DETERMINATION OF EFFECTIVE COMBINATIONS OF SELECTED LOCAL MATERIALS FOR TREATMENT OF BOREHOLE WATER AND TO COMPARE THEIR EFFECIENCY WITH MUNICIPAL WATER TREATMENT TECHNOLOGY

BY

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DECLARATION

This thesis is my original work and has not been presented for award of a degree at Maseno University or in any other University.

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DEDICATION

To my adorable parents, Mr. Aloys Agunja Olwa and Mrs. Felicitas Atieno Agunja.

ABSTRACT

Use of contaminated water risks human lives hence should be treated to meet drinking water quality guidelines. The most applied technique is municipal water treatment technology (MWTT) though inaccessible in peri-urban/rural settings leading to use of untreated water like borehole waters. Desirable water treatment processes need to be developed for provision of portable water. Local materials such as *Moringa oleifera* seed, activated clay, activated charcoal and natural zeolite have been applied individually but are not effective in safeguarding drinking water. Therefore, there is need to determine efficacy of combinations of local materials. The objectives of this study were to determine the physico-chemical parameters and *Escherichia coli* of fresh and salty borehole waters and treatment effects of individual and combinations of local materials in comparison with the World Health Organisation (WHO) guidelines. The study also determined effective treatment combination for each borehole and compared their efficiency with MWTT. Water samples from each borehole were collected in triplicate. Temperature, pH, total dissolved solids, electrical conductivity, dissolved oxygen, total solids and *Escherichia coli* were determined before treatment. The samples were treated by passing through columns containing individual and combinations of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite to determine the treatment effects by comparing with data before treatment. The different combinations were calculated from permutation formulae where order was taken into account while effective treatment combinations were determined from the least summation of variance from WHO guidelines for each parameter for a particular combination. The data was analyzed by MSTATC statistical package and ANOVA ($p \leq 0.05$) was used to determine significance differences between data. Combination V (Activated charcoal → *Moringa oleifera* seed water extract → Activated clay → Natural zeolite) was effective for fresh borehole water and was better than all individual materials on TS, activated charcoal on pH, TDS, EC and *Escherichia coli* and natural zeolite on *Escherichia coli*. Combination U (Activated charcoal → Natural zeolite → Activated clay → *Moringa oleifera* seed water extract) was effective for salty borehole water and was better than activated charcoal on pH, TDS, EC and TS and natural zeolite on TS. Effective combinations also showed better treatment effects on dissolved oxygen, total solids and *Escherichia coli* of 34.5%, 38.7% and 99.8% for combination V and 30.7%, 54.0% and 99.6% for combination U compared to 8.1%, 31.9% and 99.2% for MWTT respectively. Combinations of local materials show potentiality in contaminated water treatment.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
APHA	American Public Health Association
AWWA	American Water Works Association
CEC	Cation Exchange Capacity
CFU	Colon Forming Units
COD	Chemical Oxygen Demand
DBPs	Disinfection By-Products
DO	Dissolved Oxygen
EC	Electrical Conductivity
EDCs	Endocrine Disrupting Compounds
EPA	Environmental Protection Agency
FBW	Fresh Borehole Water
LCD	Liquid Crystal Display
LPL	Lower Permissible Limit
LSD	Least Significance Difference
MWTT	Municipal Water Treatment Technology
PL	Permissible Limit
SBW	Salty Borehole Water
TDS	Total Dissolved Solids
THMs	Trihalomethanes
TS	Total Solids
UNICEF	United Nations Children’s Fund
UPL	Upper Permissible Limit
WEF	Water Environment Federation
WHO	World Health Organization

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CHAPTER ONE

INTRODUCTION

This section highlights the background, statement of the problem, objectives, research hypothesis, justification and significance of the study.

1.1 Background of the study

Water treatment before consumption by human beings is essential so as to reduce the risk of contracting waterborne diseases. The Sanskrit writings (earliest civilizations with written records) outlined various methods of water treatment which produced better tasting drinking water assuming that good tasting water was clean (Early Water Treatment, 2009). This assumption ignored the presence of harmful organisms and sediments in contaminated water. Various improved techniques such as advanced oxidation processes, flotation, membrane filtration and reverse osmosis (Roberto *et. al*., 1999; Rubio *et. al*., 2002; Zularisam *et. al.*, 2006; Lauren *et. al.*, 2009), amongst others, have been put in use but the most applied technique worldwide is the municipal water treatment technology (MWTT).

Despite these efforts, improved water sources are often located far from user household and often occur at inconvenient locations. This results into inadequate supply and lack of water quality being the characteristics of many improved water treatment techniques (Admasu *et al*., 2002). Consequently, the disadvantaged population relies on alternative sources of water such as wells, streams, rain water, springs and individual boreholes for their domestic uses (Agbelemoge and Odubanjo, 2001). Water from these sources is usually untested before use and may be contaminated; consumption of unsafe water is harmful and could easily promote high mortality rates due to waterborne diseases (Kwakye-Nuako *et al*., 2007). Drinking water quality parameters such as temperature, pH, total dissolved solids, electrical conductivity, dissolved oxygen, total solids and *Escherichia coli* (*E. coli)* count could be associated with these untested water sources. The need to assess the quality of water from some of these alternative sources is imperative because they could have a direct effect on the health of individuals (WHO, 2002).

Research is being conducted worldwide in order to develop alternative technologies that can be used in water treatment at household levels (Oluruntande and Afuye, 2013; Coetzee *et al*., 2003; Mjengera and Mkongo, 2003; Sajidu *et al.*, 2012). Recent studies have shown the use of local materials for various water contaminants in local communities in Kenya: *Moringa oleifera* seed extract (Arama *et. al.,* 2011), clays (Chung *et al*., 2013), activated carbon (Kakoi, *et. al.,* 2015) and natural zeolite (Shikuku *et al*., 2015). These materials when individually used, realize results that are not efficacious for all drinking water quality parameters as to meet the World Health Organisation (WHO) guidelines of drinking water. *Moringa oleifera* seed extract has been used in coagulation-flocculation and bacterial decontamination and are reported to have an effect of 92-99% turbidity removal (Muyibi and Alfugara, 2003) and 90-99% reduction in faecal coliform levels (Boateng, 2001). Activated clay has also been used in the up-take of cations and anions and an earlier study indicated that it has a high adsorptive capacity (Nwokem *et al.,* 2012). On the other hand, activated charcoal has been used in adsorption of organic compounds and a study showed that it has an adsorption capacity that fits well in the Langmuir equation with maximum adsorption capacity of 454.2 mg/g (Hameed *et al.*, 2006). Natural zeolite has also been used in adsorption and re-ionization of cations/anions as it indicates significant potential as an adsorbent/ion exchange material for wastewater treatment (Shikuku *et al.*, 2015). However, there are no known studies on factorial combinations of these local materials in water treatment. Therefore, a study needs to be undertaken to determine an effective combination of local materials of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite for water treatment on fresh borehole water and salty borehole water. This is to evaluate their suitability in improving base drinking water quality parameters of temperature, pH, total dissolved solids, electrical conductivity, dissolved oxygen, total solids and *E. coli* in accordance to the WHO guidelines of safe and portable drinking water.

MWTT is a system that involves, mainly, coagulation-flocculation, sedimentation, filtration and disinfection processes in a water treatment plant (Boulder, 2011). During treatment process, commercial chemicals such as aluminium sulphate, iron sulphate and chlorine used are imported in hard currency and are usually expensive (EPA, 1997). Further, it is suspected that these commercial chemicals add more contaminants to water after treatment due to emergence of health problems especially related to residual aluminium in treated water such as Alzheimer’s disease (Crapper *et. al.*, 1973). Treated water from MWTT, at times, also fails to meet the WHO set guidelines of drinking water quality at the point-of-use manifested in occasional waterborne disease outbreaks (Quist, 1999). This is suspected to be due to the mode of delivery of treated water to the final consumer that occurs through metallic pipes that are prone to rusting after some period of time thereby further contaminating the supposedly treated water (Dietrich, 2006). Drinking water, or potable water, is defined as having acceptable quality in terms of its physical, chemical and bacteriological parameters so that it can be safely used for drinking and cooking (WHO, 2004). Therefore, there is need to determine an effective treatment combination of readily available local materials of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite due to their enumerative properties in water treatment to mimic the sequential water treatment technique in MWTT. This could necessitate the development of an alternative simple water treatment system for provision of safe water at the user households.

Groundwater has proven to be the most reliable resource to meet peri-urban/rural water demand for sub-Saharan Africa (Harvey, 2004). An effort by governments to meet the ever increasing water demand is futile resulting to use of ground water such as boreholes. Quality of groundwater varies from place to place at times depending on seasonal changes (Vaishali *et. al.*, 2013), surfaces, rocks and soils through which it moves (Seth *et. al.*, 2014). Human activities can also alter the natural composition of groundwater through industrial discharges (Govindarajan and Senthilnathan, 2014), agriculture (Moyo, 2013) and waste disposals (Bello *et. al.*, 2013). Fresh borehole water (FBW) from Maseno Center and salty borehole water (SBW) from Bondo Centre have been identified for this study because the water sources represent extreme varieties of water collection points for domestic purposes in several peri-urban/rural settings. Lake Victoria water has also been considered for this study since the MWTT plant used is on water from Lake Victoria. The above water quality parameters to be measured are water quality base parameters that reflect the possible contaminants that may be present in these borehole waters.

1.2 Statement of the problem

There is frequent waterborne disease outbreak despite the availability of modern water treatment techniques. This is due to the inaccessibility of these modern water treatment techniques that has led to use of untreated water. There is therefore need for application of local water treatment techniques that are cheap and easily accessible. Use of local materials, even though are being individually used in local water treatment, have also not met the WHO standards of drinking water. This is because each has specific effects on drinking water quality parameters. There is therefore a need for factorial combinations of local materials for water treatment for untreated water sources especially borehole waters.

1.3 Objectives of the study

1.3.1 Broad objective

To determine effective treatment combinations of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite for domestic drinking water of fresh borehole water and salty borehole water.

1.3.2 Specific objectives

The specific objectives were to:

i. Determine the physico-chemical parameters and *E. coli* of fresh borehole water and salty borehole water and to compare the data with WHO guidelines of drinking water.

ii. Determine treatment effects of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite on physico-chemical and *E. coli* count when individually used and factorially combined in treatment of fresh borehole water and salty borehole water.

iii. Determine effective factorial combination of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite in treatment of fresh borehole water and salty borehole water and compare their treatment effects with treatment effects of individual local materials.

iv. Compare treatment effects of MWTT with effective treatment combinations of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite for fresh borehole water and salty borehole water.

1.4 Research hypothesis

In case the null hypotheses do not hold, the alternative hypotheses will be accepted.

1.4.1 Null hypothesis, H_0

i. The physico-chemical parameters and *E. coli* count of fresh borehole water and salty borehole water do not meet WHO guidelines of drinking water.
ii. There are no treatment effects by individual and factorial combinations of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite in treatment of fresh borehole water and salty borehole water.
iii. There is no effective factorial combination of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite in treatment of fresh borehole water and salty borehole water and that they do not perform better than individual local natural materials.
iv. There is no difference in treatment effects between MWTT and effective factorial combinations of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite for fresh borehole water and salty borehole water and that the effective factorial combinations do not perform better than MWTT.

1.4.2 Alternative hypothesis, H_1

i. The physico-chemical parameters and *E. coli* count of fresh borehole water and salty borehole water meet WHO guidelines of drinking water.
ii. There are treatment effects by individual and factorial combinations of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite in treatment of fresh borehole water and salty borehole water.
iii. There are effective factorial combinations of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite in treatment of fresh borehole water and salty borehole water and that they perform better than individual local natural materials.

iv. There are differences in treatment effects between MWTT and effective factorial combination of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite for fresh borehole water and salty borehole water and that the effective factorial combinations perform better than MWTT.

1.5 Justification of study

Treated water from MWTT is inefficient and accessible only to a small population residing in urban areas and does not extend to a larger population found in the peri-urban/rural areas. Local materials have been individually used in water treatment but have not been efficacious since each has specific effects on drinking water quality parameters. It is therefore critical to investigate combination of local materials in water treatment that will purpose to benefit humanity through a new technology of water treatment for provision of drinking water at household levels.

1.6 Significance of study

The findings of this study will provide valuable information that could serve as a platform for use of combination of local materials for water treatment. It will also serve as an important tool for development of a new technology of simple low-cost water treatment system.

CHAPTER TWO

LITERATURE REVIEW

This section highlights the general water pollution, drinking water quality base parameters, MWTT and individual and factorial combinations of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite as local materials for water treatment.

2.1 Water pollution

In developing countries, problems of water pollution and quality degradation are increasingly becoming a threat to the national water resources. This is attributed to the increasing quest of these countries to attain industrialized status and diversification of the national development goals and Kenya is no exception to this phenomenon (Kithiia and Khroda, 2011). The contaminants that may infiltrate the water resources leading to water pollution include a wide spectrum of chemicals, pathogens and physical changes such as elevated temperature and discolouration (Revenga and Mock, 2001). In Kenya, water resources are mostly affected by agricultural, domestic and industrial wastes that lead to the aforementioned pollutants (Chimwanza *et. al*., 2006; Kobingi *et. al*., 2009; Akali *et. al*., 2011). Being one of the fundamental requirements of life, presence of high concentrations of substances in water may make it unfit for human utilization (Mayank *et al*., 2011).

Crop-growing and animal-rearing practices are activities that remove plant cover and cause disturbance of the soil. As a result, agriculture practices could be the main source of sediment pollution in the various water bodies (Novotny, 1999). In addition, it also contributes to organic chemicals especially pesticides (McKinney and Schoch, 2003) which may be present in detectable amounts in surface and underground waters far from the sites of application (Voltz *et al.,* 2007). Application of nitrogen containing fertilizers also increases nitrate concentration in underground drinking water sources causing methemoglobinemia, a life-threatening “blue baby” syndrome in young children (Yasso *et al.*, 2001).

Domestic wastes produced by the households in form of sewage and septic tank leakages do end up in the natural waters. Dumping of garbage into rivers, lakes and other water bodies may also make them the custodians of plastics, bottles and other household products (Harter, 2003). Cleaning products used by households could also contain chemicals that are used in water softening among other things and this may affect the health of all forms of life when channelled to water bodies.

Industrial wastes ranging from manufacturing, food processing, power-generating and mining and construction are also the main sources of most water pollutants (McKinney and Schoch, 2003). Manufacturing industries do contribute to highly toxic pollutants that include a variety of organic chemicals and heavy metals. In food production, water plays a major role where the major concern arises in water consumption and wastewater discharge, packaging reduction and disposal, food scraps and refuse and chemicals used in processing and cleaning (McKinney and Schoch, 2003). Power-generating industries also contribute to thermal (heat) pollution and radioactivity that can be found in ground waters through radioactive materials present in underground rocks and in surface waters, particularly effluents from uranium and enrichment plants (Rao, 2001). Mining and construction industries also have impacts on water quality through acid mine drainage, heavy metal contamination, processing chemicals, erosion and sedimentation (Mining and Water Pollution, 2011). On the other hand, water pollution is also caused by microbiological agents present in water as a result of faecal contamination (WHO, 1996). These agents include bacteria, protozoa and viruses which cause diseases such as diarrhoea, dysentery, hepatitis or typhoid fever.

Fresh borehole water and salty borehole water which usually have total dissolved solids of <1000 mg/L and □1000 mg/L respectively (Sharma, 2008), could be subjected to one or more of water pollution and quality degradation phenomena as illustrated above. This could be reflected in water by water quality base parameters of temperature, pH, total dissolved solids, electrical conductivity, dissolved oxygen, total solids and *E. coli*.

2.2 Drinking water quality base parameters

Drinking water parameters are usually tested for physico-chemical and bacteriological parameters to ensure that drinking water quality are of acceptable international/national standards (WHO, 2011). The following are the base water quality parameters used in this study:

2.2.1 Temperature

Temperature is a measure of the average kinetic energy of particles in a system, usually measured in a laboratory using a mercury thermometer. The three temperature scales in use today are Fahrenheit (F), Celsius (C) and Kelvin (K). The climatic conditions of location of a water source could influence the temperature of water from that source (Kurylyk *et. al.*, 2013). Cool waters are generally more potable for drinking purposes because warm water negatively impact on water quality by enhancing the growth of microorganisms which may increase taste, odour, colour and corrosion problems (Okoye and Okoye, 2008). Besides, increase in temperature of water decreases solubility of gases such as O_2, CO_2, N_2 and CH_4 (Yilmaz and Koc, 2014) hence a decrease in, especially, dissolved oxygen concentration which is particularly an important water quality parameter in drinking water. The WHO guidelines for drinking water recommend a temperature from 25^oC to 30^oC (WHO, 2004).

2.2.2 pH

The term pH is defined as negative of the logarithm to base 10 of the molar concentration of hydrogen ions in solution measured in units of moles per litre (Covington *et. al.*, 1985). This is as shown;

$$pH = -\log_{10} (\alpha_{H+})$$

$$\text{where } (\alpha_{H+}) = \text{hydrogen ion activity}$$

It is measured in a laboratory using a pH meter expressed in terms of pH arbitrary units (*a.u*). It ranges from 0 to 14 with 7 denoting a neutral value. A pH below 7 is termed acidic while a pH above 7 is termed basic. Contaminated water with a pH below 7 which in most cases contains elevated levels of metals especially iron and aluminium can cause damage to metal piping and has associated problems such as metallic or sour taste (Slaninova *et. al.*, 2014; Pitter, 2009; Sieliechi *et. al.*, 2010). The acidity may also increase the capacity of water to attack geological materials and leach toxic metals into the water (Ansa-Asare *et. al.*, 2009). On the other hand, contaminated water with a pH above 7 is an indication of hardness of water which is a measure of the amount of minerals, primarily calcium and magnesium it contains (UNICEF, 2008). The minerals cause an alkaline taste in drinking water and are disadvantageous in the treatment and disinfection using chlorine. The pH is considered a secondary drinking water standard and the WHO guidelines for drinking water recommend a pH from 6.5 to 8.5 (WHO, 2006).

2.2.3 Total Dissolved Solids

Total dissolved solid is a term used to describe the inorganic salts and small amounts of organic matter that are dissolved in water (WHO, 1996). It is measured in a laboratory using a TDS meter and expressed in milligrams per litre (mg/L), parts per million (ppm) or parts per trillion (ppt). The inorganic salts are made up of cations such as calcium, magnesium, potassium and sodium among others, anions such as carbonates, nitrates, hydrogen carbonates, chlorides, sulphates primarily from hard-water ions and fertilizer in agricultural/ municipal runoff (Santa Ana Regional Water Quality Control Board, 1994). The presence of high amounts of dissolved solids in drinking water may affect its taste thereby making it unpalatable while low amounts may also be unacceptable because of its flat, insipid taste (WHO, 2003). The WHO guidelines for drinking water recommend total dissolved solids of ≤500 mg/L (WHO, 2006).

2.2.4 Electrical Conductivity

Electrical conductivity is an index that represents the total concentration of soluble ions in water giving the level of salinity of drinking water (Purandara *et. al.*, 2003). Therefore, the ability of water to conduct electricity is directly related to the concentration of ions present; the more the ions, the higher the conductivity and the fewer the ions, the lower the conductivity. It is measured in a laboratory using an EC meter expressed in micro-Siemens per centimeter (µS/cm) or milli-Siemens per centimeter (mS/cm). It is used for such purposes as determination of mineralization rate, that is, the existence of minerals such as potassium, calcium and sodium (Kavcar *et al.*, 2009). The WHO guidelines for drinking water recommend an electrical conductivity of ≤1000 µS/cm (WHO, 2006).

2.2.5 Dissolved Oxygen

Dissolved oxygen is a measure of the concentration of oxygen in a liquid, such as water or wastewater, usually expressed in parts per million (ppm), milligrams per litre (mg/L) or percent (%) saturation (EPA, 2016). It enters water through air by slow diffusion across the surface of water from the surrounding atmosphere or as a by-product in the process of photosynthesis by aquatic plants (EPA, 2012; Watt, 2000). Dissolved oxygen imparts good taste to water (Bruvold and Pangborn, 1970). However, a low amount of dissolved oxygen is a result of organic matter undergoing degradation by microbial activity in the presence of dissolved oxygen resulting in deoxygenation process and swift depletion of dissolved oxygen (Bhagat *et. al.*, 2015). The WHO guideline of drinking water recommended for dissolved oxygen is ≤5 mg/L (WHO, 2002).

2.2.6 Total Solids

Total solid is a measure of all suspended, colloidal and dissolved solids in a sample of water (EPA, 2001). High levels of total solids reduce the clarity of water thus decreasing the amount of sunlight penetration the water thereby reducing the photosynthetic rate. While this may not be harmful directly, reduced clarity may also make the water less aesthetically appealing. The WHO guidelines of drinking water recommend total solids of ≤1000 mg/L (WHO, 2004).

2.2.7 *Escherichia coli*

Apart from *Escherichia coli*, other microorganisms that may be present in water include *Vibrio cholerae, Salmonella enterica* and *Shigella dysenteriae* that can cause common waterborne infections like cholera, gastroenteritis and bacillary dysentery (Cabral, 2010). However, the most commonly used microorganism as an indicator of water pollution is *Escherichia coli*. It is present in extremely high numbers, does not appreciably multiply in the environment outside its host, methods to detect it are inexpensive, simple, sensitive and specific and it survives long enough under a broad range of drinking water conditions (Edberg *et. al.*, 2000).

Escherichia coli refers to a gram-negative, non-sporulating facultative anaerobe commonly found in the lower intestines and faeces of warm-blooded organisms and reptiles (Berg, 1996; Gordon and Cowling, 2003). Its presence in water indicates faecal contamination from effluents from septic systems or sewage discharges and infiltration of domestic or wild animal faecal matter (Odonkor and Ampofo, 2013). *Escherichia coli* expressed in the number of colony forming units (CFU) of *Escherichia coli* organisms per millilitre of water, should not be found in drinking water and if found immediate action is required to identify and remove any source of faecal contamination that is found (EPA, 2009). The WHO guidelines of drinking water recommend *Escherichia coli* count of 0.0 CFU/ml of water (WHO, 2006).

There is need to assess water quality of fresh and salty boreholes before consumption in terms of selected physico-chemical parameters and *Escherichia coli* count because these water sources could be highly polluted.

2.3 Municipal water treatment technology (MWTT).

Municipal water treatment technology is the most widely applied drinking water treatment method to remove contaminants from raw water and to improve and protect water quality (Boulder, 2011). It involves several sequential processes the main ones being coagulation-flocculation, sedimentation, filtration and lastly disinfection to provide safe and potable water for human consumption. This section presents a summary of how the processes occur;

2.3.1 Coagulation-flocculation process

One of the most effective methods of removing suspended matter from water is via the process of coagulation and flocculation. Figure 2.3.1 shows coagulation-flocculation and sedimentation processes in a water treatment plant:

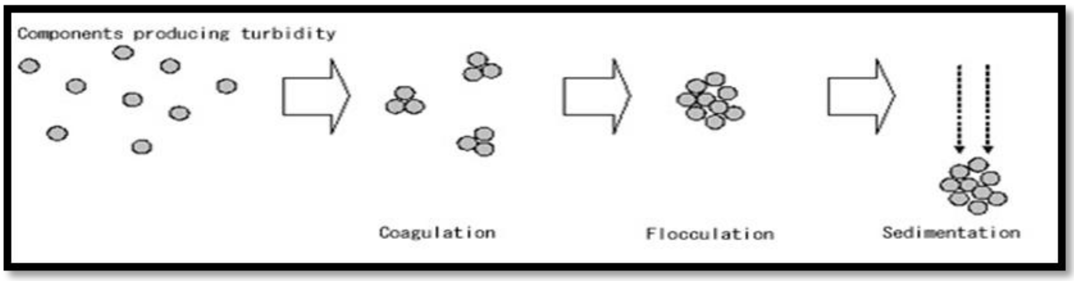

Figure 2.3.1: Process of coagulation, flocculation and sedimentation

(http://www.apec-vc.or.jp/feature_e/2006_03/2006_03_2.html)

(Accessed on 10th November, 2015).

Coagulation is the destabilization and initiation of aggregation of colloidal and finely divided suspended matter in water by the addition of a floc-forming chemical. Flocculation, on the other hand, is the agglomeration of colloidal and finely divided suspended matter in water after coagulation by gentle stirring either mechanically or by hydraulic means. Conventionally, the two main chemicals used to aid these processes are aluminium sulphate ($Al_2(SO_4)_3$) and ferric sulphate ($Fe_2(SO_4)_3$).

Turbidity in water is caused by suspended particles that have a net negative surface charge and are transport vehicles for undesirable organic and inorganic contaminants, taste, odour and colour-imparting compounds and pathogenic organisms (Raghuwanshi *et al*., 2002). The electrostatic forces therefore prevent them from agglomerating, making it impossible to remove them by sedimentation without the aid of coagulants, which carry counter-ions. The coagulants thus cause flocculation during water treatment via charge neutralization, after which the flocs settle under gravity leaving supernatant water with reduced turbidity. The high cationic charge metal salts based on aluminium or iron makes them effective for destabilizing colloids (Gregory and Duan, 2001). However, these commercial chemicals used as coagulants pose serious health effects on the users of treated water. For instance, several serious drawbacks of using aluminium salts have been pointed out, particularly concerning health problems related to residual aluminium in treated waters, such as Alzheimer’s disease (Crapper *et. al.,* 1973; Martyn *et. al.,* 1989).

Moringa oleifera seed water extract has been reported to be effective as a coagulant-flocculant in water treatment (Amagloh and Benang, 2009). This present study applied the seed extract during coagulation-flocculation processes in treatment of fresh and salty borehole waters.

2.3.2 Sedimentation process

Sedimentation process is a physical treatment process that utilizes gravity to separate suspended solids from water (Qasim *et. al.*, 2000). It follows the coagulation-flocculation process to completely remove turbidity causing particles by passing water through a settling basin or clarifier allowing for mud, sand, metal and all other sediments to settle down. Sedimentation of solid particles in water largely depends on the concentration of the particles (Haywood, 2011). At low solid concentrations, typically less than 500–1000 mg/L, settlement occurs without interference from neighboring particles. As the concentration increases, the influence of surrounding particles increases the settling rate. As the particle concentration increases further the process changes from clarification to hindered settling and thickening. As a discrete particle settles it will accelerate, under the force of gravity, until the drag force on the particle balances its weight force. At this point the particle descends at a constant velocity called the terminal settling velocity (Parsons and Jefferson, 2006). However, several factors such as particle size, water temperature, rising rate and retention time affect the sedimentation rate (Shin *et. al.*, 2001).

