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Water Quality Status of Selected Sources of Domestic Water in Kenya

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ABSTRACT

In Kenya, water scarcity is a major issue due to destruction of water catchment, poor management of water supply and contamination of national water resources. The government's long-term objective is to ensure that all citizens have access to safe drinking water. Although the government has increased the budget for improving access to water, many citizens still do not have access to potable water. The study analysed contaminants from selected sources of domestic water in the counties of Machakos, Nakuru, Kiambu and Nairobi. The following physico-chemical parameters were investigated – pH, conductivity, total suspended solids (TSS) and total dissolved solids (TDS), dissolved oxygen (DO), chemical oxygen demand (COD), anions (Cl- and PO43-), E. Coli and total coliforms. Water samples were collected from eight sampling sites in dry and wet seasons and analysed following standard methods. pH values varied from 6.3 – 9.1 in the dry season, and 6.9 – 9.5 in the wet season, conductivity from 244.0 – 5758.0 µS/cm in the dry season and 141.0 – 2004.0 µS/cm in the wet season, TDS from 113.0 – 5,824.0 mg/L in the dry season and 82.0 – 183.0 in the wet season, temperature from 24.1 – 25.2°C in the dry season and 25.3 – 25.8°C in the wet season, TSS from 0.00 – 0.01 mg/L in the dry season and 0.01 – 0.02 mg/L in the wet season, COD from 112.0 – 255.0 mg/L in the dry season and 90.6 – 154.0 mg/L in the wet season, DO varied from 2.8 – 4.2 mg/L in the dry season and 3.1 – 4.2 mg/L in the wet season, nitrates from 2.5 – 19.6 ppm, phosphates from 0.03 – 2.24 mg/L, while E. Coli varied from 13 – 4,300 CFU/ml. The values obtained for most parameters were within WHO and National Environment Management Authority (NEMA) guidelines for domestic water, except for two sites (Athi River and Portland), where pH, TDS and conductivity exceeded the guidelines. Most sites had biological contamination indicating anthropogenic contamination, rendering water unsafe. The water needs to be decontaminated to safeguard human health.

Keywords: Domestic water quality, Physico-chemical parameters, Nutrient levels and Biological contamination

I. INTRODUCTION

Global statistics show that over 1.2 billion people lack access to safe drinking water,[2] while 600 million face water scarcity. It is estimated that by 2025 many more lives will face water scarcity or water stressed conditions.[3,4] Access to safe drinking water is a basic human right and an effective policy for health protection, [5] since clean, safe and adequate freshwater is vital to the survival of all mankind.[6] The world's water resources are threatened by rapid growth in human population and as industrial and agricultural expansion.

Kenya is a water scarce country, [7] since its renewable freshwater supplies are less than 1,000 cubic metres per capita.[8] The water per capita dropped drastically from 1,853 m^3 in 1969 to 704 m^3 in 2000, to the current estimate of 540 m^3, this is below the global benchmark of 1,000 m^3/person/year. Projections for 2020, indicate that water per capita will drop to 235 m^3/person/year.[9] According to census estimates released on a regular basis, Kenya population has risen from 38.6 million in 2009 to 49.9 million in 2017.[10] According to UN estimates 45% of the Kenyan population rely on unprotected water sources – streams, lakes, ponds, dams, water vendors and unprotected wells and springs. The poor urban dwellers have been pushed to the slums, where there is no water or sanitation, and the overcrowding exacerbates the already hazardous health conditions.[12] According to Kenya vision 2030, the country aims to conserve water sources, explore new ways of water harvesting using rain water and underground water. Providing safe water and managing water sources wisely, is key to achieving the Sustainable Development Goals.

