# UNIVERSITY OF NAIROBI

**SCHOOL OF ENGINEERING**

**DEPARTMENT OF ENVIRONMENTAL AND BIOSYSTEMS ENGINEERING**


# DEVELOPMENT OF A PROTOCOL FOR EVALUATING SAND DAM WATER QUALITY AND POTABILITY IN SEMI-ARID AREAS: A CASE STUDY OF MAKUENI COUNTY


**BY**

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# Declaration / Approval

## Declaration:

This thesis is my original work and has not been presented for a degree in any other university.

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## Approval by the University Supervisors

This thesis has been submitted for examination with my approval as University Supervisor.

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## Dedication

This thesis is dedicated to my dear husband Joseph, daughter Ivanna and Dad Benard. Through your prayers, support and encouragement, I attained the resolve to undertake and accomplish this study.

## Acknowledgement

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## Abstract

Sand dams have been recommended in many places as a feasible technology for the ASAL areas due to their ability to store water with minimal evaporation, recharge underground water and raise water table, among others. In Kenya, adoption of sand dam technology has been steadily increasing. Water from the sand dams is used for drinking, domestic uses, livestock watering, and for irrigation. Water quality is paramount for drinking water. However, much emphasis is being done on the sand dam technical aspects namely hydrologic measurement and analysis, and determination of the quantity of water that will be harvested with less or no concern on the water quality and how the water quality can be affected. There is no guideline on sand dam design parameters, location and method of abstraction for optimal water quality. There is need to investigate whether water from sand dams is suitable for drinking and develop a protocol to evaluate potable water quality from sand dams.

The focus of this study was to determine water quality parameters for evaluating potability of water from sand dams, and development of a protocol for evaluating potability of water from sand dams in semi-arid areas. Water samples were collected from the sampled existing sand dams' water abstraction points within Makueni County and analyzed for heavy metals, microbiological, physical and chemical quality.

Laboratory test results showed that all tested sand dams within the study area have unsafe water for drinking in its raw form. A protocol for determining the potability of sand dams was developed. The protocol provides information on how to assess the quality of raw water from sand dams; to determine the need and extent of the water treatment to make it safe for drinking; and to examine the resultant to ascertain that it conforms to the recommended drinking water standards.

The study recommends that the '*Protocol for Evaluating Potability of Water from Sand Dams*' developed during this study be adopted before any sand dam is declared to provide safe water for drinking. It recommends that further studies on the effects of soil characteristics (within the dam site and upstream of the dam) on water quality be done.

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## List of Abbreviations

| | |
|---|---|
| KEBs | Kenya Bureau of Standards |
| NEMA | National Environment Management Authority |
| NTU | Neplelometric Turbidity Units |
| WHO | World Health organization |
| WASREB | Water Services Regulatory Board |
| UN | United Nations |
| UNICEF | United Nations Children's Emergency Fund |
| ASALs | Arid and Semi-Arid Lands |
| CIDP | County First County Integrated Development Plan |
| NGOs | non-governmental organizations |
| FBOs | faith based organizations |
| CBOs | community based organizations |
| WRMA | Water Resource Management Authority |
| WSTF | Water Services Trust Fund |
| EPA | Environmental Protection Agency |
| ERHA | Ethiopian Rainwater Harvesting Association |
| RAIN | Rainwater Harvesting Implementation Network |
| TTC | Thermotolerant Coliform |

## List of Symbols

| | |
|---|---|
| Cl | Chloride |
| F | Fluoride |
| $NH_3$ | Ammonia |
| $NO_3$ | Nitrate |
| Ca | Calcium |
| Fe | Iron |
| Pb | Lead |
| Mg | Magnesium |
| Mn | Manganese |
| Al | Aluminum |
| P | Phosphorous |
| K | Potassium |
| Cu | Copper |
| $SO_4$ | Sulphate |
| Zn | Zinc |
| Na | Sodium |
| mg/l | Milligrams per liter |
| ppm | Parts Per Million |

# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 Background

Water is the most basic necessity for humans and nature. However, increasing trend in global warming effects coupled with the increasing human population, human society is increasingly facing serious issues related to water quality and availability. Water scarcity has been a global crisis in the recent decades. The UN declared 2005 – 2015 the decade of water and many of the Millennium Development Goals focused on the same; Target 10 was to halve the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015 (UN Millennium Project, 2005).

Sustainable Development Goals (SDGs) build on the successes of the MDGs came into effect in 2016. Goal 6 focusses on clean water and sanitation targeting to achieve universal and equitable access to safe and affordable drinking water for all and improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally by 2030. Although these targets are gradually being met, many people still lack access to safe drinking water. About 663 million people worldwide still lack access to safe water; they still use unimproved drinking water sources, including unprotected wells and springs and surface water. Eight out of ten people still without improved drinking water sources live in rural areas (WHO/UNICEF, 2015).

Africa is the second driest continent in the world, after Australia where millions of people suffer from water scarcity. About 319 million people in Sub-Saharan Africa lack access to safe water; this is about half of the total global population lacking safe water (WHO/UNICEF, 2015).

Kenya lies within the Sub Saharan Africa and has a limited renewable water supply and is classified as a water scarce country. WHO/UNICEF (2015) reported that 37% of the Kenya's population (17.3 million people) lack access to protected water sources. About 43% of the people living in the rural areas use unprotected water sources. These include unprotected dug well, unprotected spring, surface water (dams, water pans and sand dams) which by definition are not safely managed.

Makueni County, located within Kenya's arid and semi-arid lands (ASALs) is one of the driest counties in Kenya. Only 36 percent of the county's residents use improved water sources with the rest relying on unimproved sources including unprotected dug well, unprotected spring, dams, water pans and sand dams (Makueni CIDP, 2013).

## 1.2 Problem Statement

Sand dams have over time been recommended as the most feasible technology for the ASAL areas due to their ability to store water with minimal evaporation, recharge underground water and raise water table, rehabilitate gullies and harvest sand which can be used for construction (ERHA and RAIN Foundation, *undated*). To this effect, sand dam technology adoption is on the rise worldwide with Kenya being recorded as a country with the highest concentration of sand dams. In Kenya, various government agencies, non-governmental organizations (NGOs), faith based organizations (FBOs) and community based organizations (CBOs) have been promoting the adoption of sand dams through funding and capacity building. Water from the sand dams is used for drinking, other domestic uses, livestock watering and irrigation purposes. Water quality is paramount for drinking water. However, much emphasis is being done on the sand dams technical aspects namely hydrologic measurement and analysis, and determination of the quantity of water that will be harvested with less or no concern on the water quality and how the water quality can be affected. Maddrell and Neal (2013) outlined a practical guideline for the situation, design and construction of sand dams. ERHA and RAIN Foundation published a Manual on Sand Dams in Ethiopia focusing on the practical approach on sand dam site selection, design and construction.

Over the years it has been cited in literature (Quinn et al., 2018, Kamel and Almula, 2016, and Maddrell and Neal, 2013) that water from sand dams is of very good quality owing to the fact that being an underground storage, water is protected from surface contaminants and as the water moves through the sand it is filtered and therefore the quality improves over time. However, there is no guideline on sand dam design parameters, location and method of abstraction for optimal water quality. Therefore, there is need to ascertain whether water from sand dams is suitable for drinking and if indeed the sand dam water is contaminated. There is need to determine what contaminants are present and then prescribe appropriate treatment method thereof through development of a protocol to determine sand dam water potability and prescribe treatment methods and uses of the different types of water.

## 1.3 Justification

About 80 percent of Kenya's land is arid and semi-arid. Drought is one of the most serious natural hazards facing the Arid and Semi-Arid Lands (ASALS) that face frequent reduction of water or moisture to significantly below the normal or expected amount (Marshall, 2011). One common and successful way to improve on water storage; that can be sustainable throughout the year inclusive of the dry seasons is by implementation of sand dams within the ASALs. However, there is scanty data and studies on sand dam water quality. In addition, there is no guideline on ways of optimizing sand dam water quality.

## 1.4 Objectives

The overall objective of the study was to assess water quality parameters and develop a protocol for evaluating water potability from sand dams.

The specific objectives of the study were to:

1. Determine and evaluate microbiological, physical, chemical and heavy metals parameters of water from sand dams.
2. Develop a protocol for evaluating potability of water from sand dams in semi-arid areas

## 1.5 Scope of Study

The scope of the study involved determination of water quality parameters for evaluating potability of sand dams, evaluation of potable water quality of sand dams. This was done by conducting investigations on the microbiological, physical and chemical quality of water stored in sand dams under different conditions. The conditions included locations of abstraction points/methods of water abstraction and maturity stage of the sand dam. Finally, a protocol for evaluating potability of water from sand dams in semi-arid areas was developed. This involved collection of water samples from the selected sand dams' abstraction points for potable water microbiological, physical and chemical quality analysis. The analysis was done with relation to location of the abstraction point/abstraction method, maturity stage of the sand dam and recommendations made for optimal potable water quality.

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Rainwater Harvesting Technologies

One of the most commonly adopted coping strategy to counter water scarcity globally is rainwater harvesting. Rainwater harvesting (RWH) is making optimum use of rainwater at the place where it falls so as to attain self-sufficiency in water supply without being dependent on remote water sources (UN-HABITAT, 2004). It is the intentional collection, storage and management of rainfall and other various forms of precipitation from different catchment surfaces (Wanyoyi, 2002).

Rainwater harvesting is an ancient practice and has been in parts of the world for over 4000 years (Worm and Hattum, 2006). Rainwater harvesting in Asia dates back to $10^{th}$ Century (Global Development Research Center, 2002) and is also popular in rural Australia, parts of India, Africa and parts of the United States. It was widely used for the provision of drinking water in the rural areas in Europe and Asia.

According to Mati (2007) and Ndunge (2015), various rainwater harvesting technologies have been in use for millennia and new ones are being developed all the time. These can be classified as:

- **Macro-catchment technologies** - This is a system that involves the collection of runoff from large areas which are at an appreciable distance from where it is being used. These technologies handle large runoff flows diverted from surfaces such as roads, hillsides, pastures. Hillside sheet/rill runoff utilization, rock catchments, sand and earth dams are examples.
- **Micro-catchment technologies** – those that collect runoff close to the growing crop and replenish the soil moisture. Micro-catchment technologies are mainly used for growing medium water demanding crops such as maize, sorghum, groundnuts and millet. Examples of these technologies are *Zai* pits, strip catchment tillage, contour bunds, semi-circular bunds and meskat-type system.
- **Rooftop harvesting technologies** - Have the advantage to collect relatively clean water.

For small-scale catchments, rainwater harvesting can be categorized according to the type of catchment surface used and, by implication, the scale of activity (Nissen-Petersen, 1999) as presented in Fig 1.

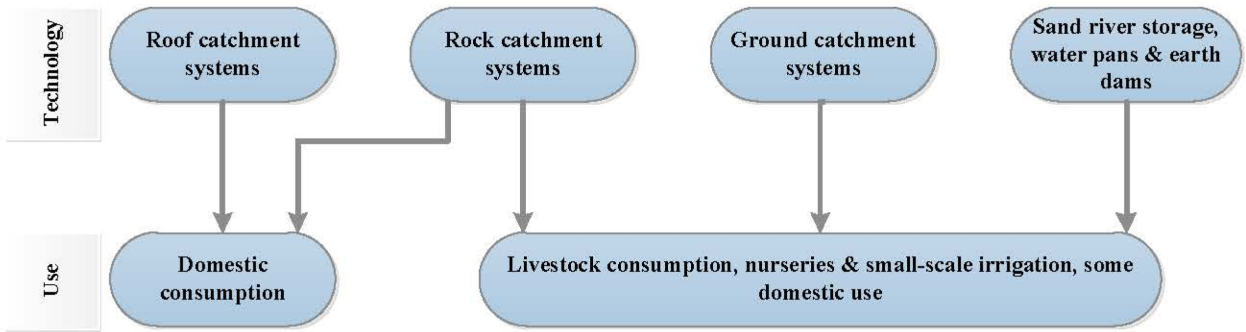



**Figure 2-1: Small-scale and medium-scale rainwater harvesting systems and uses (Gould and Nissen – Petersen, 1999)**

## 2.2 Sand Dams

Arid and semi-arid areas (ASALs) are characterized by extremely limited spatially distributed precipitation and high evaporation losses with poorly available ground water supply. Sand storage dam technique (sub surface storage dam) is used to reduce the evaporation effect. Sand dam is typical concrete embankment or wall built across an ephemeral (seasonal) stream. During the rainy season, the wall harvests sand and 20-40% of its total volume is water. The water is then abstracted using various methods depending on the intended use by the communities. There are three common methods of water abstraction from sand dams. These include traditional scoop holes, an infiltration gallery either leading a tank behind the dam and/or piped through the dam leading to a tap, and an infiltration gallery leading to a sealed shallow well in the valley side – topped with a hand pump.

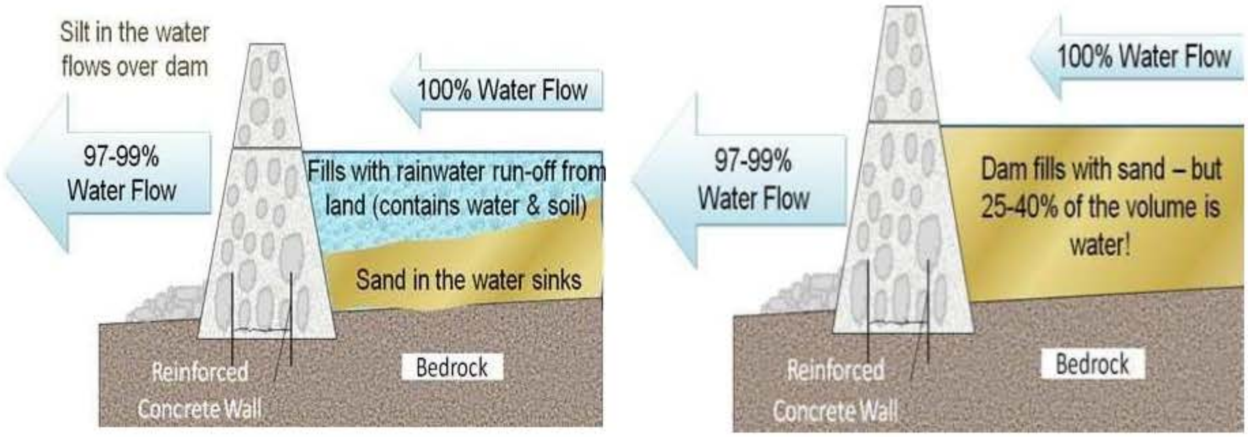



**Figure 2-2: Typical illustration of sand dams**

Sand dam is not a new technology in Kenya. It has been recorded that Kenya is a country with the highest concentration of sand dams. Water harvesting at certain points along the dry river has been widely practiced for centuries in ASALs. Sand dams' establishment has for years been promoted in the ASALs since they are the most cost-effective method of water conservation in dryland environments. Currently, various government agencies, NGOs, faith-based organizations (FBOs) and community-based organizations (CBOs) among others have established a number of sand dams in Kenyan ASAL areas. Some of the regions that are highly making use of sand dam technology in Kenya are Makueni, Kitui, Machakos, West Pokot, Baringo, Narok, Turkana and Samburu counties.