Table 2.3.2 presents length of time required for particles of different sizes to settle through the water:

Table 2.3.2: Settling time for particles of different sizes

Diameter of particle	Type of particle	Settling time through water
10 mm	Gravel	1 second
1 mm	Sand	10 seconds
0.1 mm	Fine sand	2 minutes
10 micron	Protozoa, algae, clay	2 hours
1 micron	Bacteria, algae	8 days
0.1 micron	Viruses, colloids	2 years
10 nm	Viruses, colloids	20 years
1 nm	Viruses, colloids	200 years

(Peterson, 2001)

Therefore, after the formation of flocs by *Moringa oleifera* seed water extract, the particles would be allowed to easily settle at the bottom of the container before filtration.

2.3.3 Filtration process

Filtration is the process of passing water through a porous medium with the expectation that the filtrate has a better quality than the influent; the medium is usually granular bed, such as sand, anthracite, garnet, or activated carbon (Najee, 2007). Many water treatment facilities use filtration to remove all the other remaining pollutants which could include clays and silts, natural organic matter, precipitates from other treatment processes in the facility and microorganisms. This enhances effective disinfection process since it clarifies water. As water passes through a filter bed of media, particulate matter is trapped within the media primarily by a two step process in which particles are moved to the surfaces of media grains or previously captured flocs and then become attached (adsorbed) to these surfaces (Kalibbala, 2007). A major drawback in filtration process is when the filter bed has to be removed for backwashing when the accumulation of solids causes excessive pressure drop or particle breakthrough. Even though this is critical to their proper performance, after backwashing, filtered water often does not meet turbidity and particle removal standards since the filter is now clean and the pores are at their maximum size.

Activated clay, activated charcoal and natural zeolite are porous materials and possess high adsorption capability (Nwokem *et. al*., 2012; Mohammed *et. al*., 2005; Shikuku *et. al*., 2015) This study applied the mentioned materials during filtration process in treatment of fresh and salty borehole waters.

2.3.4 Disinfection process

Disinfection is normally the last process in water treatment to destroy any pathogens which passed through the filters to prevent the spread of waterborne diseases (Parsons and Jefferson, 2006). Apart from ozone and chlorine dioxide, amongst others, chlorine is the most widely used raw water disinfectant worldwide (White, 1986). It kills most bacteria, viruses, and other microorganisms that cause disease. Chlorine in aqueous solution results into a hypochlorous acid which partly dissociates into hypochlorite ions, both which are referred to as free chlorine. The free chlorine reacts with organic and inorganic materials that are dissolved or suspended in water as well as the microorganisms. However, use of chlorine and other disinfectants have a draw-back in that it creates new potential risks because compounds known as disinfection by-products (DBPs) are formed during the treatment process, for instance, the trihalomethanes (THMs) formed exhibit potential carcinogenic activities (Kalibbala, 2007).

Moringa oleifera seed water extract possesses antibacterial activity as a result of the oil it contains which when consumed, forms a thin layer over the intestinal wall thus reducing or preventing penetration of pathogens into the intestinal walls (Nwosu and Okafor, 1995). This study applied the seed extract during disinfection process in treatment of fresh and salty borehole waters.

Figure 2.3.2 shows a general set-up of a municipal drinking water treatment plant:

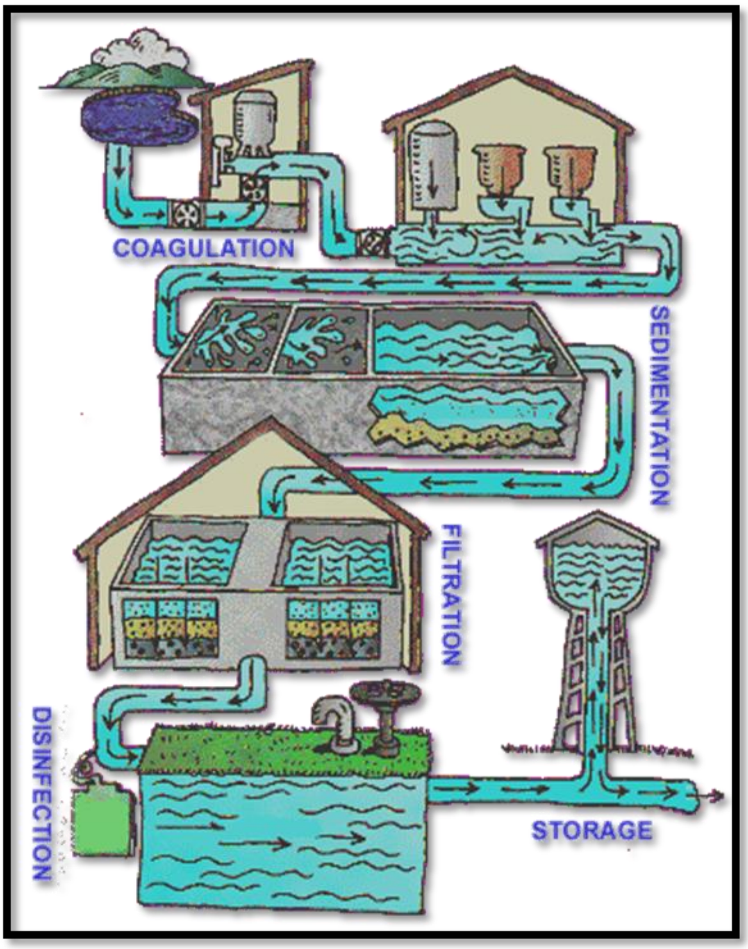

Figure 2.3.2: General set-up of municipal drinking water treatment plant

(http://www.epa.gov/safewater/kids/watertreatmentplant/index.html)

(Accessed on 10th November, 2015).

2.4 Selected local materials for water treatment

In recent years, the use of various local materials has been widely investigated as the best alternative for the currently expensive and ineffective MWTT. This is mainly because local materials can effectively be used as low cost absorbents (Shaikh and Bhosle, 2011). This study focused on *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite.

2.4.1 *Moringa oleifera* seed

Several coagulants of plant origin have been traditionally used to treat water. Special interest, however, are on the *Moringa oleifera* seeds which are increasingly being recognized as substitutes in water treatment due to their effectiveness as coagulants of raw water impurities, the multipurpose use of the *Moringa oleifera* tree and the fact that the tree is widespread in the tropical belt (Fuglie, 2001; Sajidu *et al*., 2006). The seeds treat water on two levels; both as a coagulant and an antibacterial agent. It contains dimeric, cationic, water-soluble proteins having molecular weight of 13kDa and isoelectric points between 10 and 11 (Ndabigengerese *et. al.*, 1995). The proteins bind with negatively charged particles of the contaminants through adsorption and neutralization of colloidal charges thus allowing the resulting flocs to settle to the bottom or be removed by filtration**.**

The seed extracts have been shown to have large effects of 92-99% turbidity removal (Muyibi and Alfugara, 2003) and can achieve a 90-99% reduction in faecal coliform levels (Boateng, 2001). Water treated with *Moringa oleifera* seed water extract produces less sludge volume compared to alum and ferric (Ndabigengesere and Narasiah, 1998). Other advantages of these seeds are that edible and other useful oils may also be extracted before the coagulant is fractionated; the residual solids used as animal feed and manure while the seed shell can be activated and used as an adsorbent. The coagulant is thus obtained at an extremely low or zero net financial cost. However, the main concern in using *Moringa oleifera* seed water extract for water purification is the significant increase in organic load (Okuda *et al*, 2001). Further, it is reported that water treated with this coagulant should not be stored for more than 24 hours hence not suitable for large water supply systems where the hydraulic residence time is very high (Jahn, 1988). However, a study has shown that two approaches may be used to allow the use of this seed; adsorption can be used to remove the organic load from the extracts or the active coagulating component may be extracted from the seed and used in pure or semi-pure form thus reducing the total amount of organic material added to the treatment process (Kwaambwa and Maikokera, 2007).

In this study therefore, *Moringa oleifera* seed water extract was applied during coagulation-flocculation, sedimentation and disinfection in water treatment of fresh borehole water and salty borehole water. During treatment using factorial combinations of local materials, it is expected that the other materials which have high adsorptive capacities would absorb organic materials from *Moringa oleifera* seed water extract subsequently reducing the organic load added to the treatment process thereby allowing the treated water to be stored for longer period of time. Figure 2.4.1 shows the specific *Moringa oleifera* seed used in this study:

Figure 2.4.1: Dry *Moringa oleifera* seeds

(*www.ilovemoringa.com)*

(Accessed on 24th November, 2015)

2.4.2 Activated clay

Activated clay has been considered as a low cost adsorbent since some of its derivatives can be easily prepared and regenerated (Orthman *et al*., 2006). Clays are hydrous aluminosilicates minerals of two-layered building blocks similar to a deck of cards: silicon-oxygen tetrahedron ($(Si_2O_5)^{2-}$) and aluminium octahedron (Gibbsite sheet) that make up the colloid fraction of soils, sediments, rocks and water (Tunega *et al*., 2002). The tetrahedral sheets are composed of individual tetrahedrons that share three out of four oxygen atoms arranged in a hexagonal manner with basal oxygen linked and apical oxygen pointing up/down. The octahedral sheets are composed of individual octahedrons that share edges having oxygen and hydroxyl anion groups arranged in a hexagonal manner with Al^{3+}, Mg^{2+} and Fe^{2+} serving as coordinating ions. Figures 2.4.2a and 2.4.2b show the building blocks of the clay particle:

Figure 2.4.2a: Building block of tetrahedral site

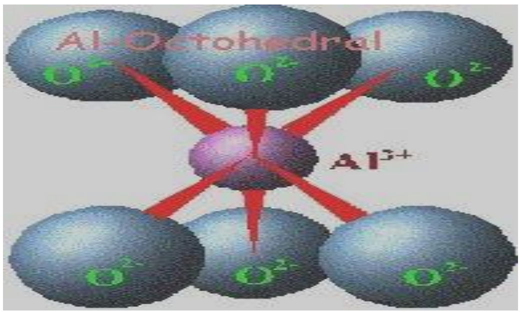

Figure 2.4.2b: Building block of octahedral site

*(https://www.**spec2000.net**/11-vshbasics.htm)*

(Accessed on 18th May, 2013)

Clay particles play an important role in the environment by acting as natural scavenger of pollutants by taking up cations and anions either through ion exchange or adsorption or both (Dizadji and Vossoughi, 2012; Naseem and Tahir, 2001). Large specific surface area, chemical and mechanical stability, layered structure, high cation exchange capacity (CEC), all have made clays excellent adsorbent materials (Babel and Kurniawan, 2003). The layers are subject to swelling and shrinking as water is absorbed and removed between the layers. Figure 2.4.2c shows a representation structure of clay particle:

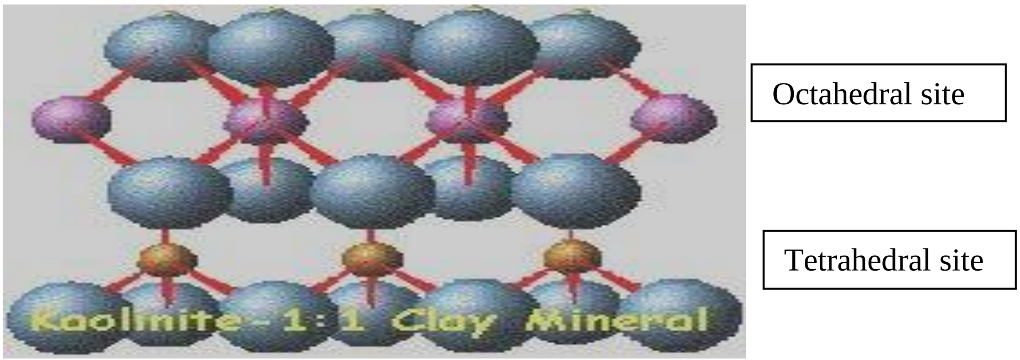

Figure 2.4.2c: Representation structure of clay particle

*(https://www.**spec2000.net**/11-vshbasics.htm)*

(Accessed on 18th May, 2013)

A study has shown the adsorptive capacity of clay, among them, the removal of congo red dye that showed a removal efficiency of 84% and 94% for natural and burnt clay respectively (Nwokem *et al*., 2012). As a coagulant, use of bentonite, a type of natural clay, produces clarified water with percentage clarity of 99%, about 14% greater than that obtained by using conventional coagulant of alum or ferric (Abdelaal, 2004).

In this study therefore, activated clay was used to play the role of filtration as a porous medium that would allow water to easily pass through and as an adsorption/ion exchange material to absorb the contaminants during water treatment of fresh borehole water and salty borehole water.

2.4.3 Activated charcoal

Charcoal is a carbonaceous material obtained from burnt animal and vegetation substances. The carbon atoms are arranged in a quasi-graphitic form in a small particle size and the large surface area and pore volume gives it a unique adsorption capacity for the removal of organic compounds responsible for taste, odour and colour in drinking water. Other components of charcoal include hydrogen and oxygen and minor quantities of nitrogen and other elements such as sulphur (Unger *et al.*, 2001). Waters taken from surface and groundwater supplies may contain many organic compounds such as phenols, pesticides, herbicides, aliphatic and aromatic hydrocarbons and their chlorinated counterparts, dyes, surfactants, organic sulphur compounds, ethers, amines, nitro compounds, and newly emerging substances such as endocrine disrupting compounds (EDCs). In addition, more than 800 specific organic and inorganic chemicals have been identified in various drinking waters, and many more are suspected to be present (Bansal and Goyal, 2005). Concerns are frequently expressed about the presence of these compounds, which can be present at levels as low as 1 mg/l. Because of their proven or suspected health and environmental effects, great efforts are made to control and/or remove them, and one of the major methods of doing this is by adsorption onto activated charcoal. The adsorption occurs through physical or chemical nature or both. Figure 2.4.3 shows a representation structure of charcoal particle:

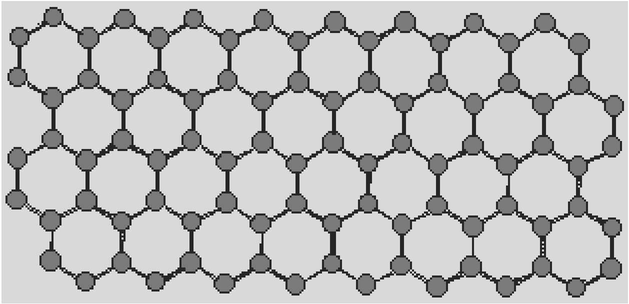

Figure 2.4.3: Representation structure of carbon particle

(Richardson, 2000)

(Accessed on 14th October, 2014)

A study on aqueous phenol adsorption using locally prepared activated charcoal from palm date pits and commercial sample (Filtrasorb-400) showed that the former exhibited a slightly higher adsorption capacity than the latter (Mohammed *et al.*, 2005). In comparing the adsorption efficiency of coconut shell-based granular activated charcoal (acid and barium chloride activation) with the adsorption efficiency of commercial carbon (Calgon carbon F-300) with respect to organic matter from a beverage industrial wastewater, it was found that the acid activated coconut shell charcoal had higher adsorption for organic matter expressed as chemical oxygen demand (COD) than the Calgon carbon F-300 at all carbon dosages (Amuda and Ibrahim, 2006). Moreover, the adsorption of methylene blue on Malaysia bamboo based activated charcoal showed that the equilibrium data for methylene blue adsorption well fitted to the Langmuir equation with maximum adsorption capacity of 454.2 mg/g (Hameed *et al*., 2006). Another study also showed that, when flow conditions are suitable, dissolved chemicals in water flowing over the charcoal surface stick to the carbon in a thin film while the water passes on (Randy, 2005).

This study therefore also employed the enumerated properties of activated charcoal in the filtration process as a porous medium that would easily allow water to pass through and an adsorbent material that would absorb the contaminants during water treatment of fresh borehole water and salty borehole water.

2.4.4 Natural zeolite

Natural zeolite is formed by an interaction of volcanic rocks and ash with alkaline underground water (Daneshvar *et. al.*, 2002). It is built up of a 3-dimensional framework of $[SiO_4]^{4-}$ and $[AlO_4]^{5-}$ tetrahedra linked by sharing oxygen atoms and weakly bonded (readily exchangeable) cations and water molecules in the pores and voids of the structure (Querol *et al*., 2002; Apak *et. al.*, 1998) that form a cage-like structure similar to a honey-comb. Water moves freely in and out of these pores but the framework remains rigid. The Kenyan natural zeolites contains several other cations that include Fe^{3+}, Ca^{2+}, Mg^{2+}, Mn^{2+}, Na^{+} and K^{+} (Shikuku *et al.*, 2015). Figure 2.4.4 shows a representation structure of natural zeolite particle:

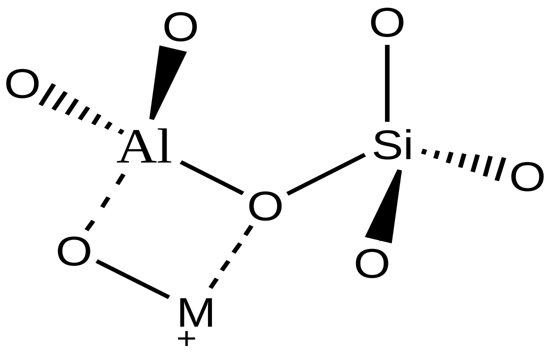

Figure 2.4.4: Representation structure of natural zeolite particle

(Kanyi *et. al.*, 2006)

Reported results of a study on their use in water purification showed that natural zeolite have a positive impact on the removal of organic matter and on organic metal complexes (iron and manganese) from raw water (Valentukeviciene and Rimeika, 2007). Other studies in Chile have also confirmed that the Chilean natural zeolite indicate significant potential as an adsorbent/ion exchange material for wastewater treatment and water reuse application (Englert and Rubio, 2005). It has also been reported that the natural zeolite from Kenya can be used in the removal of pesticides from wastewaters (Shikuku *et al.*, 2015).

In this study, natural zeolite was therefore also applied in the filtration process as a porous medium that would easily allow water to pass through and in the process absorb the contaminants during water treatment of the fresh borehole water and salty borehole water.

Each of the local materials of *Moringa oleifera* seed, activated clay, activated charcoal and natural zeolite has one or more effects on contaminated water. However, the most efficacious arrangement of these materials together as to offer the best drinking water according to WHO guidelines is not yet known. The treatment process of contaminated water before it can be used for public consumption must be based on removal of impurities to comply with various national and international guidelines. While the extent of treatment depends upon the quality of the raw water and the desired quality of treated water (Hong, 2006), the choice of which treatment to use from the great variety of available processes depends on the characteristics of the water, the types of water quality problems likely to be present and the costs of different treatments (Kalibbala, 2007).

The commonly applied MWTT requires periodical servicing and up-to-date operational skills. During the treatment process, the chemicals used which are usually expensive and are imported in hard currency, are suspected to add more contaminants to treated water. The treatment process also occurs through metallic tanks that are prone to rusting after some period of time thereby further contaminating the supposedly treated water. The eventual potable water therefore has more contaminants that have got adverse effects on human health if consumed thus exposing the inefficiency of this technology. Furthermore, it is also evident that this water treatment technology is so expensive such that the treated water is only available to a small fraction of the population mostly in urban areas at the expense of a larger population in the peri-urban and rural areas. In order to make safe water an available resource to as many people as possible, cheap, simple, robust and efficient process methods are necessary.

The use of local natural materials when individually used in water treatment has been in place in rural communities for some time now as they can be used as antibacterial, adsorption and cation exchange materials on contaminated water of any characteristic (Boateng, 2001; Shikuku *et. al.*, 2015; Nwokem *et. al.*, 2012; Mohammed *et. al.*, 2005). These materials are locally available at low net financial cost thus there is no need for importation. They are also human and environment-friendly as shown by the findings of Crapper *et. al*. (1973), Martenson *et. al*. (1995) and Kaggwa *et. al.* (2001). Use of local materials in water treatment is therefore cheap, simple and efficient in providing safe drinking water for the disadvantaged population.

Therefore, there is need to determine an effective treatment combination of readily available local materials of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite due to their enumerative properties in water treatment to mimic the sequential water treatment technique in MWTT.

CHAPTER THREE

MATERIALS AND METHODS

This section highlights the materials and methods used to realize the objectives of the study. It comprises of sampling sites, sampling design and sample collection techniques, activation of local natural materials of *Moringa Oleifera* seed, activated clay, activated charcoal and natural zeolite, water treatment experiment, data collection and statistical analysis of data collected.

3.1 Sampling sites

The fresh borehole water sample was collected from a borehole at Maseno Centre, Kisumu County (0^{o} 01’ 00’’ S, 34^{o} 36’ 00’’ E) while the salty borehole water was collected from a borehole at Bondo Centre, Siaya County (0^{o} 13’ 60’’ N, 34^{o} 22’ 0’’ E). The choice of the two borehole waters was because they are the common types of water obtained from different sources. Lake Victoria water was sampled at Dunga Water Treatment Plant point on the shores of Lake Victoria (0^{o} 84’ 42.5” S, 34^{o} 44’ 13.3” E) before treatment while treated water was sampled at the point of use at a household in Migosi Estate, Kisumu County (O^{o} 04’ 48.1” S, 34^{o} 46’ 54.1” E).

3.2 Sampling design and sample collection

Purposive sampling design was used in sample collection where water samples were collected in triplicate each from the two water sources that contained fresh and salty water. The sampling of fresh borehole water was done on 5th June, 2014 between 1000-1100 hours. The weather condition was slightly rainy and cold with the main activity around this water source being maize cultivation. The sampling of salty borehole water was done on 6th June, 2014 between 1000-1100 hours. The weather condition experienced high temperatures given out by the sun with human inhabitants around this water source. Standard procedures for collection, handling and preservation (APHA, AWWA, WEF, 2012) were followed to ensure data quality and consistency. Two sets of samples, each of 500 ml, were collected from each source; one set for physicochemical analysis in high density polyethylene bottles and the other set for bacteriological analysis in sterilized (in an autoclave at 121^{o}C for 20 minutes) glass bottles with the caps securely tightened. They were then labelled and immediately transported in a chiller box at a temperature of 4^{o}C to the laboratory to be kept in the refrigerator at the same temperature prior to analysis which was done over a period of 1 month. The temperature was maintained at 4^{o}C for the entire duration to prevent possible deterioration of quality of water samples.

3.3 Activation of selected local natural materials

Activation refers to the reversible transition of a molecule into a nearly identical chemical or physical state, with the defining characteristic being that this resultant state exhibits an increased propensity to undergo a specified chemical reaction. Activation of treatment materials was done as follows;

Moringa oleifera seed was sourced from a commercial farmer in Bondo Sub-county after identification by a botanist from the Department of Botany, Maseno University. Mature seeds showing no signs of discoloration, softening or extreme desiccation were used (Ndabigengesere and Narasiah, 1998). The seed kernels were ground to fine powder using M20 grinder (Serial Number: 01 494222, IKA-WERKE GMBH & CO., Germany). 5g of fine powder were weighed on a weighing balance in 100 ml glass beaker; 50 ml of distilled water was added to the powder to soak. The mixture was shaken on an orbital shaker for 1 minute and left to stand for 30 minutes before it was filtered using qualitative Whatman No. 1 filter paper. A volume of 10 ml of the filtrate which now contained water-soluble active ingredients for water treatment was used in the treatment of water (Schwarz, 2000; Doerr, 2005). The seed contains an active coagulating agent for water treatment that is not contained on the other parts of *Moringa oleifera* tree (Berger *et. al.*, 1984). Activation of clay was done by breaking burnt clay pot into pieces. The broken pieces were washed and rinsed three times with distilled water and dried in the oven at 110^{o}C for 2 hours (Al-Asheh *et al.*, 2003; Chaisena and Rangsriwatananon, 2004). Freshly prepared clay pots were obtained from the local community in Maseno Sub-county. Activation of charcoal also obtained from the local charcoal dealers in Maseno Sub-county was done by char of the wooden pieces being saturated with 50% phosphoric acid, followed by controlled reheating to enhance the chemical erosion of carbon atoms and three-times washing cycle with distilled water to remove the acid (Molina-Sabio *et al.*, 2003). Natural zeolite obtained from Gilgil Sub-county was activated by soaking in distilled water with continuous stirring for 30 minutes. This was repeated three times and dried in an oven at 110^{o}C for 2 hours (Djaeni *et al.*, 2010). The aim was to remove impurities and form a homogenous pore size. Each of the activated material was passed through two layers of sieves, the lower layer with an aperture of 1 mm and the upper layer with an aperture of 5 mm thus obtaining a course texture (<5 mm but □ 1 mm)of these materials that remained between the two sieves.

3.4 Water treatment experiment

The water quality parameters were determined before any treatment was done. For adsorption and cation/anion exchange treatment, the columns were packed with individual and factorial combinations of activated clay, activated charcoal and natural zeolite to a length of 5 cm long with a 0.1 g cotton wool used to separate two of the treatment materials in the columns. Volumes of 50 ml of untreated water samples were run through the columns by gravitational force with an elution power of 10 ml per hour for collection in 100 ml beaker. Since the used *Moringa oleifera* seed water extract was in liquid form of water-soluble protein ingredient for water treatment, the treatment was done in a 100 ml beaker on the bench-top separate from the column and in case it occurred in between two of the solid materials in the combination regime, the untreated water was passed through one column containing the solid materials, then through the seed filtrate in another 100 ml beaker before passing it through another column containing the other solid materials. This also enhanced the separation of the extract from the treated water. Water quality parameters were determined again after treatment to determine the treatment effects.

To obtain the number of factorial combinations of the 4 treatment materials (*Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite), mathematical permutation equation where order was taken into account was used. This was as shown below:

$$^{n}P_{r} = \frac{n!}{(n-r)!}$$

(http://mathworld.wolfram.com/Permutation.html)

(Accessed on 25th January, 2016)

where n = the number of unlike objects (*Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolites), r = the number of objects to be arranged from the unlike objects and P = ordered permutation.

In this study, n = r = 4, giving the number of factorial combinations as below:

$$^{n}P_{r} = \frac{4!}{(4-4)!}$$

$$^{n}P_{r} = \frac{4!}{(0)!}$$

At this point, it is noted that, mathematically (0)! = 1, therefore;

$$^{n}P_{r} = \frac{4!}{1} = 4!$$

Hence, $^{n}P_{r} = 4!$. Thus 4! = 4 x 3 x 2 x 1 = 24.

