EVALUATION OF THE QUALITY OF WATER IN SHALLOW WELLS AT MOKOWE VILLAGE, LAMU COUNTY

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DECLARATION

This thesis is my original work and has not been submitted to any other University for any award.

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Declaration by the Supervisors:

We confirm that the work reported in this thesis was carried out by the candidate under our supervision.

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DEDICATION

This thesis is dedicated to my mother Habiba, my father Salim, my aunt Nahiya Hassan, and the entire Kastam family.

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ABSTRACT

Inadequate supply of piped water at Mokowe village in Lamu County has forced the residents to rely on alternative water sources for their daily needs. This water demand has been alleviated through the use of shallow wells. However, most of the wells are located near residential houses below the recommended distance of 30m from the pit latrines; as required by the Ministry of public health (Kenya). This closeness contaminates the aquifer that supplies water to the wells. The study was carried out during wet and dry seasons to evaluate the physicochemical and microbial levels of water from two main shallow wells, namely Salim Hassan and Baoni, with respect to their distance from the pit latrines. Water sample from Himwa tap was collected for comparison. Sampling was carried out thrice during wet season happened in August to September 2015 and thrice during dry season happened in January-February 2016. Water samples were collected and analyzed within 24 hours for total coliforms and *Escherichia coli* (*E.coli*) by the most probable number (MPN) method. Physicochemical parameters; fluoride, nitrates and iron were analyzed using spectroscopic (DR 6000). The amount of sodium and potassium was determined using flame photometer. pH and Electrical conductivity were quantified using pH meter. Total dissolve solid (TDS) was determined by evaporation to dryness. Chloride, magnesium, calcium and total hardness were analyzed by wet methods. Odour and taste were quantified using nose and tongue respectively while colour was analyzed using visual comparison method. Total coliforms and *Escherichia coli* levels in the two wells in wet season were very high compared to dry season. Himwa tap water had nil E.coli which is within the permissible levels nevertheless, total coliform level was beyond the permissible levels. In addition, these values were beyond the acceptable level given by National Environment Management Authority (NEMA). Fluoride, magnesium and iron levels were below the allowable limits by NEMA. Chloride, nitrate, sodium, potassium, calcium, total hardness and total dissolved solid were beyond the allowable level provided by NEMA. pH of all the water samples fell within the NEMA standards for drinking water (NEMA, 2006). Himwa water had sodium, nitrate and TDS beyond permissible level while the rest were within the acceptable levels. Odour and taste of the water samples were earthy and sour respectively compared to Himwa tap water which was odourless and sweet in taste. The colour of the water samples was slightly turbid compared to Himwa tap water which was colourless. The samples were highly contaminated by microorganisms hence treatment is recommended before use. However, the physicochemical parameters exceeded the limit can be amended by addition of coagulants in the treatment process. The distance of the two wells to the nearest pit latrines was 11m. For qualitative sampling 225 questionnaires were administered to the residents of Mokowe village.

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LIST OF ABBREVIATIONS AND ACRONYMS

E.coli	Escherichia coli
EDTA	Ethyldiaminetetraacetic acid
MPN	Most Probable Number
NEMA	National Environmental Management Authority
PH	Potential Hydrogen
SH	Salim Hassan well
TDS	Total dissolved solids
TH	Total Hardness
UNEP	United Nation Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organizations
WHO	World Health Organization

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Mokowe village lies in Hindi ward in Lamu County. Lamu County is located in the Northern Coast of Kenya and is one of the six Coastal Counties in Kenya. It borders Kilifi County in the southwest, Garissa County to the north, Republic of Somalia to the northeast and the Indian Ocean to the South. The County has two (2) constituencies namely Lamu West and Lamu East. Lamu West has Amu Mkomani, Shela, Hindi, Mkunumbi, Hongwe, Bahari and Witu Ward while Lamu East has Faza, Basuba and Kiunga Ward. The main economic activities in the county include crop production, livestock production, fisheries, tourism and mining, most notably quarrying (http://www.asdsp.co.ke/index.php/lamu-county, 2016).

In Mokowe village the residents have been experiencing difficulties in accessing clean water for drinking and other household needs. Water is one of the most vital basic need that mankind needs to be supplied with. “All people, whatever their stage of development, social and economic condition, have the right to have access to drinking water in quantities and of a quality equal to their basic needs” UN conference in Mar del Plata, 1977.

Water has been used since the earliest time as a symbol by which to express devotion and purity. Some cultures, like the ancient Greeks, went as far as to worship gods who were thought to live in and command the waters. Whole cities have been built by considering the location and availability of pure drinking water (Mohabbat, 2016).

In addition, water is important in many ways, such as, drinking, washing, transportation, chemical uses, heat exchange, fire extinction, recreation and in industrial applications such as; in the production of energy (e.g. hydroelectricity) and food processing etc. (South African water quality guidelines, 1996).

Water is vital to all aspect of life and is very essential to humans, since it makes up 2/3 of human body composition; the human brain is made of 95% of water, blood 82% and lungs 90%. Therefore without water human being can only survive for a few days (Sharma *et al*, 2012).

The term water quality means the suitability of water to sustain various uses and process or a range of variable which limit water use (UNEP and WHO, 1996). Any particular use will have certain requirements e.g. limits on the concentrations of toxic substances, for drinking water use, or restrictions on temperature and pH ranges for water supporting invertebrate communities. Fresh water is a limited resource, very vital in farming, industries and even human existence, without which viable development will not be conceivable (Bartram and Ballance, 1996).

Water quality is affected by a wide range of natural and human influences. The most important of the natural influences are; geological, hydrological and climatic, since these affect the quantity and the quality of water available. Their influence is generally greatest when available water quantities are low and maximum use must be made of the limited resource leading to; for example, high salinity especially in arid and coastal areas (Meybeck *et al*, 1996).

The effects of human activities on water quality are both widespread and varied in the degree to which they disrupt the aquifer and this restricts use of water. In addition, water treatment facilities may also be poor or inadequately operated. For example, fecal water pollution might occur as a result of there being no appropriate community facilities for waste disposal or because of on-site sanitation facilities (such as latrines) which drain directly into aquifers.

In developing countries gastrointestinal infections, caused by variety of different microbes and germs, is one of the major health concerns, whilst organic load and eutrophication may be of greater concern in developed countries (in the rivers into which the sewage or effluent is discharged and in the sea into which the rivers flow or sewage sludge is dumped) (UNEP and WHO, 1996).

Pit latrines are the most common forms of sanitation in urban slums and unplanned settlements in developing countries (Chaggu, 2003). It is important to locate a latrine downhill from water sources where possible particularly in areas of fissured rock such as limestone, since feacal pollution may be carried directly through cracks and joints in the rock into the well (Ahaneku and Adeoye, 2013).

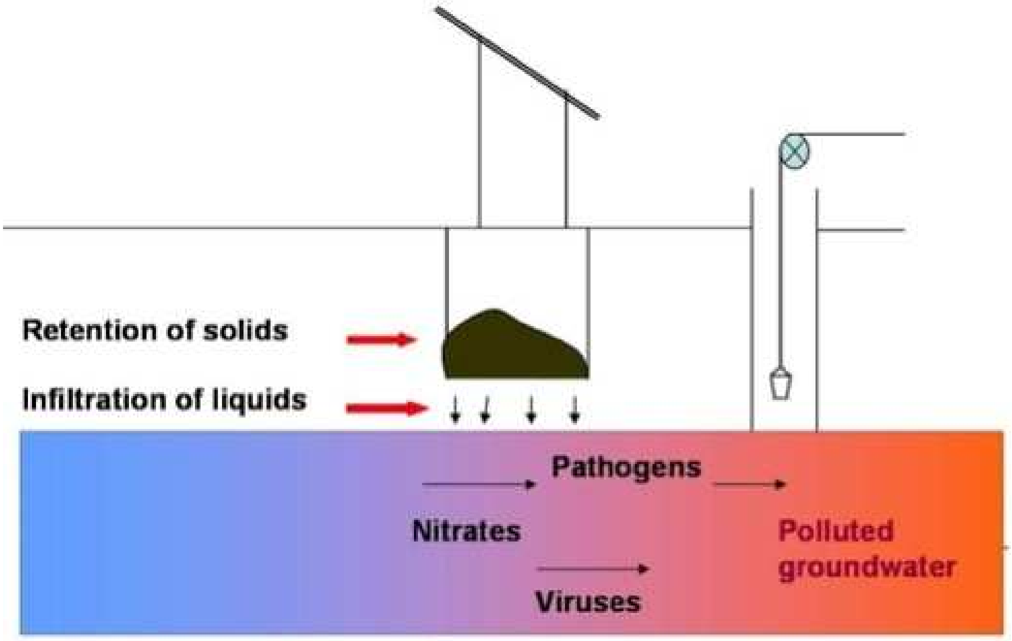

Figure 1: Groundwater Pollution by pit latrines. Source: *Tilley, 2014*.

A hole which has been dug, bored, driven or drilled into the ground for the purpose of extracting water is a well. A well is considered to be shallow if it is less than 50 feet deep. The source of a well is an aquifer. An aquifer is an underground layer of permeable soil (such as sand or gravel) that contains water and allows the passage of water (http://www.kingcounty.gov/depts/health/environmental-health/piping/drinking-water/shallow-wells.aspx December 29, 2016). Shallow wells are termed as “unprotected” since its upper part is not covered because long-range atmospheric transport of pollutant driven by wind can enter and pollute the wells; the quality of shallow wells water can also be crippled by its proximity to pit latrine, which facilitates draining of latrine waste water into the aquifer supplies water to the nearby shallow well. This may lead to an outbreak of gastrointestinal diseases.

There is concern that pit latrines may cause human and ecological health impacts associated with microbiological and chemical contamination of groundwater. Pit latrines generally lack a physical barrier, such as concrete, between stored excreta and soil and or groundwater (Prasad and Jha, 2014). Therefore, the wells should be constructed far from pit latrine at a distance of 30m radius by the Ministry of public health, Kenya. The extent to which microbes from pit latrine wastes may be transported and contaminate groundwater mostly depends on the environmental background of the area, particularly hydrological and soil condition.

In Mokowe village in Lamu County no study has been done on water quality despite the perpetual challenges of cases of gastrointestinal infections. In the study area the inhabitants have been experiencing difficulties in accessing adequate clean water for drinking and other domestic needs, as a result the people of Mokowe village relied on the slightly salty water from shallow wells for their daily needs. According to the Lamu water and sewerage company (LAWASCO), inhabitants of Mokowe village used to receive clean piped water from Amu Island. The project was initiated and managed by the Ministry of Water; however, following revenue losses incurred the supply of water to Mokowe village cut. It was at this time that the residents of the village turned on to shallow Wells as the alternative source of water to meet their demand.

In the study area shallow Wells are surrounded by households with inbuilt sanitation which are not so well designed; with poor and inadequate groundwater protection. The distance between the Wells and the pit latrines is less than what is required in the regulation; this could lead to draining of latrine waste-water into the aquifer supplying water in shallow Wells.

The inhabitants complained of gastrointestinal infections since the situation exacerbated in 1997 when cholera struck the area and this compelled the Ministry of Public Health to treat the Wells as much lives was lost. In 1998 the Ministry of water discovered a worthy water resource in Chomo, Hindi Ward, Lamu County to supply fresh clean water to the villages around including Mokowe village. This forestalled the demand by natives of these villages on shallow well and other treated water sources. Since the discovery of the new source of water, the ministry relegated the priority of shallow wells and therefore they were unattended by the Public Health officials.

The new water supply service however, the deterioration in the quality and quantity of water and did not last beyond the year 2000. This compelled the community in Mokowe to revert back to harvesting water from the shallow Wells which there after became their only source of water. Shallow Wells are therefore, very essential source of water in the study area despite being left unattended for so long and their close proximity to pit latrines.

1.2 Problem Statement

Being the cheapest system of disposing human waste, pit latrine use is on the rise in developing countries to meet the sanitation-related target of the Millennium Development Goals (Graham and Polizzotto, 2013). In the study area pit latrine is the main and well-practiced system of disposing untreated human waste; with poor and inadequate groundwater protection that could lead to contamination of water in shallow wells hence crippling its quality. Water from beneath the ground has been exploited for domestic use, livestock and irrigation since the earliest times. Although the precise nature of its occurrence was not necessarily understood, successful methods of bringing the water to the surface have been developed and groundwater use has grown consistent ever since (UNESCO *et al*, 1996).

Despite being the main source of domestic water for the residents of Mokowe village, the wells have been left unattended for long and more and more pit latrines are dug close to the shallow wells with little or no control; this decrease the distance of pit latrines to shallow wells hence heighten the chances of water to get contaminated and placing the lives of the inhabitants at risk of contracting waterborne diseases in the study area. Numerous complains of intestinal infection have been recounted by the residents therefore it was very essential to carry out a study to determine the quality of water in shallow wells at Mokowe village which could be undermined by their nearness to pit latrines at Mokowe village. If the quality of the water is not ascertained, and the problem is not solved severe outbreaks of gastrointestinal infections related to water sanitation may occur with detrimental health effects (especially to children).

1.3 Overall Objective

The overall objective of this study was to determine the physicochemical and microbial level of water in shallow wells at Mokowe village in Lamu County, Kenya.

1.3.1 Specific Objectives

- To determine sources of water for domestic usage in Mokowe village

- To determine the physicochemical properties of Baoni and Salim Hassan well water at Mokowe village during wet and dry season.
- To determine the microbial level of Baoni and Salim Hassan well water at Mokowe village during wet and dry season.

1.4 Research Question

The study was seeking to provide answers to the following questions

- What were the sources of water for domestic usage in Mokowe village?
- What were the physico-chemical properties of water in the shallow wells at Mokowe village?
- What were the microbial loads of water in shallow wells at Mokowe village?
- Was the water in the shallow wells at Mokowe village safe to drink?

1.5 Scope of the Study

The study was conducted at Mokowe village in Lamu County between August-September of 2015 for wet season and January-February of 2016 for dry season, capturing two areas within the village namely: -Majengo and Tumbo la Kati. The study area has a total of 6 wells and sampling was conducted on the two core shallow wells; one is located in Majengo and one in Tumbo la Kati which serve the inhabitants. Both quantitative and qualitative methods were applied. The study centered on conducting physiochemical and bacteriological analysis of water in the shallow wells to determine its quality. The parameters that were tested include: - *Escherichia coli*, total coliform, total dissolves solid (TDS), pH, nitrates, sodium, potassium, calcium, chloride, iron, magnesium, colour, smell and taste, fluoride and water hardness.

1.6 Justification of the study

Despite the close proximity to pit latrines, shallow wells are the main sources of water in the study area for the residents to meet their needs even though the wells have been left unattended for many years. The inhabitants have been complaining of gastrointestinal infections for so long without knowing the causative agent and that is why the study seeks to determine the quality of water in the shallow wells which could be undermined by their nearness to pit latrines at Mokowe village. The quality of water is a clear indicator of a health and wellbeing of a society. The results obtained will reveal the status of water in the shallow wells at Mokowe village. Therefore, the research will provide additional invaluable scientific information on effect of pit latrine to shallow wells in the study area hence averting any negative health effects in the community which may be occasioned by continued use of the shallow wells water without adequate information on the water quality.

1.7 Limitations of the study

Lack of laboratory in the area to carry out analysis was a huge challenge compelling travel to Mombasa for analysis.

