±0.00
Fecal Coliforms (CFU/100ml)	0.00 ±0.00	0.00 ±0.00	5.83 ±4.17	0.00 ±0.0	1.5 ±2.34	0.33 ±0.82	0.00 ±0.00	4.67 ±3.83	0.33 ±0.82	0.00 ±0.00
E. coli (CFU/100ml)	0.00 ±0.00	0.00 ±0.00	2.33 ±3.67	0.00 ±0.00	0.33 ±0.82	0.5 ±1.22	9.00 ±3.67	1.33 ±2.42	0.67 ±1.63	0.00 ±0.00

SS – Sampling site; SS1 – Chebarbar Centre, SS2 – Namgoi Centre, SS3 – Joma Hotel, SS4 – Surungai, SS5 – Kamobo Secondary school, SS6 – National Petrol Station, SS7 – Showground Water Kiosk, SS11 – Nandi Hills Market, SS12 – Nandi Hills Hospital and SS13 – Kipriria (Con. No. 9);

3.2 Comparison of Physico-chemical and Bacteriological Parameters with Drinking Water Quality Standards

The mean values of the results in **Table 2** were compared with the WHO and KEBS standards as shown **Table 3**.

Table 3. Overall mean of physico-chemical and bacteriological parameters during the study period

Parameter	Units	Overall mean - Kapsabet	Overall mean - Nandi Hills	KEBS Limit
pH	pH scale	6.9±0.25	6.9±0.30	6.5 - 8.5
Turbidity	NTUs	86.43±16.99	125.24±12.05	<1500 NTUs
EC	µScm^{-1}	1.81±2.21	12.74±4.50	<5 µS/cm
Iron	mgl^{-1}	0.43±0.36	0.55±0.35	<0.3 mg/l
Zinc	mgl^{-1}	0.10±0.07	0.76±0.28	<5 mg/l
Nitrates	mgl^{-1}	11.85±4.52	19.66±8.81	<50 mg/l
Nitrites	mgl^{-1}	0.07±0.02	0.12±0.02	<3 mg/l
Residual Chlorine	mgl^{-1}	0.34±0.09	0.31±0.09	<0.2 - 0.5 mg/l
Total Coliforms	CFU/100ml	1.71±4.71	3.81±7.33	0.00 CFU/100ml
Faecal Coliforms	CFU/100ml	1.1±2.6	0.1±3.0	0.00 CFU/100ml
E. coli	CFU/100ml	0.6±2.1	0.6±1.7	0.00 CFU/100ml

During the study, most of the water samples analyzed were within the limits for physico-chemical and bacteriological quality set by KEBS. These included electrical conductivity, zinc, nitrates, nitrites and residual chlorine (to a greater extent). However, on a number of occasions some of the parameters exceeded the limits (turbidity, iron, total and fecal coliforms; and E. coli) and hence water was not safe for human consumption. For instance, pH of 6.1 and 6.3 were recorded at the National Petrol station in November, 2022 and at Nandi Hills Market in February, 2023 respectively.

Turbidity in Nandi Hills scheme was generally above the standards set by KEBS in all the samples analyzed. This was majorly attributed to the old main line characterized by frequent bursts and lack of conventional treatment plant in Nandi Hills town. In Kapsabet town, a few cases of high turbidity were recorded. For instance, turbidities over the set standards were recorded as follows; National Petrol station recorded 22 NTUs in November, 2022, turbidity of 9 and 11 NTUs were recorded in December 2022 at Chebarbar Centre, Namgoi and Joma Hotels respectively. These arose due to major repairs in the main lines serving the above areas. In a few instances, the results for residual chlorine were found to be below the standards set by KEBS. This was observed in Nandi Hills Hospital (0.14 mg/l) in December, 2022, 0.11 mg/l and 0.12 mg/l were recorded at Nandi Hills Market and in Kipriria (Con. No. 9) in February, 2023 respectively. An extremely lowest residual chlorine concentration (0.08 mg/l) was recorded in Kamobo secondary school in April, 2023. The water samples analyzed were generally free from bacterial contamination. However, instances of presence of total and fecal coliforms were recorded especially in Joma Hotel, Kamobo secondary school and National Petrol Station as well as the sampling points in Nandi Hills scheme. The results of bacterial contamination was lower as compared to the findings of the research done in Kisii town [13] and Kakamega town [14].
The results in **Table 2** and **Table 3** can be further illustrated by **Graphs 1** and **2.**