Therefore, for the 4 local natural materials of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite, there were 24 ways of arranging the materials in sequence to offer cumulative treatment effects on contaminated water as shown below:

A: Activated clay → Activated charcoal → Natural zeolite → *Moringa oleifera* seed water extract

B: Activated clay → Activated charcoal → *Moringa oleifera* seed water extract → Natural zeolite

C: Activated clay → Natural zeolite → *Moringa oleifera* seed water extract → Activated charcoal

D: Natural zeolite → Activated charcoal → *Moringa oleifera* seed water extract → Activated clay

E: Activated charcoal → Activated clay → Natural zeolite → *Moringa oleifera* seed water extract

F: Activated charcoal → Activated clay → *Moringa oleifera* seed water extract→ Natural zeolite

G: Natural zeolite → Activated clay → *Moringa oleifera* seed water extract → Activated charcoal

H: Activated charcoal → Natural zeolite → *Moringa oleifera* seed water extract → Activated clay

I: Activated clay → Natural zeolite → Activated charcoal → *Moringa oleifera* seed water extract

J: Activated clay → *Moringa oleifera* seed water extract → Activated charcoal → Natural zeolite

K: Activated clay → *Moringa oleifera* seed water extract → Natural zeolite → Activated charcoal

L: Activated charcoal → *Moringa oleifera* seed water extract → Natural zeolite → Activated clay

M: Natural zeolite → Activated clay → Activated charcoal → *Moringa oleifera* seed water extract

N: *Moringa oleifera* seed water extract → Activated clay → Activated charcoal → Natural zeolite

O: *Moringa oleifera* seed water extract → Activated clay → Natural zeolite → Activated charcoal

P: *Moringa oleifera* seed water extract → Activated charcoal → Natural zeolite → Activated clay

Q: Natural zeolite → Activated charcoal → Activated clay → *Moringa oleifera* seed water extract

R: *Moringa oleifera* seed water extract → Activated charcoal → Activated clay → Natural zeolite

S: *Moringa oleifera* seed water extract→ Natural zeolite → Activated clay → Activated charcoal

T: Natural zeolite → *Moringa oleifera* seed water extract → Activated charcoal → Activated clay

U: Activated charcoal → Natural zeolite → Activated clay → *Moringa oleifera* seed water extract

V: Activated charcoal → *Moringa oleifera* seed water extract → Activated clay → Natural zeolite

W: Natural zeolite → *Moringa oleifera* seed water extract → Activated clay → Activated charcoal

X: *Moringa oleifera* seed water extract → Natural zeolite → Activated charcoal → Activated clay

From the arrangement shown above, the untreated water trickled down the column through the treatment materials as shown by the arrow to get water that could be safe for drinking purposes.

3.5 Determination of water quality parameters before and after treatment with individual and factorial combinations of local materials.

In this study, the physico-chemical parameters and *E. coli* count of both fresh and salty borehole waters were determined and recorded for temperature, pH, total dissolved solids, electrical conductivity and dissolved oxygen *in situ* while total solids and *E. coli* were determined *in vitro* before any treatment. The parameters were determined and recorded again in the laboratory before any treatment and the values acted as the control values. The parameters were determined after treatment with individual and factorial combinations of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite to determine the cause/effect relationship with the control values. The measurements were done in triplicate and the means recorded. Determination of water quality parameters were done according to the Standard Methods of Examination of Water and Wastewater (APHA, AWWA, WEF, 2012).

3.5.1 Determination of temperature

The temperature of 50 mL water sample was determined using Brannan 305 mercury in glass-bulb laboratory thermometer (Cleator Moor, Cumbria CA25 5QE England ± 1.0). The sample was obtained in a beaker and the thermometer mercury bulb end cleaned using de-ionized water was immersed in the beaker containing the sample. It was swirled to allow it equilibrate with the sample for one minute, suspending it away from the sides and bottom of the sample beaker to observe the temperature reading which was recorded in ^{o}C.

3.5.2 Determination of pH

The pH of 50 mL water sample was determined using a Mi 806 combined pH/EC/TDS/temperature meter from Martini Instruments (Romania, England; Serial Number: 1058787) calibrated using buffers 7 and 4 solutions. The sample was obtained in a beaker and the pH/EC/TDS/temperature meter probe was immersed in the beaker containing the sample. It was swirled to allow it to equilibrate with the sample for one minute, suspending it away from the sides and bottom of the sample beaker to observe the pH reading recorded on the LCD display after it had stabilized.

3.5.3 Determination of total dissolved solids

Total dissolved solids of 50 mL water sample were determined using a Mi 806 combined pH/EC/TDS/temperature meter from Martini Instruments (Romania, England; Serial Number: 1058787) calibrated to single point calibration using a standard solution of 1280 µS/cm at 25^{o}C. The sample was obtained in a beaker and the pH/EC/TDS/temperature meter probe was immersed in the beaker containing the sample. It was swirled to allow it equilibrate with the sample for one minute, suspending it away from the sides and bottom of the sample beaker to obtain the TDS reading recorded in mg/l on the LCD display after it had stabilized.

3.5.4 Determination of electrical conductivity

Electrical conductivity of 50 mL water sample was determined using a Mi 806 combined pH/EC/TDS/temperature meter from Martini Instruments (Romania, England; Serial Number: 1058787) calibrated to single point calibration using a standard solution of 1280 µS/cm at 25^{o}C. The sample was obtained in a beaker and the pH/EC/TDS/temperature meter probe was immersed in the beaker containing the sample. It was swirled to allow it equilibrate with the sample for one minute, suspending it away from the sides and bottom of the sample beaker to obtain the EC reading recorded in µS/cm on the LCD display after it had stabilized.

3.5.5 Determination of dissolved oxygen

Dissolved oxygen of 50 mL water sample was determined using Mi 605 portable Dissolved Oxygen meter from Martini Instruments (Romania, England; Serial Number: 1052522) calibrated to 100% in saturated air at 25^{o}C. The sample was obtained in a beaker and DO meter probe was immersed in the beaker containing the sample. It was swirled to allow it to equilibrate with the sample for one minute suspending it away from the sides and bottom of the sample beaker to obtain the DO reading recorded in mg/l on the LCD display after it had stabilized.

3.5.6 Determination of total solids

Total solids of 50 mL water sample were determined by weighing a 100 mL beaker on a weighing balance. The beaker was then filled with 50 mL water sample. The sample was evaporated in a VULCAN A-550 oven (Serial Number: DKV0824104, DENTSPLY International 570W, College Avenue, York) at 100°C for 15 minutes and the remaining residue was completely dried in a dessicator. The beaker containing the dried residue was then weighed on a weighing balance again. The total solids concentration was equal to the difference between the weight of the beaker containing the residue and the weight of the beaker without the residue recorded in grams.

3.5.7 Determination of *E. coli*

The measurement was done according to the procedure of Boundless, 2015. Tubes and empty petri-dishes were laid out and labelled as shown in Figure 3.5.7a:

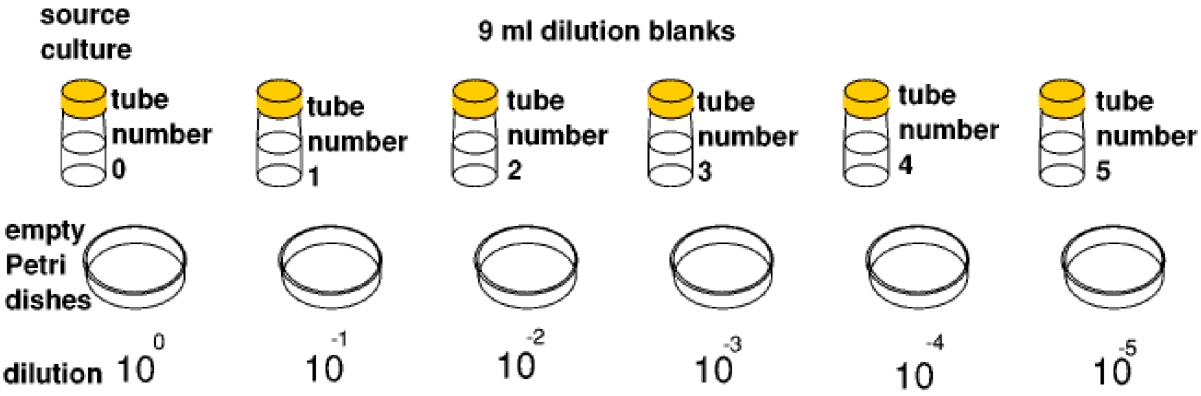

Figure 3.5.7a: Serial dilutions

Key:
Source culture: Untreated and treated borehole water for culturing, Dilution blanks: Tubes containing 9 mL of distilled water for dilution

The lids of tubes number 0 and 1 were flamed and loosened. Using a sterile pipette, 1 mL of liquid from tube number 0 was transferred to petri-dish number 0 and using the same sterile pipette, 1 mL of liquid from tube number 0 was transferred to tube number 1. The pipette was then discarded. Figure 3.5.7b shows this arrangement:

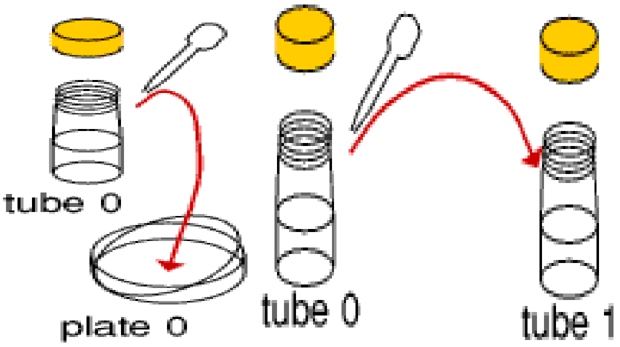

Figure 3.5.7b: First serial dilution

The edge of tube number 1 was flamed and sealed then the content was mixed gently. The process was repeated with the next tube and plate, that is, tubes number 1 and 2 were flamed and loosened. 1 mL of liquid from tube number 1 was transferred to petri-dish number 1 and also to tube number 2. The pipette was again discarded. The edge of tube number 2 was also flamed and sealed then the content was also mixed gently. The same steps were repeated 6 times moving along the chain to a total volume of 10 mL after dilution. This is as shown in Figure 3.5.7c:

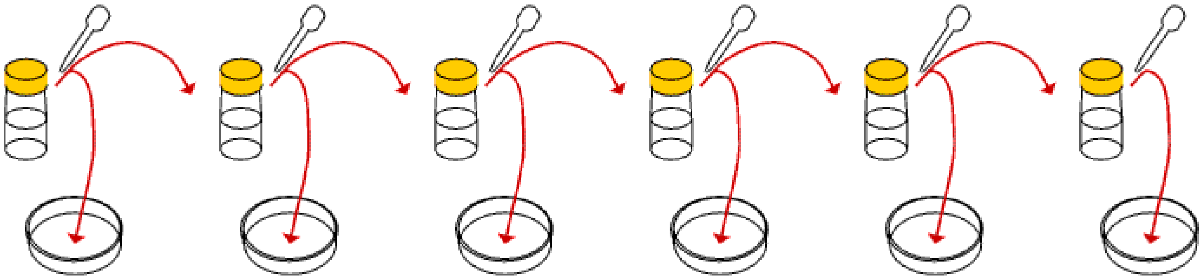

Figure 3.5.7c: Several serial dilutions

Powdered nutrient agar (Sigma-Aldrich Chemie GmbH CH-9471 Buchs, Switzerland) with a composition of meat extract: 1g/L, yeast extract: 2g/L, peptone: 5g/L, sodium chloride: 5g/L, agar: 15g/L and final pH: 7.4±0.2 at 37^{o}C was prepared by dissolving 23 grams of dehydrated agar in 1000 mL distilled water. It was then heated with frequent agitation and boiled for 1 minute to completely dissolve the powder. The medium was then sterilized by autoclaving at 121°C for 15 minutes. The medium was dispensed into tubes and left to solidify. A tube of sterilized medium was taken, the outside dried then the top and neck area was flamed. Quickly and aseptically, each petri dish lid was only slightly opened, the medium poured into the dilution liquid in the petri dishes until it covered two-thirds of the area. To culture the bacterial cells, the medium was mixed with the dilution liquid by a gentle swirling action. The petri dishes were left undisturbed flat on the bench for ten minutes to set. They were then sealed, inverted and placed in the incubator at 27°C for 24 hours. This temperature is the optimum temperature at which the bacterial cells can show significant growth. Each petri dish was then examined without opening by looking for individual colonies. Some had more colonies than can be counted while others had none. Several intermediate ones were countable. They were counted and recorded with the relevant dilution factors. In this study, the appropriate dish for counting was petri dish number 3. Thus the number of colonies was reported in terms of (a x 10^2) CFU/ml, where a = number of colonies counted.

Due to lack of any similar previous work for reference in determination of effective combination for water treatment, this study was considered a germain attempt to determine the efficacy of factorial combinations of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite in water treatment. The effective factorial combinations for FBW and SBW were therefore determined from the deviations of values of parameters measured from their WHO guidelines of drinking water for each. Where the measured value was equal to or within the range of WHO standard limit then the deviation was 0, where it was below the standard limit then the deviation was negative and where it was above the standard limit then the deviation was positive. The deviations were then squared to find the variance for all the results obtained. The variance of each parameter for a particular treatment combination regime was then summed up. At this point, the assumption was that no single parameter was deterministic, that is, its value being more important than the others. The treatment combination regime with the least summation of variance of each parameter was considered the effective combination for domestic water treatment.

After determining the effective combination for water treatment for both FBW and SBW, the combinations were subjected to treatment of Lake Victoria water that is normally subjected to MWTT, which constitutes water treatment process through stages of coagulation-flocculation, sedimentation, filtration and disinfection, for domestic purposes. The water was collected before treatment in Lake Victoria at the point of entry into MWTT plant and from a tap to indicate treated water.

3.6 Statistical analysis

The data was analyzed using MSTATC statistical package for factors of replication, type of water (fresh or salty borehole water) and treatment regime (individual and factorial combinations of local materials). Analysis of Variance (ANOVA) at $p \leq 0.05$ was used to determine significance differences between data.

CHAPTER FOUR

RESULTS AND DISCUSSION

This section highlights the results and discussion of the study. It comprises determination of physico-chemical parameters and *E. coli* count of FBW and SBW, determination of treatment effects of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite on FBW and SBW when individually used and factorially combined, determination of the effective factorial combination of *Moringa Oleifera* seed water extract, activated clay, activated charcoal and natural zeolite for water treatment of FBW and SBW and a comparison of treatment effects by MWTT and the effective factorial combinations.

4.1 Physico-chemical parameters and *E. Coli* of FBW and SBW

Water quality parameters of temperature, pH, total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO), total solids (TS) and *Escherichia coli (E. coli)* were determined at the sampling site for both FBW and SBW. The results are recorded in Table 4.1:

Table 4.1: Variations on physico-chemical parameters and *E. coli* count of FBW and SBW

Parameter	FBW	SBW	WHO limits[1,2,3]
Temperature (^oC)	25±1	32±1	25-30
pH (*a.u*)	5.83±0.02	7.04±0.03	6.5-8.5
TDS (mg/L)	237±3	3093±3	≤500
EC (µS/cm)	370±3	4837±3	≤1000
DO (mg/L)	2.47±0.01	3.00±0.02	≤5
TS (mg/L)	4200±200	2000±200	≤1000
E. coli count (CFU/mL)	$1.3x10^5$±2000	ND	0.0

Key:
Values are mean ± SD analyzed individually in triplicate, Data computed for borehole water quality, FBW: Fresh borehole water, SBW: Salty borehole water, TDS: Total dissolved solids, EC: Electrical conductivity, DO: Dissolved oxygen, TS: Total solids, *a.u*: arbitrary units, ND: Not detected, WHO limits[1]: World Health Organisation drinking water guidelines, 2002, WHO limits[2]: World Health Organisation drinking water guidelines, 2004, WHO limits[3]: World Health Organisation drinking water guidelines, 2006.

From Table 4.1, this study observed that FBW had lower values of temperature, pH, TDS, EC and DO except for TS and *E. coli* count which were higher compared to SBW values. The water sources recorded temperature of 25^{o}C for FBW and 32^{o}C for SBW. The recommended acceptable range of temperature for drinking water is between 25^{o}C and 30^{o}C (WHO, 2004). Therefore, FBW recorded temperature that was within the standard range of WHO guidelines of drinking water while SBW recorded temperature that was slightly above the standard range of WHO guidelines of drinking water. Data recorded for temperature were attributed to the climatic conditions of the geographical area of each of the water sources. This agreed with a study done by Kurylyk *et. al.,* 2013 which reported that changes in groundwater temperature will exhibit seasonality at shallow depths (1.5 m) but be seasonally constant and approximately equivalent to the change in the mean annual surface temperature at deeper depths (8.75 m). Maseno Centre, from where FBW was sampled, experienced rainy season and slightly cold weather conditions resulting to a water temperature of 25^{o}C compared to Bondo Centre, from where SBW was sampled, which experienced dry season and hot weather conditions resulting to a water temperature of 32^{o}C.

The water sources were also characterized by either a weakly acidic or weakly basic pH with FBW at pH 5.83 while SBW was at pH 7.04. The recommended acceptable range of pH for drinking water is between 6.5 and 8.5 (WHO, 2006). Thus, the pH for FBW was below the standard range of WHO guidelines of drinking water while that of SBW was within the standard range of WHO guidelines of drinking water. The difference in composition of underground rocks and recharging and accumulation rates of dissolved substances in these two underground water sources could be responsible for a higher or lower pH value. This was in agreement with an earlier report by Raposo *et al.* (2012) that if the accumulation rate is higher than the recharging rate of dissolved substances from the underground rocks, then the dissolved substances would be retained in the water source and depending on the composition of the underground rock, the water would record low or higher pH values.

The analysis of TDS and EC was performed simultaneously since EC is a direct function of TDS in water (Harilal *et al.*, 2004). The TDS and EC for SBW were far much higher than for FBW. The FBW recorded TDS and EC of 237 mg/l and 370 µS/cm respectively while SBW recorded TDS and EC of 3093 mg/l and 4837 µS/cm respectively. The recommended standard upper limit of TDS in drinking water is 500 mg/l while that of EC is 1000 µS/cm (WHO, 2006). Therefore, both TDS and EC for FBW were within the standard upper limit of WHO guidelines of drinking water while those of SBW were far much above the standard upper limit of WHO guidelines of drinking water. This is suspected to be as a result of leaching and seepage of dissolved ions from the underground rocks into the water. This implies that leaching and sippage of dissolved substances from the underground rocks were as expected more pronounced in salty borehole water thus SBW contained more dissolved ions. This was in agreement with a study by Amangabara and Ejenma (2012) which reported that dissolved substances from the underground rocks makes underground water contain more dissolved ions thus becoming saline and in effect increasing the total dissolved solids load and electrical conductivity.

The DO for SBW was higher compared to that of FBW. The DO concentration for FBW was 2.47 mg/l while SBW recorded DO concentration of 3.00 mg/l. The recommended standard upper limit of DO in drinking water is 5 mg/l of dissolved oxygen (WHO, 2002). Therefore, both were within the standard upper limit of WHO guidelines of drinking water. Sources of oxygen in water resources include slow diffusion of air from the atmosphere, a by-product of photosynthetic processes and through hydro-mechanical input (surface agitation) (EPA, 2012; Watt, 2000). It is suspected that other processes, other than slow diffusion of air from the atmosphere and hydro-mechanical input, contributed to DO levels in FBW and SBW. Studies by Radwan *et. al*. (2003) and Lin *et. al*. (2006) have shown that variations in DO in groundwater can occur due to photosynthesis of plants and algae and is removed by respiration of plants, animals and bacteria, biochemical oxygen demand degradation process, sediment oxygen demand and oxidation.

The TS for FBW were higher compared to that of SBW. FBW contained TS to the level of 4200 mg/l while that of SBW was up to the level of 2000 mg/l. The recommended standard upper limit of TS in drinking water is 1000 mg/l (WHO, 2004). This implies that both FBW and SBW had TS levels above the standard upper limit of WHO guidelines of drinking water. It is suspected that the soil structure could be loose in both the water sources and during infiltration of soil water, some solids were carried across into the water source thereby leading to accumulation of total solids.

The *E. coli* count for FBW was much higher compared to that of SBW. The FBW recorded *E. coli* count of $1.3x10^5$ CFU/ml while that of SBW was not detected and recorded as 0.0 CFU/ml. The recommended acceptable limit of *E. coli* in drinking water is 0.0 CFU/ml of water (WHO, 2006). Hence, the *E. Coli* count for FBW was above the standard limit of WHO guidelines of drinking water while that of SBW was within the standard limit of WHO guidelines of drinking water. As a result of land cultivation around the fresh borehole water, it is suspected that a lot of sediments due to loose soil structure settled at the bottom of the water source due to infiltration of soil particles beneath the earth's surface into the water column giving a conducive habitat for multiplication of the bacterial cells. A study by Pachepsky and Shelton (2011) has shown that sediments are generally good bacterial habitats and that resuspension of sediments rather than runoff from surrounding lands can create elevated concentrations of *E. coli* count. On the other hand, the undetectable limits of *E. coli* count in SBWS could be as a result of bacterial cells being denatured by the high salt concentrations in the borehole. This confirmed an earlier study by Munro *et. al.* (1989) that reported that an *E. coli* cell when subjected to an immediate osmotic upshock causes their inability to overcome the upshock by means of several osmoregulatory systems and this largely influences their subsequent extinction.

The study therefore revealed that FBW from Maseno centre did not meet WHO guidelines of drinking water in terms of pH, TS and *E. coli* count while SBW from Bondo centre did not meet WHO guidelines of drinking water in terms of temperature, TDS, EC and TS.

4.2 Treatment effects of individual local materials on FBW and SBW

The treatment effects done in the laboratory at room temperature using individual local materials are recorded in Table 4.2:

Table 1.2: Variations on treatment effect of individual local materials on FBW and SBW

Treatment	Borehole	pH (*a.u*)	TDS (mg/l)	EC (µS/cm)	DO (mg/l)	TS (mg/l)	*E. coli count* (CFU/ml)
Before treatment	FBW	5.88	134	210	2.76	4200	1.3x10^{5}
	SBW	7.08	2720	4253	3.67	2000	ND
Moringa Oleifera seed	FBW	6.11^{b}	514^{a}	803^{a}	4.87^{a}	1600^{a}	ND^{b}
	SBW	7.54^{a}	2497^{b}	3907^{b}	4.14^{a}	600^{a}	ND^{b}
Activated clay	FBW	6.27^{b}	162^{b}	253^{b}	3.76^{a}	2000^{a}	ND^{b}
	SBW	7.28^{b}	2640^{b}	4123^{b}	4.21^{a}	400^{a}	ND^{b}
Activated charcoal	FBW	2.05^{a}	2793^{a}	4367^{a}	3.52^{a}	8300^{a}	1.0x10$^{4\ b}$
	SBW	2.70^{a}	2927^{b}	4573^{b}	4.09^{a}	800^{a}	ND^{b}
Natural zeolite	FBW	7.48^{a}	192^{b}	300^{b}	3.28^{a}	3200^{a}	1.47x10$^{6\ a}$
	SBW	7.67^{a}	2690^{b}	4207^{b}	3.94^{b}	730^{a}	ND^{b}
CV%		6.25	7.94	7.95	5.11	6.47	15.99
LSD ($p \leq 0.05$)		0.44	271	423	0.29	124	3.3x10^{5}
WHO Limits[1,2,3]		6.5-8.5	≤500	≤1000	≤5	≤1000	0.0

Key:
Values are mean analyzed individually in triplicate , Data computed before and after treatment using individual local materials, FBW: Fresh borehole water, SBW: Salty borehole water, TDS: Total dissolved solids, EC: Electrical conductivity, DO: Dissolved oxygen, TS: Total solids, a.u: arbitrary units, ND: Not detected, a: Significant difference after treatment ($p \leq 0.05$), b: Not significant after treatment, CV: Coefficient of variance, LSD: Least significant difference, WHO limits[1]: World Health Organisation drinking water guidelines, 2002, WHO limits[2]: World Health Organisation drinking water guidelines, 2004, WHO limits[3]: World Health Organisation drinking water guidelines, 2006.

From Table 4.2, laboratory analysis before treatment at a room temperature of 22^{o}C showed that FBW recorded 5.88, 134 mg/L, 210 µS/cm, 2.76 mg/L, 4200 mg/L and 1.3x10^{5} CFU/ml for pH, TDS, EC, DO, TS and *E. Coli* count respectively. Laboratory analysis before treatment at a room temperature of 23^{o}C also showed that SBW recorded 7.08, 2720 mg/L, 4253 µS/cm, 3.67 mg/L, 2000 mg/L and 0.0 CFU/ml for pH, TDS, EC, DO, TS and *E. coli* count respectively. The study revealed that, after treatment, there were both positive and negative treatment effects of local materials when individually used on the quality of water measured after duration of 30 minutes after treatment. Positive treatment effects referred to recording data of water quality parameter measured that was either maintained within or brought closer to the standard range/upper limit of WHO guidelines of drinking water while negative treatment effects referred to recording data of water quality parameter measured that deviated (below or above) the standard range/upper limit of WHO guidelines of drinking water.

4.2.1 Treatment effects of *Moringa oleifera* seed water extract

After treatment at a room temperature of 26^{o}C, the pH increased to 6.11 for FBW which was still below the standard range of WHO guidelines of drinking water while that of SBW at a room temperature of 24^{o}C, increased to 7.54 and was still within the standard range of WHO guidelines of drinking water (WHO, 2006). At $p \leq 0.05$, there was no significant difference in pH after treatment of FBW while there was a marginal significant difference in pH after treatment of SBW. This study has revealed that *Moringa oleifera* seed water extract does not entirely affect the pH of water after treatment. This was in agreement with an earlier study which reported that the use of *Moringa oleifera* seed extract coagulant is capable of affecting the pH of treated water marginally but not significant enough to affect the quality of water (Aho and Agunwamba, 2014).

The TDS also increased to 514 mg/l for FBW but decreased to 2497 mg/l for SBW. The TDS for both FBW and SBW exceeded the standard upper limit of WHO guidelines of drinking water (WHO, 2006). The EC also increased to 803 µS/cm for FBW but decreased to 3907 µS/cm for SBW. The EC for FBW was within the standard upper limit of WHO guidelines of drinking water while that for SBW was above the standard upper limit of WHO guidelines of drinking water (WHO, 2006). At $p \leq 0.05$, there was significant difference in both TDS and EC after treatment of FBW suspected to be due to the fact that initial TDS and EC was low hence a higher possibility of solubility of the inorganic components of the seed in the water than attraction to the magnet-like cationic polyelectrolytes in the seed. This agreed with an earlier study which found out that when inorganic components of the *Moringa oleifera* seed water extract dissolve in water, it increases the load of ions present in treated water (Shahzad *et al.*, 2014). At $p \leq 0.05$, there was no significant difference in both TDS and EC after treatment of SBW. It is suspected that high salinity of SBW resulted into physiological and biochemical disorders of active protein ingredient rendering it inactive. This was in agreement with a study by Kao *et. al.* (2003) that reported that salinity causes ion toxicity, osmotic stress and nutritional imbalance to mineral contents of *Moringa oleifera* seed water extract.

DO for FBW increased to 4.87 mg/l while that of SBW increased to 4.14 mg/l of dissolved oxygen. Both were within the standard upper limit of WHO guidelines of drinking water (WHO, 2002). At $p \leq 0.05$, there was significant difference in DO after treatment of both FBW and SBW. It is suspected that the increase of dissolved oxygen was as a result of diffusion of air from the atmosphere into the sample container during measurement. This is in agreement with studies that showed that dissolved oxygen levels in water is as a result of slow diffusion of air from the atmosphere, photosynthetic process and water surface agitation (EPA, 2012; Watt, 2000).

