ASSESSMENT OF DRINKING WATER QUALITY IN DISTRIBUTION SYSTEM. A CASE STUDY OF KABARNET WATER SUPPLY, BARINGO COUNTY, KENYA

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ABSTRACT

Provision of good quality water by water utilities in Kenya is hampered by inefficient water supply infrastructure. Water quality deteriorates in the distribution system despite undergoing effective treatment. This study aimed at analysing the water quality of Kabarnet Water Supply in order to detect any changes in the distribution system. Water samples were obtained from the treatment plant, distribution reservoirs, and the consumer zones. The results indicated the treated water met the acceptable levels implying that the treatment plant is effective. Some of the parameters were above acceptable limits. The distribution system contributed to significant variation in the water quality parameters. Among the parameters that increased significantly in the distribution system are lead, copper and nitrates. The causes of water deterioration in the distribution system include corrosion of the iron pipes, illegal connections, leakages and bursts, water stagnation at dead-ends, over-sized storage reservoirs, and low flow rates. The remedies include replacing iron pipes with High density plastic pipes i.e. HDPE, PPR plastic pipes and redesigning the distribution system to improve on pressure and detention times in the system.

Keywords: Pipe leakages, pipe corrosion, water pollution, water supply system, water treatment.

1. INTRODUCTION

The water sector in Kenya underwent reforms to cure the problems that were inherent prior to the enactment of the water Act 2002. The reforms led to the establishment of institutions with separate and distinct functions. It also led to the separation of water resources management from the provision of water and sanitation services. Rift Valley Water Services Board (RVWSB) is one of the institutions established to provide water and sanitation services in the areas of Rift Valley drainage basin. As per the Act, the board is required to contract Water Services Providers (WSP) to provide water supply and sanitation services on its behalf in various areas. Most WSPs, including Kabarnet Water Supply Company, was developed from the water departments of the defunct County Councils and therefore inherited the entire infrastructure from them. Most of these water infrastructure facilities such as the water treatment and water distribution systems are old and inefficient.

The pipe network distribution system can cause deterioration of water quality although it may have been treated effectively by the treatment system. Among the challenges facing the water utilities is the deterioration of the quality of water during supply to consumers (Momba et al., 2000). The design and operation of distribution systems provide chances for water quality deterioration after treatment (Biyela, 2010). It is necessary to as-

sess the water quality in a distribution system as a way of ensuring good quality water to the consumer (Munavalli and Kumar, 2005).
In general water quality deterioration occurs inside the distribution pipe network due to physical, chemical and biological reactions as a result of interaction among dissolved chemical agents, deposits, pipe materials among others.

Corrosion can occur in iron water distribution pipes after a long time of use (Sarin et al., 2004). Corroded iron pipes contribute to cracking of the pipe which allows ingress of particles and contaminants from the surrounding soil surface as most of the water distribution pipes are buried. Use of substandard pvc pipe for pressurized systems results to frequent bursts in the pipe network that increase ingress of contaminants into the water distributed.

In Kenya, water rationing is common due to frequent droughts which reduce the water level in dams. Infrequent water presence in the pipeline increases the chances of water pollution. Pathogenic contamination can occur due to the regrowth of bacteria after detachment from the surface of the distribution pipe (Volk and LeChevallier, 1999). Microbial activities in the distribution system can induce corrosion in pipe walls (Chen et al., 2013). Residual chorine helps in preventing the growth of bacterial films in the distribution system (May et al., 2008, Carter et al., 2000). This ensures that the water is free from pathogens at the consumer level. This study sought to assess the water quality of Kabarnet Water Supply distribution system in order to determine whether the water quality met the acceptable limits.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

This study was conducted in Kabarnet Municipality in Baringo County. It is located about 260km northwest of Nairobi along the slopes of the Tugen Hills. The County has a population of 631, 638 with 42% water coverage (WASREB, 2015). The institution responsible for the provision of water and sanitation services to the residents of Kabarnet Municipality is Kabarnet Water Supply utility which is an agent of Rift Valley Water Services Board as per the Water Act, 2002.

2.2 Sources of Water

The main source of water is Kirandich Dam (a rock fill dam). It was completed in the year 2001. The dam details are indicated in Table 1. The water from the dam is pumped in 7 km rising mains to the distribution tanks situated at Seguton Hill and Mumol from where they are distributed by gravity to consumers.

2.3 Data Collection and Analysis

Water samples were collected from the treatment works and at the distribution system. Raw water samples of the raw and treated water were determined to ascertain the efficiency of the treatment works. Supply zones were taken as sampling sections and sampling points were chosen randomly. These zones are Kabarnet-Mosop, Kaprogonya, Riwo, Seguton, Kapropita-Chebano, Kapropita-Chepsir, Kewamoi-Kabarnet, Kapsoo-Borowonin and Kapcherebet-Turkwo.

