ASSESSMENT OF BOREHOLE WATER QUALITY AND CONSUMPTION IN YEI COUNTY SOUTH SUDAN

BY

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DISCLAIMER

I Likambo William declare that the contents in this study are of my own research, no part of it is plagiarized work and this thesis has not been submitted for a degree in any other University.

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DEDICATION

I dedicate this work to my son Adoke Samuel who was born during the course of this study and my Wife MaleniMarlen who was the source of courage to me.

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ACRONYMS

$(OH)^-$	Hydroxide
BGS	British Geological Survey
Ca^{2+}	Calcium ion
$CaCO_3$	Water Hardness as Calcium carbonate
Cfu	Colony Forming Units
Cl^-	Chloride ion
CO_2	Carbon dioxide
CO_3^{2-}	Carbonate ion
CU	Copper
DO	Dissolved Oxygen
DOC	Dissolved Oxygen Content
DS	Dry Season
DWAF	Department of Water Affairs and Forestry, South Africa
EPA	Environmental Protection Agency
F^-	Fluoride ion concentrations
FC	Faecal Coliform
Fe^{2+}	Low levels of Iron concentration
FeS_2	Iron sulfide
H^+	Hydrogen ion
H_2S	Hydrogen Sulphide
HCO_3^-	Bicarbonate ion
HNO_2	Nitrous Acid
IAS	International Aid Services
IWSSD	International Water Supply and Sanitation Decade
LCPD	Liters per person per capita per day
MDEQW	Michigan Department of Environmental Quality Water Division
MDG	Millennium Development Goals
Mg^{2+}	Magnesium ion
Na^+	Sodium ion
NGO	Non-Governmental Organization
NH_4^+	Ammonia
NO_2	Nitrogen dioxide
NO^{3-}	Nitrate ions
NO_3-N	Nitrate ion Concentration

NOC	Nitroso Compounds
pH	Acidity or Alkalinity of water
Pi	Pollution Index
PO_4^{3-}	Phosphate ion
SE	State of the Environment
SEI	Stockholm Environment Institute
SO_2	Sulphur dioxide
SO_4^{2-}	Sulphite ion
SSCCSE	South Sudan Centre for Census, Statistics and Evaluation
SSRRC	South Sudan Relief and Rehabilitation Commission
TC	Total Coliform
TDS	Total Dissolved Solids
UNEP	United Nation Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
V.I.P	Very Improved Pit Latrines
WGAASD	Water Global Annual Assessment of Sanitation and Drinking- water
WHO	World Health Organization
WS	Wet Season
WSTF	Water Sanitation Trust Fund.
WWDR	World Water Day Report
WWF	World Water Forum

ABSTRACT

The health risks associated with individual borehole water quality and quantity consumed is not clear for a third world nation like South Sudan. Spatial distribution of Physico-chemical and microbiological parameters were assessed from the rural and urban areas of Yei County in South Sudan. Water samples were collected and analyzed in the Wet Season (Mid June to July 2011) and Dry Season (February to Mid-March 2012). Factors affecting daily per capita borehole water consumption were also assessed.

The results showed that Physico-chemical parameters; pH ranged from (6.0-8.1) in the dry season, (5.5 – 7.5) wet season. Others all in (mg/L); TDS varied from (14 – 309) in dry season, (18.3-321.1) wet season; NO_3-N ranged from (0.000 – 3.8) in the dry season, (0.000-4.0) wet season, $CaCO_3$ (12-115) in the dry season, (12-111) wet season, Fe^{2+} ranged from (0.001 – 0.1) in the dry season, (0.001-0.1) wet season and F^- ranged from (0.12-2.01) in the dry season, (0.19-2.2) wet season. Micro-biological parameters; TC (cfu/100ml) ranged from (0-70) in the dry season, (0-100) wet season. FC ranged from (0-46) in the dry season, (0-75) wet season. All values increased in the wet season apart from pH that decreased. Urban boreholes produced slightly more acidic water than rural boreholes. Physico-Chemical parameters were not significantly affected by changing seasons (p>0.05) but had a significant effect on pH, TC and FC in the urban (p<0.05), while there was no significant effect in the rural (p>0.05). TDS, NO_3-N, $CaCO_3$, and F^- values were all far below the WHO standards of drinking water in both seasons with all significance levels (<0.01). TC and FC in drinking water varied significantly from WHO values (p<0.05). Rural areas had no intra variations in all the parameters for both seasons (p>0.05). There were significant inter variations in pH, TDS, NO_3-N, $CaCO_3$, F^-, TC and FC in both dry and wet seasons, all significances were ($p<0.05$). Distance from borehole, household size and changing seasons significantly affected daily per capita borehole water consumption (p<0.05). Consumption in Yei county varied from (4 – 23.8) in the wet season, (6.7 -29.5) dry season. Urban areas had higher amounts of consumption compared to rural. Households <500m from boreholes had higher daily per capita water consumption than those >1km away. It is therefore recommended to treat boreholes with pollution levels beyond the WHO limits. Survey of borehole drilling sites must be done prior to drilling to prevent areas of potential hazard to groundwater. There is need to increase accessibility to water resources.

CHAPTER 1: INTRODUCTION

1. Background

According to Chapman (1996) and BGS, (2001), groundwater is easily the most important component of the hydrological cycle, an important source of potable water in Africa and constitutes about two thirds of the freshwater resources of the world. Surface water is not evenly distributed or accessible to large sections of the global population (Diane, 2004; McDonald and Kay, 1988). Groundwater provides a reasonably constant supply for domestic use, livestock and irrigation, which is not likely to dry up under natural conditions thereby buffering the effects of rainfall variability across seasons (Hamil and Bell, 1986; Calow *et al.*, 2011). In many arid and semi-arid areas of Africa borehole water is a means of coping with water deficiencies in areas where rainfall is scarce or highly seasonal and surface water is extremely limited (David, 2011).

Boreholes sampled varied from 30m – 50m deep, but water was found in the levels between 7 to 20m. Dynamic water level is the level water drops to when the pump is operating due to draw down. Static water level is the level water rises due to infiltration and capillary action (IAS, 2008). Groundwater appears as vulnerable as surface water due to water table being near the soil surface and layers topping the table being permeable, and superficial sources of pollution being numerous (Boutin, 1987; Singh *et al.,* 2012). There is practically no geological environment at or near the earth's surface where pH will not support some form of organic life (Chapman, 1996). Pathogenic bacteria can survive long underground and may have a life span of about 4 years (Hamil and Bell, 1986). Boreholes and wells locally distort the natural flow field and create a path that opens up an additional possibility of heat and mass transfer between rock formations / aquifers, surrounding and atmosphere (Berthold 2010; Akpoveta, 2011). Indiscriminate waste disposal, poor agricultural practices, septic tanks, pit latrines and graves near boreholes, poor well construction, contribute to borehole water contamination (Sunnudo-Wilhelmy and Gill, 1999; Egwari and Aboaba, 2002; Lu, 2004; McHenry, 2011). These account for the presence of coliform bacteria in borehole water.

World population cannot be sustained without access to safe water (Braunstein, 2007). It is therefore important to conjunctly consider both water quality and quantity in water resources management (Xinghui *et al.*, 2009). Borehole water becomes unsuitable for domestic use as a resource due to contamination that makes it unfit (Holmes, 2007). The aim of water quality management is usually to minimize the health risks associated with either direct or indirect use of water (Udom *et al.,* 2002). Standards and guidelines in water quality stem from the need to protect human health (Minh *et al*., 2011). Contamination of water has increasingly become an issue of serious environmental concern after years of pollution (Akpoveta *et al*., 2011; Silderberge, 2003). Natural water contains many dissolved substances: contaminants such as bacteria, viruses, heavy metals, nitrates and salt have polluted water supplies due to inadequate treatment and disposal of wastes from humans and livestock, industrial discharges and over use of limited water resources (Singh and Mosley, 2003).

The World Health Organization (WHO) recommends that the minimum daily per capita water consumption to be 27 liters/person/day. However, many people manage with far less than 27 liters (Fraceys *et al.,* 1991). This could be because approximately 70% of the renewable water resources are unavailable for human use or under developed or unevenly distributed (Minh *et al*., 2011; Gleick, 1993). Drought, desertification and other forms of water scarcity are already estimated to affect as many as one third of the world's population, affecting consumption and migration patterns in many parts of the world (Talafre and Knabe, 2009). The increasing population pressure and rising demand for food and other services has increased demand for water (Nobumasa, 2006; Rodak and Silliman, 2011). This has increased reliance on groundwater resources thereby creating challenges among which are the provisions of adequate quantity and quality of water (WWDR, 2011). Those that are faced with a serious water shortage must either limit their use or make do with used untreated water (Clarke, 1991).

Water scarcity can stifle a nation's economy, fuel conflicts and negatively impact the environment (Minh *et al.,* 2011). However, borehole water development in Africa is seen as more amenable to poverty targeting than surface water (Kai and Jeroen, 2009; Xinghui *et al*., 2009). Moreover, it is a low cost option in the long run (Dhawan, 1991). According to (Jan *et al*., 1993), social-economic conditions improve through improvement of community water supply. This can be achieved through water security which is described as the outcome of the relationship between the availability, accessibility and use relationships (Calow *et al*., 2011). Accessibility to water reduces effort and time required to collect water hence reduction of workload on women, thus increasing the quantity of daily per capita water consumption thereby increasing production activities such as crop washing, especially small scale gardening (Cairncross, 1987).

Management is the uncertainty about the future availability of water (Minh *et al*., 2011). This uncertainty is because policy responses have concentrated on food needs and less on mobilization of resources for water interventions, despite evidence that access to safe water is of a serious and inter-related concern (Calow *et al*., 2011). The fact that water is not easily accessible to large sections of the global population defines the central management problem of borehole water resources (McDonald and Kay, 1988). Water resources policy should integrate equity, gender, efficiency and environmental consciousness (Weiwei *et al*., 2009). Women can play several complementary ways such as health educators and supervisors of water programmes. This improves the protection of public from water borne or related diseases since women are the primary providers of water at household level in Africa (SPIDER International Ltd, 1995)

Identifying the factors that affect domestic water quality and consumption is very important in management of available water resources (Keshavarzi *et al.,* 2006). This research endeavors to assess and identify anthropogenic, geographic and hydrological factors impacting borehole water quality and study the borehole water consumption patterns in the selected rural and urban areas of Yei County South Sudan.

1.1 Problem Statement

According to the WHO report (2010), South Sudan lacks adequate improved water resources, with only 40% of the water resources improved, thus 60% of the water resources are faced with pollution beyond the WHO maximum permissible limits. This inaccessibility to clean water poses a risk of water borne diseases as indicated by rampant water borne diseases like typhoid and diarrhea.

The World Health Organization recommends that the minimum daily amount of water per person should be 27litres. It is not clear how much water is explored per capita in Yei County; however it is obvious that many manage far less than 27 liters a day. Yei county had a population of 23,519 in

1983 and 201,443 people in 2010 (SSCCSE, 2010). This population is still increasing and according to Economy Watch 2011, the birth rate of Yei is at 2.14%.

The major source of water in Yei is borehole water, however, with this high birth rate coupled with high rate of refugee returnees, reliance on borehole water resources is increasing creating challenges of provision of adequate quality and quantity water. MDG.7C. Seeks to half the population of those without access to safe water. Yei County is in a crisis of increasing water scarcity coupled with poor water quality and communities reject some borehole water during specific seasons. There is a gap in knowledge of anthropogenic, geological and hydrological factors impacting on borehole water quality and the patterns of borehole water consumption to identify areas with water stress, and understand consumption patterns, like the effects of distance from the borehole, household size and changing seasons on daily per capita borehole water consumption.

1.2 Objectives

1.2.1 Main Objective

This study was aimed at assessing borehole water quality and consumption patterns in Yei County.

1.2.2 Specific Objectives

The specific objectives of this study were,

1. To examine seasonal variations in borehole water quality in the rural and urban areas of Yei County, South Sudan.
2. To assess the effect of distance from water source, household size and changing seasons on borehole water consumption in the rural and urban areas of Yei County, South Sudan.

1.2.3 Hypotheses

i. There is no significant variation of the selected physico-chemical and microbiological parameters of the borehole water from the WHO maximum permissible limits in the urban and rural areas
ii. There is no significant intra and inter seasonal variations of physico-chemical and microbiological parameters of borehole water in the rural and urban areas of Yei county.
iii. There is no significant effect of distance of household from the borehole, household size and changing seasons on the daily per capita amount of borehole water consumed.

1.3 Justification

According to the SSCCE (2010), boreholes and hand pumps provide up to 69.6% of the potable water in Central Equatoria State, with surface water providing 22.5% of the water needs of the communities, other water sources like rain and external supplies like tankers and piped water contribute about 8.9%. The population in Yei cannot be sustained without reliable access to safe water and adequate quantity. The high birth rate has led to increased reliance on borehole water. Many consumers rejected borehole water in specific seasons especially during the wet season, citing sudden change in water taste, appearance or odor, hence the need to determine quality in the dry and wet seasons. Wet Season analysis was done from Mid-June to July 2011 and Dry Season from February to Mid-March 2012.

This research will contribute to MDG 7c by determining water quality parameters and recommending for suitable action or creating awareness about water quality and water borne diseases. This research will also identify areas of water stress where less water is available for use, affecting the per capita consumption. The information from this research will be used to guide government agencies, researchers and other development organizations like NGO's to develop strategies, policies and institutional infrastructures to provide quality and accessible water resources to communities.

CHAPTER 2: LITERATURE REVIEW

2. GROUNDWATER

2.1. Ground water occurrence

The principle source of borehole water / groundwater is meteoric water, that's to say; (precipitation from rain, sleet, snow and hail), juvenile water and connate water (Gleick, 1993). Groundwater occurs in many geological formations. Nearly all rocks in the upper part of the earth's crust possess voids or pores filled with water or air; this is the vadoze / unsaturated zone. At greater depths, all empty voids are filled with water, this is the saturated zone, and hence groundwater refers only to the saturated zone below the water table. In consolidated rocks the only voids may be the fractures or fissures. The volume of water that will drain under gravity from initially saturated rock mass to the total volume of that rock is called the specific yield of that material. All water that occurs naturally beneath the earth's surface, including saturated and unsaturated zones is called sub-surface water (Chapman, 1996).

2.1.1 Host lithology

Groundwater occurs in association with geological materials containing soluble minerals; therefore its geochemistry varies with host lithology and level of aquifer (Railsback *et al*., 1996; Bruehl, 2011; Sanden *et al.*, 1986; Homsby, 1999). Low land area aquifers are large but water security is compromised by limited and poor quality surface water, restricted access to the aquifer via borehole and greater demand (Calow *et al*., 2011). Groundwater with low values of NO_3^-, Cl^- has zones characterized by confined aquifer conditions, while zones with higher DO, NO_3^- and seasonally variable Cl^- are characterized by unconfined aquifer conditions (Heejun and Kang-Kun, 1997). Limey soils and rocks release calcium ions to ground water. Materials bearing Iron Sulfide release iron. Granites may release Fluoride to groundwater. Connate and fossil water may contribute to Chloride in water. Ions all increase with depth while nitrate reduces with depth (Foster and Hirata, 1988).

2.1.2 Groundwater flow

Water aquifers are large in extent (1-10km) yet have variations in physical and chemical properties at small scales (1-l00m). This poses a challenge in predicting transport from a potential leakage source to the receptor (Sirila *et al.*, 2010). Transport of contaminants in soil is an important problem for different flow scales, from the fractured rocks to large underground aquifers (Hamrnon, 2011).

The rate, residence time and direction of groundwater flow, the movement of micro-organisms, pathogenic bacteria and viruses depends on the size of the pores on reactions within media, on the amount of food available and on their life span which affects its quality (Vladimir, 2003; Sanden, 1986). Deep, consolidated formations are characterized by slow groundwater movement, long residence times, ample opportunity for dissolution of minerals and therefore often poor natural water quality. These formations are confines under thick sequences of low permeability clays and are less vulnerable to anthropogenic influences (Chapman, 1996).

2.2. Groundwater quality

The quality of water is of vital concern for mankind since it is directly linked with human welfare. According to Ranjana (2010), the quality of public health depends to a greater extent the quality of groundwater. Though groundwater quality is believed to be quiet good compared to surface water, its quality is the sum of natural: geology of the environment and anthropogenic influences: withdrawal, land use change, and solid waste dumping (Chapman, 1996). Water quality parameters reflect the level of contamination in water resources and show whether water is suitable for human consumption. Contaminated water is unacceptable due to health effects, poor taste and aesthetic value to consumers (Suthra *et al.*, 2009).

2.2.1 Water Parameters

Physico-Chemical and Micro-biological parameters of water indicate the safety of potable water (Macdonald and Kay, 1986) and their analysis is important for public health and pollution studies (Kot *et al.*, 2000).

2.2.1.1 Physico- chemical Parameters

Temperature, pH, Colour, Turbidity, Total Dissolved Solids, Electrical Conductivity, Odour and Taste are the most important Physico-chemical properties of groundwater in relation to its quality.

pH is a measure of the hydrogen ion (H^+) available in water. The acidity of groundwater is due to the presence of organic acids in the soil as well as those of atmospheric origin infiltrated to the water (Chapman and Kimstach, 1996). Acid rain contains dissolved Carbon dioxide (CO_2), Nitrogen dioxide (NO_2) or Sulphur dioxide (SO_2) often yields an elevated Hydrogen ion (H^+) ion concentration and Carbonic acid (HCO) and may cause serious threat to groundwater pH (Hamil and Bell, 1986). The pH of rainwater is about 5.7 (Krauskopf and Bird, 1994). Increase in acidity is also attributed to the oxidation of reduced Sulphur compounds in the soils of the areas (Efe *et al.*, 2005). The pH affects the solubility and toxicity of metals by influencing chemical kinetics of important constituents. Other acids such as HNO_3, HNO_2 and humic acid are formed as a consequence of the decomposition of organic matter and sulphuric acid is produced when minerals such as pyrite (FeS_2) breakdown. High pH levels make water to become less corrosive (Gustafsson, 2003).

Alkalinity is a water characteristic that shows the capacity of water to neutralize acids by accepting Hydrogen ions (H^+) and preventing sudden changes in the acidity levels of water. Alkalinity is due to the presence of two forms of the Carbonate anions (HCO_3^-), ($CO_3^{2-)}$ and (OH^-) that act as buffer system (Chris, 2012). Borates, phosphates, silicates and other bases also contribute to alkalinity if present in groundwater. Inorganic ligands (anions) form complexes with metals (cations), this removes free divalent toxic metal ions such as Cd^{2+}, Cu^{2+}, Pb^{2+}, Zn^{2+} or methyl-metal complexes. Metal complexes are not biologically available and hence not toxic. Alkalinity is an important property when determining the suitability of water for other uses such as irrigation, or mixing with pesticides and when treating contaminated water. Alkalinity is measured in $CaCO_3$ mg/L. According to Fakoyode (2005), pH that is near to neutral (pH 7) is indicative of unpolluted water.

Carbon dioxide (CO_2) readily dissolves in water as illustrated in equation 1. The dissolved CO_2 (aq) reacts with water molecules to form Carbonic acid (H_2CO_3) as shown by equation 2 and Carbonic acid is very unstable and quickly dissociates into H^+ and a Bicarbonate ion (HCO_3^-) as demonstrated in equation 3.

At pH 6.3, the amount of CO_2 dissolved in water equals the amount of bicarbonate ion (HCO_3-). Dissolved carbon dioxide is dominant when pH is <6.3. At higher pH, basic water, HCO_3- dissociates to yield H^+ and a Carbonate ion (CO_3^{2-}) as per equation 4.

$CO_{2(g)} \leftrightarrow CO_{2(aq)}$ ……………………………………………………………………………(1)

$CO_{2(aq)} + H_2O_{(l)} \leftrightarrow H_2CO_{3(aq)}$……………………………………………………………(2)

$H_2CO_3 \leftrightarrow H^+ + HCO_3^-$ (pH 6.3)……………………………………………………..……………. (3)

$HCO_3^- \leftrightarrow H^+ + CO_3^{2-}$ (pH 10.3)……………………………………………………….………... (4)

At pH 10.3, the bicarbonate ion concentration equals the carbonate ion concentration. CO_3^{2-} is dominant at pH >10.3 and HCO_3^- dominates between pH 6.3 and 10.3. The pH of most natural water falls in the range of 6 to 9 because of the bicarbonate buffering (Chris, 2012).

Total Dissolved Solids: Total Dissolved Solids (TDS), is defined as the concentration of all dissolved minerals in the water. Natural waters contain a variety of both ionic and uncharged species in various amounts and proportions that constitute the Total Dissolved Solids (Agbaire and Oyibo, 2009). TDS in groundwater are due to enhancements of weathering of minerals from acids produced as byproducts of the degradation process. Hence TDS is a geochemical parameter that closely links the bulk conductivity to microbial degradation of hydrocarbon (Atekwanna *et al.*, 2004). High TDS, greater than 1000 mg/L, is commonly objectionable or offensive to taste.

TDS is a function of temperature and pH. At higher temperatures and lower pH groundwater dissolves more minerals. Sources of ion TDS include hard water ions (Ca^{2+}, Mg^{2+}, HCO_3^- and CO_3^{2-}), fertilizer in agricultural runoff (NH_4^+, NO_3^-, PO_4^{3-}, and SO_4^{2-}), urban runoff / salinity from tidal mixing, minerals or irrigation water (Na^+, Cl^- and K^-) and Acidic rainfall (H^+, NO_3^-, SO_3^{2-} and SO_4^{2-}).