TS for FBW decreased to 1600 mg/l while that of SBW decreased to 600 mg/l. FBW was still above the standard upper limit of WHO guidelines of drinking water while that of SBW was within the standard upper limit of WHO guidelines of drinking water (WHO, 2004). At $p \leq 0.05$, there was significant difference in TS after treatment of both FBW and SBW. This was attributed to the presence of cationic polyelectrolytes that attracted the solids present in water. This complimented an earlier study which revealed that *Moringa oleifera* seed water extract contains magnet-like natural cationic polyelectrolytes that attracts negative particles in water (Mangale *et al.*, 2012).

E. coli count for FBW decreased to undetectable limit while that of SBW remained undetected and both were recorded as 0.0 CFU/ml. Both were within the standard limit of WHO guidelines of drinking water (WHO, 2006). At $p \leq 0.05$, there was no significant difference in *E. coli* count after treatment of both FBW and SBW. However, a slight decrease in *E. coli* count on FBW is attributed to the antibacterial activity of *Moringa oleifera* seed water extract (Shailemo *et. al.*, 2016). A study reported that there is an active agent in *Moringa oleifera* seed water extract that has some antibacterial elements which inhibit the growth of bacteria cells (Boateng, 2001). This explains the findings of this present study. It could also be attributed to the attachment of the *E. coli* cells to the flocs formed due to the coagulant and flocculant nature of *Moringa Oleifera* seed in water. This corroborates findings on an earlier study that *Moringa Oleifera* seed water extract in water treatment acts as a coagulant and a flocculant thus during the process, the bacteria is substantially removed since it attaches to the flocs as they settle down to the bottom of sedimentation tank (Schwarz, 2000).

This study revealed that at $p \leq 0.05$, *Moringa Oleifera* seed water extract in water treatment had no treatment effect on pH and *E. coli* count, positive treatment effects on EC, DO and TS and negative treatment effects on TDS for FBW. Water quality parameters of EC, DO and *E. coli* count met WHO guidelines of drinking water while pH, TDS and TS did not meet WHO guidelines of drinking water. It also revealed that there were no treatment effects on TDS, EC and *E. coli* count and positive treatment effects on pH, DO and TS for SBW. Water quality parameters of pH, DO, TS and *E. coli* count met WHO guidelines of drinking water while TDS and EC did not meet WHO guidelines of drinking water.

4.2.2 Treatment effects of activated clay

After treatment at a room temperature of 29°C, pH increased to 6.27 for FBW which was still below the standard range of WHO guidelines of drinking water while pH of SBW at a room temperature of 24°C increased to 7.28 and was still within the standard range of WHO guidelines of drinking water (WHO, 2006). There was positive treatment effect on FBW since pH increased closer to WHO guidelines of drinking water and positive treatment effect on SBW since pH increased but was still within WHO guidelines of drinking water. At $p \leq 0.05$, there was no significant difference in pH after treatment of both FBW and SBW. A slight increase in pH was due to the alkalizing nature of clay particles. Oosterban (2003), reported that clay particles are alkaline with a high pH approximately □ 9 due to the presence of sodium carbonates ($NaCO_3$) in the soil either as a result of natural mineralization of soil particles or brought in by irrigation and/or flood water. When dissolved in water, sodium carbonate dissociates into two positively charged sodium cations ($2Na^+$) and a double negatively charged carbonate anion (CO_3^{2-}) and in the process produces carbondioxide (CO_2) which escapes as a gas and sodium hydroxide (NaOH) which is alkaline and gives higher pH values.

TDS of FBW increased to 162 mg/l and that of SBW decreased to 2640 mg/l. TDS of FBW was within the standard upper limit of WHO guidelines of drinking water while that of SBW was above the standard upper limit of WHO guidelines of drinking water (WHO, 2006). The EC for FBW increased to 253 µS/cm while that of SBW decreased to 4123 µS/cm. The EC of FBW was within the standard upper limit of WHO guidelines of drinking water while that of SBW was above the standard upper limit of WHO guidelines of drinking water (WHO, 2006). There was positive treatment effect on FBW since TDS increased but was still within WHO guidelines of drinking water and positive treatment effect on SBW since TDS decreased closer to WHO guidelines of drinking water. At $p \leq 0.05$, there was no significant difference in TDS and EC after treatment of both FBW and SBW. A slight increase in TDS and EC for FBW is suspected to be as a result of ease of solubility of clay particles in water with low dissolved ions while a slight decrease in TDS and EC for SBW is due to the decreasing of amounts of ions in water with large amounts of dissolved ions due to the porosity of activated clay particles that would filter out and adsorb the ions present. This was in agreement with a study that showed that initial amounts of dissolved ions in water affect the effectiveness of adsorption capacity of porous structure of clay material (Guggenheim and Martin, 1995).

DO for FBW increased to 3.76 mg/l while that of SBW increased to 4.21 mg/l of dissolved oxygen. Both were also within the standard upper limit of WHO guidelines of drinking water (WHO, 2002). There was positive treatment effect on both FBW and SBW since DO increased but was still within WHO guidelines of drinking water. At $p \leq 0.05$, there was significant difference in DO after treatment of both FBW and SBW. It is also suspected that the increase of dissolved oxygen was as a result of diffusion of air from the atmosphere into the sample container during measurement. This is in agreement with studies that showed that dissolved oxygen levels in water is as a result of slow diffusion of air from the atmosphere, photosynthetic process and water surface agitation (EPA, 2012; Watt, 2000).

TS for FBW decreased to 2000 mg/l while that of SBW decreased to 400 mg/l. The TS for FBW were still above the standard upper limit of WHO guidelines of drinking water while those of SBW were within the standard upper limit of WHO guidelines of drinking water (WHO, 2004). There was positive treatment effect on FBW since TS decreased closer to WHO guidelines of drinking water and positive treatment effect on SBW since TS decreased to within WHO guidelines of drinking water. At $p \leq 0.05$, there was significant difference in TS after treatment of both FBW and SBW. Decrease in TS of treated water for both FBW and SBW in treatment was suspected to be due to porosity and adsorption capability of clay structure. This also complimented an earlier study which revealed that decrease of ions in contaminated water passed through clay particles was due to adsorption of the ions by the porous structure of the clay particles (Guggenheim and Martin, 1995). The adsorption process was suspected to have been efficient due to the presence of high amounts of ions in the salty water than the fresh water.

E. coli count for FBW also decreased to undetectable limit while that of SBW remained undetected which were again recorded as 0.0 CFU/ml. Both were within the standard limit of WHO guidelines of drinking water (WHO, 2006). There was positive treatment effect on FBW since *E. coli* count decreased to within WHO guidelines of drinking water and positive treatment effect since *E. coli* count still remained at within WHO guidelines of drinking water. At $p \leq 0.05$, there was no significant difference in *E. coli* count after treatment of both FBW and SBW. A slight decrease in *E. coli* count was attributed to adsorption capacity of activated clay particles on different kinds of bacterial cells. Studies have reported the differences in attachment of laboratory and environmental *E. coli* isolates to soil particles. It has been found that 24% of an introduced laboratory *E. coli* strain was found to attach to soil particles compared to 81% of an environmental strain following 30 minutes of contact time between cells and soil particles (Muirhead *et al.*, 2006). The findings of this study indicate that there could have been some significant attachment of the environmental *E. coli* cells on to activated clay particle surface.

This study revealed that at $p \leq 0.05$, activated clay in water treatment had no treatment effects on pH, TDS, EC and *E. coli* count and positive treatment effects on DO and TS for both FBW and SBW. Water quality parameters of TDS, EC, DO and *E. coli* count for FBW met WHO guidelines of drinking water while pH and TS did not meet WHO guidelines of drinking water. Water quality parameters of pH, DO, TS and *E. coli* count for SBW met WHO guidelines of drinking water while TDS and EC did not meet WHO guidelines of drinking water.

4.2.3 Treatment effects of activated charcoal

After treatment, pH decreased to 2.05 at a room temperature of 28^{o}C and 2.70 at a room temperature of 24^{o}C for FBW and SBW respectively. The values were far much below the standard range of WHO guidelines of drinking water (WHO, 2006). There was negative treatment effect on both FBW and SBW since decreased to below WHO guidelines of drinking water. At $p \leq 0.05$, there was significant difference in pH after treatment of both FBW and SBW. The decrease in pH of treated water was suspected to be as a result of the presence of silicates as a component of charcoal particle that reduces the pH when dissolved in water. This finding gets support from a reported study that activated charcoal carrying inorganics and chemically active groups on its surface may alter the pH of liquids to which it is added (Parimalam *et. al*., 2013).

TDS increased to 2793 mg/l and 2927 mg/l for FBW and SBW respectively. Both values were above the standard upper limit of WHO guidelines of drinking water (WHO, 2006). The EC also increased to 4367 µS/cm and 4573 µS/cm for FBW and SBW respectively. Both values were also above the standard upper limit of WHO guidelines of drinking water (WHO, 2006). There was negative treatment effect on both FBW and SBW since TDS increased to above WHO guidelines of drinking water. There was negative treatment effect on both FBW and SBW since EC increased to above WHO guidelines of drinking water. At $p \leq 0.05$, there was a significant difference in TDS and EC after treatment of FBW while there was no significant difference in TDS and EC after treatment of SBW. Increase in TDS and EC after treatment was due to soluble inorganic compounds present in activated charcoal. A study reported that increased amounts of ions in water when passed through charcoal particles is as a result of soluble inorganic compounds from charcoal that are retained in water after treatment (Prober *et al.*, 2004).

DO for FBW increased to 3.52 mg/l while that of SBW also increased to 4.09 mg/l of dissolved oxygen. Both were again within the standard upper limit of WHO guidelines of drinking water (WHO, 2002). There was positive treatment effect on both FBW and SBW since DO increased but was still within WHO guidelines of drinking water. At $p \leq 0.05$, there was significant difference in DO after treatment of both FBW and SBW. It is also suspected that the increase of dissolved oxygen was as a result of diffusion of air from the atmosphere into the sample container during measurement. This is in agreement with studies that showed that dissolved oxygen levels in water is as a result of slow diffusion of air from the atmosphere, photosynthetic process and water surface agitation (EPA, 2012; Watt, 2000).

TS for FBW increased to 8300 mg/l while those of SBW decreased to 800 mg/l. The TS for FBW were above the standard upper limit of WHO guidelines of drinking water while those of SBW were within the standard upper limit of WHO guidelines of drinking water (WHO, 2004). There was negative treatment effect on FBW since TS increased to above WHO guidelines of drinking water and positive treatment effect on SBW since TS decreased to within WHO guidelines of drinking water. At $p \leq 0.05$, there was significant difference in TS after treatment of both FBW and SBW. The increase in TS of treated water for FBW was suspected to be due to the addition of inorganic compounds from the charcoal particles that were retained in treated water. Prober *et al.* (2004) established that inorganic compounds from charcoal particles could be dissolved in water during treatment thereby increasing the amount of solids in water. The decrease in TS of treated water for SBW was suspected to be due to adsorption of solids as a result of large surface area and pore volume of charcoal particles. This complimented an earlier study which reported that due to large surface area and pore volume, charcoal particle has a unique adsorption capacity (Baker *et al.*, 1992).

E. coli count for FBW decreased to 1.0×10^4 CFU/ml while that of SBW remained undetected and was recorded as 0.0 CFU/ml. *E. coli* count for FBW was still above the standard limit of WHO guidelines for drinking water while the count for SBW was within the standard limit of WHO guidelines of drinking water (WHO, 2006). There was positive treatment effect on FBW since *E. coli* count decreased closer to WHO guidelines of drinking water and positive treatment effect on SBW since *E. coli* still remained at within WHO guidelines of drinking water. At $p \leq 0.05$, there was no significant difference in *E. coli* count after treatment of both FBW and SBW. However, slight decrease in *E. coli* count for FBW is suspected to be as a result of excellent adsorption capacity of charcoal particle. Earlier report on *E. coli* bacteria indicates that they adhere to the attractive sites of the activated charcoal upon traversing the charcoal particle thus reducing the count (Busscher *et. al.*, 2008).

This study revealed that at $p \leq 0.05$, activated charcoal in water treatment had no treatment effect on *E. coli* count, positive treatment effects on DO and negative treatment effects on pH, TDS, EC and TS for FBW. Water quality parameter of DO met WHO guidelines of drinking water while the rest of the parameters did not meet WHO guidelines of drinking water. It also revealed that there were no treatment effects on TDS, EC and *E. coli* count, positive treatment effects on DO and TS and negative treatment effects on pH for SBW.

Water quality parameters of DO, TS and *E. coli* count met WHO guidelines of drinking water while the rest of the parameters did not meet WHO guidelines of drinking water.

4.2.4 Treatment effects of natural zeolite

After treatment at a room temperature of 29^{o}C, pH of FBW increased to 7.48 and that of SBW at a room temperature of 24^{o}C increased to 7.67 whereby both were within the standard range of WHO guidelines of drinking water (WHO, 2006). This shows that there were positive treatment effects on FBW since pH increased to within WHO guidelines of drinking water and positive treatment effects on SBW since pH increased but was still within WHO guidelines of drinking water. At $p \leq 0.05$, there was significant difference between in pH after treatment of both FBW and SBW. It is suspected that increase in pH was due to ion exchange of alkaline cations that form part of natural zeolite structure with H^+ ions in water. This also was in agreement with findings of a study which reported that increase in pH of treated water using natural zeolite could be associated with the release of weakly bound exchangeable cations such as Na^+, K^+ and/or Ca^+ in the zeolite particle as a result of cation exchange with H^+ ions (Rivera *et al.*, 2000). Due to the alkalinity of cations Na^+, K^+ and Ca^+, the pH of water would therefore increase.

TDS for FBW increased to 192 mg/l while that of SBW decreased to 2690 mg/l. The TDS for FBW was within the standard upper limit of WHO guidelines of drinking water while that of SBW was above the standard upper limit of WHO guidelines of drinking water (WHO, 2006). The EC for FBW also increased to 300 µS/cm while that of SBW also decreased to 4207 µS/cm. The EC for FBW was also within the standard upper limit of WHO guidelines of drinking water while that of SBW was above the standard upper limit of WHO guidelines of drinking water. This shows that there were positive treatment effects on FBW since TDS increased but was still within WHO guidelines of drinking water and positive treatment effects on SBW since TDS decreased closer to WHO guidelines of drinking water. There was also positive treatment effect on FBW since EC increased but was still within WHO guidelines of drinking water and positive treatment effect on SBW since EC decreased closer to WHO guidelines of drinking water. At $p \leq 0.05$, there was no significant difference in TDS and EC after treatment for both FBW and SBW. However, slight increase of TDS and EC for FBW is as a result of solubility of zeolite components in water while a slight decrease of TDS and EC for SBW is as a result of availability of a negative charged surface of the zeolite structure that would attract the positively charged ions in water. This was in agreement with a study that reported that presence of negatively charged soluble zeolite components resulting into negative surface charge of zeolite structure that would allow positively charged ions to adhere to its surface thereby reducing ion load in water (Jamil *et. al.*, 2010).

DO for FBW increased to 3.28 mg/l while that of SBW also increased to 3.94 mg/l of dissolved oxygen. Both were also within the standard upper limit of WHO guidelines of drinking water (WHO, 2002). This shows that there were positive treatment effects on both FBW and SBW since DO increased but was still within WHO guidelines of drinking water. At $p \leq 0.05$, there was significant difference in DO after treatment for FBW while there was no significant difference in DO after treatment for SBW. It is also suspected that the increase of dissolved oxygen was as a result of diffusion of air from the atmosphere into the sample container during measurement. This is in agreement with studies that showed that dissolved oxygen levels in water is as a result of slow diffusion of air from the atmosphere, photosynthetic process and water surface agitation (EPA, 2012; Watt, 2000).

TS for FBW decreased to 3200 mg/l while those of SBW also decreased to 730 mg/l. For FBW, the TS were still above the standard upper limit of WHO guidelines of drinking water while those of SBW were within the standard upper limit of WHO guidelines of drinking water (WHO, 2004). This shows that there were positive treatment effects on FBW since TS decreased closer to WHO guidelines of drinking water and positive treatment effects on SBW since TS decreased to within WHO guidelines of drinking water. At $p \leq 0.05$, there was significant difference in TS after treatment for both FBW and SBW. This is attributed to high adsorption capacity of natural zeolites. Earlier studies that were confirmed by findings in this present study showed that natural zeolite indicate a significant potential as an adsorbent material in water treatment (Englert and Rubio, 2005; Shikuku *et al.*, 2015).

E. coli count for FBW increased to 1.47×10^6 CFU/ml while that of SBW still remained undetected and was recorded as 0.0 CFU/ml. *E. coli* count for FBW was above the standard limit of WHO guidelines of drinking water while the count for SBW was within the standard limit of WHO guidelines of drinking water (WHO, 2006). This shows that there were negative treatment effects on FBW since *E. coli* count increased to above WHO guidelines of drinking water and positive treatment effect on SBW since *E. coli* count remained at within WHO guidelines of drinking water. At $p \leq 0.05$, there was significant difference in *E. coli* count after treatment of FBW while there was no significant difference in *E. coli* count after treatment of SBW. The increase in *E. coli* count for FBW was suspected to be as a result of the charge of the zeolite surface at a neutral pH. The pH after treatment was slightly neutral that largely changed the charge on zeolites surface to negative. An earlier study reported that natural zeolites as an adsorbent have negatively charged surfaces at neutral pH and since *E. coli* cell surfaces are also negatively charged, their interactions may be controlled by double-layer repulsive forces (Pal *et al.*, 2006). This would enhance the presence and subsequent multiplication of *E. coli* cell that would increase the count since *E. coli* cells would be repelled by natural zeolite surface leaving the independent for survival.

This study revealed that natural zeolite in water treatment had no treatment effects on TDS and EC, positive treatment effects on pH, DO and TS and negative treatment effects on

E. coli count for FBW. Water quality parameters of pH, TDS, EC and DO met WHO guidelines of drinking water while the rest of the parameters did not meet WHO guidelines of drinking water. It also revealed that there were no treatment effects on TDS, EC, DO and *E. coli* count positive treatment effects on pH and TS for SBW. Water quality parameters of pH, DO, TS and *E. coli* count met WHO guidelines of drinking water while TDS and EC did not meet WHO guidelines of drinking water.

4.3 Treatment effects of factorial combinations of local materials on FBW and SBW.

4.3.1: Fresh Borehole Water

The treatment effects done in the laboratory at room temperature using factorial combinations of local materials labelled A to X on FBW are recorded in Table 4.3.1:

Table 4.3.1: Variations on treatment effects of factorial combinations of local materials on FBW

	pH (*a.u*)	**TDS (mg/L)**	**EC (µS/cm)**	**DO (mg/L)**	**TS (mg/L)**	***E. coli* count (CFU/mL)**
Before treatment	5.88	134	210	2.76	4200	1.3x10^{5}
A	6.04^{b}	755^{a}	1180^{a}	4.48^{a}	1530^{a}	1.0x10$^{4\,b}$
B	3.02^{a}	1910^{a}	2980^{a}	3.24^{a}	1930^{a}	1.0x10$^{4\,b}$
C	2.30^{a}	1747^{a}	2733^{a}	4.21^{a}	860^{a}	8.0x10$^{6\,a}$
D	2.30^{a}	2110^{a}	3300^{a}	4.54^{a}	660^{a}	2.0x10$^{6\,a}$
E	5.74^{b}	1063^{a}	1657^{a}	4.06^{a}	1060^{a}	1.0x10$^{5\,b}$
F	3.24^{a}	1420^{a}	2223^{a}	3.41^{a}	540^{a}	ND^{b}
G	7.77^{a}	621^{a}	970^{a}	4.18^{a}	660^{a}	1.0x10$^{6\,a}$
H	4.37^{a}	1500^{a}	2340^{a}	3.49^{a}	860^{a}	9.0x10$^{5\,a}$
I	2.34^{a}	1190^{a}	1857^{a}	4.35^{a}	1870^{a}	4.0x10$^{6\,a}$
J	6.93^{a}	729^{a}	1140^{a}	4.19^{a}	1330^{a}	ND^{b}
K	4.11^{a}	597^{a}	933^{a}	3.69^{a}	260^{a}	1.2x10$^{7\,a}$
L	5.08^{a}	802^{a}	1253^{a}	3.81^{a}	800^{a}	ND^{b}
M	2.48^{a}	1627^{a}	2547^{a}	3.42^{a}	930^{a}	1.0x10$^{6\,a}$
N	5.01^{a}	1593^{a}	2493^{a}	3.70^{a}	330^{a}	ND^{b}
O	2.33^{a}	1837^{a}	2867^{a}	3.48^{a}	860^{a}	4.5x10$^{6\,a}$
P	5.39^{a}	1103^{a}	1723^{a}	3.67^{a}	400^{a}	1.0x10$^{4\,b}$
Q	2.64^{a}	1533^{a}	2393^{a}	3.41^{a}	3500^{a}	4.0x10$^{6\,a}$
R	5.69^{b}	1087^{a}	1700^{a}	3.05^{a}	530^{a}	ND^{b}
S	2.12^{a}	2637^{a}	4123^{a}	4.36^{a}	330^{a}	2.0x10$^{5\,b}$
T	3.69^{a}	631^{a}	990^{a}	3.06^{a}	860^{a}	1.0x10$^{7\,a}$

U	5.37^{a}	1427^{a}	2233^{a}	4.73^{a}	2400^{a}	ND^{b}
V	5.12^{a}	655^{a}	1023^{a}	3.59^{a}	1060^{a}	ND^{b}
W	3.63^{a}	610^{a}	953^{a}	3.79^{a}	4100^{a}	1.4x10$^{6\ a}$
X	2.37^{a}	2157^{a}	3370^{a}	3.56^{a}	1200^{a}	ND^{b}
CV%	6.25	7.94	7.95	5.11	6.47	15.99
LSD ($p \leq 0.05$)	0.33	201	315	0.22	93	2.5x10^{5}
WHO Limits[1,2,3]	6.5-8.5	≤500	≤1000	≤5	≤1000	0.0

Key:
Values are mean analyzed individually in triplicate, Data computed for before and after treatment with combinations of local materials A-X, FBW: Fresh borehole water, TDS: Total dissolved solids, EC: Electrical conductivity, DO: Dissolved oxygen, TS: Total solids, a.u: arbitrary units, ND: Not detected, a: Significant different after treatment ($p \leq 0.05$), b: Not significant after treatment ($p \leq 0.05$), CV: Coefficient of variance, LSD: Least significant difference, WHO limits[1]: World Health Organisation drinking water guidelines, 2002, WHO limits[2]: World Health Organisation drinking water guidelines, 2004, WHO limits[3]: World Health Organisation drinking water guidelines, 2006.

From Table 4.3.1, the study revealed that there were both positive and negative treatment effects of factorial combinations of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite on the quality of FBW measured after a duration of 30 minutes after treatment. It showed that combination A and J had an increase in pH, TDS, EC and DO and a decrease in TS and *E. coli* count. Combinations B, E, F, L, N, P, R, V and X had an increase in TDS, EC and DO and a decrease in pH, TS and *E. coli* count. Combinations C, H, I, K, M, O, Q, S, T and W had an increase in TDS, EC, DO and *E. coli* count and a decrease in pH and TS. Combination D had an increase in TDS, EC, DO and *E. coli* count and a decrease in pH and TS. Combination G had an increase in pH, TDS, EC, DO and *E. coli* count and a decrease in TS. Combination U had an increase in TDS, EC and DO and a decrease in pH, TS and *E. coli* count.

4.3.1.1 Treatment effects on pH of FBW

Before treatment at room temperature of 22^{o}C, the pH of FBW at 5.88 was below the standard range of WHO guidelines of drinking water. After treatment, combinations G and J recorded pH of 7.77 and 6.93 respectively which were within the standard range of WHO guidelines of drinking water. The rest of the combinations recorded pH ranging from 2.12 to 6.04 which were below the standard range of WHO guidelines of drinking water. At $p \leq 0.05$, there was no significant difference in pH after treatment by factorial combinations A, E and R while there was a significant difference in pH after treatment by the rest of factorial combinations. Figure 4.3.1.1 shows a graph of variation of pH of treated water against combinations of treatment materials in comparison with the WHO guidelines of drinking water:

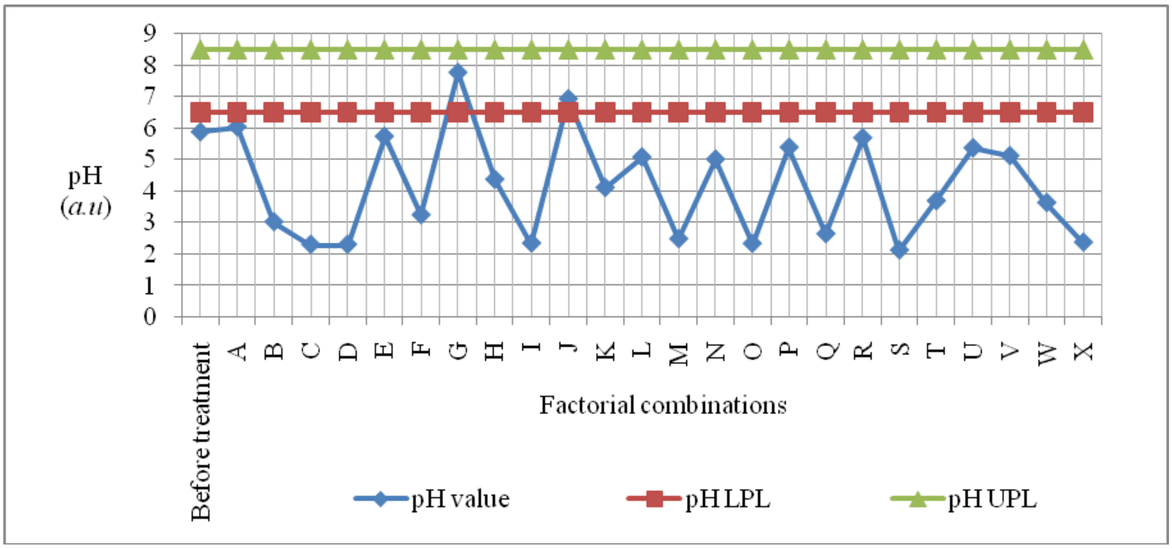

Figure 4.3.1.1: Variation of pH of water before and after treatment of FBW using factorial combinations of local natural materials in comparison with WHO guidelines of drinking water

Key:
a.u: arbitrary units, LPL: Lower permissible WHO^3 limit, UPL: Upper permissible WHO^3 limit, WHO^3: World Health Organisation guidelines of drinking water, 2006.