The sampling points were chosen in these zones such that the points were populous and easy to access. These points served as the representative points in the distribution network. The water samples were analyzed for physical and chemical and bacteriological quality. The bacteriological analysis was only done for the raw water and the treated water. The samples were analyzed at the RVWSB laboratory. The sampling period was November 2014 to January 2015 where water samples were obtained twice in a month. Specific sampling procedures for each parameter were followed. The parameters were analyzed using standard methods of testing water and wastewater (APHA, 1995). The pH of the water samples was tested using a pH/mV/Temperature meter model No. 24-D1848 from CONTROLS. Colour and residual chlorine were analyzed using a lovibond comparator 2000+ kit, while turbidity was analyzed by a HACH 2100 Q model turbidimeter. All the remaining chemical parameters; total hardness, alkalinity, chlorides, fluorides, nitrates, and copper were analyzed using a Palintest photometer 7100 Model. Appropriate reagents were applied in each case for every parameter analyzed using the Palintest photometer. Multiple tube fermentation technique was applied in the analysis of the total coliforms. The water samples were refrigerated after sampling and analyzed within 24hours after sample collection since analyses included total coliform determination.

The data were analyzed by means and standard deviations and analysis of variance (ANOVA) at 5% significance level. ANOVA of the means was done to determine the significance of the difference between the characteristics of the treated water quality and in the distribution system. The reference values for the water quality parameters were the guidelines used by the Water Services Regulatory Board (WASREB, 2008)

3. RESULTS AND DISCUSSION

3.1 Efficiency of the water treatment plant

The characteristics of the raw water were analyzed and the results are indicated in Table 2. The efficiency of the treatment plant was assessed by analyzing the quality of the treated water (Table 3). The water quality in the distribution tank was analyzed in order to check for any quality deterioration in the distribution mains from the treatment works. The results are shown in Table 3.

Table 1: *Dam design details*

Height of dam	54m
Full supply level	1774.46 MSL
Length of dam crest and spillway	120m
Spillway design capacity	300m3/s
Reservoir capacity	4 billion m3
Nominal safe yield	3.75 billion m3
Treatment plant location	Downstream end of slope

Results from Table 2 were for dry season. It was expected that variations would occur to some of the parameters such as nitrates, turbidity, and conductivity among others due to contribution from runoff. Comparing the values of the raw water (Table 2) and the treated water (Table 3), shows that the treatment plant was effective. Residual chlorine was above the minimum levels for residual disinfection.

Table 2: *Raw Water Quality characteristics*

S/No.	Parameter	Average Values
1.	Turbidity (NTU)	2.1
2.	Colour (TCU)	5
3.	Alkalinity (mg/l)	20
4.	TDS (mg/l)	140
5.	pH (Units)	8.55
6.	DO (mg/l)	10.7
7.	Nitrate (mg/l)	0.108
8.	Chloride (mg/l)	4.5
9.	Arsenic (mg/l)	0.0010
10.	Lead (mg/l)	0.0001
11.	Copper (mg/l)	0
12.	Fluoride (mg/l)	0.02
13.	Total Hardness (mg/l)	73
14.	COD (mg/l)	2.9
15.	Total coliform (MPN/100ml)	0.5

Table 3: *Treated water characteristics*

Parameter	Treatment Plant- Exit	Average at Distribution Reservoirs	WASREB Guide
pH (Units)	6.9	7.0	6.5 – 8.5
Colour (TCU)	0	0	15
Turbidity (NTU)	0.51	0.52	5
Total Hardness (mg/l)	12	10	500
Alkalinity (mg/l)	48	46	500
Chloride (mg/l)	2.1	1.7	250
Residual Chorine (mg/l)	1.6	1.5	0.2*
Fluoride (mg/l)	0.15	0.10	1.5
Nitrate (mg/l)	1	1.11	10
Copper (mg/l)	0.01	0.03	0.1
Lead (mg/l)	0.001	0.0013	0.05
Total coliform (MPN/100ml)	Nil	Nil	Nil

* Minimum value for residual disinfection

The ANOVA results for the concentration of the parameters in Table 3 show that there is no significant difference between the treated water and the water in the two distribution reservoirs ($p > 0.05$). This indicated that the rising mains from the treatment works to the storage reservoirs (tanks) did not significantly change the quality of the water.

3.2 Water Quality in the Distribution System

Monitoring of water quality changes in the distribution system is necessary to ensure that the water at the consumer points is of acceptable water quality standard. The distribution network used by Kabarnet Water Supply Company is old, particularly those within Kabarnet town. This is attributed to the integration of the old system that was supplying water from Kaptimbor reservoir. This coupled with the extended lengths of the distribution system is bound to elucidate water quality changes. The mean values of the parameters considered are illustrated in Table 4. Zone 5 experienced the most deterioration in water quality. In this Zone, the mean concentrations of lead, nitrate, copper, and turbidity were in this zone that all the other zones. This zone is supplied from an over-sized storage tank which results in long detention times. Zone 5 is characterized by dead – end network, poor junction connections resulting from unauthorized connections, line blockages and low flow velocities. In general, all the zones had higher concentrations of copper than the allowable limits. The high concentration of chloride and nitrates in zone 7 could be attributed to the presence of open storage tanks and automotive repair workshops. The open storage tank facilitates contamination from external sources such as birds' droppings.