4. DISCUSSION

4.1 pH

The pH of most of the water samples analyzed during the study period showed slight acidity (6.10 – 7.90) since most of the samples were below 7.0. However, the pH was in some instances extremely acidic due to contamination caused by damage of pipes during road construction. A study on appraising drinking water quality Ikem area in South Nigeria [15], reported that the pH was acidic due to intense use of agrochemicals in farms. The agrochemicals in the study area could also be a contributing factor because the study area is characterized by intensive tea farming. pH is an important parameter in drinking water because it affects the effectiveness of disinfection and impacts corrosion of pipes[16]. The iron pipes used in Kapsabet and Nandi Hills towns undergo continuous corrosion as a result of fluctuation in pH of the water. The study further revealed two instances where pH fell below WHO limits at National Petrol Station (at 6.3 and 6.1 in November 2022) and this therefore points to the fact that there is a higher chance of contamination as the water moves further away from the treatment plant[17]. Other studies in Temeke District in Tanzania [18], reported that low pH arose due to nitrates, chloride, carbon dioxide and or dissolved minerals. The study cited that environmental characteristic of the area such as geological location was the cause of having low pH level making water to be acidic.
During the study, it was noted that there was a little variation of pH in both the dry and wet season. The wet season registered higher values compared to dry season due to the dilution factor. Since the pH was moderate, there was no significant correlation with other physico-chemical and bacteriological parameters during the study period. Most of the water sources that were analysed had pH levels that were meeting the KEBS and WHO criteria as shown in Table 3. The means for the respective sampling sites were as depicted in Table 2. According to research, V. cholerae can flourish in mildly acidic to alkaline media (pH 6 and above) but not in strongly acidic media (pH below 5), which is what is present in the human intestinal system[19]. It is therefore necessary to undertake further studies to establish presence of V. cholerae in the drinking water in the study area.

4.2 Electrical Conductivity

The ability of natural water to conduct electric current is measured by its electrical conductivity. Electrical conductivities are primarily impacted by dissolved ions like potassium chloride and sodium chloride[20]. The trend in overall conductivity was that lower values of conductivity (ranging 60 – 118 μScm^{-1} in Kapsabet and 100 – 141 μScm^{-1} in Nandi Hills town) were obtained during low rainfall months while high conductivity values (ranging 82 – 145 μScm^{-1} in Kapsabet and 120 – 162 μScm^{-1} in Nandi Hills town) were obtained during the high rainfall months. The high levels of electrical conductivity recorded during the wet season in both towns (Figure 1) could be attributed to the seasonal variations in rainfall and human activities responsible for an increase in total dissolved solids. During the wet season, a lot of water enters the river or dam sources and it is also the season where the farmers are ploughing and planting and a lot of fertilizers are used which may be carried into the river water.
All EC values of the water samples were below the maximum WHO limit of <1500μScm-1 with a general mean of 86.43±16.99 μScm^{-1} in Kapsabet town and 125.24±12.36 μScm^{-1} in Nandi Hills town. The result of EC in this study compares well with those of other studied water supply networks[21]. According to a study in Indore city in India [20], it was found out that as the concentration of dissolved salts (usually salts of sodium, calcium and magnesium, bicarbonate, chloride and sulfate) increased in water, electrical conductivity increased proportionately.

4.3 Turbidity

Water appears foggy because of the presence of suspended materials such as clays, silts, and microorganisms. Turbidity is significant because it influences both the selection and effectiveness of treatment processes, particularly the effectiveness of chlorine disinfection because it exerts a chlorine demand, protects microorganisms, and may also encourage the growth of bacteria.[22]. The values obtained for turbidity measurements varied greatly as expected from November to April – very high turbidity values were obtained from March – April which is the wet season of the study area than from November – February (dry season). This could be due to more incidence of rainfall in the wet season. In the upstream of Kabutie River, there is sand mining, riparian crop farming and bricks making therefore, runoff during rainfall events can lead to increased sedimentation of the river thus contributing to high turbidity values determined in the wet season.

