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Assessment of the Mzima – Baricho Distribution Lines for Drinking Water, Mombasa, Kenya

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Abstract: *Water pollution occurs as a result of contamination by pathogens, chemicals and or physical objects. A large number of chemicals that either exists naturally in the soil or produced during industrial, agricultural, transportation, metal contamination and geological processes, find their way in to the water.These pollutants are responsible for both communicable and non-communicable diseases in addition to water borne diseases.*
A total of 14 sites were selected for water sampling from Mzima Springs, Baricho abstraction boreholesand along the respective water distribution lines.Chemical analyses of the samples were carried out using procedures outlined in the (APHA, 2005). The concentrations of nitrates, nitrites, phosphatesand residual chlorine were determined using the portable Palin Test meter and spectroscopically in the laboratory using HACH model V 2000 Multi analyte photometer. Trace metals were analyzed using AURORA AI 1200 atomic absorption spectro-photometer.The overall results show that Nitrites, Phosphatesandresidual chlorineare within the acceptable limits for drinking water as stipulated by the WHO standards.Manganese and iron levels in the Baricho line werefar above those recommendedby WHO whilst Nitrates levels on the Mzima water line are relatively high.

Key words: *Water pollution, chemical analysis, Mzima Springs and Baricho abstraction boreholes*

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I. Introduction

Decline in water quality is a universal matter of concern, which has been linked to human population growth, industrialization and agricultural activities and climate change. These factors together or independently causes major alterations to the hydrological cycle consequently water quality (Pazand, *et al*., 2011; UN, 2012). Its estimated around 2.1 billion people are still using unsafe drinking water (WHO, 2017). A range of different water conditions and parameters determine the health of communities, as the burden of water-related diseases is a good indicator of the state of access to water and sanitation (UNESCO, 2006)

Access to clean safe water is part of the universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. This is anchored within the Sustainable Development Goals (SDGs).The SDG number six aims to improve water quality by reducing pollution and minimizing release of hazardous chemicals by 2030 (UN, 2012; UNDP, 2006). For this to be achieved, countries need to invest in adequate infrastructure, provide sanitation facilities and protect as well as restore water related ecosystems.

Heavy metals exist as natural constituents of the earth crust and they can enter the water and food cycles through a variety of chemical and geological processes (Gbaruko and Friday, 2007). While these elements occur naturally, they are often bound up in inert compound by forming complexes (Mason et al., 2012).

Trace metals are natural components of the hydrosphere and many are necessary, in minute quantities, for the metabolism of organisms such as arsenic, copper, iron, molybdenum and tin (Ward, N.I. 1995).

Among the important components of the environmental pollutants are heavy metals and metallic related complexes which exist naturally. Some are toxic while others are essential to health but their concentration has increased tremendously as a result of anthropogenic activities (Huang et al., 2014). Aside from anthropogenic sources, contamination of water transmission systems can also be from natural sources. Metal pollution comes from both natural and anthropogenic sources (Moore, J.W. and Ramamoorthy, S. 1984).

Water distribution systems within Mombasa are made up of large networks of storage tanks, valves, pumps, and pipes that transport treated water to consumers. Water distribution systems by design include areas of vulnerability where contamination can occur. Corrosion of water pipelines, weak valves, and fixtures, can cause the degradation of drinking water quality during low pressure sessions. As water flows through distribution systems, it comes into contact with a wide range of suspended materials, some of which can cause significant changes to the quality such as disinfection agents and water additives react with organic and inorganic materials to generate toxic by-products in the water supply.

The distribution system within Mombasa is among the key component of public water supplies yet to be adequately addressed in national efforts to eradicate waterborne disease. Corrosion of the water pipelines, valves, and fixtures may lead to infiltration of heavy elements of both organic and inorganic contaminants (Galadima et al., 2011), exposing the public to chronic and life threatening disorders.. Many of these compounds exist naturally, but their concentration has increased as a result of anthropogenic activities (Huang et al., 2014)

Provision of safe drinking water and sanitation are thus some of the major challenges facing rapidly expanding urban centers such as Mombasa, and have been recognized as some of the major developmental challenges Kenya has in meeting the Millennium Development Goal of reducing by half the proportion of people without sustainable access to safe drinking water by 2015 in the Kenya Vision 2030, (UNEP, 2007).

