USE OF CONSTRUCTED WETLANDS AND SAND FILTERS TO IMPROVE THE QUALITY OF WATER IN BOMACHOGE-BORABU, KENYA

BY

CHARLES JUMBE NYABAYO

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN ZOOLOGY (ANIMAL ECOLOGY), SCHOOL OF SCIENCE, UNIVERSITY OF ELDORET, KENYA

JULY, 2016

DECLARATION

Declaration by the candidate

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Signature:………………………………Date………..………………………..
Charles Jumbe Nyabayo
(SC/PHD/Z/001/13)

Declaration by Supervisors

This thesis has been submitted for examination with our approval as university Supervisors.

Signature:…………………………………Date……..……………………………
Dr. Emily J. Chemoiwa
Department of Biological Sciences
University of Eldoret, Kenya.

Signature………………………………Date………..……………………………..
Dr. Lizzy Mwamburi
Department of Biological Sciences
University of Eldoret, Kenya.

DEDICATION

To my wife Mrs. Rael Jepkogei and my lovely sons, Brian Kibet, Belden Osoro and daughter, Elid Cherono.

ACKNOWLEDGEMENT

I would like to express my gratitude to all those who gave me the possibility to write and complete this thesis. First, I would like to give my special thanks to Almighty God, whose grace, love and care enabled me to complete this work. To God be the glory. From University of Eldoret, I am deeply indebted to my supervisors Dr. Emily J Chemoiwa and Dr. Lizzy A. Mwamburi whose corrections, stimulating suggestions and encouragement helped me in all the time of research for writing this thesis. I would like to thank Mr. Richard Nyagwachi technician Department of Biological sciences for his care and expert support during laboratory examination of samples. I want to thank Mr. Wilson Okenye chief technician biological sciences department for his encouragement and concern during data collection, coding and preparing this work. My appreciation also goes to all support staff of Biological Sciences University of Eldoret for their moral support. I gratefully acknowledge the support of my mentors' Prof. A. O. Onkware and Prof R. S. Ochieng where this thesis began and was completed with their invaluable support and encouragement, may God's grace bond us forever.

ABSTRACT

Degradation of aquatic ecosystems resulting from pollution, poor waste disposal management practices and inadequate knowledge is of concern. Water sources in developing countries are abundantly contaminated with animal and human waste, chemicals and microbial agents, thereby causing loss of vast diversity of aquatic organisms. There is need to address this problem using efficient and affordable methods. Constructed wetlands and sand filters have been effectively used individually to improve water quality and reduce pollution levels. This study aimed at integrating constructed wetlands and sand filters to improve microbiological and physico-chemical parameters of domestic water with the hope of reducing waterborne diseases and loss of aquatic life. The study was conducted between March 2015 and March 2016 in Bomachoge Sub County, Kenya. The study sites included: Bokimonge, Magenche, Bombaba and Boochi. The study evaluated the combined effects of constructed wetlands and sand filters on selected water parameters. The experimental set up was a two level factorial design with three plant-type cultures (*Colocasia esculenta* and *Cyperus esculentus* as monocultures and a polyculture of the two plants) and 4 sand grain sizes (0, 0.5, 1.0 and 2.0 mm) as factors. The study further investigated the effects of pit latrine location, construction and designs on well and spring water quality. Data was collected using questionnaires, observations, measurements and laboratory examination of selected water parameters. The collected data was coded, scored and analyzed using SPSS program and a two-way ANOVA after appropriate transformations. Results indicated that plant-type, sand grain size and an interaction between the two factors had significant effects ($P \leq 0.05$) on the 12 microbiological and physico-chemical parameters assessed in this study. Although there were no significant differences in the removal efficiency of *C. esculenta* alone and with the sand filters, the addition of sand filters statistically improved the removal efficiency of *C. esculenta.* A combination of *C. esculenta* and the sand filters had the highest removal efficiency of 98% (Total coliforms (TC)), 98% (Fecal coliforms (FC)), 99% (*E. coli* (EC)), 99% (Fecal *Streptococci* (FS)), 95% (NO_3) and PO_4 (97%). A monoculture of *C. esculentus* reduced TC (21%) and FC (9%). Addition of sand filters to *C.esculentus* improved its reduction efficiency by an additional 64% and 60% for TC and FS respectively. A polyculture of *C. esculentus* and *C. esculenta* alone reduced TC, FC and EC by an average 26%, 36% and 31% respectively and further reduced the parameters by an average 54%, 50% and 60% for TC, FC and EC respectively on addition of the sand filters. The results revealed that water from wells and springs in this study were highly contaminated. The short horizontal and vertical separation distance between the fecal disposal point and hand dug well impacted on water pollution. However, results indicated that there were 0 cfu/100mls observed above 60 meters and vertical separation distance of 1.14 meter equally recorded 0 cfu/100mls. It was concluded that *C. esculenta* was efficient in improving the quality of water to almost 0 cfu/100mls as per WHO standards. It was recommended that further research be carried out on other native plant species and sand filters in others areas of Kisii county, to determine their effects on water quality. In addition, there should be good waste disposal systems with appropriate design, location and maintenance.

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ACRONYMS AND ABBREVIATIONS

APHA: American Public Health Association.

ANOVA: Analysis Of Variance.

BOK: Bokimonge.

BOM: Bombaba.

BOO: Boochi

BOD: Biological Oxygen Demand.

CW: Constructed Wetland.

COND: Conductivity.

DO: Dissolved Oxygen.

EC: *Escherechia coli.*

FAO: Food and Agriculture Organization.

FC: Faecal Coliform

FS: Faecal *Streptococcus*

FAU: Formazin Attenuation.

IEBC: Internal Electoral and Boundaries Commission.

MAG: Magenche.

pH: Potential Hydrogen.

NTU: Nephelometric Turbidity Unit.

TC: Total Coliforms.

TEMP: Temperature.

WHO: World Health Organization.

CHAPTER ONE

INTRODUCTION

Background information

Most water sources in developing countries are unsafe for domestic use and cannot support aquatic life because they are contaminated with chemicals and microbial agents due to poor management of wastes or are inadequately treated (Cheesbrough, 2006). Consequently, this has lead to water related infections such as typhoid and amoebiasis (KCDDP, 2008). Inadequate knowledge about the routes of water contamination has created a big gap between water quality and its effects on human health and ecosystems (Olivieri *et al.*, 1977).

Utilization of contaminated water for drinking and bathing is one of the routes for water related illnesses that may result in loss of life worldwide (Sobsey *et al*., 2008). The presence of microbial and chemicals in water suggest that the water is potentially harmful to human health and aquatic life if used untreated (APHA, 2005). Hence, there is need for a sustainable, cost effective and reliable water treatment method that should provide safe drinking water by use of locally available and accessible resources in rural communities of developing countries (Sobsey *et al*., 2008). Unfortunately, some of the technologies commonly used worldwide are too expensive and complex and incompatible with local customs and beliefs (Elliott *et al*., 2008). Thus, there is need for effective yet affordable methods of water treatment that are acceptable. The most effective and less expensive water treatment methods such as vegetated wetlands and sand filters have been used individually and successfully (Elliott *et al*., 2008).

Wetlands are transitional areas between terrestrial and aquatic ecosystems (Diakova *et al.,* 2006; Davila *et al.,* 2006). They play important roles in the ecosystem such as biological filters that can assimilate large amounts of environmental contaminants therefore improving the quality of water (Sheoran, 2006). Natural wetlands are currently degraded by both natural and anthropogenic activities, which deteriorate their quality, and push them to near extinction in the process of unorganized development activities. This has given rise to the need for suitable conservation strategies and technologies of utilizing wetlands (Davila *et al.,* 2006). Unfortunately, less attention has been given to wetland losses worldwide (Reed and Brown, 1992). The degradation of the wetlands has affected their functions, affecting the ecological balance in the natural environment (Davila *et al.,* 2006).

Generally, water quality evaluation of wetlands leads to information about their misuse by indicating their pollution levels (Ignatius *et al*., 2006). Gale *et al.,* (1993) defined water quality as the overall direction and purpose of understanding aquatic life. Since the quality of aquatic life depends on the water quality, the biological integrity of wetlands is the driving force for their sound ecological functioning (Ignatius *et al*., 2006). Wetlands support a vast diversity of organisms among them fish, birds, reptiles, amphibians and mammals (Gale *et al*., 1993).

Constructed wetlands are complex engineered ecosystems designed to unload pollutants from water by enhancing processes that occur in natural wetlands within a confined environment with regulated conditions (Headley and Tanner, 2006). These wetlands have become a cost-effective, low energy, low technology solution to degradation of naturally wetlands (Ignatius *et al*., 2006). Constructed wetlands are designed to increase the predictability and efficiency of treatment, enabling use of wetlands that are less land intensive (Reed and Brown, 1992). However, there is a need to improve their design and operation with respect to their long-term ecological and environmental conservation (Coleman *et al.*, 2011).

Constructed wetlands are used around the world to treat domestic water, agricultural, industrial wastewater and storm water runoff (Coleman *et al.*, 2011). They are designed either as free-water surface wetlands with standing water or as subsurface flow wetlands with water below the soil or on the surface (Kadlec and Knight, 1996). Contaminated water moves with regulated velocity either horizontally or vertically through the established plants (Reed and Brown, 1992). Contaminated water in constructed wetlands is treated by physical, chemical and biological interactions between water and plants or uptake by plants (Weisner *et al*., 1994). In previous studies relatively few plant species were used in constructed wetlands (Richardson *et al.*, 1987). Some of the plant species used in wetlands includes *Typha* spp and *Scirpus spp* (Reed and Brown, 1992).

Some studies have reported improved wastewater treatment by use of various native plant species such as *Phragmites* and water hyacinth in wetlands (Coleman *et al.*, 2011). In addition, it is important to determine the improvement of wastewater treatment, domestication of plant species in wetlands in order to find out species-specific effects using controls to check the efficacy of pollutant removal from water (Steer *et al*., 2003). Generally, plants improve quality of wastewater through the direct uptake of nutrients, but plant contents cannot account for nutrient removal from wastewater but can influence microbial activity (Kadlec and Knight, 1996). In this regard, *Scirpus* spp and *Carex* spp been reported to have greater nutrient removal than *Typha* spp (Steer *et al*., 2003).

In addition, plants provide the attachment sites and release off carbon exudates and oxygen, believed to be the primary role in water treatment in wetlands (Tanner, 2002). Constructed wetlands, function by the providing a diverse habitat, and great benefit of increased use of native plant species and a conservation strategy since the same local plant species have been shown to provide efficient water treatment, reduced invasive and exotic plant species that may come with negative implications into the ecosystem (USEPA, 2000). Many studies have compared the performance of different plant species individually (monoculture) and combining different species (polyculture) in constructed wetlands, but more emphasis has been on monoculture performance (Fraser *et al.*, 2004). It has been hypothesized that polyculture species in a wetland maximize pollutant removal efficiency by means of species interactions and synergies (Fraser *et al.*, 2004).

Plant diversity in constructed wetland may improve tolerance to changing environmental conditions and function in stabilizing the biogeochemical processes in the controlled environment (Coleman *et al*., 2001). Combining plant species may contribute to optimal below ground biomass distribution and increase wetland productivity through more efficient use of available resources hence reducing chemical load in water (Coleman *et al*., 2001). Previous studies done on polyculture plant species used in constructed wetlands have not reported high performance in pollutant removal, and these studies are rarely replicated or they do not compare the performance of polyculture to full range of monoculture species in constructed wetlands, therefore species richness performance in constructed wetlands remains unclear (Cardinale *et al.,* 2011).

Sand filters are considered suitable for water treatment by developing communities due to their simple design, basic maintenance procedures and low labor costs (Elliott *et al*., 2008). The performance of sand filters is controlled by an ecosystem of living organisms whose activities are affected by the raw water quality and temperature (Elliott *et al*., 2008). The operation of the filters depends on sand grain sizes, flow rate, retention time and sand bed depth as the main parameters (Muhammed *et al.,* 1996). In the current study, we envisage combining the use of constructed wetlands and sand filters to improve the quality of domestic water.

The environmental degradation caused by inadequate disposal of fecal matter can be expressed by in terms of contamination of surface and underground water. This may be through seepage and soil contamination through direct contact due to poor sanitary practices (Obabori, 2009). To prevent impacts on human health, fecal matter must be properly disposed by use of conventionally accepted means (Obabori, 2009). With the emerging concern on large quantities of human and animal waste being produced, both in the form of solid and liquid wastes, their management becomes one of the key focus of sustainable development principles in resource conservation (Renkow and Otieno, 2008).

Poor hygiene conditions accelerate the fecal–oral–route of pathogen transmission (Tebbut, 1992). Pathogen levels in water and predispositions of persons play an important role in infections (Olivieri *et al.,* 1997). Fecal contamination of domestic drinking water sources such as hand dug wells and springs can be detected by the presence of indicator organisms such as fecal coliforms, *E. coli* and Fecal *Streptococcus* (APHA, 1998).The most acceptable bacterial indicators of fecal pollution in water have been the coliform group of bacteria (APHA, 1998). Generally, coliforms are capable of growth at 44.5^0C and although they are often assumed to be *Escherichia coli,* this is probably a big assumption since other strains are often present among the colonies that grow well in this temperature (Mishra *et al.*, 1968).

Many international and national standards now incorporate these indicators to determinate the quality of water (Water Quality Criteria, 1968). Another group of bacteria, the fecal streptococci, total coliforms and *E. coli* have also been advocated as indicator organisms for contaminated water for water contamination from sources like infiltration and seepage from fecal disposal points (Mishra *et al.,* 1996). A more desirable bacteriological indicator of water contamination should not only be able to identify the degree of water contamination or the presence of indicator organism, but also distinguish the source of pollution. It should identify the specific source of contamination whether from warm blooded animal or human feces, because the determination of source of fecal pollution is very important in assessment of water quality and waste management in the ecosystem (Coyne and Howell, 1994).

A greater number of *Streptococci* in all warm-blooded animals' feces are closely associated with their number in polluted water. This is the basis of identifying the source of pollution. Thus, if the fecal coliform (FC) / fecal Streptococcus (FS) ratio is above four is assumed that the fecal source is of human origin. While an FC/ FS ratio of below one is an indication that the fecal source is likely to be from other warm blooded animals. However, an FC/FS ratio of less than four and more than one indicates that the fecal source is probably of a mixture of human, animal fecal matter and industrial waste (Coyne and Howell, 1994).

Pit latrine systems are the most preferred fecal disposal structures in developing countries due to their affordability and utilization (Esrey *et al.,* 2001). Despite the numerous merits, pit latrine systems contribute to the highest risk in contaminating underground water sources such as shallow wells, springs and boreholes (Esrey *et al.,* 2001). Pit latrine facilities contaminate underground water through seepage, infiltration and direct fecal contact (Obabori, 2009). The effect of horizontal distance between hand-dug wells and pit latrines on water contamination has been studied by several authors (Morgan, 1990; Kimani and Ngindu, 2007; WHO, 2007). Both horizontal and vertical distances between pit latrines and hand-dug wells greatly influence the levels of fecal contamination of water sources (Cave and Kolsky, 1999). According to Sugden (2004) the vertical separation between the depths of a well and pit latrine should always be above 1.5 meters. This separation distance will ensure that pathogens dry and die naturally within the soils.

Testing for the presence of fecal bacteria and other physico-chemical parameters in water are a sure way of determining water quality (Cheesbrough, 2006). In the current study, the samples of effluents and influents from reservoir, vegetated constructed wetlands and sand filters were examined. The aim was to determine the levels of bacteria and physico-chemical parameters that would attest to the water quality. In addition, fecal disposal methods were assessed; Underground water sources and conditions that influence water contamination were also examined. The study sought to establish the level of pollutants in the underground water sources.

1.2 Statement of the Problem

Most water sources in developing countries are unsafe for domestic use and cannot support aquatic life because they are contaminated with chemicals and microbial agents due to poor management of wastes or are inadequately treated (Cheesbrough, 2006). The water sources used by humans and animals in Bomachoge Borabu area receive inadequate treatment in reduction of microbial and chemical pollutants. Consequently, this has lead to water related infections such as typhoid and amoebiasis (KCDDP, 2008). Inadequate knowledge about the routes of water contamination has created a big gap between water quality and its effects on human health and ecosystems (Olivieri *et al.,* 1977).

In addition, direct fetching and use of water from water sources like wells, springs and community water reservoirs by local residents contributes to the introduction of microbes and chemicals when hygienic standards are not met (Eschol *et al.,* 2009). This practice is evident in settlement areas of the current study area. It is therefore important that the relationship between water quality and health be fully embraced by engineers and researchers so that water resources users can be sensitized on water contamination and associated health impacts. It is against this background that this study was carried out to ascertain the quality of water in wells, community reservoirs and springs, and also assess the effectiveness of using constructed wetlands and sand filters in reducing the pollutant load in water sources.

1.3 Justification

The high population in Bomachoge sub county generally limits accessibility to clean water and proper disposal of fecal matter, making this area an important study area (Curtis *et al.*, 2001). The increase in human and animal population result in huge fecal output and in return poses serious health problems that are costly in terms of health management and time. Therefore research that could aid in strategic management of safe disposal of animal fecal matter and less costly methods of removing contaminants from water was necessary (Kirimi, 2008). The number of people without access to safe water and sanitation in both urban and rural areas is rising sharply in developing countries as a result of rapid increase in human population.

The study is important because it will provide the water managers and water resource users with information on less costly, reliable methods of purifying water by use of locally available resources like sand and native plants species such as *Colocasia esculenta* (Bindu *et al*., 2005) and *Cyperus. esculentus* (Steer *et al*., 2003).In the current study, these plant species will be planted in a constructed wetland as either monoculture or polyculture and their efficiency in pollution reduction determined. Results of the current study will form a basis for conservation of not only these plant species in particular but also for large scale wetland conservation. In addition, a guide on safe waste disposal methods that avoided further contamination of water sources will be established (Aulia, 1994) and thus reduced incidences of disease outbreaks, making vision 2030 achievable in Bomachoge sub-county.

1.4 Objectives

1.4.1 General objective

To determine the effects of constructed wetlands integrated with sand filters to improve the quality of water contaminated by fecal disposal facilties in Bomachoge Borabu sub-county.

1.4.2 Specific objectives

i) To determine the effects constructed wetlands vegetated with monocultures of either *Colocasia esculenta* or *Cyperus esculentus* and a polyculture of the two plants with sand filters on water quality.

ii) To determine the relationship between fecal disposal methods and water contamination in hand dug wells and natural springs of Bomachoge Borabu sub- county.

iii) To establish the effect of horizontal distance between pit latrines and hand dug wells on the levels of contaminants in water of Bomachoge Borabu sub-county.

iv) To establish the effect of vertical distance between the bottom of pit latrines and hand dug wells on the levels contaminants in water of Bomachoge Borabu sub-county.

1.5 Hypotheses

H_O. Wetlands vegetated with monocultures of either *Colocasia esculenta* or *Cyperus esculentus* or a polyculture of the two plants integrated with sand filters have no effect on the water quality.

H_O. The level of water contaminants in hand dug well and natural springs have no relationship with fecal disposal facilities in Bomachoge Borabu sub county.

H_O. There is no relationship between the horizontal distance between pit latrines and hand dug wells on the levels of contaminants in water of Bomachoge Borabu sub county.

H_O. There is relationship between the vertical distance between the base of pit latrines and hand dug wells on the levels of contaminants in water of Bomachoge Borabu sub county.

CHAPTER TWO
LITERATURE REVIEW

2.1 Effects of constructed vegetated wetlands together and sand filters on water quality

2.1.1. Use of natural and constructed wetlands

Wetlands are highly effective in purification of contaminated water, they are commonly known as biological filters and they provide protection of water sources such as lakes, estuaries and ground water (Kadlec *et al*., 1996). Although wetlands have always served this purpose, research and development of wetland treatment technology is a relatively recent phenomenon (Kadlec *et al*., 1996). The use of both natural and constructed wetlands for water and wastewater treatment has gained considerable popularity worldwide in recent years (Reddy *et al.*, 1994).

The goal of wastewater treatment is that of removal of contaminants from the water in order to decrease the detrimental impacts of humans and the rest of the ecosystem (Ignatius *et al*., 2006). The undesirable substances in water may directly or indirectly affect human or environmental health (Kadlec *et al*., 1996). Many contaminants including a wide variety of organic compounds are toxic to human and other organisms (Kadlec *et al*., 1996). There are other types of contaminants that are not toxic, but nevertheless pose an indirect threat to human wellbeing. For instance loading of nutrients like nitrogen and phosphorous to water sources can result to excessive growth of algae and unwanted vegetation, diminishing the economic and recreational values of lakes, bays, streams and springs (Kabede, 1978). Wetlands have proved to be well suited for treating municipal waste water, agricultural waste water and run offs industrial waste water and storm water runoff from urban, suburban and rural areas (Reddy *et al.*, 1994).