There were a few instances of turbidity exceeding the KEBS standards in Kapsabet town. However, in Nandi Hills town, nearly 95% of the water samples analyzed showed were exceeding the limits set by KEBS (of less than 5NTUs). The highest turbidity of 22 NTUs was recorded in National Petrol Station in November, 2022, and this was attributed to delayed repair of pipeline damaged by grading machine during road expansion. Nandi Hills town recorded a highest turbidity of 29 in the month of April, 2023. High rainfall experienced in March and April coupled with the absence of a conventional treatment plant in the town often results in abnormally high turbidity. During the wet season, turbidity ranged from 2.00 – 6.00 (Kapsabet town) and 12.00 – 29.00 (Nandi Hills town). The result of this study compared well with a similar study in Northwest Ethiopia [23] where turbidity (5.15 ± 0.006 NTU) was found to be higher than the KEBS standards.

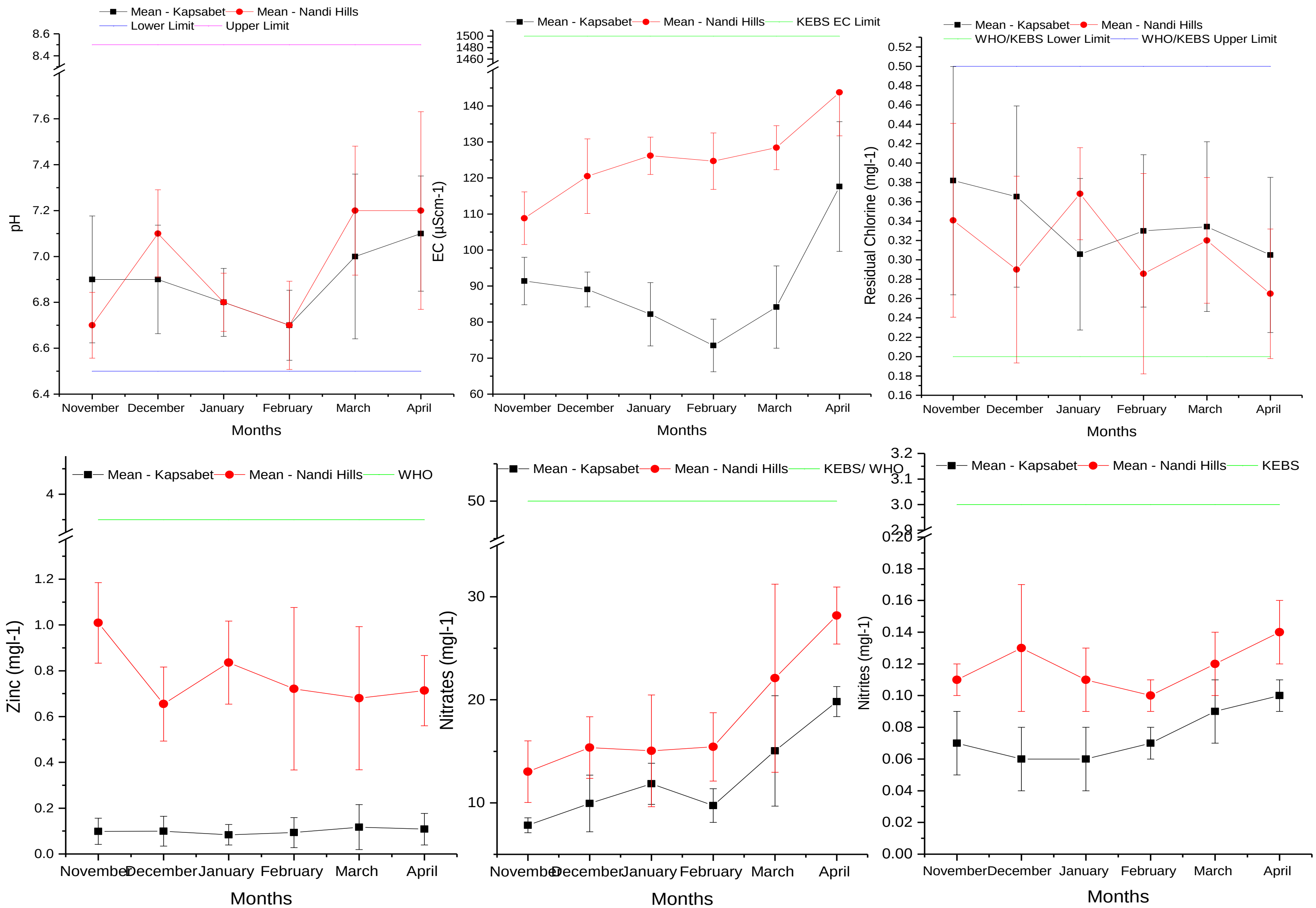

Figure 2. Graphs showing parameters within WHO and KEBS drinking water standards

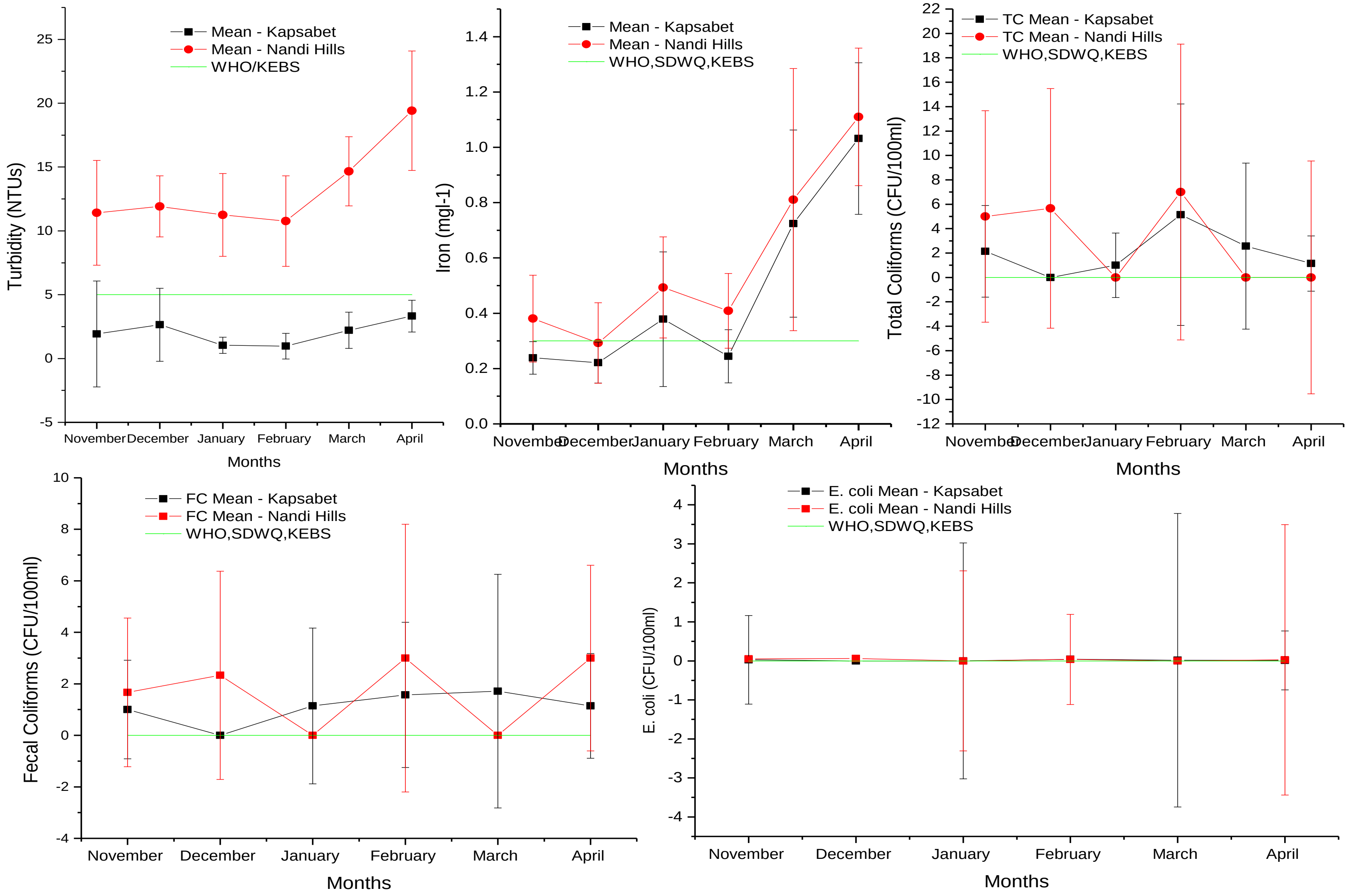

Figure 3. Graphs showing parameters exceeding WHO and KEBS drinking water standards

