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Water Quality Index of Distributed Portable Water in the City of Nairobi, Kenya

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ABSTRACT

Water quality is one of the indicators that can provide consumer confidence in drinking water distributed in the City of Nairobi. Clean water supply is important to public health hence poor quality of portable water may have negative consequences on general public health. Kenya's capital, the City of Nairobi, faces several water challenges such as water shortages which could lead to the distribution of substandard portable water. The aim of this study was to investigate the water quality index of portable water distributed in the City of Nairobi. Random sampling was done from twenty eight shops, thirty two households, twenty eight supermarkets and twenty eight water vending stations. The water samples were analysed for colour using spectrophotometry, multiparameter-photometer for the Fluoride test, Silicon ions were tested using the Microwave Plasma Atomic Emission Spectrometer and the Most Probable Number method used to analyse microbial parameters. The study indicated that 12.5 % of the household population living in Nairobi treated their water either by sterilizing or boiling. Portable water from supermarkets and shops recorded nil of *Escherichia coli* and total coliforms. However, 50 % of water samples from vending stations recorded levels ranging from 1 to 35 MPN/ 100 ml of total coliforms while 18 % recorded 1 to 8 MPN/ 100 ml of *Escherichia coli*. Moreover, a total population of 6.82 % was found to be taking water with Fluoride above the recommended limits. The recommended Fluoride level in drinking water is 1.5 $mg.L^{-1}$. The quality of selected parameters was 13.6 % within the set specifications. This means, 86.4 % of the total population in the City of Nairobi is drinking unsafe water. Households should consider boiling water as a means of treatment over chemical sterilization by use of Sodium Hypochlorite.

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1. Introduction

Portable water is defined as drinking water treated at the point-of-use which can be moved physically from place to place including bottled water in supermarkets, shops, kiosks, vending stations and households comprising of harvested water. Every human being needs access to water, which is one of the basic human rights. (UN Water, 2015). A large number of people globally still lack quality drinking water. Approximately 6 million die every year globally resulting from disasters and waterborne diseases (UN Water, 2015). Contamination of water sources by faeces or direct contact with children has been associated with about 700,000 deaths among young ones below five years of age annually (UN Water, 2015). Globally, three billion people are approximated to live under water stress by 2035 (Nganga *et al.,* 2012). Increase in urbanization stands to be the leading cause of water scarcity in Africa continent where an increase in population in urban areas is estimated. Kenya's current water per capita is 647 m^3 per year against the global standard of 1000 m^3 which is an indication of limited water supply (WRA, 2019). Unfortunately, the water per capita is projected to further decline at a rate of 359 m^3 in a year with estimations indicating that Kenya's per capita water supply will be about 235 m^3 which will translate into two-thirds short of the current per capita (WRA, 2019). The latter has been associated with the increase in population. To enhance water accessibility and the availability of safe drinking water, there is a need for quick action and planning. The aim of the National Climate Change Action Plan 2018–2022 is to improve annual water availability per capita to 1000 m^3. To achieve this goal, the plan advocates for concrete actions to strengthen the water sector's resilience by ensuring adequate access and efficient use of water for wildlife, manufacturing, agriculture, and other purposes. The planned water-related climate change actions among others include women who help to reduce water waste at the household level and, to some extent, help water agencies reduce waste. The goals of the National Climate Change Action Plan 2018–2022 also help to advance the blue economy by encouraging low-carbon actions in the maritime sector. Others include establishing coastal infrastructure that can withstand projected sea-level rises and storm surges and assisting coastal fishing communities in surviving in a changing climate. Currently, Kenya has a population of people who lack access to quality water which has caused continuous use of poor quality water or travelling long distances and queuing for water access points (Uwazi, 2010). In addition, Uwazi (2010) observed that non-marginalised people have direct access to piped water that is directly supplied to their houses at reduced costs as opposed to marginalized populations that struggle to access quality and sufficient amounts of water. Due to economic pressures of unemployment across Africa and in Kenya, the region has experienced massive rural-to-urban migration in search of greener pastures. Many of the informal settlements in Kenya lack a constant water supply. Approximately two thirds of the Africans in cities are currently living in these types of settlements (WSP, 2005). Sixty five percent of homes in 2009 were able to access improved water provision services. Between 2015 and 2016, the rate of access went up to 65.2 % (Development Initiatives, 2015). In Kenya, a sustainable supply of quality and safe water was estimated to be 60 % and 40 % in urban and rural areas respectively (Development Initiatives, 2015). Consequently, an adequate supply of quality water in terms of pH, colour, conductivity, residual Chlorine, Fluoride ions, Silicon ions, Iron (II) ions, Manganese ions, total coliform and *Escherichia coli* among others is an essential aspect of sanitation that has been on a decline. The allowable limits for the parameters are pH 6.5 to 8.5, a maximum of 50 pcu, 2500 µs,1.5 ppm, 0.1 ppm, 0.3 ppm,50 ppm in colour conductivity, Fluoride ions, Manganese ions, Iron (II) ions, Silicon ions respectively while no residual Chlorine should not be detected in the portable water.