The physical and chemical parameters were analyzed and the results compared to WHO (2004; 2011) drinking water standards to determine the quality of drinking water in Mombasa Island. Although fluoride is an important parameter in drinking water it was not done as its distribution and concentration is similar to that of fluoride rich volcanic rocks, since the coast does not have volcanic rocks fluoride in its waters is almost negligible (Nair, Manji and Gitonga1984).

II. Materials And Methods

2.1.0 Study site

Mombasa County is an island city located on the coastal lowland of Kenya with extensive low-lying areas rising from 8m above sea level in the east to about 100m in the west with an area of about 15 km^2, where the weather is influenced by monsoon winds. Apart from the Mzima springs, the coastal region in general receives surface water supplies from Baricho, Marere and from the Tiwi boreholes in the south coast area. Generally, Mombasa County receives 130,000 m^3 of water against a demand of 200,000 m^{3}daily according to NWCPC (2000) to serve the population of 1 million (KNBS, 2009) and whose main water source is 220 km from the city.

Two of the four water sources supplying water to the Mombasa municipality were studied; these are the Mzima and Baricho water sources as shown in figure 1. Samples were collected from the initial water sources of Mzima Springs and the Sabaki River, and along the distribution lines.

2.1.1 Mzima Pipeline System: Mzima Springs are located south west of the Chyulu Hills in Tsavo West National Park. The springs have been gauged since 1951 and shown a flow variation between 2.6 m^3/s (225,000 m^3/day) and 5.9 m^3/s (510,000 m^3/day) with a mean of 3.5 m^3/s (302,000 m^3/day). The current abstraction is about 0.4 m^3/s (35,000 m^3/day). Water from the spring's flows through three large pools: Hippo pool, Long pool and Chalk beach pool before discharging into the Mzima River, which is 4 km further downstream.

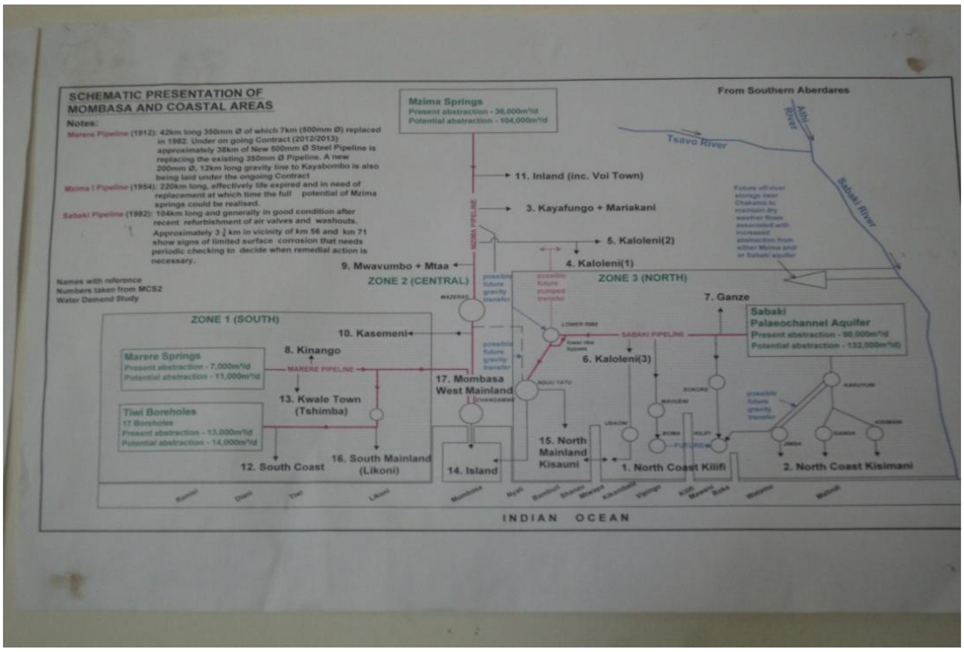

Figure1: The Coastal Water supply system

Mzima pre-stressed concrete pipeline is 220 km long and the diameter of the pipeline ranges from 0.91 m to 0.53 m and has been in operation for 50 years. Certain sections of the pipeline are prone to bursts or leakages and due to this about 15 km of the pipeline have already been replaced by steel pipes. The springs are located at an altitude of 680 m above sea level and therefore water flows by gravity to Mombasa Island (No pumping) as shown in figure 1.