4.4 Nitrates and Nitrites

Nitrates were within the recommended levels in various consumer end points with an overall mean of 11.85±4.52 mg/l and 19.66±8.81 mg/l in Kapsabet and Nandi Hills towns respectively. The WHO recommends that nitrates in drinking water be not more than 50 mg/l. Nitrates in the drinking water arises from extensive agricultural activities carried out in the study area characterized by excessive application of inorganic nitrogenous fertilizers, inadequate waste water treatment and management, and oxidation of human excreta.
Both nitrate and nitrite concentrations were below the WHO permissible limits (Table 3). The results of the study were similar to the findings of Hawassa City in Ethiopia [24] which found nitrates and nitrite levels within WHO limits. The highest nitrate and nitrite concentration was recorded in Nandi Hills town during the wet season and might be due to the over leaching of nitrate-containing organic wastes and from the use of fertilizers in the nearby tea farms.
According to a study in Temeke District in Tanzania [18], nitrate is toxic because it can be converted to nitrite ion (NO_2^-) in the stomach causing a serious illness and sometimes death in infants less than six months of age. It combines with haemoglobin giving a complete methanoglobin, in which the association constant is larger than oxyhaemoglobin thus depriving the tissue of oxygen. The symptom for acute disease is blueness of the skin. The overall mean nitrite concentration was 0.072±0.02 mg/l at the consumer end points in Kapsabet town while that of Nandi Hill town was 0.115±0.02 mg/l. In another study in Kathmandu Valley water supply network, Nepal [25], it was reported that Nitrates ranged from 0.03 to 8.11 mg N/L during the wet season and from 0.01 to 1.88 mg N/L during the dry season which were within the established drinking water quality standards.

4.5 Iron

According to the results of the study, dissolved iron was found to be higher than the limits set by WHO. Iron levels were also found to increase with distance from the treatment plant – with iron levels being lower in Namgoi and Chebarbar center and higher in Kamobo secondary school and National Petrol station. Fluctuation in iron levels in the drinking water is attributed to corrosion of iron pipes in the main lines serving the area. A similar study in Tanta City in Egypt [26] reported Iron levels were exceeding the WHO limit. From the study, there was a significant correlation between iron levels in the dry and wet seasons. During the dry season, iron concentrations ranged from 0.06 – 0.85 mg/l and 0.09 – 0.78 mg/l in Kapsabet and Nandi Hills towns respectively. On the other hand, iron concentrations during the wet season ranged from 0.06 – 0.85 mg/l and 0.09 – 0.78 mg/l in Kapsabet and Nandi Hills towns respectively. Other studies [27] have reported that iron concentration may increase despite water being of good water chemical composition when pumping water into the network as a result of picking off sediments due to changes in water flow direction or rate in water distribution network and iron penetration into water by its dissolution. With nearly 70% of the distribution system of the study area being made up of galvanized iron pipes, corrosion is inevitable. In both towns, water supply is intermittent and customers are served on a rationing programme where some pipes are closed for up to three times in a week. Cases of power outages in both towns creates back flow of water and water hammer which often results in excessive pressure on iron pipes hence bursts and leakages occur.
From the study, the overall mean iron concentration was 0.43±0.36 mg/l and 0.55±0.35 mg/l in Kapsabet and Nandi Hills towns respectively. The results of this study were overally above the WHO limits of 0.3 mg/l. Other similar studies [28] reported high Iron concentrations in drinking water in Kaunas City and cited that it was hazardous to the health of older people as it stimulated aging processes. From the study, it was also found out that the concentration of Fe had a tendency to increase with an increase in the distance from the water treatment plant. For instance, higher concentrations were observed in National Petrol Station, Kamobo Secondary school and Showground water kiosk which are located over approximately 7 kilometres from Kapsabet treatment plant.

4.6 Zinc

The permissible limit of zinc in drinking water is set at 5mg/l as by Kenya Bureau of Standards and WHO. The observation showed that the levels of zinc were within the threshold values for drinking water. Zinc had an overall mean of 0.10±0.07 mg/l in Kapsabet town and 0.76±0.28 mg/l in Nandi Hills town and hence the water was good for human consumption. Zinc is considered an essential trace metal which functions as catalyst for enzymatic activity in human bodies [29]. Drinking water with traces of zinc in very small quantities serves to reduce the possibility of deficiency in the diet[30, 31]. However, according to a study in Los Angeles [32], it's accumulation in the human body cause harmful effects such as acceleration of anemic conditions.
The results of this study compared well with findings of drinking water in Dakahlia in Egypt [33] where zinc levels were at 5.9±2.3 µg/l. Similar findings in Southwestern Uganda also reported zinc levels to be within limits permissible by local and international regulatory agencies [34]. The high pesticide use that is common in many agricultural ecosystems can be linked to the zinc levels found in the study area.