Long distance and poor roads from Mokowe to Mombasa was another tough setback that forced to fly samples to Mombasa for analysis.

CHAPTER TWO: LITERATURE REVIEW

2.1 Ground Water

Water plays a vital role in human life. In the last decade, it was observed that pollution of ground water increased drastically due to increased human activities. As a result, increasing the cases of water-borne diseases and thus heightening the public health threats. Clean water is of vital importance to a healthy and sustainable ecosystem, including to humans, flora and fauna. Growing populations, industrialization and agricultural practices lead to indiscriminate release of effluents to terrestrial and aquatic environments, resulting in severe pollution of water bodies both at the surface as well as in the subsurface environment (Yadav and Kumar, 2010).

This problem is accentuated by the limited availability of water resources due to increasing water demand as a result of growing populations especially in developing and under-developed countries, where the impacts are more severe.

The recurrence of extreme climatic events, like torrential rains and flash floods in different parts of the world, impacts on the water resources, both quantitatively and qualitatively (Patil, 2012). Ground water is water that accumulates beneath the earth surface in the soil pores and in the fracture of rock formation. Groundwater is found in vast quantities filling the spaces between grains of soil or rock; it slowly flows through aquifers; it connects with rivers, streams, lakes and wetlands; it feeds trees and vegetation (Ruth *et al*, 2015). Groundwater constitutes about 95 per cent of the fresh water on our planet (discounting the amounts locked in the polar ice caps), making it fundamental to human life and economic development. In addition to these aquifers being convenient sources of water, they also serve as are natural reservoirs with enormous storage capacity, much greater than any man-made reservoirs. For example, in the four decades up to the early 1980s an estimated 500 km^3 of groundwater, equivalent to more than three times the total volume of either Lake Kariba or Lake Nasser, was withdrawn from the Ogalalla aquifer that underlies portions of eight states in central USA (Lawrence *et al,* 2003).

Ground water, may however be contaminated by numerous pollutants similar to those that contaminate surface water. Pollution of groundwater occurs when contaminants are discharged to, deposited on, or leached from the land surface above ground water. Even if there are no industrial and domestic pollution sources in the area it is important to realize that the water may not be free from contaminants and should be tested before human consumption (Howarda *et al*, 2003). Ground water can be accessed through springs as it appears naturally to the surface or digging shallow wells and drawing the water.

2.2 Shallow Well Water Quality

Shallow well is a hole which has been dug, bored, driven or drilled into the ground for the purpose of extracting water. Shallow wells (hand-dug wells) that are usually dug <20-m deep and often tap unconfined aquifers (MacDonald and Davies, 2000). The source of a well is an aquifer. An aquifer is an underground layer of permeable soil (such as sand or gravel) that contains water and allows the passage of water. Aquifers are replenished as rainfall seeps down through the soil (Shallow Wells-KingCounty, 2014). These wells are normally uncovered and, when used for domestic supply, water is usually withdrawn by bucket. They are highly susceptible to contamination, particularly by pathogenic micro-organisms through the various pathways by which contaminants can enter the well.

Water from this source is directly used without treatment and could be fecally contaminated by its close proximity to pit latrines (Cave and Kolsky, 1999).

Concerning the safety of water, research has shown that many low income countries are off-track to reach Target 7c of the Millennium Development Goals (MDGs) for water supply and sanitation, aimed at reducing by half the proportion of people without sustainable access to safe drinking-water and basic sanitation by 2015. In spite of increasing international awareness of and attention to water and health, water sanitation and hygiene (WASH) challenges continue to plague the developing world (Bakobie *et al*, 2015).

Rural areas in developing countries do not use improved sanitation which is defined as facilities that hygienically isolated human excreta from human contact but instead depend on unimproved pit latrines. Pit latrines are extensively used in developing countries due to their low cost construction and high availability. However, the Pit latrine's design and construction is done with very little knowledge of its impact on the quality of groundwater (Dzwairo, 2006).

The existence of poorly designed pit latrines and inadequate groundwater protection has led to contamination of shallow wells thereby undermines the quality its water. Pit latrines generally lack a physical barrier, such as concrete, between stored excreta and soil. Since aquifers may drain through pit latrine downstream to water source, such as a shallow-well, it is more critical to consider the direction of groundwater flow in the construction of pit latrines facilities as well as in the sinking of the wells (Chidavaenzi *et al*, 1997). If not, contaminants from pit latrine excreta may potentially leach into groundwater, thereby threatening human health through wells (Prasad and Jha, 2014).

A study done by Harikumar and Chandran, 2013 in selected areas of Kozhikode district, Kerala state in India on bacteriological contamination of groundwater due to onsite sanitation problems showed that the groundwater samples of Calicut Corporation are bacteriologically contaminated and unsafe for drinking because of fecal contamination. Observations revealed that the contaminated wells are mostly constructed very near or down-gradient from the latrines. The level of contamination was high during monsoon (rainy) season compared to pre monsoon and post monsoon. All the samples showed the presence of *Escherichia coli* (Harikumar and Chandran, 2013). Another study done by Olufunmilayo *et al*, in 2014 in Isara-Remo, Ogun State, Nigeria on water quality of hand-dug wells close to pit latrines. This study examined the effect of pit latrine on physico-chemical and bacteriological quality of water from nearby hand-dug well. A critical examination of water samples from hand-dug wells showed significant impaction due to proximity to the pit latrines. This affected physicochemical properties of the water. It is evident that most hand-dug wells in the study area were contaminated with fecal matter that leached from nearby pit latrines, which has negative implication to achieving sustainable health. The hand-dug well water quality fell short of the WHO guidelines for drinking water quality and improved urban sanitation (Olufunmilayo *et al*, 2014.).

Study done by Ahaneku and Adeoye, 2013 in Foko slum, Ibadan, south western Nigeria on impact of pit latrines on groundwater quality and the results show that most of the shallow wells in Foko area are contaminated due to presence of coliform bacteria percolated from pit latrines. The findings revealed that a minimum lateral distance of 19.75m is required between pit latrines and shallow wells to minimize the threat of fecal contamination of the groundwater (Ahaneku and Adeoye, 2013).

Another study done by Kabongo and Kabiswa in 2008 in Bugiri town council Uganda on pit latrines and their impact on groundwater and the result revealed that the bacterial quality of groundwater drawn from 15 sites (10 shallow wells and 5 springs) had strain of fecal bacterial count in 40% (6 sites) of the water samples analyzed. The microbiological analysis for water samples from the 5 springs 40% (2 sites) confirmed the presence of faecal bacteria. It was also found that over 80% of new latrines dug get filled up with water at between 10-20 meters deep before their completion (Kabongo and Kabiswa, 2008).

2.3 Domestic water quality in Kenya

A study conducted by Kiptum and Ndambuki in 2012 in Langas, Eldoret, Kenya on well water contamination by pit latrines. The results show that the level of contamination in shallow water wells is high because they exceeded the WHO guidelines limit of zero counts for bacteria and 50 mg/L for nitrates. The main source of the contamination was found to be the nearby pit latrines that were situated close to the shallow water wells (Kiptum and Ndambuki, 2012). Another study done by Mwakio Tole in 1997 on pollution of groundwater in the coastal Kwale District, Kenya. In this study it has been shown that in Kwale District the water is generally suitable for drinking in terms of its chemical composition. However, bacteriologically, some springs, wells and boreholes are contaminated with *E. coli*. The presence of *E.coli* makes the water unsuitable for drinking.

2.4 Physico-Chemical parameters

Physico-chemical parameters are physical and chemical parameters associated with water which have an influence on its quality and which also affect the biological - constituents of the water (Oluyemi *et al*, 2010). The physical factors such as temperature, turbidity, colour, etc. can affect the aesthetics and taste of the water and may complicate the removal of microbial pathogens during water treatment (Ernest, 2013). The chemical parameters include pH, colour, taste, odor, TDS, TH, chlorides, sodium, potassium, magnesium, calcium, nitrates, iron and fluorides

2.4.1 pH

It is a measure of how acidic or basic water is. The range goes from 0-14, with 7 being neutral. pH of less than 7 indicates acidity, whereas a pH of greater than 7 indicates a base. pH is really a measure of the relative amount of free hydrogen and hydroxyl ions in the water. Water that has more free hydrogen ions is acidic, whereas water that has more free hydroxyl ions is basic (Barber, 2012).

2.4.2 Fluoride

Fluoride is highly toxic substance, in terms of acute toxicity (i.e., the dose that can cause immediate toxic consequences); it is more toxic than lead, but slightly less toxic than arsenic. Severe dental fluorosis and crippling skeletal fluorosis are the first adverse effects that fluoride can have on the body. Fluoride can cause arthritic symptoms and bone fracture well before the onset of crippling fluorosis and can affect many other tissues besides bone and teeth, including the brain and thyroid gland (Peckham *et al*, 2014).

2.4.3 Nitrate

Nitrate naturally occurring and occur in large quantities in most waters. Nitrates used as fertilizers are converted to nitrites in the soil. Excessive fertilizers, decayed vegetables and animal wastes, domestic effluents, sewage sludge, industrial discharges, leakages from refused dams contribute to the contamination of ground water by percolation over a period of time. Elevated nitrate levels may cause methemoglobinemia in infants. Prolonged intake of high levels of nitrates are linked to gastric problems due to the formation of nitrosamine. N-nitrosamine compound has been shown to cause cancer in test animals. Studies of people exposed to high levels of nitrate have not provided convincing evidence of an increased risk of cancer (Self and Waskon, 2013).

2.4.4 Iron

Iron is one of the earth's most plentiful resources. As rainwater infiltrates the soil and underlying geologic formations dissolves iron, causing it to seep into aquifers that serve as sources of groundwater for wells. Iron is mainly present in water in two forms: either the soluble ferrous iron or the insoluble ferric iron. Water containing ferrous iron is clear and colorless because the iron is completely dissolved. When exposed to air in the pressure tank or atmosphere, the water turns cloudy and a reddish brown substance begins to form. Iron is not hazardous to health, but it is considered a secondary or aesthetic contaminant. Essential for good health, iron helps transport oxygen in the blood. Most tap water in the United States supplies approximately 5 percent of the dietary requirement for iron (Illinois Department of Public Health, 2010).

2.4.5 Chloride

Chloride is widely distributed in nature, generally as sodium chloride and potassium chloride salts. An aesthetic objective of 240 mg/L has been established for chloride in drinking water. At the concentration above the aesthetic objective, chloride impart undesirable taste to water and to beverages prepared from water and may cause corrosion in the distribution system. Sodium chloride, a common ingredient in the diet of most people, is a strong electrolyte and passes through the digestive system unchanged. Chloride is, therefore, used in the assessment of water quality as an indication of possible faecal contamination or as a measure of the extent of sewage discharge into water bodies. Thus, high Chloride levels in water indicates high rate of infiltration of other effluent within the soil (Karim, 2015).

2.4.6 Calcium and Magnesium

Magnesium and Calcium are necessary in animal and human nutrition. Calcium is an essential component of bones, teeth, shells and plant structure. They play a major role in water hardness e.g., they precipitate soap. Calcium carbonate might be useful at low levels because it produces a protective coating on pipes and distribution lines. At high concentrations, however, it can clog pipes or produce harmful scales in boilers. Magnesium is also a major cause of boiler scale when hard water is used in heating system (Nollet and De Gelde, 2000).

2.4.7 Colour, Taste and Odor

Colour, taste and odor are vital measurement for determining drinking water quality. If water looks coloured, smells bad or taste swampy, people will instinctively avoid using it, even though it might be perfectly safe from the public health aspect. Colour, taste and odor problems in drinking water are often caused by organic substances such as algae or humic compound or by dissolved compound such as iron (Weiner and Matthews, 2003).

2.4.8 Sodium and Potassium

Sodium in our diets results mainly from eating table salt found within many food products. Sodium in drinking water normally presents no health risks, as about 99 percent of the daily salt intake is from food and only about one percent from water. However, elevated sodium in well water may be considered a health concern for those on a salt restricted diet. Individuals on a low sodium diet due to a high blood pressure or other medical problems are often restricted to water containing less than 20 milligrams per liter of sodium (Juned and Arjun, 2011).

Potassium is an essential in both plant and human nutrition, and occurs in ground water as a result of mineral dissolution, from decomposing plant material, and from Agricultural runoff (Lenore, 1999).

2.4.9 Total Dissolve Solids

Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and some small amounts of organic matter that are dissolved in water. TDS in drinking-water originate from natural sources, sewage, urban run-off, industrial wastewater, and chemicals used in the water treatment process, and the nature of the piping or hardware used to convey the water, i.e., the plumbing. The total dissolved solids concentration is the sum of the cations (positively charged) and anions (negatively charged) ions in the water. Therefore, the total dissolved solids test provides a qualitative measure of the amount of dissolved ions but does not tell us the nature or ion relationships. Therefore, the total dissolved solids test is used as an indicator test to determine the general quality of the water (Oram, 2012).

2.4.10 Total Hardness

Total hardness is a measure of the capacity to precipitate soap and also increases boiling point of water. Hard water is high in dissolved minerals, both calcium and magnesium. In hard water, soap reacts with the calcium (which is relatively high in hard water) to form "soap scum". When using hard water, more soap or detergent is needed to get things clean (WHO, 2003).

2.5 Microbiological Parameter

2.5.1 Total coliforms

The term “total coliforms” refers to a large group of Gram-negative, rod-shaped bacteria that share several characteristics. The group includes thermotolerant coliforms and bacteria of faecal origin, as well as some bacteria that may be isolated from environmental sources. Most coliforms also produce enzyme B-D galactosidase which can be detected with a colour forming reagent. The group generally comprises the genera *klebsiella, enterobacter and citrobacter*. Thus the presence of *total coliforms* may or may not indicate faecal contamination. In extreme cases, a high count for the total coliform group may be associated with a low, or even zero, count for thermotolerant coliforms. In the laboratory total coliforms are grown in or on a medium containing lactose, at a temperature of 35 or 37°C. They are provisionally identified by the production of acid and gas from the fermentation of lactose (Grabow, 1996).

2.5.2 *Escherichia coli*

Escherichia coli (commonly abbreviated *E. coli*) is a gram negative rod shaped bacterium that is commonly found in the lower intestines of warm blooded organisms. *E.coli* and related bacteria constitute about 0.1% of gut flora and faecal oral transmission is the major route through which pathogenic strains of the bacterium causes diseases. Cells are able to survive outside the body for a limited amount of time which makes them ideal organisms to test environmental samples for faecal contamination. *E. coli* can be differentiated from other thermotolerant coliforms by the ability to produce indole from tryptophan or by the production of the enzyme β-glucuronidase. *E. coli* is present in very high numbers in human and animal feaces and is rarely found in the absence of faecal pollution. It is considered the most suitable index of faecal contamination and as such it is the first organism of choice in monitoring (Ernest, 2013).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study Area

The study was conducted at Mokowe village in Lamu County during wet and dry seasons; August and September of 2015 and January and February of 2016 respectively. Mokowe village is located at 2° 13' 52" South, 40° 51' 31" East and is 242km from Mombasa (figure 2). The village is home to residents from many tribes, majority of them are the Swahili. The most important economic activity is fishing and farming. The predominant form of sanitation in the study area is pit latrine. The area has a total of 6 shallow Wells which are surrounded by households and the study focused on two most used shallow wells which are the main source of water for the residents.