Plate 2-1: Immature Sand Dam, Vinya Wa Mwau Sand Dam, Makueni County

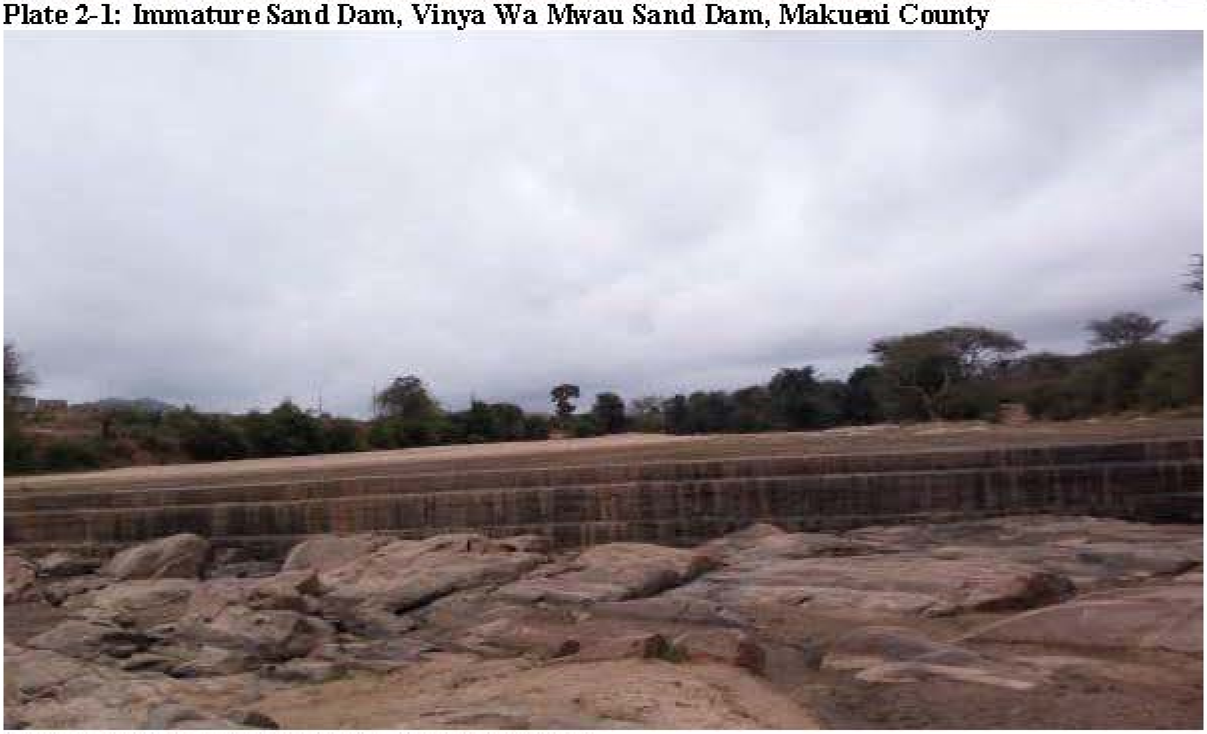


Plate 2-2: Mature Sand Dam, Makueni County

*Methods of Water Abstraction from Sand Dams*

**Plate 2-3: Scoop holes, Kaiti Sand Dam, Makueni County**

**Plate 2-4: Shallow Well Hand Pump, Vinya Wa Mwau Sand Dam, Makueni County**

### 2.2.1 Design Considerations for Sand Dams

#### 2.2.1.1 Site Selection

Site selection in dam design is a vital component. The success of any sand dam depends on the accuracy in site selection. This involves selection of suitable catchments based on its general topographical, morphological, geological and soil characteristics. Maddrell and Neal (2013) identified factors to consider when siting a sand dam and outlined them as:

- Existing scoop holes in sandy river beds especially during the long dry seasons
- Presence of vegetation that require large amounts of water to survive on the river banks such as fig trees
- Presence of visible rocky outcrops
- Ownership of the land adjacent to the site for easy access to the dam
- Slopes of adjacent and upstream river banks
- Absence of gullies upstream of the site as gullies are a sign of significant soil erosion which could put the sand dam at risk of siltation
- Availability of local construction materials

There are four pre-conditions necessary for a suitable sand dam site as published by Maddrell and Neal (2013). A sand dam must be sited where:

i. There is a seasonal river with clearly defined riverbanks
ii. The riverbed is impermeable to retain water
iii. There is sufficient sandy sediment
iv. The bedrock or a suitable impermeable layer is accessible within 3 metres below the existing riverbed surface.

#### 2.2.1.2 Water Demand & Water Yield Analysis

Water demand of sand dam beneficiaries and the possible water yield must be known before the design of a sand dam. The water that can be extracted from a sand dam reservoir (sand dam water yield) must be equal or slightly more than the beneficiaries water demand (Maddrell and Neal, 2013).

#### 2.2.1.3 Sand Dam Design

Based on the SASOL approach of sand dam design, a sand dam has four main components. These include the dam, spillway, wing walls and stilling basin (Maddrell and Neal, 2013).

*Dam Height*

The sand dam height should be designed properly to ensure that the water level and the maximum flood level will remain below the river banks after the sand dam construction (Maddrell and Neal, 2013).

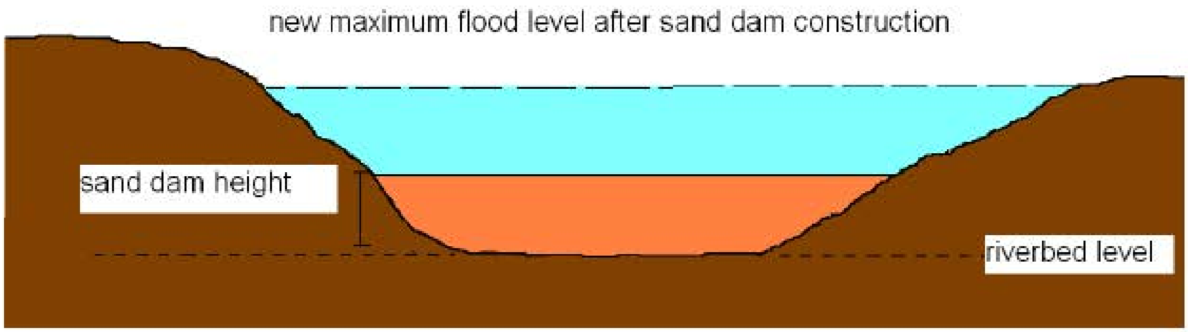



**Figure 2-3: Example of Sand Dam Height (Maddrell and Neal, 2013)**

*Spillway*

The dam spillway should be designed to enable the river to flow over its previous course and control the peak flow from flood events. This can be achieved by introducing several steps on the spillway.

*Wing walls and Stilling Basin*

Munyao et al (2004) outlined the distance the wing walls should go into the banks based on the bank characteristics as follows:

- in loose riverbanks: approximately 7 metres into the riverbanks;
- in hard soils: approximately 5 metres into the riverbanks;
- in hard and impermeable soil: approximately 0 – 1 metre into riverbanks;
- in rock formation: no need of constructing in riverbank

### 2.2.2 Previous Studies on Sand Dam Water Quality

Despite sand dam technology of harvesting rainwater in the ASALs having been in use for many decades, there is scanty data and studies on the water quality. There are only three studies that have been done recently on water quality from sand dams that were identified.

i. ***An Assessment of the Microbiological Water Quality of Sand Dams in Southeastern Kenya***

Quinn et al. (2018) conducted a microbiological water quality assessment for sand dams in Machakos and Makueni counties, Kenya. The analysis was done for water contained in sand dam through test holes and abstracted from it through covered wells and scoop holes. The assessment was specifically for thermotolerant coliform (TTC) concentration, turbidity, conductivity and PH indicators of water quality. A few samples (about 17%) of the samples collected tested positive for TTCs contrary to WHO guidelines and KEBs requirements that drinking water should have zero levels of TTC. Water from test holes and covered wells proved to be of better microbiological quality as compared to that from scoop holes. Turbidity levels for water from both scoop holes and covered wells exceeded WHO guideline levels. About 26% of the sampled scoop holes and 26% of covered wells indicated an exceedance of the conductivity levels based on WHO guidelines.

ii. ***Experimental Investigation about the Effect of Sand Storage Dams on Water Quality***

Kamel and Almula (2016) conducted an experimental investigation on the effect of sand storage dams on water quality, where a model was designed to simulate a sand dam water reservoir. A perforated pipe was used to discharge water from the model. Two types of soils were used to simulate the soil of sand dam reservoir. Raw water (rainfall) was added to the model by nozzles to the soil samples and left to settle for three (3) days and then emptied from the soil samples and collected as water samples for analysis. The tests were done for PH, Electrical conductivity, turbidity, sodium chloride, calcium, magnesium, bicarbonates, sodium and potassium water quality indicators to determine its suitability for human, livestock, and irrigation uses. The analysis indicated medium salinity and low sodium levels hence the water recommended suitable for irrigation purposes.

### iii. *Seasonal River Channel Water Exchange and Implications on Salinity Levels in Sand Dams: Case of Semi-Arid Kitui Region, Kenya*

Kitheka (2016) studied the variations of salinity levels and associated physico-chemical parameters in sandbeds of seasonal rivers in Kitui, Kenya. The physico-chemical parameters studied included salinity, TDS, and conductivity. The interaction between water in the seasonal river channels and that in the bank storage and or groundwater aquifers was also studied. Salinity, conductivity and TDS levels were found to be higher during the dry season as compared to those of wet season. Water in shallow wells and sand dams showed high levels of physico-chemical parameters. However, in general the salinity levels were within the minimum allowable limit for drinking water except in the extended drought periods.

## 2.3 Water Pollution

Water pollution is defined as the discharge by man of substances into the aquatic environment the results of which are such as to cause hazards to human health, harm to living resources and aquatic ecosystems, damage to amenities or interfere with other legitimate uses of water (Afubwa and Mwanthi, 2014).

### 2.3.1 Types of Water Pollutants

According to Afubwa, 2014, water pollutants are of organic, inorganic and microbiological origin. *Organic pollutants* are either from animals and plants or occur due to the use of organic chemicals in agriculture or vector control. *Inorganic pollutants* are chemicals that are found in soil and pollute ground water as it percolates through the soil profile. Whereas microbiological pollutants include bacteria, viruses, protozoa and helminths eggs that are of animal origin. Microbiological organisms occur in water supplies through faecal contact with water.

Water quality contamination can be divided into three main categories:

### i. *Microbial contamination*

This refers to the presence of disease-causing (or pathogenic) microbes, which are as a result of faecal materials contact with the water source. WHO considers microbial pathogens the highest priority in water treatment given their ability to cause infectious disease.

### *ii. Chemical contamination*

This includes metals, organic compounds and other chemicals that may present potential health risks. Natural water contains many chemicals, most of which have no health concerns. However, a few chemicals present human health risks when contaminated water is consumed over time.

### *iii. Physical contamination*

Physical contamination refers to conditions relating to the water's physical condition including temperature, odour, colour and turbidity. Most of these present no direct health risk, but they can influence other factors that are health risk to human.

### 2.3.2 Sources of Water Pollutants

Sources of water pollutants are classified into two major types including point source and non-point source. Point source pollutants are from a recognizable point which are usually regulated and their impacts are predictable hence have low effect. An example is an industry effluent drained into a river. Non-Point source pollutants are those with diffuse and unidentifiable sources. An example is pollutants from agriculture.

Some of the possible sand dam water pollutants are:

- Contamination by excreta and refuse being dumped in sand dams
- Contamination by diffusion from nearby latrines
- Sand dams, may be polluted by bathing, urinating or defecating (by human and animals) or disposing solid waste in them
- Discharge of poorly treated or untreated sewage
- Decomposable organic matter
- Pesticides, insecticides or herbicides from agricultural activities directly (by spraying over large areas) or indirectly with agriculture runoff
- Pathogens from biological, chemical and physical pollutants
- Suspended matter
- Industrial discharge of chemical wastes and by-products
- Oil pollution from oil spills and leakages
- Heavy metals

## 2.4 Potable Water Quality

The quality of drinking water is a powerful environmental determinant of health. Safe water is defined as water that is free from microbial, chemical and physical contamination. This includes contaminants that present a health risk such as disease-causing bacteria and toxic metals, and those that have no health risk but can make the water unpleasant to drink such as poor taste resulting from high iron levels.

Assurance of drinking water safety is a foundation for the prevention and control of waterborne diseases (WHO, 2011). Potable water quality is regulated by set quality standards; which describe the quality parameters set for drinking water. Many developed countries have specific standards applicable to their own country. In Europe and USA, European Drinking Water Directive and United States Environmental Protection Agency (EPA) respectively establishes standards for drinking water quality as required by the Safe Drinking Water Act. In countries without legislative and administrative framework for such standards, World Health Organization publishes guidelines on the standards that should be achieved. In Kenya, drinking water quality is regulated by the Kenya Bureau of Standards (KEBs) and National Environment Management Authority (NEMA) Standards.

### 2.4.1 Key Parameters for Potable Water Quality

Various water quality parameters are tested to determine its potability based on the area of study's drinking water regulating guidelines and standards. These parameters are categorized as microbiological, physical or chemical as discussed;

#### 2.4.1.1 Microbiological Parameters

*Fecal Coliforms and E. Coli*

Coliform bacteria are naturally found in the soil. Fecal Coliform bacteria exist in the intestines of warm blooded animals and humans, and are found in bodily waste, animal droppings, and naturally in soil. Most of the Fecal Coliform in fecal material (feces) is comprised of *E. coli*, and the serotype *E. coli* 0157:H7 is known to cause serious human illness (Health Canada).

The presence of Fecal Coliform and *E. coli* bacteria in sand dam water may indicate recent contamination of the water by human sewage or animal droppings which could contain other bacteria, viruses, or disease causing organisms. Thus, drinking water contaminated with these organisms can cause stomach and intestinal illness including diarrhea and nausea, and even lead to death. These effects may be more severe and possibly life threatening for babies, children, the elderly or people with immune deficiencies or other illnesses (Health Canada). KEBs/NEMA recommends Fecal Coliforms and *E. Coli* bacteria be absent in 250ml of drinking water.

#### 2.4.1.2 Physical Parameters

*Turbidity*

Turbidity is the amount of cloudiness in the water and it can vary from a river full of mud and silt where it would be impossible to see through the water (high turbidity), to a spring water which appears to be completely clear (low turbidity). Turbidity can be caused by phytoplankton; silt, sand and mud; bacteria and other germs; and chemical precipitates. For drinking water, WHO establishes that the turbidity should not exceed 5 NTU and should not be below 1 NTU.
The suspended particles absorb heat from the sunlight, making turbid waters become warmer, and so reducing the concentration of oxygen in the water (oxygen dissolves better in colder water).

*Color*

For aesthetic purposes, color is an important parameter of drinking water quality. Coloured water give the appearance of being unfit to drink, even though the water may be perfectly safe for public use. On the other hand, colour can indicate the presence of organic substances, such as algae or humic compounds. More recently, colour has been used as a quantitative assessment of the presence of potentially hazardous or toxic organic materials in water (ligmis, 2001). WHO guidelines, KEBs/NEMA standards recommend 15 true color units fit for drinking water.

*Temperature*

Temperature of water affects some of the important physical properties and characteristics of water including thermal capacity, density, specific weight, viscosity, surface tension, specific conductivity, salinity and solubility of dissolved gases (ligmis, 2001). Chemical and biological reaction rates increase with increasing temperature. The temperature of water in streams and rivers throughout the world varies from 0 to 35 °C.

*Taste*

Taste is a human perception of water quality. Human perception of taste includes sour (hydrochloric acid), salty (sodium chloride), sweet (sucrose) and bitter (caffeine). Organic materials discharged directly to water body, including falling leaves and runoff are sources of tastes and odour-producing compounds released during biodegradation (limgis, 2001). KEBs/NEMA recommends that drinking water taste should not be offensive to consumers.

#### 2.4.1.3 Chemical Parameters

*PH*

The pH of water is a measure of the acid–base equilibrium and, in most natural waters, is controlled by the carbon dioxide–bicarbonate–carbonate equilibrium system. An increased carbon dioxide concentration will therefore lower pH, whereas a decrease will cause it to rise. Temperature will also affect the equilibria and the pH. In pure water, a decrease in pH of about 0.45 occurs as the temperature is raised by 25 °C (APHA, 1989).

When human beings are exposed to extreme pH values, they suffer from eyes, skin, and mucous membranes irritation. Eye irritation and exacerbation of skin disorders have been associated with pH values greater than 11. In addition, solutions of pH 10–12.5 have been reported to cause hair fibres to swell (WHO, 1986). In sensitive individuals, gastrointestinal irritation may also occur. Exposure to low pH values can also result in similar effects. Below pH 4, redness and irritation of the eyes have been reported, the severity of which increases with decreasing pH. Below pH 2.5, damage to the epithelium is irreversible and extensive (WHO, 1986). In addition, because pH can affect the degree of corrosion of metals as well as disinfection efficiency, it may have an indirect effect on health. The World Health Organization recommends that the pH of the water be less than 8.0, because basic water does not allow for effective chlorination.