80% of Kenya is arid or semi-arid with an annual rainfall of 630 millimeters (mm) with a variation from less than 200 mm in Northern Kenya to over 1,800 mm on the slopes of Mt. Kenya. In Kenya, largely due to recurrent droughts, millions of families that rely on crops and livestock are threatened and thousands of people die each year as a result of thirst and hunger.[13]

Several research studies have been carried out which lower the quality of water: micro-organisms due to fecal contamination, sediment loads on to water bodies increasing total dissolved solids, conductivity, turbidity and colour and nutrients overload due to poor farming methods, organic waste and partially treated waste. The main objective of this study was to determine the quality of domestic water drawn from various sources in Nakuru, Machakos and Nairobi counties. [14,15,16,17]

II. METHODS AND MATERIAL

A. Study Area

The study was undertaken in three counties, namely Nairobi, Machakos and Nakuru covering lake, river, spring, dam and a borehole water sources. The study investigated physico-chemical and microbiological water quality parameters. The GPS locations and altitudes of sampling sites are summarized in Table 1.

Table 1. Distribution and GPS locations of sampling sites

Sampling sites	Location	Site description
Crayfish Hotel	Naivasha	Beach of the hotel is used for boat riding
Kamere fish landing	Naivasha	Number of activities take place: water vendors, washing of clothes and cars.
Kihoto	Naivasha	Pelican birds and canoes bringing in fish, Hyacinth in the lake and farming
Ondiri Swamp	Kikuyu Township	No Activity except for the Eastern bypass nearby
Jamhuri Dam	Race Course	Fields for horse racing
Athi River	Athi River	Agriculture
Kyoto Panda	Athi River	Tap water provided by Portland cement factory
Chiromo Borehole	Chiromo	Tap water in the pesticide lab (UON) sources water from the borehole

The location of the sampling sites are shown in Figure 1 Below.

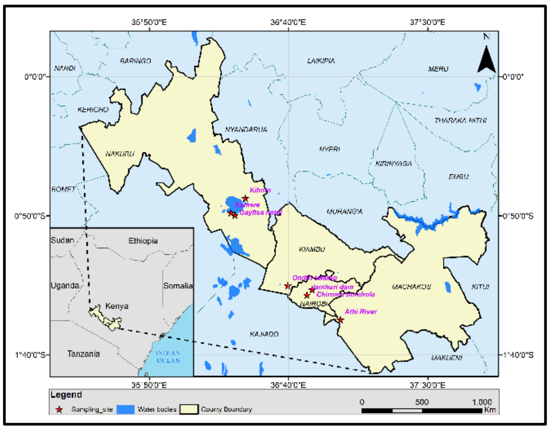

Figure 1. Location of the sampling sites

B. Test for presence of Escherichia Coli and Coliforms

Qualitative and quantitative tests were carried out to detect the presence of biological contamination in water samples. The qualitative test was carried out using 3M Petri-film *E. Coli* count plates. Each plate was inoculated with 1 ml of sample in duplicate, and incubated at 37°C for 24 hours. The number of colony forming units was calculated using the following equation:-

$$CFU = \frac{\text{Number of colonies x Dilution factor}}{\text{Amount plated (ml)}}$$

C. Physico-chemical parameters

i) Determination of pH

The pH meter model 292 MK PYE UNICAM was used for pH measurements. The meter was calibrated using buffer solutions of pH 4.0 and 7.0. After calibration, 100 ml of the sample was placed in a beaker, its pH was determined by dipping the electrode into the sample. Stable pH reading was recorded. The procedure was repeated using other samples in triplicate.

ii) Total Suspended Solids (TSS)

TSS was measured by gravimetric method. Whatman No.42 filter papers were dried in an oven at 105 ^oC for 2 hours, cooled in a desiccator and weighed.[16] The process was repeated until a constant weight was obtained. 100 ml of the sample was filtered using the dried filter paper on a Buckner funnel fitted to a vacuum pump. The filter papers were dried in an oven, cooled and weighed again. The weight of the paper before and after filtration was used to calculate the total suspended solids in mg/L. The following formula was used:

$$TSS\ (mg/L) = ((W_f - W_i) \times 10^6)/V$$

Where:-
W_f = Constant weight of filter paper + residue in grams
W_i = Constant weight of dried filter paper
V = Volume of water sample used in ml

iii) Conductivity and Total Dissolved Solids

Hanna instrument TDS/Conductivity meter was used to measure TDS and EC. The meter was calibrated using standard solutions of 1,413 µS/cm. After calibration, the conductivity of the samples was measured by dipping the probe into the samples and recording the stable reading. The same procedure was repeated for TDS.