2. Materials and Methods

2.1 Study area

The research was carried out in Nairobi, Kenya's capital City, to investigate portable water quality and provision in all the eleven sub-counties. A total of eighty eight water samples were randomly collected from thirty two households, twenty eight shops and supermarkets and twenty eight water vending stations selected depending on the population size guided by the KNBS census report of 2019, shown in the map figure 1 below.

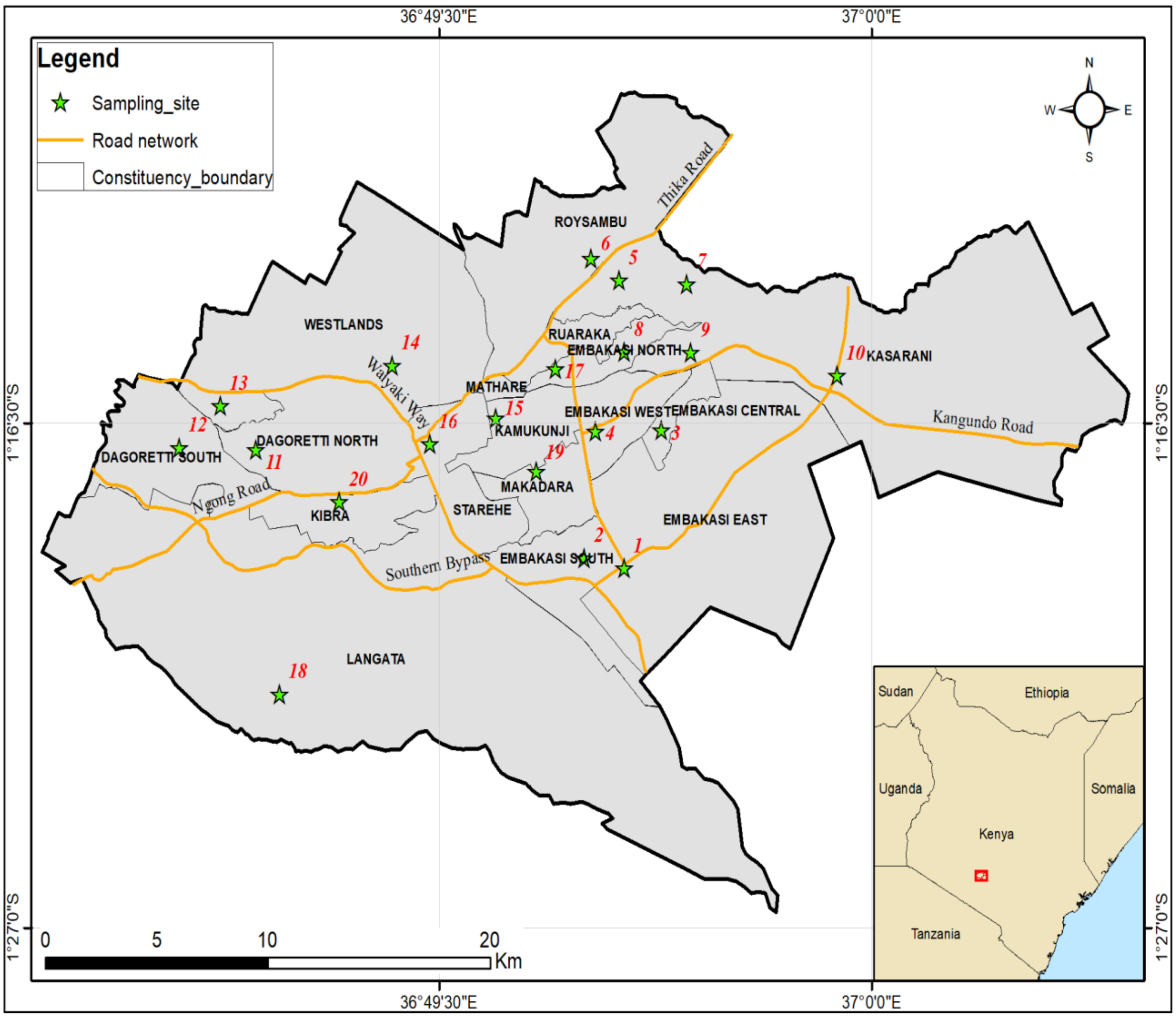

Figure 1: Study area map (The City of Nairobi)

2.1.1 Collection and Preparation of the samples

The sampling areas had almost equal population sizes as guided by the 2019 Kenya census where the questionnaire was used for every sample collected. Water samples from supermarkets and shops were collected in their original packaged polybottles while water sampled in households and water vending stations was collected using sterilized High Density Poly Ethylene (HDPE) bottles. Sterilization of HDPE bottles was done at 121^{o}C for 15 minutes. All the samples were given a special code to represent the area of collection. Samples from shops, supermarkets, households and water vending shops were labelled as SP, SM, HH and WK respectively. All the samples were transported using cooler boxes to the laboratory. The samples were immediately analysed for microbial parameters. The samples were kept in cooler boxes awaiting chemical analysis a day after sampling. Residual chlorine parameter was done onsite for all household water samples. The samples were prepared as discussed under experimental procedures.

2.2 Experimental procedures