*Total Dissolved Solids, TDS*

Total dissolved solids refers to the inorganic salts and small amounts of organic matter present in solution in water. The principal constituents are usually calcium, magnesium, sodium, and potassium cations and carbonate, hydrogencarbonate, chloride, sulfate, and nitrate anions (WHO, 2006). According to WHO (2006) specification, TDS up to 500 ppm is the highest desirable and up to 1,500 ppm is maximum permissible. The presence of dissolved solids in water may affect its taste (*Bruvold, 1969)*. However, there is no clear indication on the health effects associated with the ingestion of TDS in drinking-water.

*Electrical Conductivity, EC*

Electrical Conductivity is a measure of water capacity to convey electric current. Most dissolved inorganic substances are in the ionised form in water and contribute to conductance. The conductance of the samples gives rapid and practical estimate of the variation in dissolved mineral content of the water supply (limgis, 2001). The most desirable limit of EC in drinking water is prescribed as 1,500 μmhos/cm (Hem, 1985). However, WHO guidelines recommend a limit of 0.05S/m of EC in drinking water.

*Chloride, Cl*

Chloride occurs naturally in ground water but is found in greater concentrations where seawater and run-off from road salts can make their way into water sources. Chlorides are harmless at low levels, but high levels of sodium chloride can give drinking water an unpleasant taste.

Exposure to chlorine, hypochlorous acid, and hypochlorite ion through ingestion of household bleach occurs most commonly in children. Intake of a small quantity of bleach generally results in irritation of the oesophagus, a burning sensation in the mouth and throat, and spontaneous vomiting. In these cases, it is not clear whether it is the sodium hypochlorite or the extremely caustic nature of the bleach that causes the tissue injury (WHO, 2006). WHO guidelines, KEBs and NEMA drinking water standards require chloride level not to exceed 250 mg/l. Sodium chloride levels greater than this, can complicate existing heart problems and contribute to high blood pressure when ingested in excess.

*Fluoride, F*

Fluoride is a chemical compound that occurs naturally on the earth's crust. It is formed during rock formation and is a chemical ion of chlorine. Fluoride is one of the very few chemicals that has been shown to cause significant effects in people through drinking water (WHO, 2006). It may be found in drinking water as a natural contaminant or as an additive intended to provide public health protection from dental caries. Fluoride is useful in preventing cavities and making teeth stronger at low concentrations in drinking water. However, exposure to excessive fluoride in drinking-water, or from other sources, can result to a number of adverse effects. These include mild dental fluorosis as a result of excessive exposure to high concentrations of fluoride during teeth development (childhood), severe dental fluorosis (mottled teeth) and skeletal fluorosis which are diseases caused by excess fluoride intake.

Fluoride levels in drinking water vary from one region to another. As some regions experience excess concentration of fluoride in drinking water, others have very low concentrations and as a result are required to add fluoride in the water (artificial water fluoridation). Low levels (less than 0.1mg/l) of fluoride are associated with tooth decay (Edmunds, 1996). Removal of excess fluoride in drinking water is through a process called defluoridation.

Although there is no fixed value for the acceptable standards of fluoride levels in drinking water, WHO recommends 1.5mg/l as a level at which dental fluorosis should be minimal (WHO, 1984). In a WHO study on *fluoride in drinking water*, it was noted that mottling of teeth (dental fluorosis) is sometimes associated with fluoride levels in drinking water above 1.5 mg/l and crippling skeletal fluorosis can occur when fluoride levels exceed 10 mg/l (WHO, 2006).

*Ammonia, $NH_3$*

The presence of ammonia at higher than geogenic levels is an important indicator of faecal pollution (IOS, 1986). Taste and odour problems as well as decreased disinfection efficiency are to be expected if drinking-water containing more than 0.2 mg of ammonia per litre is chlorinated (Weil, 1975). The presence of elevated ammonia levels in raw water may interfere with the operation of manganese-removal filters because too much oxygen is consumed by nitrification, resulting in mouldy, earthy-tasting water (Dieter, 1991). The presence of the ammonium cation in raw water may result in drinking-water containing nitrite as the result of catalytic action or the accidental colonization of filters by ammonium-oxidizing bacteria (Reichert, 1984).

*Nitrate, $NO_3$*

Nitrate and nitrite are naturally occurring ions that are part of the nitrogen cycle. Nitrate and nitrite are formed endogenously in mammals, including humans. Nitrate is secreted in saliva and then converted to nitrite by oral microflora. Nitrate can reach both surface water and groundwater as a consequence of agricultural activity (including excess application of inorganic nitrogenous fertilizers and manures), from wastewater treatment and from oxidation of nitrogenous waste products in human and animal excreta, including septic tanks. (WHO, 2006). The toxicity of nitrate to humans is mainly attributable to its reduction to nitrite. The major biological effect of nitrite in humans is its involvement in the oxidation of normal Hb to metHb, which is unable to transport oxygen to the tissues. The reduced oxygen transport becomes clinically manifest when metHb concentrations reach 10% of normal Hb concentrations and above; the condition, called methaemoglobinaemia, causes cyanosis and, at higher concentrations, asphyxia. The normal metHb level in humans is less than 2%; in infants under 3 months of age, it is less than 3% (WHO, 2006).

*Calcium, Ca*

Calcium is essential to human health and inadequate intake of it can impair health. Over 99% of total body calcium is found in bones and teeth, where it functions as a key structural element. The remaining body calcium functions in metabolism, serving as a signal for vital physiological processes, including vascular contraction, blood clotting, muscle contraction and nerve transmission. Inadequate intakes of calcium have been associated with increased risks of osteoporosis, nephrolithiasis (kidney stones), colorectal cancer, hypertension and stroke, coronary artery disease, insulin resistance and obesity. Recommended levels of calcium have been set at national and international levels (WHO, 2009). In Kenya, KEBs/NEMA recommends a level of 250mg/l in drinking water.

*Magnesium, Mg*

WHO (2009) records Magnesium as the fourth most abundant cation in the body and the second most abundant cation in intracellular fluid. It is a cofactor for some 350 cellular enzymes, many of which are involved in energy metabolism. It is also involved in protein and nucleic acid synthesis and is needed for normal vascular tone and insulin sensitivity. Low magnesium levels are associated with endothelial dysfunction, increased vascular reactions, elevated circulating levels of Creactive protein and decreased insulin sensitivity. Low magnesium status has been implicated in hypertension, coronary heart disease, type 2 diabetes mellitus and metabolic syndrome. In Kenya, KEBs/NEMA recommends a level of 100mg/l in drinking water.

*Sodium (Na)*

Sodium ranks sixth among the elements in order of abundance and is present in most of natural waters (Amar, 2016). Sodium is generally found in lower concentration than Ca and Mg in freshwater. WHO recommends a maximum permissible limit of 200mg/l of drinking water. The intake of high level of Na causes increased blood pressure, arteriosclerosis, oedema and hyperosmolarity (Amar, 2016).

*Potassium (K)*

Potassium is also a naturally occurring element; however, its concentration remains quite lower compared with Ca, Mg and Na (Amar, 2016). Potassium is an essential element for human nutrition, and requirements are generally measured in grams per day. Potassium and sodium maintain the normal osmotic pressure in cells. It is a cofactor for many enzymes and is required for the secretion of insulin, creatinine phosphorylation, carbohydrate metabolism and protein synthesis (WHO, 2006). According to WHO guidelines on drinking water quality (2006), the maximum permissible limit of potassium in the drinking water is 12 ppm.

*Silicon and Silica*

Silicon (Si) is a nonmetallic element that is abundant in supply as part of various compounds in the crust of the earth. It is released to the earth's crust as a result of weathering process and released under water during volcanic activity. Whereas silica commonly known as silicon dioxide is a compound of silicon and oxygen ($Si0_2$). Silica occurs in various forms including sand, sandstone, quartz and granite. It occurs naturally in all water supplies in dissolved, suspended or colloidal form.

Naturally occurring types of silicon, sand and silicon compounds are non-toxic. However, elementary silicon has no clear mechanisms of toxicity and high concentrations of soluble silicon compounds may disturb phosphorilation. Fine particles of silicon compounds may cause silicosis, a typical profession related illness of for example mine workers or stone grinders. Pulmonary alveoluses harden and their flexibility decreases. This results in shortness of breath, panting and couching. Only inhalation of silicon particles may cause these effects. In drinking water only silicic acid is present, which is relatively safe. WHO recommends silica and silicon levels in drinking water be less than 107 ppm and 50 ppm respectively.

*Hardness*

Hardness in water supply is determined by the presence of calcium and magnesium salts. The salts are formed when calcium and magnesium combine with bicarbonates, sulfates, chlorides, and nitrates. Calcium and magnesium salts, which form hardness are classified into two categories: temporary hardness (containing carbonates), and permanent hardness (containing non-carbonates). WHO recommends hardness levels within drinking water be less than 300 ppm.

#### 2.4.1.4 Heavy Metals

*Manganese, Mn*

ATSDR (2000) records Manganese as one of the most abundant metals in Earth's crust, usually occurring with iron. It is a component of over 100 minerals but is not found naturally in its pure (elemental) form. Manganese is an element essential to the proper functioning of both humans and animals, as it is required for the functioning of many cellular enzymes (e.g. manganese superoxide dismutase, pyruvate carboxylase) and can serve to activate many others (e.g. kinases, decarboxylases, transferases, hydrolases) (IPCS, 2002). Manganese occurs naturally in many surface water and groundwater sources and in soils that may erode into these waters. However, human activities are also responsible for much of the manganese contamination in water in some areas (WHO, 2006). Although manganese concentrations in drinking water may vary with local circumstances, WHO (2006) recommends concentrations below 0.05mg/l to be acceptable to consumers. For Kenyan, situation, KEBs/NEMA recommends concentrations below 0.1mg/l in drinking water.

*Aluminum, Al*

Aluminium is the most abundant metallic element and constitutes about 8% of the Earth's crust. It occurs naturally in the environment as silicates, oxides, and hydroxides, combined with other elements, such as sodium and fluoride, and as complexes with organic matter.

*Iron, Fe*

Iron is widespread in nature, and very abundant occurring at concentration of about 50,000 mg/kg in the earth's crust. Iron occurs in minerals like biotite, magnetite, pyroxenes, ferric oxides and hydroxides. In groundwater, the common form of iron is the soluble ferrous ion ($Fe^{2+}$). When exposed to atmosphere it is oxidized to the ferric state ($Fe^{3+}$) which is insoluble and causes brown discolorations of water and introduces a bitter sweet astringent taste and stains to laundered clothes (Njoroge, 2014).

For most purposes, the iron concentrations should not exceed 0.5 mg/l. Generally, the presence of iron is common in groundwater. Iron is vital in the formation of hemoglobin in human being. The essential element iron, is a component of some enzymes notably; cytochrome and xanthine oxidase. Dietary intake of iron in excessive amount may lead to haemosiderosis or haemochromatosis. Heamosiderosis is a condition best characterized by generalized increased iron content in the body tissue, especially in the liver and reticuloendothenal system (Njoroge, 2014).

*Zinc, Zn*

Zinc is an essential and beneficial element in body growth. The clinical symptoms of zinc deficiency are anorexia, pica, impaired taste acuity, menstrual lethargy and disturbances, viz; rough, dry skin, impaired wound healing and increased susceptibility to infection, chronic deficiency in pediatric and adolescent age group causes growth retardation and delay of sexual maturation (Casey, 1980). Acute zinc toxicity results in haemodialysis, characterized by nausea, vomiting, fever and severe anemia. However, concentrations above 5 mg/l can cause a stringent taste and opalescence in alkaline waters.

*Copper, Cu*

Copper is widely distributed in the environment and is essential to human life, but potentially toxic at elevated levels of exposure. It acts like a catalyst in the formation of hemoglobin and is also involved in haemopoisis, maintenance of vascular and skeletal integrity, structure and function of central nervous system.

The symptoms of severe copper poisoning in the human body are extensive homolysis, hepatic necrosis, nephropathy and coma, and if not treated may lead to death. Wilson's disease is well known. It is characterized by inability to digest copper in the body resulting in degenerative changes in the brain and cirrhosis of the liver. The disease appears to be related to a hereditary deficiency of ceruloplasm (the blue copper containing oxidase present in the $x_2$ – globulin fraction of the human serum. Its major function is to oxidize iron to the ferric state for transport by transferring. Copper deficiency therefore causes anemia (Njoroge, 2014).

Table 2-1 shows the key parameters for potable water quality determination.

**Table 2-1: Summary of key parameters for potable water quality determination**

| S/No. | Parameter | Symbol | Units of Measurements | Guide Low | Guide High |
|---|---|---|---|---|---|
| **Microbiological Parameters** | | | | | |
| 1. | Feacal Coliforms | FC | cfu/100 ml | | ND |
| 2. | Feacal E. Coli | FCECL | cfu/100 ml | | ND |
| **Physical Parameters** | | | | | |
| 3. | Turbidity | TUB | NTU | | < 5.00 |
| 4. | Color | | True color units | | |
| 5. | Odour | | | | |
| **Chemical Parameters** | | | | | |
| 6. | PH | pH | | 6.50 | 8.50 |
| 7. | Electrical Conductivity | EC | mS cm -1 | | < 1.50 |
| 8. | Chlorides | Cl | Ppm | | < 250 |
| 9. | Fluorides | Fl | Ppm | | < 1.50 |
| 10. | Ammonium | $NH_4$ | Ppm | | < 0.50 |
| 11. | Nitrates | $NO_3$ | Ppm | | < 50.0 |
| 12. | Calcium | Ca | Ppm | | < 150 |
| 13. | Magnesium | Mg | Ppm | | < 100 |
| 14. | Sodium | Na | Ppm | | < 200 |
| 15. | Potassium | K | Ppm | | < 12.0 |
| 16. | Nitrate N | $NO_3N$ | Ppm | | < 11.3 |
| 17. | Phosphorus | P | Ppm | | < 0.20 |
| 18. | Sulphur | S | Ppm | | < 133 |
| 19. | Bicarbonate | $HCO_3$ | Ppm | | < 250 |
| 20. | Sulphate | $SO_4$ | Ppm | | < 400 |
| 21. | Silicon | Si | Ppm | | < 50.0 |
| 22. | Silica | $SiO_2$ | Ppm | | < 107 |
| 23. | Phosphate | $PO_4$ | Ppm | | < 0.61 |
| 24. | Hardness | $CaCO_3$ | Ppm | | < 300 |
| **Heavy Metals** | | | | | |
| 25. | Manganese | Mn | Ppm | | < 0.50 |
| 26. | Iron | Fe | Ppm | | < 0.30 |
| 27. | Zinc | Zn | Ppm | | < 5.00 |

| S/No. | Parameter | Symbol | Units of Measurements | Guide Low | Guide High |
|---|---|---|---|---|---|
| 28. | Copper | Cu | Ppm | | < 1.00 |
| 29. | Boron | B | Ppm | | < 0.30 |
| 30. | Molybdenum | Mo | Ppm | | < 0.07 |

*ND=Not Detectable*

**Source:** Water Services Regulatory Board (WASREB): Drinking Water Quality and Effluent Monitoring.

## 2.5 Steps in Drinking Water Quality Assessment

### 2.5.1 Development of Assessment Objectives

Development of objectives are important in any assessment as they inform different testing strategies for achievement of the objectives. Objectives of an assessment depends on its reason; what should be achieved at the end of the assessment. For drinking water quality, assessment objectives can be to verify the safety of a drinking water source, gathering of more information about a known contamination, and testing of the effectiveness of a treatment technology among others.

### 2.5.2 Determination of Key Water Quality Parameters

Due to limitations on time, funding and access to analytical services, testing water samples for every contamination is impossible. Therefore, selection of key tests relevant to the assessment objectives is important. Selection of key tests is based on the key indicators of safe water for drinking.

### 2.5.3 Choice of Testing Methods

There are variety of testing methods for water quality parameters and it is necessary to select a testing method based on the assessment objectives. Selection of testing methods should be done based on precision and detection limits of each method considered. The quality and availability of professional laboratories vary by location, so it is important to consider a certified laboratory that uses standardized testing methods.

### 2.5.4 Planning of the Testing Program

Planning of the testing program includes sample collection timing, collection team logistics and quality control measures. In addition to water samples collection and analysis, consideration of any additional data that may be required to achieve the assessment's objectives is important. This could include community members perception of the water quality and related health issues and any information on waterborne disease incidences or reports form the local health clinics and community members.