iv) Dissolved Oxygen

Dissolved oxygen was determined using Winkler's method. This process uses titration to determine DO in water samples. 300 ml glass bottle was completely filled with water sample, then immediately 'fixed' by adding 2 ml $MnSO_4$ and 2 ml Alkali Azide, the bottle was stoppered and inverted several times to dissolve brownish orange cloud (floc) formed. Then 2 ml of concentrated H_2SO_4 was added to the solution, stoppered and inverted several times to dissolve the floc. 201 ml of the sample was transferred into a titration flask and titrated with 0.1N $Na_2S_2O_3$ to a straw colour. 2 ml of starch solution was added to form a blue colour complex and titration continued until the sample turns clear. The following formula was used to calculate DO

$$DO\ (mg/L) = \frac{[\text{ml titrant x normality of titrant x 8000}]}{\text{Equivalent volume of sample titrant}}$$

D. Analysis of Nutrients

i) Nitrate Analysis

The concentration of nitrates in water was determined using Brucine method EPA 352.1. The method is based upon the reaction of the nitrate ion with Brucine sulphate in sulphuric acid solution at a temperature of 100 °C. The colour of the resulting complex is then measured using the UV-Vis Spectrophotometer at 410 nm.

Brucine-Sulfanilic acid reagent was prepared by dissolving 1g of brucine sulphate and 0.1g of sulfanilic acid in 70 ml of hot distilled water. 3 ml of concentrated hydrochloric acid was added, cooled and diluted to 100 ml using distilled water. Standard nitrate solutions of concentrations of 0.0, 0.5, 2.0, 3.0 and 4.0 mg/L were prepared and measured for absorbance. Water samples were filtered to remove particles and turbidity. The pH of each sample was adjusted to neutral using acetic acid or sodium hydroxide.

10 ml of blank and samples were taken in duplicate and placed in sample tubes. 10 ml of sulphuric acid was added to each tube and placed in a cold water bath to reach thermal equilibrium. 0.5 ml of brucine-sulfanilic acid reagent was added to each tube, swirled then placed in a water bath set at 100˚C for 25 minutes. The tubes were then transferred to a cold water bath to reach thermal equilibrium of between 20˚C - 25˚C. Absorbance of each solution was determined at 410 nm using the UV-Vis Spectrophotometer.

ii) Phosphate Analysis

Concentration of phosphate ions in water samples was determined using Bray and Kurtz extracting solution prepared by dissolving 1.11 g of analytical grade ammonium fluoride in 0.9 L of distilled water. 25 ml of previously standardized hydrochloric acid was added and made to 1L volume using distilled water. The combined reagent was prepared by mixing 50 ml of 5N sulphuric acid, 5 ml of antimony potassium tartrate solution, 15 ml of ammonium molybdate solution and 30 ml of ascorbic acid solution. To 10 ml of each standard, 1.6 ml of combined reagent was added for calibration, the same amount was also added to the samples. Absorbance of each sample was measured at 880 nm with UV-Vis Spectrophotometer using the reagent blank as reference.[17]

III. RESULTS AND DISCUSSION

A. Escherichia coli and Coliform: confirmation tests

With the exception of Kyoto Panda sampling site, all other sites had *E. Coli* and coliform contamination as shown in Table 2.0.