2.1.2 Baricho Water Works: Water from Baricho Water Works is pumped through the pipeline to Nguu - Tatu Reservoirs of capacity 18,000 m^3 which are located 10 km from Mombasa. The size of the pipeline ranges from 600 to 800 mm in diameter. From the reservoirs; water is conveyed to Mombasa North Mainland through a 0.51 m diameter gravity trunk line to Kisauni as shown in figure 2.

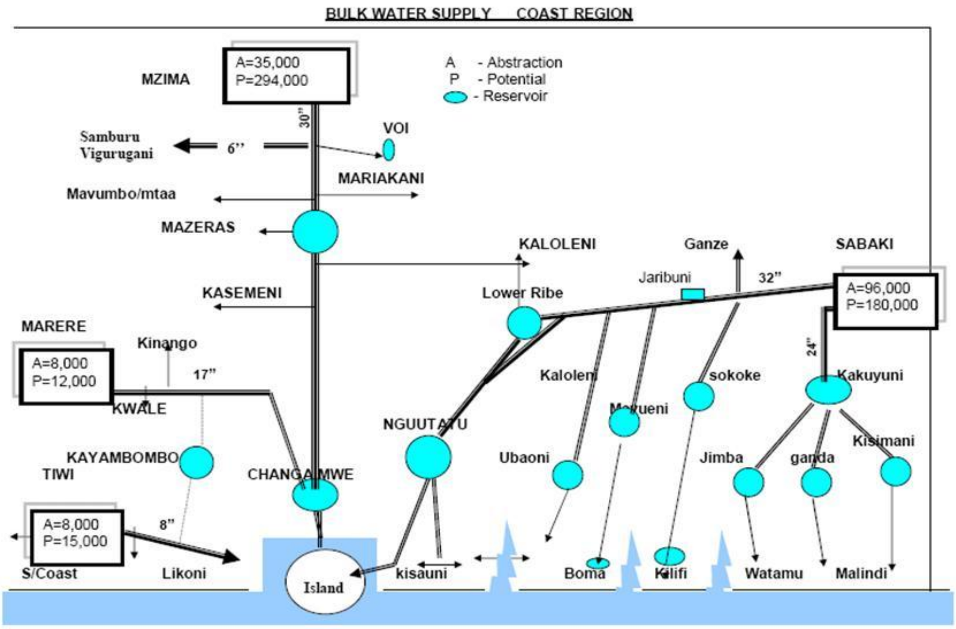

Figure.2: The Mzima and Baricho water supply Line

2.2 Sample collection and treatment

A total of 24 water samples were collected from Mzima Springs, Baricho abstraction boreholes, and along the respective water distribution lines during the dry and rainy season. Collection was done in14 sites, representing the distribution system such as the; Chlorination tanks, booster dose tanks and break pressure tanks were also measured which were in very old and rusty state. 500 ml Pyrex glass stoppered bottles cleaned with HNO_3 were used for sample collection. All bottles were rinsed with deionized water. All samples were then packed in ice-boxes for transport to the laboratory. The concentrations of manganese, nitrates, nitrites, phosphates, free residual chlorine and pH, were determined using the portable Palin Test meter and spectroscopically in the laboratory using HACH model V 2000 Multi analyte photometer. Trace metals were analyzed using AURORA AI 1200 atomic absorption spectro-photometer. Samples were further analyzed in the laboratory for the major ions employing standard methods described in Standard Methods for the Examination of Water and Waste Water (APHA, 2005).Atomic Absorption Spectrophotometer (AAS) was used for the determination of trace metals namely Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn), Cadmium (Cd), and Lead (Pb). UV-Visible Spectrophotometer was used to determine the cations ($PO_4^{3-}$and, NO_3^-) concentrations.

III. Results and Discussions

All the samples that were collected from both Mzima and Baricho water lines were very clear and had no visible colour (colorless and odorless) although the storage tanks at the source point were very rusty due to corrosion.