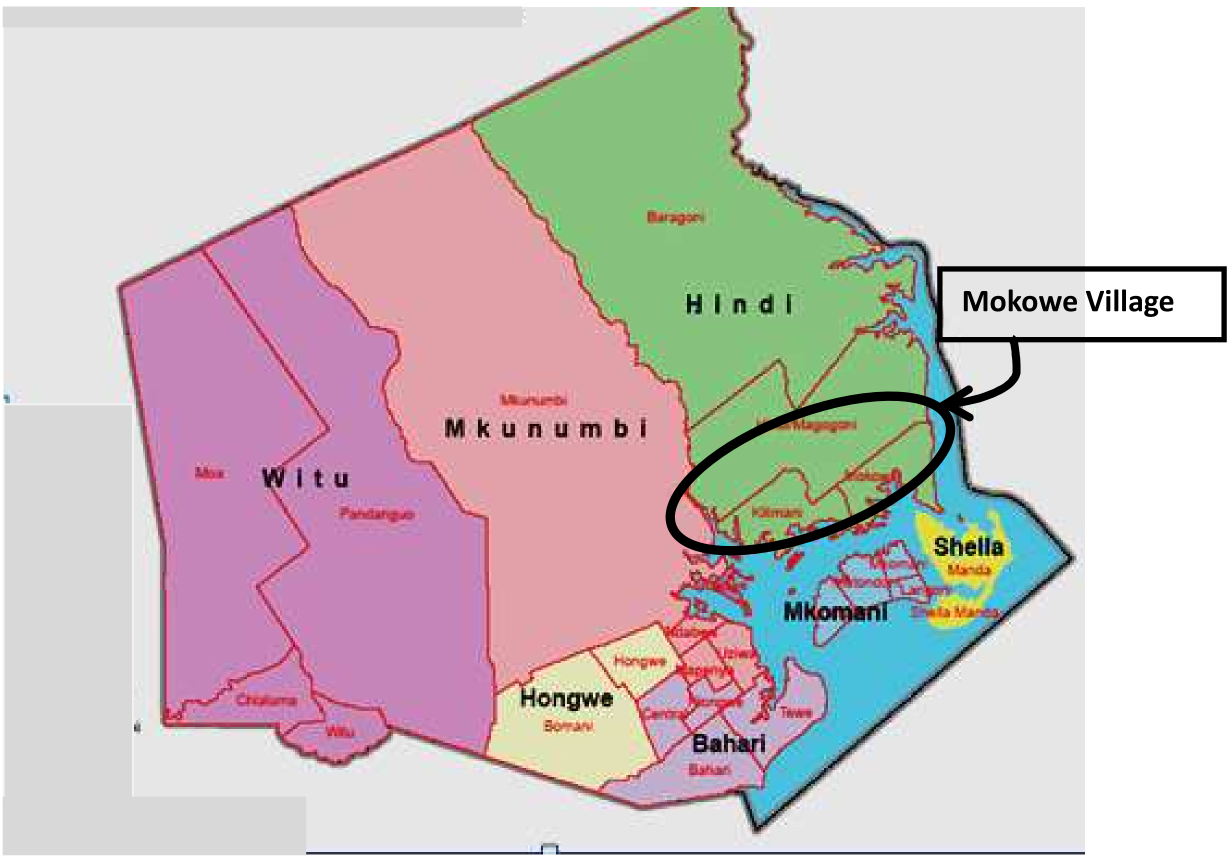

Figure 2: A Map of Lamu West Constituency showing Mokowe Village (Source: IEBC Lamu west constituency Map/Ward 2013).

3.2 Site Selection

The study focused on two areas within Mokowe village namely Tumbo la Kati and Majengo where the 2 main shallow wells are located. One well is situated in Majengo area namely Kisima cha Salim Hassan coordinate 2˚14´19.6"S, 40˚50´46.2ʺ E and the other in Tumbo la kati area namely Kisima cha Baoni coordinate 2˚14´17.4"S, 40˚50´50.5"E. The choice of the sites was based on the high population that obtains water from these wells for domestic use.

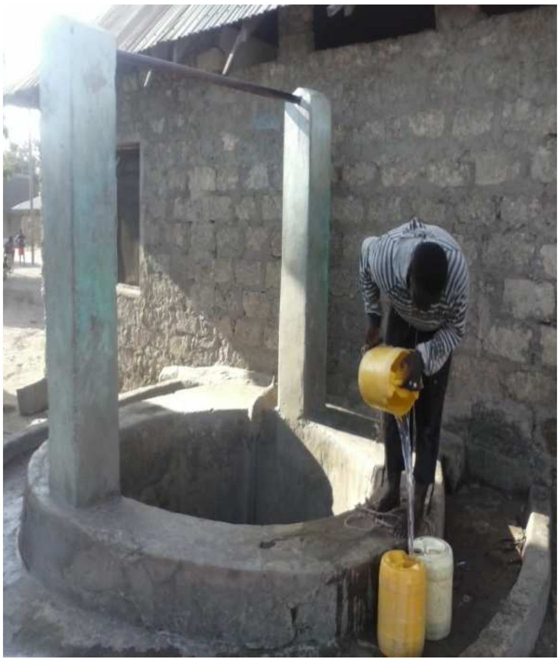

Figure 3: Shows the two main shallow wells Salim Hassan and Baoni well respectively

3.3 Sampling and Data Collection

Sampling bottles and tools were sterilized using an autoclave. The study employed purposive sampling, to select the Shallow wells for sampling. Purposive sampling involves deliberate selection of particular units of the population for constituting a sample. The researcher’s judgment is used for selecting items which were considered as representative of the population (Kothari, 2004). Two wells were selected namely Salim Hassan and Baoni, these are the only wells used by the community living in Mokowe Village owing to less salinity compared to the rest which are highly saline and unused.

The study employed both qualitative and quantitative methods. For quantitative method samples were obtained from the shallow wells using a conventional way used by the community (a bucket tied to a rope). A total of 50 samples were collected for both wet and dry season. Two samples (one for physiochemical and one for microbial test) were collected from the two most used shallow well (Baoni and Salim Hassan) in the morning at 4am before the community commenced their daily chores of drawing water from the wells. Two samples were collected after the day activities at 8pm hence making up a total of eight samples per visit. One water sample was collected from Himwa tap located in Hindi which is 7km from Mokowe for comparison. Since some of Mokowe resident buys water from Hindi for consumption and other household chores. The samples were collected in sterilized, sealed and labeled 1L polyethylene bottles for analysis. The objective of collecting sample before and after water harvesting was to show the variation of physicochemical and microbial concentration of water in the shallow wells.

The average distance of pit latrine to shallow wells was also measured. Questionnaire was employed as the main data collection instruments for qualitative method. A conventional formula of 10% was used to obtain the size of the sample (sub group) which should be the representative of the whole population. The area has 2250 households and 10% of 2250 was 225. The study applied simple random sampling procedures to obtain the respondents for questionnaires without biasness. A total of 225 questionnaires were administered to the residents of Mokowe in October 2015. Three enumerators were hired and trained on how to collect data via questionnaires over duration of 45 days.

The physicochemical parameters and microbial levels in the sampled water were tested and analyzed using standard methods and procedures in the Government Chemist Laboratories in Mombasa. Total coliform and *E.coli* were analyzed by MPN method while physicochemical parameters such as fluoride and iron were analyzed by spectroscopic (DR 6000), sodium and potassium were analyzed using flame photometer, pH was measured using pH meter, nitrates was determined by spectroscopic (DR 6000) and chloride, magnesium, calcium and total hardness were analyzed by wet methods.

3.4 Data Analysis

Two-Sample T-Test and Mann-Whitney Test were used to compare the physicochemical and microbial load between wet and dry season respectively. Wilcoxon Signed Rank Test and Paired T-test were also used to show disparity between the sampling time (8 pm and 4 am) per visit during wet and dry season.

3.5 Sampling

Samples were collected and carefully labeled as to identify sampling date (DDMMYY) and sampling site (Ward/site/Sample#) e.g. 20/08/15/MJNG/001 for the first sample collected on 20thAugust, 2015 at Majengo sampling site. The samples were then transferred in a cooler box for microbial and physicochemical determination. The purpose of putting the samples in a cooler box is to maintain low temperature to abate biochemical reaction from the microorganisms hence preserve the sample to reach the laboratory in unaltered state. Results obtained were compared to standards set by the NEMA.

3.6 Procedures used for detecting physicochemical parameter

3.6.1 pH

pH meter was first calibrated by removing electrodes from storage solution, rinsed, blot dried with soft tissue, and then placed in first buffer solution (potassium hydrogen phthalate 0.05M), rinsed thoroughly with distilled water, blot dried and then immersed in second buffer (0.025M potassium dihydrogen phosphate/0.025M disodium hydrogen phosphate). Once the meter was calibrated, the electrode was dipped in the samples and their pH recorded (Lenore *et al*, 1999).

3.6.2 Total Dissolved Solid

A sample (500 mL) was filtered and the total filtrate was transferred to a weighed evaporating dish and evaporated to dryness in an oven for 1hour at 180 ± 2°C. The sample was then cooled in a desiccator and weighed; the increase in evaporating dish weight gave the total dissolved solids (Lenore *et al*, 1999) as per the equation: -

$$\%TDS = \frac{(\text{Final weight} - \text{Initial weight}) \times 100}{\text{Initial weight}} \%$$

3.6.3 Colour

Visual comparison was method used

The visual comparison method is applicable to nearly all samples of potable water.

Water sample was poured in a Nessler tube up to 50 mL mark and colour of the sample was compared with that of the standards made from dilutions of potassium chloroplatinate and cobaltous chloride in distilled water by viewing vertically downwards while the tubes are placed on a white surface at such an angle that light is reflected upward through the columns of liquid (Lenore *et al*, 1999).

3.6.4 Odour

A cleaned odourless bottle was half filled with the sample and closed air tight. The bottle was vigorously shaken for a few seconds and the odour was quickly detected by smelling. Odour was reported as: odour free, rotten egg, burnt sugar, soapy, fishy, septic, aromatic, chlorinous, alcoholic odour or any other specific odour. In case it wasn't possible to specify the exact nature of odour, reported as agreeable or disagreeable (Lenore *et al*, 1999).

3.6.5 Taste

Water samples were taken into the mouth for sensory analysis to produce a flavor, although taste, odor, or mouth-feel may predominate, depending on the chemical substances present and were recorded as bitter, sweet, salty (Lenore *et al*, 1999).

3.6.6 Total Hardness

Water sample (25mL) was diluted to 50 mL in a porcelain casserole with distilled water. Ammonia buffer solution (2 mL) was added to give a pH reading of 10.0 (±0.1). Then 2 drops of an indicator solution (Erichrome Black T) was added and gradually titrated with EDTA (0.02M) with continuous stirring until the reddish tinge changed to blue marking the end point of titration (Lenore *et al*, 1999).Total hardness was determined by equation as:

$$\text{Hardness (EDTA) as mg CaCO}_3\text{/L} = \frac{(\mathbf{AB}) \times 1000}{\text{mL sample}}$$

Where:

A = mL titration for sample

B = mg $CaCO_3$ equivalent to 1.00mL EDTA titrant

3.6.7 Sodium

A blank sample (deionized water) and sodium calibration standards (range of; 0 to 1.0, 0 to 10, or 0 to 100 mg/L) were prepared.

Emission intensity was determined at 589 nm. Sodium was determined from the calibration curve (Skoog *et al,* 2007).

3.6.8 Fluoride

DR 6000 Spectrophotometer was used to determine fluoride concentration in water samples. Deionized water (10.0 mL) was pipetted to a sample cell. Sample (10.0 mL) was added into a sample cell. SPADNS (2.0 mL) reagent solution was pipetted into each sample cell and swirled to mix.

A 1-minute reaction time started and after the timer expired, the blank sample cell was cleaned. The blank was inserted into the cell holder, and the reading reset to zero (displayed as 0.00 mg/L). The prepared sample cell was cleaned and inserted into the cell holder. The “read” button was pressed to show results showed in mg/L (Hach Company/Hach Lange GmbH, 1989–2014).

3.6.9 Iron

DR 6000 Spectrophotometer was used to determine iron concentration in water samples

A sample of 50-mL was filled in a 50 mL mixing cylinder. One FerroMo Iron Reagent 1Powder Pillow was added to the mixing cylinder, closed and inverted several times to mix. A prepared sample (25-mL) was filled to mixing cylinder to the 25-mL mark. The contents of one FerroMo iron reagent 2 powder pillow was added to the prepared sample in the 25-mL and mixed well by inverting the mixing cylinder several times. A blue color appeared indicated the presence of iron in the sample.

A 3-minute reaction time was started and after timer expired, 10 mL of the prepared sample was poured into a sample cell. The blank was inserted into the cell holder, and the reading reset to zero. The prepared sample cell was cleaned and inserted into the cell holder. The “read” button was pressed to show results showed in mg/L (Hach Company/Hach Lange GmbH, 1989–2014).

3.6.10 Nitrate

UV spectrophotometry was used to determine Nitrate

Hydrochloric acid solution (1M, 1mL) was added to 50 mL clear filtered water sample and mixed thoroughly. Calibration standards in the range of 0-7 mgNO_3-N/L were prepared, by diluting to 50mL of clear filtered water sample. Absorbance or transmittance was read against re-distilled water set at zero absorbance or 100% transmittance. A wavelength of 220nm was used to obtain NO_3^- and a wavelength of 275nm to determine interference due to dissolve organic matter (Lenore *et al*, 1999).

3.6.11 Chloride (Cl^-)

Water sample (100mL) was poured in a conical flask. Potassium chromate (0.25M 1mL) indicator solution was added in the sample and titrated with $AgNO_3$ (0.1M) titrant to a pinkish yellow end point (Lenore *et al*, 1999). Chloride was determined by equation;

$$Cl\ mg/L = \frac{(A - B) \times N \times 35.45 \times 1000}{mL\ sample}$$

Where: A = mL titration for sample

B = mL titration for blank (distilled water blank).

N = Normality of $AgNO_3$ used

3.6.12 Potassium

Flame Emission Photometry was used to determine potassium levels

A blank (deionized water) and potassium calibration standard were prepared in stepped amount in the following applicable ranges: 0 to 1.0, 0 to 10 and 0 to 100 mg/L. Potassium content was determined at 766.5 nm (Lenore *et al*, 1999).

3.6.13 Magnesium

Magnesium content was estimated as the difference between hardness and calcium as shown in equation:

Mg mg/L = (TH as mg $CaCO_3$/L - Calcium Hardness as mg $CaCO_3$/L) x 0.243

Where: TH = Total Hardness, mg $CaCO_3$/L (Lenore *et al*, 1999).

3.6.14 Calcium

EDTA titrimetric method will be used

Water sample (50mL) was poured in a conical flask, sodium hydroxide solution (0.1M, 2mL) was added to give a pH reading of 12 to 13. Then an indicator mixture (ammonium purpurate) of 0.1 to 0.2 g was added and titrated with EDTA solution (0.01M), with continuous mixing, till the colour changes from pink to purple. End point was checked by adding 1 to 2 drops of titrant in excess to make certain that no further colour change occurs (Lenore *et al*, 1999). Calcium was determined by equation.