The water quality parameters were determined as discussed in the following sections. The chemicals and reagents used were pH standard buffer solutions, Conductivity Meter buffer solution, HI 93729-0 Fluoride LR Reagent, DPD (N,N-diethyl-p-phenylenediamine) no.1 tablets, Brilliant Green lactose (bile) broth, Kovacs reagent for indole, Sterile MacConkey Broth purple, Tryptone water, EC broth medium, Concentrated HCl and Standard solution of Manganese, Iron and Silicon. The equipment used included the pH meter, conductivity meter, COD (Chemical Oxygen Demand) and Multiparameter Photometer, LOVIBOND Chlorine (DPD) Checkit, autoclave, vortex mixer, incubator, water bath, Microwave Plasma Atomic Emission Spectrometer (MP-AES) and Weight balance.

2.2.1 Determination of Water pH

The digital pH meter was turned on and left to stand for a few minutes before being calibrated using the manufacturer's pH standard buffer solutions (pH 4.01, pH 7.01, and pH 10.01). The pH probe was completely washed with distilled water and the pH mode was switched on after 20 ml of the sample was poured into a 25 ml clean universal bottle. To ensure homogeneity between the probe and the sample, the sample was stirred with a stirring bar to achieve equilibrium. The pH was measured and recorded.

2.2.2 Determination of Water Colour

The COD (Chemical Oxygen Demand)and Multiparameter Photometer model HI83099 was turned on and the procedure for determining water colour was selected. A blank sample was prepared by filling one cuvette with 10 ml of deionized water. The instrument was zeroed by running a blank sample inside the sample container. A total of 10 ml of water sample in a cuvette was placed in the sample holder and the lid closed. READ key was pressed and the readings were recorded.