A number of physical, chemical and biological processes operate concurrently in constructed and naturally wetlands to provide contaminant removal (Kaseva, 2004). Knowledge of the basic concepts of these processes is extremely helpful for assessing the potential applications, benefits and limitations of wetland treatment systems (Reddy *et al.*, 1994).Wetlands are also capable of providing highly efficient physical removal of contaminants associated with particulate matter in water (Bindu and Ramasany, 2008). Surface water typically moves slowly through wetlands due to characteristic broadsheet flow and resistance provided by rooted and floating plants and this provides sufficient time for absorption of impurities by plants (Kadlec *et al*., 1996).

Biological removal is perhaps the most important pathway for contaminant removal in wetlands. Probably the most widely recognized biological process for contaminant removal in wetlands is plant uptake (Bindu *et al.*, 2008). Contaminants that are also in form of essential plant nutrients, such as nitrates, ammonium and phosphate, are readily taken up by wetland plants during water purification (Reddy *et al.*, 1994). However, many wetland plants are capable of uptake, and even significant accumulation of, certain toxic metals such as cadmium and lead. The rate of contaminant removal by plants varies widely, depends on the plant growth rates, concentration of the contaminant in plant tissue and plant species (Reddy *et al.*, 1994).

Constructed wetlands have been used as an alternative treatment of contaminated water, especially in developing countries (Song *et al*., 2008).Wetlands produce quality water at low cost, less operation, little energy use and help to reduce the health hazards associated with the poor waste disposal methods in most developing countries (Gilbert *et al.*,1976). Constructed wetlands systems have shown reductions of physiochemical parameters in tropical zones (Mburu *et al.*, 2008), where climatic conditions favor establishment of vegetation throughout the year (Bindu *et al.,* 2008). Constructed wetlands also reduce oxygen demands and nutrients such as nitrates and phosphates (Mburu *et al.,* 2008). Several studies have also reported that wetlands significantly reduce microbial contaminants in water hence improving water quality; the efficiency depends on other associated characteristics of a wetland and plant species (Song *et al*., 2006).

Use of native plant species for water purification in artificial wetlands is generally favored since native plants require less maintenance and pose few environmental and human risks than genetically modified species or exotic species. Properly selected native plant species are also tolerant to local climatic conditions, soils and seasonal changes (USEPA, 2000). *C. esculenta*, it is a wetland herbaceous perennial, found in the tropics and much of the sub tropics (Bindu and Ramasany, 2008). *Colocasia esculenta* have a good growth rate and they spread very fast over water masses and colonize marshy land areas (Kurien and Ramasany, 2006). The plant is a rooted emergent type of weed and spreads all over the marshy places, on the banks of main streams, canals, ponds and any other area with favorable conditions (Sankar Ganesh *et al.,* 2008). Their thick vegetation causes no harm to water bodies in which they colonize.

When *C. esculenta* spreads on surrounding land areas where soil moisture is high especially during rain seasons they develop into thick bushes harboring undesirable organisms or become breeding ground for vectors (Plates 1a and 1c) (Sankar Ganesh *et al.*, 2008). Like other weeds, *C. esculenta* have excellent growth potential and have high productivity. The plant can therefore be utilized meaningfully (Kurien and Ramasany, 2006). Researchers have been trying to find out ways of utilizing *C. esculenta*, so that the cost of eliminating it mechanically or uprooting it as a weed can be fully recovered from its benefits, the efforts include use as a source of compost and energy (Bindu and Ramasany, 2005). As part of these more research has been done on other macrophytes ranging from duckweeds, water hyacinth, cattails, reeds and sedges like *C.esculentus* as wetland plants to check pollution and ecosystem dynamics (Vaillant *et al*., 2003).

The plant species *C. esculentus* belongs to a family of monocotyledonous graminoid flowering plants known as sedges (Plate 3.1 B). *C. esculentus* provide edible tubers commonly called tigernut, nut grass or earth almond. The plant is a perennial crop cultivated particularly in tropics and subtropical areas worldwide and extensively in Africa, Asia and other European countries for their sweet tuber.

An ecosystem with greater plant richness would be expected to display a wider range of functional traits, with increasing opportunities for more efficient resource use due to the variation in survival characteristics (Cardinale *et al*., 2011). Effective resource use enhances productivity, resulting to effective performance in reducing pollutants in wetlands.

According to Cardinale *et al* (2011) environmental heterogeneity enhances complementary effects between species as evidenced by effects of species richness on pollutant removal that come from terrestrial environment (Bouchard *et al.*, 2007). In nutrient rich environment or aquatic ecosystem, strong competition for space and other scarce resources synergetic effects are likely to occur (Engelhardt and Ritchie, 2001). The performance of combined species in constructed wetlands and the link between species richness and ecosystem functioning is currently a central question in ecology (Bouchard *et al.*, 2007). The plant effectively supports food webs by recycling nutrients, as they manufacture and absorb some from the environment (Bouchard *et al*., 2007).

Wetlands are generally degraded by both natural and anthropogenic activities, which deteriorate their quality, and push them to extinction in poorly planned developmental activities and this calls for suitable conservation strategies. The significance of carrying out water quality tests in water bodies is understand the pollutant dynamics in the ecosystem so as to reduce water borne diseases and safe aquatic life. This is the integral part in wetland evaluation (Taylor *et al.*, 2002).

2.1.2. The use of sand filters in removal of pollutants from contaminated water

The sand filter method is an environmental friendly waste treatment method, which is relatively simple and inexpensive (Barret, 1989). Its principle involves percolating water through a sand bed. Grains of sand form a layer that is penetrated by the water and that stop larger particles at the intervals between grains acting like a simple sieve (Barret, 1989). Small particles are also retained by the wall effect on the grain surface when they touch a grain as they pass through the filter (Prasad *et al.*, 2006).

Generally, the smaller the diameters of the grains, the longer particles remain in the filter, the higher the filter's stopping power (Muhammad *et al.*, 1996).The sand used for slow sand filters should preferably be rounded, and free from clay or traces of clay and soil organic matter. Sand must be washed before being used (Huisman and Wood, 1974). Some studies indicate coarse sand has low treatment efficiency in removal of bacteria, turbidity and color. Decreasing sand grain sizes have been shown to increase treatment efficiency (Huisman and Wood, 1974). In practice, sand that is both finer and coarser still provides acceptable results in terms of filtration in continually operated systems (Barrett, 1989).

Research done by Jenkins *et al*., 2009 found that filters using finer sand performed significantly better in terms of bacteria and viruses removal than filters using coarser sand. Logan *et al* (2001) reported that intermittent sand filter columns of 0.6 meters sand fine grained sand columns effectively removed *Cryptosporidium* oocysts than coarse-grained sand media column where the oocysts were observed in the effluents regardless of the conditions. It was also shown in the same study that grain size was an important variable that affected the oocyst effluent concentration in the intermittent filters (Jenkins *et al*., 2009).

The sand height can be reduced to 0.48m with no change in bacteriological removal efficiency (Bellamy *et al.,* 1985). However, some studies indicate that most bacteriological purification occurs within the top 0.4meters of sand bed (Muhammad *et al*., 1996). ASCE (1991) confirmed that majority of biological processes occur in the top 0.4meters of sand bed. Muhammad *et al* (1996) reported that, bacteriological removal efficiency does not become more sensitive to depth with large sand sizes because the total surface area within the filters is reduced in a sand bed with large grains, as well as a high flow rates going through the grains.

Ferdausi and Bolkland (2000) reported that there was adequate fecal coliform removal to below 10 per 100 ml in pond filters, with only sand bed depths of about 30cm.Turbidity and color removal improves as sand depth increases below 40 cm, showing that adsorption occurs throughout the filter column in purifying water. Reduction in sand bed depth causes decrease in total surface area of the sand grain and ultimately total adsorption capacity is lowered (Muhammad *et al.*, 1996). The sand bed depth influences removal of microbial and chemical parameters in contaminated waters (Aloo *et al*., 2015).

2.2 Microbiological methods of identifying sources of fecal pollution

Many international and national standards now incorporate microbiological indicators to determinate the quality of water (APHA, 1998). Another group of bacteria, the fecal streptococci, total coliforms and *E. coli* have also been advocated as indicator organisms for contaminated water for water contamination from sources like infiltration and seepage from fecal disposal points (Mishra *et al.*, 1996).

A more desirable bacteriological indicator of water contamination should not only be able to identify the degree of water contamination or the presence of indicator organism, but also distinguish the source of pollution. It should identify the specific source of contamination whether from warm blooded animal or human feces, because the determination of source of fecal pollution is important in the assessment of water quality and waste management in the ecosystem (Coyne and Howell, 1994).

A greater number of *Streptococci* in all warm-blooded animals' feces are closely associated with their number in polluted water. This is the basis of identifying the source of pollution. It is estimated that fecal coliform and fecal *Streptococcus* ratio of above four indicates that the source is assumed to be human and an FC/ FS ratio of below one indicates that the source of feces is likely to be other warm blooded animals. In addition, an FC/FS ratio of less than four and more than one shows that its source is probably mixed pollution and industrial waste (Coyne and Howell, 1994).

Disinfection of wastewater appears to have a significant effect on the ratio of these indicators, which may result in misleading conclusions regarding the source of contaminants. The ratio is also affected by the methods for enumerating fecal *Streptococci.* For these reasons, Standard Methods described by (APHA, 1998) does not recommend FC : FS ratios as a method for differentiating between human and non- human sources of fecal contamination.

2.3 The relationship between modes of fecal disposal and underground water contamination

Safe water is an essential component or need for a healthy living. According to Sobsey and Bartram (2008), Aulia (1994) and Sterritt and Lester (1988) safe water, adequate sanitation and proper nutrition are essential health needs to be met in the developing and the developed nations. These needs contribute to reduced diseases and increased health and the lack of one can degrade the beneficial effects of others (Sobsey and Bartram, 2008).

Water plays an important role in supporting life. If contaminated, it also has a great potential of contributing to the global burden of diseases and illnesses (Rheingans *et al*., 2006). Serving the world with adequate safe drinking water and sanitation is an important prerequisite to hygienic safety, prosperity and political stability (Bartram and Balance, 1996). Rheingans *et al.*, (2006) reported that over one billion people have no access to safe drinking water globally, while 2.6 billion lack adequate sanitation leading to deaths of 1.8 million people every year from water related diarrhea diseases. Among this population it has been reported that a high percentage (90%) of children under the age of five years, are mainly from developing countries. To avoid hygienic and political disasters that impact on the world’s economy, investment in water supply and sanitation needs urgent attention in both developing and developed countries (Wilderer, 2004).

In developed countries, water related illnesses are rarely due to availability of efficient water supply and human fecal disposal systems (Jorge *et al*., 2010). However, in developing world as many as 2000 million people are without safe water supply and well-designed sanitation. As a result, the toll of water-related disease and destruction of aquatic ecosystems in these areas is frightening (Kathleen and Shordt, 2006). It is therefore important that the relationship between water quality, ecological dynamics and health be fully appreciated by the engineers and scientists concerned with water quality controls (Tebbut, 1992).

Growth and nutrition in young children are also adversely affected by contaminated water supplies, poor hygiene and inadequate sewerage UNICEF, EHP, USAID (1997). The United Nations declared 2005 - 2015 a water for life decade, a focus on water related issues and a goal of halving by 2015 the number of people with no access to sustainable safe drinking water and basic acceptable sanitation (WHO/UNICEF, 2004).The interaction between man and his waste pose challenges in the environment in which he lives (Howard *et al.,* 2003). Waste released to the surrounding by man includes; feces, urine, saliva, sweats, mucus and other substances, if not disposed safely in disposal points like flush toilets and improved pit latrines these wastes cause ecological degradation (Gregory, 2005).

Fecal contamination from sewage may lead to a variety of intestinal pathogens culminating to diseases like typhoid fever, dysentery, cholera and poliomyelitis (Coldwell and Parr, 1987). Currently many countries have put more emphasis to reduce the chances of epidemic occurrence through strict control of sewage disposal (Drangert *et al*., 1997). However, the epidemics of cholera, dysentery and typhoid fever still occur from time to time in developing countries unlike developed countries (Zachariah and Shordt, 2004).The involvement of community in decision making process is very imperative to the success of sustainable waste disposal management (Elkington and Shopley, 2009). This plays an important role in reducing human waste at community level (Kathleen and Shordt, 2006).

Self help efforts have been more successful in producing waste disposal methods such as septic tanks and latrine systems or a solid waste transfer depot than in maintaining services in a routine way (Esrey *et al*., 2001).

2.4 Underground water sources and physical characteristics that cause their contamination by fecal matter

Drinking water is water used for domestic purposes including drinking, cooking and personal hygiene (Kabede, 1978). Access to drinking water means that the source is less than 1km away from the place of use (WHO/UNICEF, 2004). Globally, by 2010, 84% of the world's population had access to piped water source through house connections or to an improved water source such as stand pipes, water kiosks, protected springs and protected hand dug wells. About 14% of the world's population had no access to improved water sources hence used unprotected wells and springs, canals lakes or rivers (UN, 2003; Kabogo and Kabiswa., 2008).

Water supply systems obtain water from ground water (aquifers) and surface water such as lakes and rivers. Majority of the 3.5 billion in people in developing countries that have access to piped water receive poor or very poor quality of service and about 80% of the piped water is received in intermittent basis (Lloyd, 1990). Microbiological contamination of water has been the world's concern since 1920s up to 1960s (Myhrstad and Haldorsen, 1984). Microbes that contaminate water include bacteria, viruses and protozoa. Fecal coliform bacteria are indicator organisms of human fecal contamination and it occurs when water is contaminated by fecal bacteria (Wright *et al*., 2004). Fecal coliforms are a group of bacteria that include many strains such as *Escherichia coli* (Cheesbrough, 2006 and Shannon, 2003). They are usually in large quantities than some pathogenic microbes that may be present in water (Olivieri *et al.,* 1977). They live in the soil and are found in large numbers in the gastro-intestinal tract of animals especially man (Macdonald *et al*., 1999).

Fecal coliforms are the standard by which microbial contamination of domestic water source is determined, and whose presence is definitive proof of water contamination by fecal matter (Sugden, 2004 and Cheesbrough, 2006). Human feces are a primary source of fecal bacteria in water (Olivieri *et al.*, 1977). Fecal coliforms enter the water supplies from the direct disposal of wastes into streams or lakes or from run-offs from wooded areas, feedlots, septic tanks and sewage plants into streams or ground water (Franceys *et al*., 1992). Bacteria from these sources can enter wells that are open at the land surface or do not have watertight casings or caps. Hand dug-wells with large openings and casings that are not well sealed make it easy for wash backs with bacteria into the well (Jorge *et al*., 2010).

Microbial contaminants in drinking water are normally introduced through oral means and bacterial coliforms are of primary concern in terms of fecal contamination of drinking water sources (Tebbut, 1992). Fecal coliforms can also enter domestic water source through run-offs or backflow of water from contaminated source, (Kleinau *et al*., 2002). Bacteria can also enter water supply through inundation or infiltration by floodwaters that commonly contain high levels of bacteria (Van der Klundert, 2000). Small depressions filled with floodwater provide a favorable breeding ground for bacteria and when inundation of such waters occurs then contamination of well water ensues (Lewis and Foster, 1980).

It has been reported that in urban settlements, sanitary sewage combined with storm run-offs contribute to pathogenic microorganisms in domestic water sources (Olivieri *et al*., 1977). Ellis (1998) and Zacharia and Shordt (2004) further noted fecal coliform contamination in various sources of drinking water. Domestic water sources that are prone to contamination by fecal coliforms include among others hand-dug wells, natural springs, streams and rivers (Sterrit and Lester, 1988). Piped and rainwater sources are usually safe from contamination unless the water is contaminated either during transportation or in storage containers.

Lloyd (1990) also demonstrated that that wells and springs were found to contain moderate levels of fecal coliforms as compared to streams and rivers that were highly contaminated. According to Cheesbrough (2006), most water sources in developing countries are unsafe for drinking because they are abundantly contaminated with microbial agents due to poor and unsustainable management of human fecal matter. Revelation from the studies by Eschol and Mahapatra (2009) and Jorge *et al.,* (2010) is a pointer to the world’s concern over the increasing global urban population and the problems associated with fecal disposal strategies.

UNICEF (1997) targeted to reduce the proportion of people without access to drinking water between 1999 and 2015 despite the challenge of increased fecal contamination. Sub-Saharan Africa has lower accessibility to drinking water with Kenya standing at 57%, Uganda at 52%, Mozambique 57% compared to countries like South Korea 92% and Singapore 100% of the population with safe drinking water (UNICEF, 1997). The situation is even more aggravated in urban areas due to overcrowding in urban slum areas that in turn stress sustainable management of water and sanitation (Bateman, 1995).

Mechanisms of transmission of fecal bacteria are poorly understood by users (Wijk and Van, 1985). It was not until cholera outbreaks were associated to fecal contamination by Snow in the 1850s that scientific community accepted that human fecal matter was a significant source of water borne diseases (Taylor *et al.*, 2002). In 2008 it was estimated that 59% of Kenyans had access to improved domestic water sources, whereby 19% of Kenyans were reported to access piped water through a house or yard connection (Gakukia *et al.,* 2010). According to WHO/UNICEF (2008), access to improved water sources in urban areas decreased from 91% in 1990 to 83% in 2008.

According to Bartram and Balance (1996), contamination of water sources by fecal coliforms in drinking water is common in developing countries and more pronounced in urban slum areas. However, the presence of fecal coliforms confirms the presence of other pathogenic bacteria in drinking water (Cheesbrough, 2006).A study done by Chemuluti *et al.*, (2002), in Kibera sub-location of Nairobi Kenya showed that drinking water was contaminated at the source and a defective water delivery system coupled with inadequate environmental sanitation were a potential source of contamination. In the Honduran communities, Trevett *et al* (2004) found that drinking water could become contaminated following its collection from communal sources such as hand-dug wells and natural springs.

2.5 General fecal disposal methods and their influence on ecosystems and human health

A large percentage of the world’s population has inadequate sanitation services and unsafe drinking water supplies (Gilbert *et al.*, 2003). Nearly 3000 million people around the world lack sanitary means of excreta disposal. Main concerns in the relationship between water, sanitation and health are effects of contaminated domestic environments on diseases associated with indiscriminate disposal of waste matter and human feces (Ahmed and Hussein, 1997). In developing countries, a small proportion (10%) of the population mainly in urban areas has access to sewerage systems and about 20% have on-site sanitation facility. 65% of the population in developing countries do not have adequate sanitation facilities (Morgan,1990).

In developing countries those who have on-site sanitation such as septic systems or latrines are still at risk because the systems are sometimes defective or do not completely protect human health (Rheingans *et al.*, 2006).The on-site system may protect an individual but its design and management may permit release of pathogens into local water bodies. Pit latrines often leach into ground water contaminating it with pathogens (Macdonald *et al.*, 1999). Such problems are aggravated in urban areas where crucial ground water resources lie beneath crowded communities not connected to sewerage systems (LaFond, 1995).

Disposal of human feces occur in several modes worldwide and will most often display a wide disparity between urban and rural areas (LaFond, 1995). Hoque *et al* (1999) reported that safe disposal of fecal matter was very poor in rural and urban slum settlements, leading to major diarrhea diseases which killed 100,000 children each year. Such cases of diarrhea demonstrated a strong biological link between the problems of poor human fecal matter disposal and contamination of domestic water sources (Franceys *et al*., 1992).

Winblad (1997) and Esrey *et al* (2001) described two types of sanitation systems that were commonly used in most parts of the world in the following fashion “drop and store” or pit latrines, and “flush and forget” or the flush toilets. Such definitions were coined to remove the wrong perception on the two fecal disposal methods in order to make them attractive as means of reducing water contamination (Stenstrom, 1997). In developing countries, pit latrines are commonly used both in urban and rural settlements (Esrey *et al.*, 2001). The disadvantage of pit latrines is that there is a possibility of contamination of domestic water sources by pathogens and chemicals in densely populated urban slums. This contamination of water sources affects human and aquatic life directly (Werner *et al.*, 2004).

According to reports by WHO/UNICEF (2004), 40% of the population in sub-Saharan Africa has no pit latrines leading to serious fecal contamination of water sources. Utilization of flush toilets is limited by availability of piped water and inadequate water supply leading to frequent use of pit latrine as an alternative disposal point (Huttly, 1990). Flush toilets are suitable for controlling contamination of domestic water, which occurs when alternative disposal structures are, used improperly (Lenton *et al*., 2005). However, usage of pit latrine usage in Africa was reported to be 0-5% in children of six months and increased with age reaching 25% by the age of 50 months (Yeager *et al.*, 1999). The authors further noted extremely low usage of pit latrines by children because of the fear of contamination from adult feces and accidents in shared and poorly constructed pit latrines. As a result the feces were disposed of on the soil (Lenton *et al*., 2005).

Children less than five years make up a significant proportion of up to 20% of population in many developing countries. This shows that the indiscriminate disposal of excreta from children is a health risk (Uneke *et al.,* 2007). A potty is the most commonly used method for collection of children feces in households within urban areas and the feces are subsequently transported to flush toilets or pit latrines (Whiteford *et al*., 1996). This disposal method of fecal matter causes contamination of water sources if it is not properly handled (Curtis *et al*., 2001; Wright *et al*., 2004).