Ca mg/L= $\frac{A \times B \times 400.8}{\text{mL sample}}$

Calcium hardness as mg $Caco_3$/L=$\frac{A \times B \times 1000}{\text{ML sample}}$

Where: A = mL titrant for sample

B = mg $CaCO_3$ equivalent to 100mL EDTA at the calcium indicator end point

3.7 Procedure of Microbial Parameters

3.7.1 Total Coliform

The Most Probable Number (MPN) method was used in determining coliform bacteria in the samples. Serial dilutions of 10^{-1} and 10^{-11} were prepared by injecting 1mL of the sample into 9mL sterile distilled water. One milliliter aliquots from each of the dilutions were inoculated into 5mL of MacConkey Broth (1:5) with inverted Durham tubes and incubated at 35°C for total Coliforms for 24 hours. Tubes showed colour change from purple to yellow and gas collected in the Durham tubes after 24 hours were identified as positive for total Coliforms. Counts per 100mL were calculated from the appropriate Most Probable Number (MPN) tables with 9 test tube readings (Abdulkadir *et al*, 2015).

3.7.2 *Escherichia coli*

E. coli (Thermotolerant Coliforms) from each of the positive tubes identified a drop was transferred into a 5mL test tube of tryptone water and incubated at 44°C for 24 hours. A drop of Kovacs' reagent was then added to the tube of tryptone water. All tubes showing a red ring colour development after gentle agitation denoted the presence of indole and were recorded as presumptive for thermotolerant Coliforms (*E coli*). Counts per 100mL were calculated from Most Probable Number (MPN) tables with 9 test tube readings (Abdulkadir *et al*, 2015).

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Microbial analysis of water sample from the two most used Shallow wells during wet and dry season.

Table 1: - The results of Microbial analysis of water sample from the two main shallow wells. One tap water sources; Himwa was used for comparison. The table also gives information on standard guideline as set by NEMA.

			WET SEASON		DRY SEASON	
Site	**Visit**	**Time**	**T. coliform**	**E.coli**	**T. coliform MPN/100ml**	**E.coli. MPN/100ml**
Salim Hassan well	1	8:00pm	>2400	>2400	>2300	220
Salim Hassan well		4:00am	>2400	>2400	1700	18
Salim Hassan well	2	8:00pm	>2400	>2400	1700	36
Salim Hassan well		4:00am	>2400	1100	1700	18
Salim Hassan well	3	8:00pm	>2400	93	2300	220
Salim Hassan well		4:00am	240	240	1700	42
Baoni well	1	8:00pm	>2400	>2400	>1300	130
Baoni well		4:00am	>2400	>2400	>2400	14
Baoni well	2	8:00pm	>2400	>2400	1700	9
Baoni well		4:00am	>2400	1100	2300	0
Baoni well	3	8:00pm	>2400	>2400	>2400	130
Baoni well		4:00am	>2400	>2400	>2400	18
Himwa Tap			1100	0	1100	0
NEMA maximum contamination level(MCL)			10	0	10	0

Water samples for both wet and dry season were analyzed within 24 hours of sampling for total coliforms and *E. coli* by the MPN method. The outcome indicates the wells were highly contaminated with Total coliforms and *E.coli* (Table 1) with the levels of total coliforms well above the NEMA recommended values. Himwa sample had *E. coli* within the recommended levels while total coliform beyond the allowable limits.

In the wet season, total coliforms ranged from highest value >2400 MPN/100 mL to lowest value of 240 MPN/100 recorded in the third sampling in September at Salim Hassan well. These levels were clearly beyond the maximum contamination levels of 10 MPN/100 recommended (NEMA, 2006). Whilst, the total Coliforms for dry season ranged from 1300 to > 2300; these were beyond the MCL by NEMA of 10 MPN/100.

E.coli levels in the two wells during wet season ranged from 93->2400MPN/100 mL, while for dry season ranged from 0-220MPN/100 mL Nevertheless, Baoni well visit 2 at 4:00Am gave a value of zero (0) which is acceptable by the NEMA standard, where as the rest were beyond the maximum contamination level (MCL) by NEMA. Total coliforms in Himwa tap water were 1100 MPN/100mL which is beyond the recommended level while *E. Coli* level was nil which is acceptable by the NEMA standard.

In the wet season both total Coliforms and *E.coli* levels in the two wells were very high compared to the dry season since P value=0.000<0.05. Below is the outcome of the Two sample T-test and Man -Whitney Test used to determine the levels of *E.coli* and total coliform during wet and dry season respectively.

4.1.1 Two-Sample T-Test and CI: *E.coli* Wet Season, *E.coli* Dry Season

	N	**Mean**	**St Dev**	**SE Mean**
E.coli 1 (Wet Season)	12	40.3	14.3	4.1
E.coli 2 (Dry Season)	12	7.03	4.87	1.4

95% CI for difference: (23.8038, 42.6909)

T-Test of difference = 0 (vs not =): T-Value = 7.61 P-Value = 0.000 DF = 13

4.1.2 Mann-Whitney Test for the Total coliform during Dry and Wet Season

	N	Median
Dry	12	44.60
Wet	12	48.99

95.4 Percent CI for ETA1-ETA2 is (-7.76, 0.00). W = 106.5.

Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.0130

One of the factors that might be attributed to the higher microbial counts in the raining season is the large amounts of water in the pits latrines. Majority of disease causing organisms lack the property to propel themselves through the environment in which they live and those that can propel themselves are not capable of traveling very great distances. Instead, pathogens are carried from one point to another within the medium in which they live and in the case of pit latrines water transports the contamination into the aquifer and nearby wells. The smaller the amount of water in the pit latrines, therefore, the lower the risk of water point contamination (Sugden, 2006). The larger the number of users, the higher the amount of water drawn from a well and the higher the hydraulic gradient between the well and the latrine, consequently the higher rate of flow to the well and hence more contamination (Kiptum and Ndambuki, 2012).

The extent to which microbes from pit latrine wastes may be transported and contaminate groundwater largely depends on the environmental context of the area, particularly hydrological and soil condition (Graham and Polizzotto, 2013).

The further the water that contains pathogens has to travel to the water table, the longer it is retained. This additional time allows for greater numbers of pathogens to die off naturally (Abdulkadir *et al*, 2014).

In the study area the Shallow wells are located very close to pit latrines and the distance between the Shallow wells and pit latrine was 11m which was below the recommended distance of 30m by the Ministry of Public Health Officers, hence, latrine waste water enters and contaminates the aquifer which supplies water into the nearby shallow wells. A vertical distance of ≥ 3–4.5 m between the bottom of the pit and the water table would maintain safe groundwater quality (Graham and Polizzotto, 2013).

Water contamination is considered to be the introduction or release into water, organisms or toxic substances that render it unfit for human consumption. Accordingly, water bodies polluted by fecal discharge from man and other animals may transport a variety of human pathogens. These microbial agents may include pathogenic bacteria, viruses, protozoa and several more complex multicultural organisms that can cause gastro-intestinal illness (Adejuwon *et al,* 2011). The presence of these organisms is an indication that water within the wells from the study area have come into contact with animal or human feaces. Total coliforms and *E. coli* are used as indicators of possible sewage contamination because they are commonly found in human feaces. Therefore, their presence in the sampled water from the selected wells suggests that pathogenic micro-organisms might also be present and consumption of water from these sources might pose a severe health risk (Abdulkadir *et al*, 2014). *E. coli* or thermotolerant coliform bacteria should not be detectable in any water intended for drinking (WHO, 2008).

Microbial contaminants (both bacterial and viral) derived from sewage can penetrate up to the depth of 90m in some aquifers. These included indicator organisms such as Coliforms which were detected in this investigation. The pit latrines were the main sources of the fecal pollution observed (Powell *et al*, 1964). From the indicators (Coliform, Enterococci and *Escherichia coli*) *Escherichia coli* is the most predictive indicator for enteric disease symptoms compared to other indicators. Among total

Coliforms and *Escherichia coli* indicators, *E. coli* is the best indicators of gastrointestinal symptoms (Abdulkadir *et al*, 2014).

4.2 Physicochemical analysis of water sample for the wet and dry season.

Table 2 show results of the physicochemical analysis of the two main shallow wells for both wet and dry season with standard guideline set by NEMA on water.

Table 2:-Physiochemical parameters of samples collected from Salim Hassan and Baoni wells for both wet and dry seasons.

Parameters	Maximum Limit by NEMA	Time	WELLS PER VISIT DURING WET SEASON						WELLS PER VISIT DURING DRY SEASON						Himwa Tap
			Baoni			Salim Hassan			Baoni			Salim Hassan			
			1	2	3	1	2	3	1	2	3	1	2	3	
Sodium	**200(mg/L^{-1})**	8pm	872	860	720	1120	1220	1160	722	720	720	1200	1200	1210	350
		4am	740	740	714	1220	1160	1100	840	842	840	1180	1182	1180	
Fluoride	**1.5(mg/L^{-1})**	8pm	1.22	1.27	0.8	0.7	1.21	0.8	0.72	0.68	0.70	0.84	0.88	0.82	1.2
		4am	0.78	0	0.66	0.83	0.66	0.82	1.26	1.24	1.26	0.7	0.8	0.7	
Nitrates	**10(mg/L^{-1})**	8pm	14	0	20	12	1.2	12	16	14	18	10	12	12	22
		4am	0	1.4	32	0	1.1	11	22	20	22	12	10	10	
Chloride	**240(mg/L^{-1})**	8pm	660	540	450	620	640	580	460	462	462	650	652	653	200
		4am	480	452	540	656	596	652	550	550	550	590	590	590	
Potassium	**100(mg/L^{-1})**	8pm	472	360	280	452	480	456	280	280	280	398	398	398	55
		4am	300	300	340	480	460	430	350	352	352	462	460	460	
Magnesium	**100(mg/L^{-1})**	8pm	36.2	29.76	8.5	12.4	8.64	16.2	6.42	6.42	6.42	34.2	34.2	34.2	7.5
		4am	6.72	8.64	8.22	35.52	17.28	32.4	30.2	30.0	30.0	16.4	16.2	16.2	
Calcium	**150(mg/L^{-1})**	8pm	134.2	168	120.2	174.4	174.4	162.2	120	122	122	130.8	130	130	82
		4am	120	118.4	118.2	132.8	163.2	142.4	170	170	170	160.0	160.2	160	
pH	**6.5-8.5**	8pm	7.62	7.57	7.62	7.56	7.52	7.58	7.4	7.4	7.4	7.6	7.2	7.4	7.2
		4am	7.72	7.53	7.82	7.61	7.59	7.4	7.48	7.46	7.4	7.4	7.4	7.2	
Total Hardness	**300(mg/L^{-1})**	8pm	482	544	330	462	472	482	330	332	332	448	450	452	280
		4am	328	332	340	480	480	402	550	550	550	462	460	462	
TDS	**1200(mg/L^{-1})**	8pm	3200	2700	2200	3300	3300	3120	2450	2450	3100	3120	3120	3120	1800
		4am	2300	2200	2600	3180	3200	3200	2800	2800	3820	3300	3400	3300	
Iron	**0.3(mg/L^{-1})**	8pm	0.01	0.01	0.02	0	0	0	0.01	0.01	0.01	0.1	0.1	0.1	0.01
		4am	0.05	0.01	0.05	0.01	0	0.02	0.01	0.01	0.01	0.01	0.01	0.01	

The outcome of the analysis for both wet and dry season was compared to the acceptable levels designed by NEMA to portray the suitability of water from Baoni and Salim Hassan wells for consumption. Odour of the water samples collected from the two main shallow wells in both wet and dry season were earthy-musty attributed by natural biological process compared to Himwa tap water which was odourless. Water from the two well had a sour taste compared to Himwa tap water which was sweet. The water samples were colourless in wet season and turbid during dry season; turbidity in the dry season was attributed to low water levels in the two wells as bucket use to draw the water from the well unsettled water leading to turbidity while Himwa water was colourless. The pH values of all the water samples ranged from 7.2 to 7.82 which fell within the NEMA standards for drinking water (NEMA, 2006). Sodium levels ranged from 714-1220 mg/L^{-1} that exceeded the (NEMA, 2006) standard guideline of 200mg/L. Fluoride values for both wells during wet and dry seasons ranged from 0-1.27mg/L^{-1} that are below the standard limit of 1.5mg/L^{-1}while Himwa water had 1.2mg/L^{-1}. Nitrate levels of the water sample from the two shallow wells during both wet and dry season ranged from 0-32 mg/L^{-1}. However, Baoni and Salim Hassan well visit1 at 8 pm and visit 3 at both 8 pm and 4 am respectively during wet season were beyond the maximum allowable limits. Similarly nitrate levels of the water sample from Salim Hassan well visit 1 at 4am, visit 2 and 3 at 8pm during dry season were beyond the acceptable levels. Baoni well visit 1, 2 and 3 at both 8pm and 4 am for the dry season had nitrate levels beyond the maximum allowable limits (Max limit of 10mg/L^{-1}). Himwa water had nitrate level beyond the maximum allowable limits. Magnesium values were below the permissible level of 6.72-36.2mg/L^{-1} (Max limit of 100mg/L^{-1}). Chloride and potassium values 450-660mg/L^{-1} and 280-480 mg/L^{-1}respectivelyof the two shallow wells were beyond the limits by NEMA of chloride 200mg/$L^{-1}$and of potassium 100mg/L^{-1}

compared to Himwa tap water with potassium and chloride levels fell within the maximum allowable limits.

The total hardness values of the samples collected from the two shallow wells ranged from 330-544mg/L^{-1}that exceeded the limit of 300mg/L^{-1}compared to Himwa tap water with 280mg/L^{-1} which was within permissible level. The total dissolved solids of all the samples collected ranged from 1800-3800mg/L^{-1}and exceeded the standard guideline (Max limit of 1200mg/L^{-1}) however, iron levels from all the samples ranged from 0-0.1 which is below the limits of 0.3mg/L^{-1}(NEMA, 2006). Calcium level of the two shallow wells Baoni well visit 2 at 8pm, Salim Hassan well visit 1 and 3 at 8pm, visit 2 at 8pm and 4am in wet season, Baoni visit 1,2 and 3 and Salim Hassan visit 1,2 and 3 at 4am in dry season, respectively exceeded the acceptable levels laid down by NEMA while the rest values of calcium from the two shallow wells in both wet and dry season and Himwa water were below the limits set of 150 mg/L. Two-sample t-test and Mann-Whitney test were employed to show comparison between wet and dry season however, the outcomes were not responding since P-value (significant levels) were beyond 0.05. Average levels were used to show comparison and it was apparent that wet season had the highest concentration of Physicochemical compared to dry season since mean and median level revealed by both Two sample t-test and Mann Whitney respectively showed wet season was high compared to dry season. Below is the outcome of the analysis below.

Two-Sample T-Test and CI: Dry Season, Wet Season

Two-sample T for Physico-chemical test in DRY SEASON vs WET SEASON

	N	Mean	St Dev	SE Mean
WET Season	11	1.62	1.57	0.47
DRY Season	11	1.58	1.22	0.37

95% CI for difference: (-1.222887, 1.301849)

-Test of difference = 0 (vs not =): T-Value = 0.07 P-Value = 0.948 DF = 18

Mann-Whitney Test and CI: for Physico-chemical test in Dry Season, Wet Season

	N	Median
WET SEASON	11	2.174
DRY SEASON	11	1.876

Point estimate for ETA1-ETA2 is 0.202
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.6936

4.2.1 Variation of the parameters at different time intervals for the Wet Season

Normality test was carried out to ascertain the analysis tool to be employed in depicting the variation in concentration of the parameters before and after harvesting water between the two sampling time per visit.