2.2.3 Determination of Fluoride Ions

The COD and Multiparameter Photometer model HI83099 was turned on and the Fluoride determination method was selected. A total of 1 mL of HI 93729-0 Fluoride LR Reagent was added to two separate cuvettes where one cuvette was filled to the mark (10 ml) using deionised water and the other cuvette with the water sample. The cuvettes were capped and inverted several times to obtain a homogenous solution. The cuvette with deionised water was first placed in the sample holder and the lid closed. The Timer was pressed and the countdown was done for two minutes and the display showed "-0.0-". By this, the meter was zeroed and ready for measurement. The same procedure was repeated for water sample analysis. The results for the fluoride ion content of the water samples obtained from the multiparameter photometer readings were displayed in milligrams per litre of Fluoride.

2.2.4 Determination Total Coliform and *Escherichia coli*

The water samples were injected into bottles and tubes and were thoroughly mixed by inverting the bottle at least 10 times (Guruvayurappan et al., 2017). Inoculation of the sterile MacConkey Broth bottles was done by introducing 50 ml of water sample to a bottle containing 50 ml of MacConkey broth (double strength). Each of the five universal bottles carrying 10 ml (double strength) broth received 10 ml of the water sample. Each of the five tubes carrying 5 ml of (single strength) soup received 1 ml of water sample. An inverted Durham tube was included in each bottle to collect gas. The tubes were made from small Durham tubes, whereas the medical flat bottles were made out of medium Durham tubes. Stoppers and loose caps were used to incubate the inoculated broths in a water bath at 35 ^{o}C for 48 hours. After 24 hours, the bottles were examined and regarded as positive reactions. Positive reactions were those which had turbidity due to bacterial growth and gas formation in the Durham tubes, together with acid production noted by the change of broth colour from purple to yellow). The remaining bottles that did not display any or all of these changes were re-incubated and tested for positive reactions after 48 hours.

By incubating one of the brilliant green lactose (bile) broths at 35 ^{o}C for 48 hours and looking for gas production, the presence of coliform organisms was confirmed. Presumptive *E.coli* was proven by incubating a tube of tryptone water for 24 hours at 44°C and testing for indole production, then adding 0.3 ml of Kovacs' reagent to the tryptone water tube. The presence of indole was established by the formation of a pinkish ring after moderate addition of the Kovacs reagent (a mixture of isoamyl alcohol, para-dimethylaminobenzaldehyde (DMAB), and concentrated hydrochloric acid). The most likely quantities of coliform organisms and presumptive *E.coli* in 100 ml of the sample were calculated using the Most Probable Number (MPN) (Guruvayurappan et al., 2017).

2.2.5 Determination of Silicon ions

Microwave Plasma Atomic Emission Spectrometer (MP-AES) model 4210 was used to analyse Silicon Ions. 20 ml of water samples were prepared by adding 3 drops of concentrated HCl to increase the rate of oxidation. A ready-to-use 1000 ppm standard solution of Silicon was used. The water samples were nebulized into radio-frequency microwave plasma. Spectra of elements were dispersed by grating spectrometer and intensities were measured by photomultiplier tubes. The concentrations of the water samples were deduced from the calibration graph obtained from the standard solutions.

3. Results and Discussion

3.1 pH

The pH values averages for the water samples collected from the selected points in the city are shown in Figure 2 below.