3.1 The Mzima Water Line

Samples were collected from the Mzima water line and their mean nutrient levels were analyzed as shown in table 1. All the 7 sampling sites has produced parameters which some were within the WHO limits and some above like nitrates (NO_3) as shown in table 1. The pH, chlorine, nitrite and phosphates values were all within the accepted limits, although Nitrates were higher in all the sampling sites with the highest value at the Voi sampling site.

Table 1: Mean Parameter Levels in Mzima Water Line

Sample Site	pH	Cl	NO_3	NO_2	PO_4
Mzima springs	7.65	0.01	1.20	0.00	0.01
Tsavo west	7.70	0.01	6.20	0.00	0.01
Tsavo east	7.69	0.01	6.23	0.00	0.01
Voi	7.75	0.08	6.60	0.00	0.04
Maungu	7.74	0.06	5.90	0.00	0.04
Mariakani	7.79	0.06	5.45	0.00	0.03
Mazeras	7.84	0.14	5.41	0.01	0.05
WHO	6.5 – 8.5	0.2 – 0.5	5.00	0.03	0.05

3.2 The Baricho Water Line

Samples were collected from the Baricho water line and their mean parameter levels were analyzed as shown in table 2. All the 7 sampling sites has produced parameters which were within the WHO limits

Table 2: Mean Parameter Levels in Baricho Water Line

Sample Site	pH	Cl	NO_3	NO_2	PO_4
Baricho	8.20	0.22	1.66	0.01	0.01
Sabaki	8.12	0.21	1.60	0.01	0.02
Mbale	8.09	0.20	1.52	0.01	0.01
Jaribuni	7.85	0.11	2.14	0.01	0.03
Chonyi	7.93	0.11	2.03	0.03	0.02
Kaloleni	7.84	0.18	2.17	0.02	0.01
Nguutatu	7.97	0.20	2.16	0.05	0.01
WHO	6.5 – 8.5	0.2 – 0.5	5.00	0.05	0.05

3.3 Temperature

Temperature plays an important role in the physical, chemical and biological qualities of water (Park and Fayer, 2007) as it determines various parameters such as pH, conductivity, saturation level of gases and various forms of alkalinity etc. The speed of a chemical reaction in water increases as the temperature of the water increases which may reduce the solubility of gases and amplifies the taste and odour.

The temperature of the water was generally cool; the temperature values were in the range of 24.125 – 25.967 ^{0}C respectively as shown in figure 3. Cool water is generally more palatable than warm water, and temperature will have an impact on the acceptability of a number of other inorganic constituents and chemical contaminants that may affect taste. High water temperature reduces the ability of water to hold essential dissolved gases like oxygen and may increase problems related to taste, odour, colour and corrosion (WHO, 2011).

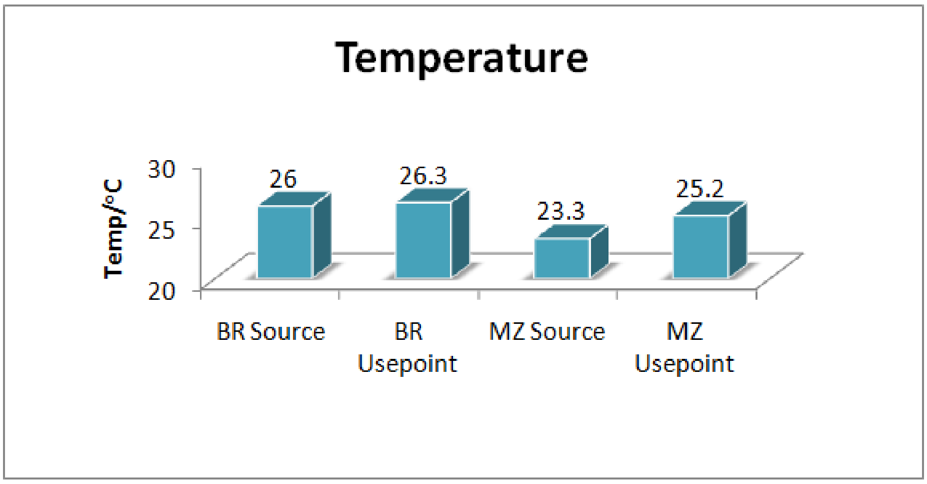

Figure 3: Comparison of temperature between the source and user point

Comparison of temperatures at water source and at user point has shown an increase in temperature on both the Baricho (BR) user point and Mzima (MZ) user point than from their respective sources as shown in figure 3. The annual mean temperature is 26.4 ^oC and it can reach a maximum of 32 ^oC, therefore the temperature obtained in this study is considered normal as it's closely reflected the ambient air temperature.