4.2.2 Baoni well: Visit 1, mid of August 2015

The outcome of normality test shows that the data was not normally distributed (figure 4). Data that is normally distributed would have plots attached or close to the straight line after conducting normality test.

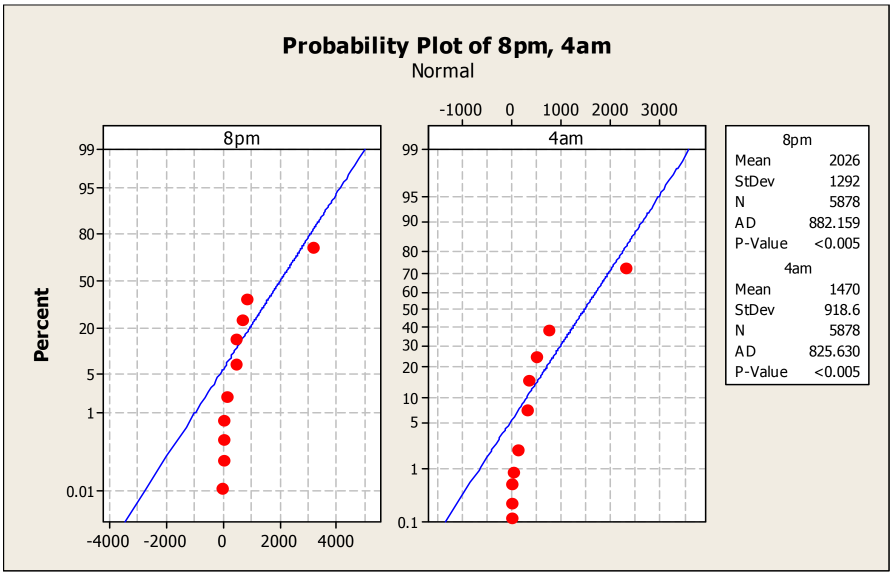

Figure 4: Probability plot (Q-Q plot) for Baoni well visit 1.

The graph below shows the data is normally distributed after being transformed. Wilcoxon test was used to compare the concentration of the parameters from the sample obtained from Baoni well between 8pm and 4am.

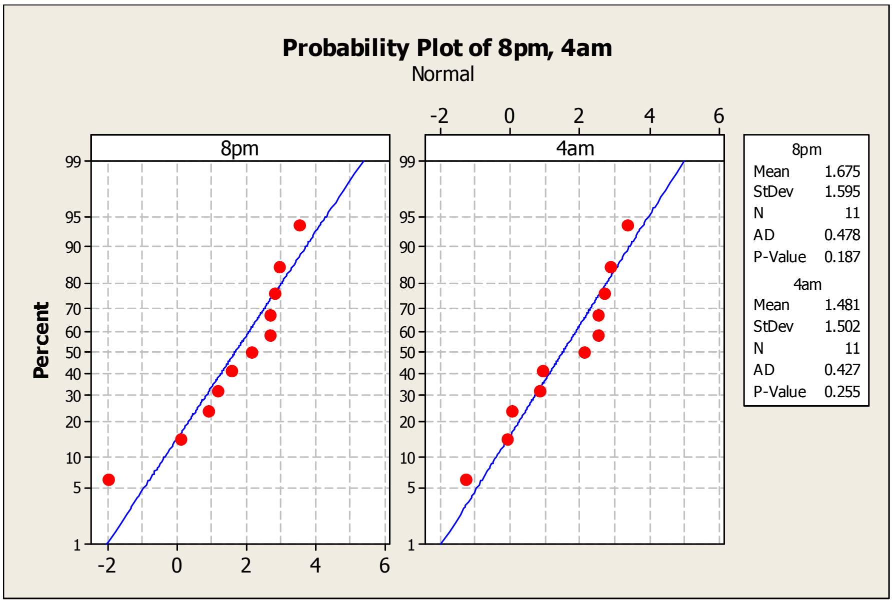

Figure 5: Q-Q plot for Baoni well visit 1.

A test was carried out using Minitab to determine the disparity of the physicochemical parameter during the two sampling time (8pm and 4am). The outcome suggested that there was variation in concentration of the parameters at 4am and at 8pm (P value 0.007, 0.012 respectively) since P-value was less than 0.05. Below is the outcome of the analysis tested using Minitab: -

Wilcoxon Signed Rank Test: 8pm, 4am

Test of median = 0.000000 versus median > 0.000000

	N	N for Test	Wilcoxon Statistic	P	Estimated Median
8pm	11	11	61.0	0.007	1.880
4am	11	10	50.0	0.012	1.555

4.2.3 Baoni well: 15 Days after the first visit.

The data was first tested for normality and the outcome showed the data was not normally distributed. The data was then transformed using $\log_{10}$ to attain the normality. The normality of the data was clearly shown in the graph below.

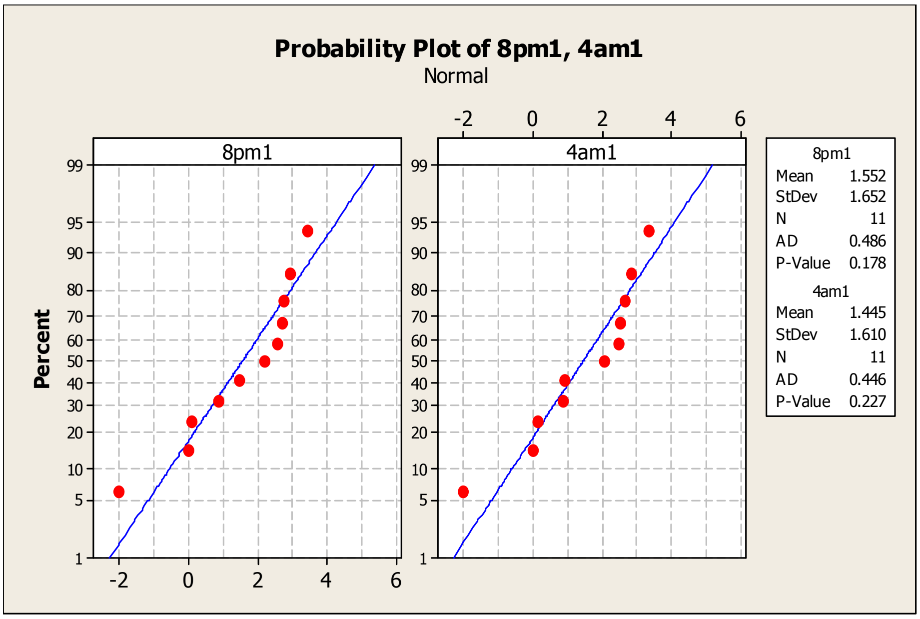

Figure 6: Probability plot for Baoni well visit 2.

Wilcoxon Signed Rank Test was used to compare the concentration of the physicochemical parameters before the residents fetched water at 4am and after the day activity at 8pm in Baoni well visit 2. The results revealed the existence of variation in of the physicochemical parameters at 4am and at 8pm, this was propped up by P-value that was less than 0.05. Below is the outcome of the analysis tested using Minitab: -

Wilcoxon Signed Rank Test: 8pm, 4am

Test of median = 0.000000 versus median not = 0.000000

	N	N for Test	Wilcoxon Statistic	P	Estimated Median
8pm	11	10	51.0	0.019	1.717
4am	11	10	51.0	0.019	1.589

4.2.4 Baoni well: 15 days after the second visit

Normality test of the data was done to the transformed data since the real data was non-normal. The normality of the data was clearly shown in the graph below

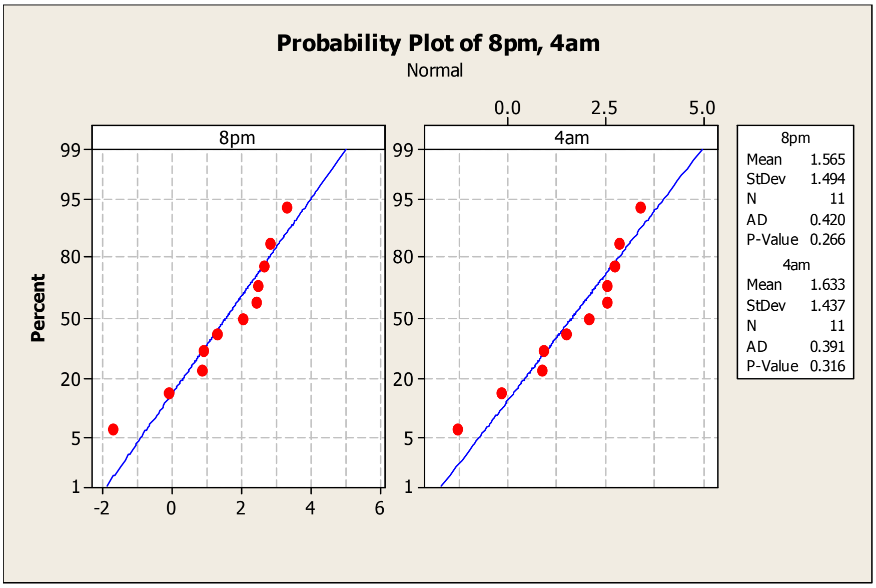

Figure7: Probability plot for Baoni well visit 3.

Wilcoxon Signed Rank Test was employed to show the disparity of the physicochemical parameter between 8pm and 4am in Baoni well visit 3. The outcome suggested the existence of variation of physicochemical parameters before (4am) and after (8pm) water harvesting in Baoni well. However, the P-value was less than 0. Below is the outcome of the analysis tested using Minitab: -

Wilcoxon Signed Rank Test: 8pm, 4am

Test of median = 0.000000 versus median > 0.000000

	N	N for test	Wilcoxon Statistic	P	Estimated Median
8pm	11	11	60.0	0.009	1.712
4am	11	11	61.0	0.007	1.756

4.2.5 Salim Hassan well: Visit 1, mid of August.

The data was transformed using Log_{10} to obtain the normality since the real figures were non-normal. Below Q-Q plot clearly showed the transformed data was normally

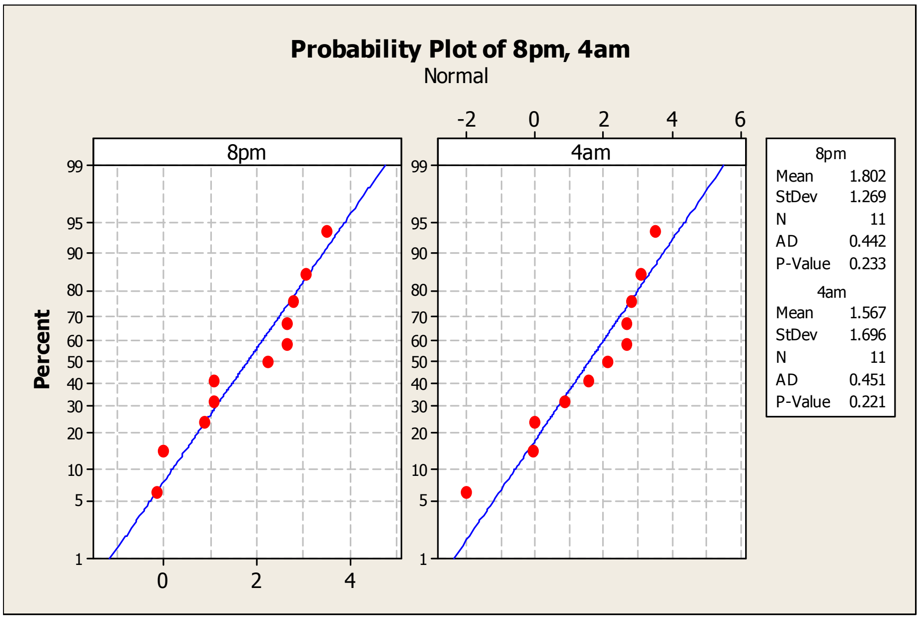

Figure 8: Probability plot for Salim Hassan well visit 1.

Wilcoxon Signed Rank Test was employed to show difference in concentration of the physicochemical parameters between 8pm and 4am in Salim Hassan well visit 1. The outcome was tested at 95% confidence level and showed the presence of variation of the physicochemical parameters at 4am and at 8pm. The P-value was less than 0.05. Below is the outcome of the analysis tested using Minitab: -

Wilcoxon Signed Rank Test: 8pm, 4am

Test of median = 0.000000 versus median > 0.000000

	N	N for Test	Wilcoxon Statistic	P	Estimated Median
8pm	11	10	54.0	0.004	1.851
4am	11	10	50.0	0.012	1.731

4.2.6 Salim Hassan well: 15 day after the first visit.

The graph below showed the data was normally distributed after transforming the data using Log_{10} to obtain the normality. Wilcoxon Signed Rank Test was used to prove the existence of difference in concentration of physicochemical parameters between 8pm and 4am in S.H well visit 2.

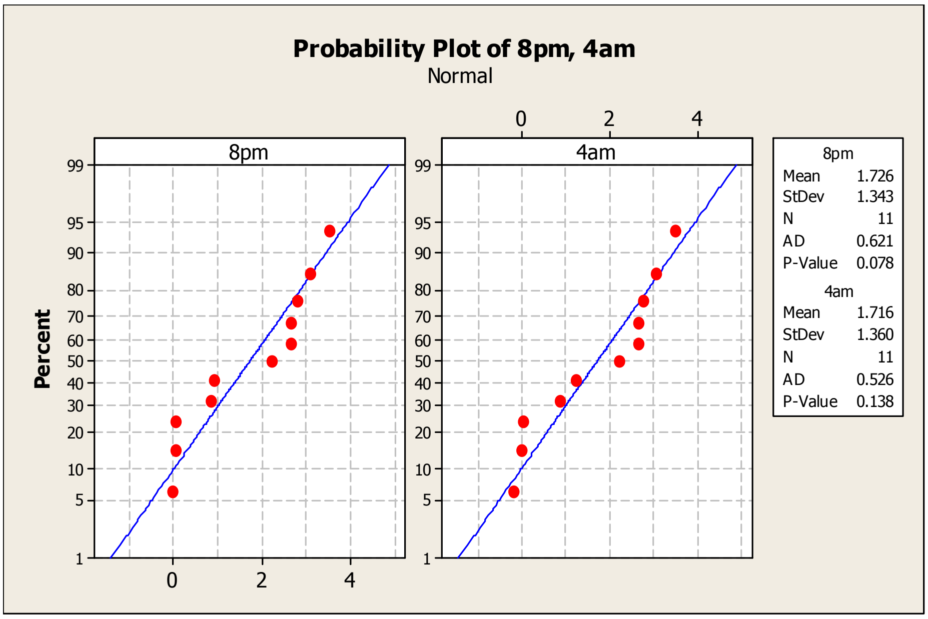

Figure 9: Q-Q plot for Salim Hassan well visit 2.

The outcome was tested at 95% confidence level and showed the existence of variation in concentration of the physicochemical parameters at 8pm and 4am at Salim Hassan well. However, the P-values were less than 0.05. Below is the outcome of the analysis tested using Minitab: -

Wilcoxon Signed Rank Test: 8pm, 4am
Test of median = 0.000000 versus median > 0.000000

	N	N for Test	Wilcoxon Statistic	P	Estimated Median
8pm	11	10	55.0	0.003	1.767
4am	11	10	53.0	0.005	1.739

4.2.7 Salim Hassan: 15 days after the second visit.

Initially normality test for untransformed data was carried out to ascertain normality of the data unfortunately the outcome showed data not normally distributed hence compelling to transform the data. However, the outcome of the transformed data suggested that the data was normally distributed. Below the graph shows the data was normally distributed.