It can be deduced from Table 5 that there was a general increase in the mean and maximum values as water was transmitted from the treatment plant. ANOVA indicated that there was significant difference in the quality characteristics of treated water and at the distribution system ($p < 0.05$). This implied that the distribution system contributed to changes in the quality of water. It is a concern that the concentration of metallic compounds of lead and copper increased beyond the acceptable limits. The appearance of colour at the distribution system shows corrosion of the pipe material. High Nitrate contamination could be attributed to the nitrification of ammonia released during decay of chloramines (Zhang et al., 2009, Woolschlager et al., 2005). The possible causes of water quality deterioration include illegal connections, low flow rates, dead-end connections, leakages, prolonged water shortages and over-sized storage tanks. Over-sized tanks lead to long detention times and receding residual chlorine levels (Woolschlager et al., 2005, Grayman et al., 2004). More than 50% of the zones experienced higher than the recommended levels of turbidity. This could be attributed to the ingress of silt and clay particles at leaking joints and metal deposits as a result of corrosion coupled with low velocities. Long retention times in the distribution network can also accelerate internal corrosion (Engelhardt et al., 2000).

Table 4: *Water quality characteristics in the zones*

Parameter	Zones									WASREB Guide
	1	2	3	4	5	6	7	8	9	
Fluoride (mg/l)	0.11	0.20	0.17	0.30	0.32	0.29	1.02	0.68	0.62	1.5
Lead (mg/l)	0.00	0.002	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.05
Nitrate (mg/l)	1.4	1.5	1.1	5	61	2.6	34	19	15	10
Chloride (mg/l)	11	30	20	19	71	101	304	131	236	250
Copper (mg/l)	0.04	0.02	0.02	0.04	2.73	0.02	0.04	0.02	0.02	0.1
Hardness (mg/l)	42	62	128	252	196	426	270	320	354	500
pH (Units)	6.5	6.4	6.0	7.5	7.2	7.5	7.7	7.8	8.2	6.5-8.5
TDS (mg/l)	84	141	70	308	404	544	901	681	876	1500
Colour (TCU)	5.41	3.51	3.45	3.72	2.93	3.12	3.18	2.46	3.33	15
Turbidity (NTU)	2.12	3.78	2.76	1.39	5.94	1.8	0.86	0.84	4.4	5
Alkalinity (mg/l)	53	67	28	277	366	393	240	247	238	500

1- Kabarnet-Mosop 2- Kaprogonya, 3- Riwo, 4-Seguton, 5-Kapropita-Chebano, 6:-Kapropita-Chepsir 7-Kabarnet-Kewamoi, 8-Kapsoo-Borowonin, 9- Kapcherebet-Turkwo

Table 5: *Comparison of water quality characteristics*

Parameter	Water treatment Plant	Distribution System	
		Mean Values	Maximum
Fluoride (mg/l)	0.2	0.4 ± 0.3	0.8 ± 0.6
Lead (mg/l)	0.001	0.000 ± 0.010	0.010 ± 0.010
Nitrate (mg/l)	1.0	15.5 ± 20.3	27.8 ± 32.0
Chloride (mg/l)	2.1	102.6 ± 104.6	221.0 ± 175.7
Copper (mg/l)	0.01	0.33 ± 0.90	0.42 ± 1.09
Hardness (mg/l)	12.0	227.7 ± 131.9	404.7 ± 173.2
pH (mg/l)	6.9	7.2 ± 0.7	8.0 ± 0.4
Colour (mg/l)	0.00	3.46 ± 0.82	6.81 ± 4.59
Turbidity (mg/l)	0.51	2.65 ± 1.74	8.48 ± 10.28
Alkalinity (mg/l)	48.0	212.0 ± 134	414.0 ± 336.8

4. CONCLUSIONS AND RECOMMENDATION

The drinking water distribution system for Kabarnet Water Supply is old. The old ductile iron water pipes contribute to the deterioration of water quality from the treatment works to the consumer taps. The main causes of water quality changes include corrosion, leakages in pipe joints, pipe bursts, over-sized storage reservoirs, low flow rates, dead end networks, and cross-contamination during the frequent repairs and maintenance, and improper fittings and connections as a result of unauthorized water supply lines. There is a need to replace the iron pipes with plastic (High Density Poly-ethylene (HPDE) and PPR pipes in places where much pressure is not expected in order to avoid corrosion-induced water quality changes. The other measures include a redesign of the distribution system in order to improve the pressure and velocities, adoption of a looped network to minimize water stagnation at dead ends. There is also need to improve designs by introduction of fittings like pressure reducing valves and Air Valves where necessary to manage high pressures, water hummer and pipe pitting and within the system. This reduces chances of corrosion and bursts.

This study was limited to physical and chemical changes in the water distribution system. More studies need to be carried out to determine potential pathogenic contamination in the distribution system. It is also necessary to evaluate the residual chlorine levels along the distribution network as a result of the interaction among physical, chemical and biological agents in the water and the pipe system. The use of simulation models to describe the water quality variations along the system is another interesting area for research.

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