### 2.5.5 Testing

#### i. *Sterilization of Equipment*

To avoid contamination of the water samples, it is essential to maintain a sterile working environment. It is advisable to wear gloves when handling the water samples and sterilize the water sample collection containers. The lab area should also be sterilized before and after use

#### ii. *Sample Collection*

Sample collection should be done carefully to ensure that they are a true representative of the typical water conditions. For example, if sampling from a tap, water should be let to run for several minutes to flush the system before collection.

Sufficient volume of water should be collected to facilitate proper analysis of the planned tests as well as repetition in the case of a mistake. All sample bottles must be clearly labelled with the site location ID, date and time. After collection, the samples should be kept cool and processed within 24 hours to minimize cases of bacteria growth or die-off before analysis as this changes the water quality.

#### iii. *Sample Analysis*

Sample analysis will depend on the chosen testing method for each water quality parameter. For example, analyzing control samples with known concentrations of target substances to verify the accuracy of your testing method is generally necessary as a quality control practice.

In addition, if a sample is divided at any point, it is advisable to shake the sample vigorously for 10 seconds beforehand to ensure that the sub-samples are representative of the whole.

### 2.5.6 Data Analysis and Interpretation

Results should be interpreted with caution owing to the possible introduction of errors during sampling and analysis processes. A water source should not be considered safe until a consistent history of sustained tests accounting for seasonal changes in conditions.

## 2.6 Conclusions on Literature Review

There is much information in literature on rainwater harvesting technologies and their classifications, general information on potable water quality and key parameters for potable water determination and steps in drinking water quality assessment. There is literature on sand dams as a feasible rainwater harvesting technology within the ASALs. The information available on sand dams has much emphasis on the technical aspects namely hydrologic measurement and analysis, and determination of the quantity of water that will be harvested with less or no concern on the water quality and how the water quality can be affected. Hence the need for this study.

# CHAPTER THREE

## 3.0 METHODOLOGY

### 3.1 Study Area

This study was conducted in Makueni County to form a representation of other ASALs in Kenya. Makueni County was selected as the study area because;

- It is a county where sand dam technology adoption is high as compared to other ASALs within the country and there is no report on water quality from the sand dams.
- It is an area where there is adequate literature on the sand dams done by various organizations including Makueni County Government, Africa Sand Dam Foundation (ASDF), Excellent Development and Utooni Development Organization among others.

### 3.1.1 Location of Study Area

Makueni County lies within the arid and semi-arid ecological zones of the eastern region of Kenya. It lies between Latitude 1° 35′ and $3^0$ 00 South and Longitude 37°10′ and 38° 30′East and covers an area of 8,034.7 $Km^2$. The county borders several counties which include Kajiado to the West, Taita Taveta to the South, Kitui to the East and Machakos to the North as shown in Fig 3-1 (Makueni CIDP, 2013). The County is divided into six (6) sub-counties including Makueni, Mbooni, Kaiti, Kibwezi East, Kibwezi West and Kilome.

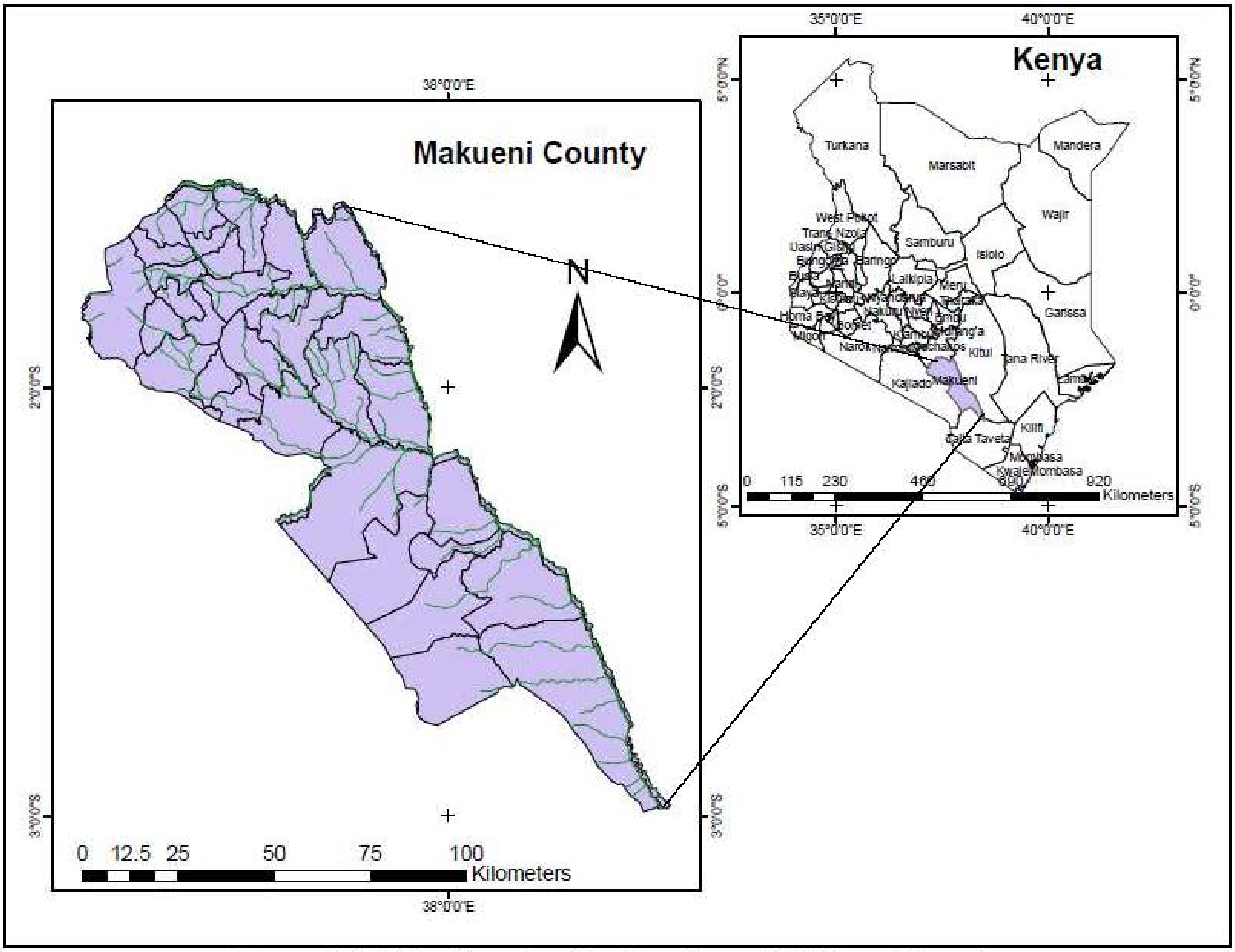



**Figure 3-1: Map Showing the Location of Makueni County**

### 3.1.2 Population

The 2015 projected population in Makueni County stands at 961,738 with 468,298 male and 493,442 female (Kenya National Bureau of Statistics, 2013). The annual population growth rate stands at 1.4 per cent and it is projected that the population will increase to 989,050 by 2017.

### 3.1.3 Climate and Rainfall

Makueni County experiences bimodal rainy seasons, with the long rains occurring in March /April and the short rains in November/December. The hilly parts of Mbooni and Kilungu receive between 800-1400mm of rainfall per year which has high potential for crop production. There are extremely high temperatures of 35.8$^{0}$C which are experienced in the low-lying areas of the County leading to high evaporation which worsens the dry conditions (Makueni CIDP, 2013). Normally, the rains are sometimes unreliable, erratic and inadequate.

Human activities such as farming on hill tops, charcoal burning and sand harvesting have led to the county's adverse climate change and variability which includes insufficient rain and prolonged dry spells among others (Makueni CIDP, 2013). As a result, the county experiences severe water scarcity. The community has adopted sand dam construction to mitigate these effects of water scarcity due to their capability of retaining water in harsh climatic conditions.

### 3.1.4 Water Resources and Management

The main river in Makueni County is Athi River, which is perennial and fed by tributaries such as Kambu, Kiboko, Kaiti, Thwake and Mtito Andei, which drain from various parts of the county. A few other streams flow from the Mbooni and Kilungu Hills but their flow becomes irregular as they move to the low-lying areas. These rivers provide a high potential for both large and small-scale irrigation (Makueni CIDP, 2013).

Water demand in the county is estimated at 22,113m$^3$/day with supply being 13,607m$^3$/day, 63 percent lower than the demand. Households trek an average of eight (8) kilometers to and from water sources and only 36 percent of residents use improved water sources with the rest relying on unimproved sources which include unprotected dug well, unprotected spring, surface water (dams, water pans and sand dams); (Makueni CIDP, 2013).

## 3.2 Sampling of Sand Dams

Owing to the expansive nature of the Makueni County, limitations of time and cost, it was not possible to study all the existing sand dams, and therefore sampling was done. A two-stage cluster sampling technique was used. Makueni County has one major permanent river which is Athi River. Athi River has various tributaries including Kambu, Kaiti, Kiboko, Mtito Andei, Thwake, Thange, Uani, Muooni, Tawa and Kiangini. The County was therefore divided into ten (10) clusters based on these sub-catchments. Four (Kaiti, Uani, Tawa and Thwake) of the ten clusters were selected to form a sampling frame. A sample size five was determined and divided equally among the selected clusters. Random selection of the sand dams was done within each of the chosen cluster as shown in Table 3-1.

**Table 3-1: Sampled Sand Dams**

| Sand Dam/Site | River Basin | GPS Location | | | Method of Water Abstraction | Remark |
|---|---|---|---|---|---|---|
| | | Northing (m) | Easting (m) | Elevation (m) | | |
| A. Kaiti Sand Dam | Kaiti River | 9804061 | 346910 | 1105 | Scoop hole | Mature |
| B. Kaiti Sand Dam | Kaiti River | 9803755 | 347170 | 1129 | Piped with a Tap | Mature |
| C. Vinya Wa Mwau Sand Dam | Kyanthei River | 9825406 | 340412 | 1180 | Shallow well with a hand pump | Immature |
| D. Kiaoni Sand Dam | Tawa River | 9826723 | 338377 | 1182 | Scoop hole | Mature |
| E. Kwa Veleki Sand Dam | Kikumu River | 9828575 | 326377 | 1387 | Scoop hole | Mature |

***Note: Kaiti Sand Dam** currently has two methods of water abstraction and therefore it was treated as two different sites so as to determine the effect of method of water abstraction on the water quality*

## 3.3 Determination of Water Quality Parameters for Evaluating Potability of Water from Sand Dams

Potability testing is done to determine if the water is safe to drink and the amount and types of impurities present. Potability determination is commonly based upon appropriate local, national and international standards and guidelines based on various water quality parameters. The key water quality parameters for drinking water was determined based on literature. Based on WHO/KEBs/NEMA guidelines for standard drinking water quality, some of the key parameters for evaluating potability of water identified are presented in Table 2-1. This study was based on the identified key potable water quality parameters in Table 2-1.

### 3.3.1 Sample Collection

To determine the standard potable water quality, water samples were collected from the five (5) sampled sand dams' (Kaiti, Vinya Wa Mwau, Kiaoni and Kwa Veleki Sand Dams)' abstraction points and tested for 30 key microbiological, physical, chemical and heavy metals parameters shown in Table 2-1 to determine whether they meet international World Health Organization (WHO) guidelines and the national Kenya Bureau of Standards (KEBs) for potable water.

To avoid contamination, the water samples were collected in sterile one (1) litre bottles and great care taken to prevent accidental contamination of the sterile bottle or water sample during sampling and transportation to the water testing laboratory. All sampling bottles were labelled appropriately and stored in a coolant with well-regulated temperatures during transportation from Makueni County to the testing laboratory; CropNuts Laboratory Services in Nairobi.

### 3.3.2 Data Analysis

Table 3-2 shows the methodology used in the lab tests analysis for the 30 water quality parameters for each of the five sand dams. For each sample, three analyses were done and their readings taken.

**Table 3-2: Water Quality Analysis Methods**

| Parameter | Method | Principle |
|---|---|---|
| Water pH | Potentiometric | |
| Water EC | Potentiometric | |
| Water P, Ca, Mg, K, Na, Mn, Fe, Cu, Mo, B, Zn, S, Si +Heavy metals | Atomic Emission spectrometry ( ICP- OES) | When plasma energy is given to an analysis sample from outside, the component elements (atoms) are excited. When the excited atoms return to low energy position, emission rays (spectrum rays) are released and the emission rays that correspond to the photon wavelength are measured. The element type is determined based on the position of the photon rays, and the content of each element is determined based on the rays' intensity. |
| Ammonium | Colorimetric | Ammonia reacts with hypochlorite ions generated by the alkaline hydrolysis of sodium dichloro-isocyanurate to form monochloramine. This reacts with salicylate ions in the presence of sodium nitroprusside at around pH 12.6 to form a blue compound (Rayment and Lyons, 2011). The absorbance of this compound was measured spectrophotometrically at wavelength 660nm and was related to the ammonia concentration by means of a calibration curve. |

| Parameter | Method | Principle |
|---|---|---|
| Nitrate Nitrogen | Colorimetric | Nitrate is quantitatively reduced to Nitrite ($NO_2$) by a redox reaction with a granulated cadmium metal in the presence of a suitable buffer. The nitrite thus produced was then reacted with the griess reagents to form a strongly coloured azo dye that is measured spectrophotometrically at 540nm. |
| Chloride | Colorimetric | Chloride reacts with mercury (II) thiocyanate to form a soluble non ionic compound. The thiocyanate ions released react in acid solution with iron (III) nitrate to form a red/brown iron (III) thiocyanate complex. The resulting intensity of the stable colour produced was measured spectrophotometrically at a wavelength of 480nm and was related to the chloride concentration by means of a calibration curve. |
| Bicarbonate | Colorimetric | Alkalinity was determined by measuring the absorbance of the complex formed when a sample was reacted with bromophenol blue in a pH 3.5 phthalate buffer, spectrophotometrically at 400nm. |
| Fluoride | Colorimetric | Fluoride was allowed to react at a pH of 4.5 with the red chelate formed between cerous nitrate and alizarin fluorine blue. The absorbance of the resulting blue complex was measured at wavelength 620nm. |
| Turbidity | Turbidimeter | Turbidity in a liquid is caused by the presence of finely divided suspended particles. When a beam of light is passed through a sample, the loss of intensity of transmitted light due to the scattering effect of particles suspended in it was measured and reported as turbidity. |
| Faecal Coliforms & F. E.Coli | ISO 9308-2:2012 method – Enumeration | Enumeration of Escherichia coli and coliform bacteria -- Part 2: Most probable number method |

### 3.4 Evaluation of Potable Water Quality of Sand Dams in Makueni County

Analysis of potable water quality from sand dams within Makueni County was done based on the lab tests results. The lab test results from water samples collected within the study area were evaluated to check their compliance with WHO guidelines, NEMA/KEBs standards for potable water.

## 3.5 Development of a Protocol for Evaluating Potability of Water from Sand Dams

A protocol for evaluating potability of water from sand dams was prepared based on the findings from this study.

### 3.5.1 Establishment of the main purpose of the Protocol

The main purpose of the protocol providing information on how to assess quality of raw water from sand dams and ways to disseminate the results to the relevant authorities and stakeholders was developed.

### 3.5.2 Determination of minimum data set for potable water quality evaluation

Principle component analysis (PCA) was used to establish a minimum data set (MDS) with the most appropriate indicators for potable water quality and only factors with eigenvalues >1 were considered.

### 3.5.3 Development of guidelines for evaluating potability of water from sand dams

Guidelines on how to use the water quality parameter/indicators to determine whether water from sand dams is safe were developed. Major components of a protocol including materials, methods, s

tandards, data interpretation and references were also developed.

Recommendations on the appropriate water treatment process requirements were also developed.

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSIONS

This study involved determination of water quality parameters for evaluating potability of sand dams, evaluation of potable water quality of sand dams within Makueni County and development of a protocol for evaluating potability of water from sand dams in semi-arid areas.

Water samples were collected from the sampled existing sand dams' water abstraction points within Makueni County and analyzed for heavy metals, microbiological, physical and chemical quality.

The results and discussion are presented in the subsequent sections.

### 4.1 Potable Water Quality of Sand Dams in Makueni County

The average values of lab test results of the water samples collected from Makueni County were as shown in Tables 4-1, 4-2 and 4-3.