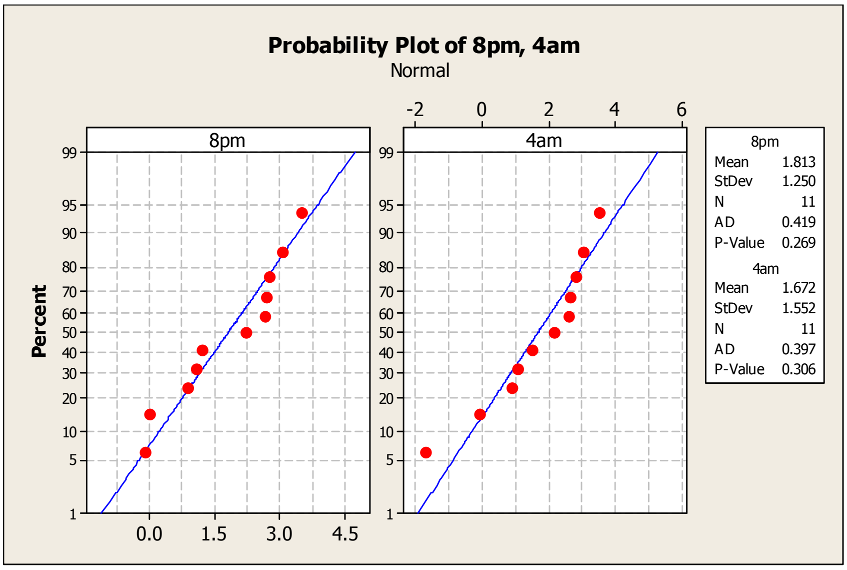

Figure 10: Q-Q plot for Salim Hassan well visit 3.

Wilcoxon Signed Rank Test was used to show the difference in concentration of the physicochemical parameter between 8pm and 4am in S.H well visit 3. The outcome was tested at 95% confidence level and shows that there was variation in concentration of the physicochemical parameters at 8pm and 4am. However, the P-values were less than 0.05. Below is the outcome of the analysis tested using Minitab: -

Wilcoxon Signed Rank Test: 8pm, 4am

Test of median = 0.000000 versus median > 0.000000

	N	N for Test	Wilcoxon Statistic	P	Estimated Median
8pm	11	10	54.0	0.004	1.845
4am	11	11	60.0	0.009	1.835

4.2.8 Variation of the parameters at different time intervals for the Dry Season.

Sampling for the dry season was conducted in January-February 2016, however, the data obtained after analysis at the Government Chemist laboratory was tested for normality and proved to be non-normal. The data was subsequently transformed using Log_{10} and tested for normality. The outcome was positive (data was normally distributed) and the graph below showed the normality of the data.

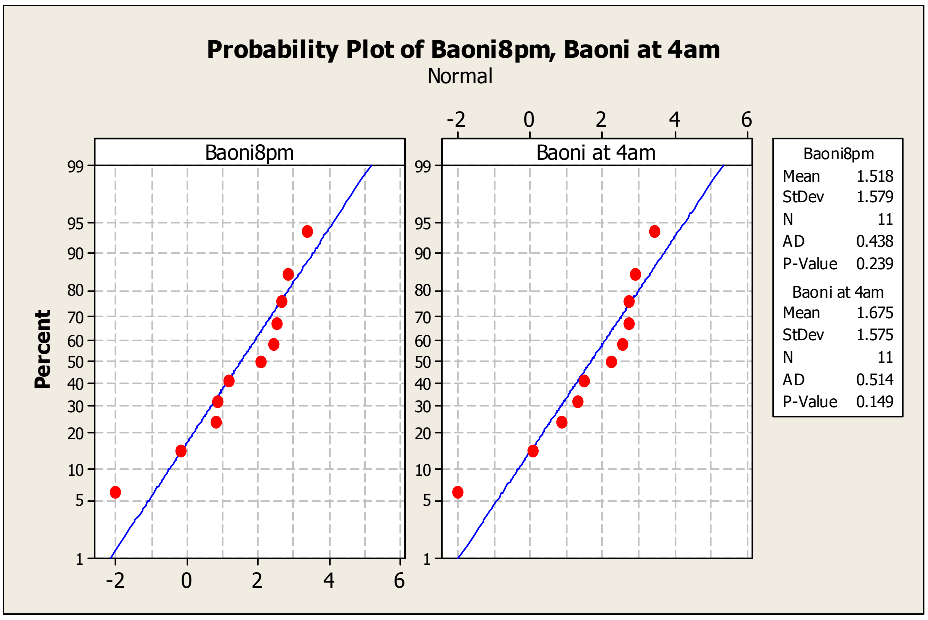

Figure 11: Probability plot of Baoni well visit 1 dry season.

Paired T-test was run to reveal if there was variation of the physicochemical parameters before the resident reaped water at 4am and after the day activity at 8pm. The outcome of the paired T-test suggested that there was variation in concentration of the physicochemical parameters before and after water harvesting since P-value was less than 0.05 (P-Value = 0.020<0.05). See the outcome of analysis below: -

Paired T-Test and CI: Baoni 8pm, Baoni at 4am

	N	Mean	St Dev	SE Mean
Baoni8pm	11	1.51759	0.47622	1.57514
Baoni at 4am	11	1.57944	1.67485	0.47492
Difference	11	0.157259	0.188042	0.056697

T-Test of mean difference = 0 (vs not = 0): T-Value = -2.77 P-Value = 0.020

4.2.9 Baoni well:15 Days after the first visit

The data was transformed using $\log_{10}$ since it was non-normal, however the outcome of the transformation attained normality. See the graph below: -

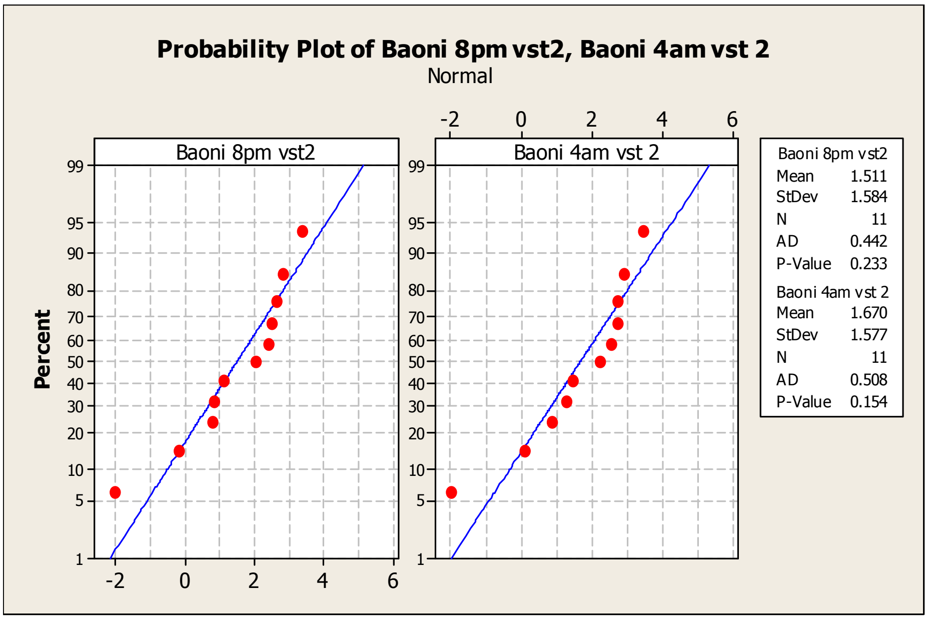

Figure 12: -Probability plot of Baoni well visit 2 dry season.

Paired T-test was applied to check if there was disparity of the physicochemical parameters before the resident harvested water at 4am and after the day activity at 8pm. The outcome of the paired T-test demonstrated the existence of variation in concentration of the physicochemical parameters before the natives of Mokowe drawn water from the well at 4am and after the day activity at 8pm since P-value was less than 0.05. Below is the outcome of analysis carried out using Minitab.

Paired T-Test and CI: Baoni 8pm visit2, Baoni 4am visit 2

	N	Mean	St Dev	SE Mean
Baoni 8pm	11	1.51102	1.58377	0.47752
Baoni 4am	11	1.670	1.57707	0.47550
Difference	11	0.159391	0.187985	0.056680

T-Test of mean difference = 0 (vs not = 0): T-Value = -2.81 P-Value = 0.018

4.2.10 Baoni well: 15 days after the second visit

Transformed data was tested for normality and turn to be positive (normally distributed) since the real figures tested negative (not normally distributed) after normality test. The graph below shows normality of the transformed data.

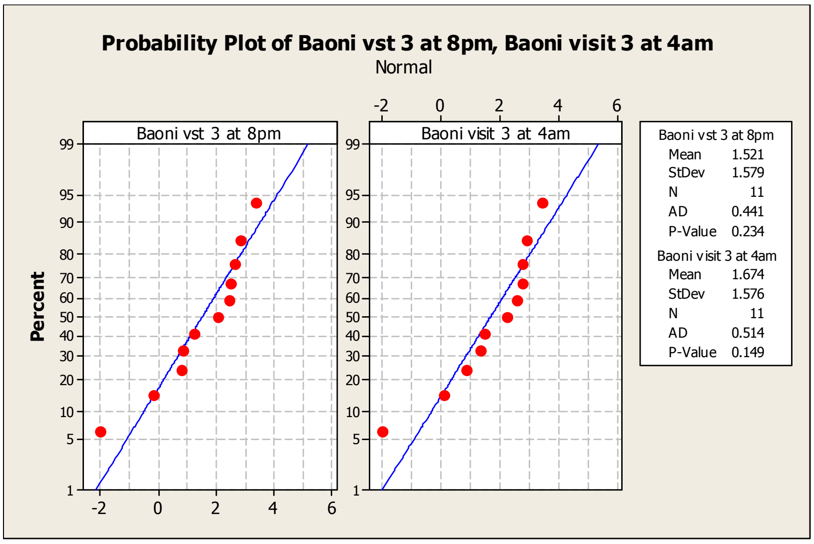

Figure 13: -Probability plot of Baoni well visit 3 dry season.

Paired T-test was employed to check if there was variation of the physicochemical parameters before the resident harvested water at 4am and after the day activity at 8pm. The results of the paired T-test showed that there was variation of the physicochemical parameter before and after water harvesting from the shallow wells. This is clearly supported by the outcome of the paired t-test which shows that the p-value was less than 0.05. P-Value = 0.023<0.05. Below is the outcome of analysis carried out using Minitab.

Paired T-Test and CI: Baoni visit 3 at 8pm, Baoni visit 3 at 4am

	N	Mean	St Dev	SE Mean
Baoni8pm	11	1.52127	1.57555	0.47615
Baoni4am	11	1.67439	0.188838	1.57920
Difference	11	0.153120	0.056937	0.47505

T-Test of mean difference = 0 (vs not = 0): T-Value = -2.69 P-Value = 0.023

4.2.11 Salim Hassan well: Early January of 2016

Normality test of the data was done to the transformed data since the real data was non-normal. The normality of the data was clearly shown in the graph below.

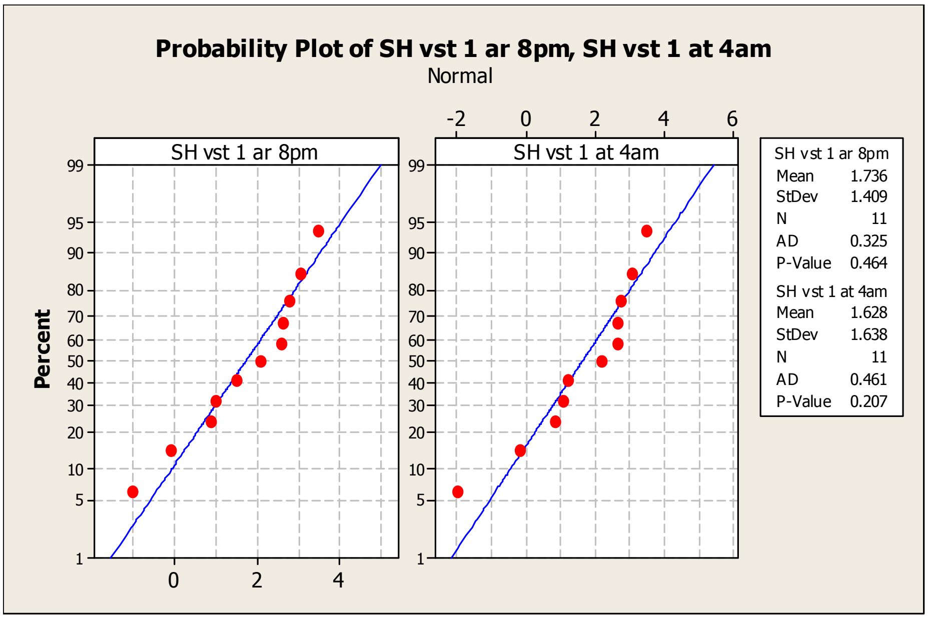

Figure 14:- Probability plot of Salim Hassan well visit 1 dry season.

Wilcoxon Signed Rank Test which is a non-parametric form of paired t-test was used to check if there was variation in concentration of the physicochemical parameters before the resident harvested water at 4am and after the day activity at 8pm. The results of the analysis demonstrated that there was disparity of the physicochemical parameters before and after water harvesting from the well since P-values was less than 0.05. Below is the outcome of analysis carried out using Minitab.

Wilcoxon Signed Rank Test: SH visit 1 at 8pm, SH visit 1 at 4am

Test of median = 0.000000 versus median not = 0.000000

	N	N for Test	Wilcoxon Statistic	P	Estimated Median
SH at 8pm	11	11	61.5	0.013	1.825
SH at 4am	11	11	60.0	0.018	1.846

4.2.12 Salim Hassan: 15 Days after the first visit.

Normality test was run to the transformed data to obtain normality. The outcome was very positive as illustrated below: -

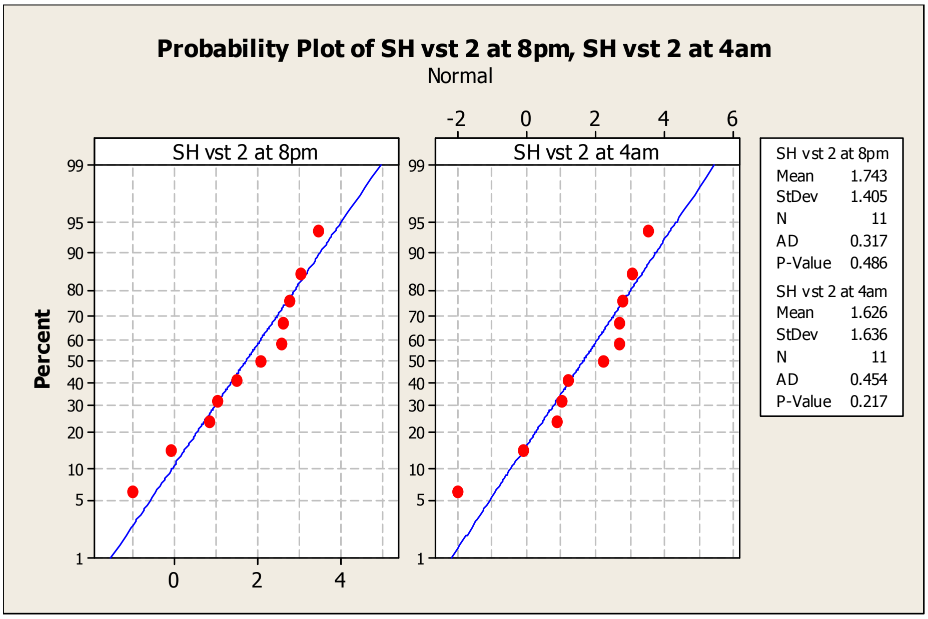

Figure 15:- Probability plot of Salim Hassan well visit 2 dry season.