4.7 Residual Chlorine

The value of residual chlorine for water samples collected from the two towns varied from the lowest value of 0.04 mg/l. The mean residual chlorine was 0.34±0.09 in Kapsabet town while the mean for Nandi Hills town was 0.31±0.09. There were instances when residual chlorine was below the WHO limits of 0.2 – 0.5 mg/l and was attributed to contaminant intrusion especially as a result of interference of pipelines at the specific areas. In most cases, low residual chlorine was recorded in Joma Hotel and Kamobo Secondary school (Kapsabet town) and Nandi Hills Market and Hospital. The result of the low residual chlorine showed a strong correlation with presence of total and fecal coliforms. According to a study in Oman [35], it was reported that Water without residual chlorine was more likely to be contaminated with total coliforms. The study findings also indicated that most samples obtained from piped water had residual chlorine of less than 0.2ppm which is lower than the minimum threshold recommended by WHO.

Other studies have also compared well with the findings of this work[36]. In general, chlorination is done sufficiently in both towns since knowledge of residual chlorine concentration at various locations in drinking water distribution system is essential final check to the quality of water supplied to the consumers. From the result of the study, it was evident that with the intermittent water supply in both towns, the residual chlorine at farthest node is sensitive to water supply hours and travelling time of chlorine. In most cases, the residual chlorine was observed to have a decreasing trend with increase in distance from the treatment plant. A study in Kisii town also report that residual chlorine was, in some instances, found to have fell below the KEBS standards (0.04 mg/l)[13]. The study reported that the failure to meet the minimum effective concentration of chlorine led to microbial contamination of tap water in Kisii town.

4.8 Total and Fecal Coliforms

Physico-chemical properties that had significant relationship with presence of total coliforms in household drinking water was chlorine residue ($p = 0.002$). Water without residual chlorine was found to be more likely to be contaminated with total coliforms [37]. In Kapsabet Town, the mean total coliform for the entire study period was found to be 1.71±4.71 with a mean total coliform of 1.66±4.70 during the dry season and 1.86±4.93 in the wet season. In Nandi Hills Town, an overall mean total coliform for the entire study period was found to be 3.81±7.33 with a mean total coliform of 3.53±7.41 during the dry season and 4.50±7.79 during the wet season. Similar findings were reported in a study in Yangon City [38].

In general, total coliforms were detected in 8 water samples in Kapsabet town and 5 samples in Nandi Hills scheme. All the mentioned samples were found to have fecal coliforms and out of the above 5 samples in Kapsabet town and 4 samples in Nandi Hills scheme had E. coli. It was observed that water had no coliforms at both treatment plants and hence the efficiency of water treatment was confirmed. Presence of E. coli was an indication of direct contamination by human waste. The result of the study showed a strong correlation between residual chlorine and total, fecal coliforms and E. coli. For instance, water samples that had residual chlorine below 0.2 mg/l, recorded presence of total, fecal coliforms and E. coli. In Kapsabet town, the results showed ranges of total coliforms (0.00 – 22.00 CFU/100ml), fecal coliforms (0.00 – 12 CFU/100ml) and E. coli (0.00 – 9.00 CFU/100ml) while in Nandi Hills town ranges of total coliforms (0.00 – 21.00 CFU/100ml), fecal coliforms (0.00 – 9.0 CFU/100ml) and E. coli (0.00 – 6.00 CFU/100ml).

Coliforms should not be present in drinking water for it to be considered safe for human consumption[39]. According to a study in Mianwali in Punjab[40], drinking water with E. coli colonies between 1 – 10 is categorized as low risk. In the two towns studied, Joma Hotel had highest prevalence of total coliforms and E. coli with generally a nearly higher risk. This could as a result of poor piping system at the hotel characterized by leakages and water pipes passing through drainages. In Nandi Hills, E. coli was prevalent at the market and can be associated with improper human waste disposal at the upper side of the market which has informal settlements and the area is often experiencing pipe bursts and leakages that may at times take longer to repair or go unnoticed. The results of E. coli in the study area were similar to the findings of bacteriological contamination of water supply in Isiolo, Kenya[41]. The risk of cross-contamination across the water supply chain should be reduced by implementing proper water handling facilities at the point-of-use level. In order to ensure quality water is supplied, thorough routine maintenance on the water supply pipes that transport water from the water treatment plant to consumers' homes must be done including clearing the clogged pipes that serve as breeding grounds for bacteria.[42].