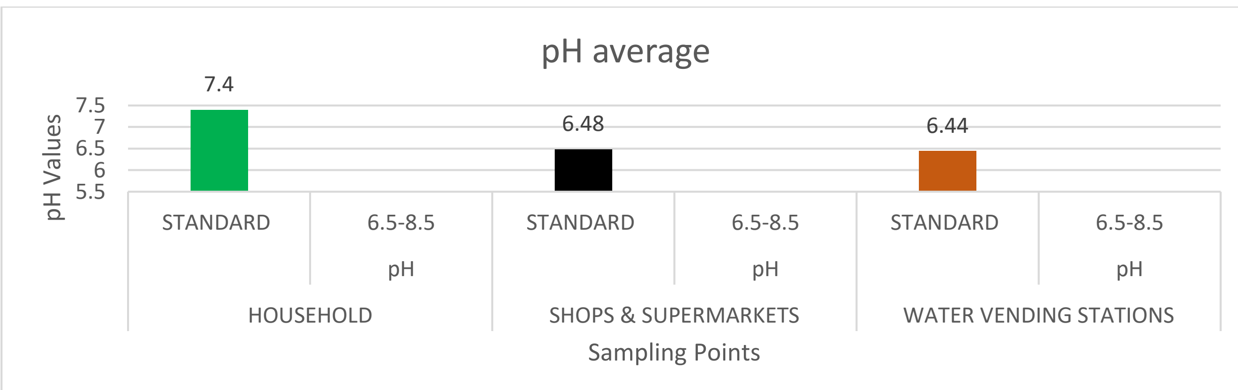

Figure 1: Average pH comparisons

The sample pH averages include 7.48, 6.48 and 6.44 for households, shops & supermarkets and water vending stations respectively. The standard deviation for the three group categories was ±0.54. The study showed that out of eighty eight samples collected in the City of Nairobi, twenty six samples had pH values which were not within the KS EAS (Kenya Standard East Africa Standard) standards, representing 29.6 % of the total samples. The highest pH recorded was 8.95 for sample HHEMWK001 collected from Embakasi sub-county for the household water samples while the lowest pH was 5.5, for the SPDSWOD001 bottled water from Woodley in Kibra sub-county as shown in figure 2 above. The pH recorded for the household water samples included the HHUNMTV001 sample from Westlands and HHHWWA003 from Dagoretti sub-counties. HHUNMTV001 was a spring water from Rurii ward, Westlands sub-county. According to the survey carried out using a questionnaire that was randomly administered during sampling, the first respondent explained how the nearby residents fetch water from the water spring for household purposes. The pH, below the accepted KS EAS standards, could be attributed to the water sample obtained from the springs by the residents. Spring water is a type of underground water whose Physico-chemical properties may be affected by the geological properties of the underground rocks. Sample HHHWWA003 was a household sample collected from Waithaka ward in the Dagoretti sub-county. It was from harvested water. All the other samples collected from the same area were within the KS EAS standards. The samples which were not within the accepted range could be due to contamination during harvesting and water storage facility. The study further showed that water samples that recorded pH values below 6.5 were collected from shops, supermarkets and water vending stations. The average pH values for the water samples collected from Households, Shops, Supermarkets and vendors are compared in Figure 2 above. Household samples had the highest average pH recording 7.40 while water vending stations had the lowest pH average of 6.44 which is 0.04 less compared to shops and supermarket samples. Table 1 Bottled water samples from selected sources in Nairobi. The coded water samples from various sources in the city that were analyzed are presented in table 1 below.

Table 1: Bottled water samples from selected sources in Nairobi

Bottled water	**Brand codes**	**pH Values**	**Source**	**Subcounty**	**KS- EAS standards**
Brand 1	SPDSWOD001 SPDSWOD002 SPDSWOD003 SPDSWOD004	5.5 5.79 5.87 6.32	Woodley ward	Kibra sub-county	6.5 – 8.5
Brand 2	SMQUHUR002 SMQUHUR003 SMQUHUR003	6.46 6.43 6.4	Huruma	Mathare sub-county	
Brand 3	SMACGAR001 SMACGAR002 SMACGAR003 SMACGAR004	6.41 6.33 6.27 6.03	Garage	Kamukunji sub-county	
Brand 4	SMKECBD001 SMKECBD002 SMKECBD004	6.44 6.45 6.42	Central Business district (CBD)	Starehe sub-county	
Brand 5	SMNVCBD001 SMNVCBD003 SMNVCBD004	6.45 6.46 6.43			
Vending Station	WKNJIR001 WKNJIR002 WKNJIR003 WKNJIR004	6.12 6.11 6.18 6.04	Njiru	Njiru sub-county	
	WKRUA004	6.46	Ruai		
Household	HHEMWK001 HHEMWK002	8.95 8.67	Juakali	Embakasi sub-county	