Poor chemical quality of water is a health risk in the long term for consumers. Urban waste waters are often high in nutrients concentrations (macronutrients Na, Ca, P, K, Mg and micronutrients Fe, Zn, Cu,) and other chemicals which can stress the bacterial populations, in rainy seasons they are washed to the groundwater by infiltration (Thomas, 1995). The chemical composition of groundwater may be altered by the precipitation of ions from solution to form insoluble compounds.

Nitrate: Nitrate contamination of groundwater results from leaching of fertilizer, septic tank leachate, unsewered sanitation, pit latrines, animal waste or human waste mineralization of decomposing or oxidation of decaying matter by soil micro-organisms (Beauchamp, 2003; Spalding and Exner, 1993; Suthra *et al.*,2009). Unutilized urea leached to groundwater for micro-organisms to degrade is also another source of groundwater nitrate (Singh, 2012). According to USGS (2012), nitrate concentrations of greater than 3mg-N/L indicate a fairly direct connection of water with source of pollution.

Nitrate can readily be transported beneath the soil zone because it is relatively soluble and not prone to ion exchange (Stumm and Morgan, 1996). Nitrate can be endogenously reduced to nitrite, which can then undergo nitrosation reaction in the stomach with amines to form a variety of N-nitroso compounds (NOC). These compounds are carcinogens, thereby causing health hazards like impairing the ability of the blood to carry oxygen (Blue-baby syndrome or infantile methemoglobinemia), gastrointestinal cancer, Alzheimer disease, vascular dementia, adsorptive secretive functional disorders of the intestinal mucosa, multiple sclerosis, Non-Hodgkin's lymphoma and hypertrophy of thyroid (Suthra, 2009) and (Macdonald and Kay, 1986). In Aarlborg Denmark, water had a relatively high nitrate content of about 30mg/l and there was a slightly greater frequency of stomach cancer (Hamil and Bell, 1986). Nitrate contamination can be treated by technologies such as ion exchange; denitrification and reverse osmosis or anaerobic reduction in the subsurface which can limit Nitrate contamination of groundwater (Kapoor and Viraraghavan, 1997)

Calcium carbonate: Hardness refers to the ability of water to form suds with soap. Hard water leaves a ring in the bathtub, forms soap curds in clothing, and builds up scale in boilers and kettles (Wittmann *et al.*, 1998). Hardness is divided into two: Carbonate hardness Ca $(HCO_3)_2$ and non-Carbonated hardness Mg $(HCO_3)_2$. Non hardness is due to presence of salts such as Calcium Chloride ($CaCl_2$), Magnesium Sulphate ($MgSO_4$) and Magnesium Chloride ($MgCl_2$) (APHA, 1998; Burton and Pitt, 2002; Chris 2012). Any hardness greater than the alkalinity represents non-Carbonate hardness is measured as Calcium Carbonate mg/L. Hardness is classified as soft, moderately hard, hard and very hard (EPA, 1986). Areas with limestone formations have a higher hardness and alkalinity due to the dissolution of Bicarbonates and Carbonates. Calcium in groundwater is derived from Calcite, Aragonite, Dolomite, Anhydrite and Gypsum. In igneous and metamorphic rocks calcium is supplied by the feldspars, pyroxenes and amphiboles and the less common minerals such as Apatite and Wollastonite (Chris, 2012). Water hardness is an important component of water because it has a bearing on the portability of water. Water can be classified based on its hardness according to table 2.1. This helps to distinguish water for human consumption and other uses.

Table 2.1.Classification of water hardness as $CaCO_3$ mg/L (EPA, 1986).

Classification	**$CaCO_3$ equivalent (mg/L)**
Soft	< 75
Moderately hard	75 - 150
Hard	150 - 300
Very Hard	>300

Iron: Iron is not toxic, but imparts objectionable taste to water and may leave brown stains on porcelain and in clothing. Objectionable taste is due to reduced form (Fe^{2+} and HS), on exposure to air, water becomes reddish brown due to Ferric Hydroxide and prolonged consumption of such water may lead to liver disease (Ranjana, 2010). Largest contributors of iron in groundwater are minerals contained within the underlying bedrock, soil and sand, the most common is Ferrous Iron and borehole, limestone, shale and coal which often contain the Iron rich mineral Pyrite, acidic rain also releases Iron into groundwater (BGS, 2003; Lenntech, 2009). Iron content increases with depth (Dennis, 2002).

An aquifer in which groundwater is in a mildly oxidized state and a near neutral pH, the most likely Iron is Fe^{3+} and is tied up in solid phases (BGS, 2003). At a given temperature changing from their oxidized form / giving up of electrons (Fe^{3+} and SO^{2-}) to the reduced (accepting electrons) form requires a decrease in redox potential (dissolved oxygen) or a decrease in pH. Nitrate to Nitrogen gas, Fe^{3+} (insoluble) to Fe^{2+} (soluble), Sulphate to Hydrogen Sulphide and at very low redox potential, Methane formation occurs (Drever, 1982). Reduction / treatment of iron can be achieved by using a water softener, Potassium Permanganate or green sand filters and aeration (addition of oxygen to water) all aid in precipitation of Iron.

Salts may be concentrated in the groundwater as result of evaporation and transpiration. This depends on vegetative cover, warmth, soil type, and climate (Soveri, 1985).

2.2.1.2 Micro-biological parameters

Total and Faecal coliforms: According to Bodoczi (2010), the sanitary quality of water is appreciated by the presence or absence of pathogenic micro-organisms indicated by presence of coliforms. There is practically no geological environment at or near the earth's surface where pH will not support some form of organic life, also at this depth water pressures are not high enough to deter microbial activity (Chapman, 1996). Pathogenic bacteria can survive long underground and may have a life span of about 4 years (Hamil and Bell, 1986). Coliform group of bacteria are a large group of disease causing bacteria that inhabit intestine of man and animals (Sigh *et al.*, 2011). WHO (1985), specified that potable drinking water should be devoid of total and faecal coliforms in any given water source, MPN (maximum permissible number) of 0cfu/100ml.

Faecal Coliforms: Faecal Coli presence are the most reliable indicators of faecal bacterial contamination of surface and groundwater waters in different countries (WHO, 1989). Faecal coliform bacteria are bacteria found in faeces, they are subset of a larger group of organisms known as coliform bacteria which are facultative anaerobes that can survive in the absence of oxygen, gram negative, non-spore forming, rod-shaped bacteria that ferment lactose, producing gas and acid at about high temperatures of 35^{O}C. Human waste contaminant in water causes water borne diseases such as diarrhea, typhoid, hepatitis and flu-like symptoms such as nausea, vomiting, fever (FAO, 1995). High coliform counts in water samples are an indication of poor sanitary conditions in the community. According to Adekunle *et al*., (2007) and (Hamil and Bell, 1986) inadequate and unhygienic handling of solid wastes in the rural and urban areas leads to high concentrations of microbial organisms.

In 2006, the Environmental Protection Agency (EPA) published the ground water rule in the United States to keep microbial pathogens out of public water sources to reduce disease incidence associated with disease causing micro-organisms (EPA, 2012).

2.2.1.3 Categories used for water quality assessment

The microbial content is a very important water quality parameter because of its bearing on human health. Water can be classified based on microbial quality as shown in table 2.2; for human use safely.

Table 2.2. Classification of water micro-biological limits (DWAF,1996)

Parameter	**Good**	**Marginal**	**Poor**
TC	10 cfu.100 ml^{-1}	11-100 cfu.100 ml^{-1}	> 100 cfu.100 ml^{-1}
FC	0 cfu.100 ml	1-10 cfu.100 ml^{-1}	> 10 cfu.100 ml^{-1}

Cfu = colony forming units, good = fit for human consumption, poor = poses a health risk

1. Good (negligible risk of microbial infection; fit for human consumption)
2. Marginal (slight risk of microbial infection; must be treated before consumption)
3. Poor (risk of infectious disease transmission; not fit for human consumption)

2.3.1 Leaching of pollutants into groundwater

Leachate contains dissolved organic substances, chemically reduced inorganic substances like Ammonia, Iron, and Manganese which vary according to the hydrology of the site and the chemical and physical conditions within the site

The migration of contaminants is controlled by advection in the fracture, exchange between the fracture and the matrix, sorption and molecular diffusion in the low permeability matrix, organic content, saturation level of groundwater, pH, grain size porous matrix, iso-electric point of virus, colloids and bacteria in groundwater aquifers impact contaminant migration rates by either facilitation if they have a smaller retardation factor (Bekhit *et al.,* 2009; Parker *et al.,* 2008; John and Rose, 2005). The aquifer is eventually recharged by the influent seepage of surface water, so that some proportion of the pumpage from the borehole is now obtained from the surface source (Hamil and Bell, 1986; Christiansen *et al.,* 2008).

2.3.2. Contaminant transport in groundwater

The flow in ground water is generally slow and the response to surface and subsurface pollution loading is often gradual and contamination levels occur due to natural process of precipitation, infiltration and recharge to aquifers (Hammon, 2011; Homsby, 1999). Migration of dangerous contaminants and agrochemicals through the vadoze zone is a possible pollution pathway for vulnerable drinking water resources (Andricevic *et al.*, 2011). Table 2.3 shows the classification of land fill sites based upon their hydrology, this can be used by managers to identify appropriate sites used for filling of wastes that result to minimal or no ground water contamination.

However, borehole construction defects such as insufficient casing depth, improper sealing of the space between the casing and the borehole, corroded or cracked borehole casing and poor well seals or caps can allow sewage, surface water or insects to carry coliform bacteria into the borehole (MDEQW, 1999; Kinniburg and Edmunds, 1986).

Table 2.3. Classification of Landfill sites based upon their hydrology after Barber, (1982)

Designation	**Description**	**Hydrology**
Fissured site, or site with rapid subsurface liquid flow	Material with well developed secondary permeability features	Rapid movement of leachate via fissures, joints or through coarse sediments. Possibility of little dispersion in the groundwater or attenuation of pollutants
Natural dilution, dispersion and attenuation of leachate	Permeable materials with little or no significant secondary permeability	Slow movement of leachate into the ground through an unsaturated zone. Dispersion of leachate in the groundwater, attenuation of pollutants (sorption, biodegradation) probable
Containment of leachate	Impermeable deposits such as clay or shales, or sites lined with impermeable materials or membranes	Little vertical movement of leachate-. Saturated conditions exist within the base of the landfill.

2.4. Borehole site selection

Location of boreholes far from any source of potential pollution avoids water contamination (Akpoveta, 2011). Assessment of the type and loads of contaminants transported from landfill site to the adjacent aquifer and the extent of leachate plumes within the groundwater is used for site investigation and borehole positioning based on geophysical measurements and positioning based on the Bayesian expert system for flow field modeling (Abbaspour *et al.*, 2000).

2.4.1. Purification of groundwater by Soil

As water passes through fine grained porous media such as soil and rock, impurities are removed by filtration. Some substances react with minerals in the soil/rock and some are oxidized and precipitated from solution (Homsby 1999). Adsorption may also occur in argillaceous or organic material (Adekunle *et al.*, 2007).   According to Vladimir (2003), the capacity to retain, adsorb, detoxify and immobilize micro pollutants such as nutrients, organic chemicals and metals is not constant. Land use can impact soil retention potential for micro pollutants. High organic matter content in soil causes a high retention potential for micro-pollutants (Vegter, 1995). A higher organic matter content causes a high retention potential for micro-pollutants. There is a decrease in organic carbon when soil becomes barren (MacDonald and Kay, 1986). Movement of pathogens through unconsolidated strata to deep water supply wells is unlikely (Kinniburg and Edmunds, 1986).

Physical barriers can be used to contain groundwater contaminants of subsurface origin. The design of such barriers normally emphasizes the achievement of low hydraulic conductivity to reduce advective contaminant transport (Hillel and Rabideau, 2000).

2.4.2. Recommended distance between domestic water wells and sources of pollution

Ground water pollutants have the ability to move through soil particles to the groundwater, soil purification processes can break thus rendering groundwater highly susceptible to pollution. Hence the need to locate boreholes and wells at recommended safe distances from potential contaminants as in Table 2.4.

Table 2.4.Safe distance between boreholes / wells and source of contaminants (Romero, 1970).

Source of pollution	**Distance (m)**
Septic tank	15
Latrines	45
Cemetery	250
Sewage farms	30
Infiltration ditches	30
Percolation zone	30
Pipes with watertight joints	3
Other pipes	15
Dry wells	15

2.5. Impacts of consuming contaminated water

Impact of water borne diseases on children is greater than the combined impact of HIV/AIDS, tuberculosis and malaria (WGAASD, 2010). Many people drink borehole water without any form of treatment, because of lack of access to basic methods of water treatment and ignorance of hazards associated with the ingestion of contaminated water (Anaele, 2004).

Several cases of infections due to consumption of contaminated water by pathogenic bacteria have been reported in many parts of the world, sometimes causing epidemics followed by loss of human life (Angulo *et al.*, 1997). In the 19th C in Britain, it was a common practice to obtain groundwater and to dispose off sewage via earth closets; this resulted into contamination of groundwater and outbreak of cholera. Typhoid broke out in Corydon, after an infected workman defecated into a borehole, while chlorination equipment broke down. Yorkshire was affected by gastroenteritis in 1980 as a result of the Braham borehole becoming contaminated by leaking sewer and a polluted surface stream which passed within 8m of the well (Angulo *et al.*, 1997). At least 30,000 people per day die in the third world because they have inadequate water and sanitation facilities (United Nations, 2010). The control of water pollution in developing countries is a necessity.

2.6. Impact of Dry and Wet Seasons on groundwater Quality

Seasonal variations change the aesthetic quality of the water and bring discomfort amongst consumers. Seasonal variations in water quality arise due to variations in ecological activity, precipitation and geology of the area. Artesian boreholes / rock wells constructed in unconsolidated sediments tend to respond slowly to rainfall, possibly several days or weeks later because of the poor permeability of the confining layer (MGS, 2012). When boreholes penetrate fractured material in an area of thin overburden, they respond quickly to percolated water from the rain (Singh *et al.*, 2012). The eco-system, characteristics of the surrounding area, residence time and geological characteristics affect the physico-chemical and micro-biological seasonal variations of groundwater parameters (Howarth and McGillivray, 2001; Sanden, 1986).

2.7. Need for Groundwater exploitation

Boreholes and wells are groundwater types that form an integral part of water supply systems in rural and urban areas especially in Africa, and therefore are indispensable because of inadequate public water supply systems (Pickering and Owen, 1995; MacDonald *et al.,* 2005; Calow *et al.*, 2010). Over one billion people lack access to clean safe water worldwide, up to 300 million rural people in Sub Sahara Africa have no access to safe water supplies and this is on the rise (NAS, 2009). There is an increasing demand for large amounts of water as health and sanitation improve (Agnew and Anderson, 1992). Without safe water near households, the health and livelihood of families can be severely affected (United Nations, 2010; MacDonald *et a*l., 2005). Borehole water use is associated with a lower childhood risk to diarrhea compared to surface water in Bangladesh (Wu *et al*., 2011). To solve such issues relating to water borne diseases, boreholes can provide safe and convenient water supply since it is evenly distributed, affordable with quiet good quality and not affected by seasonal changes hence its sustainable(Cloutier and Rowley, 2011; Akpoveta, 2011; Adekunle *et al.*, 2007). The only realistic option for meeting rural water demands is through groundwater exploitation (MacDonald *et a*l., 2005). A large population of the world especially in sub-Sahara Africa depends on groundwater as their main source of domestic water (Sha, 2004), this is because it is accessible anywhere, less capital intensive to develop and maintain and is less susceptible to pollution and seasonal fluctuation, naturally has good quality (Bresline, 2007)

Water resources availability is of significance to regional social-economic development and is seen as a limiting factor in human development (Xinghui *et al.,* 2009; McDonald and Kay, 1988; Clarke, 1991). Groundwater plays a vital role in the development of arid and semi-arid zones (Ranjana, 2010) and its development especially borehole water in Africa is seen as more amenable to poverty targeting than surface water (Kai and Jeroen, 2009). A greater proportion of household income may need to be spent on water delivered from private sources, such as tankers to supplement lack of water locally (Sirila *et al.,* 2010).

2.7.1 Water security

Water security mapping can help identify vulnerable areas and changes to monitoring systems can ensure early detection of pollution problems (Akpoveta, 2011). Water security includes efforts in reduction of effort and time required to collect water, reduction in workload of women, improvement of availability of water, increasing the quantity of water consumed per capita per day and increasing production activities such as crop washing especially small scale gardening as social conditions which could be improved by developing community water supply (Jan *et al.,* 1993). Increasing the coverage of groundwater based rural water supplies can significantly increase the reliance of rural communities to climate variability (Calow *et al.,* 2011).

2.7.2 Borehole water Availability and Accessibility

About 70% of the earth's surface is covered by water, of all the water on earth approximately 3% is fresh water and less than 1% of the world's fresh water is accessible for human use (Suthra *et al.,* 2009). Water shortages and difficulties in accessing water affect domestic and productive livelihoods of communities. Proximity to water resources increases per capita consumption and encourages water use for vegetation and fruit production **(**Lane and Robinson, 2002). Therefore, there is need to increase reliability of sources by improving water coverage and prioritizing vulnerable areas (Calow *et al.,* 2011).

The world is facing a water crisis and it is indispensable that there is not enough clean water available to meet today's populations' needs (Agnew and Anderson, 1992; WWF, 2000; Evan and Slobodan, 2011). Access to adequate supplies of good quality drinking water continues to be limited among many rural and peri- urban communities of Africa, despite several years of water improvement programmes (Musa *et al.,* 1999; Mireille*et al.,* 2011). Climate change alters hydrological cycle ranging from evaporation, precipitation, runoff, groundwater to re-charge, decreasing seasonal rainfall trends (McGuire *et al*., 2002; Akpodiogaga and Odjugo, 2010; (Edet *et al.*, 2011). The trend of the world per capita water consumption is decreasing as population grows due to limited and depletion of water resources (Nobumasa, 2006). This crisis results into concentration of users around the limited sources of water, thus increase in contamination and transmission of water borne diseases (Edet *et al.*, 2011).

2.8. Integrated water resources Management.

Over 2.6 billion people are not using improved sanitation and nearly 900 million people are not using an improved source of drinking water worldwide (WGAASD, 2010). According to the WHO report (2010), South Sudan lacks adequate improved water resources, with only 40% of the water resources improved, thus 60% of the water resources are faced with severe pollution.

Water is monitored and managed so that development may be sustained over a long term through provision of adequate and quality water (Mitchell, 1990; Lu, 2004). Awareness of increasing water scarcity has driven efforts for improved water resources infrastructure and management strategies, hence global modeling of water resources in terms of supply and demand (Evan and Slobodan, 2011; Silliman and Rodak, 2011). Changes on earth surface were negligible until population numbers started to increase (Goldewijk, 2000; Lu, 2004). Fresh water is no longer taken for granted as a plentiful and always available resource. The issue is developing effective water management tools which enable us to match local water supply and demand in terms of both quality and quantity (Shafique *et al,* 2001; Qin and Xu, 2011; Jeffrey, 2000).

The results of groundwater quality are representative of the actual site conditions and interpreted in the context of those conditions thus, groundwater pollution is site specific (Zemansky, 2000; Homsby 1999). In management of boreholes, identification of factors that contribute to groundwater contamination is important in reducing the risks posed by them (Ellap and Komur, 2007; Vanclooster. 2005; Rosenbom *et al.*, 2009). The quality of water is to be determined and if contaminated disinfected before use (Miranda *et al.*, 2011; Hamil and Bell, 1986).

Policy responses have concentrated on food needs and less on mobilization of resources for water interventions, despite evidence that access to safe water is a serious and inter-related concern (Calow *et al.*, 2011). Water resources policy on planning and allocation should integrate equity, efficiency and environmental consciousness. A stable water rights system should be strengthened in multi dimensions, focusing on security and flexibility to be an effective incentive for development and conservation of water resources (Weiwei *et a*l, 2009).

Community participation in the planning of water services delivery in rural community is vital in meeting water needs because their expectations are met (Koekemoer, 2009; Sirila *et al.,* 2010; Talafre and Knabe, 2009).

Gender inequality is manifested through women's lower status, income, power in making decisions, opportunities, and access to education services / resources when it comes to water and sanitation (WSTF, 2009). A successful management of water resources can be achieved with full involvement of women in several complementary ways such as health educators and supervisors of water programmes (Jan *et al*., 1993; SPIDER International Ltd., 1995).

CHAPTER 3: MATERIALS AND METHODS

3. MATERIALS AND METHODS

3.1 Study Area

Yei is a county in the Central Equatoria State of South Sudan. Its geographic coordinates are 4° 6' 0.00"N, 30° 40' 12.00"E (Latitude: 4.1000; Longitude: 30.6700). Its altitude ranges from 600 to 3000m above sea level. The terrain of Yei consists of mainly flat plateau with medium mountains. Yei River flows across the county to meet the various water needs of the people. The climate is tropical and the annual rainfall varies from 700 to 1300mm of rainfall. Yei has two rainy seasons, the first starts from April to July and the Second from August to December. The average daily temperatures vary between 25^{o}Cand 35^{o}C.

In 2010 Yei had a population of 201,443 people (SSCCE, 2010). This number is still increasing due to the high rate of refugee returnees coupled with the high birth rate of 2.14% (Economy Watch, 2011). Fig 3.1 below shows the map of Yei County located in Central Equatoria State, Republic of South Sudan.