Informal fecal disposal in open fields by adults and children has also been reported by Aulia (1994), Traore (1994) and Whiteford *et al* (1996).The authors further noted that indiscriminate disposal of feces near or in bushes close to homesteads was associated with contamination of drinking water sources leading to increased cases of diarrheal outbreaks. Further reports also indicate that defecation in the bush, open field and soil caused water contamination by fecal coliforms (Ana *et al*., 2004).

Prevalence of household-soil defecation in both rural and urban areas was reported to vary with age (Yeager *et al*., 1999). Most studies have also shown prevalence to vary among children with infants preferring soil defecation compared to older children (Traore, 1994; Bateman, 1995). Feces deposited on soil also attracted different responses in terms of social tolerance in accordance to the age of the person and feces characteristics (Ana *et al*., 2004).

In most cases feces are often disposed of near the surface of water resources because of convenience of predisposition. This trend was found to be common in both rural and urban areas (Falken, 1980). The main problem with this form of deposition is that fecal materials are frequently washed into water sources or transferred by people directly or indirectly to water sources (Dhaneshwar *et al*., 1985). In some parts of India, Africa and South-east Asia, “night-soil” deposition is a widespread practice. Defecation usually occurs on squatting slabs in city drains and also close to water points like boreholes, springs and streams, raising the likelihood of contamination of these water sources (Kalbermatten *et al*., 1982). In peri-urban areas, Katcha latrines (usually a bucket) are the most commonly preferred disposal methods where wastes are discharged directly into canals or soils near water sources (Lee and Bastemijer, 1991).

A study carried out by Dhaneshwar *et al* (1985) indicated that slightly less than a half of the households disposed fecal matter haphazardly on soils around their houses while only 28% of households disposed fecal matter in pits with 25% of individuals using open field defecation. The authors attributed these unsafe disposal methods to be responsible for the contamination of domestic water sources (Barbao *et al.*, 1969). Similar observations were made in other areas where the households had neither direct access to water source nor access to appropriate sanitation facility like pit latrine system (Kleinau *et al*., 2002).

Sanitation in urban areas of Kenya was reported to be 27% of the urban populations accessing private improved sanitation (Guardian Development Network, 2010). In addition, 51% of the population used shared latrines, while open field defecation was estimated to be 18% for both rural and urban areas (WHO/UNICEF, 2008). In Korogocho slums of Nairobi, private individuals use handcarts with drums that are used to empty sludge from pit latrines, usually at a fee. This mode of fecal disposal has a risk of spill over which may lead to contamination of drinking water sources (Guardian Development Network, 2010). A study carried out in Nairobi also revealed a new trend of using pay-toilets in slums but the cost has remained prohibitive with residents preferring disposal of excreta in plastic bags, a practice commonly known as “flying toilets” (KWAHO, 2001).

It is estimated that 10% of Kenyan population use bush or other informal methods of fecal disposal in rural areas where only 38.4% has access to piped water (Guardian Development Network, 2010). These findings and others (Bateman, 1995; KWAHO, 2001 and Ministry of water review, 2009) highlight the challenges facing provision of safe water and sanitation to the Kenyan population by 2015 as stipulated in the millennium goals. The mode of disposal of human fecal matter has a great bearing in contamination of domestic water sources and has been the subject of intense studies (Soper, 2002; Howard *et al*., 2003) Domestic water sources in both rural and urban areas were found to be contaminated mainly through surface water flow, storm water runoffs from residential areas, seepage from pit latrines, and sewerage leakages (LaFond, 1995).

Fecal disposal facilities are usually rich sources of fecal coliforms that make water unsafe for human and aquatic life (Lloyd, 1990). The chances of contaminating domestic water sources by human fecal matter are dependent on the magnitude of exposure of the water source to the disposal facility (Stenstrom *et al.,* 1997). Domestic water sources which are not protected from soil erosion, deforestation and overgrazing are prone to contamination by fecal matter (Ahmed and Hussein, 1997). Improper protection of hand dug wells, poor design, as well poor location of the domestic water sources have been shown to facilitate contamination (Guo, 1989). According to Wihuri (1989), deficiency of water source protection, free drainage led to infiltration of polluted surface water and runoffs down into unprotected natural springs, susceptible aquifers and wells.

Reports by United Nations (2003) indicated that unsanitary practices around public tap water sources formed a major source of water contamination. The reports further noted that drainage systems and increased population in urban settlements posed a challenge of drinking water quality. Moreover reports on sanitary inspection and quality monitoring indicated that hand-dug wells, boreholes, natural springs and rainwater tanks were contaminated by human feces as a result of lack of protection (Lloyd, 1990). A study by Norconsult (1981) indicated moderate levels of fecal contamination in wells and springs that were attributed to runoffs and poor protection of water sources.

The quality of water may also vary with rainfall. For instance, Cave and Kolsky, (1999) revealed that spring water quality varied with rainfall and average microbial loading increased significantly during the rainy seasons. Increase in contamination resulted from direct contamination from surface run-offs due to inadequate protection and rising water tables that permit flooding of latrines and has greater likelihood of microbial and chemical transport to the springs which result in affecting aquatic life and cause human illnesses (Lloyd, 1990).

Improving sanitation in developing nations has been complicated by rapid urbanization that has led to mushrooming of informal settlements at the periphery of principal settlements. Such informal settlements are densely populated with poor quality housing and they frequently lie outside the remit of the municipal waste management authority (Kabogo and Kabiswa, 2008).

2.6 Effects of horizontal and vertical separation distances between pit latrines and hand dug wells on levels of underground water contamination

Microbiological contamination of water supplies is influenced by physical parameters like vertical separation between water table and bottom of the pit latrine, horizontal separation between pit latrine and the hand dug wells, as well as design of pit latrine (Sugden, 2004). Pit latrines pose problems when ground water is shallow and the pit latrine is in the ground water or close to it. There is no soil barrier to protect underground water from fecal contamination through infiltration or seepage from pit latrine contents (Cave and Kolsky, 1999). Location of a hand dug well must be preferably uphill and at least 30 meters from pit latrine.

Dzwairo *et al* (2006) noted that shallow wells near pit latrines with shorter vertical separation distance between their depths indicated elevated levels of fecal coliforms. Contamination of hand-dug well water is also associated with use of contaminated water withdrawal containers and poor sanitary practices around the water point, which lead to direct or indirect introduction of coliforms by water resource users (Agarwal, 1981). Shorter horizontal separation distance between pit latrine and well water lead to contamination of surface water and ground water due to inflow of water through contaminated soil which end up in drinking water sources (Dhaneshwar *et al*., 1985).

Sugden, (2004) reported that the depth of the pit latrine should be above the water table during all the seasons. A separation distance of 1.5 meters between the base of the pit latrine and water table was required to ensure that pit latrine contents remained intact without contaminating underground water. Agarwal (1981) further reported that the water table must be at least 3metres below the bottom level of pit latrine, as above this, the quality of the well or underground water is equal to that of the surface water.

Macdonald *et al* (1999) and Dzwairo *et al* (2006) also noted that, the greater the distance between the base of the pit latrine and the water table the more time was required for pathogens to seep from the pit into the ground water, thus allowing more fecal coliforms to die naturally. A situation was observed by Lewis and Foster (1980) was that fecal coliforms were detected 10 meters away from a newly constructed pit latrine that penetrated the water table within three months. This was a clear indication that pit latrine contents directly contaminated water in the hand dug well through seepage.

Brown *et al* (1979) reported that most fecal coliform bacteria are found within 30cm beneath pit latrines and a few 120cm below. It was therefore noted that increase in distance decreased fecal coliforms count in soil and that a wider vertical separation distance between the water table and the base of the pit latrine reduces fecal contamination of underground water. Cogger *et al* (1988) found substantial although not total removal of fecal coliform bacteria when fecally contaminated water passed through sandy soil.

McCoy and Ziebell (1975) revealed that aggregated soils like sands and loamy sands show a high degree of purification or removal of fecal coliforms from water. (Magdoff *et al.*, 1974) further noted complete removal of fecal coliforms in a 90cm column containing sand underlain by silt loam and incomplete removal of fecal coliforms in column containing a variety of sand and clay mixtures. This revealed that the movement of fecal coliforms through soil was influenced by soil type.

In densely populated areas, when a pit latrine is full it is difficult to get some space to construct a new one (Traore, 1994). This necessitates continued use of an already full pit latrine, leading to contamination of soils around pit latrine ground after overflow; contaminated soils are finally washed into water sources by run-offs or infiltration (Wijk and Van, 1985). The situation gets complicated when a new pit is dug where space is limited as this reduces further the distances between the residential houses, water source and the pit latrine (Werner *et al.*, 2004).

2.7 Microbial and physico- chemical water parameters

The water quality parameters of greater concern are pH, dissolved oxygen (DO), Biological Oxygen Demand (BOD), nitrates, phosphates, temperature, and conductivity (Larsdotter, 2006). In addition, bacteriological parameters are also used as indicators of water quality. The most commonly used bacteria forms are fecal coliforms, total coliforms, *E. coli* and fecal *Streptococcus.*

2.7.1 Physico-chemical water parameters

Temperature

Water temperature is affected by air temperature, storm water runoff, groundwater inflows, turbidity, and exposure to sunlight (Coleman *et al.,* 2011). In considering the health of organisms, it is necessary to consider their maximum temperature and optimum temperature. The maximum temperature is the highest water temperature at which the organism will live for a few hours. The optimum temperature is the temperature at which it will thrive (APHA, 1998).

Potential Hydrogen (pH)

pH is the measure of a solution's acidity (Tebbut, 1992). In water, a small number of water (H_2O) molecules will dissociate into hydrogen ions (H^+) and hydroxide ions (OH^-). Other compounds entering the water may react with these, leaving an imbalance in the numbers of hydrogen and hydroxide ions (Sharon, 1997). When more hydrogen ions react, more hydroxide ions are left in solutions and the water becomes basic. However, when more hydroxide ions react, more hydrogen ions are left and the water becomes acidic. pH is a measure of the number of hydrogen ions and thus a measure of acidity (Weiner, 2003).

Water with extremely high or low pH is lethal (Trevett *et al.*, 2004). The pH values of drinking water should be 7 and any deviation either negative or positive from this neutral value affects the quality of drinking water. Water with high or low pH affects human health. In addition, water with relatively low pH (acidic) may reduce hatching success of fish eggs and irritate fish and other aquatic water bugs, gills and damage membranes (Tebbut, 1992). Thus, pH and other associated physico-chemical parameters affect the ecosystem by changing the diversity of organisms (Soper, 2002). Amphibians are particularly vulnerable, probably because their skin is so sensitive to pollutants. This is the most likely cause of drop in amphibian numbers worldwide (Taylor *et al.,* 2002). An unhealthy population negatively influences to the environment (WHO, 2007).

Turbidity

Turbidity is a measure of how particles suspended in water affect water clarity. It is an important indicator of suspended sediments and erosion levels (Sharon, 1997). Typically it will increase sharply during and after rainfall, as a result of sediments being carried into the water sources hence high turbidity (Weiner, 2003). Elevated turbidity will also raise water temperature. Low dissolved Oxygen, prevent light from reaching aquatic organisms which may affect their physiological processes and in broad perspective influence dynamics of the ecosystem (Sharon, 1997).

Conductivity

This is a measure of the capability of a solution such as water in a stream, well, spring or river to pass an electric current. This is an indicator of the concentration of dissolved electrolyte ions in water (Weiner, 2013). It doesn’t show the specific ions in the water. However, significant increase in conductivity may be an indicator that polluting discharges have entered the water source (Sharon, 1997). High conductivity will result from the presence of various ions including nitrates, phosphates and sodium. The basic units of measurements for conductivity are micromhos per centimeter (µmhos/cm) or microsiemens per centimeter (µs/cm). It’s a measure of the inverse of the amount of resistance that an electric charge meets in travelling through the water (Weiner, 2013). Distilled water has a conductivity ranging from 0.5 to 3µs/cm; while most streams range from 50 to 1500 µs/cm. Freshwater streams ideally should have conductivity between 150 to 500µs/cm to support aquatic life (Sharon, 1997).

Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD)

Dissolved Oxygen is molecules of oxygen present in water. Plants and animals cannot directly use the oxygen that is part of the water molecules (H_2O), instead they depend on dissolved oxygen for respiration (Weiner, 2003). Oxygen enters streams, springs, rivers, wells and other water bodies from the surrounding air and as a product of photosynthesis from aquatic plants. Consistently high levels of dissolved oxygen are best for a healthy ecosystem (Sharon, 1997). Levels of dissolved oxygen vary depending on factors including water temperature, time of the day, season, depth, altitude and rate of flow (Tebbut, 1992). Water at higher temperature and altitudes will have less dissolved oxygen (Tebbut, 1992).

Dissolved oxygen reaches its peak during the day. At night, it decreases as photosynthesis stops while oxygen consuming processes such as respiration and oxidation continue throughout the night (Tebbut, 1992 and Weiner, 2013). Human interactions with environment usually affect dissolved oxygen in streams, springs, rivers and wells among others (Weiner, 2013). The effects are caused by adding oxygen consuming organic wastes such as sewage, nutrients, changing the flow of water, raising the water temperature and addition of chemicals (Tebbut, 1992). Dissolved oxygen is measured in mg/l and 7-11mg/l is suitable for survival of aquatic life, while 0-2 mg/l is not enough for survival of aquatic life (Weiner, 2013).

Biological Oxygen Demand is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic materials present in a given water sample, at a given temperature over a specific period (FAO, 2007). While dissolved oxygen tells how much oxygen is available, a BOD test tells how much oxygen is being consumed (Tebbut, 1992). BOD is determined by measuring the dissolved oxygen level in a freshly collected sample and comparing it to dissolved oxygen level in a sample that was collected at the same time but incubated under specific conditions for certain number of days (APHA, 1998). The difference in the oxygen readings between the two samples is the BOD. The standard units for BOD are mg/l. Natural and unpolluted water has a BOD of 5 mg/l or less while raw sewage may have BOD levels ranging from 150-300 mg/l (APHA, 1998).

Nitrates

Nitrogen is abundant on earth, accounting for about 78% of the total air. Most plants cannot use it in this form, but legumes and blue green algae have the ability to convert nitrogen gas into nitrates (NO_{3-}), which can be used by plants (FAO, 2007). Plants use nitrates to build protein, and animals that eat plants also use organic nitrogen to build protein. When plants and animals die or excrete waste, this nitrogen is released into the environment as NH_4^+ (Ammonium) (FAO, 2007). The ammonium ions are then oxidized to nitrites (NO_2^-) and then nitrates (NO_3^-) by bacteria. Nitrogen in this form is common in freshwater aquatic ecosystems. Nitrates enters underground water from natural sources like decomposition of dead plants and animals as well as human sources such as fertilizer and sewage effluents (Tebbut, 1992).

Nitrate is measured in mg/l and the natural concentration of nitrate is usually less than 1 mg/l. Concentrations over 10mg/l may cause an impact on aquatic life (Weiner, 2013). Sensitive fish like salmon can tolerate a concentration of 0.06 mg/l as optimum. Water with low dissolved oxygen may slow the rate at which ammonium is converted to nitrite (NO_2-) and finally nitrate (NO_3-) (Tebbut, 1992).

Phosphates

Phosphate (PO_4^{-3}) is a compound derived from phosphorous and oxygen. Phosphorous is required in small quantities for plant growth and metabolic reactions in animals and plants (Pant *et al.*, 2001). Phosphates are short supply in most water bodies, with even small amounts causing significant plant growth and having a large effect on aquatic ecosystems (APHA, 1998).

Phosphates-induced algal blooms may initially enhance dissolved oxygen through photosynthetic processes, but may die after blooms and cause rapid reduction in oxygen due to decomposition (Sugden, 2004). This reduction in DO may change type of plants that live in that particular ecosystem, resulting in ecological imbalance (Pant *et al.*, 2001). The main sources of phosphates include sewage, detergents, fertilizer, animal wastes and disturbed land. Phosphates do not cause human health risks except in extreme levels. It is measured in mg/l (Pant *et al.*, 2001).

2.7.2 Bacteriological water parameters

Fecal coliforms

This coliform group has been used as an indicator of contamination by human and warm-blooded animals (Cheesbrough, 2006). Fecal coliforms normally grow in the large intestines of humans and are present in large numbers in the feces of humans (Mburu *et al.,* 2008). They are also found in the waste of warm blooded animals such as birds and mammals and may find their way into water bodies through fecal discharges or seepage especially in poorly designed disposal facilities (Mburu *et al.,* 2008). These fecal coliforms organisms are able to ferment lactose at 44.5^0C within 48 hours (APHA, 1998).

The presence of fecal coliform bacteria in water bodies indicates the possible detection of pathogenic organisms that can cause waterborne diseases like diarrhea, cholera and others (Sugden, 2004). Contamination of surface water, shallow wells and rivers is a challenge that is caused by inadequate sewage disposal systems facilities (Sobsey, 2003). Coliforms also enter water in hand-dug wells through backflows from contaminated ground and containers (Eschol *et al.,* 2009). Hand dug wells that are not protected or do not have a cover could be contaminated by seepage and infiltration through the soil (Eschol *et al.,* 2009).

Total coliforms

The coliform group includes a number of genera and species of bacteria which have common biochemical and morphological attributes that includes gram negative, non-spore forming rods that ferment lactose in 24-48 hours at 35^0C (APHA, 1998). Most coliforms also produce enzyme B-D galactosidae that can be detected with a color-forming reagent (Mallin *et al*., 2000). The group generally comprises the genera *Klebsiella*, *Enterobacter* and *Citrobacter* (Mallin *et al*., 2000). Identification or detecting these bacteria in water is a definitive indication of water contamination by feces or inefficient water treatment systems (Eschol *et al.,* 2009).

Escherechia coli

Escherichia coli are a Gram negative rod shaped bacterium that is commonly found in the lower intestines of warm blooded animals (Mallin *et al.*, 2000). *E. coli* and other similar bacteria comprises of about 0.1% of the gut and oral transmission is the main route through which disease causing organisms reach the human body to cause diseases (APHA, 1998). *E. coli* can be differentiated from other thermo-tolerant coliforms by their ability to produce the enzyme β-glucuronidase or production of indole from typtophan (Ryan and Ray, 2004).

Normally, *E. coli* are present in very large numbers in human and animal fecal matter and are rarely found in the absence of fecal pollution (APHA, 1998). These bacteria are considered as the most suitable indicator of fecal contamination in water treatment systems and as they are the first organism of choice in surveillance of drinking water quality (Tebbut, 1992).

Fecal *Streptococcus*

The feces of humans and animals contain large numbers of Streptococci bacteria that can be classified as belonging to the fecal Streptococci group (Ryan and Ray, 2004). Cultural methods analogous to the coliform tests have been developed to determine the presence and concentration of these bacteria in water samples (APHA, 1998). In 1950’s there was a great deal of in these indicator bacteria as they were thought to be only of faecal origin and thus would be more specific than was total coliform test

(Mallin *et al.,* 2000). This group of bacteria is primarily found only in the feces of warm-blooded animals, but now it has been found that subtypes of these groups might be associated with insects (Tebbut, 1992).

The fecal *Streptococci* numbers in animal feces are normally higher than that of fecal coliforms under standard conditions. This explains the idea that the ratio of the fecal coliforms and fecal *Streptococcus* (FC/FS) in a water sample would be an indication of the source of fecal contamination either by human or animal (Ryan and Ray, 2004). Fecal S*treptococcus* is found usually in feces in small quantities and their presence in water indicates water pollution by fecal matter (Mallin *et al.,* 2000).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The study was conducted in Bomachoge sub-county of Kisii County (Figure 3.1). The sub-county has a population of 107, 199 (National census 2009). The topography of the sub County is mainly hilly with several ridges and excellent drainage system. The area has a highland equatorial climate with reliable annual average rainfall of 1,500mm that is reliable (KCDDP, 2008). The study area was classified into four sub-divisions based on administrative locations for the purpose of this study, namely; Magenche, Bokimonge, Boochi and Bombaba (Fig. 3.1).