**Table 4-1: Microbiological and Physical Lab Test Results of Water from Sampling Sites**

| Site | Microbiological Parameters | | Physical Parameters | | |
|---|---|---|---|---|---|
| | FC (cfu/100 ml) | FCECL (cfu/100 ml) | Turbidity (NTU) | Color (True color units) | Odour |
| A | 8 | ND | 3.77 | Clear | Without odour |
| B | > 180 | ND | 65.3 | Clear | Without odour |
| C | 50 | ND | 3.23 | Clear | Without odour |
| D | 90 | 2 | 6.73 | Clear | Without odour |
| E | > 180 | 2 | 17.2 | Clear | Without odour |
| ND=Not Detectable | | | | | |

**Table 4-2: Heavy Metals Lab Test Results of Water from Sampling Sites**

| Site | Mn (ppm) | Fe (ppm) | Zn (ppm) | Cu (ppm) | B (ppm) | Mo (ppm) |
|---|---|---|---|---|---|---|
| A | 0.91 | 0.23 | 0.71 | < 0.01 | 0.058 | < 0.01 |
| B | 0.093 | 0.098 | 0.011 | < 0.01 | 0.033 | < 0.01 |
| C | 4.55 | 0.36 | 0.026 | < 0.01 | 0.046 | 0.014 |
| D | 1.11 | 0.074 | 0.015 | < 0.01 | 0.033 | < 0.01 |
| E | 3.27 | 4.22 | < 0.01 | < 0.01 | 0.028 | < 0.01 |

**Table 4-3: Chemical Lab Test Results of Water from Sampling Sites**

| Site | pH | EC mS/cm | Cl ppm | Fl ppm | $NH_4$ Ppm | $NO_3$ ppm | Ca ppm | Mg ppm | Na ppm | K ppm | $NO_3N$ ppm | P Ppm | S ppm | $HCO_3$ ppm | $SO_4$ ppm | Si ppm | $SiO_2$ ppm | $PO_4$ ppm | $CaCO_3$ ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **A** | 7.95 | 1.45 | 266 | 1.02 | < 0.01 | 11.3 | 70.1 | 44 | 131 | 4.52 | 2.55 | 0.045 | 44.8 | 230 | 134 | 12.9 | 27.6 | 0.14 | 356 |
| **B** | 7.45 | 0.68 | 69.9 | 0.42 | < 0.01 | 2.21 | 36.7 | 15.5 | 65.1 | 4.32 | 0.5 | 0.042 | 47.8 | 119 | 143 | 7.61 | 16.3 | 0.13 | 155 |
| **C** | 7.48 | 1.03 | 9.22 | 1.27 | < 0.01 | 1.81 | 99.2 | 47.9 | 44 | 3.89 | 0.41 | 0.048 | 1.65 | 662 | 4.94 | 55.3 | 118 | 0.15 | 444 |
| **D** | 7.42 | 0.53 | 19.2 | 0.19 | < 0.01 | 1.28 | 41.9 | 12.2 | 33.2 | 3.49 | 0.29 | 0.047 | 59.5 | 86.3 | 178 | 10.8 | 23.1 | 0.14 | 155 |
| **E** | 7.39 | 0.24 | 20.3 | 0.74 | 0.78 | 0.89 | 8.96 | 3.6 | 32.1 | 2.12 | 0.2 | 0.048 | 0.22 | 91 | 0.66 | 6.49 | 13.9 | 0.15 | 37.2 |

Sand has been used as a filter material in water purification since the history of water filtration. However, it is important to have a relatively clean source of water that is free from all forms of pollution and contamination including microbiological organisms, chemicals and heavy metals, since sand cannot provide sufficient filtration for potable water.

In this light, it was noted from the laboratory test results that all sand dams in the studied area have unsafe water for drinking in its untreated form. Most of the drinking water quality parameters tested were within the required limits (optimum levels) as shown in Appendix A. However, some key parameters were below or above the recommended levels for drinking water, thus rending the water unsafe for drinking as discussed in the subsequent section.

### 4.1.1 Fecal Coliforms Bacteria

KEBs standards recommend drinking water to have zero presence of coliforms bacteria. However, all water samples tested indicated presence of coliforms bacteria. Fecal Coliforms bacteria was present in all the tested sand dams with two sites indicating high risk as shown in Fig 4-1.

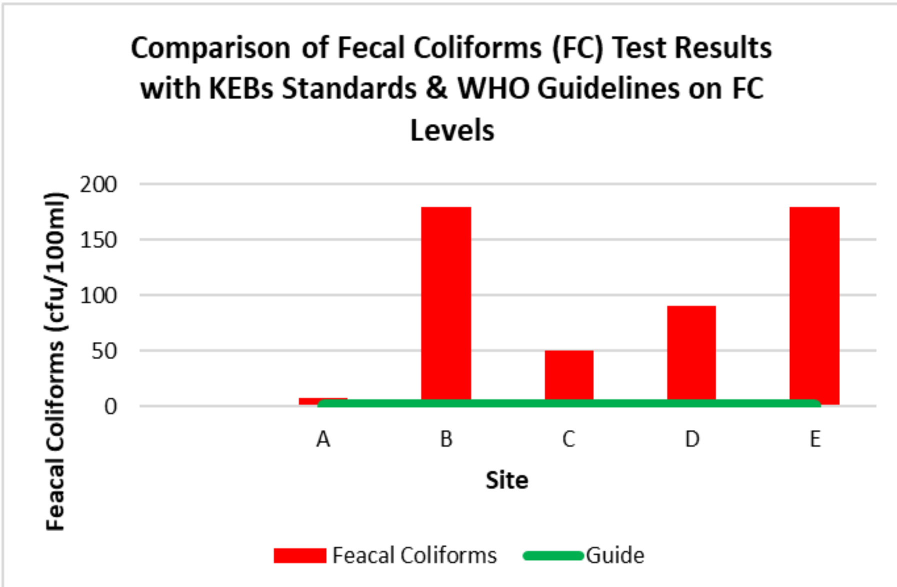



**Figure 4-1: Fecal coliforms (FC) Test Results**

*Escherichia coli (E. coli)* bacteria was also found to be present in two of the tested samples as shown in Fig 4-2.

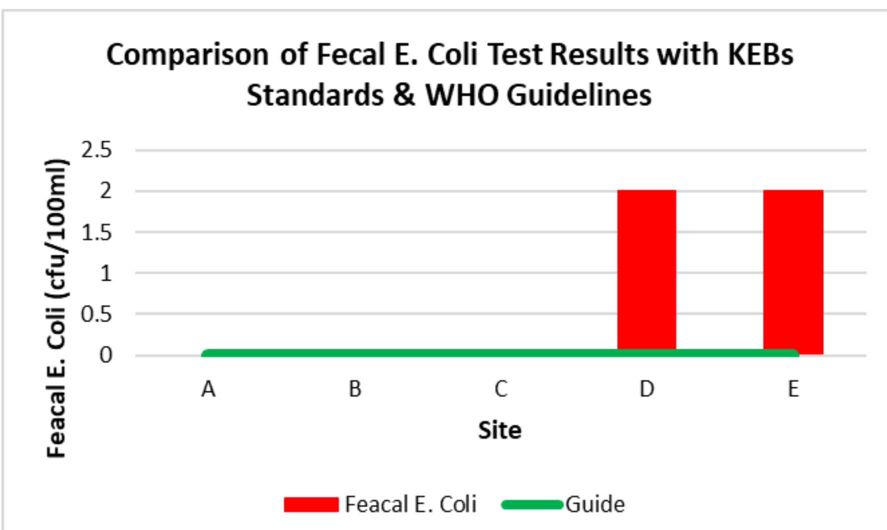



**Figure 4-2: *E. Coli* Test Results**

Coliform bacteria are found in the environment and feces of all warm-blooded animals and human beings and may not cause illnesses. However, presence of coliform bacteria in drinking water implies that the water system could contain disease-causing organisms and or pathogens.

If fecal coliform bacteria or *E. coli* are present in a water system, it is an indication of recent fecal contamination, which may pose an immediate health risk to anyone consuming the water in its raw form. Drinking water with coliform bacteria increases the risk of contracting water-borne illnesses. During the data collection exercise, it was noted that the sand dams are not protected from fecal pollution and animals graze around the river banks as others drink water directly from the sand dams and as result defecate and urinate on the sand dams. Pit latrines are the common way of disposing human waste in the area and this could also be a major contributor of fecal pollution of the sand dams. For instance, Site B (Kaiti Sand Dam) which is downstream of Wote Town (as shown in Fig 4-3) which is highly populated has high fecal coliforms levels. In addition, the method of water abstraction from sand dams may have an effect on the presence of *E. coli*. For instance, water obtained from tap and shallow well as methods of water abstraction from sand dams showed no presence of *E. coli* counts. Fecal coliforms in these sites were also lower as compared to those in the samples collected from the traditional scoop holes.


**Figure 4-3: Map showing the location of Kaiti Sand Dam**

When coliforms have been detected, repairs or modifications of the water system may be required. Boiling the water is advised until disinfection and retesting can confirm that contamination has been eliminated. A defective well is often the cause when coliform bacteria are found in well water.

In addition, it is recommended that protective measures such as; securing and fencing the sand dams to keep off animals and human from the sand dams, establishment of different watering points for livestock and domestic drinking use, discouraging the consumers from drawing water directly from the sand dams using traditional scoop holes method and advising them on appropriate point-of-use water disinfection for all domestic uses.

### 4.1.2 Turbidity

Turbidity being the amount of cloudiness in the water as an indicator of suspended materials in water can be caused by phytoplankton; silt, sand and mud; bacteria and other germs; and chemical precipitates. It is often caused by soil runoff. For drinking water, it is recommended that the turbidity should not exceed 5 NTU and should not be below 1 NTU. This might not be the case if drinking water is obtained directly from surface and subsurface water sourced like sand dams and used in its raw state.

Findings of this study indicated high turbidity than the recommended values in some sites as shown in Fig 4-4. One similarity of these sites is the method of water abstraction. Water abstracted from sand dams by traditional scoop holes method of abstraction showed high turbidity as compared to those using other methods of abstraction. Water abstracted from sand dam by use of shallow well and hand pump indicated optimum levels of turbidity.

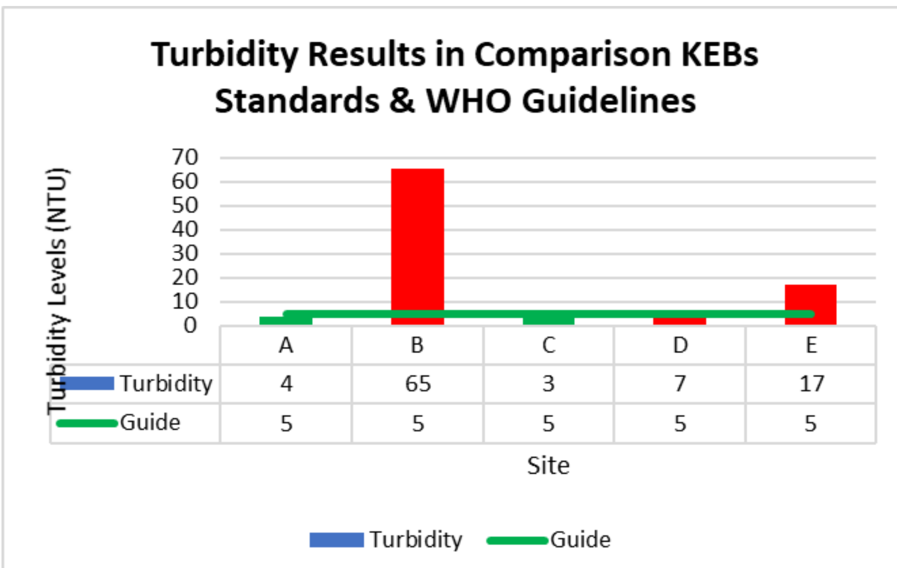



**Figure 4-4: Turbidity levels of tested Water Samples**

High turbidity reduces the aesthetic quality of drinking water significantly It can also increase the cost of drinking water treatment. To abstract water within the recommended turbidity levels, it is therefore recommended that the consumers be discouraged from using the traditional scoop holes method of abstraction and adopt other methods which indicated low turbidity such as the use of shallow wells. In addition, it is recommended that over exploitation of plant cover and overgrazing around the sand dams especially during the dry seasons be discouraged. To abstract water from sand dams with the required/low turbidity levels,

### 4.1.3 Chlorides

WHO guidelines, KEBs and NEMA standards of drinking water require chloride levels not to exceed 250 mg/l. However, the sample obtained from tapped water from Site A (Kaiti Sand Dam) indicated high levels of chlorides as shown in Fig 4-5. The difference in chloride levels in the water obtained from tapped source (site A) and that from traditional scoop holes (Site B) may be associated with the combination of the sand dam water and borehole water as indicated by Wote town residents. Sodium chloride levels greater than the recommended 250 mg/l can complicate existing heart problems and contribute to high blood pressure when ingested in excess. High levels of sodium chloride can also give drinking water an unpleasant taste.

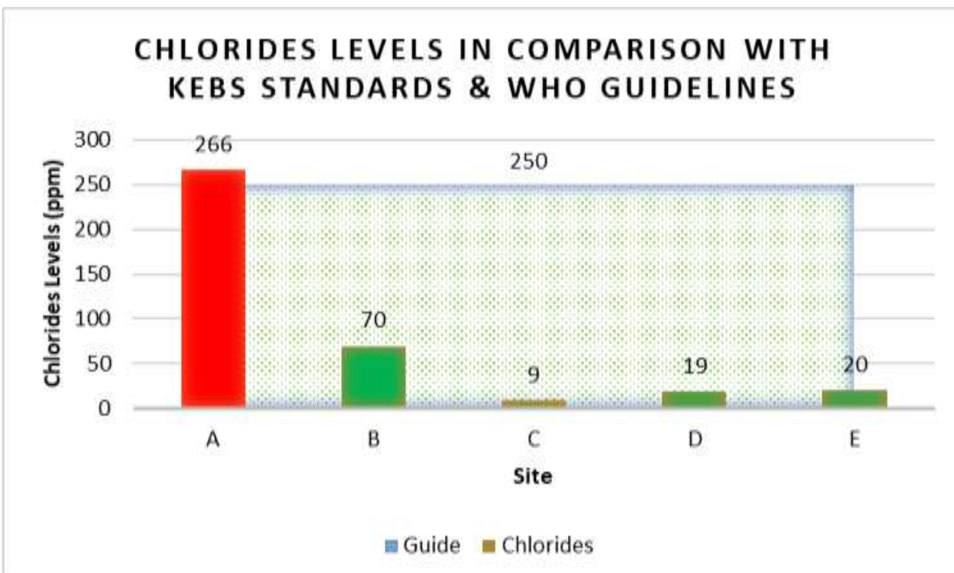



**Figure 4-5: Chloride levels Test Results**

When high levels of chloride are detected in drinking water sources, electrodialysis and distillation processes can be used to reduce the chloride content. Reverse Osmosis which removes 90 - 95% of the chlorides can also be used.

### 4.1.4 Ammonium

It is recommended that drinking water should have ammonium levels of less than 0.5 mg/l. The presence of ammonia at higher levels than this indicate presence of fecal contamination and cause taste and odor problems in drinking water. Higher level than the recommended value of ammonium was detected in Site E (Kwa Veleki Sand Dam) as shown in Fig 4-6. The dam is near various human settlements as shown in Fig 4-7. The high levels of ammonium could be as a result of presence of pit latrines which are the sole method of human waste disposal in the area. It is therefore recommended that the water be disinfected with chlorine before use.