The study revealed that at $p \leq 0.05$, combinations A, E and R had no treatment effects on pH while combinations G and J recorded positive treatment effects that met WHO guidelines of drinking water. The rest of the combinations recorded negative treatment effects that did not meet WHO guidelines of drinking water.

4.3.1.2 Treatment effects on TDS and EC of FBW

Before treatment, TDS at 134 mg/L was within the standard upper limit of WHO guidelines of drinking water. All combinations had TDS ranging from 610 mg/L to 2637 mg/L which were above the standard upper limit of WHO guidelines of drinking water. Before treatment, EC at 210 µS/cm was within the standard upper limit of WHO guidelines of drinking water.

However, after treatment, combinations G, K, T and W recorded EC of 970 µS/cm, 933 µS/cm, 990 µS/cm and 953 µS/cm respectively which were within the standard upper limit of WHO guidelines of drinking water. The rest of the combinations recorded EC ranging from 1140 µS/cm to 4123 µS/cm which was above the standard upper limit of WHO guidelines of drinking water. At $p \leq 0.05$, there was significant difference in TDS and EC after treatment by all the factorial combinations. Figures 4.3.1.2a and 4.3.1.2b show graphs of variations of TDS and EC respectively of treated water against combinations of treatment materials in comparison with WHO guidelines of drinking water:

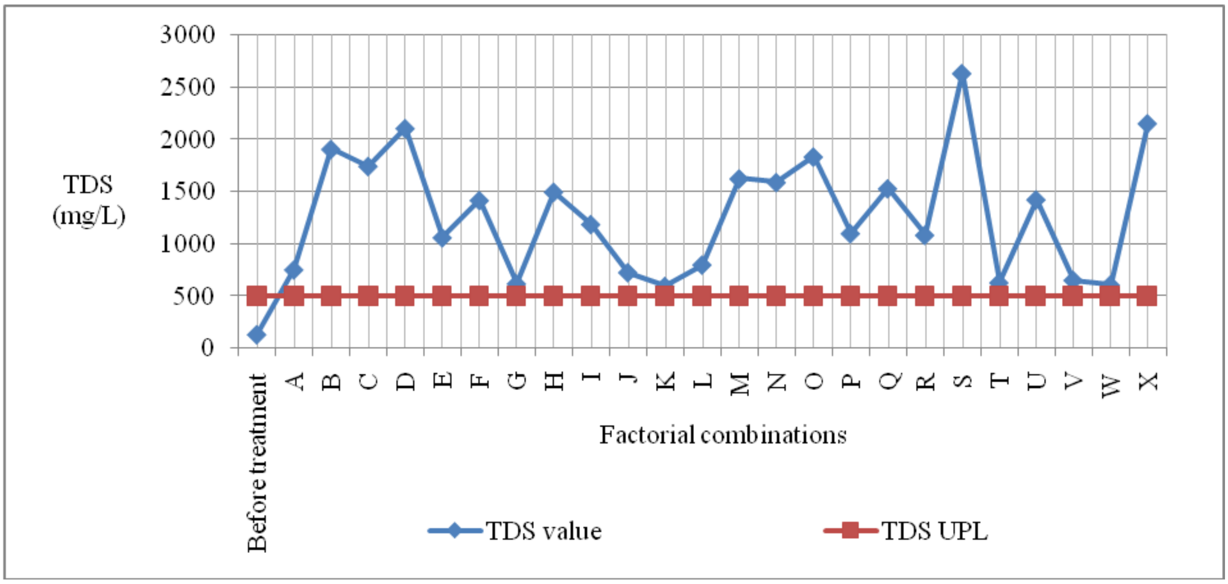

Figure 4.3.1.2a: Variation of TDS of water before and after treatment of FBW using factorial combinations of local natural materials in comparison with WHO guidelines of drinking water

Key:
TDS: Total dissolved solids, UPL: Upper permissible WHO[3] limit, WHO[3]: World Health Organisation guidelines of drinking water, 2006.

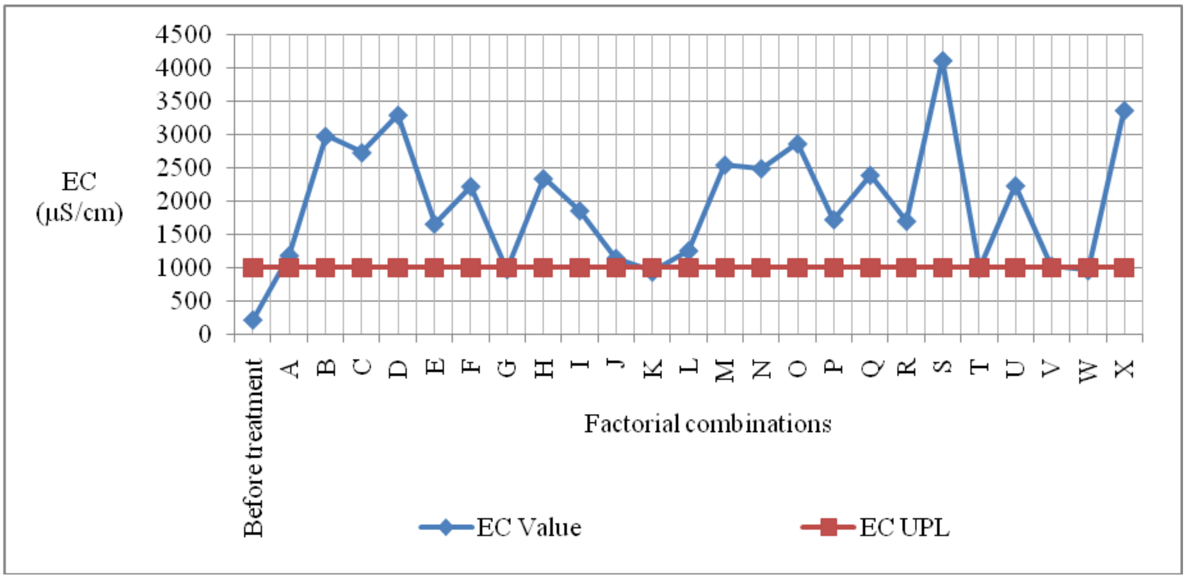

Figure 4.3.1.2b: Variation of EC of water before and after treatment of FBW using factorial combinations of local natural materials in comparison with WHO guidelines of drinking water

Key:
EC: Electrical conductivity, UPL: Upper permissible WHO[3] limit, WHO[3]: World Health Organisation guidelines of drinking water, 2006.

The study revealed that at p≤0.05, all the combinations recorded negative treatment effects on TDS that did not meet the WHO guidelines of drinking water. However, combinations A, G, J, K, L, T, V and W were closer to WHO guidelines of drinking water. It also revealed that combinations G, K, T and W recorded positive treatment effects that met WHO guidelines of drinking water while the rest of the combinations recorded negative treatment effects that did not meet WHO guidelines of drinking water.

4.3.1.3 Treatment effects on DO of FBW

Before treatment, DO at 2.76 mg/L was within the standard upper limit of WHO guidelines of drinking water. However, after treatment, all combinations recorded DO ranging from 3.06 mg/L to 4.73 mg/L which were still within the standard upper limit of WHO guidelines of drinking water. At p≤0.05, there was significant difference in DO after treatment by all the factorial combinations. Figure 4.3.1.3 shows a graph of variation of DO of treated water against combinations of treatment materials in comparison with WHO guidelines of drinking water:

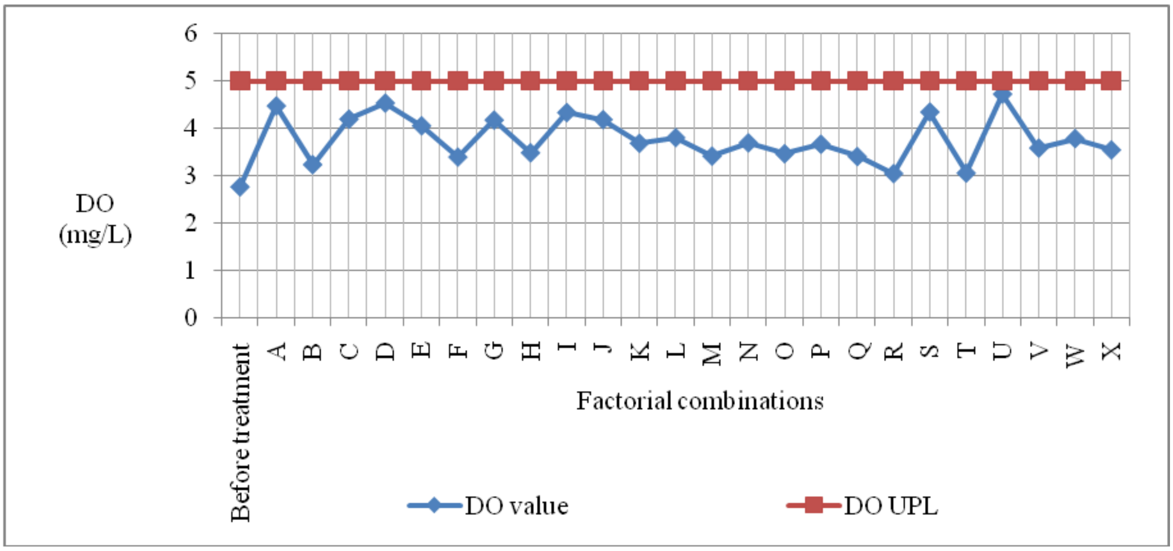

Figure 4.3.1.3: Variation of DO of water before and after treatment of FBW using factorial combinations of local natural materials in comparison with WHO guidelines of drinking water

Key:
DO: Dissolved oxygen, UPL: Upper permissible WHO[1] limit, WHO[1]: World Health Organisation guidelines of drinking water, 2002.

The study revealed that at p≤0.05, all the combinations recorded positive treatment effects that met WHO guidelines of drinking water.

4.3.1.4 Treatment effects on TS of FBW

Before treatment, TS at 4200 mg/L was above the standard upper limit of WHO guidelines of drinking water. However, after treatment, factorial combinations A, B, E, I, J, Q, U, V, W and X recorded TS ranging from 1060 mg/L to 4100 mg/L which were above the standard upper limit of WHO guidelines of drinking water while the rest of the combinations recorded TS ranging from 260 mg/L to 930 mg/L that were within the standard upper limit of WHO guidelines of drinking water. At p≤0.05, there was significant difference in TS after treatment values by all the factorial combinations. Figure 4.3.1.4 shows a graph of variation of TS of treated water against combinations of treatment materials in comparison with the WHO guidelines of drinking water:

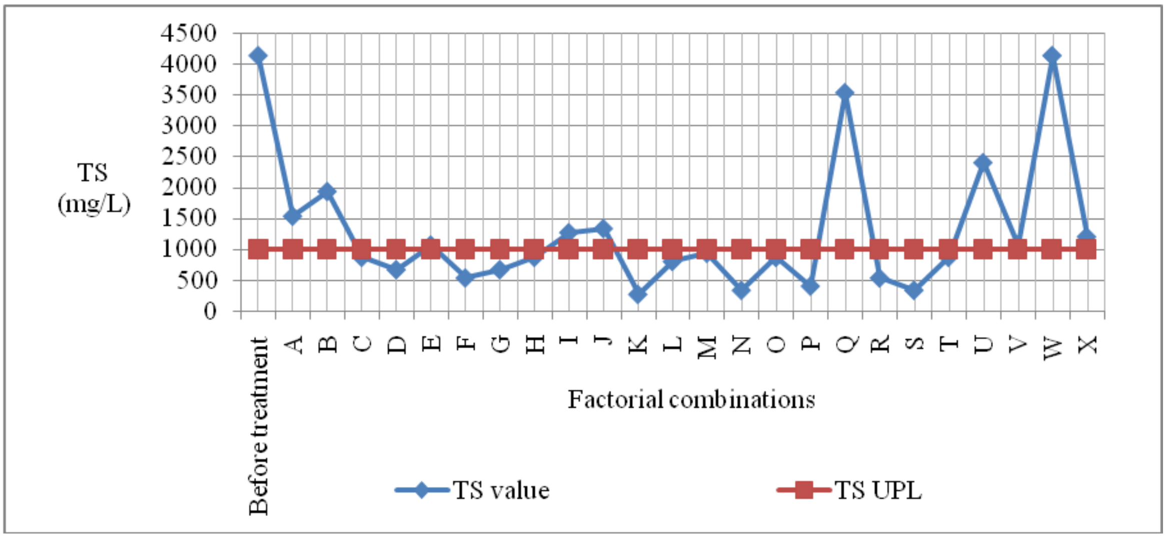

Figure 4.3.1.4: Variation of TS of water before and after treatment of FBW using factorial combinations local natural materials in comparison with WHO guidelines of drinking water

Key:
TS: Total solids, UPL: Upper permissible WHO^2 limit, WHO^2: World Health Organisation guidelines of drinking water, 2004.

The study revealed that at p≤0.05, all the combinations recorded positive treatment effects on TS. However, combinations A, B, E, I, J, Q, U, V, W and X did not meet WHO guidelines of drinking water while the rest of the combinations met WHO guidelines of drinking water.

4.3.1.5 Treatment effects on *E. coli* count of FBW

Before treatment, *E. coli* count at 1.3×10^5 CFU/mL was above the standard limit of WHO guidelines of drinking water. However, after treatment, combinations F, J, L, N, R, U, V and X recorded 0.0 CFU/ml which were within the standard limit of WHO guidelines of drinking water. The rest of the combinations recorded *E. coli* counts ranging from 1.0×10^4 CFU/mL to 1.2×10^7 CFU/mL which were above the standard limit of WHO guidelines of drinking water. At p≤0.05, there was significant difference in *E. coli* count after treatment by factorial combinations C, D, G, H, I, K, M, O, Q, T and W while there was no significant difference in *E. coli* count after treatment by the rest of the combinations. Figure 4.3.1.5 shows a graph of variation of *E. coli* count of treated water against combinations of treatment materials in comparison with the WHO guidelines of drinking water:

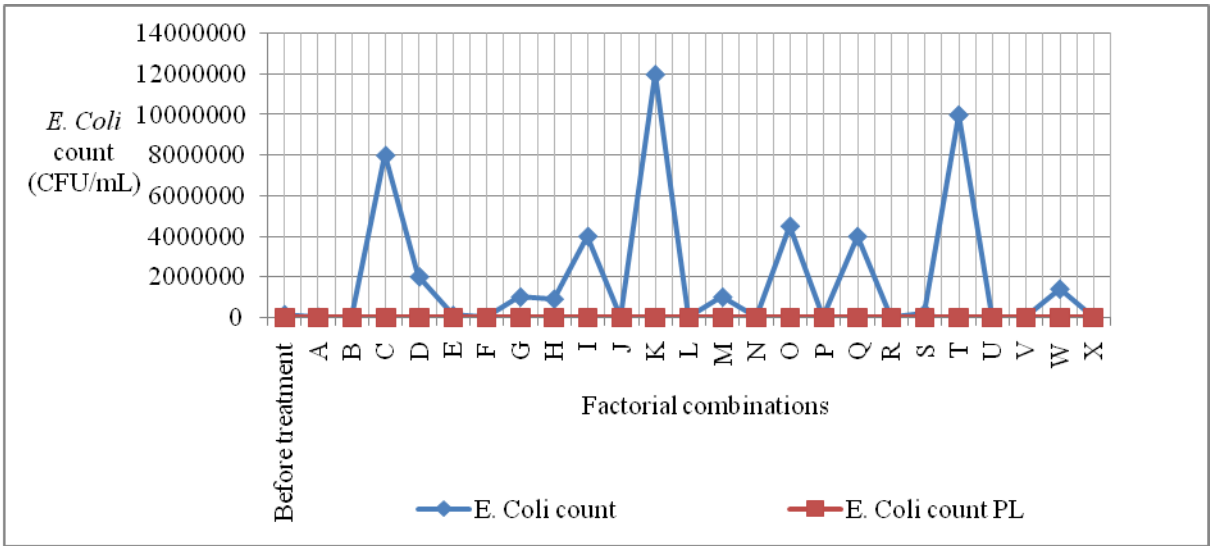

Figure 4.3.1.5: Variation of *E. coli* count of water before and after treatment of FBW using factorial combinations of local natural materials in comparison with WHO guidelines of drinking water

Key:
E. coli: Escherichia coli, Permissible WHO^3 limit, UPL: WHO^3: World Health Organisation guidelines of drinking water, 2006.

The study revealed that at p≤0.05, combinations A, B, E, F, J, L, N, P, R, U, V and X had no treatment effects on *E. coli* count while the rest of the combinations recorded negative treatment effects. Combinations F, J, L, N, R, U, V and X met WHO guidelines of drinking water while the rest of the combinations did not meet WHO guidelines of drinking water.

4.3.2 Salty Borehole Water

The treatment effects done in the laboratory at room temperature using combinations of local materials are recorded in Table 4.3.2:

Table 4.3.2: Variations on treatment effect of factorial combinations of local natural materials on SBW

	pH (*a.u*)	**TDS (mg/L)**	**EC (µS/cm)**	**DO (mg/L)**	**TS (mg/L)**	***E. coli* count (CFU/mL)**
Before treatment	7.08	2720	4253	3.67	2000	ND
A	5.95^{a}	2927^{a}	4577^{a}	3.98^{a}	330^{a}	$2.0x10^{6\ a}$
B	3.81^{a}	3563^{a}	5567^{a}	2.90^{a}	260^{a}	$1.2x10^{6\ a}$
C	2.82^{a}	3853^{a}	6020^{a}	2.82^{a}	600^{a}	$2.0x10^{4\ b}$
D	4.10^{a}	2950^{a}	4610^{a}	2.61^{a}	530^{a}	$1.0x10^{4\ b}$
E	5.82^{a}	2727^{b}	4267^{b}	4.06^{a}	1200^{a}	$1.6x10^{6\ a}$
F	5.00^{a}	3147^{a}	4920^{a}	2.10^{a}	1660^{a}	ND^{b}
G	2.79^{a}	3947^{a}	6163^{a}	3.51^{b}	660^{a}	$5.6x10^{5\ a}$
H	5.66^{a}	2790^{b}	4360^{b}	3.86^{b}	1130^{a}	ND^{b}
I	5.08^{a}	2887^{b}	4517^{b}	4.01^{a}	460^{a}	$8.6x10^{6\ a}$
J	4.89^{a}	3097^{a}	4840^{a}	2.73^{a}	600^{a}	ND^{b}
K	2.38^{a}	3617^{a}	5653^{a}	2.70^{a}	530^{a}	$6.4x10^{5\ a}$
L	4.33^{a}	3063^{a}	4790^{a}	2.79^{a}	1130^{a}	$1.0x10^{5\ b}$
M	5.62^{a}	2770^{b}	4330^{b}	4.48^{a}	400^{a}	$8.0x10^{5\ a}$
N	2.90^{a}	3310^{a}	5177^{a}	1.84^{a}	260^{a}	$8.0x10^{4\ b}$
O	2.03^{a}	3207^{a}	5017^{a}	1.89^{a}	460^{a}	$6.0x10^{6\ a}$
P	3.72^{a}	2840^{b}	4440^{b}	1.94^{a}	600^{a}	ND^{b}
Q	6.16^{a}	2750^{b}	4297^{b}	4.16^{a}	1330^{a}	$2.0x10^{6\ a}$
R	2.94^{a}	2837^{b}	4437^{b}	4.02^{a}	800^{a}	$1.0x10^{4\ b}$
S	2.12^{a}	3133^{a}	4900^{a}	3.79^{b}	930^{a}	$2.0x10^{5\ b}$
T	2.71^{a}	3257^{a}	5087^{a}	2.74^{a}	1260^{a}	$2.0x10^{4\ b}$
U	6.56^{a}	2617^{b}	4087^{b}	3.91^{a}	600^{a}	ND^{b}
V	4.40^{a}	3030^{a}	4740^{a}	3.91^{a}	330^{a}	ND^{b}
W	2.48^{a}	3480^{a}	5440^{a}	3.94^{a}	260^{a}	ND^{b}
X	2.47^{a}	2840^{b}	4440^{b}	3.80^{b}	660^{a}	ND^{b}
CV%	6.25	7.94	7.95	5.11	6.47	15.99
LSD $p \leq 0.05$	0.33	201	315	0.22	93	$2.5x10^{5}$
WHO Limits[1,2, 3]	6.5-8.5	≤ 500	≤ 1000	≤ 5	≤ 1000	0.0

Key:

Values are mean analyzed individually in triplicate, Data computed for before and after treatment with combinations of local materials, SBW: Salty borehole water, TDS: Total dissolved solids, EC: Electrical conductivity, DO: Dissolved oxygen, TS: Total solids, a.u: arbitrary units, ND: Not detected, a: Significant difference, b: Not significant, CV: Coefficient of variance, LSD: Least significant difference, WHO limits[1]: World Health Organisation drinking water guidelines, 2002, WHO limits[2]: World Health Organisation drinking water guidelines, 2004, WHO limits[3]: World Health Organisation drinking water guidelines, 2006.

From Table 4.3.2, the study revealed that there were both positive and negative treatment effects of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite when factorially combined on the quality of water measured after 30 minutes after treatment. It showed that combinations A, E, I, M, Q, R, S and T had an increase in TDS, EC, DO and *E. coli* count and a decrease in pH and TS. Combinations B, C, D, G, K, L, N and O had an increase in TDS, EC and *E. coli* count and a decrease in pH, DO and TS. Combinations F, J and P had an increase in TDS and EC, a decrease in pH, DO and TS and no effect on *E. coli* count. Combinations H, V, W and X had an increase in TDS, EC and DO, a decrease in pH and TS and no effect on *E. coli* count. Combination U had an increase in DO, a decrease in pH, TDS, EC and TS and no effect on *E. coli* count.

4.3.2.1 Treatment effects on pH of SBW

Before treatment, the pH at 7.08 was within the standard range of WHO guidelines of drinking water. After treatment, only combination U recorded pH of 6.56 which was within the standard range of WHO guidelines of drinking water. The other combinations recorded pH ranging from 2.03 to 6.16 which were below the standard range of WHO guidelines of drinking water. At $p \leq 0.05$, there was significant difference in pH after treatment by all the factorial combinations. Figure 4.3.2.1 shows a graph of variation of pH of treated water using combination of treatment materials in comparison with the WHO guidelines of drinking water:

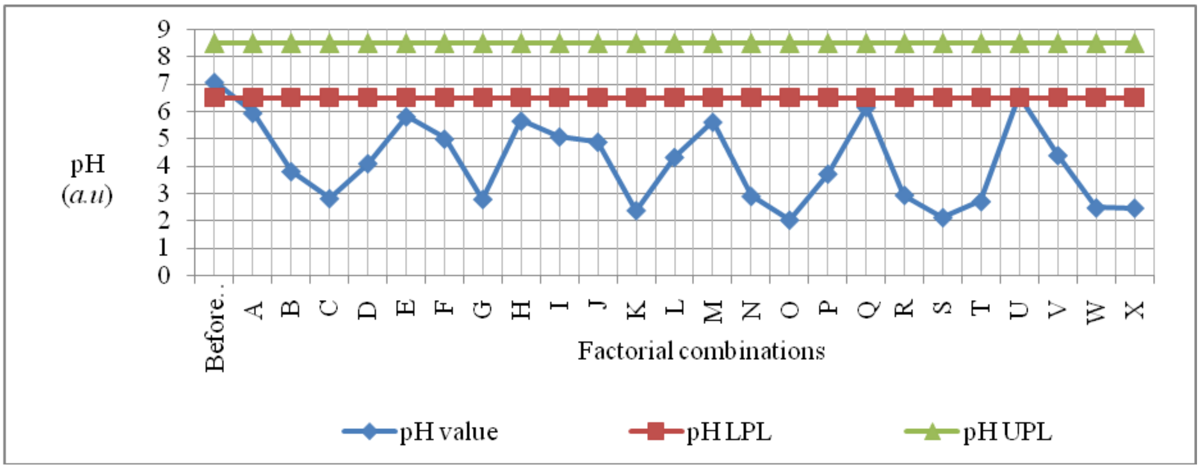

Figure 4.3.2.1: Variation of pH of water before and after treatment of SBW using factorial combinations of local natural materials in comparison with WHO guidelines of drinking water

Key:
a.u: arbitrary units, LPL: Lower permissible WHO^3 limit, UPL: Upper permissible WHO^3 limit, WHO^3: World Health Organisation guidelines of drinking water, 2006.

The study revealed that at $p \leq 0.05$, only combination U recorded positive treatment effect while the rest of the combinations recorded negative treatment effects. All the combinations did not meet WHO guidelines of drinking water.

4.3.2.2 Treatment effects on TDS and EC of SBW

Before treatment, TDS at 2720 mg/L was above the standard upper limit of WHO guidelines of drinking water. After treatment, all the factorial combinations recorded TDS ranging from 2617 mg/L to 3947 mg/L which were still above the standard upper limit of WHO guidelines of drinking water. On the other hand, before treatment, EC at 4253 µS/cm was above the standard upper limit of WHO guidelines of drinking water. After treatment, again, all the combinations recorded EC ranging from 4087 µS/cm to 6163 µS/cm which were also still above the standard upper limit of WHO guidelines of drinking water. At $p \leq 0.05$, there was no significant difference after treatment by combinations E, H, I, M, P, Q, R, U and X while there was significant difference after treatment by the rest of the combinations for both TDS and EC. Figures 4.3.2.2a and 4.3.2.2b show graphs of variations of TDS and EC respectively of treated water using combination of treatment materials in comparison with WHO guidelines of drinking water:

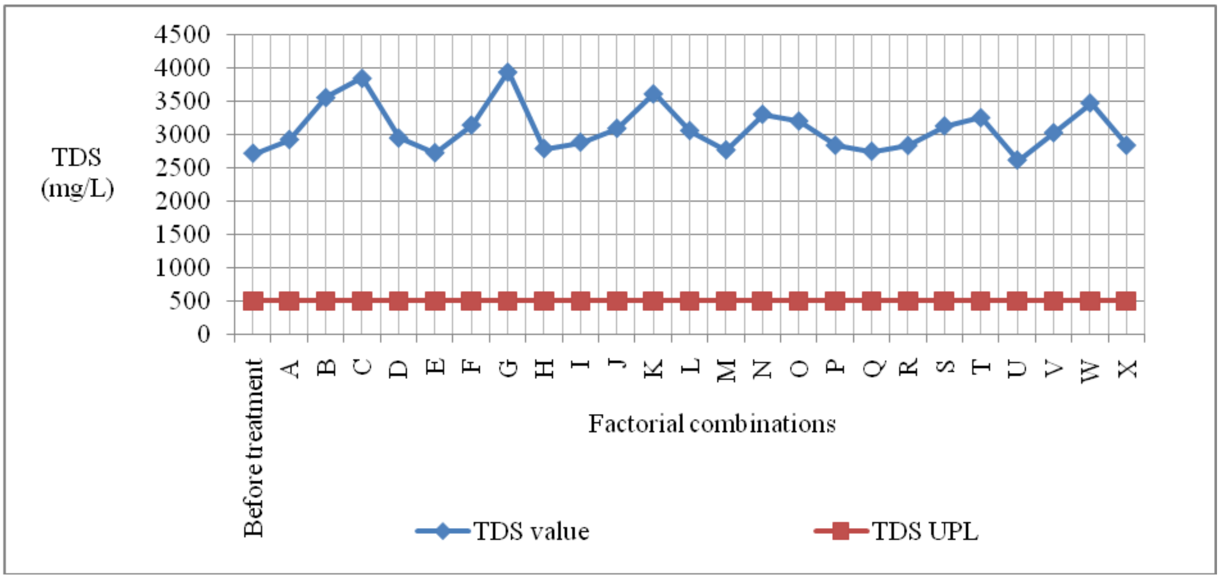

Figure 4.3.2.2a: Variation of TDS of water before and after treatment of SBW using factorial combinations of local natural materials in comparison with WHO guidelines of drinking water

Key:
TDS: Total dissolved solids, UPL: Upper permissible WHO[3] limit, WHO[3]: World Health Organisation guidelines of drinking water, 2006.