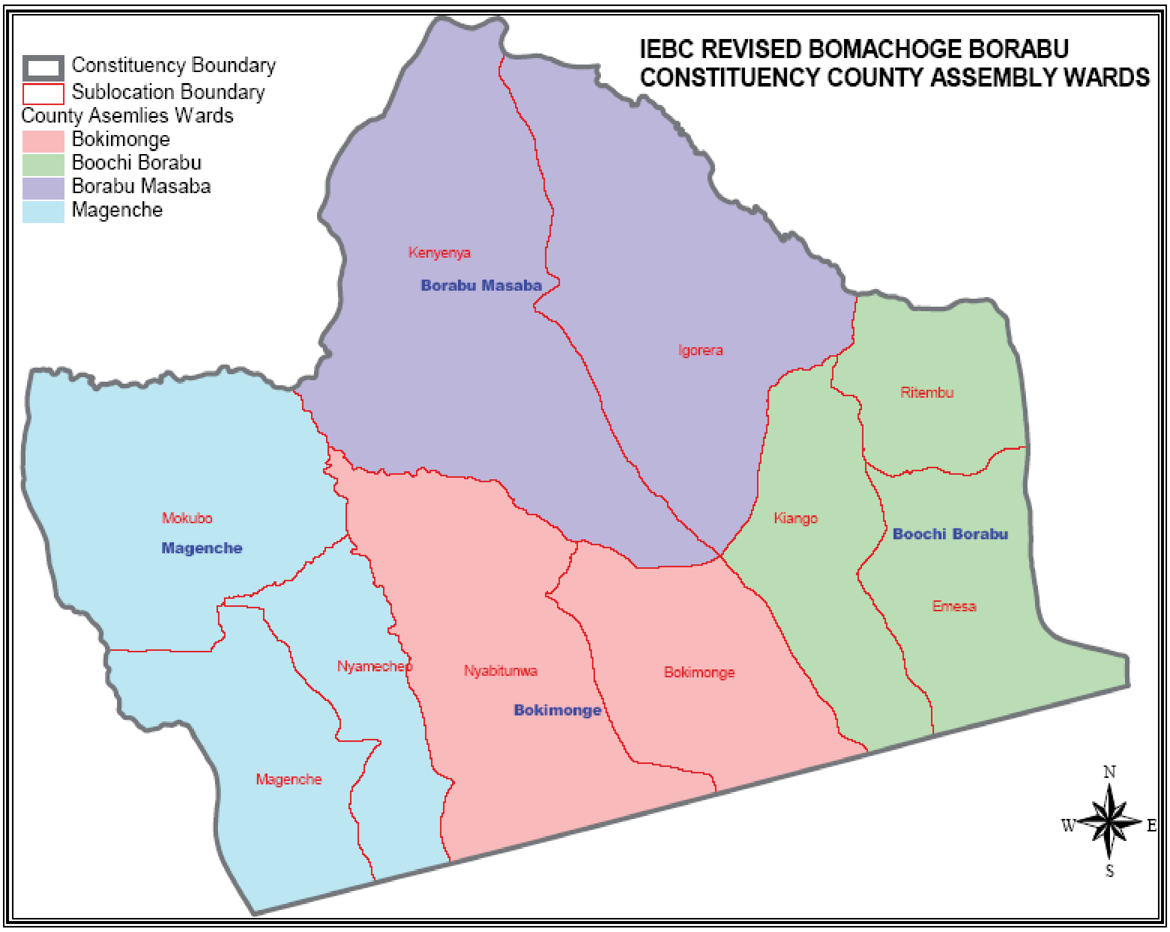

Figure 3.1.A map showing Bomachoge Borabu sub county study area (IEBC, 2009)

3.2 Determination of the effects of constructed wetlands and sand filters on the quality of water

3.2.1 Construction of water reservoir

The reservoir was constructed using stone blocks measuring 30cm by 15cm by 10cm, ballast, cement and polyethene sheets. The reservoir measured were 2 m by 2 m by 1m. After construction, the reservoir was filled with water from the communal water reservoir that was constructed by the community for domestic use and watering animals.

3.2.2 Construction of wetlands

Three wetlands measuring 1.5m by 1.5m by 1m were constructed downhill after the reservoir about 3 meters apart using clay bricks (30cm by 15cm by 10cm), ballast and cement and polyethene sheets were used to prevent water leakages. The floors of wetlands were made in such a way that velocities of incoming waters from the reservoir were reduced to allow wetlands' plants to interact with water contents before it flowed out. The flow rates of water in the constructed wetlands were reduced to about 120litres/day by reducing the gradient of delivery pipes.

3.2.3 Collection, preparation and planting of plants' shoots in wetlands

Young shoots of selected native plants *C. esculenta* and *C. esculentus* were collected from the surrounding natural wetland. Care was taken to avoid disturbing the naturally ecosystem (Plate 3.2). The shoots were washed carefully using de-ionized water before they were planted in the constructed wetlands. The shoots were planted in the three constructed wetlands at a density of 20shoots/m^2.A monoculture of *C. esculenta* was planted in wetland A (Plate 3.1a), *C. esculentus* in wetland B (Plate

3.1b) and a mixture of the two plants in wetland F (Plate 3.1f). Water from community reservoir was carefully put in the experimental reservoir E (Plate 3.1e) that fed the constructed wetlands through the polyvinylchloride pipes.

The loading rate of water was 20Lm^{-2}/day^{-1}. Macrophyte shoots were allowed to establish themselves in the constructed wetlands for 2 months in order to have a proper biological transport system (Taylor *et al.*, 2002), prior to the start of experiment. Water was allowed to flow constantly into each wetland for ten consecutive months.

Key; *A- Colocasia esculenta*, B- *Cyperus esculentus*, C- Natural spring and stream, D- experimental area view, D- Established plants around Reservoir, E- Reservoir and F- pipes connection reservoir and wetlands.

Plate 3.1 Established constructed wetlands and reservoir in Magenche area

3.2.4 Water sample collection from constructed wetlands and reservoir

The wetlands were established in an identified location near the existing natural spring and fresh water stream (Plate 3.1c) in Magenche area. This was an experimental area and the set up was designed carefully and did not affect the existing natural spring and native plants in the wetland. The 16 samples were collected separately from three wetlands and reservoir (control). Sampling protocols described by American Public Health Association (APHA) were strictly followed during sample collection (APHA, 2005). Each sample was collected in sterilized 250 ml bottles with caps. Care was taken not to allow bubbles into sample bottles. The samples were kept in a cooler box and transported immediately to laboratory for examination. The bacteriological and physico-chemical tests were carried out on fresh samples since samples for bacteriological should not be kept longer than six hours (Tebbut, 1992).

3.2.5 Assembling of sand filters

In assembling of sand filters, three factors were considered, sand grain sizes, constant retention time and sand bed depth (Muhammad *et al.*, 1996). Nine sand filters were assembled using plastic pipes tightly covered at the bottom and fitted with steel valves to regulate outflow of water (Plate 3.2). Each of the sand filters had a height of 2 m. The filters were raised and fixed firmly on a flat timber under a waterproof roof to allow effluent flow freely (Plate 3.2). Different sand grain sizes were prepared using sieves of 2mm, 1mm, and 0.5mm (Plate 3.3). The resultant grain sizes were sterilized in the oven at105^0C and put in the pipes in sterile conditions to form a complete and operational sand filters, whereby depths were kept constant. The three different sand grain sizes were placed in labeled pipes up to a depth of 2 meters. The influent from sand filters was from the reservoir. Twenty water samples were collected from the reservoir using sterilized bottles. Another 16 samples from each filter were collected after every two weeks in order to maintain a constant retention time. In addition, sixteen samples were collected from each of the three wetlands. These samples were transported within six hours to University of Eldoret Biotechnology laboratories for analysis.

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Plate 3.2 Sand filters with stainless valves and sand filters connected with wetlands

Plate 3.3 Sieves 0.5mm, 1mm and 2mm

3.2.6 Experimental design

The design of the experiment was 3×4 factorial design (Figure 3.2) with the two plants (*C. esculenta*, *C. esculentus* and a combination of the two plants) together with sand grain sizes (0.5,1 and 2mm and a control) being factors. The control (0mm sand grain size) was sampled after each of the three wetlands and before the water passed through the sand filters (Figure 3.2).

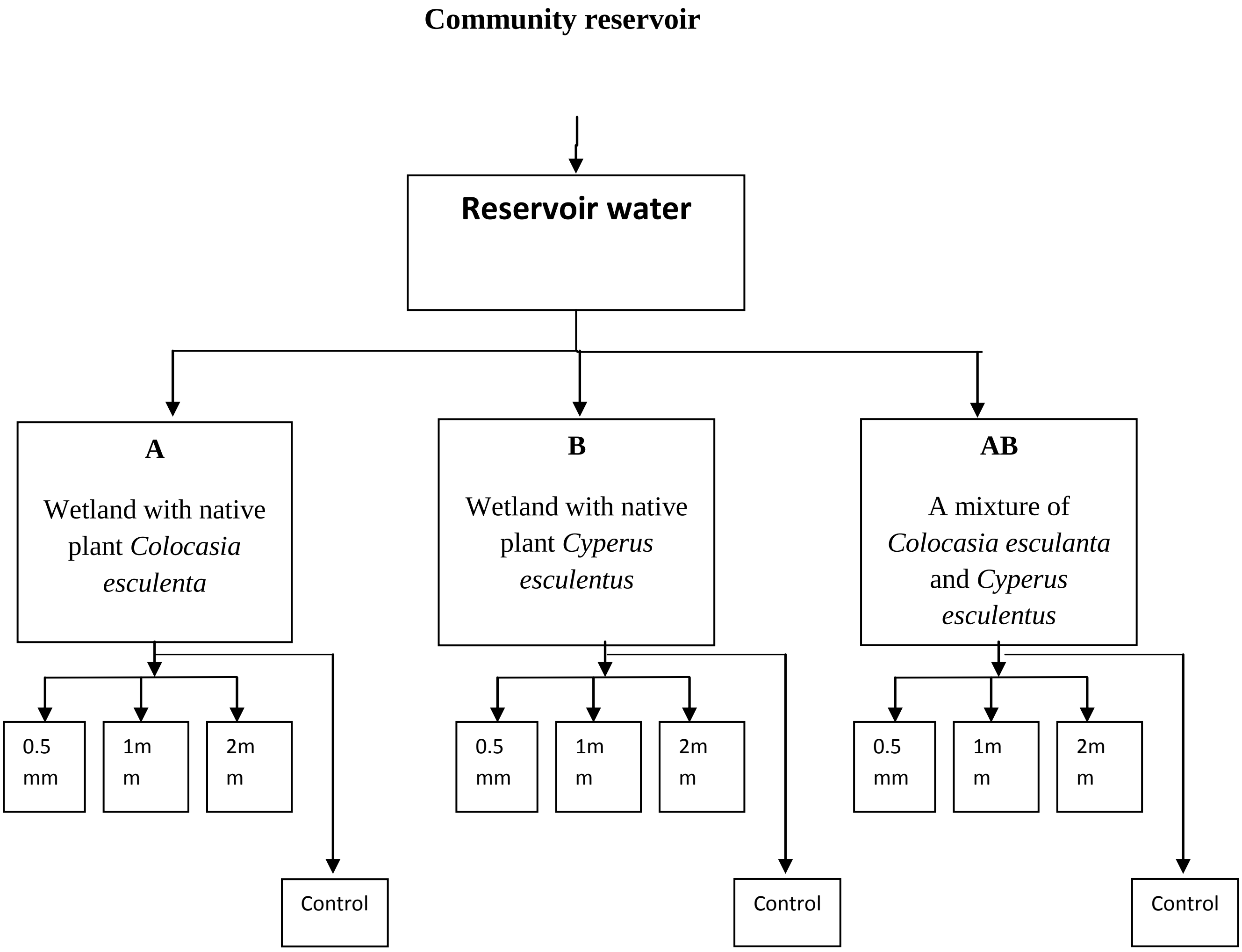


Figure 3.2: A figure showing reservoir water flowing through vegetated wetlands and sand filters of different grain sizes.

The water reservoir, constructed wetlands, sand filters were 3 meters apart. The three sites were connected by plastic pipes.

3.2.7 Bacteriological tests of water samples

Test for fecal coliforms

The test for fecal coliforms in water samples was done using a modified membrane filtration technique described in APHA (1998). Sampled water was placed into a measuring cylinder. About 10 ml of dilution water was added to the funnel before filtration was done to aid in uniform dispersion of bacteria suspension over the entire effective filtration surface. A sterile membrane filter paper was placed over a porous plate using a sterile forceps. The grid side of the filter membrane was then placed facing-up. The funnel unit was carefully placed over the receptacle and locked in place.

The water sample was passed through filter membrane under partial vacuum. A 30-50ml sterile buffered water sample was used to rinse the filter between the samples. The funnel was unlocked after all the water was filtered and sterile forceps were used to remove the filter membrane which then was placed on prepared M-ENDO medium (Appendix 2) in a flask and gently swirled to avoid entrapment of air. The liquid medium was used and the culture sample was saturated with 1.8-2.0ml of M-ENDO agar. The agar was placed directly on the Petri dish then incubated for 22 to 24 hours at 37^0C ± 0.5. After incubation, the number of bacteria colonies were counted and expressed as colonies in 100ml of sample water.

Test for fecal *Streptococcus*

The test for fecal *Streptococcus* was done using Bile Esculine Azide Agar, a selective media for isolating fecal *Streptococcus* from water samples. A 1 ml sample was drawn from each tube containing a different sample dilution and placed in the Petri dish using a sterile pipette (Appendix 5). Molten agar was then poured into mixture and incubated at 37.0 ±0.5 ^{0}C for 48 hrs. Blackening colonies in the media denoted the presence of fecal *Streptococcus.* Absence of black colonies indicated negative results (APHA, 1998).

Colilert test for total coliforms and *E. coli* in water samples

Colilert-18 is a test for detecting total coliforms and *E. coli* in water; it is based on patented defined substrate technology (DST). Colilert-18 is capable of simultaneously detecting total coliforms and *E. coli* within 18 hours. When total coliforms metabolize Colilert-18 nutrient indicator ONPG, the sample turns yellow. When *E. coli* metabolizes Colilert-18, the nutrient indicator MUG, the sample fluoresces.

A 100 ml of water sample was added to sterile plastic jar which was tightly sealed and shaken until all the contents dissolved, the reagent mixture was then poured into a quanti tray/2000 and tray sealed, the sealed tray was incubated for 48 hours at 37±0.5 ^{0}Cfor observation of total coliforms. Observation showing yellow equal to or greater than the comparator when incubated at 37±0.5 ^{0}C indicated the presence of total coliforms. However, observations of yellow and fluorescence equal to or greater than the comparator when incubated at 37±0.5 ^{0}C indicated positive *E. coli*. Fluorescence was observed with a 6-watt, 365-nm UV light within 5inches of the sample in a dark environment. Light was directed towards the sample and away from the eyes (House, 2004).

3.2.8 Measurements of physicochemical water quality parameters

Turbidity

Turbidity was measured by following absorptometric method, where a stored program number for turbidity was entered, and when a program number was selected the FAU unit for turbidity was displayed and zero icon. A blank was prepared by placing a10 ml sample of de-ionized water or blank into the cell holder and capping tightly. Zero FAU was displayed in the screen and after reading it was taken out. After this a 10 ml of sample water was placed into the cell holder and the key was pressed and readings taken (APHA, 1998).

Phosphate (PO_4)

The amino acid method was used in determination of phosphates in water samples. A HACH calorimeter (DR/820) (Plate 3.4) was used in the measurements. Phosphorous was measured in mg/L. The stored program number for reactive phosphorous was selected and mg/L, $PO_4$and zero appeared in the screen. A 1ml sample of Molybdate reagent was added to a 25 ml sample using 1 ml calibrated dropper. The sample was mixed well and placed in the cell holder and tightly covered with the instrument cap, after 10 minutes the key was selected, the result in mg/LPO_4 was displayed (FAO, 2007).

Nitrate (NO_3^--N)

The Cadmium Reduction method was used to measure the nitrate levels of collected water samples. This was achieved using the HACH colorimeter (DR/820) (Plate 3. 4). Nitrates in water were measured in mg/L. The stored program number was entered. For high range nitrate nitrogen (NO_3^--N), program mg/L, NO_3^-N was selected and the zero icon was displayed. Contents of one Nitra Ver 5 Nitrate reagent powder pillow was added to a prepared 10 ml sample according to supplier's instructions, sealed with the cap of the cell (Appendix 3) and one-minute reaction time allowed. The read button was selected and the result in mg/LNO_3^-N was displayed and readings recorded (APHA, 1998).

Plate 3.4: DR/820 Colorimeter

Measurement of Dissolved Oxygen

The DO was measured using a HANNA DO meter (H1 9143) (Plate 3.5).To reduce errors that might affect oxygen levels during transportation from the field, the initial measurement of dissolved oxygen was done in the area where samples were collected. The machine calibrations were adjusted to read or display 100% active air concentration and the tip of the probe was immersed into the sample in a container and the machine allowed to stabilize before obtaining the actual level of oxygen in parts per million (ppm) which is equivalent to mg/l (APHA, 1998). This was recorded for each water sample that was tested.

Plate 3.5: SX716 Dissolved Oxygen Meter

Measurements of Biological Oxygen Demand

Biological Oxygen Demand measurements, in the current study initial DO values were recorded in the field and the same samples incubated at 20^0C for 5days in dark bottles. This was in order to avoid some processes like photosynthesis and respiration that may release or consume oxygen hence affecting its concentration. Final DO was recorded at the end of 5days. BOD_5= Final DO-Initial DO and the value obtained were referred to as $BOD_{5,}$ 5 represents 5days of incubation (APHA, 1998). The values were tabulated.

Determination of conductivity

Conductivity is the measure of how well water can pass an electric current. It is an indirect measure of the presence of inorganic dissolved solids such as nitrates, phosphates, sodium, magnesium, calcium, iron and many others. The presences of these substances increased conductivity in water body. In the current study conductivity of water samples were measured in the field a using JENWAY 3405 Electrochemical analyzer (Plate 3.6). Conductivity was measured in µs/cm (FAO, 2007).

Plate 3.6: DDS 307A Conductivity meter

Temperature measurement

Water temperature is a controlling factor for aquatic life. In this study temperature was measured using a HACH thermometer. Temperature measurements were done in the study area and readings recorded in ^{0}C.

Measurement of Potential of Hydrogen (pH)

In the present study pH of the samples were measured using a pH meter (Plate 3.7) in the area of study (Weiner, 2013). The results were tabulated.

Plate 3.7: JENWAY pH Meter 3305

3.2.9 Data analysis

The experimental design was a 3×4 factorial with two factors and 16 replicates. The two factors comprised plant type and sand size. Percent reduction values of the physicochemical and bacteriological parameters were transformed using Arcsine √ (%/100) for normal distribution and homogeneity of variances then analyzed using a two way Analysis of variance (ANOVA) using SPSS program Version 20. Transformed data were used in statistical analysis at 95% confidence level. Means for the various bacteriological and physico-chemical water parameters were separated using Tukey's test.

3.3 Determination of the relationship between fecal disposal methods and contamination of hand dug wells and natural springs

A cross-sectional study design was used to sample households and the water sources collected between March 2015 and March 2016 at an interval of one week. Water sources from which samples were collected included hand dug wells and natural springs. The samples were collected using sterilized bottles (250 ml) that were stored in a cooler and transported to the laboratory (APHA, 1998).

3.3.1 Water sampling procedure

Sampling procedures described by American Public Health Association (APHA) were followed. Sample bottles were autoclaved at 115^0C. Samples from hand-dug wells and springs were collected by suspending sample bottles of 250ml capacity using a rope and weighted with metal mass (approximately 50g) to facilitate sinking through water column. Samples collected were labeled and placed in a cool box containing ice blocks and then transported within six hours to University of Eldoret biotechnology laboratories for analysis.

3.3.2 Determination of microbiological parameters

Microbiological parameters were determined using similar methods as described in section 3.2.7.

3.3.3 Determination of physicochemical parameters

Physicochemical parameters were determined using similar methods as described in section 3.2.8.

3.3.4 Data analysis

Logarithmic transformation was made to allow use of completely randomized design. The design was used to compare the overall, among and within areas and the level of bacteriological contaminants such as fecal coliforms, fecal *Streptococcus*, total coliforms, and *Escherichia coli*, nitrates, Phosphates, BOD, DO and turbidity and phyisco-chemical parameters.

Determination of the association of fecal indicator organisms and associated physicochemical parameters was performed. Enumeration of total coliforms was done in both springs and hand-dug wells of Bokimonge, Bombaba, Boochi and Magenche areas so as to ascertain levels of contamination of these waters sources. The number of cfus/100ml was determined by bacteria colony counter machine. Data from questionnaires were coded, scored and analyzed using SPSS statistical program and one way ANOVA after appropriate transformations.

3.4 Assessments of disposal facilities and measurements of separation distances and depths between pit latrines and hand dug wells

Assessment of fecal disposal facilities was done using questionnaires and observations. The survey targeted the use of pit latrines, animal's sheds, bushes as informal fecal waste disposal methods. Measurements of horizontal distance between pit latrines and hand-dug wells were done. The details on depths of the pit latrines and hand-dug wells were obtained from homesteads through interview in all selected areas of study of Bomachoge sub county. Appropriate measurements were done using a tape measure to establish the actual distances in meters, centimeters, feet and inches.

3.4.1 Data analysis

Statistical analysis of the results of this objective was done using Microsoft Excel and one way randomized analysis of variance ANOVA. All statistical tests were estimated at 95% level of confidence. Measured parameters whose effects were analyzed using Microsoft Excel were distance of pit latrine and hand dug well, whereby distance was an independent variable while fecal coliforms dependent variable. In addition, the separation depth between the hand-dug wells and pit latrines was an independent variable while fecal coliforms level the dependent variable in analysis of their relationship. Utilization of disposal facilities and water sources was calculated in percentages.

3.5 Calculation of fecal coliforms and fecal *Streptococcus* ratios (FC/FS)

The FC/FS for reservoir was calculated by dividing the mean number of fecal coliforms count to the mean number of fecal *Streptococcus* count using Microsoft Excel. The FC/FS ratio of greater than 4 indicates that the fecal matter source is human, the FC/FS ratio of less than 0.7 indicates that the source of fecal matter is from warm blooded animal animals. FC/ FS ratios between 0.7 and 4 could probably be a mixture of human and warm blooded animal feces (Coyne and Howell, 1994).