3.4 pH

The pH for both the source point and user point as shown in figure 4 were within the acceptable range of WHO 6.5 - 8.5. The comparison of pH at water source and at user point has shown an increase on the Mzima (MZ) user point than from the source as shown in figure 4. This is likely due to recontamination during transportation and storage

The pH of the water entering the distribution system must be controlled to minimize the corrosion of water mains and pipes in household water systems. Failure to do so can result in the contamination of drinking-water and in adverse effects on its taste and appearance. Since it is one of the most important operational water quality parameters, a control is necessary at all stages of water treatment to ensure satisfactory water. The pH is also a useful indicator of the chemical balance in water.

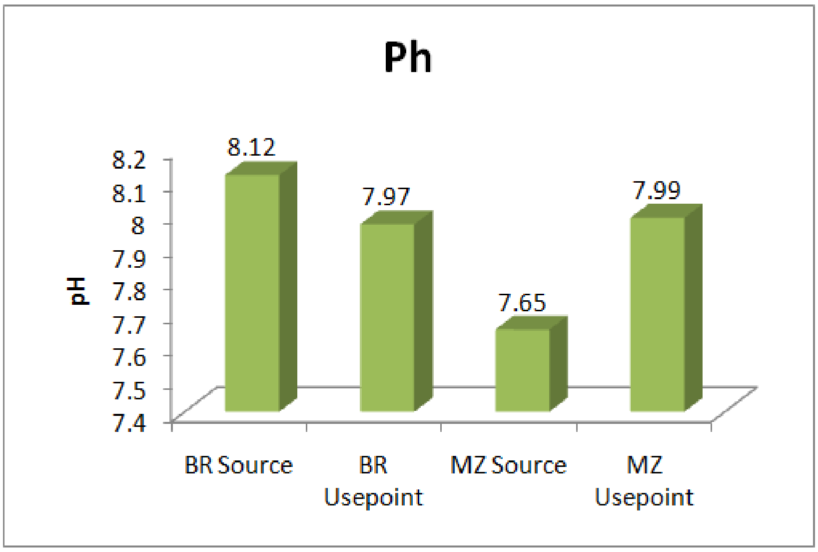

Figure 4: Comparison of pH between the source and user point

The pH should preferably be less than 8.5 and greater than 7.0for effective disinfection with chlorine. A lower pH than this will mean the water is likely to be corrosive & within the distribution system pH to be ideally less than 8.5. Failure to minimize corrosion can result in the contamination of drinking-water and affects its taste and appearance. A higher pH of greater than 7 contributes to the stability of water and controls its aggressiveness to pipes and appliances. (Webber et al., 1989)

3.5 Chlorine

Chlorine is mostly used as an oxidant in drinking-water treatment in addition to disinfectant and bleach widely used both industrially and domestically. Comparison of residual chlorine at water source and at user point has shown an increase on the both the Baricho (BR) user point and Mzima (MZ) user point than from their respective sources as shown in figure 5.

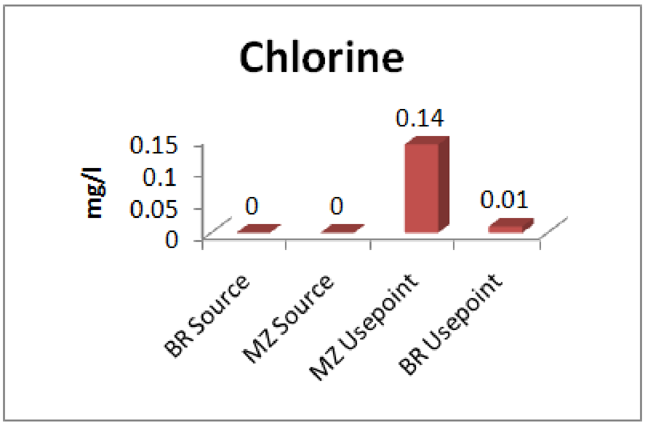

Figure 5: Comparison of Residual Chlorine between the source and user point

The small amount of chlorine typically used to disinfect water does not pose risks to human health. The World Health Organization (WHO) has established a guideline value of 5 mg/l for chlorine in drinking water, meaning that such concentrations are considered acceptable for human consumption