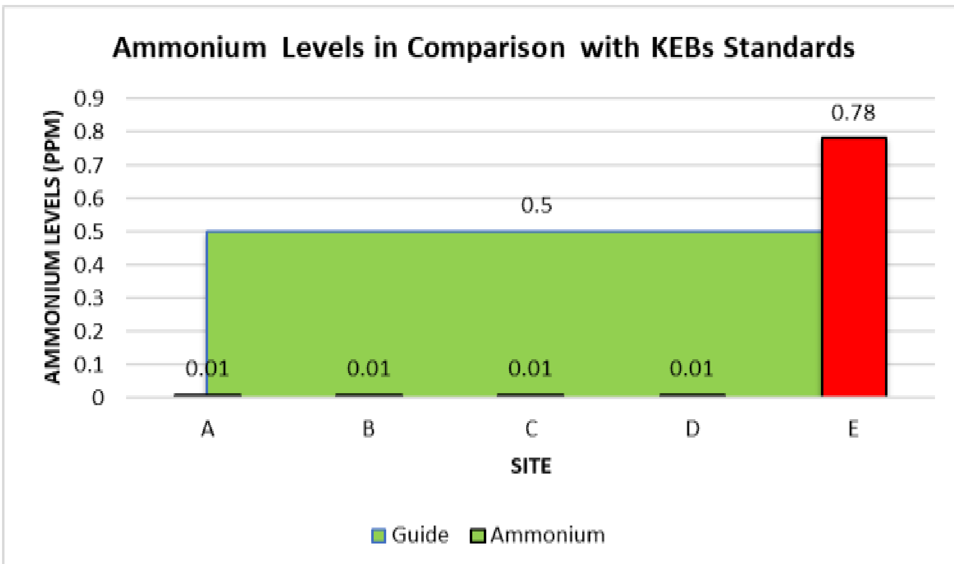



**Figure 4-6: Ammonium Levels Test Results**


**Figure 4-7: Google Map showing Kwa Veleki Sand Dam**

### 4.1.5 Bicarbonate

WHO recommends for drinking water to contain less than 250 mg/l of bicarbonate. On the contrary, Site C (Vinya Wa Mwau Sand Dam) was found to have around 662 mg/l of bicarbonate (as shown in Fig 4-8) which is way above the recommended levels of bicarbonate in drinking water. High levels of bicarbonate in drinking water has no adverse health effects. However, the water is likely to have undesirable/poor taste. Bicarbonate alkalinity is introduced in water bodies by carbon dioxide dissolving carbonate containing minerals and it is usually associated with high PH values (>8.5), which require acidification for effective chlorine treatment.

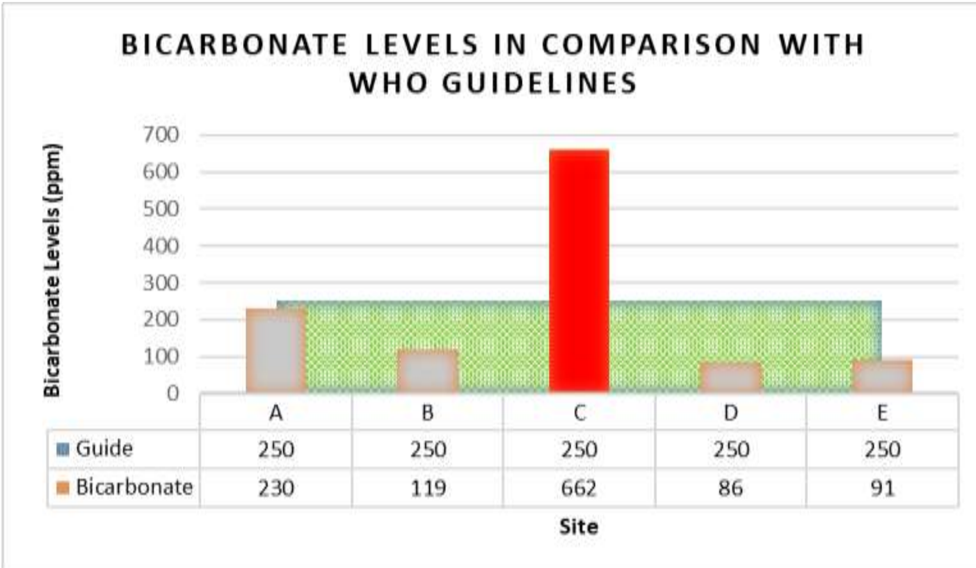



**Figure 4-8: Bicarbonate Levels of the Sampled Sites**


**Figure 4-9: Google Map showing the location of Vinya Wa Mwau Sand Dam**

Analyses of the field data and the map of the location of Vinya Wa Mwau Sand Dam shown in Fig 4-9 doesn't show any land activity that could lead to the high bicarbonate levels. However, it is recommended a detailed analysis of the soils within the dam site and upstream of the dam be done to determine the cause.

### 4.1.6 Silicon and Silica

WHO recommends silica and silicon levels in drinking water be less than 107 ppm and 50 ppm respectively. Some sites were found to have higher values than the recommended levels as shown in Figs 4-10 and 4-11. However, in drinking water only silicic acid is present and has no adverse health effects. High levels of silica can cause dandruff-like symptoms of hair flaking. Build-up of silica can choke hair follicle causing the hair to fall out. For human health purposes, it is recommended that higher levels of silica than the recommended values in drinking water be removed.

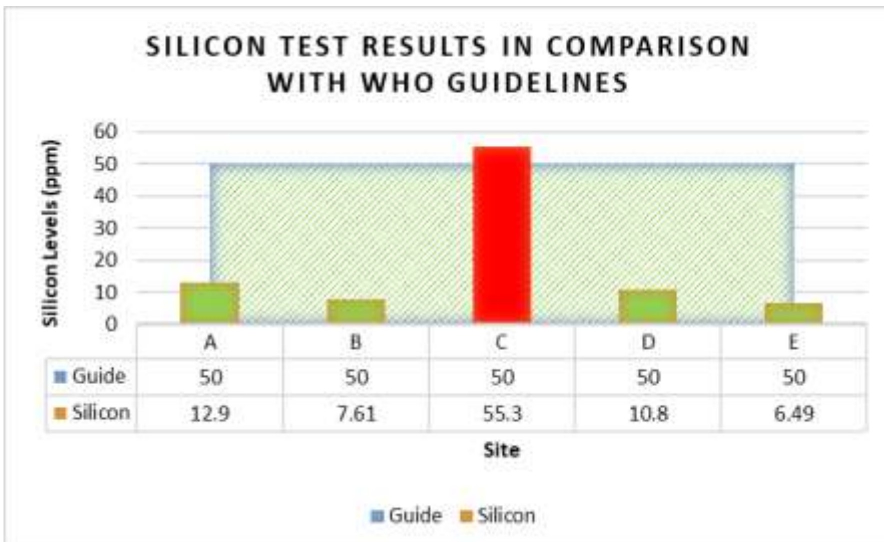



**Figure 4-10: Silica Levels of the Tested Samples**

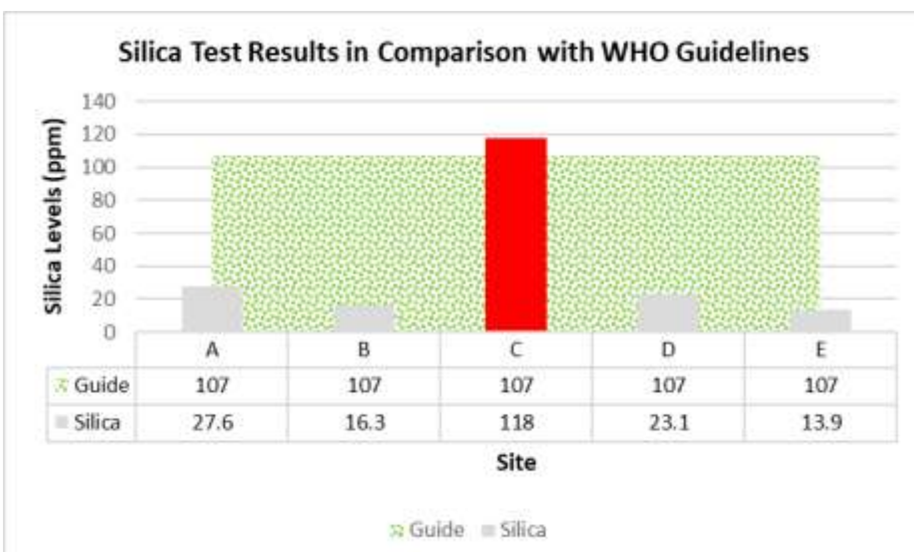
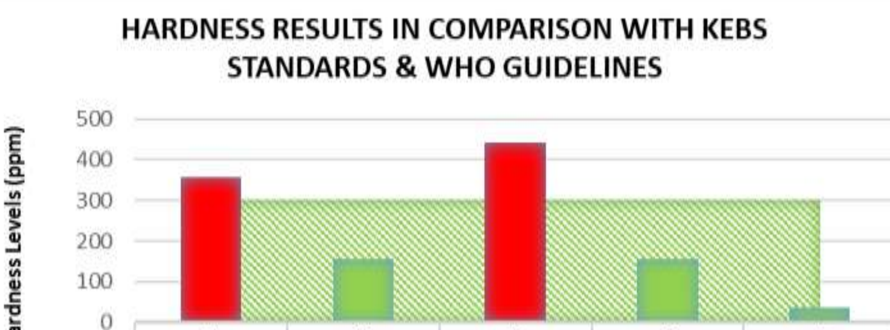



**Figure 4-11: Silicon Levels of the Tested Samples**

### 4.1.7 Hardness

Hardness in water supply is determined by the presence of calcium and magnesium salts. KEBs Standards and WHO guidelines recommends hardness levels within drinking water not to exceed 300 ppm. However, two of the studied water sources indicated high levels of hardness than the recommended values as shown in Fig 4-12.




| | A | B | C | D | E |
|---|---|---|---|---|---|
| Guide | 300 | 300 | 300 | 300 | 300 |
| Hardness | 356 | 155 | 444 | 155 | 37.2 |

**Figure 4-12: Hardness Levels of the Tested Samples**

Hard water has no known adverse health effects. However, cardiovascular mortality has been linked with the effect of magnesium or hardness on drinking water in some epidemiological studies although it has not been proved yet. In this light, when drinking water sources have tested positive on hardness beyond the recommended levels, caution must be taken on the use of the water for potable purposes in its raw form.

### 4.1.8 Manganese and Iron

Manganese and Iron occur naturally on the earth's crust as minerals. They are very common in drinking water sources. They both occur in water sources when water percolates through soil and rock, dissolves them and carries them into groundwater. If the water supply is piped in iron pipes, the pipes can corrode and leach the iron into the water supply.

For drinking water, KEBs recommends that the manganese and iron levels should not exceed 0.5 mg/l and 0.3 mg/l respectively. However, some sites had higher levels of manganese and iron as shown in Fig 4-13 and 4-14.

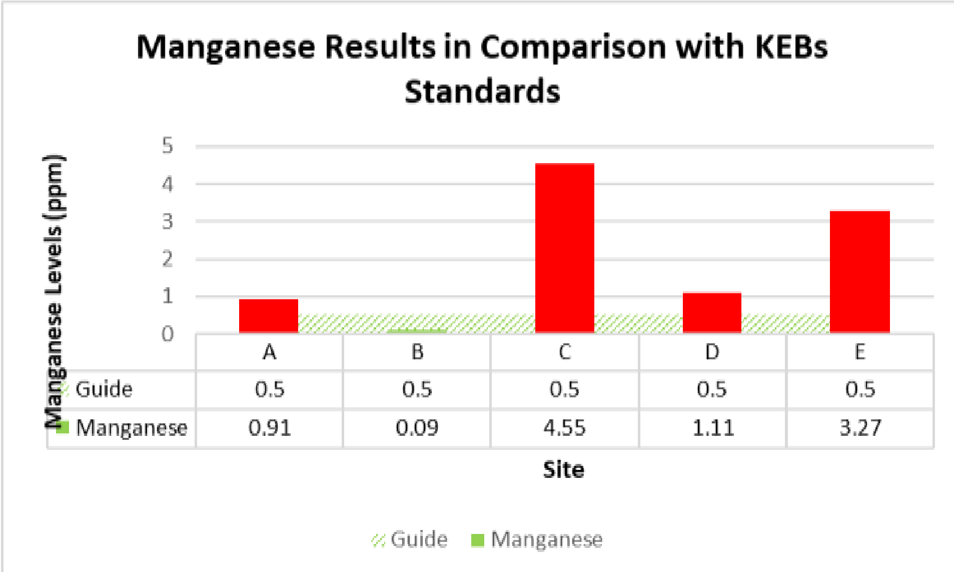



**Figure 4-13: Manganese Levels of the Tested Samples**

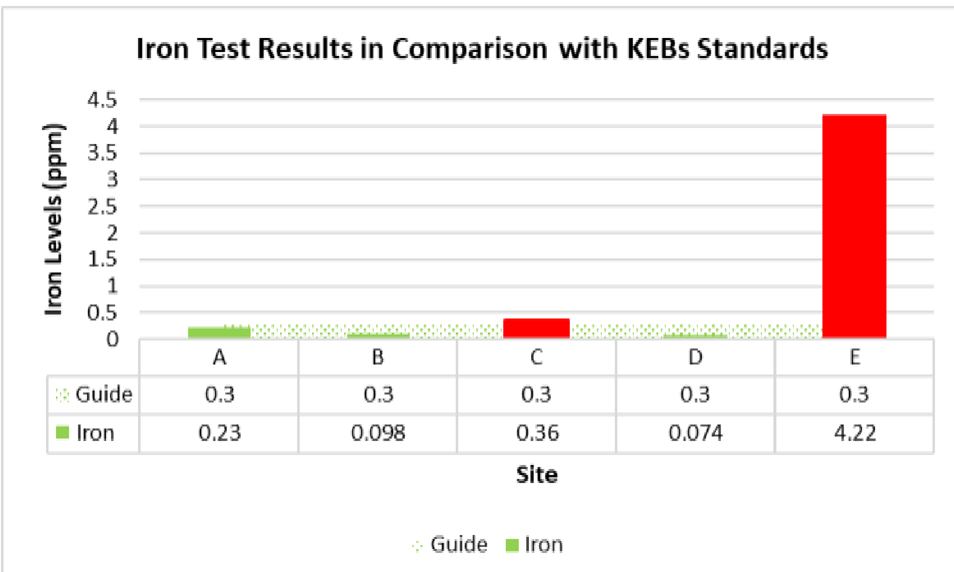



**Figure 4-14: Iron Levels of the Tested Samples**

Both manganese and iron may not have hazardous health implications. However, they cause brown discolorations of water and introduces a bitter sweet astringent taste and stains to laundered clothes (Njoroge, 2014). If dietary intake of iron in excessive amount may lead to haemosiderosis or haemochromatosis. Heamosiderosis is a condition best characterized by generalized increased iron content in the body tissue, especially in the liver and reticuloendothenal system (Njoroge, 2014).

If drinking water shows positive undesirable manganese and iron test results, it is recommended to source for an alternative drinking water source and adopt appropriate treatment methods. Aeration method is recommended for iron removal.

### 4.2 Minimum Data Set Determination

Principle Components (PCs) with eigen values >1 were used in establishing the MDS and factor 1 with an eigen value of 1.395 and cumulative % of 69.7% as shown in Table 4-4 was selected for microbial indicators. For physicochemical indicators factors 1, 2, 3 and 4 were selected as shown in Table 4-5. For the microbial indicators FC (0.84) and FCECL (0.84) showed high positive factor loading indicating that fecal coliforms concentration should be checked for potable water quality from sand dams. In factor 1 of physicochemical indicators of potable water quality pH (0.83), EC (0.99), Mg (0.95) and $CaCO_3$ (0.91) showed high positive factor loading. In factors 2, 3 and 4, Si (0.80), $SiO_2$ (0.80), $PO_4$ (0.88), P (0.80), $NH_4$ (0.67) and TUB (0.67) also showed positive factor loading indicating that they should be considered in the evaluation of sand dam water quality for potable purposes.

**Table 4-4: Result of PCA with Microbial indicators of potable water quality**

| | **Factor 1** |
|---|---|
| Eigenvalue | 1.39 |
| Variability (%) | 69.74 |
| Cumulative % | 69.74 |
| **Factor loading** | |
| FC | 0.84 |
| FCECL | 0.84 |

**Table 4-5: Result of PCA with Physicochemical indicators of potable water quality**

| | **Factor 1** | **Factor 2** | **Factor 3** | **Factor 4** |
|---|---|---|---|---|
| Eigenvalue | 8.93 | 6.99 | 2.83 | 1.25 |
| Variability (%) | 44.64 | 34.97 | 14.15 | 6.24 |
| Cumulative % | 44.64 | 79.61 | 93.76 | 100.00 |
| **Factor Loadings** | | | | |
| pH | 0.83 | -0.36 | 0.43 | -0.03 |
| EC | 0.99 | -0.11 | 0.03 | 0.01 |
| Mg | 0.95 | 0.29 | -0.09 | 0.02 |
| $CaCO_3$ | 0.91 | 0.34 | -0.21 | -0.04 |
| Si | 0.49 | 0.80 | -0.36 | 0.01 |
| $SiO_2$ | 0.49 | 0.80 | -0.36 | 0.01 |
| $PO_4$ | -0.04 | 0.88 | 0.45 | -0.17 |
| P | -0.15 | 0.80 | 0.34 | -0.48 |
| $NH_4$ | -0.65 | 0.28 | 0.67 | 0.23 |
| TUB | -0.35 | -0.50 | -0.43 | 0.67 |

## 4.3 Protocol for Evaluating Potability of Water From Sand Dams in Semi-Arid Areas

This study has showed that water from sand dams may not be safe for drinking in its raw state. Different sand dams have different water pollutants and there is need to develop a protocol for determining the potability of water from sand dams.