Wilcoxon Signed Rank Test was used to prove the existence of disparity of the physicochemical parameters between 8pm and 4am. The outcome of wilcoxon test demonstrated that there was variation in the concentration of physicochemical parameters before and after water harvesting from the well since P-values was less than 0.05. Below is the outcome of analysis carried out using Minitab: -

Wilcoxon Signed Rank Test: SH visit 2 at 8pm, SH visit 2 at 4am

Test of median = 0.000000 versus median not = 0.000000

	N	N for Test	Wilcoxon Statistic	P	Estimated Median
SH 8pm	11	11	62.0	0.011	1.838
SH 4am	11	11	60.0	0.018	1.826

4.2.13 Salim Hassan well: 15 days after the second.

The graph below shows data was normally distributed. Wilcoxon test was used to show the disparity of physicochemical parameters between 8pm and 4am.

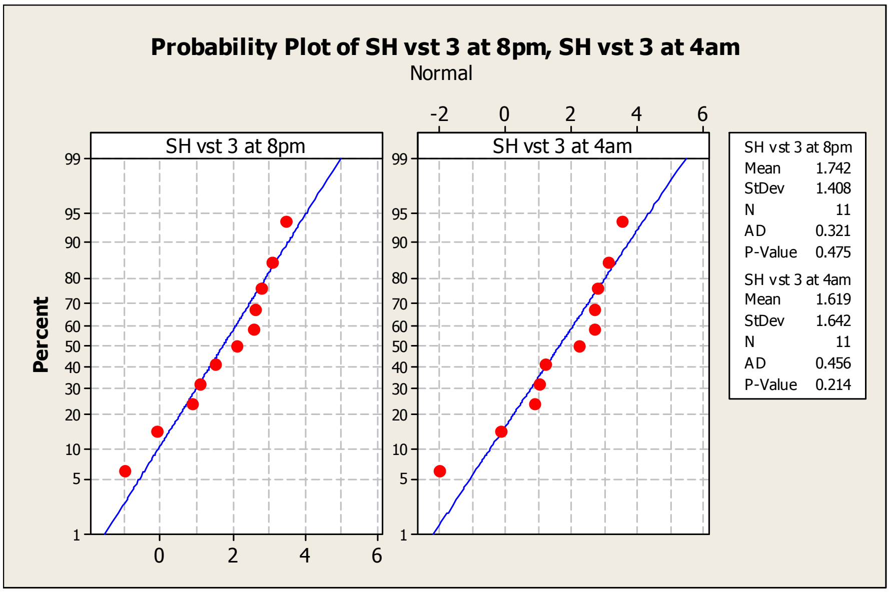

Figure 16: Probability plot of Salim Hassan well visit 3 dry season.

The outcome suggested that there was the disparity of the physicochemical parameters of before (4am) and after (8pm) water harvesting, since the P-values are less than 0.05. Below is the outcome of analysis carried out using Minitab: -

Wilcoxon Signed Rank Test: SH visit 3 at 8pm, SH visit 3 at 4am

Test of median = 0.000000 versus median not = 0.000000

	N	N for test	Wilcoxon Statistic	P	Estimated Median
SH 8pm	11	11	62.0	0.011	1.841
SH 4am	11	11	60.0	0.018	1.823

4.3 Questionnaire Analysis

A total of 225 questionnaires were administered to deliberately target the residents of Mokowe with the objective of obtaining information on the duration they have lived in the village, their main source of water, for how long have they been using their main source of water, method of accessing water, safety of the wells and finally if they have ever contacted any gastrointestinal infection and how often. Another questionnaire was designed to capture response from the water vendors.

4.3.1 Residence Time of the Population in Mokowe Village.

A total of 225 people were interviewed and 12% of the interviewee had resided for less than 2 years, 19% between 2-5 years, 23% between 5-10 years and finally 45% for more than 10 years. This indicated that majority are true inhabitant of Mokowe village (Figure 17).

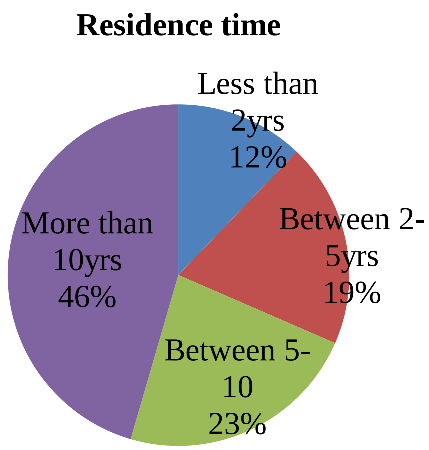

Figure 17: Residence time in Mokowe Village.

4.3.2 Main Source of Water.

The results of main source of water are represented in Figure 18 below. A total of 91% of the respondents used well water as their major source of domestic water, since tap water wasn't reliable. Majority of the villagers live below the poverty lines and cannot afford to buy water from the nearby village, thus inclining on shallow wells some of which have no covered on the top. However, 9% said they used tap water to alleviate their needs; they are middle class and said to have been buying water from the nearby Village (Hindi). None were using boreholes or reservoir (Figure 18).

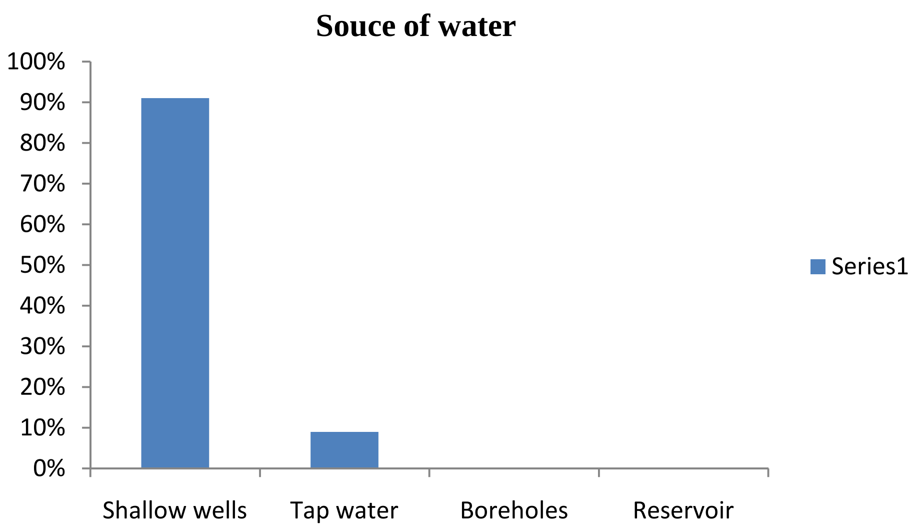

Figure 18: Source of water

4.3.3 Reliability of the Supplying System for those using Tap Water.

A total of 92% of the respondents use shallow well and reported N/A because the question was not applicable to them, 8% in Figure 19 said that the system was not reliable and could stay for 6 months without getting tap water hence forced to look for alternative ways. None reported yes to the reliability of the supplying system.

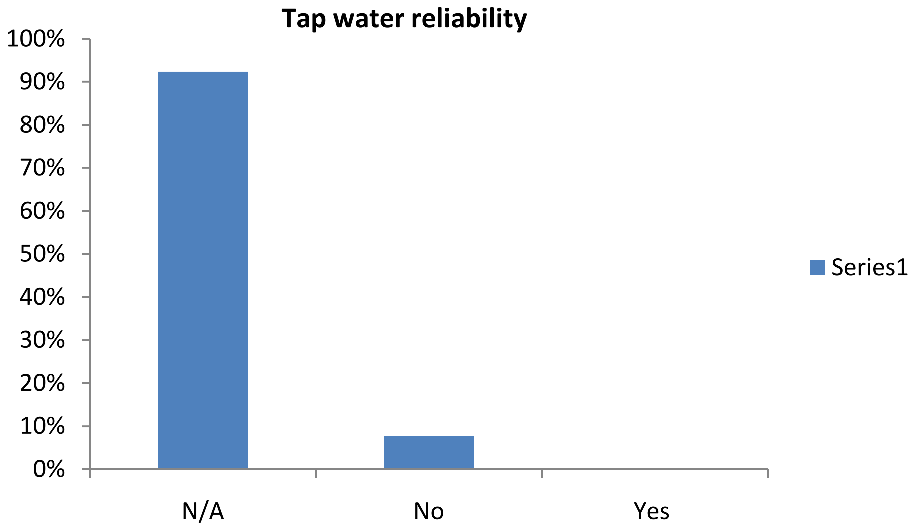

Figure 19: Tap water reliability.

4.3.4 Alternative Source of Water.

A 100% of the respondents stated shallow wells as their only alternative source of domestic water. This was attributed to accessibility of the wells as they were located close to them. However, since the majority of the residents are poor they pay no cash to access water from the wells. None mentioned boreholes, water point or other sources.

4.3.5 Duration of Using Shallow Wells.

The results of duration of using shallow wells are represented in Figure 20 below. Most of the respondents have been using shallow wells for more than 10 years and despite challenges of sickness shallow well remain the only source of water for Mokowe residents. 21% have been using shallow wells between 5-10 year and 17% have been using shallow between 2-5 years and less than 2 years respectively.

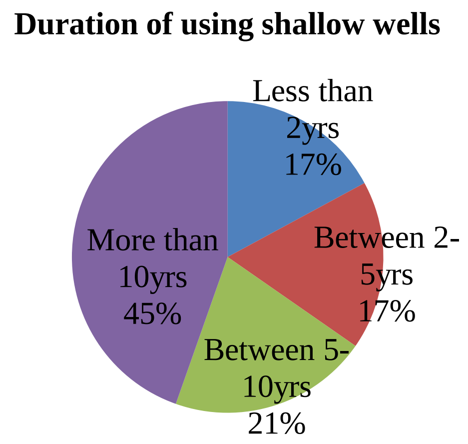

Figure 20: Duration of using shallow wells.

4.3.6 Access of water from the shallow wells.

The outcome of access of water from the shallow wells is represented in Figure 21 below. A total of 62% of the interviewees are poor and have been fetching water by themselves however, 37% are middle class and have been buying water from the vendors and 1% didn't answer the question.

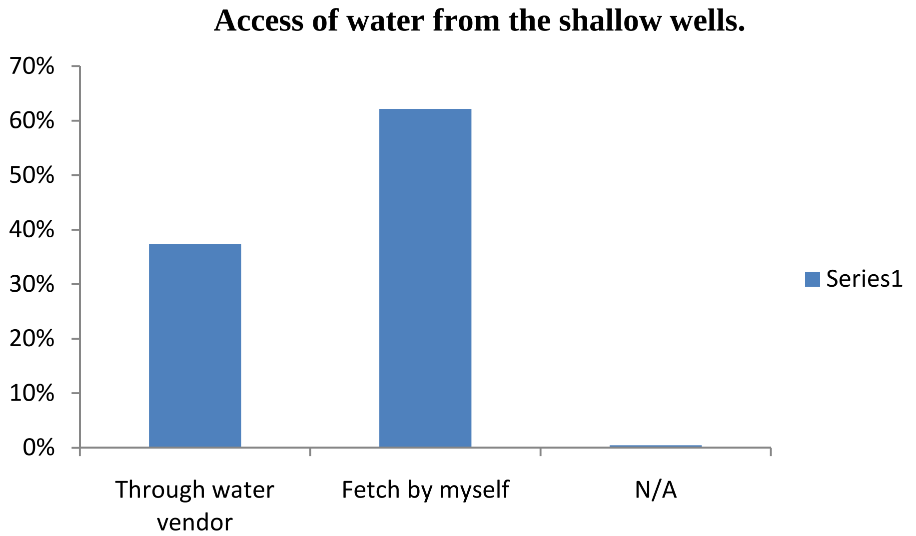

Figure 21: Access of water from the shallow wells.

4.3.7 Water Usage.

A total of 44% have been using water between 80-120L per day claiming the family size was big and the only sole reason that compelled them to use large volume of water, 34% have been using more than 120L of water, 20% of the respondents have been using water between 50-80L of water and 2% have been using water between 20-40L of water per day. (Figure 22).

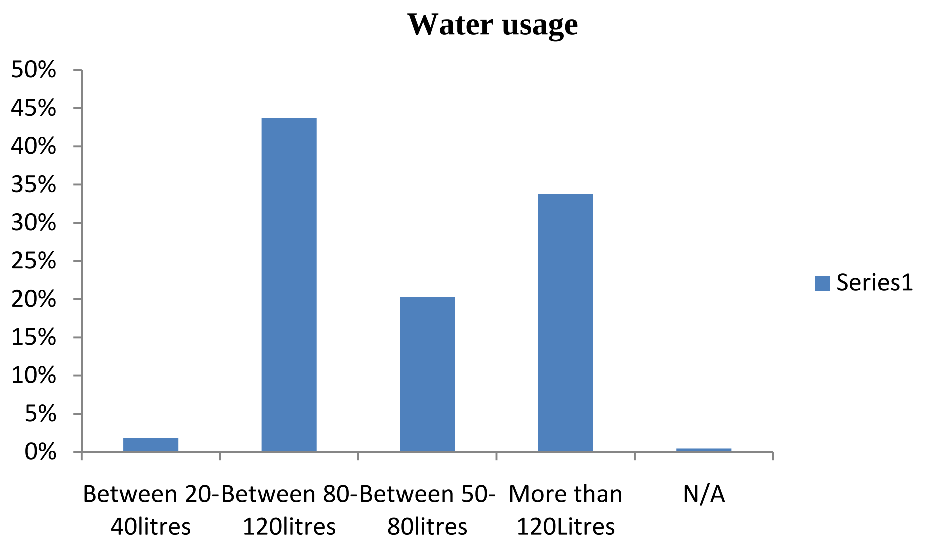

Figure 22: Water usage.

4.3.8 Safety of the Water in Shallow Well.

A total of 67% of the respondents have been using water from the well hence safe for consumption due to numerous efforts made by public health officers to lessen the infection. The efforts include; taking care of the wells in case of an outbreak in the neighboring village and by engaging the community through community health workers whose obligation have been to disseminate chlorine tablet in household and trained them on how to use it, 32% the quality of the water is not safe and 1% didn't answer the question (Figure 23).