3.6 Nitrates

The nitrate levels for all the sites sampled during both the dry and wet seasons were below the water quality standards (5 mg/l) set by WHO guidelines as shown in figure 6. Comparison of nitrate at water source and at user point has shown an increase on both the Baricho (BR) user point than from the sources as shown in figure 6.

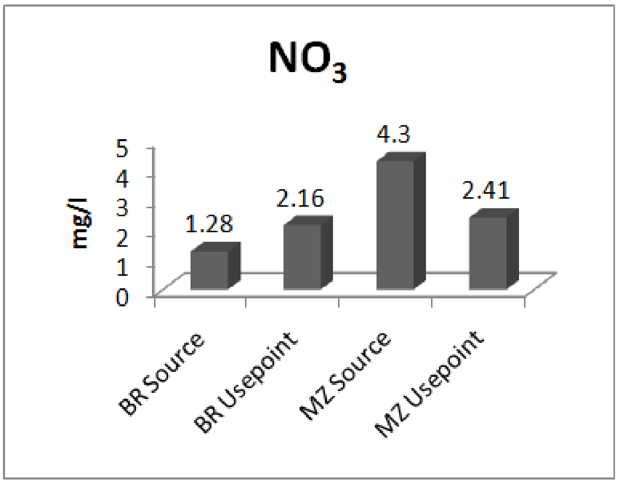

Figure 6: Comparison of Nitrate between the source and user point

Nitrate can reach both surface water and groundwater as a consequence from wastewater disposal, leaching from natural vegetation and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks (WHO, 2011), this is likely the reason of the increase in nitrates in Baricho use point.

3.7 Phosphates

The phosphate levels in water samples in all cases were below the KEBS limits (10.0 mg/l) thus, safe for domestic use. The natural levels of phosphate usually range from 0.005 to 0.05 mg/l.

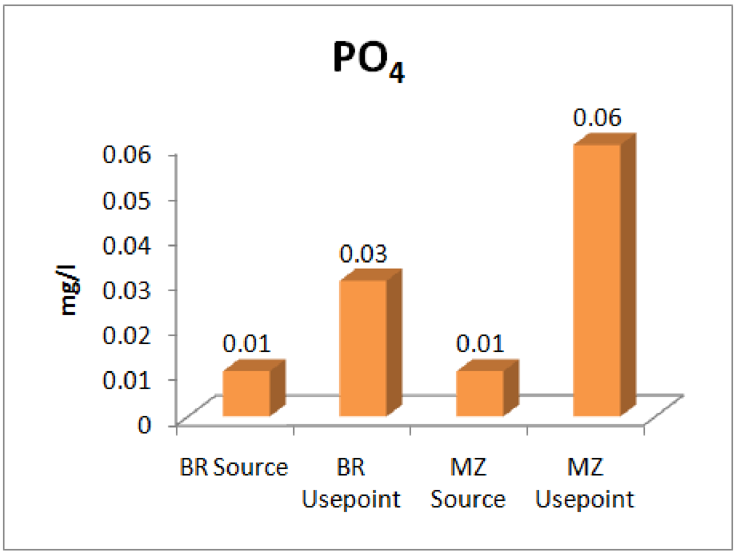

Figure 7: Comparison of Phosphate between the source and user point

Comparison of phosphate at water source and at user point has shown an increase on both the Baricho (BR) user point and Mzima (MZ) user point than from their respective sources as shown in figure 7. Phosphates enter waterways through different sources such as fertilizers, pesticides, pulp and paper industry, cleaning compounds, phosphate-containing rocks and solid or liquid wastes and this is likely the reason of the increment at usepoint than the source point.

3.8 Lead

The Baricho source and its user point have higher levels of lead than the recommended 0.015 mg/l and also in comparison to the Mzima source and user point as shown in figure 8.