CHAPTER FOUR

RESULTS

4.1 Effects of constructed wetlands and sand filters on bacteriological and physicochemical parameters of water

4.1.1 Bacteriological parameters

Plant type and sand grain sizes significantly affected the levels of bacteriological parameters in the present study (Table 4.1). The interactions between plant type and sand grain size also had significant effects on the six bacteriological parameters (Table 4.1).

Total coliforms

Colocasia esculenta reduced total coliforms by approximately 98%. Further filtration through the sand filters did not significantly reduce the number of total coliforms. *Cyperus esculentus* alone reduced total coliforms by 21%. Subsequent filtration through the sand filters reduced total coliforms further by an average of 60%. The 0.5mm, 1mm and 2mm sand grain sizes did not significantly differ in their reduction of total coliforms (Table 4.2).

A polyculture of *C. esculenta* and *C. esculentus* reduced total coliforms by approximately 26%. Integrating the two plants with the 0.5mm sand filter reduced the total coliforms further by an average of 50%. The 1mm and 2mm sand filters in combination with the two plants reduced total coliforms by approximately 83% and 88% respectively (Table 4.2).

Fecal coliforms

A monoculture of *C. esculenta* reduced fecal coliforms by approximately 98% and did not significantly reduce the number of fecal coliforms after passing through the three sand filters. *C. esculentus* alone decreased fecal coliforms by 3%. However, successive

Table 4.1. Analysis of variance summary for the effect of two plant types and sand grain size on microbiological parameters

	Microbiological Parameters											
	Total coliforms		**Fecal coliforms**		***E coli***		**Fecal Streptococci**		**BOD**		**DO**	
Source of variation	**F ratio**	**P value**	**F ratio**	**P value**	**F ratio**	**P value**	**F ratio**	**P value**	**F ratio**	**P value**	**F ratio**	**P value**
Plant type (PT)	3.76	0.030**	268.22	0.00**	237.42	0.00**	16.65	0.00**	311.59	0.00**	94. 18	0.000**
Sand size (SS)	394.93	0.000**	227.82	0.00**	163.03	0.00**	21.42	0.00**	34.52	0.00**	36.57	0.000**
PT ×SS	97.94	0.000**	60.07	0.00**	43.14	0.00**	5.79	0.00**	8.93	0.00**	2.17	0.048**

Key; **= significant at P≤ 0.0

Filtration through the sand filters reduced fecal coliforms by 75%. The 0.5mm, 1mm and 2mm did not differ significantly in their reduction of fecal coliforms. A polyculture of *C. esculenta* and *C. esculentus* plant species reduced fecal coliforms by approximately 36%. When the two plants were combined with 0.5mm and 1mm sand filters, the number of fecal coliforms was reduced further by 40%. The 2mm sand filter in combination with two plants reduced fecal coliforms by 96% (Table 4.2).

Escherichia coli

Colocasia esculenta alone removed *E. coli* by approximately 98%. All the sizes of sand filters did not significantly reduce the number of *E. coli* further. *C. esculentus* alone reduced *E. coli* by 11%. However, further filtration through the sand filters reduced *E. coli* by approximately 60%. The 0.5, 1 and 2mm did not significantly differ in their reduction of *E. coli*. A combination of *C. esculenta* and *C. esculentus* alone reduced *E. coli* by approximately 31%. When the two plants were combined with 0.5mm sand filter, the number of *E. coli* was reduced by a further 82%. The 1 and 2mm sand filters in combination with two plants reduced *E. coli* by 97% and 96% respectively (Table 4.2).

Fecal *Streptococcus*

Colocasia esculenta alone removed fecal *Streptococcus* by approximately 99%. All the three sand filters in combination with *C. esculenta* did not significantly reduce the number of fecal *Streptococcus*. *C. esculentus* alone decreased fecal *Streptococcus* by 9%. Further filtration through the sand filters reduced fecal *Streptococcus* by a further 70%. The sand filters did not significantly differ in the removal of fecal

Streptococcus. A combination of *C. esculenta* and *C. esculentus* decreased fecal *Streptococcus* by approximately 9%.

Table 4. 2. Mean (±se) percent reduction of microbiological parameters using two plants and three sand grain (0.5, 1 and 2mm) filters

Factors		**Mean (%) Reduction± SE**					
Plant Type	**Sand Size**	**Total coliforms**	**Fecal coliforms**	***E. coli***	**Fecal Streptococci**	**BOD**	**DO**
Colocasia esculenta	**0mm**	97.97±1.06d	98.06±1.40e	98.02±1.34f	99.52±0.57c	61.53±18.06d	67.38±12.53b
	0.5mm	98.77±0.88d	99.20±0.95e	99.21±0.56f	99.28±0.49c	79.70±8.85de	90.13±2.04c
	1mm	98.83±0.40d	98.62±0.61e	99.25±0.41f	98.99±0.55c	100.00±0.01e	77.19±5.58c
	2mm	98.00±0.63d	98.09±0.65e	99.57±0.35f	99.28±0.41c	69.68±11.50d	87.68±2.44d
Cyperus esculentus	**0mm**	21.34±18.45a	2.99±28.81a	11.24±35.53a	8.75±29.98a	-147.37±21.97a	72.43±10.82bc
	0.5mm	82.85±3.11c	66.72±6.37c	72.11±8.57d	74.96±6.21b	-20.56±19.59b	87.92±3.86d
	1mm	86.53±3.58c	79.81±7.33d	62.27±8.38c	81.38±4.64bc	-26.56±19.90b	89.80±2.94d
	2mm	85.14±2.52c	87.09±2.95e	73.47±5.99d	82.33±5.05bc	-121.52±18.51a	91.81±2.40d
Colocasia esculenta* and *Cyperus esculentus	**0mm**	25.64±13.84a	36.17±15.46b	30.52±22.26b	8.67±135.94a	29.15±14.24c	37.42±29.81a
	0.5mm	77.51±3.39b	76.18±5.00d	82.05±8.38e	79.17±31.11b	90.23±5.99e	69.04±11.17b
	1mm	82.95±4.28c	78.40±5.64d	96.47±1.76f	89.39±16.01bc	87.22±6.39e	62.05±15.62b
	2mm	87.77±2.45c	95.58±1.18e	95.65±1.36f	92.19±12.55c	86.66±8.04e	62.44±13.67b
F value		**97.94**	**60.07**	**43.14**	**5.79**	**8,93**	**2.17**
Effect		**	**	**	**	**	**

Means followed by the same letter within the same column are not significantly different at P ≤ 0.05.

** = significant

When the two plants were combined with the sand filters, and the number of fecal *Streptococcus* was reduced by 79%, 89% and 92% respectively (Table 4.2).

Biological Oxygen Demand (BOD)

*Colocasi*a *esculenta* alone reduced BOD by approximately 62%. The sand filters (0.5, 1 and 2mm) when combined with *C. esculenta* reduced BOD by 80%, 100% and 70% respectively. *C. esculentus* alone increased BOD by 147%. Further filtration through the sand filters (0.5, 1 and 2mm) reduced BOD by a further 126%, 120% and 25% respectively. A combination of *C. esculenta* and *C. esculentus* plant species alone increased BOD 29%. Sand filters (0.5, 1 and 2mm) reduced BOD further by approximately 60% (Table 4.2).

Dissolved Oxygen (DO)

*Colocasi*a *esculenta* alone reduced DO by approximately 67%. The sand filters (0.5, 1 and 2 mm further removed DO by 90%, 77% and 88% respectively. *C. esculentus* alone reduced DO by 72%. Further filtration through the sand filters decreased DO by a further average of 15%. A combination of *C. esculenta* and *C. esculentus* reduced DO by 37%. The sand filters in combination with the two plants reduced DO further by approximately 25% (Table 4.2).

4.1.2 Physico-chemical parameters

Plant type and sand grain sizes significantly affected the levels physicochemical parameters (Table 4.3). The interactions between plant type and sand grain size also had significant ($p \leq 0.05$) effects on all physicochemical parameters except pH whose levels were no significantly affected (Table 4.3).

Table 4.3. Analysis of variance summary for the effect of two plant types and sand grain size on physicochemical parameters

	Parameters											
	NO_3		PO_4		Temperature		pH		Conductivity		Turbidity	
Source of variation	**F ratio**	**P value**	**F Ratio**	**P value**	**F ratio**	**P value**	**FP ratio**	**value**	**FP ratio**	**value**	**F ratio**	**P value**
Plant type (PT)	315.51	0.000**	129.76	0.000**	50.85	0.000**	0.64	0.531	3.65	0.030**	6.82	0.000**
Sand grain size (SS)	10.67	0.000**	160.94	0.000**	25.60	0.000**	1.07	0.363	8.32	0.000**	9.95	0.001**
PT ×SS	2.65	0.017**	60.12	0.000**	4.78	0.000**	0.88	0.512	1.18	0.317	2.51	0.024**

NO_3=Nitrates, PO_4=Phosphate

**= significant at $P \leq 0.05$

Nitrates (NO_3)

Colocasia esculenta removed nitrates by 86%. The sand filters further removed nitrates by approximately 10% (Table 4.4). *C. esculentus* alone increased nitrate by 23% and sand filter of 0.5 and 2mm reduced the nitrate by 15 and 7% respectively. While the 1mm sand filter reduced nitrates by 36% (Table 4.4). Combining *C. esculenta* and *C. esculentus* reduced nitrates by 39%. Ensuing filtration through the sand filters reduced nitrates by a further about 30%.

Phosphates (PO_4)

Colocasia esculenta reduced phosphates by 95%. The sand filters did not significantly reduce phosphates any further when integrated with *C. esculenta* (Table 4.4). *C. esculentus* alone increased phosphates by 26%. The 0.5, 1.0 and 2mm sand filters reduced the phosphates by 81%, 88% and 83% respectively. Combination of *C. esculenta* and *C. esculentus* alone removed phosphates by approximately 40% and further reduced by 75, 85 and 88% when the three sand filters (0.5, 1 and 2mm) were combined with the two plants.

Temperature

Colocasia esculenta reduced temperature by 19%. Sand filters of different sand grain sizes conversely increased temperature by approximately 45% (Table 4.4). *C. esculentus* alone increased temperature by 18%. Combining the plant with the sand filters increased the temperature by a further 40%. Combination of *C. esculenta* and *C. esculentus* alone reduced temperature by 14%. Further filtration through the 0.5 and 2 mm sand filters of increased temperature by 1% and 3% respectively. Conversely, sand grain sizes of 1mm reduced temperature by 1% (Table 4.4).

Table 4.4 Mean (±se) percent reduction of physicochemical parameters using two plants and three sand grain (0.5, 1 and 2mm) filters

Factors		**Mean (%) Reduction ± SE**					
Plant type	**Sand size**	**NO_3**	**PO_4**	**Temperature**	**pH**	**Conductivity**	**Turbidity**
Colocasia esculenta	**0mm**	86.35±3.47de	95.23±2.98d	18.91±2.03e	15.98±9.19b	64.78±16.76c	65.04±18.57b
	0.5mm	95.14±2.26e	97.29±1.84d	-62.34±6.62a	-0.48±23.20a	77.76±3.68c	88.69±3.20b
	1mm	95.75±2.19e	97.24±1.71d	-68.76±3.64a	16.66±9.89b	85.56±3.01c	90.06±2.39bc
	2mm	96.12±2.11e	96.05±1.52d	-72.16±6.45a	15.73±9.48b	78.60±13.58c	89.41±2.85b
Cyperus esculentus	**0mm**	-23.16±47.4a	-26.74±39.80a	-17.88±6.15b	19.39±15.99b	8.25±17.31b	67.16±10.08b
	0.5mm	-8.19±39.50a	80.45±6.48c	-61.42±5.90a	12.25±10.73b	79.69±13.54c	88.22±3.35b
	1mm	13.05±28.05b	88.08±2.90c	-67.89±5.68a	12.90±9.06b	79.98±13.38c	89.64±2.37b
	2mm	-5.99±39.37a	82.80±4.50c	-59.37±5.11a	13.19±9.24b	80.65±13.66c	93.17±2.24bc
Colocasia esculenta* and *Cyperus esculentus	**0mm**	39.44±21.09c	39.82±22.56b	13.95±2.38de	14.89±6.85b	-22.80±18.01a	-17.16±15.70a
	0.5mm	76.54±7.26d	78.38±11.41c	-1.17±9.31c	12.27±7.44b	59.78±c	73.73±14.03b
	1mm	71.82±5.64d	84.61±8.50c	1.20±6.38d	12.26±4.25b	66.34±17.34c	75.04±15.61b
	2mm	71.82±5.64d	87.74±6.88c	-3.17±6.86c	11.76±5.62b	70.42±14.24c	85.37±8.14b
F value		**2.65**	**60.12**	**4.78**	**0.88**	**1.18**	2.51
Effect		**	**	**	NS	**	**

Means followed by the same letter within the same column are not significantly different at $P \leq 0.05$

NO_3=Nitrates, PO_4=Phosphate, ** = Significant

pH

Generally, plant type and sand grain sizes did not significantly influence the pH. *C. esculenta* reduced pH by 16%. The 0.5 mm sand increased pH by 0.5% whereas 1 and 2 mm sand filters reduced pH by approximately 17% and 16% respectively (Table 4.4). *C. esculentus* alone reduced pH by 19%. All the three sand filters did not significantly reduce pH values of water further. Combining *C. esculenta* and *C. esculentus* reduced pH by 15%. Subsequent filtration through sand filters of sand grain sizes of 0.5 and 2mm did not reduce pH significantly.

Conductivity

Colocasia esculenta reduced conductivity by 65%. Ensuing filtration through the three sand filters did not significantly reduce conductivity further (Table 4.4). *C. esculentus* alone reduced conductivity by 8% and further filtration through the sand filters reduced conductivity by an average of 80%. A combination of *C. esculenta* and *C. esculentus* alone increased conductivity by 23%. The sand filters (0.5, 1 and 2mm) reduced conductivity by 60, 66 and 70% respectively (Table 4.4).

Turbidity

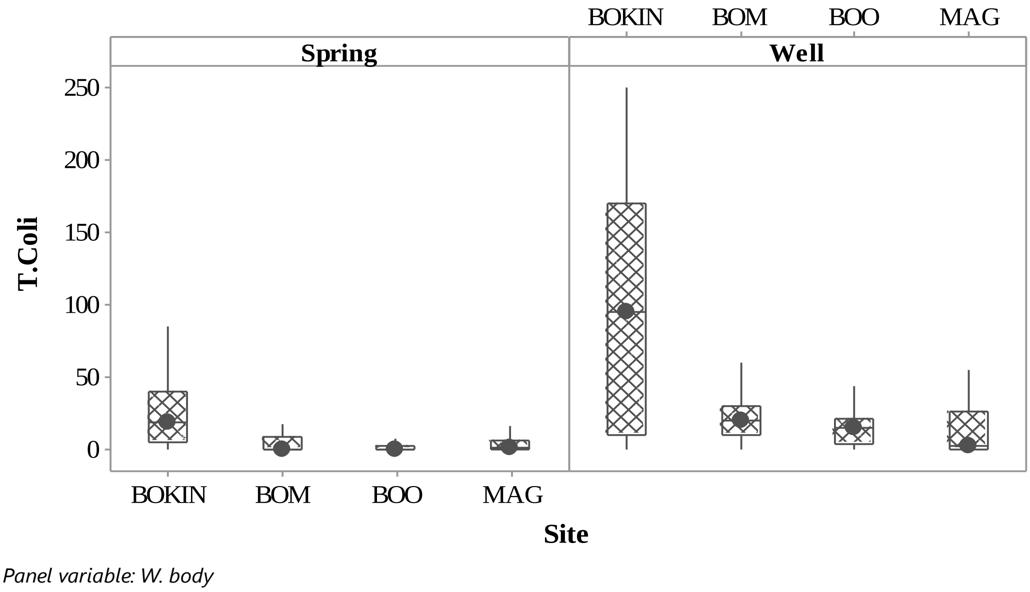
Colocasia esculenta reduced turbidity by 65%. All the three sand filters further reduced turbidity by approximately 90% (Table 4.4). *C. esculentus* alone reduced turbidity by 67%. However, further filtration through the sand filters reduced the turbidity by approximately 90%. A combination of *C. esculenta* and *C. esculentus* alone increased turbidity by 17%. Conversely, sand filters (0.5, 1, 2.mm) reduced turbidity by 74, 75 and 85% respectively.

4.2Assessment of water quality in springs and hand dug wells

4.2.1 Microbiological parameters

Total coliforms

The results of total coliforms in the springs and hand-dug wells are shown in the Figure 4.1.There were no significant differences in total coliforms count ($p<0.05$) among the springs and wells in all the areas of study areas except Bokimonge which recorded a significant difference ($p<0.05$) among and within springs and wells (Appendix 6).

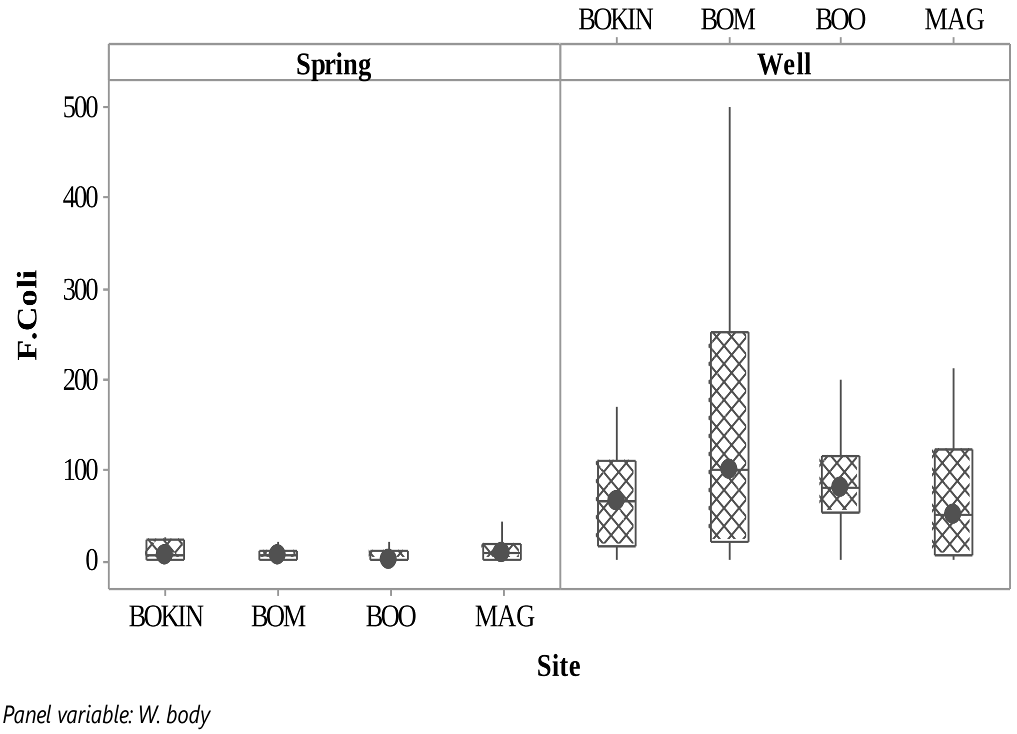


BOKIN=Bokimonge, BOM= Bombaba, BOO= Boochi, MAG= Magenche, T.Coli= Total coliforms

Figure 4.1: The level of total coliforms count in cfu/100 ml in springs and hand dug wells of Bokimonge, Bombaba, Boochi and Magenche.

Fecal coliforms

The results of fecal coliforms (Figure 4.2) shows that there were no significant differences in fecal coliforms count ($p<0.05$) among the springs, but there were significant differences ($p<0.05$) between springs and wells in all the four study areas (Appendix 6 and 7). The springs had below 25 cfus/100 ml whereas all wells had recorded a range of 50cfus/100 ml to 250 cfus/100 ml (Figure 4.2).