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the findings above, it was evident that the status of the distribution system has a great impact on the water quality being supplied to customers at any given time. It can be concluded that, holding factors constant, the electrical conductivity, zinc and iron, nitrates and nitrite levels in the water samples analyzed were within the standards set by WHO and KEBS and hence qualifies the water as suitable for human consumption. The parameters that were majorly within the set standards included residual chlorine, total and fecal coliforms and pH. Iron content and turbidity were majorly exceeding the standards for most of the analyzed water samples during the study period. In the entire study period, drinking water leaving the Kapsabet treatment works is of good quality and meeting the standards at 99% purity levels showing that the plant was efficient in treating water.

In general, the levels of most of the physicochemical properties were high in all the sampling sites during the dry season while they were low during the dry season.

It can also be concluded that there was a significant difference between the physico-chemical and bacteriological parameters at Nandi Hills town with most of the parameters exceeding the WHO standards as compared to Kapsabet town. The distribution network of Nandi Hills town is extremely old and is prone to frequent bursts and leakages. The pipelines are composed of old asbestos, GI and PVC conduits which are easily corroded and not rust proof. The absence of a conventional waste water treatment in Nandi Hills and Kapsabet towns greatly contribute to the high chances of contamination of water supplies in both towns. The two towns also do not have proper drainage systems for channeling run off waters. The water quality from the treatment facility to the customer taps is getting worse because of the old ductile iron water pipes. Corrosion, leaks at pipe joints, pipe bursts, extremely large storage reservoirs, low flow rates, dead end networks, cross-contamination during routine maintenance, and improper fittings and connections as a result of illegal water supply lines are the main causes of changes in water quality.

5.2 Recommendations

In the view of the major findings of the study and the conclusions above, the following were recommended;

To the Government of Kenya – Since most of the water quality parameters in Nandi Hills town exceeded the standards set by WHO and

KEBS, it is recommended that the GoK should construct a new water treatment plant for the town. This will improve the quality and quantity of water supplied to the customers and hence reduce incidences of water-related diseases. The GoK should also focus on improving on advanced equipment for managing water distribution infrastructure so as to eliminate inefficient tools and equipment used during major repairs on bursts. The GoK should also construct sewage disposal infrastructure for both towns. The GoK also needs to come up with policies that govern augmentation of existing water treatment infrastructure to minimize the effects of ageing networks on drinking water quality especially as towns continue to expand. The GoK should also subsidize operation costs for water companies to facilitate them to be able to undertake rehabilitation of target areas that have been identified as areas of frequent contamination.
To the County Government of Nandi – The constant interference of pipelines by roadworks often results into contaminant intrusion to the water supply network. The county government should provide way leaves for pipelines to avoid damage by road machines. The County government should also provide high density polyethylene pipes to replace the GI and PVC pipes so as to reduce on corrosion and frequent bursts. The public health officers and other relevant stakeholders should not only collect water samples from sources but also from households regularly to ascertain its bacteriological quality and provide water safety promotion education to the general public.
To Kapsabet Nandi Water and Sanitation Company Limited – Being the entity charged with the responsibility of supplying good quality water, the entity must ensure that at all times, all the physico-chemical water quality parameters are within the acceptable levels for human consumption. The entity should also conduct regular spot checks and surveillance to ensure water at the customer end taps are safe for human consumption and take necessary response action in cases of extreme water contamination. The water service provider should also consider adopting booster chlorination with a view to maintaining adequate levels of residual chlorine throughout the distribution system. The water company should also acquire an automated system for real time monitoring of drinking water quality at the consumer end points and that can be able to give alarm on deviations from WHO standards. It is further recommended that the water company acquires more advanced water quality testing equipment and equip the laboratory with modern technology tools.
To the consumers – The consumers are highly recommended to carry out regular inspection of their service lines with a view to averting possible contamination resulting damaged pipes. The entities offer public services such as hotels and schools must ensure the pipeline is intact all the time and free from fecal contamination. Most towns and schools in Kenya have experienced increased outbreaks of water borne diseases such as cholera and dysentery.

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