3.1.1. Location of Yei County

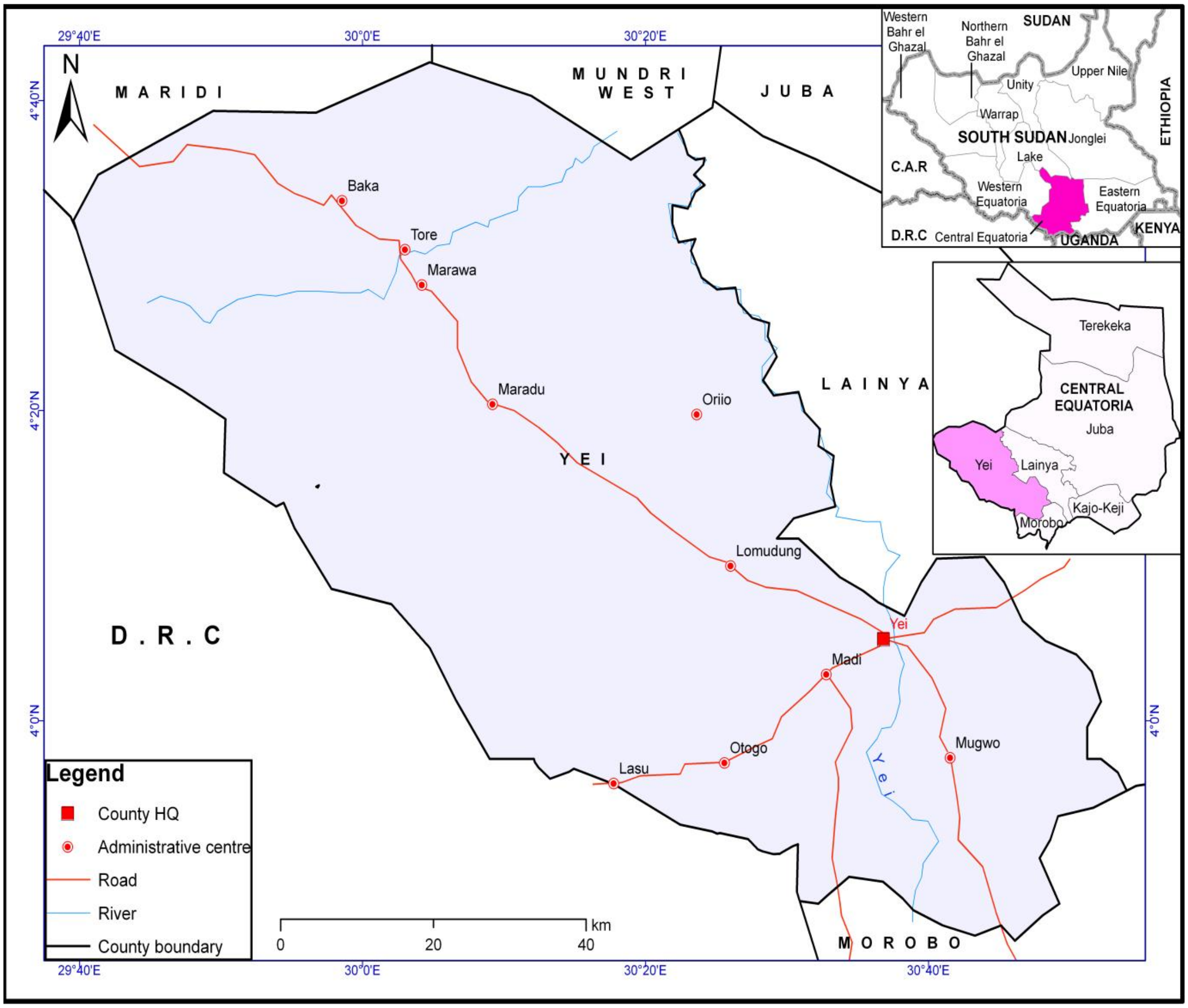

Fig 3.1. Map of Yei County, South Sudan (UNDP)

3.1.2 Sample site selection

The figure 3.2 shows the schematic description of sample site/borehole selection across the Payams in Yei County. A Payam in South Sudan is an equivalent of a County in Uganda.

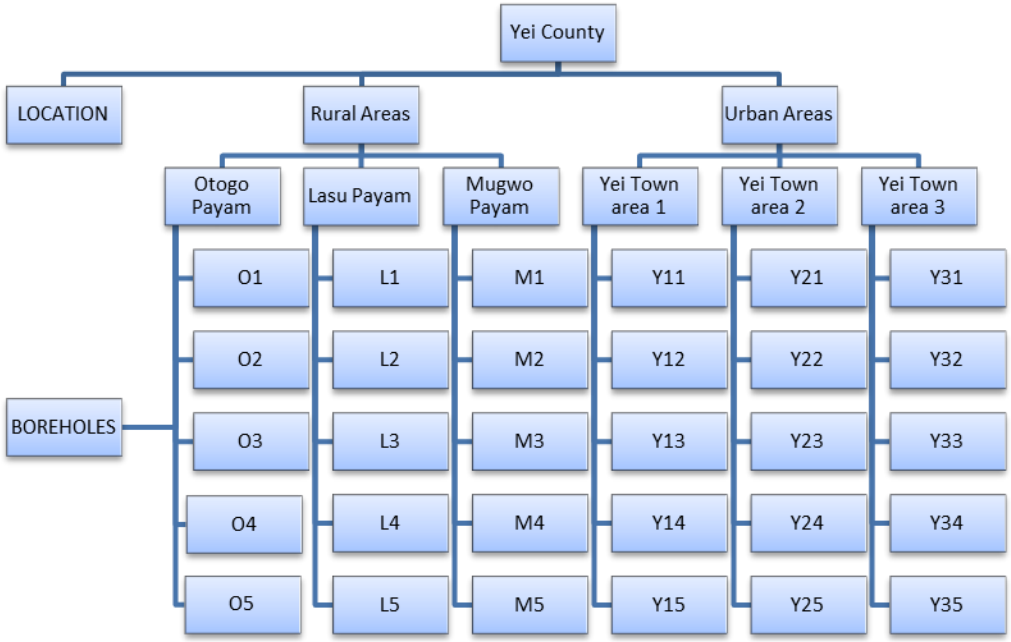

Fig 3.2. Schematic description of sample site selection

3.1.3 Population Distribution across Yei County

Population density or population distribution across the land criterion was used to determine rural and urban areas. Yei County has five payams, three rural payams were randomly chosen and one urban Payam was purposively chosen using the population density criterion. Table 3.1 shows the population density of the payams in Yei County as per 2010 statistics.

Table 3.1 Population density in each Payam in Yei County, (SSCCE, 2010)

Payams in Yei county	**Population**	**Area (sq.km)**	**Density (people/sq.km)**
Otogo	28986	1048.7	27.6
Lasu	15676	1889.8	8.3
Mugwo	21735	1145.6	19.0
Yei Town	111268	987.87	112.6
Tore	23778	1595.7	14.9
Total	**201443**	**6667.67**	**30.2**

Three (3) Payams: Otogo (27.6 people per square Km), Lasu (8.3 people per square Km) and Mugwo (19 people per square Km) were chosen to represent the rural Payams. Yei town was densely populated with a vast majority living there (112.6 people per square Km), therefore it was chosen to be the urban Payam. Since Yei town was the only area that was densely populated, it was divided into 3 parts i.e. Yei Town area 1, Yei Town area 2 and Yei Town area 3. Simple random sampling was used to select fifteen (15) boreholes from the rural and fifteen (15) from the urban. Five (5) boreholes from each of the 3 rural payams and five (5) from each of the 3 areas of the urban Payam were selected for sampling.

3.1.4 Mapping of the Study area

Garmin GPS 60 was used to obtain geographic co-ordinates of each borehole. ESRI ARC GIS version 9.3 was used to map study area and sampling points in Yei County.

3.1.5 Sample sites and areas of data collection

The figure 3.3 is a map of Yei county showing the locations of various rural and urban boreholes selected for this study. The boreholes are named according to their respective villages.

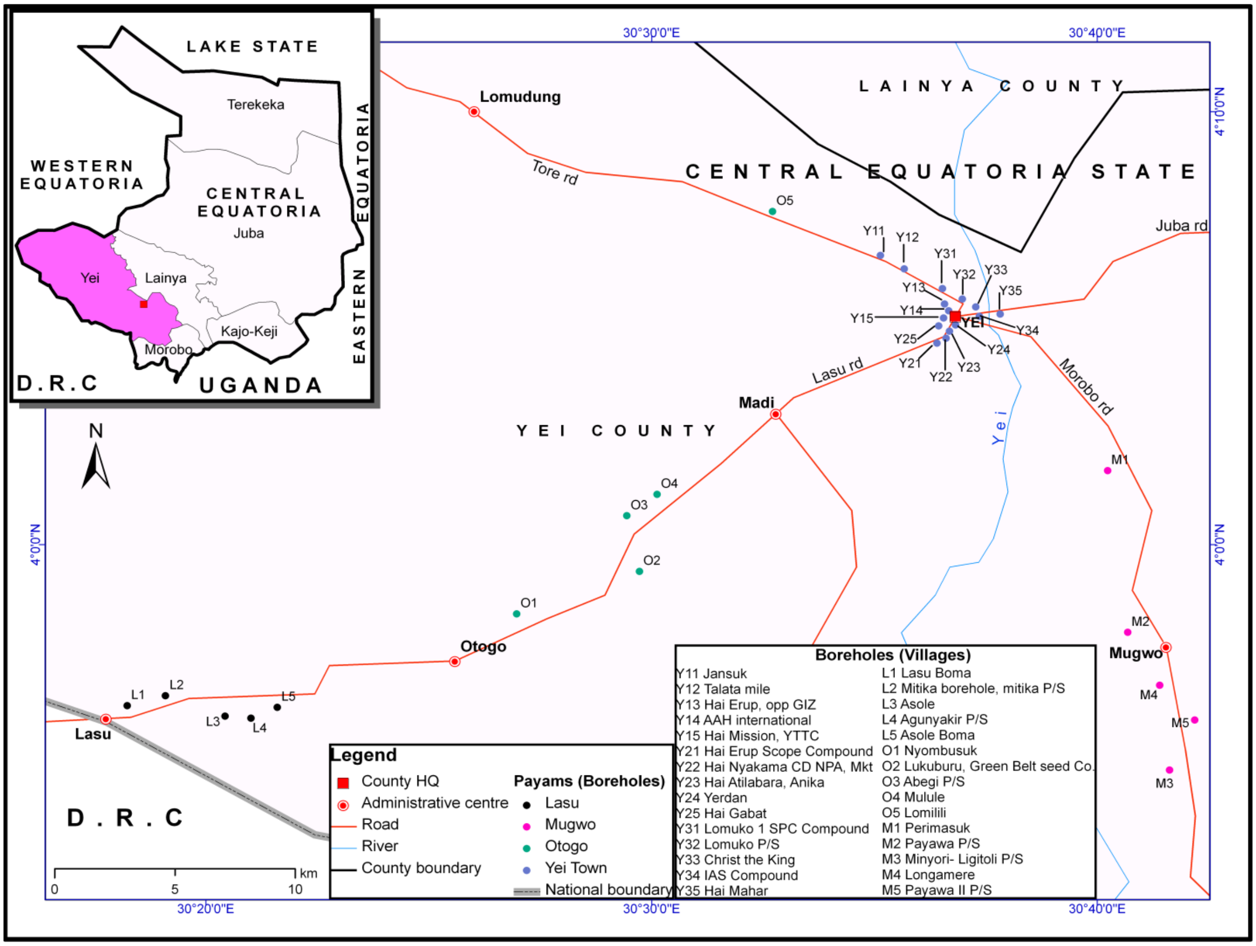

Fig 3.3 Map of Yei County showing selected boreholes

3.2 Determination of seasonal variations in borehole water quality

3.2.1 Collection and Preparation of Samples

Each borehole was flushed for 3 minutes to remove any externally induced contamination. The borehole taps were disinfected with Sodium Hypochlorite (NaOCl) and neutralized with Sodium Thiosulphate ($Na_2S_2O_3$) to eliminate any contamination due to anthropogenic activity or any external natural occurrence.

Glass water bottles (250mls) were sterilized by addition of Sodium Thiosulphate (0.1ml). The boreholes were then pumped to fill the water bottles leaving an air space of 2.5cm to create space for oxygen such that organisms do not die before testing in the laboratory. The bottles were marked for identification using the labels for each borehole. The bottles were then transported to the laboratory in an insulated box to prevent external factors like high temperatures from changing some of the water parameters. Analysis commenced within 12hrs of sampling (APHA, 1998).

3.2.2.1 Physico-chemical Analyses

The Physic-Chemical parameters pH and Total Dissolved Solids (TDS in mg/L) were measured.

A multi-purpose pH meter model D46 (pH/MV/^{O}C meter) was used to determine the pH of the borehole water. TDS meter - 4-HMD was used to determine the Total Dissolved Solids in borehole water. All the physical parameters were measured on site. Each borehole was pumped for about 3 minutes to flush out the water that had got external influence. The borehole was then pumped to fill a bucket. These parameters were all measured by dipping the respective instruments into the bucket.

Nitrate (NO_3-N), Calcium hardness as Calcium Carbonate ($CaCO_3$), Iron LR, and Fluoride (F^-) were the Chemical parameters analyzed using the Wagtech test instructions. Palin test kit and Wagtech photometer 5000 was used to determine the frequency readings. Respective calibration charts were then used to determine concentrations of these parameters.

Water samples were analyzed in the laboratory of IAS, Yei office. All parameters were measured on the same day of sampling. Some safety and complementary instructions were also got from (APHA, 1998).

3.2.2.2 Micro-biological Analyses

Indicator organisms Total coliforms and Faecal Coliforms in colony forming units/100ml (cfu/100ml) were analyzed from the water bottles named in 3.2.2 using Wagtech Potalab 2 (APHA, 1998).

3.2.2.3 Quality Control

The quality parameters were analyzed in triplicate to yield a mean that showed the trueness (Valcarel, 2000). Analytical quality control was ensured by blanks and standard solutions which ensured the accuracy and reproducibility of the results (Akpoveta *et al*., 2011)

3.3.0 Determination of seasonal variations in borehole water consumption

The data for this study was collected from a survey of households who obtained their water from the boreholes both in the rural and urban using a structured questionnaire (Appendix 18). For each borehole, ten (10) households were randomly selected using simple random sampling criteria. Five households were less than 500m from the borehole and five were more than 1km from the borehole. The questionnaire addressed seasonal domestic borehole water use patterns, characteristics such as gender, age, employment levels which depicted income, education levels and household size.

Purposive sampling was used to identify key informants. These included County Water Department officials, Borehole water committees, Public Health Centre (PHC) and Public Health Unit (PHU) workers, and Payam chiefs. Key informant interviews were held to get information about the distribution of boreholes across Yei County, waterborne diseases related to consumption of borehole water and per capita water consumption.

3.3.1 Calculation of Daily per capita borehole water consumption (LCPD)

Equation 5 shows the equation used for calculation of daily per capita borehole water consumption (Keshavarzi *et al.*, 2006).

$$\text{Liters/person/capita/day (LCPD)} = \frac{\text{Liters consumed in household/da}}{\text{Household size (No.)}} \quad \text{.. (5)}$$

3.3.2 Design of Survey

Three hundred households in Yei County that obtain their water from boreholes were surveyed. The rural and urban Payams each had One hundred fifty (150) households interviewed. Figure 3.4 shows schematic description of the design of the survey for borehole water consumption.

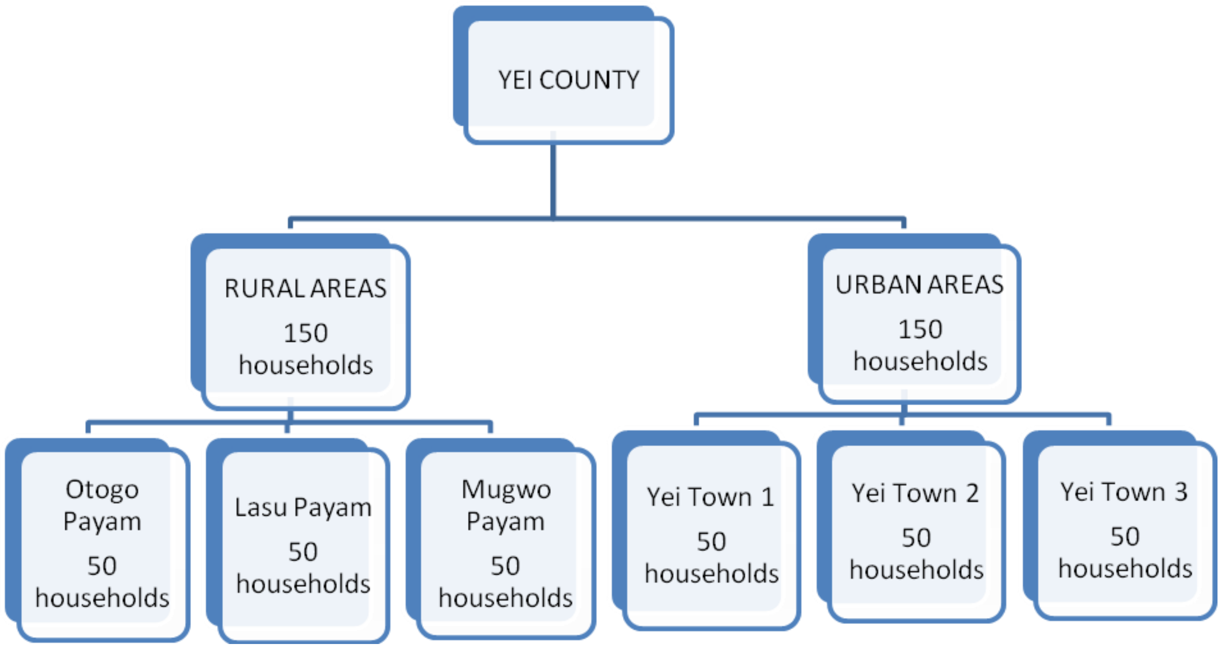

Fig 3.4 Schematic design of the survey

3.4 Data Analysis

3.4.1 Level of pollution analysis using Pollution Index (Pi)

Pi was used to show the level of pollution of borehole water by each parameter. The critical value being 1.0 and values greater than 1.0 indicate significant degree of pollution while values less than 1.0 show no pollution/ danger of pollution (Akpoveta *et al*., 2011).

Pollution index (Pi) according to Akpoveta *et al.* (2011) is expressed as a function of the concentration of individual parameter values against the baseline standard (WHO permissible value). It is given as below in equation 6.

$$\text{Pollution index (Pi)} = \frac{\text{Concentration}}{\text{Standard}} \ldots\ldots\ldots\ldots \quad (6)$$

The statistical significance of pollution was then affirmed by T test one sample analysis, to compare each parameter value with the WHO permissible standard for drinking water (WHO, 1985). Classification of water hardness as calcium carbonate and micro-biological pollution levels categorized by (EPA, 1986) and (DWAF, 1996) respectively were also used to analyze the pollution levels of borehole water in the different localities.

3.4.2 Intra variation data analysis

One Way ANOVA was used to compare the spatial variations of physico-chemical and micro-biological parameters within the rural and within the urban for both seasons.

3.4.3 Inter variation data analysis

T test 2 sample analysis was used to compare the spatial variations of physico-chemical and micro-biological parameters in the rural with those from the urban and also determine the statistical inter seasonal (dry and wet) on borehole water parameters.

3.4.4 Impact of distance of household from borehole on daily per capita water consumption

Genstat vr 13.3 ANOVA general treatment structure (no blocking) was used to show the statistical effect of distance from the borehole on per capita water consumption.

3.4.5 Impact of household size on daily per capita water consumption

Simple regression analysis was used to show the statistical effect of household size on the daily per capita consumption of borehole water. All statistical statements reported are at the $P<0.05$ levels.

R^2 gives the percentage of variance in the dependent variable (daily per capita consumption) which is predictable from the independent variable (Household size). It shows the extent to which independent variable can predict the dependent variable. The closer the R^2 is to 1.0 the better the fit of regression line and greater the effect of the independent variable on the dependent variable or the better the explanatory power. These regression trend lines can be used to predict effect of population increase on per capita water consumption.

3.4.6 Impact of changing seasons on borehole water consumption

T test 2 sample analysis was used to compare the effect of dry and wet seasons on daily per capita borehole water consumption.

CHAPTER 4: RESULTS

4.1 Introduction

This chapter focuses on the results and discussions of the data collected from the seasonal borehole water quality and consumption patterns in Yei County. The Physico-Chemical parameters analysed included pH and TDS. The Chemical parameters included Nitrates (NO_3-N), Calcium hardness as Calcium Carbonate ($CaCO_3$) and Iron (Fe^{2+}). The Micro-biological parameters included Total Coliform (TC) and Faecal Coliform (FC).

The results on borehole water consumption focused on the impacts of distance to the boreholes, number of house hold members and seasonality on daily per capita consumption in liters per person per day. Generic information about sex, age groups, education levels and kind of employment was also derived from the questionnaire. The results of the rural areas were compared to those in the urban to determine the impact of population density or urbanization on borehole water quality and consumption.

4.1.2 Summary of Physico-chemical and Microbiological parameters

Physico-chemical parameters; pH reduced during the wet season, and the urban areas produced more acidic borehole water compared to the rural areas. Total dissolved solids increased during the wet season, with the urban boreholes producing water with higher values compared to the rural. Nitrate, Calcium Carbonate and Iron concentrations in borehole water all increased during the wet season. However, unlike other chemical parameters, Calcium Carbonate concentrations in the rural areas were greater than those in the urban areas. *Micro-biological parameters*; Total coliform and Faecal coliform bacteria count in borehole water increased during the wet season. The wet season had higher counts in both parameters compared to the dry season (Table 4.1).