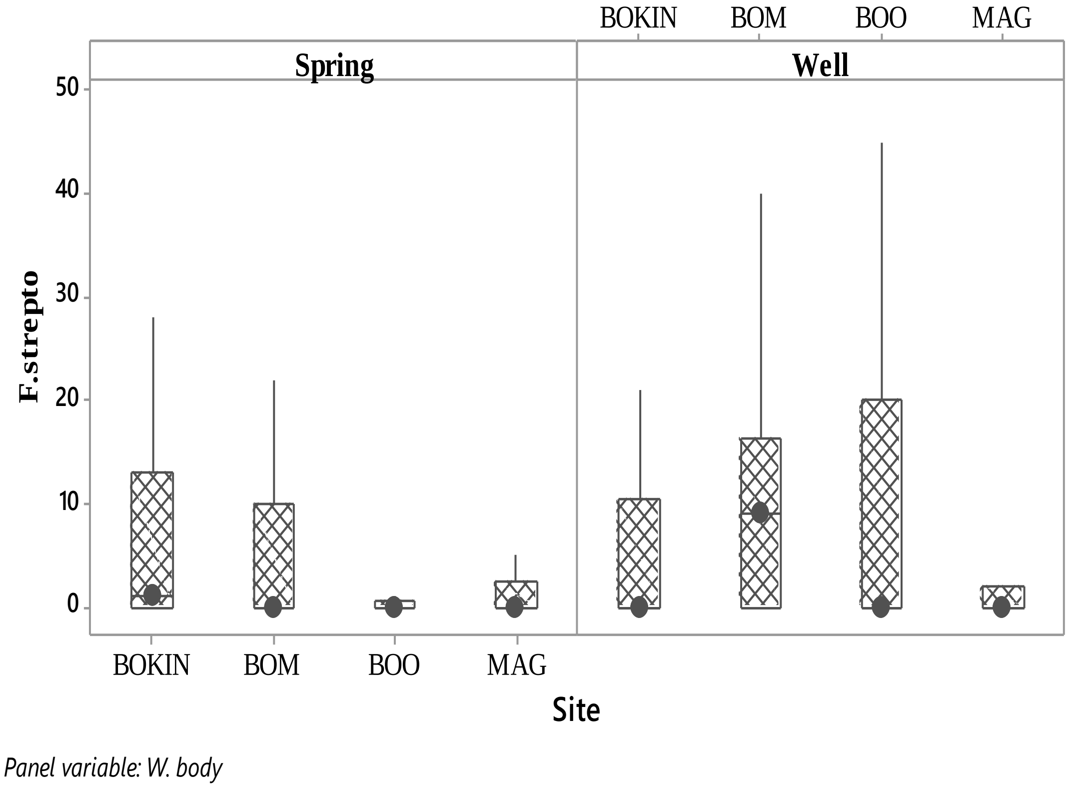


BOKIN=Bokimonge, BOM=Bombaba, BOO= Boochi, MAG= Magenche, F.Coli= Faecal coliforms.

Figure 4.2. Levels of fecal coliforms in both springs and wells of Bomachoge Borabu sub county

Fecal *Streptococcus*

The fecal *Streptococcus* results in the Figure 4.3 show that there were no significant differences in fecal *Streptococcus* count ($p<0.05$) among majority of springs and wells, but there were significant differences ($p<0.05$) between Bombaba wells and other springs and wells in other areas of study. The springs had 2 cfus/ 100 ml whereas all wells had recorded a mean of 5 cfus/100 ml.



BOKIN=Bokimonge,BOM=Bombaba,BOO=Boochi,MAG=Magenche,F.Strepto=Faecal Streptococcus.

Figure 4.3.The level of fecal *Streptococcus* in springs and hand dug wells of Bomachoge Borabu

E. coli

Results of the *E. coli* in the Figure 4.4 show that there were no significant differences in *E. coli* count ($p<0.05$) among springs, but there was a significant difference ($p<0.05$) between springs and wells. Significant differences ($p<0.05$) were recorded among the wells in all selected study areas (Appendix 6). The springs had below 25 cfus/ 100ml whereas all wells had recorded a range of 5 to 120 cfus/ 100ml.

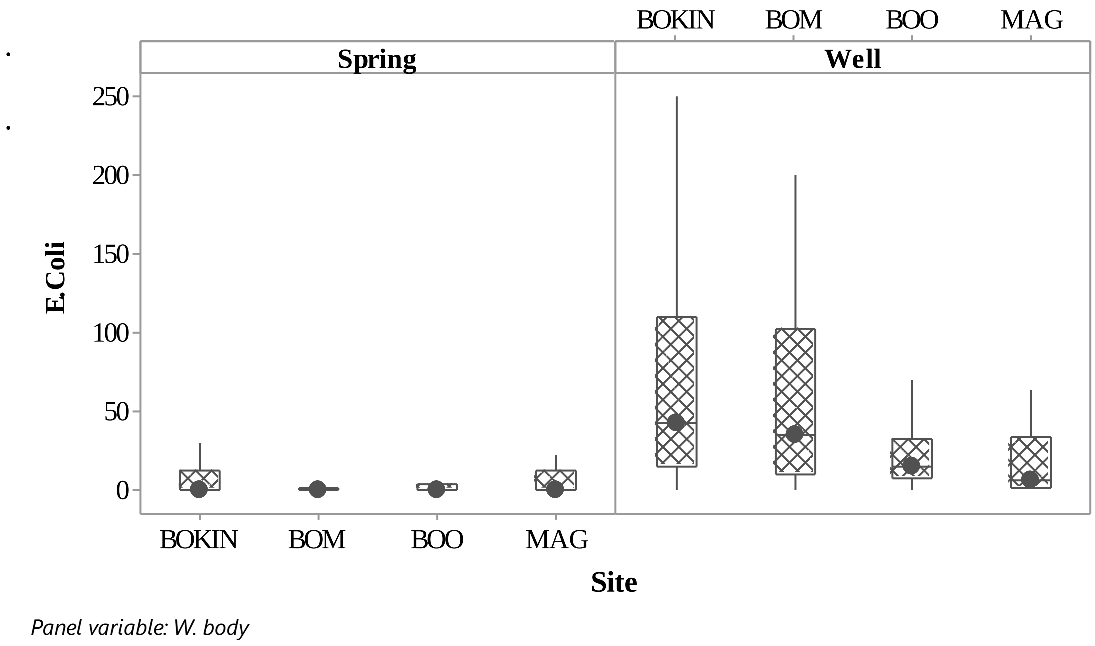
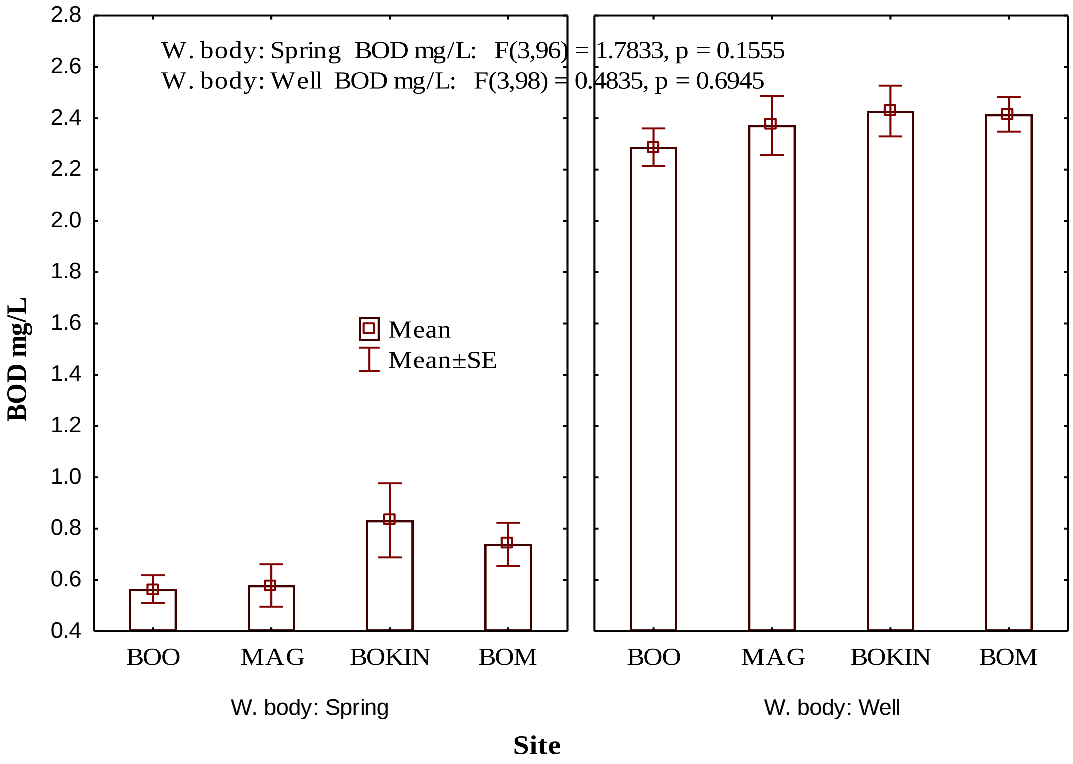


Figure 4.4. Levels of *Escherichia coli* in springs and wells of Bomachoge Borabu sub county

Biological Oxygen Demand (BOD)

The BOD levels were found to be significantly different ($p < 0.05$) between the springs and wells (Figure 4.5). The BOD of the springs was the lowest compared to the wells. The BOD of the springs in Boochi and Magenche were found to be insignificantly different ($p > 0.05$). A similar trend was observed in Bokimonge and Bombaba. The BOD means for springs ranged between 2.3 and 2.5mg/l compared to springs wells whose means were found to range from 0.6 to 0.8mg/l.

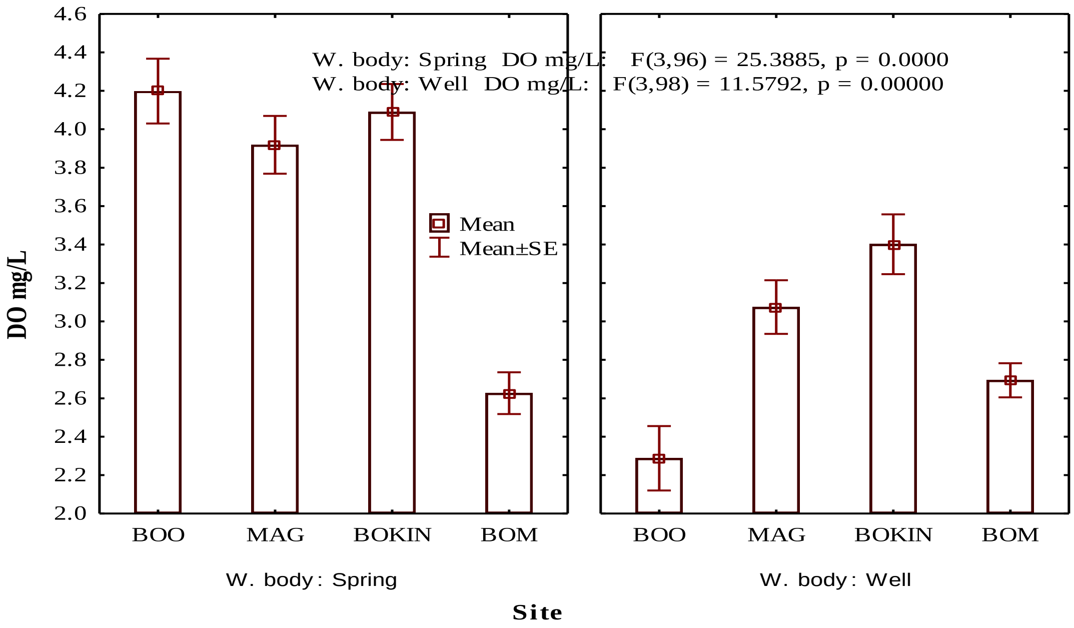


BOKIN=Bokimonge, BOM=Bombaba, BOO= Boochi, MAG= Magenche, W= Water, BOD=Biological oxygen demand.

Figure 4.5: BOD levels in water samples collected from springs and wells of Bomachoge Borabu sub county

Dissolved Oxygen (DO)

Results showed that DO was highest in samples collected from springs compared to the wells (Figure 4.6).This difference was significant (p<0.05). Within the springs there were no significant differences among Boochi, Magenche and Bokimonge water samples, significant differences were observed between springs in Bombaba. Samples from wells had significant differences (p<0.05) within all study areas. Samples from springs were found to have the highest dissolved oxygen of 4.2mg/l while samples from wells had 3.2mg/l as the highest concentration of dissolved oxygen.



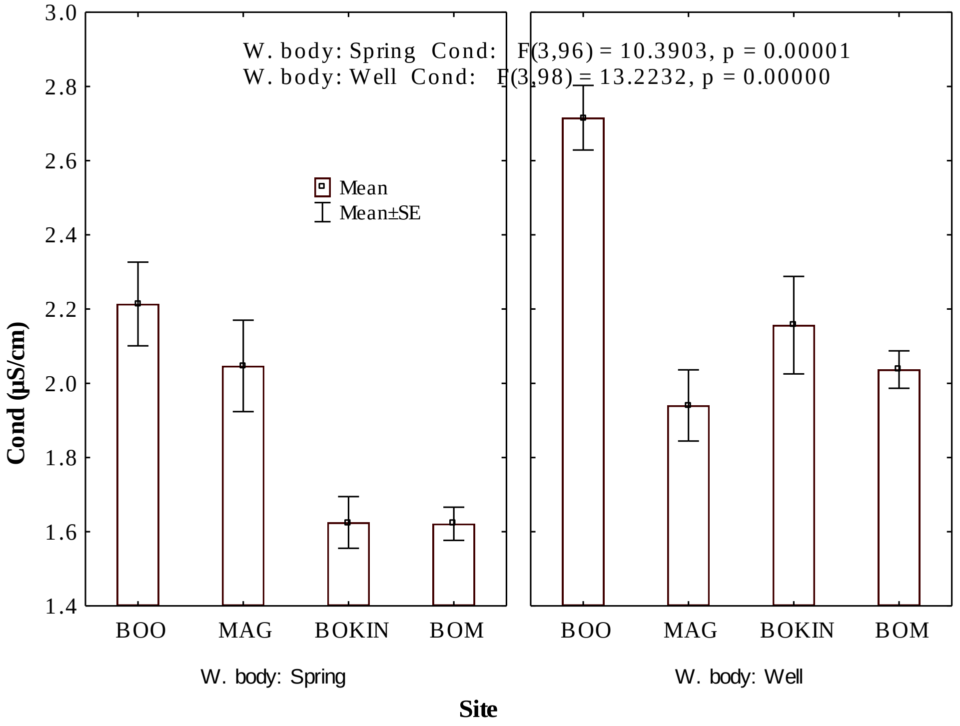
BOKIN=Bokimonge, BOM=Bombaba, BOO= Boochi, MAG= Magenche, W= Water, DO= Dissolved oxygen.SE=standard error

Figure 4.6: Concentrations of dissolved oxygen in samples collected from springs and wells of Bomachoge Borabu sub county.

4.2.2 Physicochemical Parameters

Conductivity

Generally, conductivity varied among and within study areas. Electrical conductivity of water samples from both springs and wells was found to be significantly different (p=0.00) (Figure 4.7). In springs conductivity ranged between 1.6 and 2.2 µs/cm for the wells, conductivity ranged between2.0 and 2.8µs/cm.

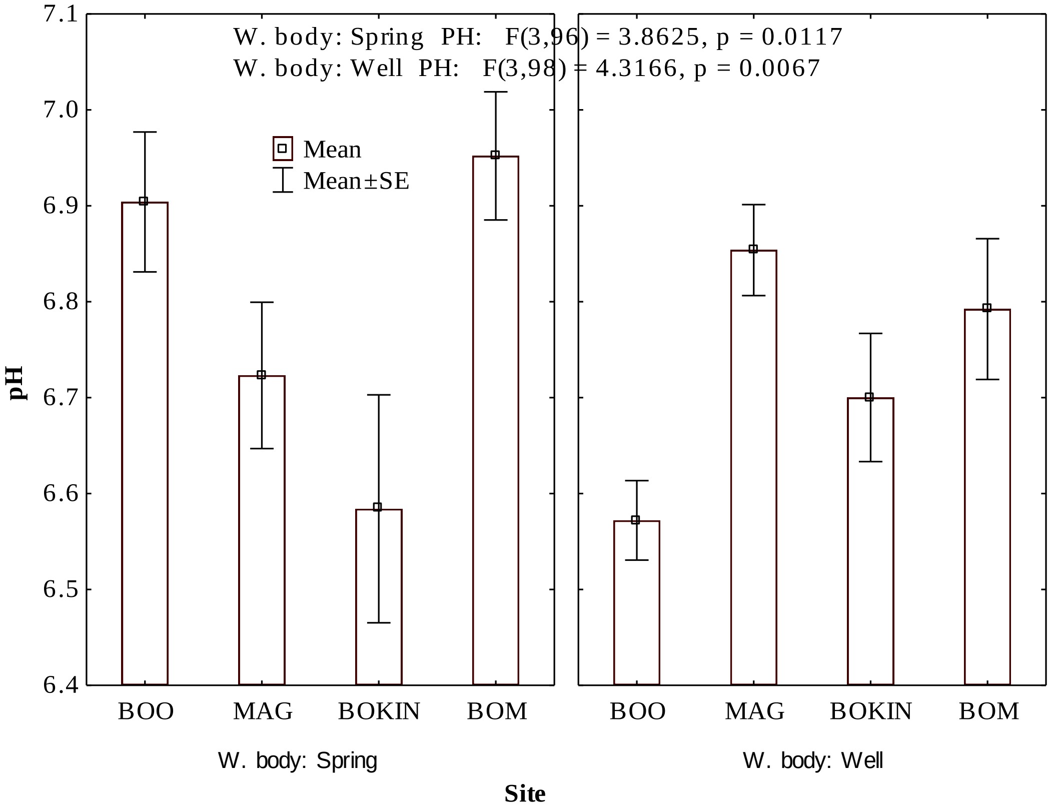


BOKIN=Bokimonge, BOM=Bombaba, BOO= Boochi, MAG= Magenche, Cond= Conductivity, W=water

Figure 4.7 Conductivity of water samples from springs and wells of Bomachoge Borabu sub county

pH

The pH values were found to be significantly different (p<0.05) among and within well and springs (Figure 4.8). Spring water samples pH values were found to range between 6.6 to 6.9 and 6.6 to 7.0 for the wells. Springs in Bombaba recorded the highest pH level while Bokimonge recorded the lowest. Water samples from wells were found to have lowest and highest pH values for Boochi and Magenche respectively.

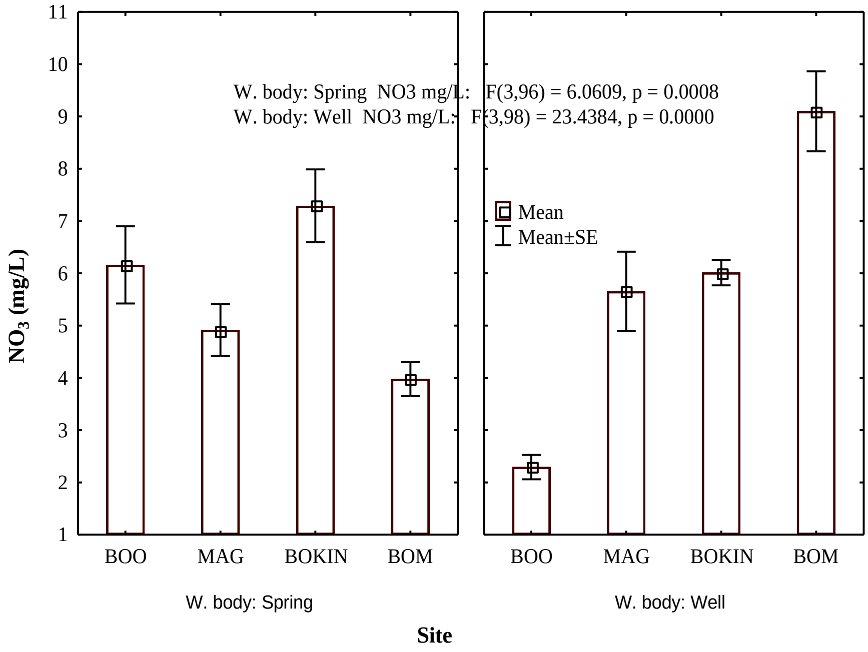


***BOKIN=Bokimonge, BOM=Bombaba, BOO= Boochi, MAG= Magenche, W= Water*.**

Figure 4.8 pH values of water samples from springs and wells of Bomachoge Borabu sub county

Nitrates

Nitrate concentrations were significantly different ($p<0.05$) within the water samples collected from springs, with the highest concentration of 7.5mg/l and the lowest was 4.0mg/l (Figure 4.9). The concentrations of nitrates were found to be significantly different between water samples from all wells except for those samples collected from Magenche and Bokimonge that had similar concentrations. The highest and lowest recorded concentrations from the wells were 9.0 and 2.5mg/l for Bombaba and Boochi respectively.