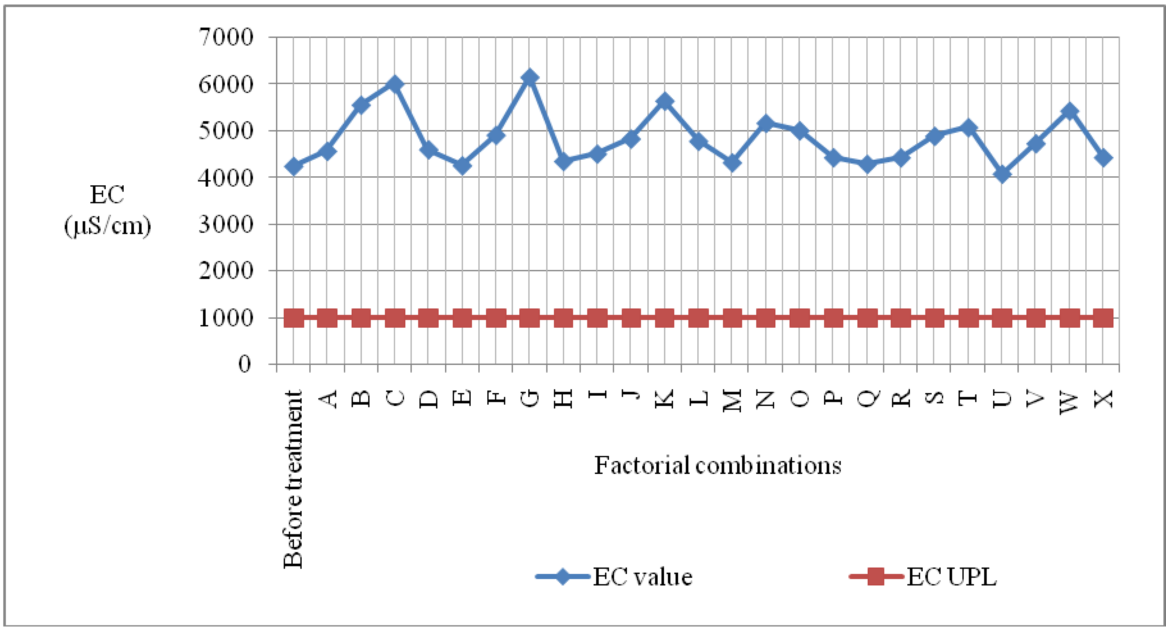

Figure 4.3.1b: Variation of EC of water before and after treatment of SBW using factorial combinations of local natural materials in comparison with WHO guidelines of drinking water

Key:
EC: Electrical conductivity, UPL: Upper permissible WHO[3] limit, WHO[3]: World Health Organisation guidelines of drinking water, 2006.

The study revealed that at $p \leq 0.05$, combinations E, H, I, M, P, Q, R, U and X had no treatment effects on both TDS and EC while the rest of the combinations recorded negative treatment effects. All the combinations did not meet WHO guidelines of drinking water.

4.3.2.3 Treatment effects on DO of SBW

Before treatment, DO at 3.67 mg/L was within the standard upper limit of WHO guidelines of drinking water. After treatment, all combinations recorded DO ranging from 1.84 mg/L to 4.48 mg/L which were still within the standard upper limit of WHO guidelines of drinking water. At $p \leq 0.05$, there was no significant difference after treatment by combinations G, H, S and X while there was significant difference after treatment by the rest of the combinations. Figure 4.3.2.3 shows a graph of variation of DO of treated water using combination of treatment materials in comparison with WHO guidelines of drinking water:

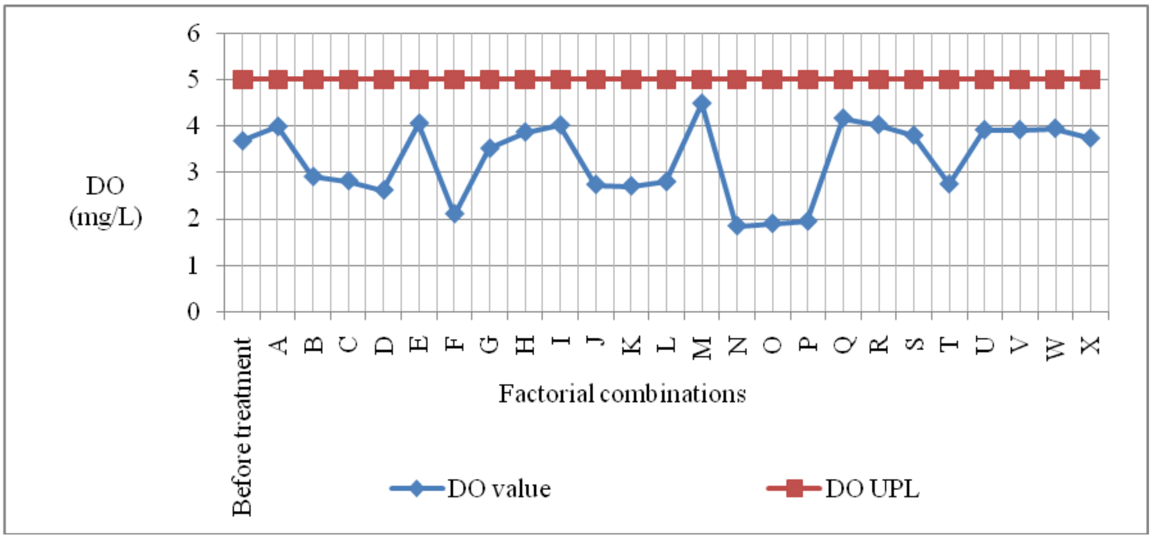

Figure 4.3.2.2: Variation of DO of water before and after treatment of SBW using factorial combinations of local natural materials in comparison with WHO guidelines of drinking water

Key:
DO: Dissolved oxygen, UPL: Upper permissible WHO[1] limit, WHO[1]: World Health Organisation guidelines of drinking water, 2002.

The study revealed that at p≤0.05, combinations G, H, S and X had no treatment effects on DO while the rest of the combinations recorded positive treatment effects. All the combinations met WHO guidelines of drinking water.

4.3.2.4 Treatment effects on TS of SBW

Before treatment, TS at 2000 mg/L was above the standard upper limit of WHO guidelines of drinking water. After treatment, factorial combinations E, F, H, L, Q and T recorded TS ranging from 1130 mg/L to 1660 mg/L which were still above the standard upper limit of WHO guidelines of drinking water. The other combinations recorded TS ranging from 260 mg/L to 930 mg/L which were within the standard upper limit of WHO guidelines of drinking water. At p≤0.05, there was significant difference in TS by all the factorial combinations. Figure 4.3.2.4 shows a graph of variation of TS of treated water using combination of treatment materials in comparison with WHO guidelines of drinking water:

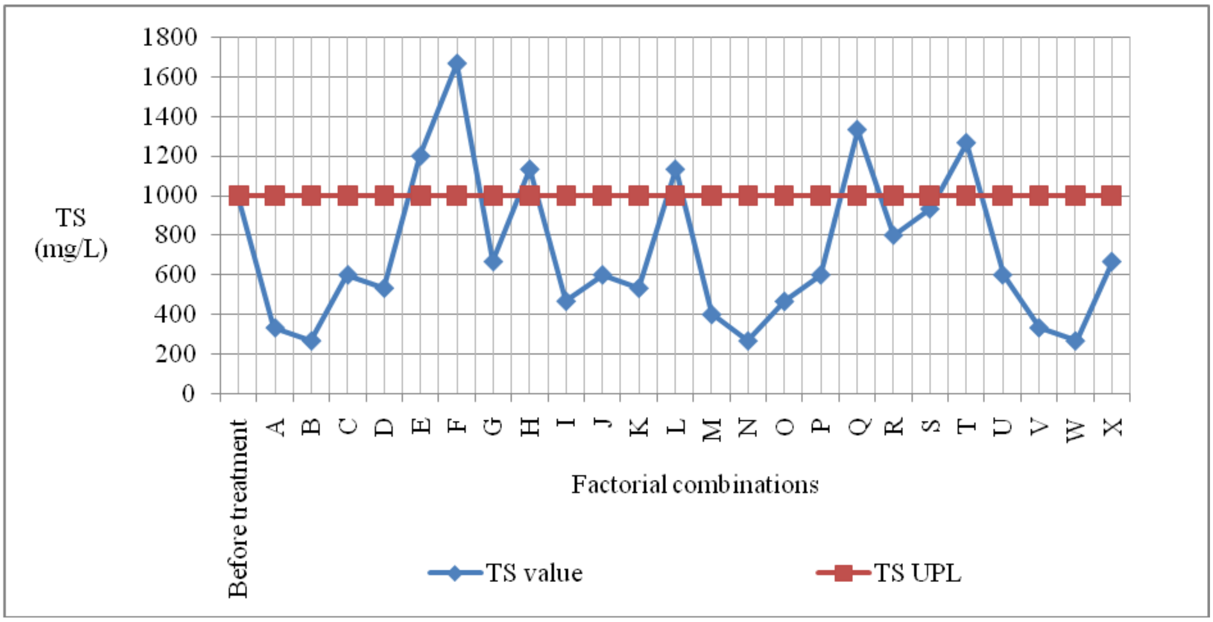

Figure 4.3.2.4: Variation of TS of water before and after treatment of SBW using factorial combinations of local natural materials in comparison with WHO standards of drinking water

Key:
TS: Total solids, UPL: Upper permissible WHO^2 limit, WHO^2: World Health Organisation guidelines of drinking water, 2004.

The study revealed that at $p \leq 0.05$, all the combinations recorded positive treatment effects on TS. However, combinations E, F, H, L, Q and T did not meet WHO guidelines of drinking water while the rest of the combinations met WHO guidelines of drinking water.

4.3.2.5 Treatment effects on *E. coli* count of SBW

Before treatment, *E. coli* count at 0.0 CFU/mL was within the standard limit of WHO guidelines of drinking water. However, after treatment, combinations F, H, J, P, U, V, W and X recorded *E. coli* count of 0.0 CFU/mL which were within the standard limit of WHO guidelines of drinking water. The other combinations recorded *E. coli* counts ranging from 1.0×10^4 CFU/mL to 8.0×10^6 CFU/mL which were above the standard limit of WHO guidelines of drinking water. At $p \leq 0.05$, there was significant difference after treatment by combinations A, B, E, G, I, K, M, O and Q while there was no significant difference after treatment by the rest of the other combinations. Figure 4.3.2.5 shows a graph of variation of *E. coli* count of treated water using combination of treatment materials in comparison with the WHO guidelines of drinking water:

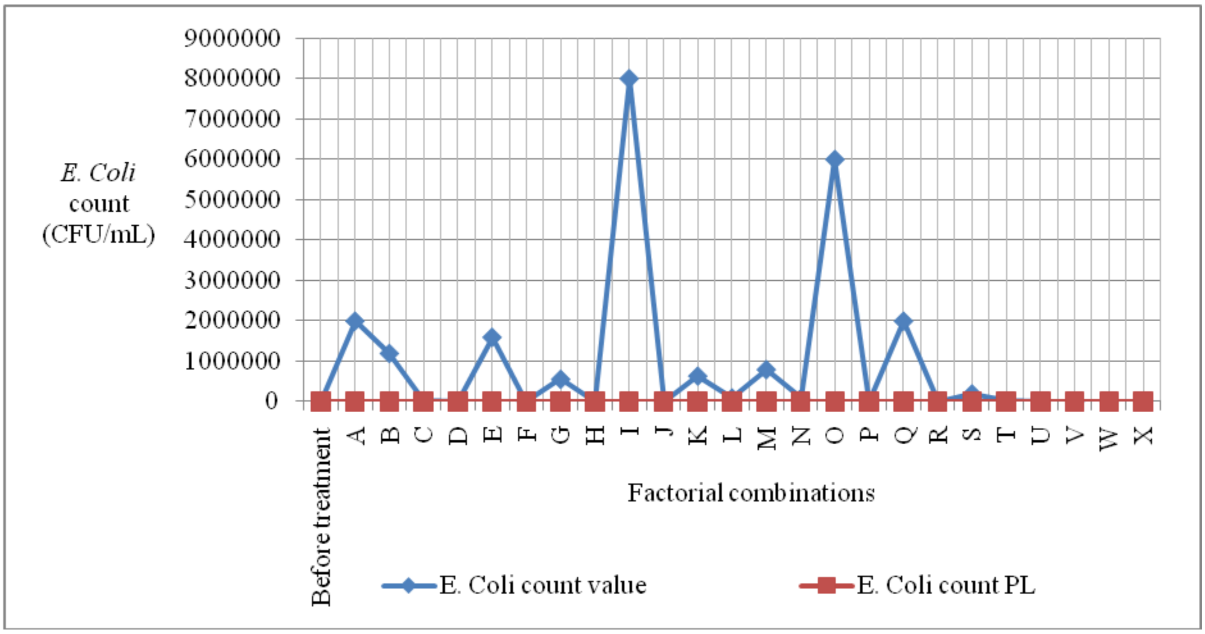

Figure 4.3.2.5: Variation of *E. coli* count of water before and after treatment of SBW using factorial combinations of local natural materials in comparison with WHO guidelines of drinking water

Key:
E. coli: Escherichia Coli, Permissible WHO[3] limit, UPL: WHO[3]: World Health Organisation guidelines of drinking water, 2006.

The study revealed that at $p \leq 0.05$, combinations C, D, F, H, J, L, N, P, R, S, T, U, V, W and X had no treatment effects on *E. coli* count while the rest of the combinations recorded negative treatment effects. Combinations F, H, J, P, U, V, W and X met WHO guidelines of drinking water while the rest of the combinations did not meet WHO guidelines of drinking water.

4.4 The effective factorial combination of local materials for domestic water treatment on FBW and SBW

According to WHO guidelines of drinking water, the acceptable limit for *E. coli* count is 0.0 CFU/mL. The reference point for the determination of the effective combinations of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite in water treatment was therefore the *E. coli* count for each combination regime that was equaling to 0.0 CFU/mL. Table 4.4a shows variance of treated FBW quality from the standard limits of WHO guidelines of drinking water for each parameter measured for those combination regimes where *E. coli* count equals to 0.0 CFU/mL:

Table 4.4a: Variance of water quality of treated FBW from WHO guidelines of drinking water

Factorial Combination	**Δ pH**	**Δ TDS (mg/L)**	**Δ EC (µS/cm)**	**Δ DO (mg/L)**	**Δ TS (mg/L)**	**Δ *E. coli* count (CFU/mL)**	**SUMMATION**
F	10.63	846400	1495729	0.00	0.0	0.0	2342139.63
J	0.00	52441	19600	0.00	108900	0.0	180941.00
L	2.02	91204	64009	0.00	0	0.0	155215.02
N	2.22	1194649	2229049	0.00	0	0.0	3423700.22
R	0.66	344569	490000	0.00	0	0.0	834569.66
U	1.28	859329	1520289	0.00	1960000	0.0	4339619.28
V	1.90	24025	529	0.00	3600	0.0	28155.90
X	17.06	2745649	5616900	0.00	40000	0.0	8402566.06

Key:

Values are variance of treated water from WHO guidelines of drinking water for each parameter measured.

From Table 4.4a, the effective combination of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite for treatment of fresh borehole water was combination V (Activated charcoal → *Moringa oleifera* seed water extract → Activated clay → Natural zeolite) since it had the least summation of variance from WHO standard limits for the water quality parameters.

Table 4.4b shows variance of treated SBW quality from the standard limits by the WHO guidelines of drinking water for each parameter measured for those combination regimes where *E. coli* count equals to 0.0 CFU/mL:

Table 4.4b: Variance of water quality of treated SBW from WHO guidelines of drinking water

Factorial Combination	Δ pH	Δ TDS (mg/L)	Δ EC (μS/cm)	Δ DO (mg/L)	Δ TS (mg/L)	Δ *E. coli* count (CFU/mL)	SUMMATION
F	2.25	7006609	15366400	0.00	435600	0.0	22808611.25
H	0.71	5244100	11289600	0.00	16900	0.0	16550600.71
J	2.59	6744409	14745600	0.00	0	0.0	21490011.59
P	7.73	5475600	11833600	0.00	0	0.0	17309201.73
U	0.00	4481689	9529569	0.00	0	0.0	14011258.00
V	4.41	6400900	13987600	0.00	0	0.0	20388504.41
W	16.16	8880400	19713600	0.00	0	0.0	28594016.16
X	16.24	5475600	11833600	0.00	0	0.0	17309216.24

Key:
Values are variance of treated water from WHO guidelines of drinking water for each parameter measured.

From Table 4.4b, the effective factorial combination of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite for treatment of salty borehole water was combination U (Activated charcoal → Natural zeolite → Activated clay → *Moringa Oleifera* seed water extract) since it had the least summation of variance from WHO standard upper limits for the water quality parameters.

Table 4.4c shows variation in treatment effect between individual and effective combinations of *Moringa Oleifera* seed water extract, activated clay, activated charcoal and natural zeolite on FBW:

Table 4.4c: Variation in treatment effect between individual and effective combination of treatment materials on FBW.

Treatment	**pH (*a.u*)**	**TDS (mg/L)**	**EC (µS/cm)**	**DO (mg/L)**	**TS (mg/L)**	***E. Coli* count (CFU/mL)**
Moringa Oleifera seed	6.11^{a}	514^{b}	803^{b}	4.87^{a}	1600^{a}	0.0^{b}
Activated clay	6.27^{a}	162^{a}	253^{a}	3.76^{b}	2000^{a}	0.0^{b}
Activated charcoal	2.05^{a}	2793^{a}	4367^{a}	3.52^{b}	8300^{a}	1.0x10^{4b}
Natural zeolite	7.48^{a}	192^{a}	300^{a}	3.28^{a}	3200^{a}	1.47x10^{6a}
Combination V	5.12	655	1023	3.59	1060	0.0
CV%	6.25	7.94	7.95	5.11	6.47	15.99
LSD ($p \leq 0.05$)	0.44	271	423	0.29	124	3.3x10^{5}
WHO Limits^{1,2,3}	6.5-8.5	≤500	≤1000	≤5	≤1000	0.0

Key:

Values are mean analyzed individually in triplicate, Data computed for treatment effects of individual local materials against effective combination V, FBW: Fresh borehole water, TDS: Total dissolved solids, EC: Electrical conductivity, DO: Dissolved oxygen, TS: Total solids, a.u: arbitrary units, a: Significant difference, b: Not significant, CV: Coefficient of variance, LSD: Least significant difference, WHO limits^{1}: World Health Organisation drinking water guidelines, 2002, WHO limits^{2}: World Health Organisation drinking water guidelines, 2004, WHO limits^{3}: World Health Organisation drinking water guidelines, 2006.

From Table 4.4c, at $p \leq 0.05$, there was significant difference in treatment effects on pH and TS between combination V and all the treatment materials. There was no significant difference in treatment effects on both TDS and EC between combination V and *Moringa oleifera* seed water extract while there was significant difference with activated clay, activated charcoal and natural zeolite. There was significant difference in treatment effects on DO between combination V and *Moringa oleifera* seed water extract and natural zeolite while there was no significant difference with activated clay and activated charcoal. There was no significant difference in treatment effects on *E. Coli* count between combination V and *Moringa oleifera* seed water extract, activated clay and activated charcoal while there was significant difference with natural zeolite. However, Combination V performed better than activated charcoal in bringing pH, TDS and EC closer to WHO guidelines of drinking water. Combination V also performed better than *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite on TS and better than activated charcoal and natural zeolite on *E. coli* count. Treatment effect on DO was similar between combination V and the four treatment local materials since the water quality parameter was within WHO guidelines of drinking water for each after treatment.

Table 4.4d shows variation in treatment effect between individual and effective factorial combinations of *Moringa Oleifera* seed, activated clay, activated charcoal and natural zeolite on SBW:

Table 4.4d: Variation in treatment effect between individual and effective factorial combination of treatment materials on SBW.

Treatment	pH (*a.u*)	TDS (mg/L)	EC (µS/cm)	DO (mg/L)	TS (mg/L)	*E. Coli* count (CFU/mL)
Moringa Oleifera seed	7.54^a	2497^b	3907^b	4.14^b	600^b	0.0^b
Activated clay	7.28^a	2640^b	4123^b	4.21^a	400^a	0.0^b
Activated charcoal	2.70^a	2927^a	4573^a	4.09^b	800^a	0.0^b
Natural zeolite	7.67^a	2690^b	4207^b	3.94^b	730^a	0.0^b
Combination U	6.56	2617	4087	3.91	600	0.0
CV%	6.25	7.94	7.95	5.11	6.47	15.99
LSD ($p\leq0.05$)	0.44	271	423	0.29	124	$3.3x10^5$
WHO Limits	6.5-8.5	≤500	≤1000	≤5	≤1000	0.0

Key:
Values are mean analyzed individually in triplicate, Data computed for treatment effects of individual local materials against effective combination U, SBW: Salty borehole water, TDS: Total dissolved solids, EC: Electrical conductivity, DO: Dissolved oxygen, TS: Total solids, *a.u*: arbitrary units, a: Significant difference, b: Not significant, CV: Coefficient of variance, LSD: Least significant difference, WHO limits^1: World Health Organisation drinking water guidelines, 2002, WHO limits^2: World Health Organisation drinking water guidelines, 2004, WHO limits^3: World Health Organisation drinking water guidelines, 2006.

From Table 4.4d, at $p\leq0.05$, there was significant difference in treatment effects on pH between combination U and all the treatment materials. There was no significant difference in treatment effects on both TDS and EC between combination U and *Moringa Oleifera* seed water extract, activated clay and natural zeolite while there was significant difference with activated charcoal. There was no significant difference in treatment effects on DO between combination U and *Moringa Oleifera* seed water extract, activated charcoal and natural zeolite while there was significant difference with activated clay. There was no significant difference in treatment effects on TS between combination U and *Moringa Oleifera* seed water extract while there was significant difference with activated clay, activated charcoal and natural zeolite. There was no significant difference in treatment effects on *E. oli* count between combination U and each of the treatment materials. However, Combination U performed better than activated charcoal in bringing pH, TDS, EC and TS closer to WHO guidelines of drinking water. Combination U also performed better than natural zeolite on TS. Treatment effect on DO was also similar between combination U and the four treatment local materials since the water quality parameter was within WHO guidelines of drinking water for each after treatment.

4.5 Comparison of treated water by MWTT and effective factorial combination of local materials for FBW and SBW.

The lake water samples in triplicate were also subjected to treatment using the effective treatment combinations V (Activated charcoal → *Moringa Oleifera* seed → Activated clay → Natural zeolite) for FBW and U (Activated charcoal → Natural zeolite → Activated clay → *Moringa Oleifera* seed) for SBW. The water quality parameters of lake water were determined before treatment and after treatment for both MWTT and combinations V for FBW and U for SBW for comparison purposes. Table 4.5 shows variations in treatment effects of MWTT and effective combinations V and U of local materials on Lake Victoria water:

Table 4.5: Variations in treatment effects of MWTT and effective treatment combination V for FBW and U for SBW on Lake Victoria water

		After treatment using					
	Before treatment	**MWTT**	**Combination V (FBW)**	**Combination U (SBW)**	**CV%**	**LSD (p≤0.05**	**WHO Limits^{1,2,3}**
Temperature (^{o}C)	28	28	28	28	0.00	0	25-30
pH (*a.u*)	6.18	6.87	6.38	6.63	0.54	0.09	6.5-8.5
TDS (mg/L)	1033	577	704	2113	4.75	137	≤500
EC (µS/cm)	1613	901	1100	3300	4.67	210	≤1000
DO (mg/L)	9.59	8.81	6.28	6.64	0.45	0.09	≤5
TS (mg/L)	1877	1277	1150	863	0.43	14	≤1000
E. Coli count (CFU/mL)	□$1.2x10^{7}$	$9.7x10^{4}$	$2.0x10^{4}$	$5.3x10^{4}$	16.42	$1.3x10^{6}$	0.0

Key:
Values are mean analyzed individually in triplicate, FBW: Fresh borehole water, SBW: Salty borehole water, MWTT: Municipal water treatment technology, TDS: Total dissolved solids, EC: Electrical conductivity, DO: Dissolved oxygen, TS: Total solids, *a.u*: arbitrary units, a: Significant difference, b: Not significant, CV: Coefficient of variance, LSD: Least significant difference, WHO limits^{1}: World Health Organisation drinking water guidelines, 2002, WHO limits^{2}: World Health Organisation drinking water guidelines, 2004, WHO limits^{3}: World Health Organisation drinking water guidelines, 2006.