### 4.3.1 Main Purpose of the Protocol

The main purpose of this protocol was to provide information on how to assess the quality of raw water from sand dams; to determine the need and extent of the water treatment to make it safe for drinking; and to examine the finished water to ascertain that it conforms to the recommended drinking water standards.

The protocol will be able to determine the trend of sand dam water quality over time, identify any sources of contamination and provide information to the public health authorities and communities who are the sand dams beneficiaries.

### 4.3.2 Minimum Parameters for Evaluation

Based on the potential water contaminants, the minimum parameters to be evaluated for sand dam potable water quality can be determined and categorized as microbiological, physical, chemical or heavy metals. The minimum data set (MDS) determined with the principle component analysis (PCA) for sand dam potable water assessment comprise of microbial indicators including FC and FCECL; and physicochemical indicators including pH, EC, Mg, $CaCO_3$, Si, $SiO_2$, $PO_4$, P, $NH_4$ and TUB.

**Table 4-6: Summary of the parameters to be evaluated in potable water quality determination**

| S/No. | Parameter | Symbol | Units of Measurements | Guide Low | Guide High |
|---|---|---|---|---|---|
| **Microbiological Parameters** | | | | | |
| 1. | Feacal Coliforms | FC | cfu/100 ml | | ND |
| 2. | Feacal E. Coli | FCECL | cfu/100 ml | | ND |
| **Physical Parameters** | | | | | |
| 3. | Turbidity | TUB | NTU | | < 5.00 |
| 4. | Color | | True color units | | |
| 5. | Odour | | | | |
| **Chemical Parameters** | | | | | |
| 6. | PH | pH | | 6.50 | 8.50 |
| 7. | Electrical Conductivity | EC | mS cm -1 | | < 1.50 |
| 8. | Chlorides | Cl | Ppm | | < 250 |
| 9. | Fluorides | Fl | Ppm | | < 1.50 |
| 10. | Ammonium | $NH_4$ | Ppm | | < 0.50 |
| 11. | Nitrates | $NO_3$ | Ppm | | < 50.0 |
| 12. | Calcium | Ca | Ppm | | < 150 |
| 13. | Magnesium | Mg | Ppm | | < 100 |
| 14. | Sodium | Na | Ppm | | < 200 |
| 15. | Potassium | K | Ppm | | < 12.0 |
| 16. | Nitrate N | $NO_3N$ | Ppm | | < 11.3 |
| 17. | Phosphorus | P | Ppm | | < 0.20 |
| 18. | Sulphur | S | Ppm | | < 133 |
| 19. | Bicarbonate | $HCO_3$ | Ppm | | < 250 |
| 20. | Sulphate | $SO_4$ | Ppm | | < 400 |
| 21. | Silicon | Si | Ppm | | < 50.0 |
| 22. | Silica | $SiO_2$ | Ppm | | < 107 |
| 23. | Phosphate | $PO_4$ | Ppm | | < 0.61 |

| S/No. | Parameter | Symbol | Units of Measurements | Guide Low | Guide High |
|---|---|---|---|---|---|
| 24. | Hardness | $CaCO_3$ | Ppm | | < 300 |
| **Heavy Metals** | | | | | |
| 25. | Manganese | Mn | Ppm | | < 0.50 |
| 26. | Iron | Fe | Ppm | | < 0.30 |
| 27. | Zinc | Zn | Ppm | | < 5.00 |
| 28. | Copper | Cu | Ppm | | < 1.00 |
| 29. | Boron | B | Ppm | | < 0.30 |
| 30. | Molybdenum | Mo | Ppm | | < 0.07 |
| *ND=Not Detectable* | | | | | |

### 4.3.3 Sand Dam Characterization

When collecting water samples at a sand dam, it is important to collect data on the sand dam characteristics including the maturity state of the dam, method of water abstraction from the dam, Global Positioning System (GPS) coordinates, population density of the water users, and land use activities within the surrounding area and upstream of the water source.

### 4.3.4 Water Samples Collection

Samples should be collected from the points at which water is delivered to the consumer and or the sand dam water abstraction points. The water samples collected should be tested in a certified laboratory.

To avoid contamination, the water samples should be collected in sterile bottles and great care taken to prevent accidental contamination of the sterile bottle or water sample during sampling and transportation to the water testing laboratory. All sampling bottles should be labelled appropriately and stored in a coolant with well-regulated temperatures during transportation. The samples should be transported to the testing laboratory as soon as possible within six (6) hours of collection. The quantities for samples to be collected should be as indicated in Table 4-3.

**Table 4-7: Quantities of Samples to be Collected**

| S/No. | Analysis | Sample Quantity (litres) |
|---|---|---|
| 1. | General standard drinking water | 1 |
| 2. | Bacteriological | 1 |
| 3. | Metals | 1 |

### 4.3.5 Frequency of Testing

In order to keep a track record of the sand dams water quality for domestic purposes, regular evaluations should be done. It is recommended that the water quality assessment be done twice in a year covering the dry and wet seasons.

### 4.3.6 Reporting

The analysis results for all samples tested in the field or sent to the laboratory during the evaluation should be duly recorded and compiled. The compiled report should show all necessary information including the location from where the sample was taken, data, time, results of the test and recommendations of the appropriate corrective measure where necessary.

The report should also be shared with the sand dam water consumers to ensure that the necessary corrective measures are followed to the later. Fig 4-15 shows a schematic diagram of the procedures to be followed during sand dam potable water quality evaluation.

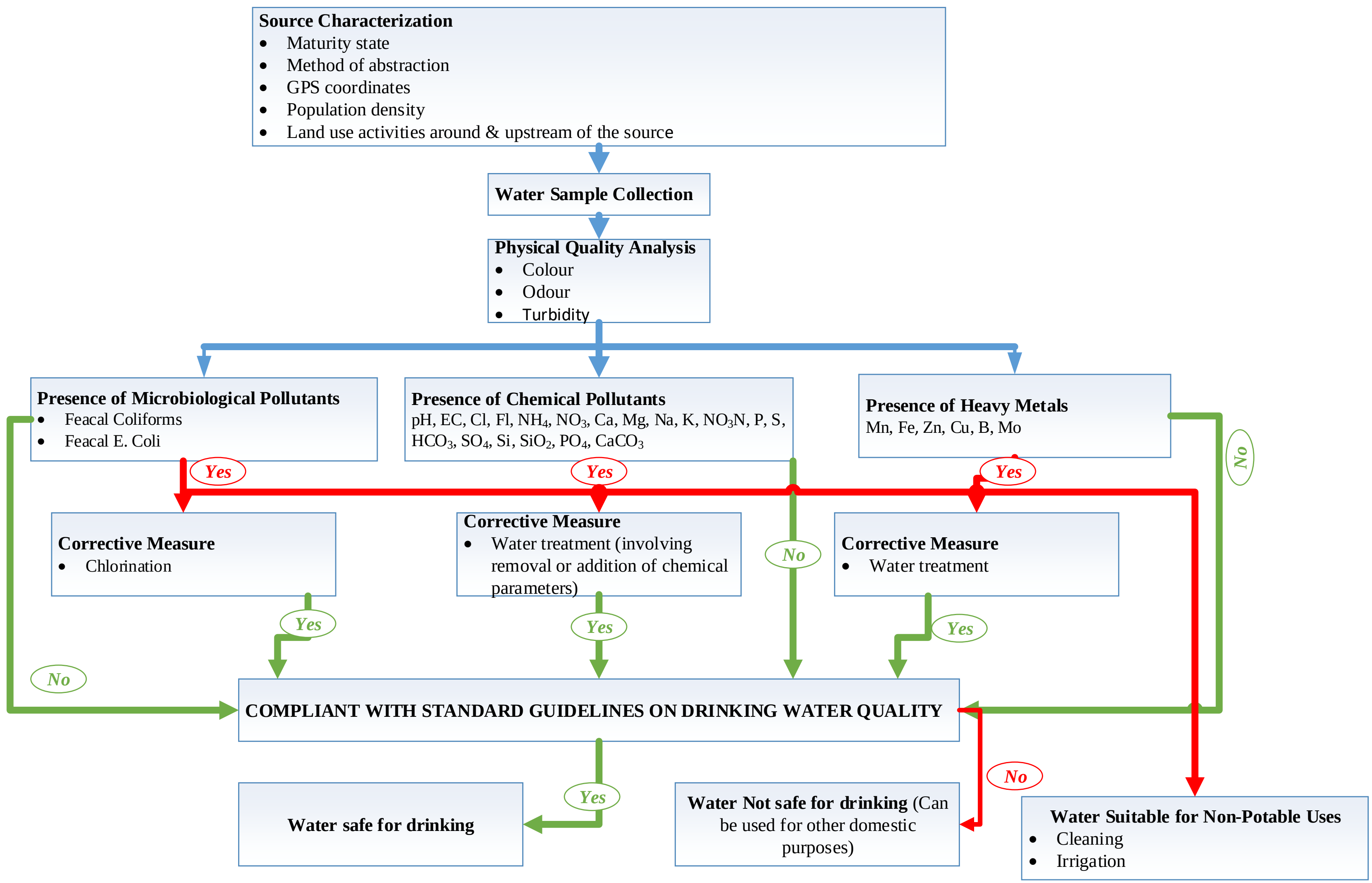



**Figure 4-15: Schematic diagram of a Protocol for evaluating Potability of Sand Dam water**

# CHAPTER FIVE

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusions

This study evaluated potability of sand dam water quality. The conclusions of the study are:

1. In the evaluation of potable water quality from sand dams, it is important to consider the three main categories of water quality indicators including the microbiological, physical and chemical indicators.
2. The minimum data set of parameters for evaluating sand dam water quality include Microbial indicators (FC & FCECL) and physicochemical indicators (pH, EC, Mg, $CaCO_3$, Si, $SiO_2$, $PO_4$, P, $NH_4$ and TUB).
3. Sand dams have unsafe water for drinking in its raw form. Therefore, for sand dam water to be potable, the sand dams need appropriate protection from all forms of pollution and contamination; and people who source potable water from sand dams need to be sensitized on the dangers of drinking untreated sand dams water and the need to adopt some forms of point-of-use water treatment for the safety of their health. Hence water from sand dams should not be used for drinking unless the water quality has been ascertained by testing the water in a certified laboratory and the water found to satisfy the recommended standards for drinking water.
4. Sand dam maturity (when a sand dam is filled with sand with 25-40% of its volume being water) is very crucial for optimal water quality. This was evident by the water quality results from Vinya Wa Mwau Sand Dam, a newly constructed immature sand dam which had most of its water quality indicators above the acceptable levels.

5. A '*Protocol for Evaluating Potability of Water from Sand Dams*' was developed during this study & it is recommended for use before any sand dam is declared safe for drinking water provision.

## 5.2 Recommendations

The recommendations of the study are:

1. This study assessed sand dam water quality during the dry season when it is considered as the time when sand dams are most required sources of water in the ASALs. For a proper trend of sand dam water quality over time, further studies of the water quality should be done for alternative season covering the rainy season when pollution is more prone.

2. Detailed analysis of the effects of soil characteristics (within the dam site and upstream of the dam) on water quality be done.
3. Future testing of the protocol should be done.

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**APPENDICES**

## 7.1 Appendix A: Results Analysis

**Water Source: Kaiti Sand Dam, Scoophole (Site A)**

| S/No. | Parameter | Symbol | Units of Measurements | Guide Low | Guide High | Result | Low | Optimum | High | Method of Lab Analysis |
|---|---|---|---|---|---|---|---|---|---|---|
| **Microbiological Parameters** | | | | | | | | | | |
| 1. | Feacal Coliforms | FC | cfu/100 ml | | ND | **8** | | | | ISO 9308-2 |
| 2. | Feacal E. Coli | FCECL | cfu/100 ml | | ND | **ND** | | | | ISO 9308-2 |
| **Physical Parameters** | | | | | | | | | | |
| 3. | Turbidity | TUB | NTU | | < 5.00 | **3.77** | | | | Turbidimetry |
| 4. | Color | | True color units | | | **Clear** | | | | |
| 5. | Odour | | | | | **Without odour** | | | | |
| **Chemical Parameters** | | | | | | | | | | |
| 6. | PH | pH | | 6.50 | 8.50 | **7.95** | | | | Potentiometric |
| 7. | Electrical Conductivity | EC | mS cm -1 | | < 1.50 | **1.45** | | | | Potentiometric |
| 8. | Chlorides | Cl | Ppm | | < 250 | **266** | | | | Colorimetric |
| 9. | Fluorides | Fl | Ppm | | < 1.50 | **1.02** | | | | Colorimetric |
| 10. | Ammonium | $NH_4$ | Ppm | | < 0.50 | **< 0.01** | | | | Colorimetric |
| 11. | Nitrates | $NO_3$ | Ppm | | < 50.0 | **11.3** | | | | Colorimetric |
| 12. | Calcium | Ca | Ppm | | < 150 | **70.1** | | | | Spectroscopy |
| 13. | Magnesium | Mg | Ppm | | < 100 | **44.0** | | | | Spectroscopy |
| 14. | Sodium | Na | Ppm | | < 200 | **131** | | | | Spectroscopy |
| 15. | Potassium | K | Ppm | | < 12.0 | **4.520** | | | | Spectroscopy |
| 16. | Nitrate N | $NO_3N$ | Ppm | | < 11.3 | **2.55** | | | | Colorimetric |

| S/No. | Parameter | Symbol | Units of Measurements | Guide Low | Guide High | Result | Low | Optimum | High | Method of Lab Analysis |
|---|---|---|---|---|---|---|---|---|---|---|
| 17. | Phosphorus | P | Ppm | | < 0.20 | **0.045** | | | | Spectroscopy |
| 18. | Sulphur | S | Ppm | | < 133 | **44.8** | | | | Spectroscopy |
| 19. | Bicarbonate | $HCO_3$ | Ppm | | < 250 | **230** | | | | Colorimetric |
| 20. | Sulphate | SO4 | Ppm | | < 400 | **134** | | | | Spectroscopy |
| 21. | Silicon | Si | Ppm | | < 50.0 | **12.9** | | | | Spectroscopy |
| 22. | Silica | $SiO_2$ | Ppm | | < 107 | **27.6** | | | | Spectroscopy |
| 23. | Phosphate | $PO_4$ | Ppm | | < 0.61 | **0.14** | | | | Spectroscopy |
| 24. | Hardness | $CaCO_3$ | Ppm | | < 300 | **356** | | | | Calculated |
| **Heavy Metals** | | | | | | | | | | |
| 25. | Manganese | Mn | Ppm | | < 0.50 | **0.91** | | | | Spectroscopy |
| 26. | Iron | Fe | Ppm | | < 0.30 | **0.23** | | | | Spectroscopy |
| 27. | Zinc | Zn | Ppm | | < 5.00 | **0.71** | | | | Spectroscopy |
| 28. | Copper | Cu | Ppm | | < 1.00 | **< 0.01** | | | | Spectroscopy |
| 29. | Boron | B | Ppm | | < 0.30 | 0.058 | | | | Spectroscopy |
| 30. | Molybdenum | Mo | Ppm | | < 0.07 | < 0.01 | | | | Spectroscopy |
| *ND=Not Detectable* | | | | | | | | | | |