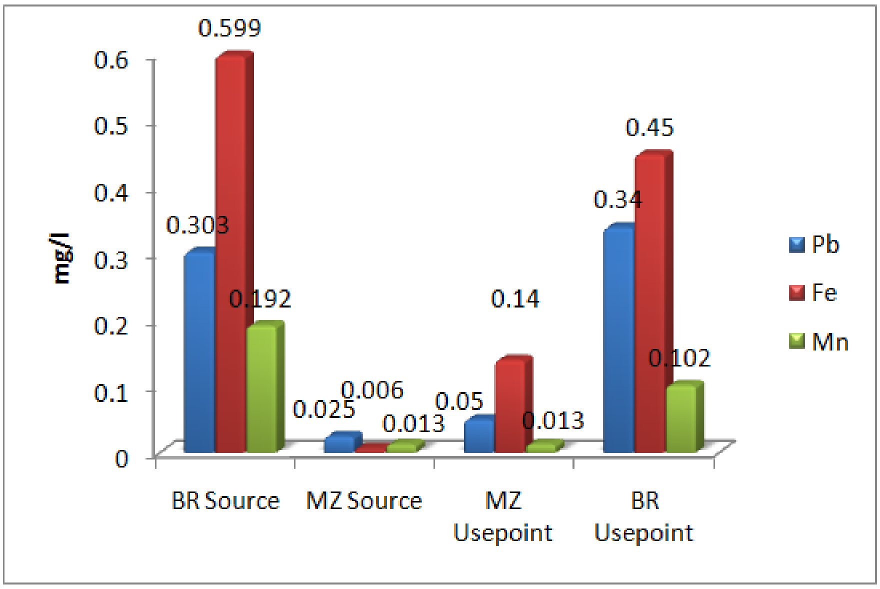

Figure 8: Comparison of trace metal ions between the source and user point

Lead is present in tap water to some extent as a result of its dissolution from natural sources but from household plumbing systems in which the pipes solder, fittings, or service connections to homes contain lead. Lead is a cumulative general poison and associated with several health hazards like anemia (Moore. 1988), reproductive effects (Wildt *et al*. 1983). Lead and other metals like Al and Cd exhibit extreme toxicity even at trace levels (Merian, 1991). From a drinking water perspective, the almost universal use of lead compounds in plumbing fittings and as solder in water distribution systems is important (Moore. 1988). Lead pipes may be used in older distribution systems and plumbing although the current PVC and uPVC pipes also contain lead compounds that can be leached from them and result in high lead concentration in drinking water (Zhang and Lin, 2015).

3.9 Iron and Manganese

Iron and manganese are common household water contaminants with no known direct health effects at levels found in water. These minerals will not harm you, but they may cause reddish-brown or black stains on clothes or household fixtures. (WHO, 2003)

Iron is the most abundant element, by weight, in the earth's crust and the second most abundant metal in earth's crust. It is an essential element in human nutrition. The minimum daily requirement of iron is ranged from about 10 to 50 mg/day (FAO/WHO 1988)

Iron is rarely found in nature but most commonly found in nature in the form of its oxides, as the iron ions Fe^{2+} and Fe^{3+} readily combine with oxygen- and sulfur-containing compounds to form oxides, hydroxides, carbonates, and sulfides.

Manganese is one of the most abundant metals in Earth’s crust and naturally occurring in many surface water and groundwater sources, particularly in anaerobic or low oxidation conditions, and this is the most important source for drinking-water. Manganese occurs naturally in many food sources, and the greatest exposure to manganese is usually from food (WHO, 2003).

Manganese, usually occurring with iron, is used principally in the manufacture of iron and steel alloys, as an oxidant for cleaning, bleaching and disinfection (as potassium permanganate) and as an ingredient in various products.(ATSDR, 2008)