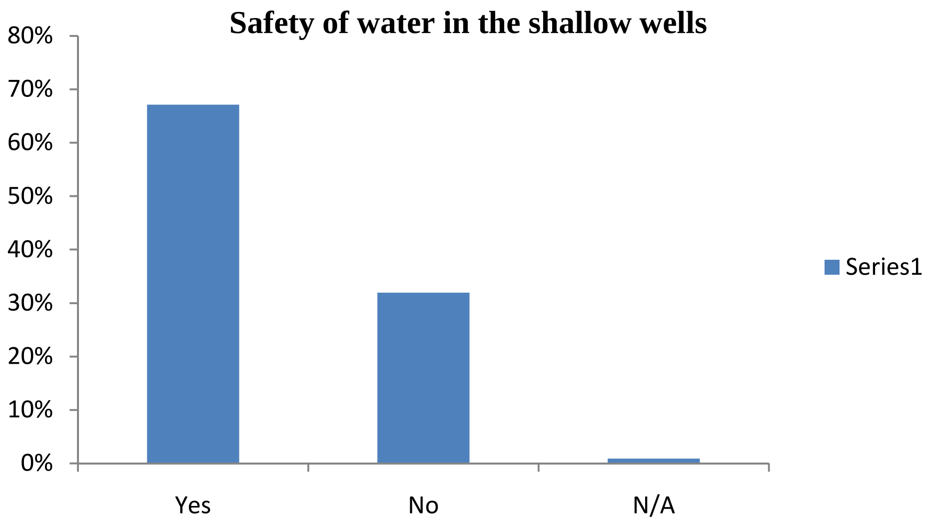

Figure 23: Safety of water in the shallow well.

4.3.9 Monitoring of the Wells by Public Health Officers.

The results of Monitoring of the wells by public health officers are represented in Figure 24 below. A total of 82% of the respondents said the wells were attended by the public health officers only in case of an outbreak in the neighboring village, 17% the wells were not attended by the officer and 1% didn't answer the question.

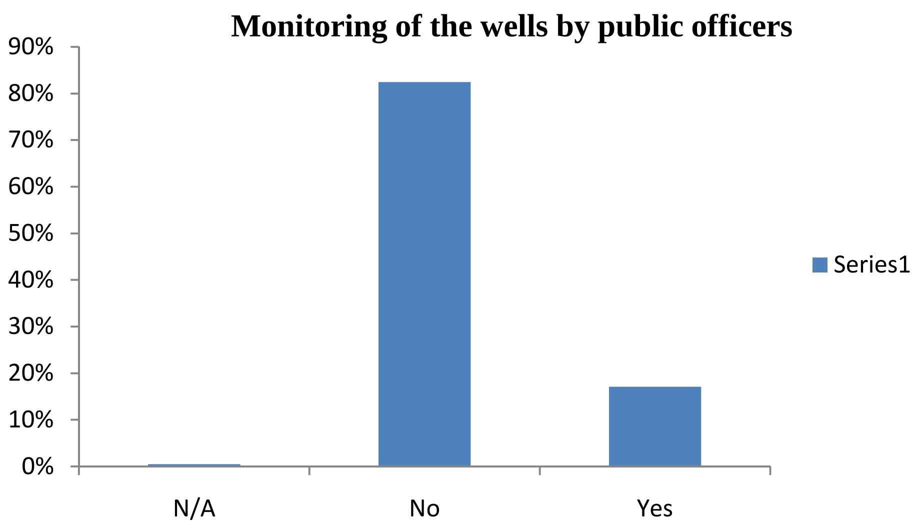

Figure 24: Monitoring of the wells by public health officers.

4.3.10 Contracting of Gastrointestinal Infections

A total of 82% have not contacted gastrointestinal infections, 17% have contacted the infection and 1% didn't answer the question (Figure 25**)**.

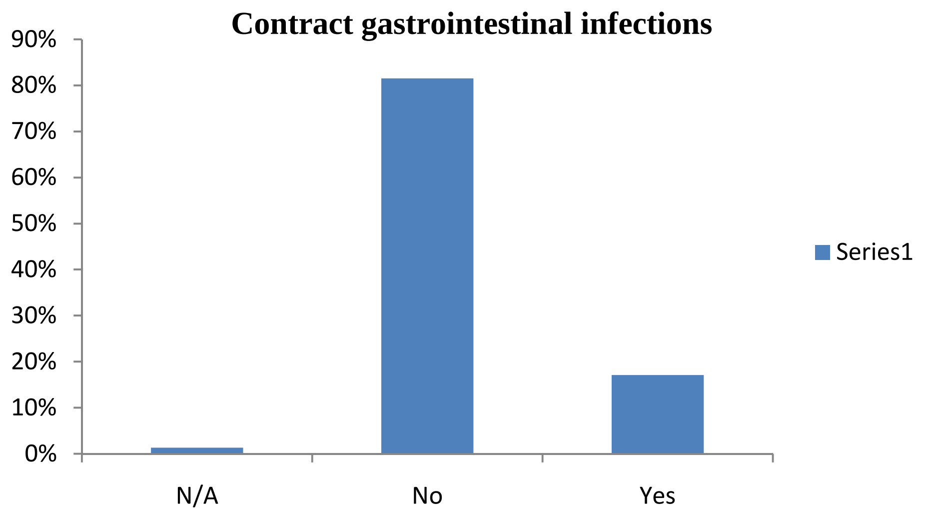

Figure 25: Contraction of gastrointestinal infections by the respondents.

4.3.11 Frequency of the Infections

The results of frequency of the infection are represented in Figure 26 below. A total of 87% said they haven't contacted the infection, 8% have suffered the infection once per year and 5% have been contracted the infection between 2-3 times per year (Figure 26).

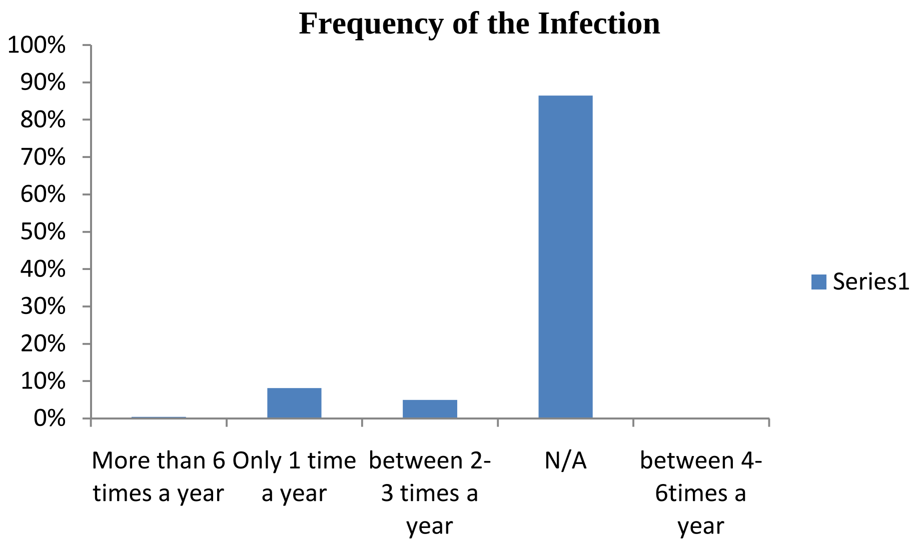

Figure 26: Frequency of the infections.

4.3.12 Boiling Water before Use

A total of 54% have not been boiling water before use perhaps could have been using chlorine tablet, 46% have been boiling water before use (Figure 27).

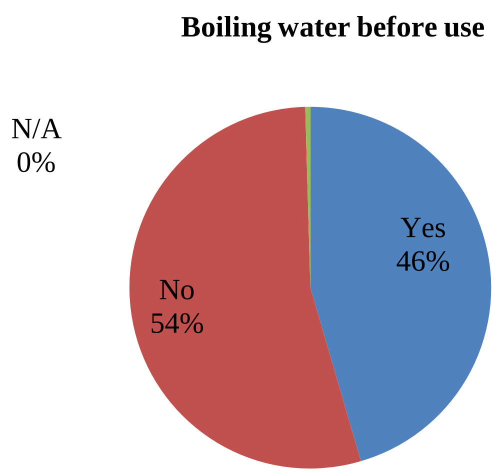

Figure 27: Boiling water before use.

4.4. WATER VENDORS QUESTIONNAIRE.

4.4.1 Shallow Wells of Choice

In the study area there were 12 Water vendors offering services to the residents of Mokowe village. A total of 12 questionnaires were prepared and administered to the 12 Water Vendors. The outcome of the survey was; 92% of the respondents have been harvesting water in Baoni the reasons being: Baoni well has substantial amount of water, low salinity levels and it takes time to dry, 2% have been harvesting water in Salim Hassan well the well is located close to them.

Shallow well usage by water vendor

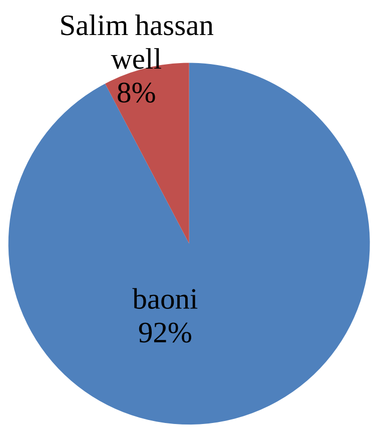

Figure 28: Shallow well usage by water vendor.

4.4.2 Choice of Wells.

A total of 92% of the respondents said Baoni well have been their main source of water and as its holds large volume of water. However, 8% said that Salim Hassan well has been their main source of water due close proximity to the households located at Majengo area (Figure 29).

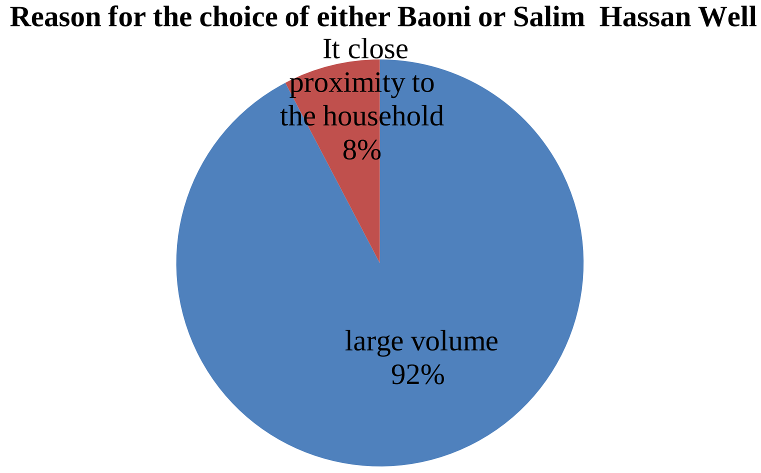

Figure 29: Reason for the choice of either Baoni or Salim Hassan Well.

4.4.3 Volumes of water harvested by vendor per day

The results of volumes of water harvested are represented in Figure 30 below. A total of 42% of the respondents have been harvesting water between 200-400L of water, 33% have been harvesting more than 800L of water, 17% have been obtaining 120-200L of water and 8% have harvesting 450-800L of water.

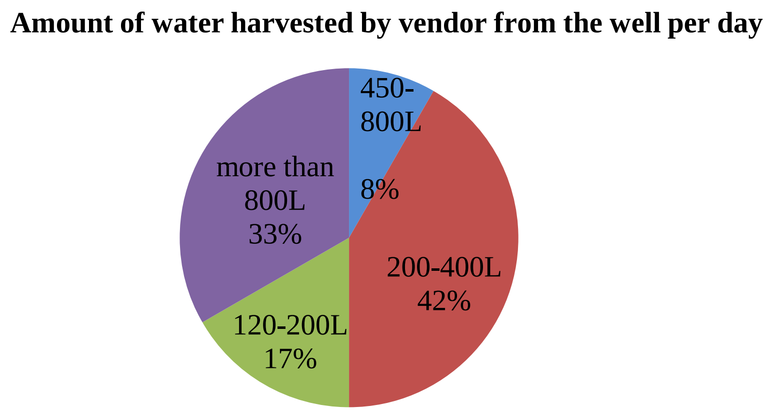

Figure 30: Amount of water harvested by vendors from the wells per day.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

The results showed that Shallow wells were found to be the main source of water at Mokowe village. A total of 91% of the respondents uses shallow wells as their main source of domestic water. More water sources should be created to avoid enormous pressure on the two main shallow wells which has led to drying of the wells.

This study examined the quality of water in shallow wells at Mokowe village in Lamu County and compared with water from Himwa tap. The finding shows that the water from the two main shallow wells was not safe for consumption. The bacteriological levels were very high beyond the permissible limits by NEMA, hence treatment is recommended before use. Some Physico-chemical parameter such as fluoride, magnesium and iron levels were below the acceptable limits by NEMA while the remaining parameters fell beyond the NEMA permissible limits for portable water standards. This can be amended by addition of coagulant in the treatment process. Himwa water was not safe for drinking owing to high levels of total coliform which is beyond the permissible levels. Treatment of water is recommended before use. Most of physicochemical parameters were within the acceptable limits except for sodium and nitrate which were beyond the acceptable limits, this can be amended by addition of coagulant such as alum. The distance between the pit latrines and the two wells was 11m.

The Public Health Officers should enforce set procedures for sinking wells and enhance enlightenment campaign on the danger of sitting shallow wells close to pit latrines. The government should ensure adequate and efficient public water supply through the provision of piped water.

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APPENDICES

APPENDIX1: Questionnaire targeting the residents of Mokowe village in Lamu County

The questionnaire was prepared for the partial fulfillment of my Master in Environmental Science and will not be used to solicit money. The interview process will be confidential and will not capture the particulars of a respondent. Your contribution will facilitate the study and the outcome will hopefully bring reforms to the residents of Mokowe village.

Please tick where necessary;

1. How long have you lived in Mokowe Village?

☐ Less than 2 years ☐ Between 2-5 years

☐ Between 5-10 years ☐ More than 10 years

2. What is the **main source** of water at Mokowe village?

☐ Boreholes ☐ Shallow wells

☐ Tap water ☐ Reservoir

If the **main source** of water is not tap water; go to **Question 4**.

3. If it is tap water is its supplying system reliable?

☐ Yes ☐ No

4. If **No** what is the alternative source of water? Tick all applicable

☐ Boreholes ☐ Shallow wells

☐ Other sources ☐ Water Point

If the alternative source of water is not the shallow wells go to **Question 9**.

5. For how long have you been using water in shallow wells?

☐ Less than 2 years ☐ Between 2-5 years

☐ Between 5-10 years ☐ More than 10 years

6. How do you access water from the shallow wells? Tick all applicable

☐ Through water vendor ☐ Fetch by yourself

7. Do you think the water from the shallow wells is safe?

☐ Yes ☐ No

8. Do you know if the shallow wells are attended by the Public Health Officer?

☐ Yes ☐ No

9. Have you experienced gastrointestinal infection?

☐ Yes ☐ No

10. If **YES**, how often do you get gastrointestinal infection?

☐ Only 1 time a year ☐ Between 2-3 times a year

☐ Between 4-6 times year ☐ More than 6 times a year

11. Do you boil or treat the water before use?

☐ Yes ☐ No

APPENDICES 2: Questionnaire targeting water vendor atMokowe village in Lamu County.

This part is specifically for Water Vendor

Which well do you harvest water mostly?

☐ Baoni   Salim Hassan ☐

Reason why you decided to harvest water from aforementioned well?

How many litres do you supply to household per day?

☐ 120-200L   200-400L ☐

☐ 450-800L   >800L ☐

Thank you so much for your cooperation