Brands 1, 2, 3, 4 and 5 of bottled water as shown in table 1 above were all out of KS-EAS standards. Out of eight samples collected from two supermarkets in the Central Business District of Nairobi City, six samples recorded a pH value of less than 6.5. This reflected 75 % out of specification for the pH parameter. This could have been attributed to inefficient treatment methodology where acidic cations were not efficiently osmotically eliminated. The vending station water samples as shown in table 1 above had pH values ranging from 6.04 to 6.46 indicating a 100 % out of specification for the pH parameter. Again, the pH values below the limit recorded were attributed to inefficient treatment methodology where acidic cations were not efficiently osmotically eliminated. It was observed that only two household water samples as shown in table 1 above had a pH above 8.5 KS EAS standard (Kenya Standard East Africa Standard) recording pH values of 8.95 and 8.67. The pH values above the limit recorded could have been attributed to alkaline-contaminated storage conditions or inefficient water treatment methodology.

3.2 Colour of the Water Samples

The colour value averages for the water samples collected from the selected points in the city are shown in Figure 3 below.

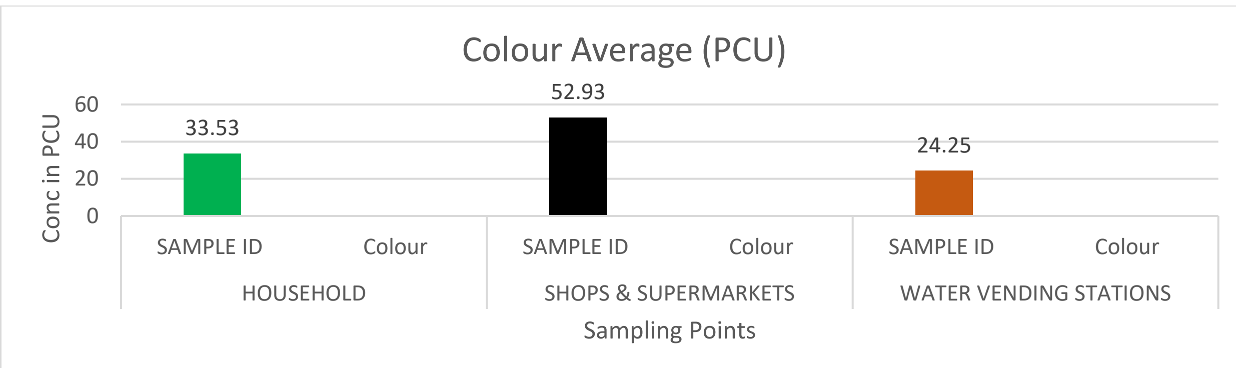

Figure 3: Average Colour levels from various water sources

According to KS EAS 12:2018 – potable water specifications, colour specification is divided into two; natural portable water with a maximum of 50 PCU/TCU and treated portable water of up to 15 PCU/TCU. The household water samples were categorized as natural portable water while shops, supermarkets and water vending stations samples were classified as treated portable water. From a total sample size of thirty two, five household water samples were above the limit of 50 PCU reflecting 15.61 % out of limit. However, the average colour values for the household samples were within the limit recording 33.53 PCU. The results showed that 15.61 % of the population living in the city of Nairobi are drinking household water that is not colour compliant. The percentage of colour compliance in household water samples could be attributed to the source of the water some harvesting while others boiled the water before drinking. Shops and supermarkets samples recorded an average of 52.93 PCU. In addition, two samples from a sample size of twenty eight were within 15 PCU specifications indicating that 7.14 % of people drinking bottled water from supermarkets and shops in the city of Nairobi are drinking water that is safe.

The data shows inefficiency of treatment methodology and more specifically filtration process. This could be the possible reason why only 7.14 % of sample were within KS EAS 12:2018 – potable water specifications. Only 25 % of water vending station samples were found to be within 15 PCU specifications, while only seven samples from a sample size of twenty eight ranged from 5 PCU to 14 PCU. The average colour test was 24.25 PCU. Although the average is out of limit, the value is far below the shops and supermarkets average colour test results showing how efficient filtration process in water vending stations is as compared to bottled water in shops and supermarkets. The average colours for the water samples collected from the households, shops and supermarkets and from the vendors are compared in figure 3 above. According to the study, water samples from shops and supermarkets had a colour value of 52.53 PCU, households at 33.53 PCU, and finally samples from vendor stations at 24.25 PCU with the three categories having a standard deviation of ±14.64.