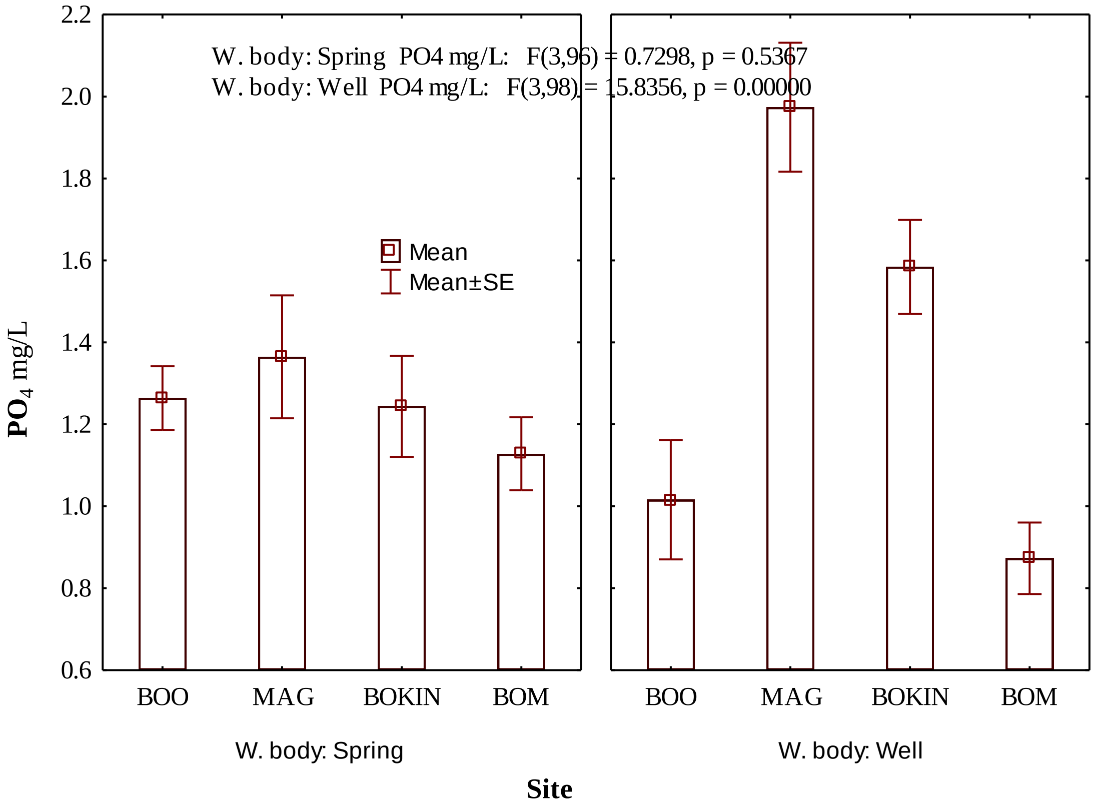


BOKIN=Bokimonge, BOM=Bombaba, BOO= Boochi, MAG= Magenche, W= Water, $NO_{3=}$ *Nitrate.*

Figure 4.9 Concentrations of nitrates in collected water samples from springs and wells of Bomachoge sub county

Phosphates

Phosphates concentration within the collected samples from springs were not found to be significantly different (p=0.5367) in all sampling sites (Figure 4.10). Samples from both springs and wells were found to be significantly different (p<0.005) in concentrations of phosphates. In addition, Samples from various sites of wells were found to be significantly different.

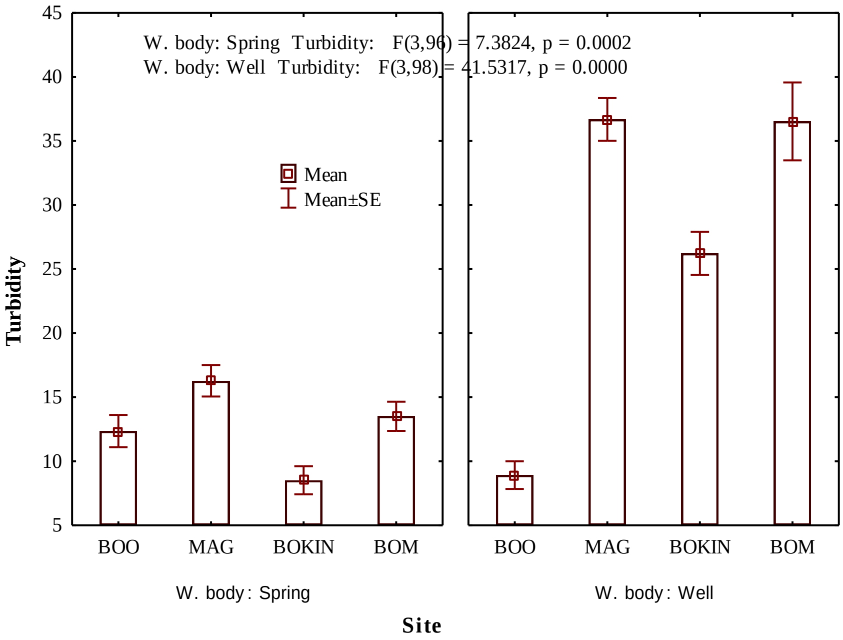


***BOKIN=Bokimonge, BOM=Bombaba, BOO= Boochi, MAG= Magenche, W= Water, PO4= Phosphate*.**

Figure 4.10: Concentration of phosphates in water samples collected from springs and wells of Bomachoge sub county

Turbidity

Turbidity levels were found to be significantly different ($p<0.005$) among and within the water samples from springs and wells of various sites (Figure 4.11). Generally turbidity was highest in wells than springs. Notably within wells of Boochi which recorded the lowest turbidity levels.



BOKIN=Bokimonge, BOM=Bombaba, BOO= Boochi, MAG= Magenche, W= Water.

Figure 4.11: Turbidity levels in NTU for collected water samples from springs and wells

4.3 The effects of vertical and horizontal distances between pit latrine and wells on the quality of water hand- dug wells of Bomachoge Borabu sub county

Results indicate that the fecal coliforms in water hand dug wells within and among Bomachoge Borabu sub study sites did not differ significantly from multivariate analysis (Appendix 10).

4.3.1 Bokimonge area

Results showed that the number of fecal coliforms (cfu/100 ml) decreased as the horizontal distance between pit latrines and hand dug wells increased (Figure 4.12).There was a significant (P<0.05) relationship between distance and fecal coliform count in Bokimonge area whereby the minimum distance that recorded no fecal coliforms was about 52 meters (R=67.6%).

Results also showed that the fecal coliforms count (cfu/100 ml) decreased as the vertical distance between depths of pit latrines and hand dug wells increased (Figure 4.13). There was a significant (P<0.05) relationship between vertical distance between depths of wells and pit latrines and fecal coliform count in Bokimonge area and in this case a minimum distance beyond which no fecal coliform was recorded is 52 inches (R=69.0%)(Figure 4.13).

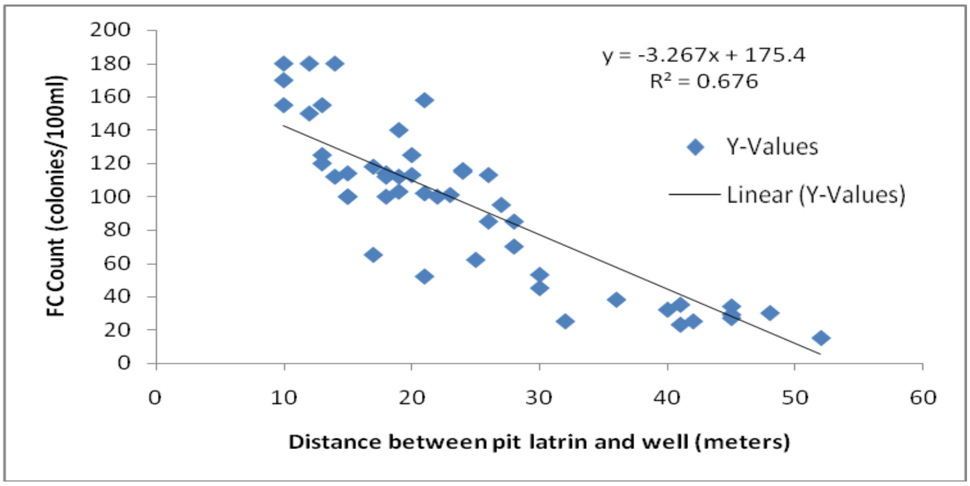


Figure 4.12 The relationship between the horizontal distance of the pit latrine and well to fecal coliforms count in hand-dug wells

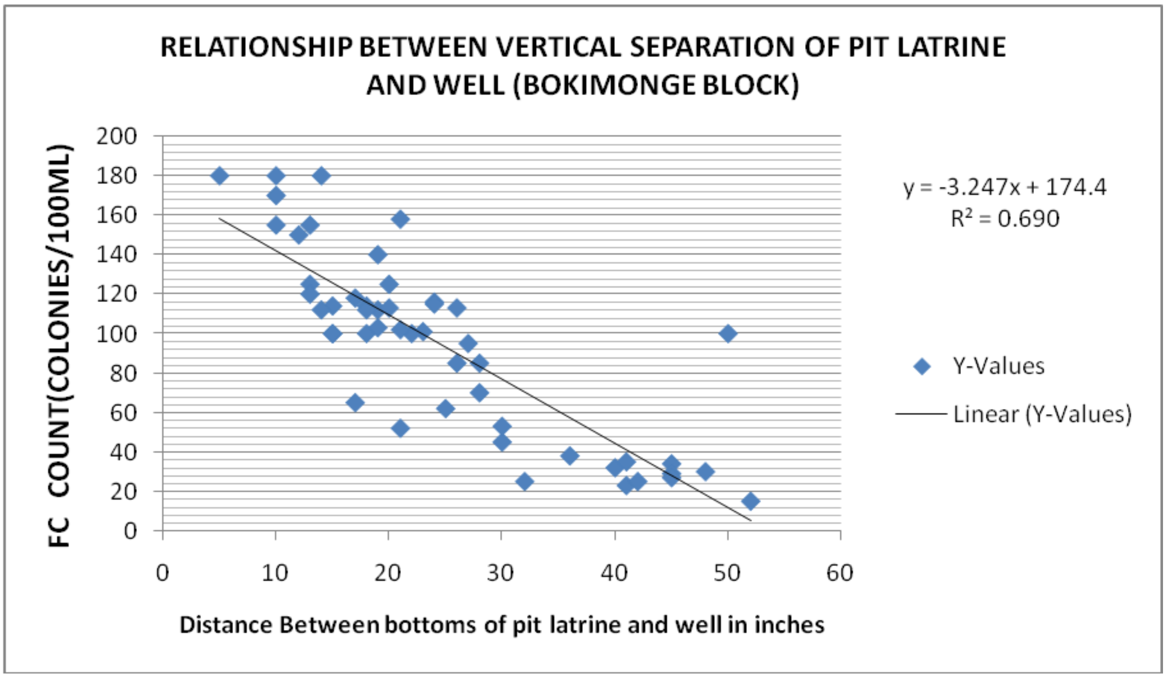


Figure 4.13.The relationship between the vertical distances of the bottoms of pit latrines and wells to that of fecal coliform count in hand dug wells (Bokimonge area)

Results showed that the spring and well water sources were the most preferred (62%) (Figure 4.14).

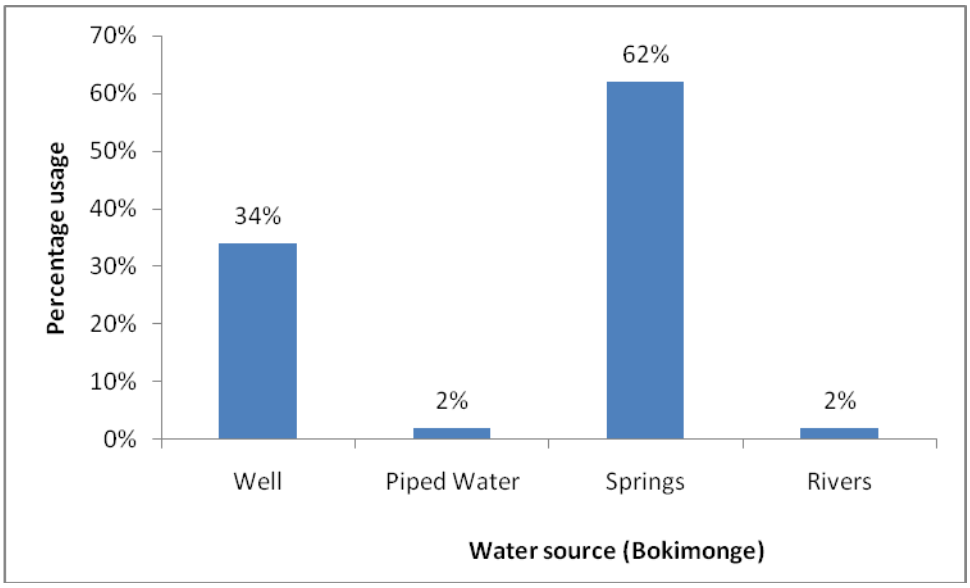


Figure 4.14: Percent usage of domestic water sources in Bokimonge area

Results also showed that pit latrines systems were the most preferred method of fecal disposal with the highest usage of 76% (Figure 4.15).

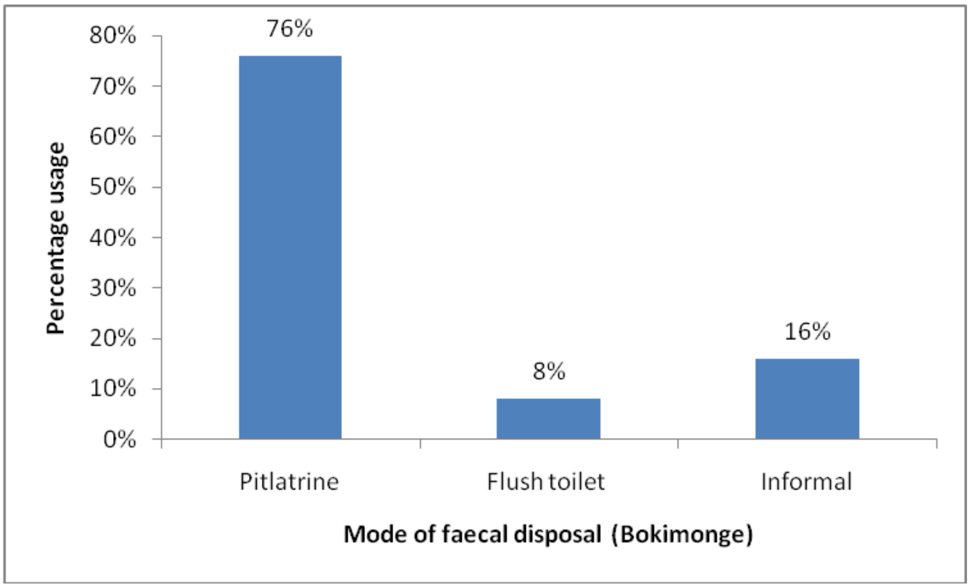


Figure 4.15 Percent usage of mode of fecal disposal in Bokimonge area

4.3.2 Mangeche area

Results show that the fecal coliforms count (cfu/100 ml) decreased as the vertical distance between depths of pit latrines and hand dug wells increased (Figure 4.16).There was a significant ($P<0.05$) relationship between vertical distance between depths of wells and pit latrines and fecal coliform count. Minimum vertical distance of about 42 inches recorded no fecal coliform R= 49.8% (Figure 4.16).

The fecal coliforms count (cfu/100 ml) decreased as the horizontal distance between pit latrines and hand dug wells increased (Figure 4.17).There is a significant ($P<0.05$) relationship between horizontal distance between wells and pit latrines and fecal coliform count in Magenche area, and minimum horizontal distance of about 28 meters had no fecal coliform observed R=24.6% (Figure 4.17).

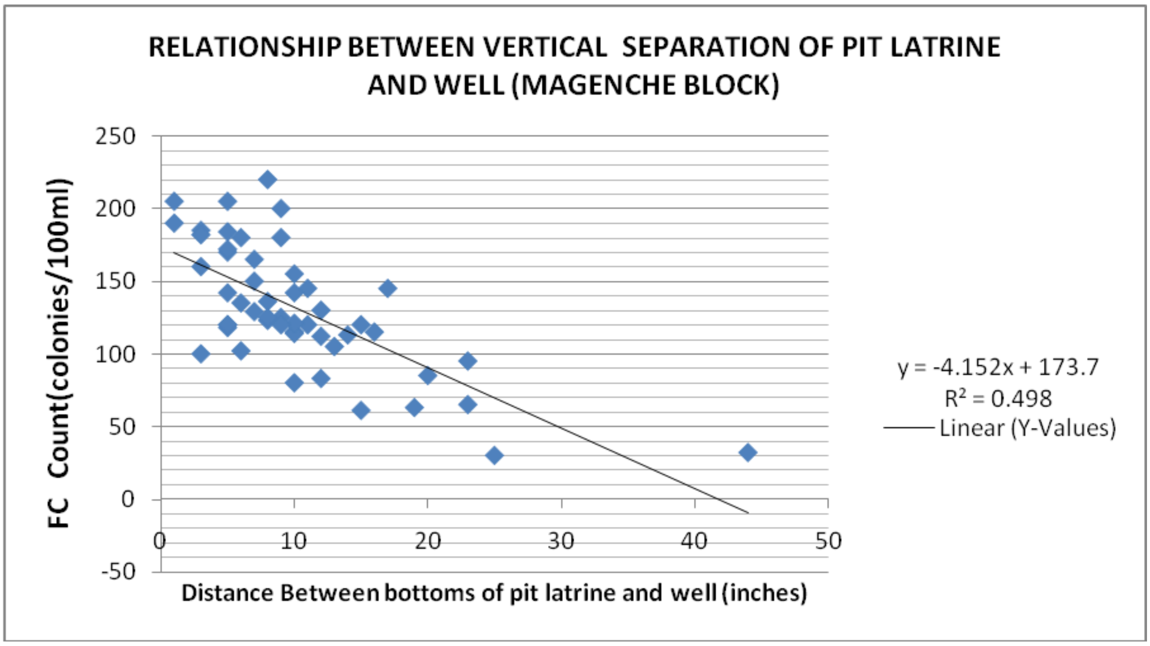


Figure 4.16 The relationship between vertical distance of bottoms of pit latrines and wells to fecal coliform count in Magenche area

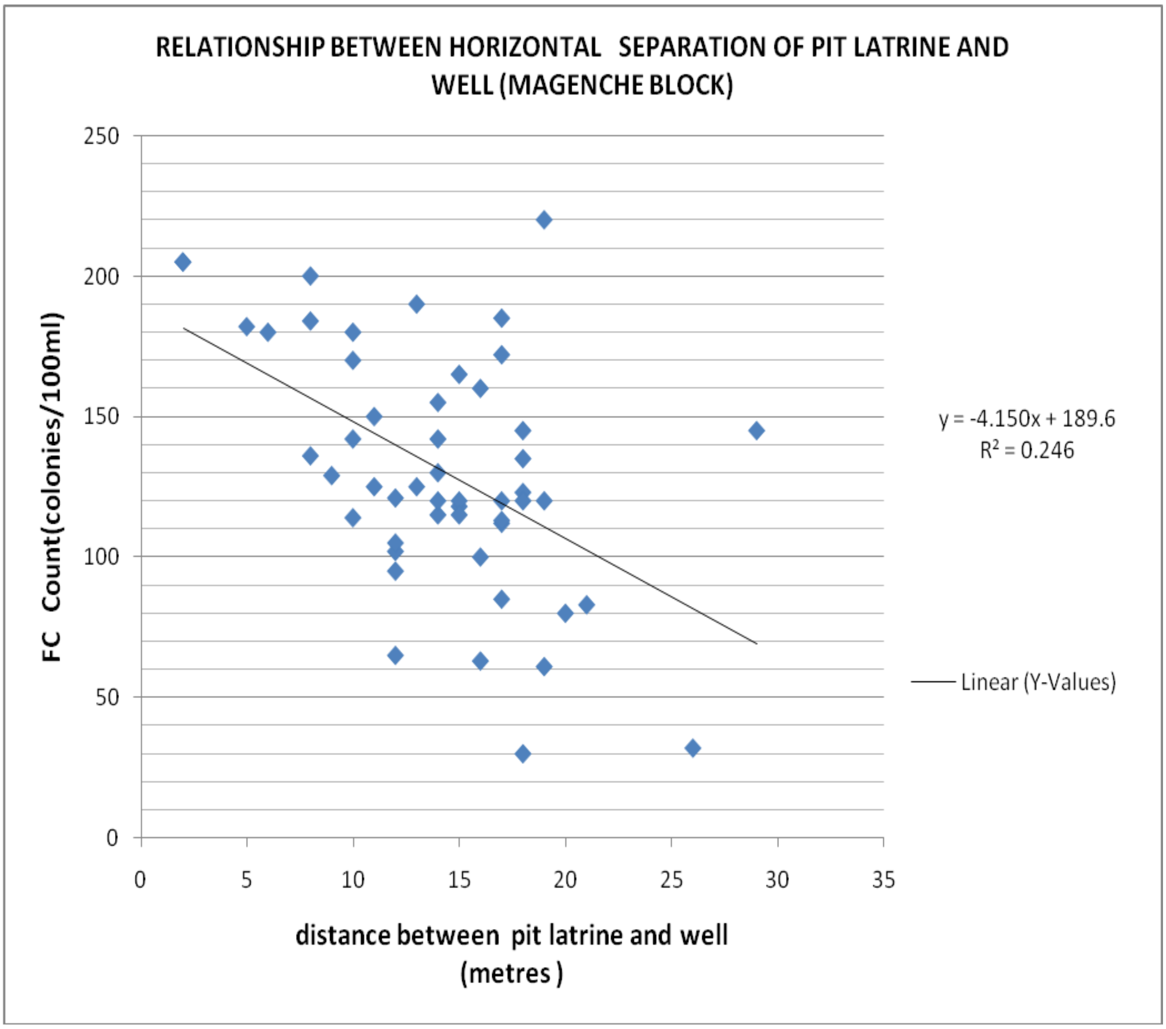


Figure 4.17 The relationship between horizontal distance of the pit latrines and wells to fecal coliform count in Magenche area

Well water was the most preferred source of water in Magenche with 75% usage (Figure 4.18). Results also indicated that the modes of fecal disposal were 10, 10and 80% for flush toilets (Figure 4.19).