Table 4.1 Summary of the Physico-chemical and Microbiological parameter results

	Location	**Dry Season**			**Wet Season**		
Parameters		**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**	**Mean**
pH	Rural	6.7	8.1	7.4	6.3	7.5	7
	Urban	6	7.8	6.9	5.5	7.3	6.5
TDS (mg/L)	Rural	14	223	97.6	55.5	230	113.1
	Urban	44.8	309.6	144.9	49.1	321.1	156.7
Nitrate (mg/L)	Rural	0	2.61	0.331	0	2.8	2.369
	Urban	0.002	3.8	1.157	0.015	4	1.257
Calcium carbonate (mg/L)	Rural	39	115	74.3	46	111	79.4
	Urban	12	98	52.9	12	110	58.2
Iron (mg/L)	Rural	0.002	0.07	0.027	0.002	0.1	0.031
	Urban	0.001	0.1	0.017	0.001	0.103	0.022
Fluoride (mg/L)	Rural	0.15	1.2	0.56	0.19	1.5	0.68
	Urban	0.12	2.01	0.98	0.19	2.2	1.1
TC (cfu/100ml)	Rural	0	30	6.5	0	40	9.6
	Urban	15	70	37.4	20	100	54.7
FC (cfu/100ml)	Rural	0	12	2.6	0	21	4.5
	Urban	5	46	19.7	12	75	34.3

4.2 Intra Variations of borehole water parameters

4.2.1 Physico-chemical Parameters

One way ANOVA was used to find the statistical variation of parameters within the rural and within the urban areas of Yei County.

The (Table 4.2.1) below shows statistical variations of Physico-Chemical parameters within the rural and within the urban in the same season. This was to show significant differences of these parameters in borehole water spatially and identity immediate impacts on borehole water quality.

Table 4.2.1 Statistical variations in Physico-chemical parameters within the rural and within the urban

	Rural Areas		**Urban Areas**	
Variate	F probability (0.05)		F probability (0.05)	
	Dry Season	Wet Season	Dry Season	Wet Season
pH	0.376	0.352	0.389	0.490
TDS (mg/L)	0.276	0.246	0.723	0.719

4.2.1.1 Intra Variations in the rural areas

From the one way ANOVA (Table 4.2.1), the statistical variation of the selected Physico-chemical parameters in rural areas during the dry and wet season were all $p>0.05$. Therefore there was no statistical difference of Physico-Chemical parameters within the 3 rural areas (Otogo, Lasu and Mugwo) during the dry season and also during the wet season. The dry season had no effect on the spatial variation of physical parameters in the rural areas. The wet season had no significant effect on variation of pH and TDS in the rural areas.

4.2.1.2 Intra variations in the urban areas

The statistical variation of the selected Physico-Chemical parameters within the urban areas during the dry and during the wet season were all $p>0.05$. Therefore there was no statistical difference of Physico-chemical parameters within the 3 urban areas (Yei Town area 1, Yei Town area 2 and Yei

Town area 3) during the dry and wet seasons. Figures 4.2.1a and 4.2.1b show intra and inter spatial variations in physical parameters of borehole water in the rural and urban areas for both seasons.

4.2.1.3 Intra and Inter seasonal variations of Physico-chemical water parameters assessed in the rural and urban areas

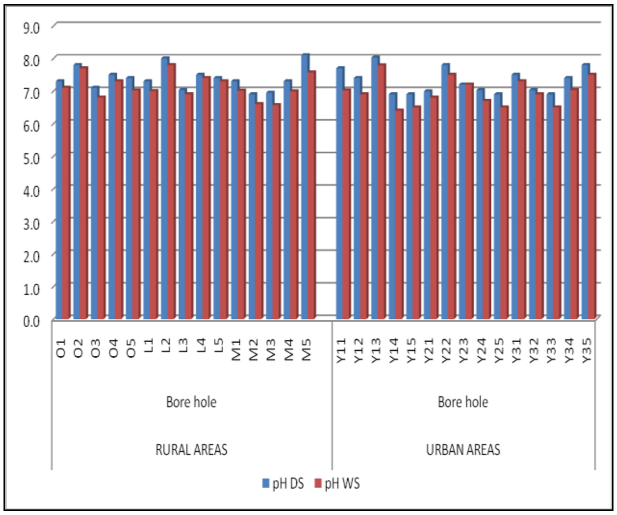

Fig 4.2.1a Variations of pH

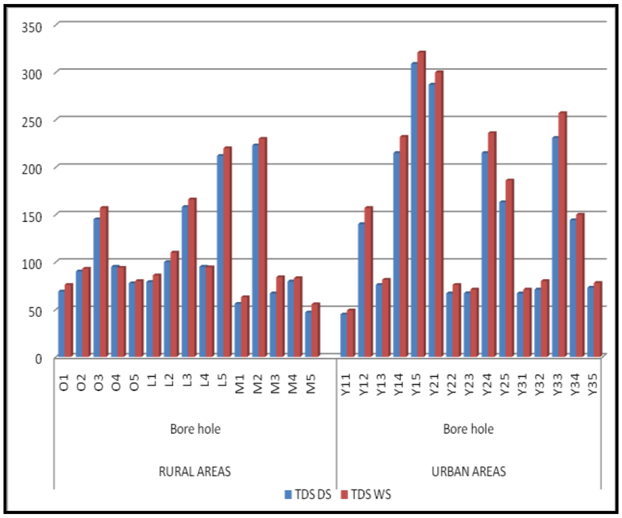

Fig 4.2.1b Variations of TDS (mg/L)

4.2.2 Intra variation of Chemical parameters

One way ANOVA was used to statistically determine Variations of Chemical parameters within the Rural and within the urban areas as shown in (Table 4.2.2) below.

Table 4.2.2 Statistical intra variations in chemical parameters within the rural and within the urban

	Rural Areas		**Urban Areas**	
Variate (mg/L)	F probability (0.05)		F probability (0.05)	
	DS	WS	DS	WS
Nitrate	0.607	0.606	0.171	0.168
Calcium carbonate	0.359	0.371	0.507	0.464
Iron	0.781	0.678	0.269	0.479
Fluoride	0.594	0.480	0.488	0.518

4.2.2.1 Intra variations in the rural and urban areas

From the one way ANOVA (Table 4.2.2), the statistical variation of the above chemical parameters within rural areas and within urban areas were all $p>0.05$ in both seasons. Therefore there was no significant variation in these parameters within the rural and urban areas in each season.

Figures 4.2.2a - 4.2.2d show intra and inter spatial variations in Chemical characteristics of borehole water in the rural and urban areas for both seasons.

4.2.2.2 Intra and Inter seasonal variations of chemical water parameters assessed in the rural and urban areas

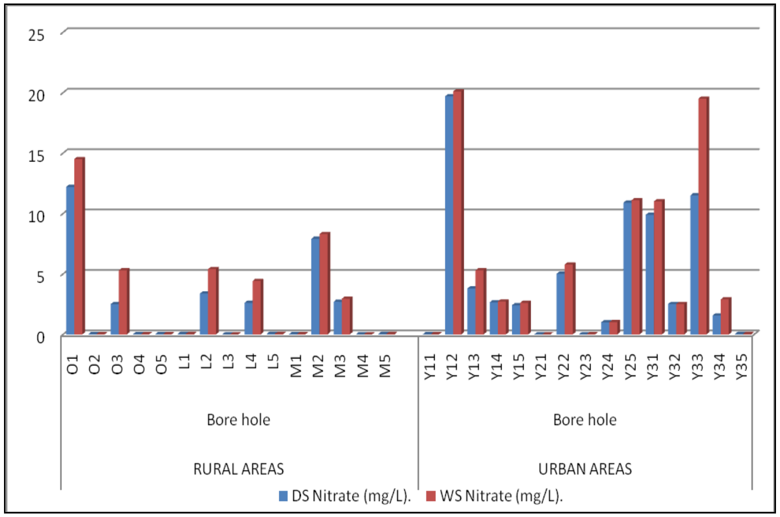

Fig 4.2.2a Variations of Nitrate

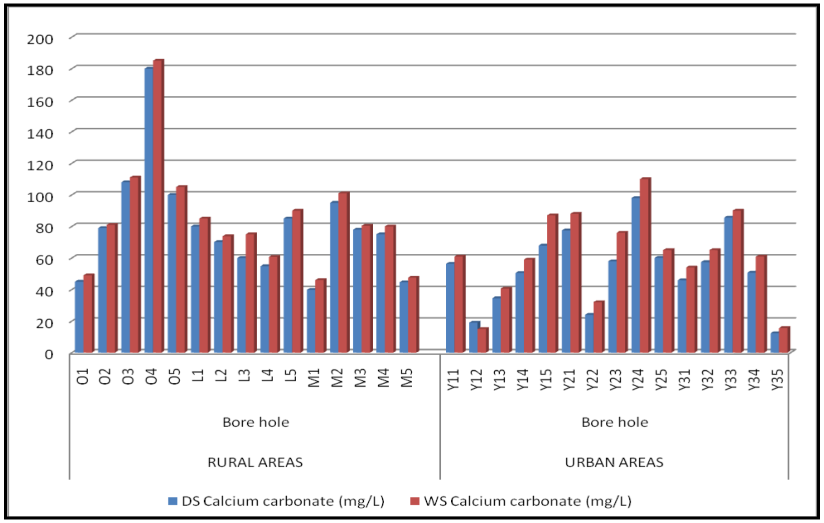

Fig 4.2.2b Variations of $CaCO_3$

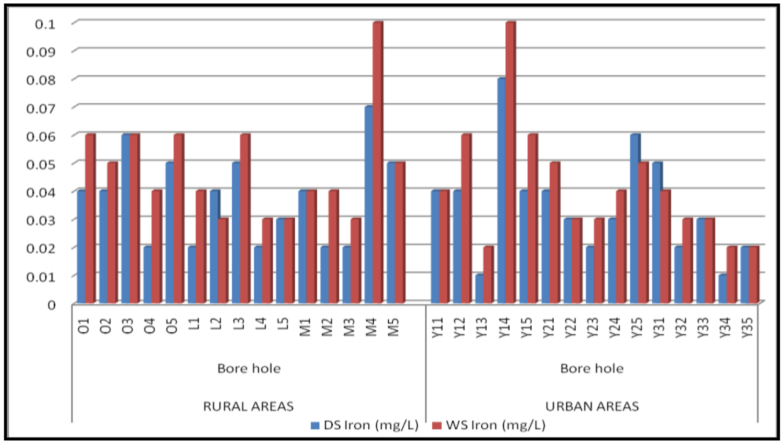

Fig 4.2.2c Variations of Iron

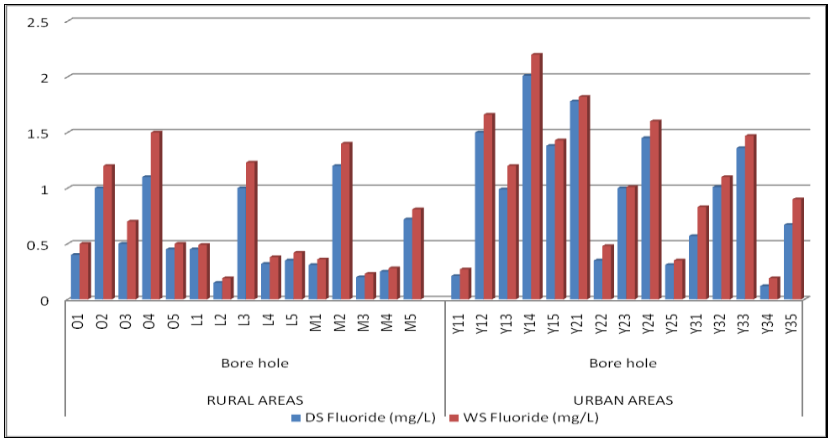

Fig 4.2.2d Variations of Fluoride

4.2.3 Intra Variations of Micro-biological parameters

4.2.3.1 One way ANOVA summary

The (Table 4.2.3) below shows statistical micro-changes in micro-biological parameters in borehole water within the areas of same locality and during the same season. This provides data to be used as a management tool to protect and manage borehole water resources during the different seasons.

Table 4.2.3 Statistical variations of micro-biological parameters within the rural and urban

	Rural Areas		**Urban Areas**	
Variate (cfu/100ml)	F probability (0.05)		F probability (0.05)	
	Dry Season	Wet Season	Dry Season	Wet Season
TC	0.293	0.225	0.778	0.822
FC	0.325	0.249	0.555	0.617

4.2.3.2 Intra variations in the rural and urban areas

From the one way ANOVA (Table 4.2.3), the statistical variation of micro-biological parameters in rural and urban areas were all $p>0.05$ in both seasons. Therefore there was no statistical difference in micro-biological parameters within the 3 rural areas and also within the 3 urban areas for both seasons. Figures 4.2.3a and 4.2.3b show intra and inter spatial variations in micro-biological parameters of borehole water in the rural and urban areas for both seasons.

4.2.3.3 Intra and Inter seasonal variations of micro-biological water parameters assessed in the rural and urban areas

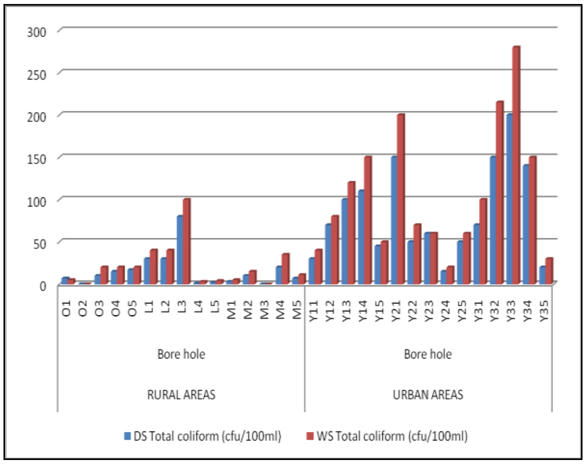

Fig 4.2.3a Variations of Total coliforms

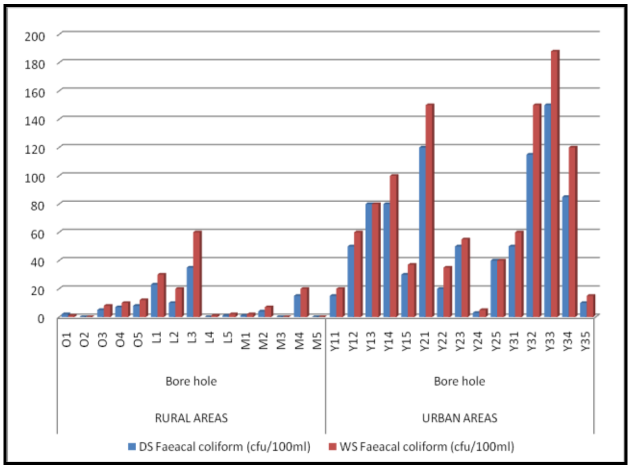

Fig 4.2.3b Variations of Faecal coliform

4.3 Inter Variations of Water Quality Parameters

A statistical comparison between rural and urban Parameters and a the effect of dry and wet seasons on parameters was done using T test 2 sample analysis

4.3.1 Inter variation of physico-Chemical parameters

4.3.1.1 t test 2 sample analysis summary

It is important to compare water quality in the rural areas with that from urban areas. This helps to identify impacts of population density and human activity on water quality. The (Table 4.3.1) below shows statistically how different rural physical borehole water quality paramters are from the urban parameters.

Table 4.3.1 Statistical variation in Physico-Chemical parameters between the rural and urban

Variate	**F probability (0.05)**	
	Dry Season	Wet Season
pH	0.0031	0.0031
TDS (mg/L)	0.0931	0.0724

From the t test 2 sample analysis (Table 4.3.1), significance variations between the rural and urban pH of borehole water were all $p<0.05$. Therefore pH in the rural areas varied greatly from the pH in urban areas for both seasons. While TDS significance values were $p>0.05$ for both seasons. Therefore there was no significant difference in TDS concentrations between the rural and urban area borehole water for both seasons.

4.3.2 Inter variation of Chemical parameters

4.3.2.1 T test 2 sample analysis summary

Rural water quality varies from that of the urban, this may affect the level of occurrence of water borne diseases in these areas. The (Table 4.3.2) below shows how the chemical parameters in borehole water vary statistically from the two areas.

Table 4.3.2 Statistical variations of chemical parameters between the rural and urban areas

Variate (mg/L)	**F probability (0.05)**	
	Dry Season	Wet Season
Nitrate	0.037	0.031
Calcium carbonate	0.017	0.023
Iron	0.226	0.362
Fluoride	0.025	0.038

From the t test 2 sample analysis (Table 4.3.2), NO_3-N, $CaCO_3$, and F^-, were all $p<0.05$ for both seasons. Therefore there was significant difference between the rural and urban borehole water concentrations of these parameters during the dry and wet season. While Iron significance variations were $p>0.05$ in both season, therefore there was no significant difference in the iron levels in the rural compared to those in the urban in both seasons.

4.3.3 Inter Variations of Micro-biological Parameters

4.3.3.1 Summary of t test 2 sample analysis

High population density and intense human activity contribute to the micro-biological quality of water. It is therefore important to statistically compare the micro-biological quality of water in the rural areas with that from the urban areas to show the levels of variation as in the (Table 4.3.3) below.

Table 4.3.3 Statistical variations in microbiological parameters between the rural and urban

Variate (cfu/100ml)	**F probability (0.05)**	
	Dry Season	Wet Season
TC	$4.19x10^{-7}$	$1.1x10^{-8}$
FC	$1.11x10^{-6}$	$3.32x10^{-7}$

From the t test 2 sample analysis (Table 4.3.3), total coliform and faecal coliform counts were significantly different between the rural and urban during both the dry and wet seasons $p<0.05$.

4.4 The Level of borehole water pollution

Pollution index by Akpoveta *et al.*, (2011), water quality classification by DWAF (1996) for total and faecal coliforms (Table 2.2), clasification by EPA, (1986) for water hardness as Calcium Carbonate (Table 2.1) and a comparision with WHO recommended values for the other parameters were used to determine the level of pollution and variation of parameters from the recommended values (Appendix 1). The pollution index for each parameter are shown on Appendices 11-13.

4.4.1 Statistical variance of Physico-chemical parameters from WHO values

The table 4.4.1 below shows the summary of the results of t test one sample statistical analysis, comparision of physical-chemical parameters with WHO standard values.

Table 4.4.1 Statistical variations of the selected physical-chemical parameters from WHO values

	Rural Areas		**Urban Areas**	
Variate	F probability (0.05)		F probability (0.05)	
	Dry Season	Wet Season	Dry Season	Wet Season
pH	0.00055	1	0.439	0.00138
TDS(mg/L)	1.77×10^{-13}	2.464×10^{-13}	2.99×10^{-10}	9.65×10^{-10}

From the t test one sample analysis (Table 4.4.1), Physico-chemical parameter values of TDS in the rural and urban borehole water varied significantly from the WHO permissible limits in both dry and wet seasons. The significance levels were all $p<0.05$. pH significance values during the wet season in rural areas (1.0) and in the dry season in urban areas (0.439) were $p>0.05$, therefore there was no significant difference in the pH values of borehole water in the rural areas during the wet season and dry season in the urban areas from the pH 7.0 of pure drinking water.

From the pH pollution index of borehole water (Appendix 11a and 11b), in the rural areas during the dry season, 86.7% of the boreholes had pH values greater than pH 7 of pure drinking water, while 13.3% had their pH values less than 7 during the dry season (pH 6.7 – 8.1). In the wet season, 66.7% of the boreholes had pH values significantly greater than 7.0 while 33.3% of the boreholes had pH values less than 7 (pH 6.3 – 7.5)

In the urban areas, 60% of the boreholes had pH values greater than 7, while 40% had their pH values less than 7 during the dry season (pH 6.0 – 7.8). In the wet season, 20% (pH 5.5 – 7.3) of the boreholes had water pH greater than 7, while 80 % had pH less than 7. Therefore borehole water became more acidic in the wet season compared to the dry season.

The pollution index for TDS showed that the water was not polluted as per the parameter, all were $P_i<1.0$. There was a general increase in the Pi of TDS in the wet season compared to the dry season in both rural urban areas, which showed that values increased in the wet season.

4.4.1.2 Comparison of the selected Physico-chemical parameters with WHO recommended values

To show the intensity of water pollution, physical parameters were compared with recommended values according to WHO. The figures 4.4.1a and b show their graphical variations.