After treatment at the same temperature of 28^{o}C, MWTT, combination V and combination U increased the pH to 6.87, 6.38 and 6.63 respectively. The pH for MWTT and combination U were within the standard range of WHO guidelines of drinking water while that of combination V was below the standard range of WHO guidelines of drinking water. MWTT and combination V decreased the TDS to 577 mg/L and 704 mg/L respectively while combination U increased the TDS to 2113 mg/L. The TDS for each were still above the standard upper limit of WHO guidelines of drinking water. Similarly, MWTT and combination V decreased the EC to 901 µS/cm and 1100 µS/cm respectively while combination U increased the EC to 3300 µS/cm. The EC for MWTT was within the standard upper limit of WHO guidelines of drinking water while that of combinations V and U were above the standard upper limit of WHO guidelines of drinking water. MWTT, combination V and combination U decreased the DO to 8.81 mg/L, 6.28mg/L and 6.64 mg/L respectively. All the recorded values were still above the standard upper limit of WHO guidelines of drinking water. MWTT and combinations V and U all decreased the TS to 1277 mg/L, 1150 mg/L and 863 mg/L respectively. The TS for MWTT and combination V were still above the standard upper limit of WHO guidelines of drinking water while that of combination U was within the standard upper limit of WHO guidelines of drinking water. The *E. Coli* count decreased in MWTT, combination V and combination U to $9.7x10^4$ CFU/mL, $2.0x10^4$ CFU/mL and $5.3x10^4$ CFU/mL respectively. All the values were still above the standard limit of WHO guidelines of drinking water. There was significant difference after treatment of Lake Victoria water for each of the 3 treatment methodologies (MWTT, combination V and combination U) for all the water quality parameters measured. The effective combinations also showed better treatment effects on dissolved oxygen, total solids and *E. Coli* count of 34.5%, 38.7% and 99.8% for combination V and 30.7%, 54.0% and 99.6% for combination U compared to 8.1%, 31.9% and 99.2% for MWTT respectively on Lake Victoria water.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

Data was collected for temperature, pH, TDS, EC and DO at the sampling site and TS and *E. coli* count immediately after transportation to the laboratory for both FBW and SBW. FBW recorded values of 25^{o}C, 237 mg/L, 370 µS/cm and 2.47 mg/L for temperature, TDS, EC and DO respectively that were within the standard range/upper limit of WHO guidelines of drinking water and values of 5.83, 4200 mg/L and 1.3x10^{5} CFU/mL for pH, TS and *E. coli* count respectively that were not within the standard range/upper limit of WHO guidelines of drinking water. SBW recorded values of 7.04, 3.00 mg/L and 0.0 CFU/mL for pH, DO and *E. coli* count respectively that were within the standard range/upper limit of WHO guidelines of drinking water and 32^{o}C, 3093 mg/L, 4837 µS/cm and 2000 mg/L for temperature, TDS, EC and TS respectively that were not within the standard range/upper limit of WHO guidelines of drinking water.

Water samples were treated using individual and factorial combinations of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite. For individual local materials on FBW, *Moringa oleifera* seed water extract recorded values of 803 µS/cm, 4.87 mg/l and 0.0 CFU/ml for EC, DO and *E. coli* count respectively that were within the standard range/upper limit of WHO guidelines of drinking water and 6.11, 514 mg/l and 1600 mg/l for pH, TDS and TS respectively that were not within the standard range/upper limit of WHO guidelines of drinking water. Activated clay recorded values of 162 mg/l, 253 µS/cm, 3.76 mg/l and 0.0 CFU/ml for TDS, EC, DO and *E. coli* count respectively that were within the standard range/upper limit of WHO guidelines of drinking water and 6.27 and 2000 mg/l for pH and TS respectively that were not within the standard range/upper limit of WHO guidelines of drinking water. Activated charcoal recorded value of 3.52 mg/l for DO that was within the standard range/upper limit of WHO guidelines of drinking water and 2.05, 2793 mg/l, 4367 µS/cm, 8300 mg/l and 1.0×10^4 CFU/ml for pH, TDS, EC, TS and *E. coli* count respectively that were not within the standard range/upper limit of WHO guidelines of drinking water. Natural zeolite recorded values of 7.48, 192 mg/l, 300 µS/cm and 3.28 mg/l for pH, TDS, EC and DO respectively that were within the standard range/upper limit of WHO guidelines of drinking water and 3200 mg/l and 1.47×10^6 CFU/ml for TS and *E. coli* count respectively that were not within the standard upper limit of WHO guidelines of drinking water.

For individual local materials on SBW, *Moringa oleifera* seed water extract recorded values of 7.54, 4.14 mg/l, 600 mg/l and 0.0 CFU/ml for pH, DO, TS and *E. coli* count respectively that were within the standard range/upper limit of WHO guidelines of drinking water and 2497 mg/l and 3907 µS/cm TDS and EC respectively that were not within the standard range/upper limit of WHO guidelines of drinking water. Activated clay also recorded values of 7.28, 4.21 mg/l, 400 mg/l and 0.0 CFU/ml for pH, DO, TS and *E. coli* count respectively that were within the standard range/upper limit of WHO guidelines of drinking water and 2640 mg/l and 4123 µS/cm for TDS and EC respectively that were not within the standard range/upper limit of WHO guidelines of drinking water. Activated charcoal recorded values of 4.09 mg/l, 800 mg/l and 0.0 CFU/ml for DO, TS and *E. coli* count respectively that were within the standard upper limit of WHO guidelines of drinking water and 2.70, 2927 mg/l and 4573 µS/cm for pH, TDS and EC respectively that were not within the standard range/upper limit of WHO guidelines of drinking water. Natural zeolite also recorded values of 7.67, 3.94 mg/l, 730 mg/l and 0.0 CFU/ml for pH, DO, TS and *E. coli* count respectively that were within the standard range/upper limit of WHO guidelines of drinking water and 2690 mg/l and 4207 µS/cm for TDS and EC respectively that were not within the standard range/upper limit of WHO guidelines of drinking water.

For factorial combinations of local materials on FBW, combinations G and J recorded values of 7.77 and 6.93 for pH respectively that were within the standard range of WHO guidelines of drinking water. All combinations recorded values for TDS that were above the standard upper limit of WHO guidelines of drinking water. Combinations G, K, T and W recorded values of 970 µS/cm, 933 µS/cm, 990 µS/cm and 953 µS/cm respectively for EC that were within the standard upper limit of WHO guidelines of drinking water. All combinations recorded values for DO that were within the standard upper limit of WHO guidelines of drinking water. Combinations C, D, F, G, H, K, L, M, N, O, P, R, S and T recorded values of 860 mg/L, 660 mg/L, 540 mg/L, 660 mg/L, 860 mg/L, 260 mg/L, 800 mg/L, 930 mg/L, 330 mg/L, 860 mg/L, 400 mg/L, 530 mg/L, 330 mg/L and 860 mg/L respectively for TS that were within the standard upper limit of WHO guidelines of drinking water. Combinations F, J, L, N, R, U, V and X recorded values of 0.0 CFU/mL each for *E. coli* count that were within the standard limit of WHO guidelines of drinking water.

For factorial combinations of local materials on SBW, all combinations recorded values for pH, TDS and EC that were not within the standard range of WHO guidelines of drinking water. However, all combinations recorded values for DO that were within the standard upper limit of WHO guidelines of drinking water. Combinations A, B, C, D, G, I, J, K, M, N, O, P, R, S, U, V, W and X recorded values of 330 mg/L, 260 mg/L, 600 mg/L, 530 mg/L, 660 mg/L, 460 mg/L, 600 mg/L, 530 mg/L, 400 mg/L, 260 mg/L, 460 mg/L, 600 mg/L, 800 mg/L, 930 mg/L, 600 mg/L, 330 mg/L, 260 mg/L and 660 mg/L respectively that were within the standard upper limit of WHO guidelines of drinking water. Combinations F, H, J, P, U, V, W and X recorded values of 0.0 CFU/mL each of *E. coli* count that were within the standard limit of WHO guidelines of drinking water.

The effective combinations that recorded the best water quality guidelines for drinking purposes were combination V (Activated charcoal → *Moringa oleifera* seed water extract → Activated clay → Natural zeolite) for FBW and combination U (Activated charcoal → Natural zeolite → Activated clay → *Moringa oleifera* seed water extract) for SBW. Combination V recorded values of 3.59 mg/l and 0.0 CFU/ml for DO and *E. coli* count respectively that were within the standard range/upper limit of WHO guidelines of drinking water while pH at 5.12 was below the standard range and TDS, EC and TS at 655 mg/l, 1023 µS/cm and 1060 mg/l were slightly above the standard upper limit of WHO guidelines of drinking water. Combination U recorded values of 6.56, 3.91 mg/l, 600 mg/l and 0.0 CFU/ml for pH, DO, TS and *E. coli* count respectively that were within the standard range/upper limit of WHO guidelines of drinking water while TDS and EC at 2617 mg/l and 4087 µS/cm respectively were above the standard upper limit of WHO guidelines of drinking water.

On comparing treatment effects of individual treatment materials on FBW with combination V (effective combination for FBW), there was significant difference in terms of TDS and EC for activated clay, activated charcoal and natural zeolite while there was no significant difference for *Moringa Oleifera* seed water extract. There was significant difference for all treatment materials for pH and TS. In terms of DO, there was significant difference for *Moringa Oleifera* seed water extract and natural zeolite while there was no significant difference for activated clay and activated charcoal. There was significant difference in *E. Coli* count for natural zeolite while there was no significant difference for *Moringa oleifera* seed water extract, activated clay and activated charcoal. On comparing treatment effects of individual treatment materials on SBW with combination U (effective combination for SBW), there was significant difference in terms of pH for all treatment materials. In terms of TDS and EC, there was significant difference for activated charcoal while there was no significant difference for *Moringa oleifera* seed water extract, activated clay and natural zeolite. For DO, there was significant difference for activated clay while there was no significant difference for *Moringa oleifera* seed water extract, activated charcoal and natural zeolite. In terms of TS, there was significant difference for activated clay, activated charcoal and natural zeolite while there was no significant difference for *Moringa oleifera* seed water extract. There was no significant difference in terms of *E. coli* count for all treatment materials.

Treatment effects on Lake Victoria water using MWTT, combination V (effective combination for FBW treatment) and combination U (effective combination for SBW treatment) were compared. On comparing treatment effect of MWTT and combination V, there was significant difference in temperature, pH, DO and TS while there was no significant difference in TDS, EC and *E. coli* count. On comparing treatment effect of MWTT and combination U, there was significant difference in all the measured parameters except *E. coli* count that did not differ significantly.

5.2 Conclusions

From this study, it can be concluded that;

i. Fresh borehole water and salty borehole water are polluted.

ii. There are positive and negative treatment effects using individual and factorial combinations of local materials on treatment of FBW and SBW.

iii. Combination V (Activated charcoal → *Moringa oleifera* seed water extract → Activated clay → Natural zeolite) is the effective treatment combination for fresh borehole water while combination U (Activated charcoal → Natural zeolite → Activated clay → *Moringa oleifera* seed water extract) is for salty borehole water.

The effective combinations also performed better than individual local materials on FBW and SBW.

iv. Treatment effects on Lake Victoria water by effective treatment combinations V and U are better than municipal water treatment technology.

5.3 Recommendations

This study recommends that;

i. Fresh and salty borehole waters should not be used for drinking purposes before treatment processes.

ii. A factorial combination of local materials in water treatment is a potential water treatment system.

iii. Use of effective factorial combinations V for fresh borehole water and U for salty borehole water could be adopted in local communities for borehole water treatment.

iv. Effective factorial combinations of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite could be applied in treatment of Lake Victoria water.

5.4 Suggestions for future research

i. A study should be done to determine the optimum residence treatment time for water within the treatment set-up.

ii. A study should be done on determination of level of specific water contaminants such as heavy metals and pesticides using the effective factorial combinations of local natural materials of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite.

iii. A study should be done to optimize the amount of *Moringa oleifera* seed water extract, activated clay, activated charcoal and natural zeolite *vis-a-vis* that of water during treatment.

iv. A study should be undertaken to analyze activated clay to ascertain the attachment of *E. coli* cells onto clay surface.

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APPENDICES

```
Function: FACTOR




Experiment Model Number 8:
     Two Factor Randomized Complete Block Design




Data case no. 1 to 174.




Factorial ANOVA for the factors:
     Replication (Var 1: Replication) with values from 1 to 3
     Factor A (Var 2: Borehole) with values from 1 to 2
     (1-FBWS, 2-SBWS)
     Factor B (Var 3: Treatment) with values from 1 to 29
     (1-Control, 2-Moringa Oleifera seed, 3-Activated clay,
     4-Activated charcoal, 5-Natural zeolite, 6-Combination A,
     7-Combination B, 8-Combination C, 9-Combination D,
     10-Combination E, 11-Combination F, 12-Combination G,
     13-Combination H, 14-Combination I, 15-Combination J,
     16-Combination K, 17-Combination L, 18-Combination M,
     19-Combination N, 20-Combination O, 21-Combination P,
     22-Combination Q, 23-Combination R, 24-Combination S,
     25-Combination T, 26-Combination U, 27-Combination V,
     28-Combination W and 29-Combination X)
```

APPENDIX I: Treatment effects on pH

```
Variable 5: pH (a.u)

Grand Mean = 4.411   Grand Sum = 767.490   Total Count = 174


              T A B L E   O F   M E A N S

  1   2   3               5              Total
-------------------------------------------------------
  1   *   *              4.404          255.430
  2   *   *              4.474          259.510
  3   *   *              4.354          252.550
-------------------------------------------------------
  *   1   *              4.374          380.530
  *   2   *              4.448          386.960
-------------------------------------------------------
  *   *   1              6.480           38.880
  *   *   2              6.823           40.940
  *   *   3              6.775           40.650
  *   *   4              2.375           14.250
  *   *   5              7.573           45.440
  *   *   6              5.995           35.970
  *   *   7              3.413           20.480
  *   *   8              2.563           15.380
  *   *   9              3.197           19.180
  *   *  10              5.780           34.680
  *   *  11              4.117           24.700
  *   *  12              5.280           31.680
  *   *  13              5.012           30.070
  *   *  14              3.708           22.250
  *   *  15              5.910           35.460
  *   *  16              3.243           19.460
  *   *  17              4.703           28.220
  *   *  18              4.047           24.280
  *   *  19              3.953           23.720
  *   *  20              2.180           13.080
  *   *  21              4.555           27.330
  *   *  22              4.398           26.390
  *   *  23              4.315           25.890
  *   *  24              2.118           12.710
  *   *  25              3.200           19.200
  *   *  26              5.962           35.770
  *   *  27              4.762           28.570
  *   *  28              3.057           18.340
  *   *  29              2.420           14.520
-------------------------------------------------------
  *   1   1              5.883           17.650
  *   1   2              6.110           18.330
  *   1   3              6.267           18.800
  *   1   4              2.053            6.160
  *   1   5              7.480           22.440
  *   1   6              6.040           18.120
  *   1   7              3.017            9.050
  *   1   8              2.303            6.910
  *   1   9              2.297            6.890
  *   1  10              5.740           17.220
```

```
  *   1  11              3.237            9.710
  *   1  12              7.767           23.300
  *   1  13              4.367           13.100
  *   1  14              2.337            7.010
  *   1  15              6.927           20.780
  *   1  16              4.110           12.330
  *   1  17              5.080           15.240
  *   1  18              2.477            7.430
  *   1  19              5.007           15.020
  *   1  20              2.330            6.990
  *   1  21              5.390           16.170
  *   1  22              2.637            7.910
  *   1  23              5.693           17.080
  *   1  24              2.117            6.350
  *   1  25              3.687           11.060
  *   1  26              5.367           16.100
  *   1  27              5.123           15.370
  *   1  28              3.633           10.900
  *   1  29              2.370            7.110
  *   2   1              7.077           21.230
  *   2   2              7.537           22.610
  *   2   3              7.283           21.850
  *   2   4              2.697            8.090
  *   2   5              7.667           23.000
  *   2   6              5.950           17.850
  *   2   7              3.810           11.430
  *   2   8              2.823            8.470
  *   2   9              4.097           12.290
  *   2  10              5.820           17.460
  *   2  11              4.997           14.990
  *   2  12              2.793            8.380
  *   2  13              5.657           16.970
  *   2  14              5.080           15.240
  *   2  15              4.893           14.680
  *   2  16              2.377            7.130
  *   2  17              4.327           12.980
  *   2  18              5.617           16.850
  *   2  19              2.900            8.700
  *   2  20              2.030            6.090
  *   2  21              3.720           11.160
  *   2  22              6.160           18.480
  *   2  23              2.937            8.810
  *   2  24              2.120            6.360
  *   2  25              2.713            8.140
  *   2  26              6.557           19.670
  *   2  27              4.400           13.200
  *   2  28              2.480            7.440
  *   2  29              2.470            7.410
----------------------------------------------------
```

```
            A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                Degrees of  Sum of         Mean       F
Value    Source      Freedom   Squares       Square     Value    Prob
-----------------------------------------------------------------------
  1     Replication  2          0.422         0.211       2.7726   0.0667
  2     Factor A     1          0.238         0.238       3.1243   0.0798
  4     Factor B    28        395.351        14.120     185.6540   0.0000
  6     AB          28        142.623         5.094      66.9748   0.0000
 -7     Error      114          8.670         0.076
-----------------------------------------------------------------------
        Total      173        547.304
-----------------------------------------------------------------------


     Coefficient of Variation: 6.25%

     s_ for means group 1:     0.0362       Number of Observations: 58
      y

     s_ for means group 2:     0.0296       Number of Observations: 87
      y

     s_ for means group 4:     0.1126       Number of Observations: 6
      y

     s_ for means group 6:     0.1592       Number of Observations: 3
      y



=======================================================================
```

APPENDIX II: Treatment effects on TDS

Variable 6: TDS (mg/l)

```
Grand Mean = 2124.920   Grand Sum = 369736.000   Total Count = 174


              T A B L E   O F   M E A N S

  1   2   3               6              Total
-------------------------------------------------------
  1   *   *            2158.448       125190.000
  2   *   *            2059.810       119469.000
  3   *   *            2156.500       125077.000
-------------------------------------------------------
  *   1   *            1211.563       105406.000
  *   2   *            3038.276       264330.000
-------------------------------------------------------
  *   *   1            1427.167         8563.000
  *   *   2            1505.333         9032.000
  *   *   3            1401.000         8406.000
  *   *   4            2860.000        17160.000
  *   *   5            1441.000         8646.000
  *   *   6            1840.667        11044.000
  *   *   7            2736.667        16420.000
  *   *   8            2800.000        16800.000
  *   *   9            2530.000        15180.000
  *   *  10            1895.000        11370.000
  *   *  11            2283.333        13700.000
  *   *  12            2283.667        13702.000
  *   *  13            2145.000        12870.000
  *   *  14            2038.333        12230.000
  *   *  15            1913.000        11478.000
  *   *  16            2106.833        12641.000
  *   *  17            1932.500        11595.000
  *   *  18            2198.333        13190.000
  *   *  19            2451.667        14710.000
  *   *  20            2521.667        15130.000
  *   *  21            1971.500        11829.000
  *   *  22            2141.667        12850.000
  *   *  23            1962.000        11772.000
  *   *  24            2885.000        17310.000
  *   *  25            1944.000        11664.000
  *   *  26            2021.667        12130.000
  *   *  27            1842.333        11054.000
  *   *  28            2045.000        12270.000
  *   *  29            2498.333        14990.000
-------------------------------------------------------
  *   1   1             134.333          403.000
  *   1   2             514.000         1542.000
  *   1   3             162.000          486.000
  *   1   4            2793.333         8380.000
  *   1   5             192.000          576.000
  *   1   6             754.667         2264.000
  *   1   7            1910.000         5730.000
  *   1   8            1746.667         5240.000
  *   1   9            2110.000         6330.000
  *   1  10            1063.333         3190.000
```

```
  *   1  11            1420.000           4260.000
  *   1  12             620.667           1862.000
  *   1  13            1500.000           4500.000
  *   1  14            1190.000           3570.000
  *   1  15             729.333           2188.000
  *   1  16             597.000           1791.000
  *   1  17             801.667           2405.000
  *   1  18            1626.667           4880.000
  *   1  19            1593.333           4780.000
  *   1  20            1836.667           5510.000
  *   1  21            1103.000           3309.000
  *   1  22            1533.333           4600.000
  *   1  23            1087.333           3262.000
  *   1  24            2636.667           7910.000
  *   1  25             631.333           1894.000
  *   1  26            1426.667           4280.000
  *   1  27             654.667           1964.000
  *   1  28             610.000           1830.000
  *   1  29            2156.667           6470.000
  *   2   1            2720.000           8160.000
  *   2   2            2496.667           7490.000
  *   2   3            2640.000           7920.000
  *   2   4            2926.667           8780.000
  *   2   5            2690.000           8070.000
  *   2   6            2926.667           8780.000
  *   2   7            3563.333          10690.000
  *   2   8            3853.333          11560.000
  *   2   9            2950.000           8850.000
  *   2  10            2726.667           8180.000
  *   2  11            3146.667           9440.000
  *   2  12            3946.667          11840.000
  *   2  13            2790.000           8370.000
  *   2  14            2886.667           8660.000
  *   2  15            3096.667           9290.000
  *   2  16            3616.667          10850.000
  *   2  17            3063.333           9190.000
  *   2  18            2770.000           8310.000
  *   2  19            3310.000           9930.000
  *   2  20            3206.667           9620.000
  *   2  21            2840.000           8520.000
  *   2  22            2750.000           8250.000
  *   2  23            2836.667           8510.000
  *   2  24            3133.333           9400.000
  *   2  25            3256.667           9770.000
  *   2  26            2616.667           7850.000
  *   2  27            3030.000           9090.000
  *   2  28            3480.000          10440.000
  *   2  29            2840.000           8520.000
-------------------------------------------------------
```

```
          A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                  Degrees of  Sum of      Mean          F
Value    Source    Freedom    Squares    Square       Value      Prob
-----------------------------------------------------------------------
  1     Replication  2     368921.115    184460.557       6.4751   0.0022
  2     Factor A     1 145154240.092 145154240.092   5095.3233   0.0000
  4     Factor B    28  29026750.874   1036669.674     36.3900   0.0000
  6     AB          28  24931388.575    890406.735     31.2558   0.0000
 -7     Error      114   3247602.218     28487.739
-----------------------------------------------------------------------
        Total      173 202728902.874
-----------------------------------------------------------------------


     Coefficient of Variation: 7.94%

     s_ for means group 1:    22.1623       Number of Observations: 58
      y

     s_ for means group 2:    18.0954       Number of Observations: 87
      y

     s_ for means group 4:    68.9054       Number of Observations: 6
      y

     s_ for means group 6:    97.4470       Number of Observations: 3
      y



=======================================================================
```

APPENDIX III: Treatment effects on EC

Variable 7: EC (µS/cm)

```
Grand Mean = 3321.609   Grand Sum = 577960.000   Total Count = 174


              T A B L E   O F   M E A N S

  1   2   3               7              Total
-------------------------------------------------------
  1   *   *            3374.138        195700.000
  2   *   *            3220.172        186770.000
  3   *   *            3370.517        195490.000
-------------------------------------------------------
  *   1   *            1893.678        164750.000
  *   2   *            4749.540        413210.000
-------------------------------------------------------
  *   *   1            2231.667         13390.000
  *   *   2            2355.000         14130.000
  *   *   3            2188.333         13130.000
  *   *   4            4470.000         26820.000
  *   *   5            2253.333         13520.000
  *   *   6            2878.333         17270.000
  *   *   7            4273.333         25640.000
  *   *   8            4376.667         26260.000
  *   *   9            3955.000         23730.000
  *   *  10            2961.667         17770.000
  *   *  11            3571.667         21430.000
  *   *  12            3566.667         21400.000
  *   *  13            3350.000         20100.000
  *   *  14            3186.667         19120.000
  *   *  15            2990.000         17940.000
  *   *  16            3293.333         19760.000
  *   *  17            3021.667         18130.000
  *   *  18            3438.333         20630.000
  *   *  19            3835.000         23010.000
  *   *  20            3941.667         23650.000
  *   *  21            3081.667         18490.000
  *   *  22            3345.000         20070.000
  *   *  23            3068.333         18410.000
  *   *  24            4511.667         27070.000
  *   *  25            3038.333         18230.000
  *   *  26            3160.000         18960.000
  *   *  27            2881.667         17290.000
  *   *  28            3196.667         19180.000
  *   *  29            3905.000         23430.000
-------------------------------------------------------
  *   1   1             210.000           630.000
  *   1   2             803.333          2410.000
  *   1   3             253.333           760.000
  *   1   4            4366.667         13100.000
  *   1   5             300.000           900.000
  *   1   6            1180.000          3540.000
  *   1   7            2980.000          8940.000
  *   1   8            2733.333          8200.000
  *   1   9            3300.000          9900.000
  *   1  10            1656.667          4970.000
```

```
  *   1  11            2223.333          6670.000
  *   1  12             970.000          2910.000
  *   1  13            2340.000          7020.000
  *   1  14            1856.667          5570.000
  *   1  15            1140.000          3420.000
  *   1  16             933.333          2800.000
  *   1  17            1253.333          3760.000
  *   1  18            2546.667          7640.000
  *   1  19            2493.333          7480.000
  *   1  20            2866.667          8600.000
  *   1  21            1723.333          5170.000
  *   1  22            2393.333          7180.000
  *   1  23            1700.000          5100.000
  *   1  24            4123.333         12370.000
  *   1  25             990.000          2970.000
  *   1  26            2233.333          6700.000
  *   1  27            1023.333          3070.000
  *   1  28             953.333          2860.000
  *   1  29            3370.000         10110.000
  *   2   1            4253.333         12760.000
  *   2   2            3906.667         11720.000
  *   2   3            4123.333         12370.000
  *   2   4            4573.333         13720.000
  *   2   5            4206.667         12620.000
  *   2   6            4576.667         13730.000
  *   2   7            5566.667         16700.000
  *   2   8            6020.000         18060.000
  *   2   9            4610.000         13830.000
  *   2  10            4266.667         12800.000
  *   2  11            4920.000         14760.000
  *   2  12            6163.333         18490.000
  *   2  13            4360.000         13080.000
  *   2  14            4516.667         13550.000
  *   2  15            4840.000         14520.000
  *   2  16            5653.333         16960.000
  *   2  17            4790.000         14370.000
  *   2  18            4330.000         12990.000
  *   2  19            5176.667         15530.000
  *   2  20            5016.667         15050.000
  *   2  21            4440.000         13320.000
  *   2  22            4296.667         12890.000
  *   2  23            4436.667         13310.000
  *   2  24            4900.000         14700.000
  *   2  25            5086.667         15260.000
  *   2  26            4086.667         12260.000
  *   2  27            4740.000         14220.000
  *   2  28            5440.000         16320.000
  *   2  29            4440.000         13320.000
--------------------------------------------------------
```

```
              A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K               Degrees of Sum of      Mean          F
Value    Source   Freedom    Squares    Square       Value      Prob
-----------------------------------------------------------------------
  1     Replication  2    895559.770    447779.885      6.4230   0.0023
  2     Factor A     1 354783744.828 354783744.828   5089.0183   0.0000
  4     Factor B    28  70866982.759   2530963.670     36.3041   0.0000
  6     AB          28  60865288.506   2173760.304     31.1804   0.0000
 -7     Error      114   7947573.563     69715.558
-----------------------------------------------------------------------
        Total      173 495359149.425
-----------------------------------------------------------------------


     Coefficient of Variation: 7.95%

     s_ for means group 1:    34.6698       Number of Observations: 58
      y

     s_ for means group 2:    28.3077       Number of Observations: 87
      y

     s_ for means group 4:   107.7927       Number of Observations: 6
      y

     s_ for means group 6:   152.4419       Number of Observations: 3
      y



=======================================================================
```