3.3 Fluoride Ions

The Fluoride Ions values averages for the water samples collected from the selected points in the city are shown in Figure 4 below.

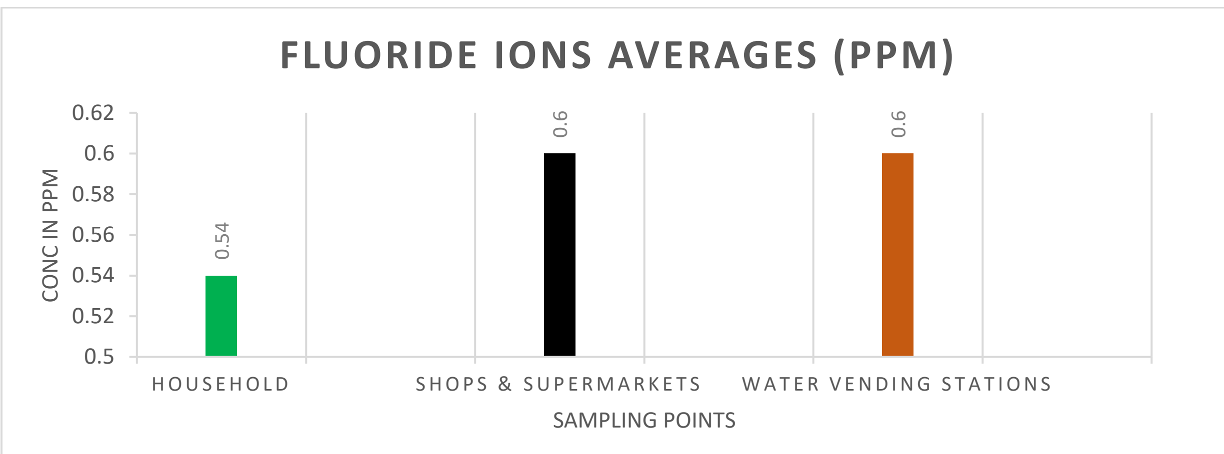

Figure 4: Average Fluoride levels from various water sources

Out of eighty eight samples that were collected in the city of Nairobi, six sample results were above 1.5 ppm as per KS EAS 153:2018 – standard on purified water and KS EAS 12:2018 – potable water specifications reflecting 6.82 %. This means that 6.82 % population in the City of Nairobi is drinking unsafe water with Fluoride levels above 1.5 ppm, exposing approximately 300,000 people to Fluoride contamination risks. All the water samples collected in Dandora, Njiru sub-county WKDANPH2001, WKDANPH2002, WKDANPH4003, WKDANPH4004 were above 1.5 ppm recording 1.82 ppm, 1.78 ppm, 1.90 ppm and 1.83 ppm respectively. The level of Fluoride is possibly due to lack of treatment before freely distributing to the entire population in Dandora and the geological structure of the sampling area since the water comes from boreholes sunk by the government. One bottled water sample collected in CBD, Starehe sub-county recorded 1.76

ppm while another household water sample collected in Juakali, Embakasi sub-county recorded 1.93 ppm. The variation in the other samples was noted to be negligible. All the averages were within 1.5 ppm specification. Both shops and supermarkets and water vending stations recorded an average of 0.6ppm while household samples recorded an average of 0.54. The three categories had a standard deviation of ±0.04. All the averages were within 1.5 ppm as per KS EAS 153:2018 – standard on purified water and KS EAS 12:2018 – potable water specifications.

3.4 Silicon Ions

The Silicon ion values averages for the water samples collected from the selected points in the city are shown in Figure 4 below.