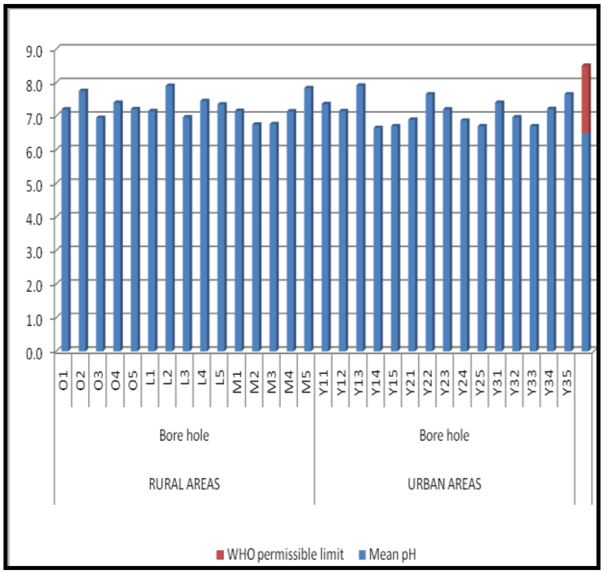

Fig 4.4.1a Comparison of pH with recommended values

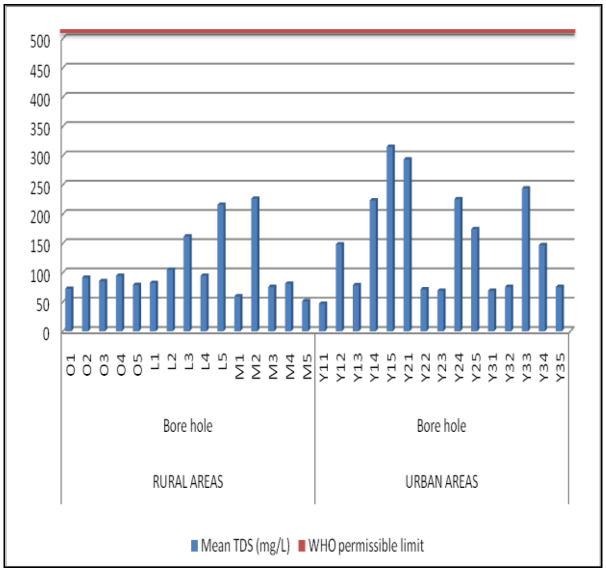

Fig 4.4.1b Comparison of TDS with recommended values

4.4.2 Statistical Variations of Chemical parameters from the WHO recommended values

The (table 4.4.2) below shows the summary of the results of statistical comparision of chemical parameters with WHO standard values. To show how significantly different they were from the recommended values.

Table 4.4.2 Statistical variations of chemical parameters from WHO values

	Rural Areas		**Urban Areas**	
Variate (mg/L)	F probability (0.05)		F probability (0.05)	
	Dry Season	Wet Season	Dry Season	Wet Season
Nitrate	1.39×10^{-16}	4.30×10^{-16}	9.16×10^{-14}	1.57×10^{-13}
Calcium carbonate	3.95×10^{-12}	3.61×10^{-12}	9.7×10^{-13}	6.14×10^{-12}
Iron	0.559	0.919	0.062	0.254
Fluoride	5.94×10^{-8}	0.014	0.0044	0.023

From the t test one sample analysis (Table 4.4.2); Nitrate, Calcium Carbonate and Fluoride concentrations in the rural and urban borehole water varied greatly from the WHO maximum permissible limits in both dry and wet seasons, $p<0.05$. However, Iron levels in the rural and urban areas were not significantly different from the WHO permissible limits in both dry and wet season, $p>0.05$.

4.4.2.1 Pollution index for Chemical parameters

From the pollution index (Appendix 12a and 12 b), Chemical parameters (Nitrate and Calcium Carbonate) were all $Pi<1.0$. This showed that all the parameters were far below the maximum recommended values by WHO in drinking water. While Pi of Iron and Fluoride showed some boreholes had concentrations of greater than the WHO maximum recommended values where $Pi >1.0$. The increase in Pi during the wet season showed that these parameters increased in concentration during the wet season as compared to the dry season.

4.4.2.2 Comparison of Chemical parameters with recommended values

To show the intensity of water pollution, chemical parameters were compared with recommended values according to WHO. The figures 4.4.2a – 4.4.2e show their graphical variations. This aids decision makers to make appropriate changes.

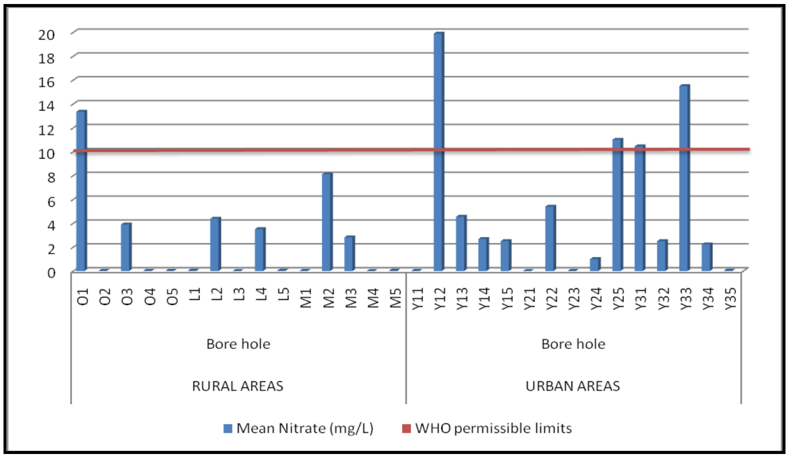

Fig 4.4.2a Comparison of Nitrate levels with WHO recommended values

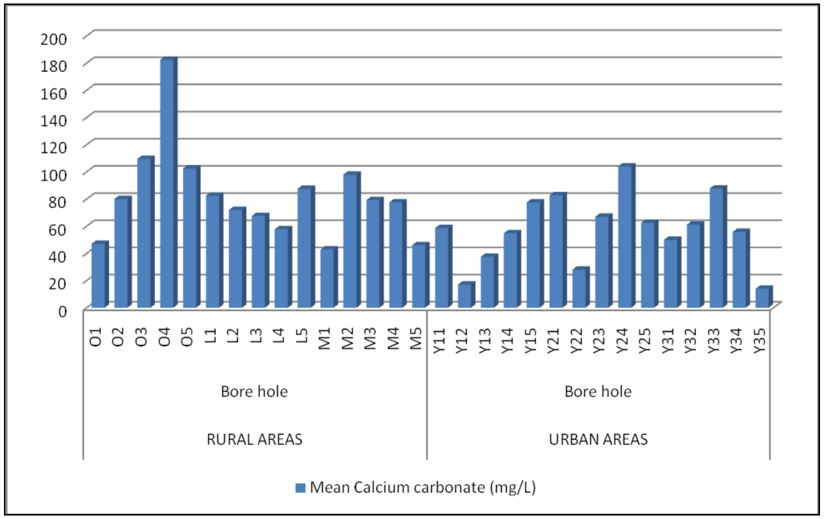

Fig 4.4.2b CaCO$_3$ mg/L levels in borehole water

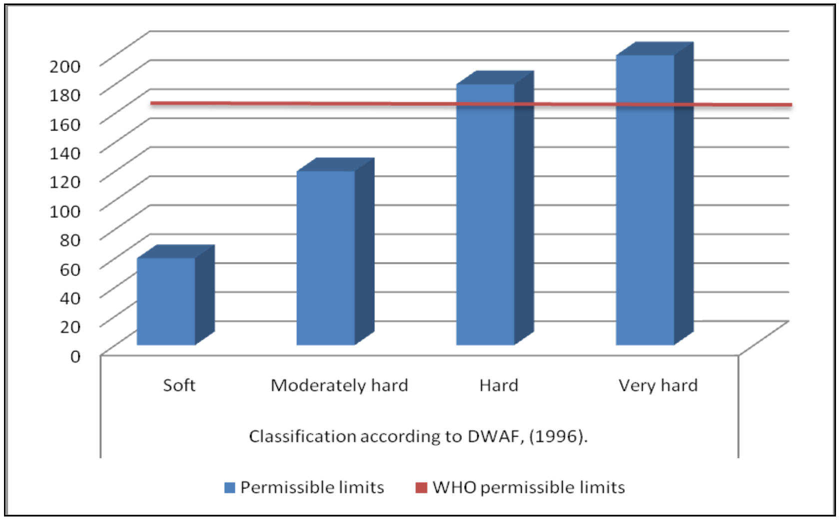

Fig 4.4.2c Recommended limits of CaCO$_3$ by DWAF and WHO.

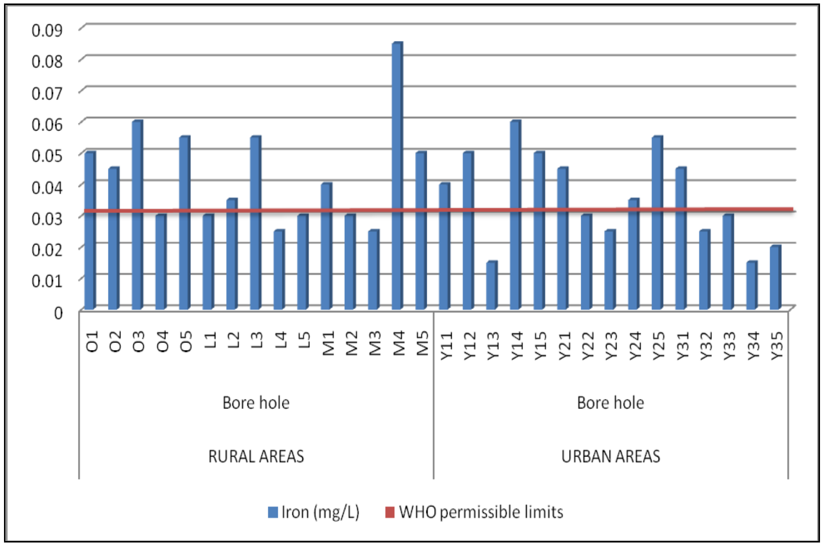

Fig 4.4.2d Comparision of Iron concentrations with WHO values

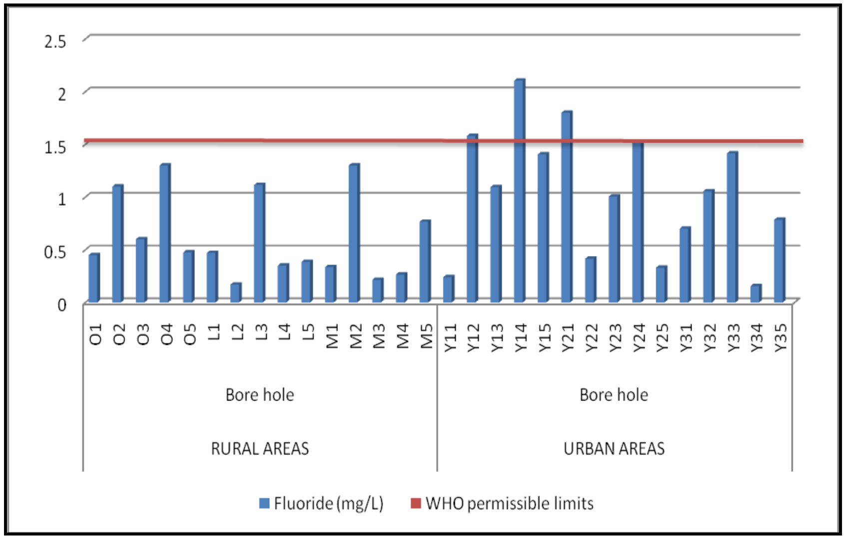

Fig 4.4.2e Comparision of Fluoride concentrations with WHO values

4.4.3 Statistical Variations of Micro-biological parameters from the WHO recommended values

The (Table 4.4.3) below shows the summary of the results of statistical comparision of micro-biological parameters with WHO standard values. This is to show how significantly different they were from the recommended values, this helps decision makers to draw governing laws and measures to protect health effects on humans

Table 4.4.3 Statistical variations of microbiological parameters from WHO values

	Rural Areas		**Urban Areas**	
Variate (cfu/100ml)	F probability (0.05)		F probability (0.05)	
	Dry Season	Wet Season	Dry Season	Wet Season
TC	0.0067	0.0035	$4.3x10^{-7}$	$1.41x10^{-7}$
FC	0.0078	0.0071	$2.98x10^{-6}$	$1.2x10^{-6}$

From the t test one sample analysis (Table 4.4.3), total coliform and faecal coliform counts in the rural and urban borehole waters varied greatly from the WHO maximum permissible value of 0 cfu/100ml in both the dry and wet seasons. There significant levels were all $p<0.05$.

4.4.3.1 Categorization of water quality based on Micro-biological parameters

From the (Table 2.2 and Appendix 13a and 13b), in the rural areas using, Total Coliform count (cfu/100ml) classification: 86.7% of the boreholes were categorized as good, 13.3% were marginal while 0% were poor during the dry season. While in the wet season, 60 % were good, 40% were marginal with 0% poor. Total coli form count increased in the wet season though not to the worst levels. Faecal coli form count classification: 33.3% of the boreholes were categorized as good, 60% were marginal while 6.7% during the dry season. While in the wet season, 26.7 % were good, 60% were marginal with 13.3% poor. Faecal coliform count in borehole water increased in the wet season.

In the urban areas using Total coliform count classification: 0% of the boreholes were categorized as good, 100% as marginal, and 0% as poor during the dry season, while in the wet season, 0%

were categorized as good, 93.3% were marginal and 6.7% were poor. Faecal coliform count classification: 0% of the boreholes were categorized as good, 13.3% as marginal, and 86.7% as poor during the dry season, while in the wet season, 0% were categorized as good, 0% were marginal and 100% were poor. Hence faecal coliform increased in borehole water during the wet season. Total and faecal coliform contamination was greatest in the urban areas. Fig 4.3a and 4.3c show TC and FC counts as compared to figures 4.3b and 4.3d recommended limits.

4.4.3.2 Variations in micro-biological parameters from permissible limits

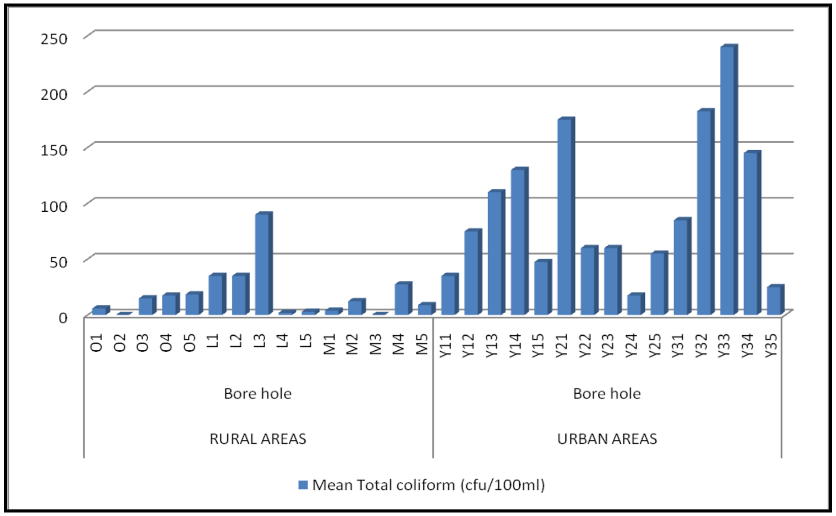

Fig 4.4.3a Total coliform counts in borehole water

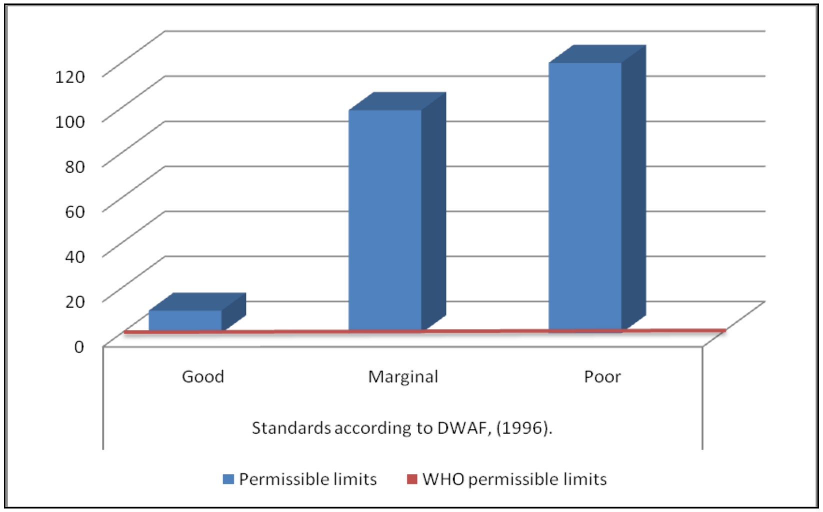

Fig 4.4.3b TC (cfu/100ml) classification according to DWAF and WHO

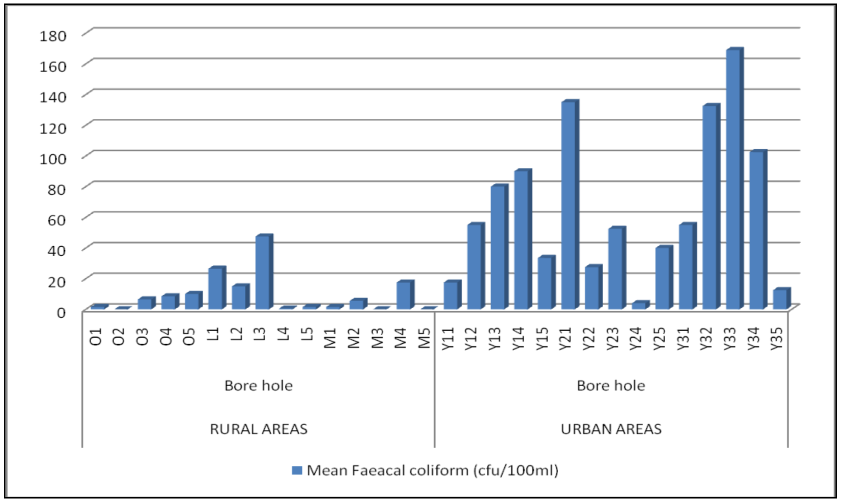

Fig 4.4.3c Faecal coliform counts in borehole water

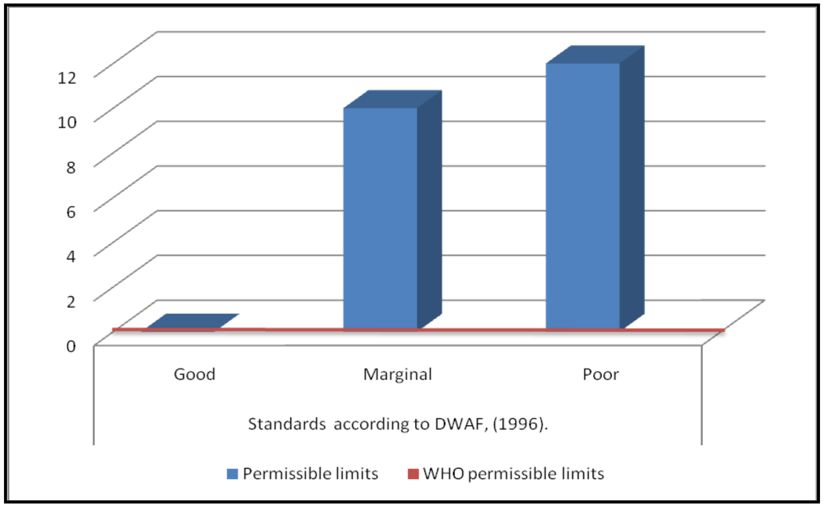

Fig 4.4.3d FC (cfu/100ml) classification according to DWAF and WHO

4.5 Results of Borehole water Consumption patterns

4.5.1 Demographics of Households and Respondents

A total of 300 households were surveyed in Yei County, one hundred fifty (150) were from the rural areas of Otogo, Lasu and Mugwo Payams and one hundred fifty (150) were from the urban areas of Yei Town 1, Yei Town 2 and Yei Town 3. Each of these areas had fifty (50) households surveyed. Each household had 1 respondent who was either head of households (husbands / wives) or in charge of the households.

4.5.1.1 Frequency distribution of households and respondents

The (Table 4.5.1) below is a summary of the gender of respondents, marital status, age groups as got from each household, levels of education attained and employment.

Table 4.5.1 Frequency distribution of respondents and demographics of households surveyed

Characteristic	Rural	Urban areas	Yei County	% Rural	% Urban	% Yei county
Gender of respondents						
Female	118	121	239	39.33	40.33	79.7
Male	32	29	61	10.67	9.66	20.3
Marital Status						
Married (Polygamous)	97 (35)	90 (21)	187 (56)	32.33 (18.72)	30 (11.23)	62.33 (29.95)
Single	21	12	33	7	4	11
Divorced	21	30	51	7	10	17
Widowed	11	18	29	3.67	6	9.67
Age groups						
Adults (>18yrs)	500	576	1076	49.8	59.9	54.7
Teenagers (13-17) yrs	206	188	394	20.5	19.6	20.1
Children (1-12) yrs	298	197	495	29.7	20.5	25.2
Education levels						
None	541	343	884	53.9	35.7	45
Primary	371	414	785	36.9	43.1	39.9
Secondary	78	147	225	7.8	15.3	11.5
Tertiary	14	57	71	1.4	5.9	3.6
Employment levels						
None	500	489	989	49.8	50.9	50.3
Self employed	357	301	658	35.6	31.3	33.5
Informal	120	120	240	11.9	12.5	12.2
Formal	27	51	78	2.7	5.3	4.0

The survey in Yei county as per the (Table 4.7.1), ***Gender***: 239 respondents (79.7%) were females, the rural areas had 118 females (39.33%) while 121 respondents were from the urban areas (40.33%).Sixty one (61) of the respondents were males (20.3%), the rural areas had 32 male respondents (10.67%) while 29 were from the urban areas (9.66%).

Marital Status: From (Table 4.9.1), 187 respondents were married (62.33%) out of which 56 were polygamous (29.95%). In the rural areas 97 were married (32.33%) out of which 35 were polygamous (18.72). In the urban areas 90 were married (30%) out of which 21 were polygamous (11.23%). The study area had 33 single respondents (11%). The rural area had 21 single households (7%), while the urban had 12 single respondents (4%). Fifty one (51) of the respondents were divorce (17%), the rural areas had 21 divorced respondents (7%) while the urban had 30 which made a percentage of 10. The widowed respondents in Yei County were 29 which was a percentage of 9.67%, the rural areas had 11 widowed respondents (3.67%) while the urban areas had 18 which was (6%).