Table 2 CFU at each sampling Site

Sampling Site	CFU/ml
Kihoto	240
Crayfish Hotel	55
Kamere fish landing	4,080
Jamhuri Dam	1,720
Chiromo Borehole	13
Ondiri Swamp	180
Kyoto Panda	0
Athi River	168

These values clearly indicate that the water sources are affected by faecal contamination, hence unsafe.[18] On the other hand the water provided by the Portland cement Company at Kyoto Panda was found safe for use, since it met the permissible level for WHO criteria of 0 cfu/ml. If the cfu is less than 30 like in the case Chiromo Borehole, the source of contamination could be the tap which is handled by many people who may contaminate the water. At Kamere, there were several activities that could contribute to contamination; particularly washing of clothes, watering of cows and donkeys and animal wastes and run-off from human activities such as the surrounding kiosks.

B. Physico-chemical parameters:

i) pH and Temperature

The pH values are within acceptable limits of NEMA (6.5 – 8.5) except for Kyoto Panda site. This is tap water that is provided by Portland cement Company as part of their corporate responsibility. The water is treated with sodium carbonate which may contribute to high pH. Temperature variability could also affect pH values. As temperature increases, pH tends to decrease due to ionization that causes pH of the water to drop. Seasonal changes also have slight effect on pH

Table 3. Seasonal Variation of pH with Temperature

Season		Jamhuri Dam	Ondiri Swamp	Chiromo Bore Hole	Crayfish Hotel	Kamere Fish landing	Kihoto	Athi River	Kyoto Panda
Dry	pH	7.8± 0.30	6.6±0.80	8.4±0.40	8.7±0.20	7.1±0.30	7.0±0.70	8.4±0.10	9.1±0.10
Wet		7.7± 0.60	6.3±0.60	8.3±0.30	7.4±0.10	7.5±0.10	8.0±0.20	8.2±0.60	9.5±1.00
Dry	Temp.	24.6±0.10	24.6±0.06	25.2±0.25	24.4±0.15	24.9±0.15	25.1±0.20	24.0±0.57	24.3±0.35
Wet		25.8±0.31	25.4±0.06	25.6±0.00	25.9±0.10	25.6±0.06	25.6±0.10	25.3±0.15	25.8±0.10

ii) Conductivity and Total Dissolved Solids

Conductivity ranged from 244 µS/cm – 5,785 µS/cm during the dry season and 141 µS/cm – 2006 µS/cm during the wet season. Two sites exceeded the WHO allowable limit of 1,000 µS/cm (Figure 2). This could be attributed to a high concentration of dissolved ions in water, which also contributes to high conductivity values at these two sites. Athi River has a lot of farming activity near it, pumps use water from the river to water the crops. They may use fertilizers or manure to improve crop yield. The run off during watering or rain may increase the concentration of TDS in the river. Conductivity and TDS are positively correlated.