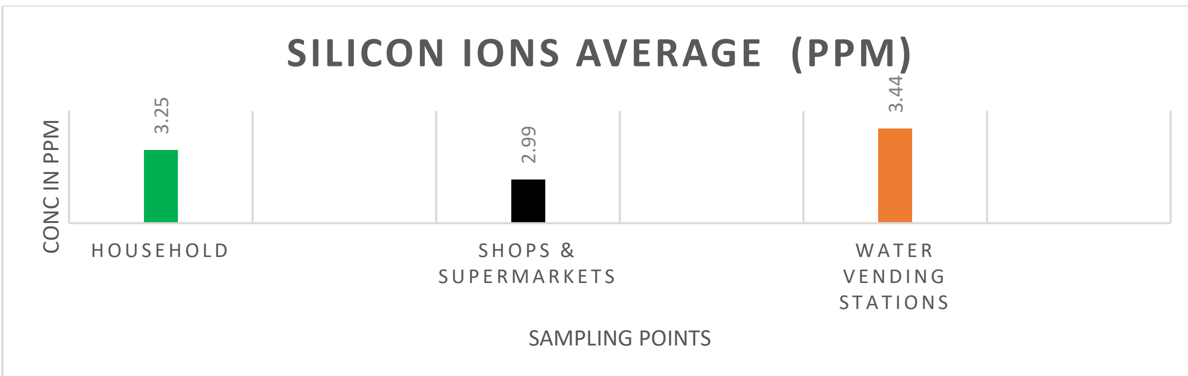

Figure 5: Silicon ion levels in the various water sources

All the samples analysed for Silicon ions were within the KS EAS 153:2018 standard on purified water and KS EAS 12:2018 standard on potable water, with specifications of 50 ppm maximum. Bottled water samples collected in supermarkets and shops were ranked last in Silicon ion test having an average concentration of 2.99 ppm while water samples collected in water vending stations recorded an average concentration of 3.44 ppm which was still within the 50 ppm allowable limits. Water samples coded HHALHR003 collected from households recorded a concentration of 10.23 ppm while HHALHR002 recorded concentration of 0.56 ppm. Silicon ion comparison between household, shops and supermarkets and water vending stations recording 3.25 ppm, 2.99 ppm and 3.44 ppm respectively as shown in figure 5 above. The standard deviation for the three categories was ±0.23. Water samples from water vending stations recorded the highest Silicon ions average concentrations of 3.44 ppm while shops and supermarkets reported the least at 2.99 ppm. However, all the averages were within the 2018 standard on purified water and KS EAS 12:2018 standard on potable water as shown in figure 5 above.

3.5 Total Coliform and *Escherichia coli*

All the bottled water samples collected in shops and supermarket recorded <1 MPN/Index 100mL for both Total Coliform and *Escherichia coli* tests. This showed that the bottled water that is distributed in the city of Nairobi is thoroughly treated for microbial parameters and that the microbial treatment methods in use were efficient. However, out of twenty eight water vending samples in different sub-counties, only thirteen samples recorded <1 MPN/Index 100 mL in both Total Coliform and *Escherichia coli* tests*.* This depicted that 53.57 % of water vending stations in the City of Nairobi are distributing drinking water that is non-compliant with microbial properties, which indicated that the population is exposed to unsafe water in water vending stations. The out of compliance in microbial of water vending stations samples could be attributed to ineffective microbial treatment methods where the owners opt not to use the correct amounts of Chlorine to kill micro-organisms for cost reduction reasons. Out of thirty two water samples in the eleven sub-counties of the City of Nairobi, only eleven samples were found to be within KS EAS 153:2018 – standard on purified water and KS EAS 12:2018 – potable water specifications for Total Coliform and *Escherichia coli* test. The compliance level for the household category was 35 %. This demonstrates that 65 % of Nairobi's household population is drinking water that is unsafe in terms of microbial properties. The non-compliance in households could be associated with non-hygienic storage facilities, lack of water treatment and storage for longer durations. Four samples recorded >180 MPN/100 ml in Total Coliform showing microbial contamination.

4. Conclusions

The water quality index of the portable water distributed in the City of Nairobi was 13.6 % against the set specifications. Boiling drinking water, one of the point-of-use water treatment methods, was more effective with 100 % compliance than the use of Sodium Hypochlorite with 50 % compliance.

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