APPENDIX IV: Treatment effects on DO

Variable 8: DO (mg/l)

```
Grand Mean = 3.590   Grand Sum = 624.660   Total Count = 174


              T A B L E   O F   M E A N S

  1   2   3               8              Total
-------------------------------------------------------
  1   *   *               3.575           207.370
  2   *   *               3.584           207.850
  3   *   *               3.611           209.440
-------------------------------------------------------
  *   1   *               3.782           329.010
  *   2   *               3.398           295.650
-------------------------------------------------------
  *   *   1               3.217            19.300
  *   *   2               4.505            27.030
  *   *   3               3.983            23.900
  *   *   4               3.805            22.830
  *   *   5               3.608            21.650
  *   *   6               4.230            25.380
  *   *   7               3.072            18.430
  *   *   8               3.515            21.090
  *   *   9               3.577            21.460
  *   *  10               4.057            24.340
  *   *  11               2.755            16.530
  *   *  12               3.848            23.090
  *   *  13               3.673            22.040
  *   *  14               4.178            25.070
  *   *  15               3.462            20.770
  *   *  16               3.198            19.190
  *   *  17               3.303            19.820
  *   *  18               3.953            23.720
  *   *  19               2.770            16.620
  *   *  20               2.685            16.110
  *   *  21               2.803            16.820
  *   *  22               3.787            22.720
  *   *  23               3.538            21.230
  *   *  24               4.072            24.430
  *   *  25               2.900            17.400
  *   *  26               4.322            25.930
  *   *  27               3.750            22.500
  *   *  28               3.865            23.190
  *   *  29               3.678            22.070
-------------------------------------------------------
  *   1   1               2.760             8.280
  *   1   2               4.873            14.620
  *   1   3               3.760            11.280
  *   1   4               3.520            10.560
  *   1   5               3.277             9.830
  *   1   6               4.480            13.440
  *   1   7               3.240             9.720
  *   1   8               4.210            12.630
  *   1   9               4.543            13.630
  *   1  10               4.057            12.170
```

```
  *   1  11               3.407            10.220
  *   1  12               4.183            12.550
  *   1  13               3.487            10.460
  *   1  14               4.347            13.040
  *   1  15               4.193            12.580
  *   1  16               3.693            11.080
  *   1  17               3.813            11.440
  *   1  18               3.423            10.270
  *   1  19               3.703            11.110
  *   1  20               3.477            10.430
  *   1  21               3.670            11.010
  *   1  22               3.410            10.230
  *   1  23               3.053             9.160
  *   1  24               4.357            13.070
  *   1  25               3.060             9.180
  *   1  26               4.733            14.200
  *   1  27               3.590            10.770
  *   1  28               3.793            11.380
  *   1  29               3.557            10.670
  *   2   1               3.673            11.020
  *   2   2               4.137            12.410
  *   2   3               4.207            12.620
  *   2   4               4.090            12.270
  *   2   5               3.940            11.820
  *   2   6               3.980            11.940
  *   2   7               2.903             8.710
  *   2   8               2.820             8.460
  *   2   9               2.610             7.830
  *   2  10               4.057            12.170
  *   2  11               2.103             6.310
  *   2  12               3.513            10.540
  *   2  13               3.860            11.580
  *   2  14               4.010            12.030
  *   2  15               2.730             8.190
  *   2  16               2.703             8.110
  *   2  17               2.793             8.380
  *   2  18               4.483            13.450
  *   2  19               1.837             5.510
  *   2  20               1.893             5.680
  *   2  21               1.937             5.810
  *   2  22               4.163            12.490
  *   2  23               4.023            12.070
  *   2  24               3.787            11.360
  *   2  25               2.740             8.220
  *   2  26               3.910            11.730
  *   2  27               3.910            11.730
  *   2  28               3.937            11.810
  *   2  29               3.800            11.400
-------------------------------------------------------
```

```
          A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                 Degrees of  Sum of        Mean          F
Value    Source     Freedom    Squares        Square        Value   Prob
-----------------------------------------------------------------------
  1     Replication  2          0.040          0.020      0.6020
  2     Factor A      1          6.396          6.396    190.2295   0.0000
  4     Factor B    28         42.509          1.518     45.1547   0.0000
  6     AB           28         35.382          1.264     37.5835   0.0000
 -7     Error       114          3.833          0.034
-----------------------------------------------------------------------
        Total       173         88.161
-----------------------------------------------------------------------


     Coefficient of Variation: 5.11%

     s_ for means group 1:     0.0241       Number of Observations: 58
      y

     s_ for means group 2:     0.0197       Number of Observations: 87
      y

     s_ for means group 4:     0.0749       Number of Observations: 6
      y

     s_ for means group 6:     0.1059       Number of Observations: 3
      y



=======================================================================
```

APPENDIX V: Treatment effects on TS

```
Variable 9: TS (mg/l)

Grand Mean = 1201.207   Grand Sum = 209010.000   Total Count = 174


              T A B L E   O F   M E A N S

  1   2   3              9            Total
-------------------------------------------------------
  1   *   *          1200.862         69650.000
  2   *   *          1211.638         70275.000
  3   *   *          1191.121         69085.000
-------------------------------------------------------
  *   1   *          1660.690        144480.000
  *   2   *           741.724         64530.000
-------------------------------------------------------
  *   *   1          3100.000         18600.000
  *   *   2          1100.000          6600.000
  *   *   3          1200.000          7200.000
  *   *   4          4550.000         27300.000
  *   *   5          1965.000         11790.000
  *   *   6           930.000          5580.000
  *   *   7          1095.000          6570.000
  *   *   8           730.000          4380.000
  *   *   9           595.000          3570.000
  *   *  10          1130.000          6780.000
  *   *  11          1100.000          6600.000
  *   *  12           660.000          3960.000
  *   *  13           995.000          5970.000
  *   *  14          1165.000          6990.000
  *   *  15           965.000          5790.000
  *   *  16           395.000          2370.000
  *   *  17           965.000          5790.000
  *   *  18           665.000          3990.000
  *   *  19           295.000          1770.000
  *   *  20           660.000          3960.000
  *   *  21           500.000          3000.000
  *   *  22          2415.000         14490.000
  *   *  23           665.000          3990.000
  *   *  24           630.000          3780.000
  *   *  25          1060.000          6360.000
  *   *  26          1500.000          9000.000
  *   *  27           695.000          4170.000
  *   *  28          2180.000         13080.000
  *   *  29           930.000          5580.000
-------------------------------------------------------
  *   1   1          4200.000         12600.000
  *   1   2          1600.000          4800.000
  *   1   3          2000.000          6000.000
  *   1   4          8300.000         24900.000
  *   1   5          3200.000          9600.000
  *   1   6          1530.000          4590.000
  *   1   7          1930.000          5790.000
  *   1   8           860.000          2580.000
  *   1   9           660.000          1980.000
  *   1  10          1060.000          3180.000
```

```
  *   1  11             540.000          1620.000
  *   1  12             660.000          1980.000
  *   1  13             860.000          2580.000
  *   1  14            1870.000          5610.000
  *   1  15            1330.000          3990.000
  *   1  16             260.000           780.000
  *   1  17             800.000          2400.000
  *   1  18             930.000          2790.000
  *   1  19             330.000           990.000
  *   1  20             860.000          2580.000
  *   1  21             400.000          1200.000
  *   1  22            3500.000         10500.000
  *   1  23             530.000          1590.000
  *   1  24             330.000           990.000
  *   1  25             860.000          2580.000
  *   1  26            2400.000          7200.000
  *   1  27            1060.000          3180.000
  *   1  28            4100.000         12300.000
  *   1  29            1200.000          3600.000
  *   2   1            2000.000          6000.000
  *   2   2             600.000          1800.000
  *   2   3             400.000          1200.000
  *   2   4             800.000          2400.000
  *   2   5             730.000          2190.000
  *   2   6             330.000           990.000
  *   2   7             260.000           780.000
  *   2   8             600.000          1800.000
  *   2   9             530.000          1590.000
  *   2  10            1200.000          3600.000
  *   2  11            1660.000          4980.000
  *   2  12             660.000          1980.000
  *   2  13            1130.000          3390.000
  *   2  14             460.000          1380.000
  *   2  15             600.000          1800.000
  *   2  16             530.000          1590.000
  *   2  17            1130.000          3390.000
  *   2  18             400.000          1200.000
  *   2  19             260.000           780.000
  *   2  20             460.000          1380.000
  *   2  21             600.000          1800.000
  *   2  22            1330.000          3990.000
  *   2  23             800.000          2400.000
  *   2  24             930.000          2790.000
  *   2  25            1260.000          3780.000
  *   2  26             600.000          1800.000
  *   2  27             330.000           990.000
  *   2  28             260.000           780.000
  *   2  29             660.000          1980.000
-------------------------------------------------------
```

```
                A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                 Degrees of   Sum of      Mean          F
Value    Source    Freedom     Squares      Square       Value      Prob
-----------------------------------------------------------------------
  1     Replication  2      12218.103      6109.052      1.0128   0.3664
  2     Factor A     1   36735646.552  36735646.552   6090.2697   0.0000
  4     Factor B    28 135473296.552   4838332.020    802.1295   0.0000
  6     AB          28 118831903.448   4243996.552    703.5968   0.0000
 -7     Error      114    687631.897      6031.859
-----------------------------------------------------------------------
        Total      173 291740696.552
-----------------------------------------------------------------------


     Coefficient of Variation: 6.47%

     s_ for means group 1:    10.1979       Number of Observations: 58
      y

     s_ for means group 2:     8.3266       Number of Observations: 87
      y

     s_ for means group 4:    31.7066       Number of Observations: 6
      y

     s_ for means group 6:    44.8399       Number of Observations: 3
      y



=======================================================================
```

APPENDIX VI: Treatment effects on *Escherichia coli*

Variable 10: *E. Coli* (CFU/ml)

```
Grand Mean = 1285862.069   Grand Sum = 223740000.000
 Total Count = 174


                 T A B L E   O F   M E A N S

  1   2   3              10                Total
-------------------------------------------------------
  1   *   *         1284551.724      74504000.000
  2   *   *         1210422.414      70204500.000
  3   *   *         1362612.069      79031500.000
-------------------------------------------------------
  *   1   *         1749655.172     152220000.000
  *   2   *          822068.966      71520000.000
-------------------------------------------------------
  *   *   1           65000.000        390000.000
  *   *   2               0.000             0.000
  *   *   3               0.000             0.000
  *   *   4            5000.000         30000.000
  *   *   5          735000.000       4410000.000
  *   *   6         1005000.000       6030000.000
  *   *   7          605000.000       3630000.000
  *   *   8         4010000.000      24060000.000
  *   *   9         1005000.000       6030000.000
  *   *  10          850000.000       5100000.000
  *   *  11               0.000             0.000
  *   *  12          780000.000       4680000.000
  *   *  13          450000.000       2700000.000
  *   *  14         6300000.000      37800000.000
  *   *  15               0.000             0.000
  *   *  16         6320000.000      37920000.000
  *   *  17           50000.000        300000.000
  *   *  18          900000.000       5400000.000
  *   *  19           40000.000        240000.000
  *   *  20         5250000.000      31500000.000
  *   *  21            5000.000         30000.000
  *   *  22         3000000.000      18000000.000
  *   *  23            5000.000         30000.000
  *   *  24          200000.000       1200000.000
  *   *  25         5010000.000      30060000.000
  *   *  26               0.000             0.000
  *   *  27               0.000             0.000
  *   *  28          700000.000       4200000.000
  *   *  29               0.000             0.000
-------------------------------------------------------
  *   1   1          130000.000        390000.000
  *   1   2               0.000             0.000
  *   1   3               0.000             0.000
  *   1   4           10000.000         30000.000
  *   1   5         1470000.000       4410000.000
  *   1   6           10000.000         30000.000
  *   1   7           10000.000         30000.000
  *   1   8         8000000.000      24000000.000
  *   1   9         2000000.000       6000000.000
```

```
  *   1  10           100000.000        300000.000
  *   1  11                0.000             0.000
  *   1  12          1000000.000       3000000.000
  *   1  13           900000.000       2700000.000
  *   1  14          4000000.000      12000000.000
  *   1  15                0.000             0.000
  *   1  16         12000000.000      36000000.000
  *   1  17                0.000             0.000
  *   1  18          1000000.000       3000000.000
  *   1  19                0.000             0.000
  *   1  20          4500000.000      13500000.000
  *   1  21            10000.000         30000.000
  *   1  22          4000000.000      12000000.000
  *   1  23                0.000             0.000
  *   1  24           200000.000        600000.000
  *   1  25         10000000.000      30000000.000
  *   1  26                0.000             0.000
  *   1  27                0.000             0.000
  *   1  28          1400000.000       4200000.000
  *   1  29                0.000             0.000
  *   2   1                0.000             0.000
  *   2   2                0.000             0.000
  *   2   3                0.000             0.000
  *   2   4                0.000             0.000
  *   2   5                0.000             0.000
  *   2   6          2000000.000       6000000.000
  *   2   7          1200000.000       3600000.000
  *   2   8            20000.000         60000.000
  *   2   9            10000.000         30000.000
  *   2  10          1600000.000       4800000.000
  *   2  11                0.000             0.000
  *   2  12           560000.000       1680000.000
  *   2  13                0.000             0.000
  *   2  14          8600000.000      25800000.000
  *   2  15                0.000             0.000
  *   2  16           640000.000       1920000.000
  *   2  17           100000.000        300000.000
  *   2  18           800000.000       2400000.000
  *   2  19            80000.000        240000.000
  *   2  20          6000000.000      18000000.000
  *   2  21                0.000             0.000
  *   2  22          2000000.000       6000000.000
  *   2  23            10000.000         30000.000
  *   2  24           200000.000        600000.000
  *   2  25            20000.000         60000.000
  *   2  26                0.000             0.000
  *   2  27                0.000             0.000
  *   2  28                0.000             0.000
  *   2  29                0.000             0.000
--------------------------------------------------------
```

```
                    A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K            Degrees of   Sum of       Mean               F
Value Source  Freedom     Squares      Square            Value     Prob
-----------------------------------------------------------------------
 1 Replication 2    671838422413.813 335919211206.906   7.9457   0.0006
 2 Factor A    1  37428103448275.880 37428103448275.880 885.3135 0.0000
 4 Factor B   28 691400420689655.300 24692872167487.690 584.0780 0.0000
 6 AB         28 467359096551724.100 16691396305418.720 394.8134 0.0000
 -7 Error    114   4819540077586.250 42276667347.248
-----------------------------------------------------------------------
Total        173 1201678999189655.000
-----------------------------------------------------------------------

     Coefficient of Variation: 15.99%

     s_ for means group 1: 26998.2973       Number of Observations: 58
      y

     s_ for means group 2: 22044.0174       Number of Observations: 87
      y

     s_ for means group 4: 83941.1176       Number of Observations: 6
      y

     s_ for means group 6: 118710.6670       Number of Observations: 3
      y
=======================================================================
```

Title: COMPARISON OF MWTT WITH COMBINATIONS V (FBWS) AND U (SBWS)

```
Function: FACTOR



Experiment Model Number 7:
     One Factor Randomized Complete Block Design



Data case no. 1 to 12.



Factorial ANOVA for the factors:
     Replication (Var 1: Replication) with values from 1 to 3
     Factor A (Var 2: Treatment) with values from 1 to 4
     (1-Before Treatment, 2-MWTT, 3-Effective combination V and
                4-Effective combination U)
```

APPENDIX VII: Temperature of effective combinations versus MWTT

```
     Variable 3: Temperature (°C)

     Grand Mean = 28.000   Grand Sum = 336.000   Total Count = 12


                   T A B L E   O F   M E A N S

       1   2              3              Total
     -------------------------------------------------
       1   *            28.000          112.000
       2   *            28.000          112.000
       3   *            28.000          112.000
     -------------------------------------------------
       *   1            28.000           84.000
       *   2            28.000           84.000
       *   3            28.000           84.000
       *   4            28.000           84.000
     -------------------------------------------------



          A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                Degrees of   Sum of         Mean          F
Value    Source      Freedom    Squares       Square       Value  Prob
-----------------------------------------------------------------------
  1     Replication       2       0.000         0.000      0.0000
  2     Factor A          3       0.000         0.000      0.0000
 -3     Error             6       0.000         0.000
-----------------------------------------------------------------------
        Total            11       0.000
-----------------------------------------------------------------------


     Coefficient of Variation: 0.00%

     s_ for means group 1:     0.0000       Number of Observations: 4
      y

     s_ for means group 2:     0.0000       Number of Observations: 3
      y



=======================================================================
```

APPENDIX VIII: pH of effective combinations versus MWTT

```
Variable 4: pH (a.u)

Grand Mean = 6.516   Grand Sum = 78.190   Total Count = 12


              T A B L E   O F   M E A N S

  1   2              4             Total
-------------------------------------------------
  1   *            6.512             26.050
  2   *            6.530             26.120
  3   *            6.505             26.020
-------------------------------------------------
  *   1            6.180             18.540
  *   2            6.873             20.620
  *   3            6.380             19.140
  *   4            6.630             19.890
-------------------------------------------------



       A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                Degrees of   Sum of       Mean        F
Value    Source    Freedom     Squares      Square     Value    Prob
-----------------------------------------------------------------------
  1     Replication   2          0.001        0.001      0.5232
  2     Factor A      3          0.816        0.272    216.2184   0.0000
 -3     Error         6          0.008        0.001
-----------------------------------------------------------------------
        Total        11          0.825
-----------------------------------------------------------------------


     Coefficient of Variation: 0.54%

     s_ for means group 1:     0.0177       Number of Observations: 4
      y

     s_ for means group 2:     0.0205       Number of Observations: 3
      y



=======================================================================
```

APPENDIX IX: TDS of effective combinations versus MWTT

```
Variable 5: TDS (mg/l)

Grand Mean = 1106.833   Grand Sum = 13282.000   Total Count = 12


              T A B L E   O F   M E A N S

  1   2              5             Total
-------------------------------------------------
  1   *          1120.000          4480.000
  2   *          1096.250          4385.000
  3   *          1104.250          4417.000
-------------------------------------------------
  *   1          1033.333          3100.000
  *   2           576.667          1730.000
  *   3           704.000          2112.000
  *   4          2113.333          6340.000
-------------------------------------------------



         A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                Degrees of   Sum of        Mean       F
Value    Source      Freedom    Squares      Square    Value     Prob
-----------------------------------------------------------------------
  1     Replication    2       1168.167      584.083      0.2115
  2     Factor A       3   4385387.667  1461795.889    529.4497 0.0000
 -3     Error          6     16565.833     2760.972
-----------------------------------------------------------------------
        Total         11   4403121.667
-----------------------------------------------------------------------


Coefficient of Variation: 4.75%

s_ for means group 1:    26.2725       Number of Observations: 4
 y

s_ for means group 2:    30.3368       Number of Observations: 3
 y


=======================================================================
```

APPENDIX X: EC of effective combinations versus MWTT

```
     Variable 6: EC (µS/cm)

     Grand Mean = 1728.583   Grand Sum = 20743.000   Total Count = 12


                   T A B L E   O F   M E A N S

       1   2               6               Total
     -------------------------------------------------
       1   *            1750.000          7000.000
       2   *            1712.000          6848.000
       3   *            1723.750          6895.000
     -------------------------------------------------
       *   1            1613.333          4840.000
       *   2             901.000          2703.000
       *   3            1100.000          3300.000
       *   4            3300.000          9900.000
     -------------------------------------------------



          A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                 Degrees of   Sum of      Mean         F
Value    Source       Freedom    Squares     Square      Value    Prob
-----------------------------------------------------------------------
  1     Replication      2       3028.167    1514.083    0.2326
  2     Factor A         3  10687932.250 3562644.083  547.1941   0.0000
 -3     Error            6      39064.500    6510.750
-----------------------------------------------------------------------
        Total           11  10730024.917
-----------------------------------------------------------------------


     Coefficient of Variation: 4.67%

     s_ for means group 1:    40.3446       Number of Observations: 4
      y

     s_ for means group 2:    46.5859       Number of Observations: 3
      y



=======================================================================
```

APPENDIX XI: DO of effective combinations versus MWTT

Variable 7: DO (mg/l)

```
Grand Mean = 7.831   Grand Sum = 93.970   Total Count = 12


              T A B L E   O F   M E A N S

  1   2              7             Total
-------------------------------------------------
  1   *              7.825           31.300
  2   *              7.847           31.390
  3   *              7.820           31.280
-------------------------------------------------
  *   1              9.590           28.770
  *   2              8.813           26.440
  *   3              6.277           18.830
  *   4              6.643           19.930
-------------------------------------------------



        A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                 Degrees of   Sum of     Mean       F
Value    Source       Freedom    Squares   Square    Value      Prob
-----------------------------------------------------------------------
  1     Replication      2         0.002    0.001      0.6882
  2     Factor A         3        23.657    7.886   6322.4282   0.0000
 -3     Error            6         0.007    0.001
-----------------------------------------------------------------------
        Total           11        23.666
-----------------------------------------------------------------------


     Coefficient of Variation: 0.45%

     s_ for means group 1:     0.0177       Number of Observations: 4
      y

     s_ for means group 2:     0.0204       Number of Observations: 3
      y



=======================================================================
```

APPENDIX XII: TS of effective combinations versus MWTT

```
     Variable 8: TS (mg/l)

     Grand Mean = 1291.667   Grand Sum = 15500.000   Total Count = 12


                   T A B L E   O F   M E A N S

       1   2               8              Total
     -------------------------------------------------
       1   *            1290.000          5160.000
       2   *            1287.500          5150.000
       3   *            1297.500          5190.000
     -------------------------------------------------
       *   1            1876.667          5630.000
       *   2            1276.667          3830.000
       *   3            1150.000          3450.000
       *   4             863.333          2590.000
     -------------------------------------------------



          A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K                 Degrees of   Sum of     Mean        F
Value    Source       Freedom    Squares   Square     Value      Prob
-----------------------------------------------------------------------
  1     Replication      2       216.667    108.333       3.5455   0.0963
  2     Factor A         3  1637966.667 545988.889  17868.7273   0.0000
 -3     Error            6       183.333     30.556
-----------------------------------------------------------------------
        Total           11  1638366.667
-----------------------------------------------------------------------


     Coefficient of Variation: 0.43%

     s_ for means group 1:     2.7639       Number of Observations: 4
      y

     s_ for means group 2:     3.1914       Number of Observations: 3
      y



=======================================================================
```

APPENDIX XIII: *Escherichia coli* count of effective combinations versus MWTT

```
    Variable 9: E. coli (CFU/ml)

 Grand Mean = 3042416.667   Grand Sum = 36509000.000   Total Count = 12

                   T A B L E   O F   M E A N S

      1   2              9              Total
    -------------------------------------------------
      1   *        3042000.000      12168000.000
      2   *        3293250.000      13173000.000
      3   *        2792000.000      11168000.000
    -------------------------------------------------
      *   1       12000000.000      36000000.000
      *   2          97000.000        291000.000
      *   3          20000.000         60000.000
      *   4          52666.667        158000.000
    -------------------------------------------------



          A N A L Y S I S   O F   V A R I A N C E   T A B L E

  K           Degrees of   Sum of       Mean              F
Value  Source Freedom    Squares       Square            Value      Prob
-----------------------------------------------------------------------
1 Replication 2    502504166666.672 251252083333.336    1.0066   0.4198
2 Factor A    3 320962158250000.000 106987386083333.300 428.6478 0.0000
-3 Error      6   1497556500000.000 249592750000.000
-----------------------------------------------------------------------
Total        11 322962218916666.700
-----------------------------------------------------------------------


     Coefficient of Variation: 16.42%

     s_ for means group 1: 249796.2920       Number of Observations: 4
      y

     s_ for means group 2: 288439.9129       Number of Observations: 3
      y
```

APPENDIX XIV: Students' *t*-Table

Students' *t*-Table

cum. prob	***t* .50**	***t* .75**	***t* .80**	***t* .85**	***t* .90**	***t* .95**	***t* .975**	***t* .99**	***t* .995**	***t* .999**	***t* .9995**
one-tail	**0.50**	**0.25**	**0.20**	**0.15**	**0.10**	**0.05**	**0.025**	**0.01**	**0.005**	**0.001**	**0.0005**
two-tails	**1.00**	**0.50**	**0.40**	**0.30**	**0.20**	**0.10**	**0.05**	**0.02**	**0.01**	**0.002**	**0.001**
df											
1	0.000	1.000	1.376	1.963	3.078	6.314	12.71	31.82	63.66	318.31	636.62
2	0.000	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	22.327	31.599
3	0.000	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841	10.215	12.924
4	0.000	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604	7.173	8.610
5	0.000	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032	5.893	6.869
6	0.000	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707	5.208	5.959
7	0.000	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499	4.785	5.408
8	0.000	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.355	4.501	5.041
9	0.000	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250	4.297	4.781
10	0.000	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169	4.144	4.587
11	0.000	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106	4.025	4.437
12	0.000	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055	3.930	4.318
13	0.000	0.694	0.870	1.079	1.350	1.771	2.160	2.650	3.012	3.852	4.221
14	0.000	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977	3.787	4.140
15	0.000	0.691	0.866	1.074	1.341	1.753	2.131	2.602	2.947	3.733	4.073
16	0.000	0.690	0.865	1.071	1.337	1.746	2.120	2.583	2.921	3.686	4.015
17	0.000	0.689	0.863	1.069	1.333	1.740	2.110	2.567	2.898	3.646	3.965
18	0.000	0.688	0.862	1.067	1.330	1.734	2.101	2.552	2.878	3.610	3.922
19	0.000	0.688	0.861	1.066	1.328	1.729	2.093	2.539	2.861	3.579	3.883
20	0.000	0.687	0.860	1.064	1.325	1.725	2.086	2.528	2.845	3.552	3.850
21	0.000	0.686	0.859	1.063	1.323	1.721	2.080	2.518	2.831	3.527	3.819
22	0.000	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819	3.505	3.792
23	0.000	0.685	0.858	1.060	1.319	1.714	2.069	2.500	2.807	3.485	3.768
24	0.000	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797	3.467	3.745
25	0.000	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.787	3.450	3.725
26	0.000	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779	3.435	3.707
27	0.000	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771	3.421	3.690
28	0.000	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763	3.408	3.674
29	0.000	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756	3.396	3.659
30	0.000	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.750	3.385	3.646
40	0.000	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704	3.307	3.551
60	0.000	0.679	0.848	1.045	1.296	1.671	2.000	2.390	2.660	3.232	3.460
80	0.000	0.678	0.846	1.043	1.292	1.664	1.990	2.374	2.639	3.195	3.416
100	0.000	0.677	0.845	1.042	1.290	1.660	1.984	2.364	2.626	3.174	3.390
1000	0.000	0.675	0.842	1.037	1.282	1.646	1.962	2.330	2.581	3.098	3.300
z	0.000	0.674	0.842	1.036	1.282	1.645	1.960	2.326	2.576	3.090	3.291
	0%	50%	60%	70%	80%	90%	95%	98%	99%	99.8%	99.9%

Confidence Level