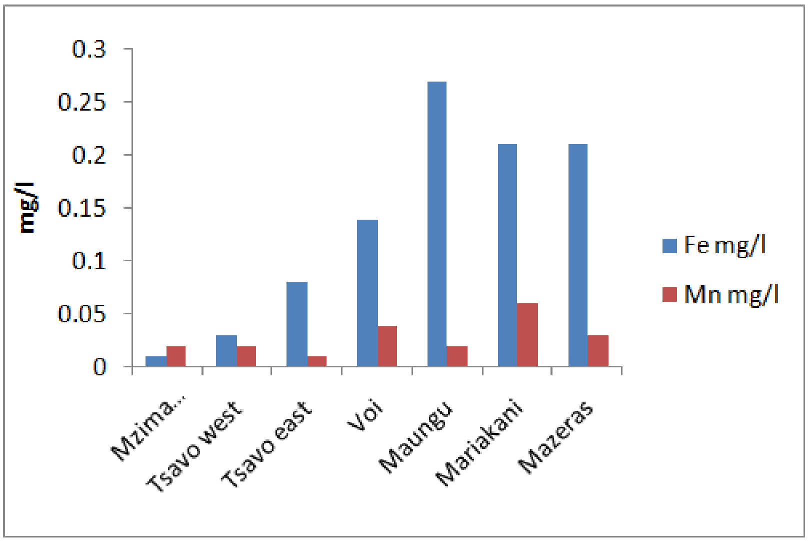

Figure 9: Mean Trace Metal Levels in Mzima Water Line

Levels of Manganese exceed the WHO standard of 0.05 mg/l in the Baricho water line, but are within acceptable limits in the Mzima water line. Whilst the levels of Iron at the Mzima source and user point well below the accepted standard of 0.3 mg/l but higher in the Baricho source and user point as shown in figure 8 this trend is seen also in all the sample sites for both Mzima and Baricho as shown in figure 9 and 10 respectively
The levels of iron at Baricho water line have exceeded the acceptable limits which have led to the accumulation of deposits in the distribution system that has formed a coating on pipes, which may slough off as a black precipitate. Concentrations of the range 0.2 – 0.5 mg/l are usually acceptable to consumers.

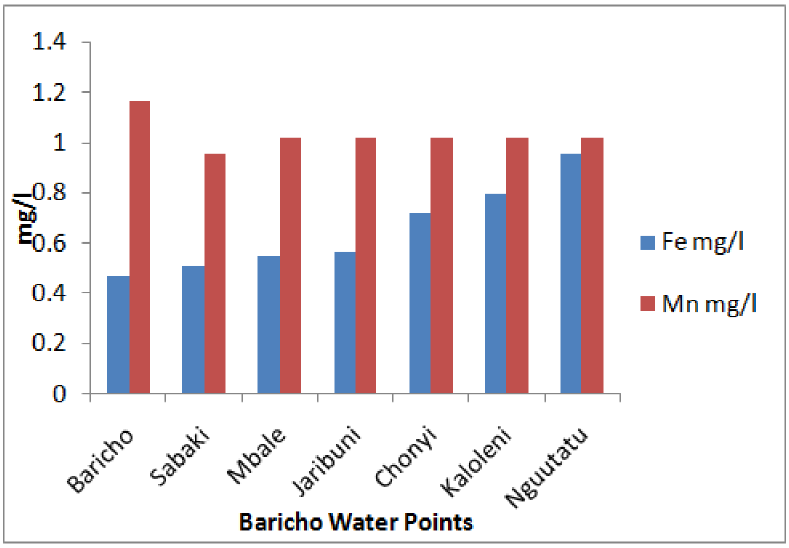

Figure 10: Mean Trace Metal Levels in Baricho Water Line

The health effects from over-exposure of manganese are dependent on the route of exposure, the chemical form, the age at exposure, and an individual's nutritional status (USEPA, 2004).

IV. Conclusion

Water from both Mzima and Baricho water lines meet most of the chemical portability standards. Both the Mzima and Baricho had seven (7) sampling sites where parameters levels were analysed and found that the samples which were collected from the Baricho water line has produced parameters which were almost within the WHO limits. The Mzima water line showed that the pH, chlorine, nitrite and phosphates values were all within the accepted limits, although Nitrates were higher in all the sampling sites with the highest value at the Voi sampling site.

The study has led to conclude that the quality of water samples studies were mostly within acceptable limits of physico -chemical parameters studied other than Iron, lead and manganese. Manganese and iron levels in the Baricho line werefar above those recommended by WHO whilst Nitrates levels on the Mzima water line are relatively high. It is with this regards that the water from these lines should be treated properly before its usage as drinking water to avoid probable adverse effects and water quality should be continuously monitored for the welfare of human beings.

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