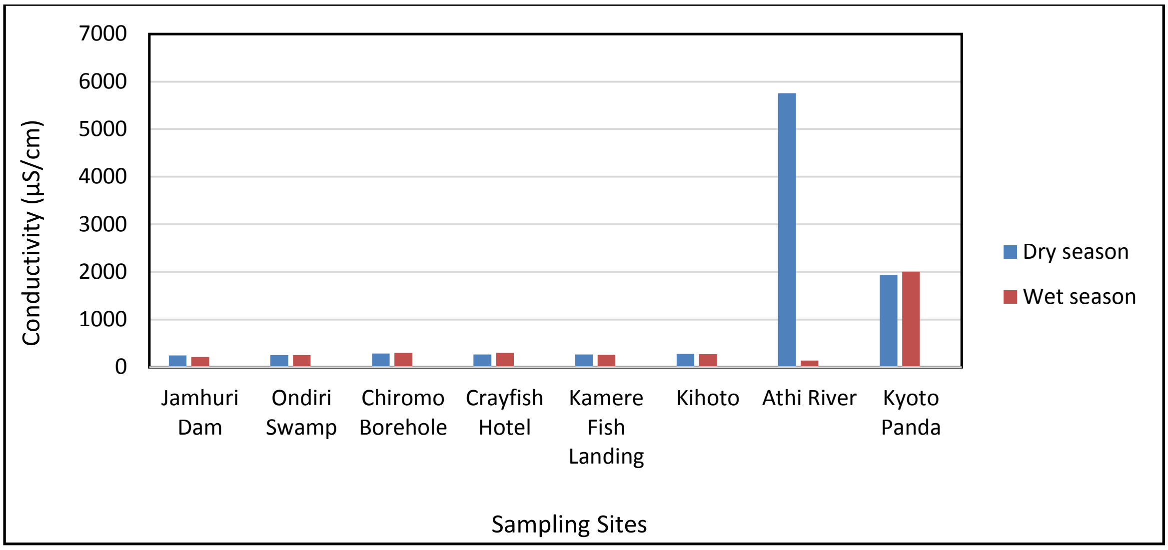

Figure 2. TDS variation during the dry and wet season

iii) Dissolved Oxygen

This is a measure of dissolved oxygen in water and a key indicator of water quality. The DO values ranged from 4 mg/L – 14.4 mg/L. Two sites Kyoto Panda and Ondiri Swamp both registered 4 mg/L which were below allowable limits of WHO (5 mg/l). This may indicate presence of oxygen demanding wastes at Ondiri swamp that may reduce the amount of dissolved oxygen available, another factor is that the swamp is not exposed to atmospheric oxygen since it is under vegetation, hence dissolution of oxygen from the air is minimal. The other values indicate that there is sufficient dissolved oxygen in the water for the survival of aquatic life. The Athi River site has pumps that continuously

C. Nutrients

Nitrate and Phosphate Analysis

Water systems need to be protected from pollution that consumes oxygen necessary for aquatic life. At elevated level, nitrates cause harmful effects, since they provide nutrients for growth of algae polluting water systems. Nitrate levels ranged from 2.5 mg/L – 19.5 mg/L (Figure 3). However, allowable limits according to NEMA should not exceed 10 mg/L. Samples for Athi River exceeded this limit indicating that this water was polluted. Phosphate levels ranged from 0.05 mg/L – 2.24 mg/L. The levels that exceed 0.1 mg/L will accelerate growth of algae that may result in death of fish and aquatic organisms. Three sampling sites exceeded the 0.1 mg/L limit, Jamhuri Dam, Athi River and Kyoto Panda. Phosphates enter waterways from human and animal waste and fertilizer run-off. Source of pollution at Jamhuri Dam could be horse waste since they are watered at this point, while the levels at Athi River could be associated with fertilizer run-off from the farms19,20,21.

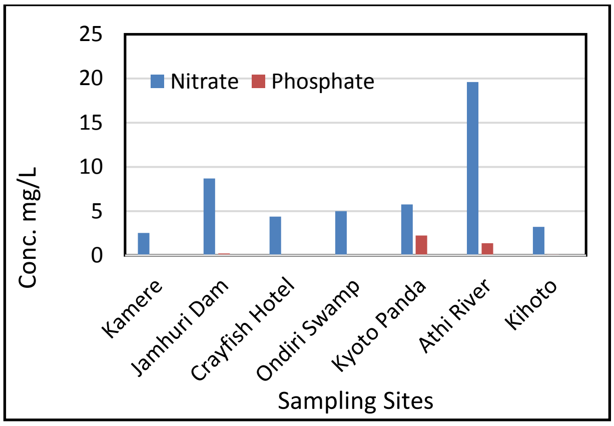

Figure 3. Variation of Nitrates and Phosphates in Water

IV. CONCLUSION

The data obtained in this study suggests that the water sources are contaminated by physico-chemical, biological and nutrients. The Athi River posted the highest values for most parameters that were above WHO permissible limits. Despite the fact that the residents in this area had access to tap water provided by Portland cement factory, the use of river water for irrigation of crops made them prone to water borne diseases. There is need for sound management of water resources to reduce incidences of waterborne diseases in the study area. In addition, the water resources authority should ensure that water sources used for irrigation and drinking meet the set standards.

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