**Water Source: Kaiti Sand Dam, Piped with a Tap (Site B)**

| S/No. | Parameter | Symbol | Units of Measurements | Guide Low | Guide High | Result | Low | Optimum | High | Method of Lab Analysis |
|---|---|---|---|---|---|---|---|---|---|---|
| **Microbiological Parameters** | | | | | | | | | | |
| 1. | Feacal Coliforms | FC | cfu/100 ml | | ND | **> 180** | | | | ISO 9308-2 |
| 2. | Feacal E. Coli | FCECL | cfu/100 ml | | ND | **ND** | | | | ISO 9308-2 |
| **Physical Parameters** | | | | | | | | | | |
| 3. | Turbidity | TUB | NTU | | < 5.00 | **65.30** | | | | Turbidimetry |
| 4. | Color | | True color units | | | **Clear** | | | | |
| 5. | Odour | | | | | **Without odour** | | | | |
| **Chemical Parameters** | | | | | | | | | | |
| 6. | PH | pH | | 6.50 | 8.50 | **7.45** | | | | Potentiometric |
| 7. | Electrical Conductivity | EC | mS cm -1 | | < 1.50 | **0.68** | | | | Potentiometric |
| 8. | Chlorides | Cl | ppm | | < 250 | **70** | | | | Colorimetric |
| 9. | Fluorides | Fl | ppm | | < 1.50 | **0.42** | | | | Colorimetric |
| 10. | Ammonium | NH4 | ppm | | < 0.50 | **< 0.01** | | | | Colorimetric |
| 11. | Nitrates | $NO_3$ | ppm | | < 50.0 | **2.2** | | | | Colorimetric |
| 12. | Calcium | Ca | ppm | | < 150 | **36.7** | | | | Spectroscopy |
| 13. | Magnesium | Mg | ppm | | < 100 | **15.5** | | | | Spectroscopy |
| 14. | Sodium | Na | ppm | | < 200 | **65** | | | | Spectroscopy |
| 15. | Potassium | K | ppm | | < 12.0 | **4.32** | | | | Spectroscopy |
| 16. | Nitrate N | $NO_3N$ | ppm | | < 11.3 | **0.50** | | | | Colorimetric |
| 17. | Phosphorus | P | ppm | | < 0.20 | **0.042** | | | | Spectroscopy |
| 18. | Sulphur | S | ppm | | < 133 | **47.8** | | | | Spectroscopy |
| 19. | Bicarbonate | $HCO_3$ | ppm | | < 250 | **119** | | | | Colorimetric |

| S/No. | Parameter | Symbol | Units of Measurements | Guide Low | Guide High | Result | Low | Optimum | High | Method of Lab Analysis |
|---|---|---|---|---|---|---|---|---|---|---|
| 20. | Sulphate | $SO_4$ | ppm | | < 400 | **143** | | | | Spectroscopy |
| 21. | Silicon | Si | ppm | | < 50.0 | **7.6** | | | | Spectroscopy |
| 22. | Silica | $SiO_2$ | ppm | | < 107 | **16.3** | | | | Spectroscopy |
| 23. | Phosphate | $PO_4$ | ppm | | < 0.61 | **0.13** | | | | Spectroscopy |
| 24. | Hardness | $CaCO_3$ | ppm | | < 300 | **155** | | | | Calculated |
| **Heavy Metals** | | | | | | | | | | |
| 25. | Manganese | Mn | ppm | | < 0.50 | **0.09** | | | | Spectroscopy |
| 26. | Iron | Fe | ppm | | < 0.30 | **0.10** | | | | Spectroscopy |
| 27. | Zinc | Zn | ppm | | < 5.00 | **0.01** | | | | Spectroscopy |
| 28. | Copper | Cu | ppm | | < 1.00 | **< 0.01** | | | | Spectroscopy |
| 29. | Boron | B | ppm | | < 0.30 | **0.033** | | | | Spectroscopy |
| 30. | Molybdenum | Mo | ppm | | < 0.07 | **< 0.01** | | | | Spectroscopy |
| *ND=Not Detectable* | | | | | | | | | | |

**Water Source: Vinya Wa Mwau Sand Dam (Site C)**

| S/No. | Parameter | Symbol | Units of Measurements | Guide Low | Guide High | Result | Low | Optimum | High | Method of Lab Analysis |
|---|---|---|---|---|---|---|---|---|---|---|
| **Microbiological Parameters** | | | | | | | | | | |
| 1. | Feacal Coliforms | FC | cfu/100 ml | | ND | **50** | | | | ISO 9308-2 |
| 2. | Feacal E. Coli | FCECL | cfu/100 ml | | ND | **ND** | | | | ISO 9308-2 |
| **Physical Parameters** | | | | | | | | | | |
| 3. | Turbidity | TUB | NTU | | < 5.00 | **3.23** | | | | Turbidimetry |
| 4. | Color | | True color units | | | **Clear** | | | | |
| 5. | Odour | | | | | **Without odour** | | | | |
| **Chemical Parameters** | | | | | | | | | | |
| 6. | PH | pH | | 6.50 | 8.50 | **7.48** | | | | Potentiometric |
| 7. | Electrical Conductivity | EC | mS cm -1 | | < 1.50 | **1.03** | | | | Potentiometric |
| 8. | Chlorides | Cl | Ppm | | < 250 | **9** | | | | Colorimetric |
| 9. | Fluorides | Fl | Ppm | | < 1.50 | **1.27** | | | | Colorimetric |
| 10. | Ammonium | $NH_4$ | Ppm | | < 0.50 | **< 0.01** | | | | Colorimetric |
| 11. | Nitrates | $NO_3$ | Ppm | | < 50.0 | **1.8** | | | | Colorimetric |
| 12. | Calcium | Ca | Ppm | | < 150 | **99.2** | | | | Spectroscopy |
| 13. | Magnesium | Mg | Ppm | | < 100 | **47.9** | | | | Spectroscopy |
| 14. | Sodium | Na | Ppm | | < 200 | **44** | | | | Spectroscopy |
| 15. | Potassium | K | Ppm | | < 12.0 | **3.89** | | | | Spectroscopy |
| 16. | Nitrate N | $NO_3N$ | Ppm | | < 11.3 | **0.41** | | | | Colorimetric |
| 17. | Phosphorus | P | Ppm | | < 0.20 | **0.048** | | | | Spectroscopy |
| 18. | Sulphur | S | Ppm | | < 133 | **1.7** | | | | Spectroscopy |
| 19. | Bicarbonate | $HCO_3$ | Ppm | | < 250 | **662** | | | | Colorimetric |
| 20. | Sulphate | $SO_4$ | Ppm | | < 400 | **5** | | | | Spectroscopy |

| S/No. | Parameter | Symbol | Units of Measurements | Guide Low | Guide High | Result | Low | Optimum | High | Method of Lab Analysis |
|---|---|---|---|---|---|---|---|---|---|---|
| 21. | Silicon | Si | Ppm | | < 50.0 | **55.3** | | | | Spectroscopy |
| 22. | Silica | $SiO_2$ | Ppm | | < 107 | **118.0** | | | | Spectroscopy |
| 23. | Phosphate | $PO_4$ | Ppm | | < 0.61 | **0.15** | | | | Spectroscopy |
| 24. | Hardness | $CaCO_3$ | Ppm | | < 300 | **444** | | | | Calculated |
| **Heavy Metals** | | | | | | | | | | |
| 25. | Manganese | Mn | Ppm | | < 0.50 | **4.55** | | | | Spectroscopy |
| 26. | Iron | Fe | Ppm | | < 0.30 | **0.36** | | | | Spectroscopy |
| 27. | Zinc | Zn | Ppm | | < 5.00 | **0.03** | | | | Spectroscopy |
| 28. | Copper | Cu | Ppm | | < 1.00 | **< 0.01** | | | | Spectroscopy |
| 29. | Boron | B | Ppm | | < 0.30 | **0.046** | | | | Spectroscopy |
| 30. | Molybdenum | Mo | Ppm | | < 0.07 | **0.014** | | | | Spectroscopy |
| *ND=Not Detectable* | | | | | | | | | | |

**Water Source: Kiaoni Sand Dam (Site D)**

| S/No. | Parameter | Symbol | Units of Measurements | Guide Low | Guide High | Result | Low | Optimum | High | Method of Lab Analysis |
|---|---|---|---|---|---|---|---|---|---|---|
| **Microbiological Parameters** | | | | | | | | | | |
| 1. | Feacal Coliforms | FC | cfu/100 ml | | ND | **90** | | | | ISO 9308-2 |
| 2. | Feacal E. Coli | FCECL | cfu/100 ml | | ND | **2** | | | | ISO 9308-2 |
| **Physical Parameters** | | | | | | | | | | |
| 3. | Turbidity | TUB | NTU | | < 5.00 | **6.73** | | | | Turbidimetry |
| 4. | Color | | True color units | | | **Clear** | | | | |
| 5. | Odour | | | | | **Without odour** | | | | |
| **Chemical Parameters** | | | | | | | | | | |
| 6. | PH | pH | | 6.50 | 8.50 | **7.42** | | | | Potentiometric |
| 7. | Electrical Conductivity | EC | mS cm -1 | | < 1.50 | **0.53** | | | | Potentiometric |
| 8. | Chlorides | Cl | Ppm | | < 250 | **19** | | | | Colorimetric |
| 9. | Fluorides | Fl | Ppm | | < 1.50 | **0.19** | | | | Colorimetric |
| 10. | Ammonium | $NH_4$ | Ppm | | < 0.50 | **< 0.01** | | | | Colorimetric |
| 11. | Nitrates | $NO_3$ | Ppm | | < 50.0 | **1.3** | | | | Colorimetric |
| 12. | Calcium | Ca | Ppm | | < 150 | **41.9** | | | | Spectroscopy |
| 13. | Magnesium | Mg | Ppm | | < 100 | **12.2** | | | | Spectroscopy |
| 14. | Sodium | Na | Ppm | | < 200 | **33** | | | | Spectroscopy |
| 15. | Potassium | K | Ppm | | < 12.0 | **3.49** | | | | Spectroscopy |
| 16. | Nitrate N | $NO_3N$ | Ppm | | < 11.3 | **0.29** | | | | Colorimetric |
| 17. | Phosphorus | P | Ppm | | < 0.20 | **0.047** | | | | Spectroscopy |
| 18. | Sulphur | S | Ppm | | < 133 | **59.5** | | | | Spectroscopy |
| 19. | Bicarbonate | $HCO_3$ | Ppm | | < 250 | **86** | | | | Colorimetric |

| S/No. | Parameter | Symbol | Units of Measurements | Guide Low | Guide High | Result | Low | Optimum | High | Method of Lab Analysis |
|---|---|---|---|---|---|---|---|---|---|---|
| 20. | Sulphate | $SO_4$ | Ppm | | < 400 | **178** | | | | Spectroscopy |
| 21. | Silicon | Si | Ppm | | < 50.0 | **10.8** | | | | Spectroscopy |
| 22. | Silica | $SiO_2$ | Ppm | | < 107 | **23.1** | | | | Spectroscopy |
| 23. | Phosphate | $PO_4$ | Ppm | | < 0.61 | **0.14** | | | | Spectroscopy |
| 24. | Hardness | $CaCO_3$ | Ppm | | < 300 | **155** | | | | Calculated |
| **Heavy Metals** | | | | | | | | | | |
| 25. | Manganese | Mn | Ppm | | < 0.50 | **1.11** | | | | Spectroscopy |
| 26. | Iron | Fe | Ppm | | < 0.30 | **0.07** | | | | Spectroscopy |
| 27. | Zinc | Zn | Ppm | | < 5.00 | **0.02** | | | | Spectroscopy |
| 28. | Copper | Cu | Ppm | | < 1.00 | **< 0.01** | | | | Spectroscopy |
| 29. | Boron | B | Ppm | | < 0.30 | **0.033** | | | | Spectroscopy |
| 30. | Molybdenum | Mo | Ppm | | < 0.07 | **< 0.01** | | | | Spectroscopy |
| *ND=Not Detectable* | | | | | | | | | | |

**Water Source: Kwa Veleki Sand Dam (Site E)**

| S/No. | Parameter | Symbol | Units of Measurements | Guide Low | Guide High | Result | Low | Optimum | High | Method of Lab Analysis |
|---|---|---|---|---|---|---|---|---|---|---|
| **Microbiological Parameters** | | | | | | | | | | |
| 1. | Feacal Coliforms | FC | cfu/100 ml | | ND | **> 180** | | | | ISO 9308-2 |
| 2. | Feacal E. Coli | FCECL | cfu/100 ml | | ND | **2** | | | | ISO 9308-2 |
| **Physical Parameters** | | | | | | | | | | |
| 3. | Turbidity | TUB | NTU | | < 5.00 | **17.20** | | | | Turbidimetry |
| 4. | Color | | True color units | | | **Clear** | | | | |
| 5. | Odour | | | | | **Without odour** | | | | |
| **Chemical Parameters=** | | | | | | | | | | |
| 6. | PH | pH | | 6.50 | 8.50 | **7.39** | | | | Potentiometric |
| 7. | Electrical Conductivity | EC | mS cm -1 | | < 1.50 | **0.24** | | | | Potentiometric |
| 8. | Chlorides | Cl | Ppm | | < 250 | **20** | | | | Colorimetric |
| 9. | Fluorides | Fl | ppm | | < 1.50 | **0.74** | | | | Colorimetric |
| 10. | Ammonium | $NH_4$ | ppm | | < 0.50 | **0.78** | | | | Colorimetric |
| 11. | Nitrates | $NO_3$ | ppm | | < 50.0 | **0.9** | | | | Colorimetric |
| 12. | Calcium | Ca | ppm | | < 150 | **9.0** | | | | Spectroscopy |
| 13. | Magnesium | Mg | ppm | | < 100 | **3.6** | | | | Spectroscopy |
| 14. | Sodium | Na | ppm | | < 200 | **32** | | | | Spectroscopy |
| 15. | Potassium | K | ppm | | < 12.0 | **2.12** | | | | Spectroscopy |
| 16. | Nitrate N | $NO_3N$ | ppm | | < 11.3 | **0.20** | | | | Colorimetric |
| 17. | Phosphorus | P | ppm | | < 0.20 | **0.048** | | | | Spectroscopy |
| 18. | Sulphur | S | ppm | | < 133 | **0.2** | | | | Spectroscopy |
| 19. | Bicarbonate | $HCO_3$ | ppm | | < 250 | **91** | | | | Colorimetric |

| S/No. | Parameter | Symbol | Units of Measurements | Guide Low | Guide High | Result | Low | Optimum | High | Method of Lab Analysis |
|---|---|---|---|---|---|---|---|---|---|---|
| 20. | Sulphate | $SO_4$ | ppm | | < 400 | **1** | | | | Spectroscopy |
| 21. | Silicon | Si | ppm | | < 50.0 | **6.5** | | | | Spectroscopy |
| 22. | Silica | $SiO_2$ | ppm | | < 107 | **13.9** | | | | Spectroscopy |
| 23. | Phosphate | $PO_4$ | ppm | | < 0.61 | **0.15** | | | | Spectroscopy |
| 24. | Hardness | $CaCO_3$ | ppm | | < 300 | **37** | | | | Calculated |
| **Heavy Metals** | | | | | | | | | | |
| 25. | Manganese | Mn | ppm | | < 0.50 | **3.27** | | | | Spectroscopy |
| 26. | Iron | Fe | ppm | | < 0.30 | **4.22** | | | | Spectroscopy |
| 27. | Zinc | Zn | ppm | | < 5.00 | **< 0.01** | | | | Spectroscopy |
| 28. | Copper | Cu | ppm | | < 1.00 | **< 0.01** | | | | Spectroscopy |
| 29. | Boron | B | ppm | | < 0.30 | **0.028** | | | | Spectroscopy |
| 30. | Molybdenum | Mo | ppm | | < 0.07 | **< 0.01** | | | | Spectroscopy |
| *ND=Not Detectable* | | | | | | | | | | |

## 7.2 Appendix B: Maps


**Figure 7-1: Map Showing Kiaoni Sand Dam**

### 7.3 Appendix C: Photographs

**Plate 7-1: Kaiti Sand Dam**

**Plate 7-2: Water Abstraction by Traditional Scoop Holes at Kaiti Sand Dam**

**Plate 7-3: Donkeys ferrying water from Kaiti Sand Dam to Wote Town**

**Plate 7-4: Vinya Wa Mwau Sand Dam**


**Plate 7-5: Kiaoni Sand Dam**

**Plate 7-6: Kwa Veleki Sand Dam**