Age groups: Age groups were categorized into three (3) i.e. Adults ≥18 years, Teenagers (13 -17 years) and children (0-12) years. The study area had 1,076 adults (54.8%), the rural areas had 500 adults (25.4%) while the urban areas had 576 adults (29.3%). The rural areas had the largest number of adults. The study area had 394 teenagers (20.1%), the rural areas had 206 (10.5%) and the urban areas had 188 (9.6%). The rural areas had the largest number of teenagers. The study area had four hundred ninety five (495) Children (25.2%), the rural areas had 298 (15.2%) and the urban areas had 197 (10%).

4.5.2 A summary of Average daily per capita borehole water consumption

The (Table 4.5.2) below shows a summary of the minimum, maximum and average daily per capita borehole water consumption in both dry and wet seasons and the effect of distance from borehole water resource on the consumption of water.

Table 4.5.2 Summary of borehole water consumption in Yei County

	Rural			**Urban**		
	Minimum	**Maximum**	**Mean**	**Minimum**	**Maximum**	**Mean**
Dry season (L/person/day)	8.8	21	13.1	12.5	29.5	17.1
Wet season (L/person/day)	4.0	20	9.7	6.7	23.8	12.7
<500m from B/H	6.7	21	12.8	10.0	29.5	18.7
>1Km from B/H	4.0	18.8	10.0	6.7	26.0	14.7

Generally from (Table 4.5.2), more borehole water was consumed by households during the dry season and the amount of consumption reduced with increase of distance of household from the water source. The maximum daily per capita amount of borehole water consumed was 29.5L and it was in the urban areas during the dry season by the household which was less than 500m from the borehole. The least amount of borehole water consumed was 4L/person/day, this was recorded during the wet season by a household more than 1km from the borehole.

The daily per capita borehole water consumption was higher in urban areas compared to the rural areas in both seasons (Appendix 16 and 17).

4.5.3 Variation from the Minimum recommended value (27L/person/day)

4.5.3.1 Summary of T test one sample analysis

The WHO organization recommends that the minimum daily water consumption per person be 27L/person/day. The (Table 4.5.3) below shows how statistically different borehole water consumption in Yei county is different from the recommended minimum value.

Table 4.5.3 Statistical variation of daily per capita consumption from the WHO recommended value

	Urban	**Rural**
	F probability (0.05)	**F probability (0.05)**
Dry Season	0.0003	$1.7x10^{-6}$
Wet Season	0.000236	$7.5x10^{-6}$
<500m	0.017518	0.000901
>1km	0.004154	0.000129

From (Table 4.5.3), there was a significant statistical variation of daily per capita amount of borehole water consumed from the minimum recommended value of 27L/person/day by WHO. The significant was pronounced in the rural areas compared to the urban, and more so during the wet season when other sources of water become available for consumption. The significance also increased with increase of distance of household from the water source, with the rural areas being more affected than urban areas.

4.5.4 Impact of Distance from borehole on seasonal per capita water consumption

The study area had a total of 300 households, 150 were less than 500m from the borehole and 150 were more than 1km from the water source. Genstat vr 13.3 ANOVA general treatment structure (no blocking) was used to show the statistical effect of distance from the borehole on per capita water consumption.

4.5.4.1 A summary of Genstat output

Distance of households from water source affects the amount of daily water use, the (Table 4.5.4) below shows the statistical effect of distance on the amount of water consumed, by comparing the amount of the water consumed by the households that were less than 500m from borehole with those that were more than 1km from the borehole.

Table 4.5.4 Statistical variations of daily per capita borehole water consumption

Analysis of variance	
Variate (daily per capita water consumption)	F pr.
Rural Per capita consumption in Dry season (L/day)	<.001
Rural Per capita consumption in Wet season(L/day)	<.001
Urban Per capita consumption in Dry season(L/day)	<.001
Urban Per capita consumption in Wet season(L/day)	<.001

From the ANOVA summary (Table 4.5.4), impact of distance on per capita consumption in the rural and urban areas was significant all (<0.001) for both dry and wet seasons, which were all p<0.05. There is a significant effect of distance from the borehole on daily per capita water consumption in Yei County. The per capita water consumption is dependent on the distance from the borehole. Figure 4.5 shows the graphical effect of distance from the borehole on daily per capita water consumption across the selected study areas in Yei County for both seasons.

4.5.4.2 Effect of distance from borehole on daily per capita water consumption

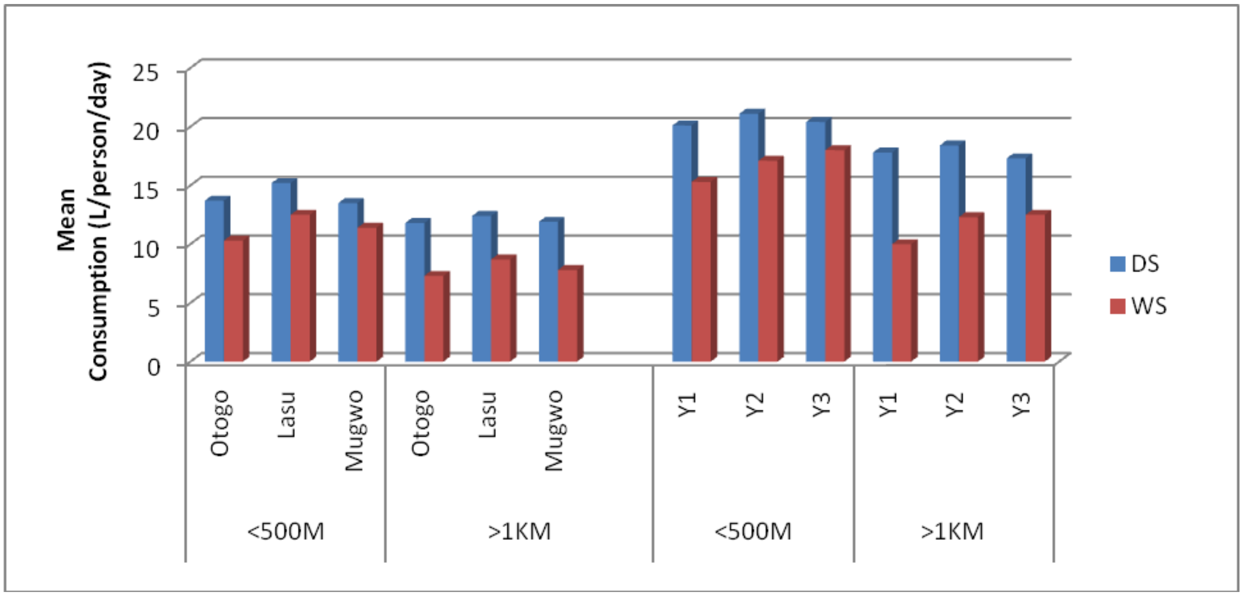

Fig 4.5.4 Effect of distnace from borehole on amount of water consumed. DS=Dry Season, WS=Wet Season.

4.5.5 Effect of household size on daily per capita consumption

From (Fig 4.5.5a – 4.5.5d), the simple regression analysis equations in the rural and urban areas are summarized in the (Table 4.5.5) below.

4.5.5.1 A summary of regression equation trend lines

Household size affects the amount of daily water consumption per person. The (Table 4.5.5) below shows the statistical impact of household size on the amount consumed per person.

Table 4.5.5 Regression equations showing relationships between household size and per capita borehole water consumption

Distance	**Rural areas**		**Urban areas**	
	DS	**WS**	**DS**	**WS**
<500m	y=-0.265x+16.2 R^2=0.087	y=-0.318x+13.93 R^2=0.114	y=-0.509x+25.31 R^2=0.397	y=-0.285x+19.41 R^2=0.151
>1Km	y =-0.138x+13.29 R^2=0.052	y=-0.095x+8.656 R^2=0.020	y = 0.234x+19.63 R^2=0.031	y=-0.136x+12.65 R^2=0.012

From the regression equations on (Figures 4.5.5a -4.5.5d), summarized on (Table 4.5.5), during the dry season in the rural areas, an increase in household size reduced the per capita water consumption, while in the urban areas, during the dry season an increase in household size increased the daily per capita borehole water consumption for households more than 1km from water source.

During the wet season in the rural areas an increase in household size reduced per capita borehole water consumption for households >1km from the water source. However, the relationship was not strong with R^2=0.0020. The households <500m from borehole, an increase in household size led to slight increase in per capita water consumption. During the wet season in the urban areas, an increase in household size reduced the daily per capita amount of borehole water consumption as indicated by the negative regression equation. Since R^2 values were nearing 1.0 for households <500m and >1km, there was a great explanatory power of the effect of household size on daily per capita water consumption.

4.5.5.2 Effect of household size on daily per capita consumption

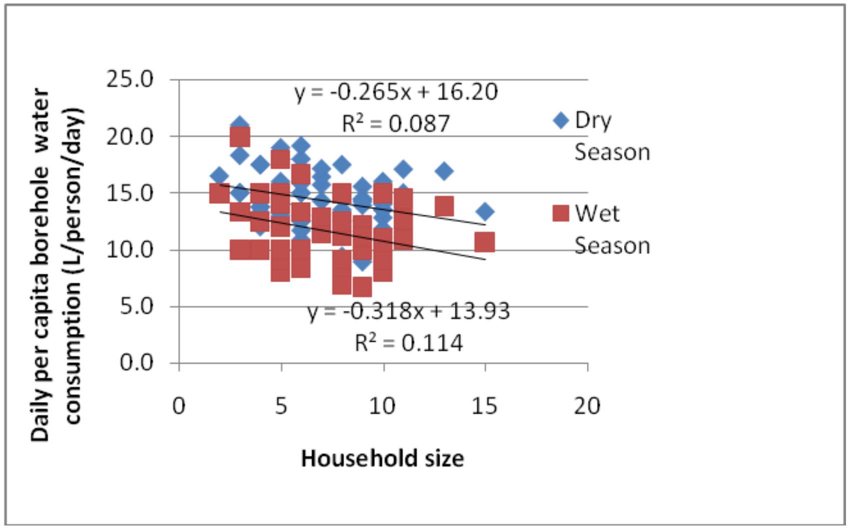

Fig 4.5.5a Rural Households < 500m from borehole.

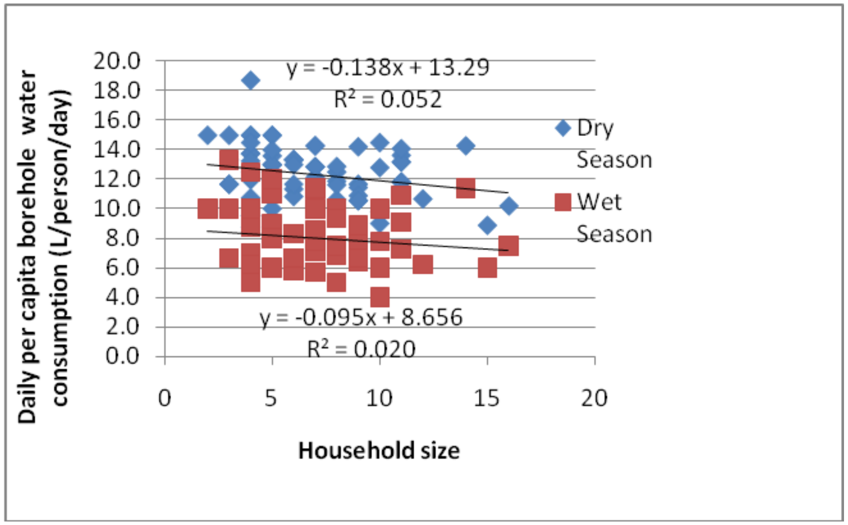

Fig 4.5.5b Rural households >1km from borehole.

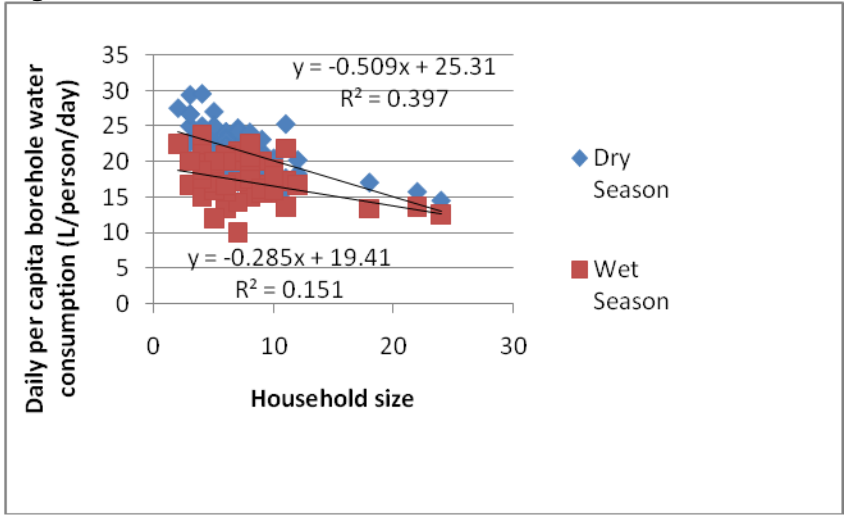

Fig 4.5.5c Urban households <500m from borehole

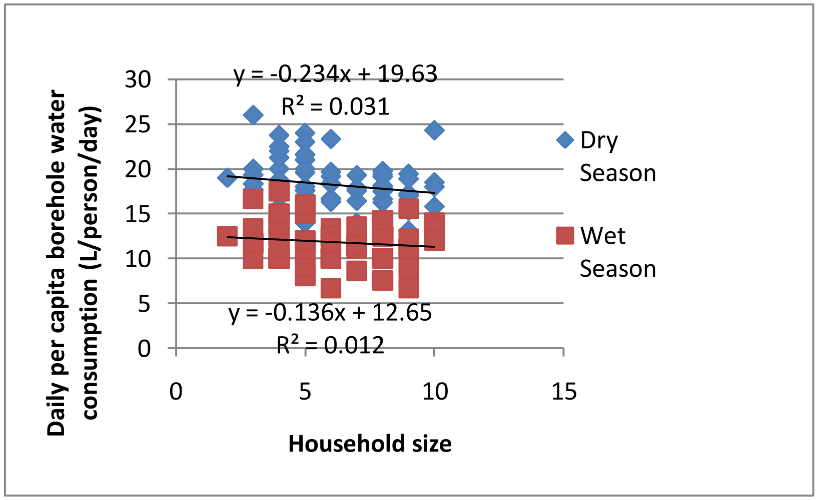

Fig 4.5.5d Urban households >1km from borehole

4.5.6 Effect of dry and wet seasons on daily per capita borehole water consumption

4.5.6.1 Summary of t test 2 sample analysis results

Dry and wet seasons affects the amount of borehole water consumption, the (Table 4.5.6) below shows statistical variation in the amount consumed per person in the rural and urban areas during the dry and wet season.

Table 4.5.6 Statistical variations of daily per capita borehole water consumption in dry and wet seasons

Variate (Comparing Dry and Wet seasons)	**F probability (0.05)**
Daily per capita consumption in Rural areas	0.48445
Daily per capita consumption in Urban areas	2.2×10^{-5}
Daily per capita consumption in Yei county	5.3×10^{-5}

From the results of the t test 2 sample analysis (Table 4.5.6), there was a significant effect (5.3×10^{-5}) of dry and wet seasons on daily per capita borehole water consumption in Yei County $p<0.05$. Therefore the amount of daily per capita borehole water consumption during the dry season was different from that during the wet season. Figures 4.5.6a - 4.5.6d show the graphical effect of changing seasons on daily per capita borehole water consumption in both the rural and urban areas.

4.5.6.2 Effect of changing seasons on daily per capita borehole water consumption

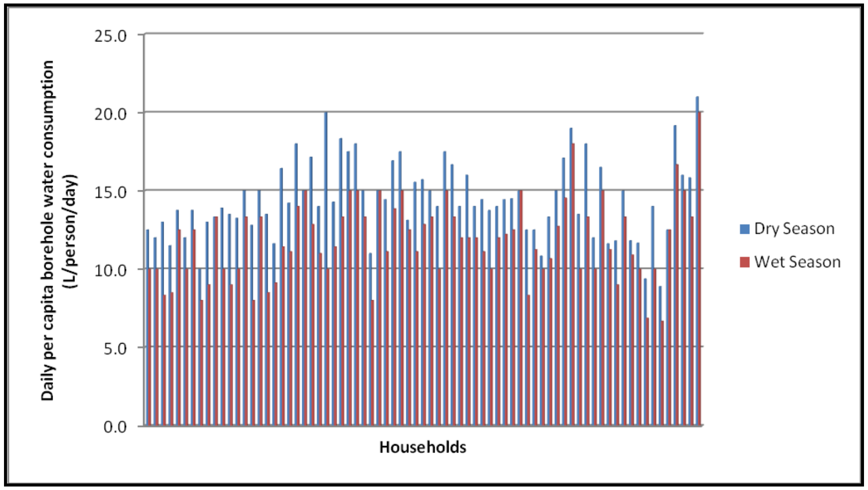

Fig 4.5.6a Rural households<500m from borehole

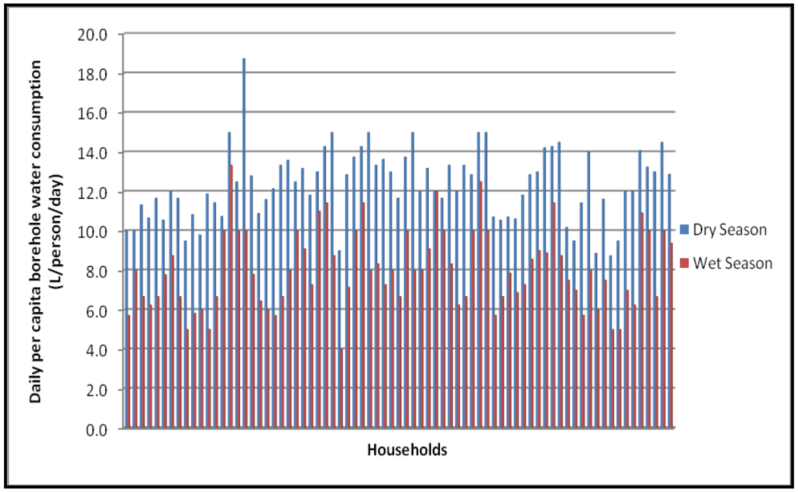

Fig 4.5.6b Rural households >1km from borehole

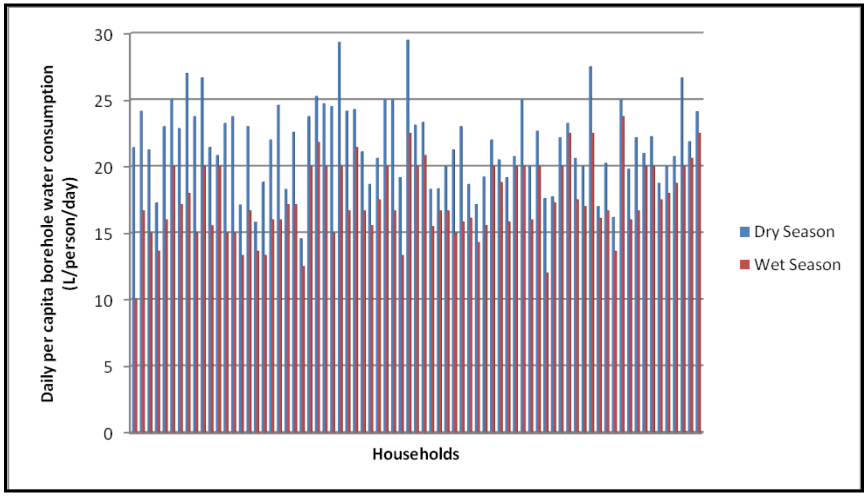

Fig 4.5.6c Urban households<500m from borehole

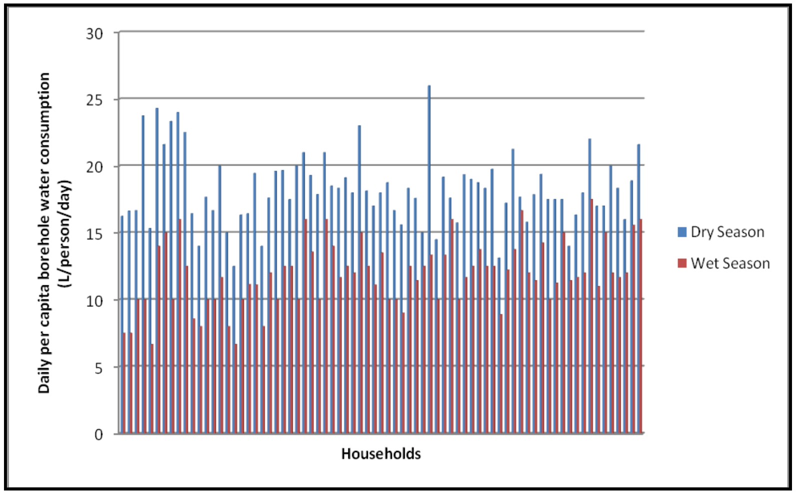

Fig 4.5.6d Urban households>1km from borehole

However, there was no significant effect (0.48445) of dry and wet seasons on daily per capita borehole consumption in the rural areas $p>0.05$. Therefore the amount of daily per capita borehole water consumed in the rural areas was not statistically different during the dry and wet seasons. The per capita consumption in the rural areas did not vary greatly in both seasons. There was a significant effect (2.2×10^{-5}) of dry and wet seasons on daily per capita borehole consumption in the urban areas $p<0.05$. Therefore, the daily per capita consumption in the urban areas in the two seasons was statistically different.

CHAPTER 5: DISCUSSION OF RESULTS

5.1 Physico-Chemical Parameters

pH**:** The lower pH values in the wet season are attributed to rain water which was charged to groundwater. The pH of rainwater is about 5.7 (Krauskopf and Bird, 1994). Low pH in borehole water near the defaecation sites and dump sites is attributed to Sulphur and amino acid compounds from human and animal excreta. The Organic matter depletes oxygen resulting in a negative redox potential, creating an elevated Dissolved Oxygen Content (DOC) in soil which facilitates biological activity, the Carbon dioxide, Ammonia, Methane (humic acid) produced during decomposition of the waste materials percolates (Adekunle *et al.*, 2007; Efe*et al.*, 2005). Under such conditions, Fe^{2+} is dissolved and if the redox potential becomes low enough, Sulphate is transformed to Hydrogen Sulphide (Efe *et al.*, 2005). Increase in TC and FC counts increase during the wet season leads to slight decrease in the pH of the borehole water (Korkka-Niemi and Laikari 1994).

In comparison to this study, effect of wet and dry seasons on borehole water pH produced contrasting results with those found by Agbaire and Oyibo (2009) in Abraka Ethiope, Nigeria in their study of seasonal borehole water quality where borehole water became alkaline in the wet season (pH 6.2 to 8.00) and acidic in the dry season (pH 6.3 to 7.1), though the range of their pH values were similar.

Similar results were found on studies done on borehole water and groundwater pH. A study on boreholes by Korkka-Niemi and Laikari (1994) showed that the water pH ranged from acidic to alkaline. A study of borehole water in Nigeria by Eniola *et al.* (2005), showed that pH of borehole water fell within the range of 6.54 to 7.80. A study of the impact of seasonality on borehole water pH by Heejun and Kang-Kun, (1997) showed that pH ranged from 5.5 to 7.2 during the dry season and 5.5 to 6.6 during the wet season.

Groundwater becomes more acidic during the wet season. This pH range is close to neutrality and would allow the growth of most bacterial species. A comparison of groundwater quality of deep exploited aquifers in Jiangyin city by Quing-hai *et al.* (2007), China showed that pH of borehole water increased in acidity from the year 1998 to 2005 though values were still within the WHO acceptable limits. This is an indication that groundwater becomes more acidic with population growth, industrialization and civilization. The WHO maximum permissible limits of drinking water pH lie between 6.5 – 8.5.

***Total Dissolved Solids**:* Similar results were attained in a study of boreholes by Agbaire and Oyibo (2009) who showed that TDS concentrations varied from Ugep area (44.47mg/L) and Anantigha area (157.59 mg/L) in Nigeria. They also studied variations in Abraka Ethiope, which showed that TDS values were higher in the wet season (0.39 to 7.11mg/L) compared to the dry season (0.00 to 2.11mg/L). They attributed this to different forms of leachate during the rain season. According to Edet and Worden (2009), the high concentrations in TDS and EC can be attributed to seawater influence, changing seasons and tidal periods. Agbaire and Oyibo (2009), found the values in both seasons to be far below the WHO permissible limits.

In contrast to this study, results of borehole water quality in Kotputli town, India by Ranjana (2010), showed that during dry season, concentrations of solids were higher than rainy season. According to Chapman (1996), a higher TDS concentration during the dry season only happens in shallow groundwater affected by evapotranspiration which increases the proportions of the TDS

Nitrate: Similar results were found in a study of groundwater quality by Munoz-Carpena *et al.,* (2005) in South Florida agricultural area U.S.A. who showed that some nitrate concentrations were below the WHO acceptable limits of 10mg/L while others were above the limit. The study also showed higher Nitrate concentrations in the rainy season. A study by Adekunle *et al.,* (2007) of groundwater quality in a typical rural settlement in Southwest Nigeria showed that Nitrate levels in some borehole water exceeded the WHO permissible limits of 10mg/L. Another study by Hedge and Puranik (1996) revealed that borehole water in Hubli city India was polluted by Nitrate and concluded that all the groundwater samples were unsuitable for drinking without treatment especially during the rainy season. It is apparent that many countries in Europe and probably the World are suffering from nitrate pollution or are likely to do so in the nearby future (Hamil and Bell, 1986).

Calcium carbonate: Similar results were found in South Korea by Heejun and Kang-Kun, (1997) who showed that groundwater had 12.1 to 61mg/L $CaC0_3$ at the end of dry season and 15.2 to

85.3mg/L during the wet season. Water hardness increased during the wet season. A study of seasonal variations in some physico-chemical properties of borehole water in Abraka, Nigeria by Agbaire and Oyibo (2009) showed that some water samples were soft, since had concentrations below 75mg/L $CaCO_3$ and the water under study was all potable. Low concentrations of ions and metals are due to the non acidic nature of the water. Solubility of metals hence increase in ions is permissible at pH values less than 5 (Etu-Efiofor and Od igi, 1983)

Iron: Similar results were found in a study by Ocheri (2010), Benue State, Nigeria who showed that more boreholes had Iron concentrations above the WHO permissible limits of 0.03 mg/L during the rainy season, and during the dry season few had concentrations exceeding the permissible limits. A study in Ghana showed that some of the boreholes contained excessive iron concentrations. Water from these boreholes has been rejected due to coloration effect (Peligba *et al.*, 1991).

Contrasting results about seasonal effect were found by Edet and Worden (2009), whose concentrations ranged from 0.01 to 0.06 during the dry season and 0.01 to 0.04 during the wet season, with a higher concentration during the dry season compared to the wet season. However, the general iron values were similar to the ones in this study.

Fluoride: Similar results were found in a study by Suthra *et al.* (2009), in Northern Rajasthan India who showed that Fluoride concentrations varied from 0.014 to 0.13mg/L. According to Feenstra *et al.,* (2007), fluoride concentrations in borehole water in Kenya, South Africa and India can range from under 1mg/L to more than 35mg/L. Fluoride in groundwater may be due to the interaction between water and fluoride bearing minerals in host rock. Concentrations in different areas vary according to the geological formation and amount of rainfall.

A water quality assessment in rural Cambodia showed that a shallow aquifer was chemically less of a health risk than deep aquifer, however, micro-biological contamination was considerable in boreholes and shallow wells and contamination can be removed by simple household water treatment (Bennett *et al*., 2010) and (Sampson, 2008). A study of groundwater in Kotputli town, India by Ranjana (2010), showed that there were no major seasonal variations in chemical properties of borehole water, he attributed it to the fact that the rainfall in the state was below average, and groundwater recharge was very little. A study on boreholes by Korkka-Niemi and Laikari (1994) showed that if the water pH ranges from acidic to alkaline, this causes the degree of mineralization to vary from weak to strong and the chemical composition of groundwater will relatively be close to that of the soil topping. The acidity or alkalinity of water is related to the soil pH of the region (Takem *et al.*, 2010).

5.3 Micro-biological Parameters

Total and Faecal coliforms: Presence of faecal coliforms or Escherichia coli is used as an indicator for the presence of any of water borne pathogens (Chukwurah, 2001; Okpokwasili and Akujobi, 1996). This research found out that most boreholes had TC and FC counts greater than the WHO recommended value of 0cfu/100ml. The wet season had higher counts than the dry season, with the urban boreholes being more contaminated than the rural.

Similar results were attained in a study by Adekunle *et al.,* (2007) of groundwater quality in a typical rural settlement in Southwest Nigeria which showed that Total and Faecal coliform counts in borehole water exceeded WHO permissible limits though some met the permissible limit of 0 cfu/100ml. The wet season had greater TC and FC counts compared to the dry season. The effect of distance from pollution sources was much more defined for faecal and total coliform counts. A study by Potgieter *et al*., (2005) in Limpopo province, South Africa showed that coliform counts in borehole water were increased in the wet season due to leaching to ground water. Study by Rogbesan *et al.* (2002) who found that borehole water with the highest total coliform count also have the highest faecal coliform count (Rogbesan *et al.,* 2002).

Bacteriological analysis of borehole water in Uli, Nigeria by Ibe and Okplenye (2005), found faecal coliform colonies vary from 4-74 cfu/100ml. Highest counts were consistently found in the sample from Cagramento Lodge, where the borehole was located in an unsanitary environment, near a pit latrine. A study of borehole water by Nyati (2004) in Binduraperi- urban areas Zimbabwe showed that borehole water had seasonal fluctuations, with higher total and faecal coliform counts in the wet season. Here cases of typhoid, cholera and dysentery were reported from the provincial hospital. A study by Musa *et al.,* (1999) in Omdurman, Northern Sudan among nomadic pastoralists showed that faecal coliform counts were in excess of WHO standards, and the highest values were at the end of the rainy season.

Contrasting seasonal results were found in a study by Bodoczi (2010), in Romania where the values were highest in dry season/ summer when air temperatures were high causing the increase in the micro-organism development. Indicator values were higher in areas that were situated near heavy anthropogenic influence and urbanization (Bodoczi, 2010)

Lack of sanitary facilities and availability of V.I.P. pit latrines, discharge of waste water without prior treatment, indiscriminate dumping of waste contribute to borehole water contamination where people still practice open defaecation (Potgieter *et al.,* 2005**;** Nola *et al*., 2011 and Erah *et al.,* 2002) A study of coliform contaminants in Ibadan city Nigeria by Olusegun (2010) and supported by Anaele (2004), showed the pollution of boreholes was due to indiscriminate drilling of boreholes near pit latrines toilet and poor drainage systems. According to Potgieter *et al.,* (2005), the contamination depends on seasonal variations and resistance of particular bacteria to environmental conditions. The low TC and FC count in the dry season is attributed to the water being low in the dry season, due to lack of recharge, this affects the oxygen content which in turn decreases the multiplication of bacteria (Brady and Ray 1996). Low temperatures in the dry season could also reduce the amount of Oxygen available and hinder the bacterial process (Money, 1988). A water quality assessment in rural Cambodia showed that a shallow aquifer was chemically less of a health risk than deep aquifer, however, micro-biological contamination was considerable in shallow boreholes. However, contamination can be removed by simple household water treatment (Bennett *et al.,* 2010; Sampson, 2008).

5.4 Consumption Patterns

Similar results were reported in a study by Sandiford *et al.,* (1990) in Nicaragua who showed that a decrease in the distance from household to the water source from 1000m to 10m was associated with an increase in per capita water consumption of 20%. Proximity to water resources increases per capita consumption and encourages water use for vegetation and fruit production **(**Lane and Robinson, 2002). A study by Calow *et al.*, 2011, found per capita water consumption to be up to 3L/person/day in Mozambique. Therefore, there is need to increase reliability of sources by improving water coverage and prioritizing vulnerable areas.

A study by Keshavarzi *et al.,* (2006), in Ramjerd area Iran and supported by Sandiford *et al.*, (1990) showed that household size, age and educational levels of the household affect per capita water consumption and concern for use of water for hygiene. Manual hand pumps reduce the amount of per capita borehole water consumption since a lot of energy is used to produce little amounts of water and create congestion at water points increasing water related conflicts (Cloutier and Rowley, 2011). Water is subjected to ownership, trade and pricing based on supply and demand economics and others consider it a common good, subject to principles of human rights and environmental protection (Braunstein, 2007). These conceptual dynamics lower the daily per capita consumption of borehole water.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Dry and wet seasons had impacts on all borehole water parameters determined. They all increased in the wet season except for pH that decreased in the wet season; therefore borehole water became more acidic in the wet season. Generally there was a higher degree of water pollution in the wet season even to objectionable levels in some boreholes. There was variation in all the parameters between the rural and urban areas, where Total and Faecal coliforms varied significantly. Water pH, Total coliform and Faecal coliform affected mostly urban boreholes while iron concentrations were higher in rural boreholes which could be attributed to the impact of high anthropogenic activity.

Distance from borehole, household size and changing seasons all affected amount of borehole water consumed in liters per person per capita per day. Generally the rural communities consumed less amounts of water on daily per capita basis compared to the urban communities in both seasons. Daily per capita water consumption was higher in dry season compared to the wet season due to the lack of other water sources like seasonal surface waters and rain water.

6.2 Recommendations

1. Local communities, borehole management committees together with County Health Personnel should Monitor anthropogenic activities near the boreholes and carry out sanitary inspections so that hygiene and sanitation is maintained around the borehole water resources. Safe distance between the borehole and potential sources of groundwater pollution as per (Table 2.4) should be considered. Development of management and monitoring strategies for each borehole is necessary since groundwater pollution is site specific. Regular water quality assessments and treatment of polluted water be conducted.
2. South Sudan Relief and Rehabilitation Commission (SSRRC) in partnership with NGO's should conduct Water Security Mapping to help identify vulnerable areas where there is high water stress, such that these areas are given priority when it comes to allocation of boreholes.
3. The Government through County water department should explore and employ Water harvesting and Conservation Techniques across Yei County, since borehole water which is the main source of domestic water is not evenly distributed. This is registered successful in West Mundri County, Western Equatoria, especially in Schools and hospitals.
4. There is need for increased number of boreholes in Yei County especially in rural areas where very low amounts of daily per capita water consumption were recorded. This could increase daily per capita consumption by reducing congestion, and proximity since increased access to water resources is associated with a lower risk of water borne diseases.
5. NGO's together with County water technicians should use Submersible solar pumps to create water yards such that several taps are made available from a single borehole to solve the issue of slow manual hand pumps which also increase the time for collecting water. Aweil County in Northern Bahre-Gazel and Raja County in Western Bahre-Gazel have employed water yards from single boreholes and consumption of water has increased in these areas.

6. There is need for formation of borehole management committees and training of local borehole technicians in case of breakdowns. In Mundri West County, water technicians repair minor damages.
7. The Central Government should come up with water policies to govern water resources development and use across the Nation. This should be accompanied by institutional framework to implement the policies; this promotes equity and sustainability in water resources use.

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APPENDICES

Appendix 1. The WHO maximum permissible limits for Drinking water

S/No.	Parameters	WHO Guide line values	Rationale
	Physico-Chemical		
1	pH	6.5 - 8.5	Aesthetically acceptable
2	Total Dissolved Solids (mg/L)	≤ 500	Taste of water is good
3	Nitrate (mg/L)	10	Aesthetic effect
4	Calcium hardness (mg/L)	150	Acceptable taste
5	Iron Total LR (mg/L)	0.03	Brownish discoloration, metallic taste
6	Fluoride (mg/L)	1.5	Tooth staining
7	Chloride (mg/L)	250	Acceptable taste
	Micro-biological		
8	Total Coliform (cfu/100ml)	0	Clinical infections
9	Faecal Coliform (cfu/100ml)	0	Clinical infections

Appendix 2. Summary of the Physico-Chemical and Microbiological parameter results

	Location	Dry Season			Wet Season		
Parameters		Minimum	Maximum	Mean	Minimum	Maximum	Mean
pH	Rural	6.7	8.1	7.4	6.3	7.5	7
	Urban	6	7.8	6.9	5.5	7.3	6.5
TDS (mg/L)	Rural	14	223	97.6	55.5	230	113.1
	Urban	44.8	309.6	144.9	49.1	321.1	156.7
Nitrate (mg/L)	Rural	0	2.61	0.331	0	2.8	2.369
	Urban	0.002	3.8	1.157	0.015	4	1.257
Calcium carbonate (mg/L)	Rural	39	115	74.3	46	111	79.4
	Urban	12	98	52.9	12	110	58.2
Iron (mg/L)	Rural	0.002	0.07	0.027	0.002	0.1	0.031
	Urban	0.001	0.1	0.017	0.001	0.103	0.022
Fluoride (mg/L)	Rural	0.15	1.2	0.56	0.19	1.5	0.68
	Urban	0.12	2.01	0.98	0.19	2.2	1.1
TC (cfu/100ml)	Rural	0	30	6.5	0	40	9.6
	Urban	15	70	37.4	20	100	54.7
FC (cfu/100ml)	Rural	0	12	2.6	0	21	4.5
	Urban	5	46	19.7	12	75	34.3

Appendix 3. Seasonal Variations in pH values between the rural and urban boreholes

RURAL							URBAN					
	OtogoPayam		LasuPayam		MugwoPayam		Yei Town Payam area 1		Yei Town Payam area 2.		Yei Town Payam area 3.	
BH	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS
1	7.3	7.1	7.5	7.0	7.3	7.2	6.5	6.5	6.5	6.5	7.3	7.0
2	7.5	7.2	8	7.5	6.7	6.3	6.0	5.5	7.8	7.1	7.1	6.6
3	7.3	6.7	7.4	6.9	6.9	6.5	7.6	7.3	6.5	6.3	7.0	6.5
4	7.5	7.0	7.5	7.1	7.2	6.6	6.3	6.0	7.0	6.5	7.2	6.8
5	7.4	7.2	7.4	7.2	8.1	7.5	7.0	6.5	6.7	5.7	7.0	6.7

BH= Borehole, DS= Dry Season, WS= Wet Season.

Appendix 4.Seasonal Variations in Total Dissolved Solids (mg/L) between the rural and urban boreholes

RURAL							URBAN					
	OtogoPayam		LasuPayam		MugwoPayam		Yei Town Payam area 1		Yei Town Payam area 2.		Yei Town Payam area 3.	
BH	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS
1	69.0	76.6	79.5	86.1	56.7	63.2	44.8	49.1	287.2	300.5	67.0	71.4
2	90.1	93.9	100.0	110.2	223.0	230.0	140.8	157.4	67.3	76.4	71.2	80.5
3	14.0	18.3	158.3	166.7	67.3	84.8	75.9	81.3	67.1	71.1	231.5	257.0
4	95.5	94.4	95.2	94.5	79.5	83.1	215.0	232.9	215.6	236.9	144.1	150.6
5	77.7	80.0	212.0	220.0	46.9	55.5	309.6	321.1	163.5	186.3	73.1	78.3

Appendix 5. Seasonal Variations in Nitrate (mg/L) between the rural and urban boreholes

RURAL							URBAN					
	Otogo Payam		Lasu Payam		Mugwo Payam		Yei Town Payam area 1		Yei Town Payam area 2.		Yei Town Payam area 3.	
BH	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS
1	0.000	0.000	0.028	0.032	0.020	0.026	0.011	0.015	0.002	0.019	1.200	1.600
2	0.023	0.025	0.038	0.050	2.100	2.300	1.080	1.220	1.120	1.180	2.510	2.510
3	0.025	0.025	0.001	0.001	0.002	0.004	3.800	4.000	0.002	0.025	0.035	0.340
4	0.021	0.028	2.610	2.800	0.001	0.001	2.650	2.720	1.000	1.008	0.060	0.080
5	0.021	0.021	0.042	0.045	0.028	0.030	2.410	2.610	1.450	1.500	0.030	0.035

Appendix 6. Seasonal Variations in Calcium carbonate (mg/L) between the rural and urban boreholes

RURAL							URBAN					
	OTOGO PAYAM		LASU PAYAM		MUGWO PAYAM		YEI TOWN PAYAM AREA 1		YEI TOWN PAYAM AREA 2		YEI TOWN PAYAM AREA 3	
BH	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS
1	45	49	80	85	39	46	56	60	77	88	45	54
2	79	81	70	74	95	101	19	15	24	32	59	65
3	108	111	60	75	80	81	34	39	57	57	84	87
4	115	108	55	60	75	80	51	59	98	110	50	61
5	85	103	85	90	44	47	67	71	60	63	12	12

Appendix 7. Seasonal Variations in Iron (mg/L) between the rural and urban boreholes

RURAL							URBAN					
	OtogoPayam		LasuPayam		MugwoPayam		Yei Town Payam area 1		Yei Town Payam area 2.		Yei Town Payam area 3.	
BH	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS
1	0.040	0.041	0.020	0.025	0.040	0.045	0.021	0.024	0.001	0.007	0.004	0.006
2	0.023	0.025	0.035	0.030	0.002	0.002	0.004	0.006	0.003	0.034	0.001	0.001
3	0.060	0.060	0.021	0.022	0.026	0.030	0.001	0.002	0.002	0.003	0.030	0.031
4	0.020	0.024	0.002	0.003	0.070	0.100	0.002	0.023	0.026	0.030	0.100	0.103
5	0.010	0.012	0.030	0.033	0.005	0.008	0.023	0.028	0.006	0.005	0.025	0.029

Appendix 8. Seasonal Variations in Fluoride (mg/L) between the rural and urban boreholes

RURAL							URBAN					
	OtogoPayam		LasuPayam		MugwoPayam		Yei Town Payam area 1		Yei Town Payam area 2.		Yei Town Payam area 3.	
BH	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS
1	0.40	0.50	0.45	0.49	0.31	0.36	0.21	0.27	1.78	1.82	0.57	0.83
2	1.00	1.20	0.15	0.19	1.20	1.40	1.50	1.66	0.35	0.48	1.01	1.10
3	0.50	0.70	1.00	1.23	0.20	0.23	0.99	1.20	1.00	1.01	1.36	1.47
4	1.10	1.50	0.32	0.38	0.25	0.28	2.01	2.20	1.45	1.60	0.12	0.19
5	0.45	0.50	0.35	0.42	0.72	0.81	1.38	1.43	0.31	0.35	0.67	0.90

Appendix 9. Seasonal Variations in Total Coliform (cfu/100ml) between the rural and urban boreholes

RURAL							URBAN					
	Otogo Payam		Lasu Payam		Mugwo Payam		Yei Town Payam area 1		Yei Town Payam area 2.		Yei Town Payam area 3.	
BH	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS
1	7	5	30	40	3	5	30	40	35	56	70	100
2	0	0	15	17	10	15	40	70	50	75	35	55
3	10	16	8	18	0	0	25	30	34	65	15	40
4	0	2	1	3	0	0	50	75	15	20	65	75
5	5	8	2	4	7	11	45	50	32	40	20	30

Appendix 10. Seasonal Variations in Faecal Coliform (cfu/100ml) between the rural and the urban boreholes

RURAL							URBAN					
	OtogoPayam		LasuPayam		MugwoPayam		Yei Town Payam area 1		Yei Town Payam area 2.		Yei Town Payam area 3.	
BH	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS
1	2	1	12	21	1	2	13	19	13	28	46	75
2	0	0	6	9	4	7	23	55	22	35	13	24
3	5	8	3	7	0	0	14	17	16	35	15	37
4	0	0	0	1	0	0	25	42	5	12	33	46
5	3	5	1	2	2	5	24	37	24	35	10	17

Appendix 11a. Pollution index for Physical parameters

LOCATION	PH		TDS	
	Dry Season	Wet Season	Dry Season	Wet Season
RURAL	1.04	1.01	0.14	0.15
	1.07	1.03	0.18	0.19
	1.04	0.96	0.03	0.04
	1.07	1.00	0.19	0.19
	1.06	1.03	0.16	0.16
	1.07	1.00	0.16	0.17
	1.14	1.07	0.20	0.22
	1.06	0.99	0.32	0.33
	1.07	1.01	0.19	0.19
	1.06	1.03	0.42	0.44
	1.04	1.03	0.11	0.13
	0.96	0.90	0.45	0.46
	0.99	0.93	0.13	0.17
	1.03	0.94	0.16	0.17
	1.16	1.07	0.09	0.11

Appendix 11b. Pollution index for physical parameters in the urban areas

LOCATION	PH		TDS	
	Dry Season	Wet Season	Dry Season	Wet Season
URBAN	0.93	0.93	0.09	0.10
	0.86	0.79	0.28	0.31
	1.09	1.04	0.15	0.16
	0.90	0.86	0.43	0.47
	1.00	0.93	0.62	0.64
	0.93	0.93	0.57	0.60
	1.11	1.01	0.13	0.15
	0.93	0.90	0.13	0.14
	1.00	0.93	0.43	0.47
	0.96	0.81	0.33	0.37
	1.04	1.00	0.13	0.14
	1.01	0.94	0.14	0.16
	1.00	0.93	0.46	0.51
	1.03	0.97	0.29	0.30
	1.00	0.96	0.15	0.16

Appendix 12a. Pollution index for Chemical parameters in Rural borehole water

	Nitrate		**$CaCO_3$**		**Iron**		**Fluoride**	
	Dry Season	**Wet Season**	**Dry Season**	**Wet Season**	**Dry Season**	**Wet Season**	**Dry Season**	**Wet Season**
RURAL	0.000	0.000	0.225	0.245	1.333	1.367	0.267	0.333
	0.002	0.003	0.395	0.405	0.767	0.833	0.667	0.800
	0.003	0.003	0.540	0.555	2.000	2.000	0.333	0.467
	0.002	0.003	0.575	0.540	0.667	0.800	0.733	1.000
	0.002	0.002	0.425	0.515	0.333	0.400	0.300	0.333
	0.003	0.003	0.400	0.425	0.667	0.833	0.300	0.327
	0.004	0.005	0.350	0.370	1.167	1.000	0.100	0.127
	0.000	0.000	0.300	0.375	0.700	0.733	0.667	0.820
	0.261	0.280	0.275	0.300	0.067	0.100	0.213	0.253
	0.004	0.005	0.425	0.450	1.000	1.100	0.233	0.280
	0.002	0.003	0.195	0.230	1.333	1.500	0.207	0.240
	0.210	0.230	0.475	0.505	0.067	0.067	0.800	0.933
	0.000	0.000	0.400	0.405	0.867	1.000	0.133	0.153
	0.000	0.000	0.375	0.400	2.333	3.333	0.167	0.187
	0.003	0.003	0.220	0.235	0.167	0.267	0.480	0.540

APPENDIX 12b. Pollution index for Chemical parameters in Urban borehole water

	Nitrate		**$CaCO_3$**		**Iron**		**Fluoride**	
	Dry Season	**Wet Season**	**Dry Season**	**Wet Season**	**Dry Season**	**Wet Season**	**Dry Season**	**Wet Season**
URBAN	0.001	0.002	0.280	0.300	0.700	0.800	0.140	0.180
	0.108	0.122	0.095	0.075	0.133	0.200	1.000	1.107
	0.380	0.400	0.170	0.195	0.033	0.067	0.660	0.800
	0.265	0.272	0.255	0.295	0.067	0.767	1.340	1.467
	0.241	0.261	0.335	0.355	0.767	0.933	0.920	0.953
	0.000	0.002	0.385	0.440	0.033	0.233	1.187	1.213
	0.112	0.118	0.120	0.160	0.100	1.133	0.233	0.320
	0.000	0.003	0.285	0.285	0.067	0.100	0.667	0.673
	0.100	0.101	0.490	0.550	0.867	1.000	0.967	1.067
	0.145	0.150	0.300	0.315	0.200	0.167	0.207	0.233
	0.120	0.160	0.225	0.270	0.133	0.200	0.380	0.553
	0.251	0.251	0.295	0.325	0.033	0.033	0.673	0.733
	0.004	0.034	0.420	0.435	1.000	1.033	0.907	0.980
	0.006	0.008	0.250	0.305	3.333	3.433	0.080	0.127
	0.003	0.004	0.060	0.060	0.833	0.967	0.447	0.600

APPENDIX 13a. Micro-biological water quality classification according to DWAF, (1996).

	Dry Season		Wet Season			Dry Season		Wet Season	
	TC	category	TC	category		FC	category	FC	category
RURAL AREAS	7	G	5	G		2	M	1	M
	0	G	0	G		0	G	0	G
	10	G	16	M		5	M	8	M
	0	G	2	G		0	G	0	G
	5	G	8	G		3	M	5	M
	30	M	40	M		12	P	21	P
	15	M	17	M		6	M	9	M
	8	G	18	M		3	M	7	M
	1	G	3	G		0	G	1	M
	2	G	4	G		1	M	2	M
	3	G	5	G		1	M	2	M
	10	G	15	M		4	M	7	M
	0	G	0	G		0	G	0	G
	0	G	0	G		0	G	0	G
	7	G	11	M		2	M	5	P

TC: Total coliform, FC: Faecal coliform, G: Good quality, M: Marginal quality, P: Poor quality.

APPENDIX 13b. Micro-biological water quality classification according to DWAF, (1996).

	Dry Season		**Wet Season**			**Dry Season**		**Wet Season**	
	TC	category	TC	category		FC	category	FC	category
URBAN AREAS	30	M	40	M		13	P	19	P
	40	M	70	M		23	P	55	P
	25	M	30	M		14	P	17	P
	50	M	75	M		25	P	42	P
	45	M	50	M		24	P	37	P
	35	M	56	M		13	P	28	P
	50	M	75	M		22	P	35	P
	34	M	65	M		16	P	35	P
	15	M	20	M		5	M	12	P
	32	M	40	M		24	P	35	P
	70	M	100	P		46	P	75	P
	35	M	55	M		13	P	24	P
	15	M	40	M		15	P	37	P
	65	M	75	M		33	P	46	P
	20	M	30	M		10	M	17	P

TC: Total coliform, FC: Faecal coliform, G: Good quality, M: Marginal quality, P: Poor quality.

Appendix 14. Summary of average consumption per area of study

	Distance	**<500m**	**<500m**	**>1km**	**>1km**
	Location	DS	WS	DS	WS
Rural areas	Otogo	13.7	10.3	11.8	7.3
	Lasu	15.2	12.5	12.4	8.7
	Mugwo	13.5	11.4	11.9	7.8
Urban areas	Yei town 1	20.1	15.3	17.8	10.0
	Yei town 2	21.1	17.1	18.4	12.3
	Yei town 3	20.4	18.0	17.3	12.5

DS= Dry Season WS= Wet Season

Appendix 15. Average Household members and respective daily per capita water consumption

		<500M from the water source			**>1KM from the water source**		
		Av. H/H size	Av. Consumption Dry Season	Av. consumption Wet Season	Average H/H size	Av. Consumption Dry Season	Av. consumption Wet Season
Rural	Otogo	6.2	13.9	10.8	6.7	11.9	7.5
	Lasu	6.4	15.2	12.5	6.2	13.2	8.8
	Mugwo	7.3	14.2	12.2	7.4	12.0	7.7
Urban	Yt1	8.0	21.9	16.2	6.0	18.3	10.4
	Yt2	6.8	22.0	17.5	5.8	18.5	12.3
	Yt3	6.3	21.3	18.6	5.6	18.0	12.9
YEI COUNTY		**6.8**	**18.1**	**14.6**	**6.3**	**15.3**	**9.9**

Appendix 16. Seasonal Per capita borehole water consumption data in the selected three rural areas

RURAL AREA 1 (OTOGO PAYAM)						
B/H	H/H No.	DS	WS	H/H No.	DS	WS
<500m from B/H				> 1Km from B/H		
O1	6	12.5	10.0	7	10.0	5.7
O1	4	12.0	10.0	5	10.0	8.0
O1	6	13.0	8.3	6	11.3	6.7
O1	10	11.5	8.5	12	10.7	6.3
O1	4	13.8	12.5	3	11.7	6.7
O2	9	12.0	10.0	9	10.6	7.8
O2	4	13.8	12.5	4	12.0	8.8
O2	5	10.0	8.0	9	11.7	6.7
O2	5	13.0	9.0	4	9.5	5.0
O2	3	13.3	13.3	6	10.8	5.8
O3	9	13.9	10.0	10	9.8	6.0
O3	10	13.5	9.0	8	11.9	5.0
O3	4	13.3	10.0	9	11.4	6.7

RURAL AREA 2 (LASU PAYAM)						
B/H	H/H No.	DS	WS	H/H No.	DS	WS
	<500m from B/H			> 1Km from B/H		
L1	7	14.3	11.4	11	11.8	7.3
L1	3	18.3	13.3	5	13.0	11.0
L1	4	17.5	15.0	7	14.3	11.4
L1	5	18.0	15.0	4	15.0	8.8
L1	6	15.0	13.3	10	9.0	4.0
L2	10	11.0	8.0	7	12.9	7.1
L2	4	15.0	15.0	4	13.8	10.0
L2	9	14.4	11.1	14	14.3	11.4
L2	13	16.9	13.8	5	15.0	8.0
L2	4	17.5	15.0	6	13.3	8.3
L3	8	13.1	12.5	11	13.6	7.3
L3	9	15.6	11.1	5	13.0	8.0
L3	7	15.7	12.9	6	11.7	6.7

RURAL AREA 3 (MUGWO PAYAM)						
B/H	H/H No.	DS	WS	H/H No.	DS	WS
	<500m from B/H			> 1Km from B/H		
M1	4	15.0	15.0	7	10.7	5.7
M1	6	12.5	8.3	9	10.6	6.7
M1	8	12.5	11.3	7	10.7	7.9
M1	6	10.8	10.0	8	10.6	6.9
M1	15	13.3	10.7	11	11.8	7.3
M2	11	15.0	12.7	7	12.9	8.6
M2	11	17.1	14.5	5	13.0	9.0
M2	5	19.0	18.0	9	14.2	8.9
M2	10	13.5	10.0	7	14.3	11.4
M2	6	18.0	13.3	4	14.5	8.8
M3	5	12.0	10.0	16	10.2	7.5
M3	2	16.5	15.0	4	9.5	7.0
M3	8	11.6	11.3	7	11.4	5.7

O3	3	15.0	13.3	4	10.8	10.0
O3	10	12.8	8.0	3	15.0	13.3
O4	3	15.0	13.3	4	12.5	10.0
O4	8	13.5	8.5	4	18.8	10.0
O4	8	11.6	9.1	10	12.8	7.8
O4	7	16.4	11.4	9	10.9	6.4
O4	9	14.2	11.1	5	11.6	6.0
O5	5	18.0	14.0	7	12.1	5.7
O5	4	15.0	15.0	6	13.3	6.7
O5	7	17.1	12.9	5	13.6	8.0
O5	10	14.0	11.0	8	12.5	10.0
O5	3	20.0	10.0	11	13.2	9.1

L3	6	15.0	13.3	4	13.8	10.0
L3	5	14.0	10.0	5	15.0	8.0
L4	8	17.5	15.0	5	12.0	8.0
L4	6	16.7	13.3	11	13.2	9.1
L4	5	14.0	12.0	5	12.0	12.0
L4	5	16.0	12.0	3	11.7	10.0
L4	5	14.0	12.0	6	13.3	8.3
L5	9	14.4	11.1	4	12.0	6.3
L5	4	13.8	10.0	3	13.3	6.7
L5	5	14.0	12.0	7	12.9	10.0
L5	9	14.4	12.2	4	15.0	12.5
L5	4	14.5	12.5	2	15.0	10.0

M3	10	11.8	9.0	5	14.0	8.0
M3	3	15.0	13.3	15	8.9	6.0
M4	11	11.8	10.9	8	11.6	7.5
M4	6	11.7	10.0	4	8.8	5.0
M4	8	9.4	6.9	4	9.5	5.0
M4	5	14.0	10.0	4	12.0	7.0
M4	9	8.9	6.7	4	12.0	6.3
M5	8	12.5	12.5	11	14.1	10.9
M5	6	19.2	16.7	4	13.3	10.0
M5	10	16.0	15.0	6	13.0	6.7
M5	6	15.8	13.3	10	14.5	10.0
M5	3	21.0	20.0	8	12.9	9.4

Appendix 17. Seasonal Per capita borehole water consumption data for the three urban areas in Yei County

URBAN AREA 1						
B/H	H/H No.	DS	WS	H/H No.	DS	WS
<500m from B/H				> 1Km from B/H		
Y11	7	21.4	10.0	8	16.3	7.5
Y11	6	24.2	16.7	8	16.6	7.5
Y11	4	21.3	15.0	6	16.7	10.0
Y11	11	17.3	13.6	4	23.8	10.0
Y11	5	23.0	16.0	9	15.3	6.7
Y12	5	25.0	20.0	10	24.3	14.0
Y12	7	22.9	17.1	5	21.6	15.0
Y12	5	27.0	18.0	6	23.3	10.0
Y12	4	23.8	15.0	5	24.0	16.0
Y12	3	26.7	20.0	4	22.5	12.5
Y13	9	21.4	15.6	7	16.4	8.6
Y13	6	20.8	20.0	5	14.0	8.0
Y13	4	23.3	15.0	3	17.7	10.0
Y13	8	23.8	15.0	6	16.7	10.0

URBAN AREA 2						
B/H	H/H No.	DS	WS	H/H No.	DS	WS
<500m from B/H				> 1Km from B/H		
Y21	7	24.7	20.0	4	20.0	10.0
Y21	4	24.5	15.0	5	21.0	16.0
Y21	3	29.3	20.0	7	19.3	13.6
Y21	6	24.2	16.7	8	17.9	10.0
Y21	7	24.3	21.4	5	21.0	16.0
Y22	9	21.1	16.7	10	18.5	14.0
Y22	9	18.7	15.6	3	18.3	11.7
Y22	8	20.6	17.5	8	19.1	12.5
Y22	5	25.0	20.0	5	18.0	12.0
Y22	3	25.0	16.7	5	23.0	15.0
Y23	6	19.2	13.3	8	18.1	12.5
Y23	4	29.5	22.5	9	17.0	11.1
Y23	9	23.1	20.0	10	18.0	13.5
Y23	6	23.3	20.8	4	18.8	10.0

URBAN AREA 3						
B/H	H/H No.	DS	WS	H/H No.	DS	WS
<500m from B/H				> 1Km from B/H		
Y31	4	20.8	20.0	2	19.0	13
Y31	3	25.0	20.0	4	18.8	14
Y31	5	20.0	16.0	6	18.3	13
Y31	3	22.7	20.0	8	19.8	13
Y31	5	17.6	12.0	9	13.1	9
Y32	11	17.7	17.3	9	17.2	12
Y32	6	22.2	20.0	4	21.3	14
Y32	4	23.3	22.5	3	17.7	17
Y32	8	20.6	17.5	10	15.8	12
Y32	5	20.0	17.0	7	17.9	11
Y33	2	27.5	22.5	8	19.4	14
Y33	9	17.0	16.1	4	17.5	10
Y33	12	20.3	16.7	4	17.5	11
Y33	11	16.2	13.6	4	17.5	15

Y13	18	17.1	13.3	3	20.0	11.7
Y14	6	23.0	16.7	5	15.0	8.0
Y14	22	15.8	13.6	6	12.5	6.7
Y14	6	18.8	13.3	6	16.3	10.0
Y14	5	22.0	16.0	7	16.4	11.1
Y14	5	24.6	16.0	9	19.4	11.1
Y15	7	18.3	17.1	5	14.0	8.0
Y15	7	22.6	17.1	5	17.6	12.0
Y15	24	14.6	12.5	5	19.6	10.0
Y15	4	23.8	20.0	6	19.7	12.5
Y15	11	25.3	21.8	8	17.5	12.5

Y23	10	18.3	15.5	6	16.7	10.0
Y24	12	18.3	16.7	5	15.6	9.0
Y24	6	20.0	16.7	6	18.3	12.5
Y24	4	21.3	15.0	7	17.6	11.4
Y24	6	23.0	15.8	4	15.0	12.5
Y24	9	18.7	16.1	3	26.0	13.3
Y25	7	17.1	14.3	4	14.5	10.0
Y25	9	19.2	15.6	6	19.2	13.3
Y25	4	22.0	20.0	5	17.6	16.0
Y25	10	20.5	18.8	4	15.8	10.0
Y25	6	19.2	15.8	3	19.3	11.7

Y33	4	25.0	23.8	7	14.0	11
Y34	10	19.8	16.0	6	16.3	12
Y34	6	22.2	16.7	5	18.0	12
Y34	5	21.0	20.0	4	22.0	18
Y34	8	22.3	20.0	5	17.0	11
Y34	4	18.8	17.5	4	17.0	15
Y35	10	20.0	18.0	5	20.0	12
Y35	4	20.8	18.8	3	18.3	12
Y35	3	26.7	20.0	5	16.0	12
Y35	8	21.9	20.6	9	18.9	16
Y35	8	24.1	22.5	5	21.6	16

Appendix 18. Questionnaire

Dear respondent,

You have been selected in the above titled study which is being carried out as part of an education research in partial fulfillment of the requirements for the award of a Master's of Science degree in Environment and Natural Resources of Makerere University. Your co-operation in filling this questionnaire will lead to the success of the survey. Responses shall be treated confidentially and apply only for education purposes.

Date of Survey:……………………………………..

Name of Respondent:………………………………

Signature of Respondent:…………………………..

BACKGROUND INFORMATION

1. SEX: (i) Male ☐ (ii) Female ☐
2. AGE: (i) (10-18) ☐(ii)(19-25)☐(iii) (26-40) ☐(iv) (41-60) ☐(v) (61 and above) ☐
3. MARITAL STATUS: (i) Single☐ (ii) Married ☐(iii) Divorced ☐v) Widowed ☐

4. Details of your Household:

Members of Household	Number	Sex	Age	Employment				Education level	Water consumed/day in litres	
				Formal	Informal/ part time	Self employed	None		Borehole	Other sources
Head of the House/Father										
Spouse/Wife										
Sons										
Daughters										
External Family members										

Hint on level of education: (i) Primary (ii) Secondary (iii) Vocational (iv) Tertiary

5. What are the sources of the water that you consume as a household? (i) Borehole water ☐
   (ii) Rain water ☐(iii) River water ☐(iv) Stream water ☐v) Well water ☐
   State any other sources of water that you use?...
6. What is the overall number of 20 liter jerry cans of water that you use as a family. Considering all sources of water?..........................
7. How many 20 liter jerry cans of borehole water tdo you use as a family in?..
8. Is the amount of water you use as a family sufficient for you? (i) Yes ☐(ii) No ☐
9. Would you consume more amounts of water given the right conditions? If so How many more liters would you consume?...
10. Is there any variations in amount of water consumed in dry and wet seasons? If yes, by what amounts…………………………………………………………………………………
11. What are the major hindrances in use of more water for your household?
    ……………………………………………………………………………………………..
12. Do you boil borehole water before drinking? (i) Yes ☐ (ii) No ☐
    If yes, why?...
13. What negative things have you found with the water itself/ Quality?
    (i) Taste ☐ (ii) colour ☐(iii) Odor ☐
    State any other thing that you dislike about the water?..
14. What human activities are being carried out about 30m from the borehole?
    (i) Toilet establishment ☐i) Animal farm ☐) Agricultural practices ☐
    (iii) Grave yard ☐ (iv) Petrol Station ☐
    State any other activities…………………………………………………………………
15. What challenges have you faced or identified with the use of borehole water resources? (i) Quantity ☐i) Quality ☐i) Distance ☐) Seasonality ☐Fees ☐
    (vi) Restrictions to the amount of water consumed per household ☐
    (vii) Management ☐(viii) Congestion ☐ . If management state areas of concern
    ……………………………………………………………………………………………

State any other challenges?...

16. What are your observations about the quality of borehole water, comparing the dry and wet seasons……………………………………………………………………………………….

………………………………………………………………………………………………..

17. What suggestions do you have for improving borehole water quality and services?

(i)……………………………………………………………………………………….

(ii)……………………………………………………………………………………..

(iii)……………………………………………………………………………………….

(iv)……………………………………………………………………………………….