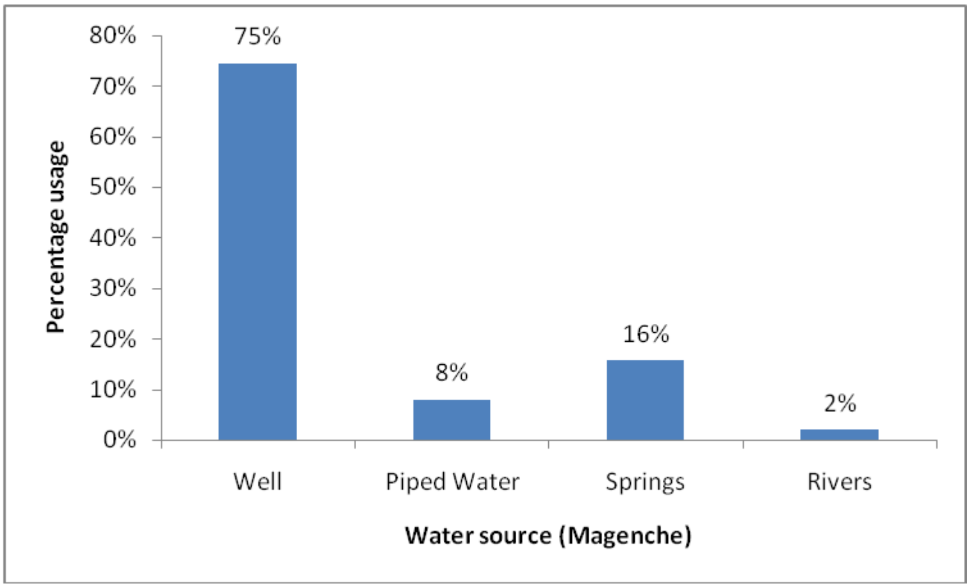


Figure 4.18 Percent usage of domestic water sources in Magenche area

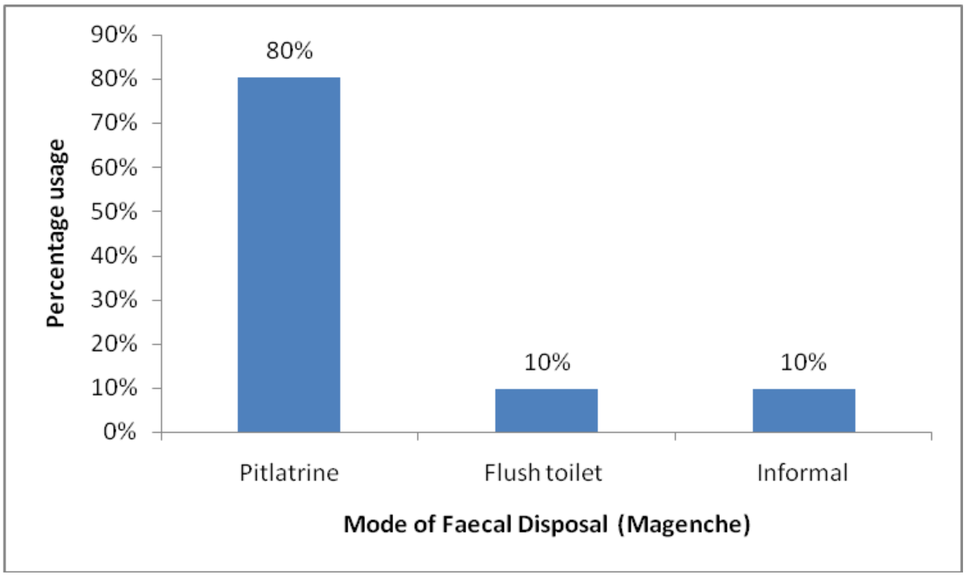


Figure 4.19 Percent usage of modes of fecal disposal in Magenche area

4.3.3 Bombaba area

Results show that the fecal coliforms count (cfu/100 ml) decreased as the horizontal distance between pit latrines and hand dug wells increased (Figure 4.20). There was a significant ($P<0.05$) relationship between horizontal distance between wells and pit latrines and fecal coliform count, results indicated that a horizontal distance of about 75meters was the minimum distance at which the fecal coliforms were not observed R=68.2% (Figure 4.20).

Results also showed that the fecal coliforms count (cfu/100 ml) decreased as the vertical distance between depths of pit latrines and hand dug wells increased. There was a significant ($P<0.05$) relationship between vertical distance between depths of wells and pit latrines and fecal coliform count and at a minimum vertical distance of about 45 inches there was no fecal coliform observed R=43.1% (Figure 4.21).

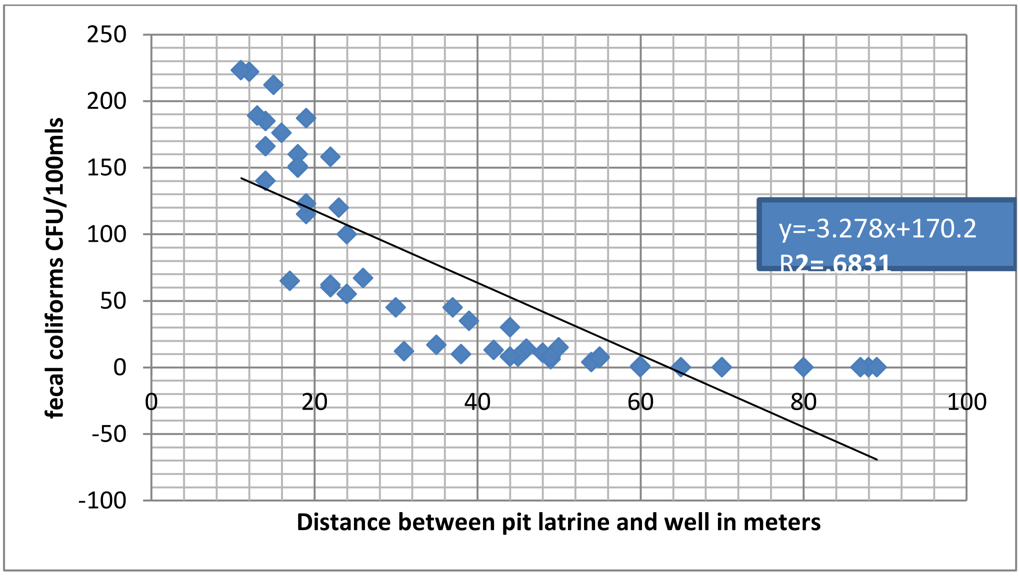


Figure 4.20 The relationship between horizontal distance of pit latrines and wells to that of fecal coliform count in Bombaba area

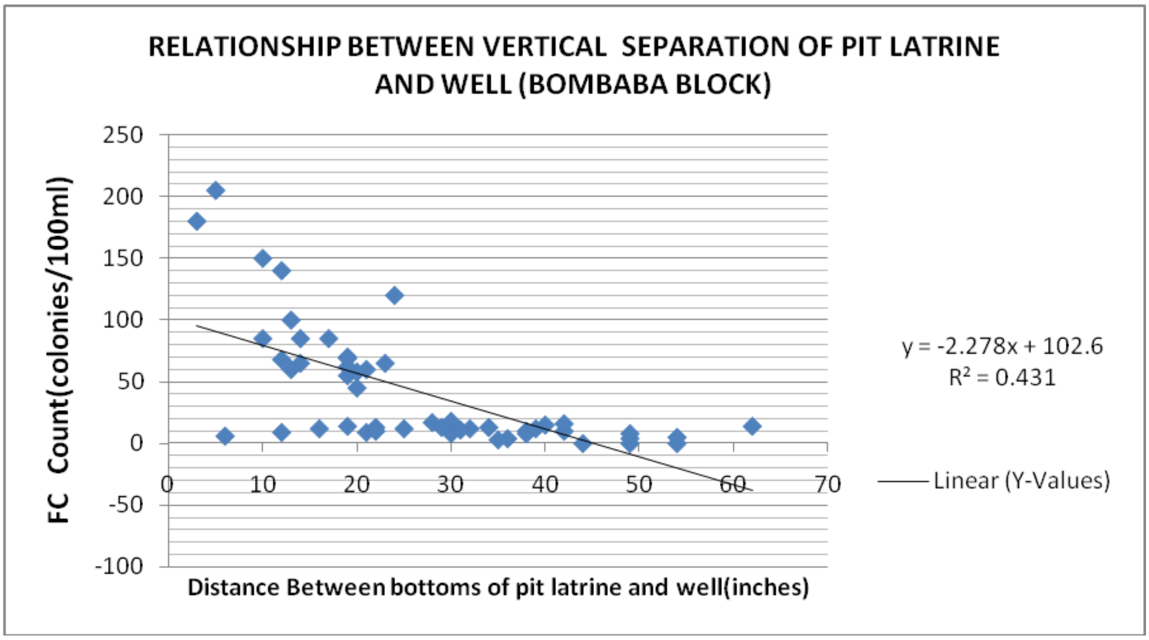


Figure 4.21 The relationship between vertical distance of the bottoms of pit latrines and wells to fecal coliform count in Bombaba area

Results also showed spring (55%) and well water (37%) sources were the most preferred sources of domestic water in Bombaba area (Figure 4.22).

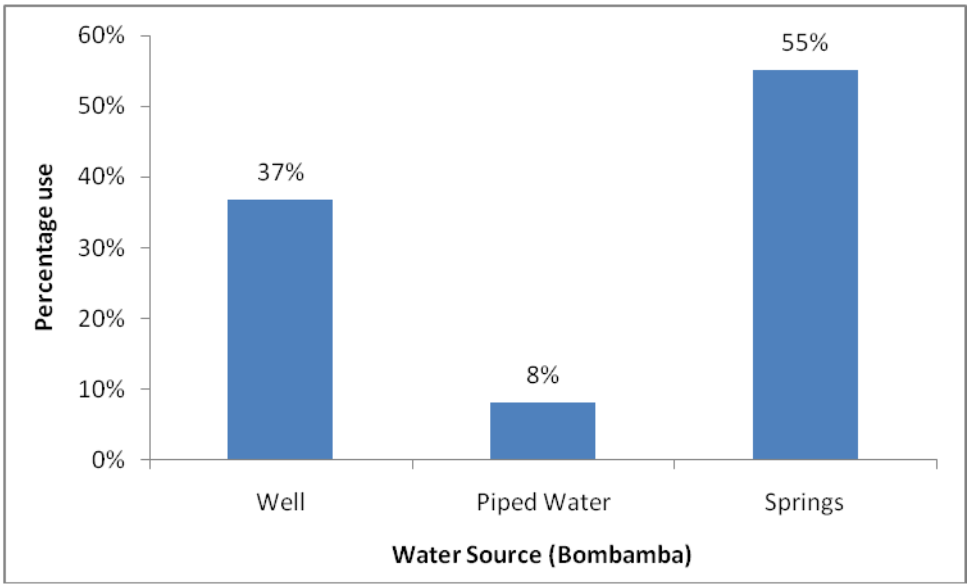


Figure 4.22 Percent usage of domestic water sources in Bombaba area

Pit latrines systems were the most preferred method of fecal disposal with the highest usage of 78% (Figure 4.23).

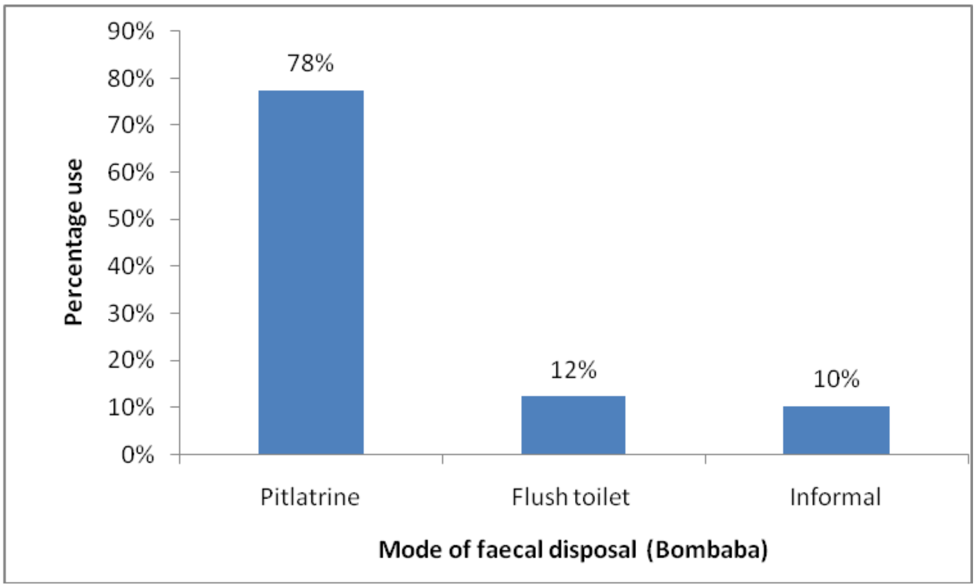


Figure 4.23. Percent usage of modes of fecal disposal in Bombaba area

4.3.4 Boochi area

Results showed that the fecal coliforms count (cfu/100 ml) decreased as the horizontal distance between pit latrines and hand dug wells increased. There was a significant (P<0.05) relationship between horizontal distance between wells and pit latrines and fecal coliform count and a minimum horizontal distance of about 48 meters beyond which no fecal coliforms were observed R=55% (Figure 4.24).

Results also showed that the fecal coliforms count (cfu/100 ml) decreased as the vertical distance between depths of pit latrines and hand dug wells increased (Figure 4.25). There was a significant (P<0.05) relationship between vertical distance between depths of wells and pit latrines and fecal coliform count and a minimum vertical distance of about 45 inches beyond which no fecal coliform was observed, R=57.2% (Figure 4.25).

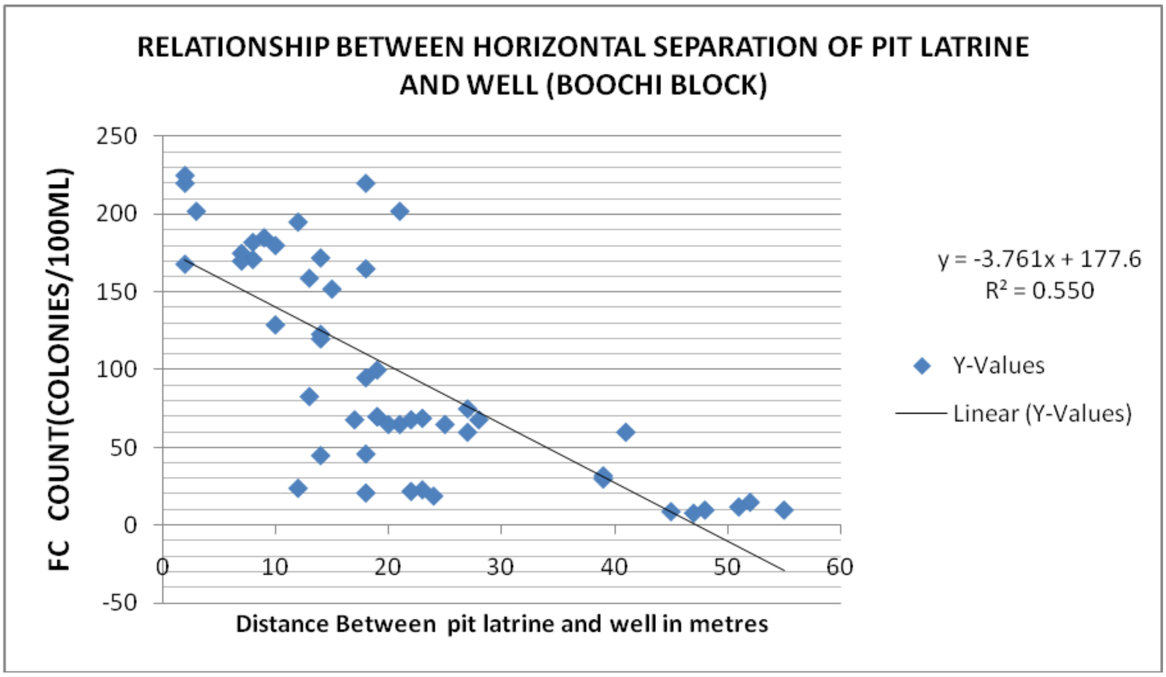


Figure 4.24 The relationship between distance of pit latrines and wells to fecal coliform count in Boochi area

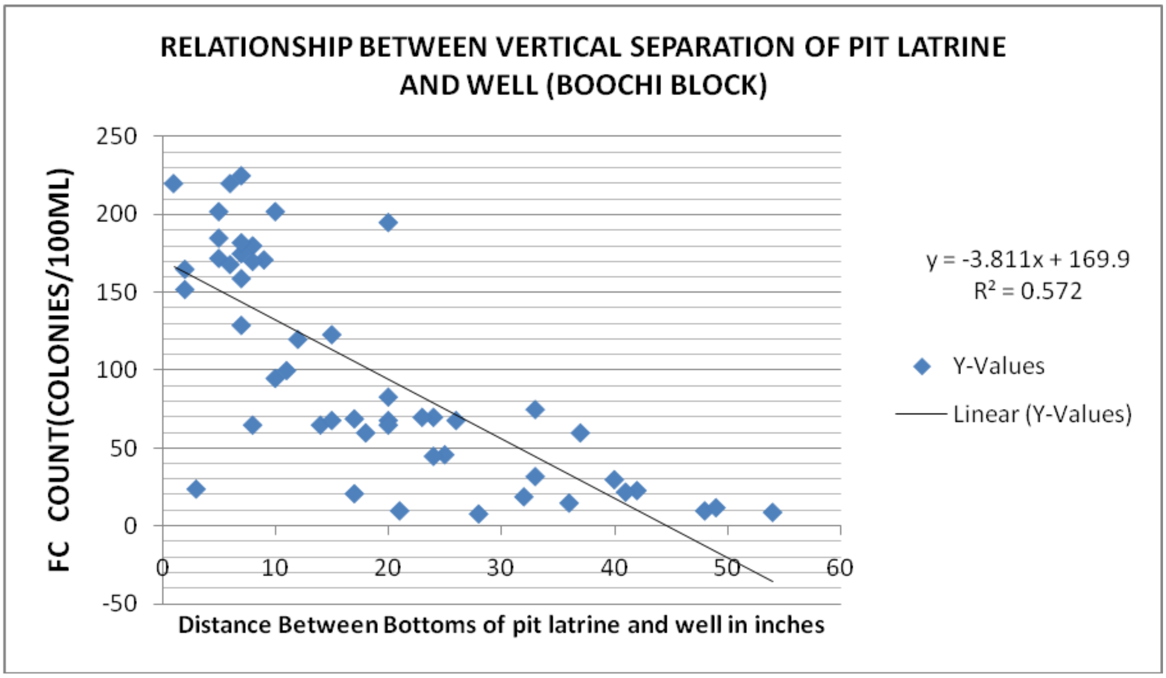


Figure 4.25 The relationship between vertical distance of the bottoms of pit latrines and wells to fecal coliform count in Boochi area

Results indicated that spring (62%) and well water (34%) sources were the most preferred domestic water sources in Boochi area (Figure 4.26).

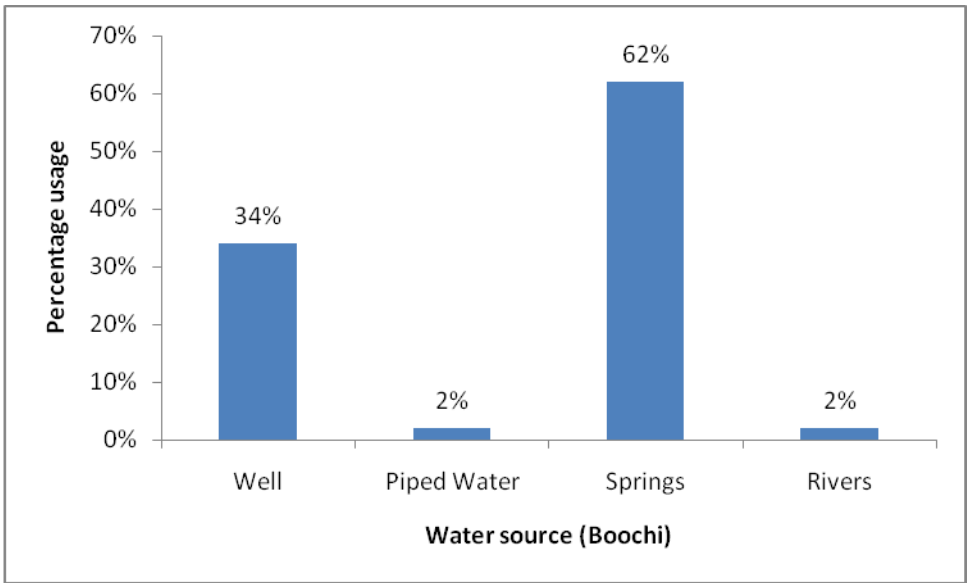


Figure 4.26. Percent usage of domestic water sources in Boochi area

Pit latrines systems were the most preferred mode of fecal disposal with the highest usage of 78% in Boochi area (Figure 4.27).

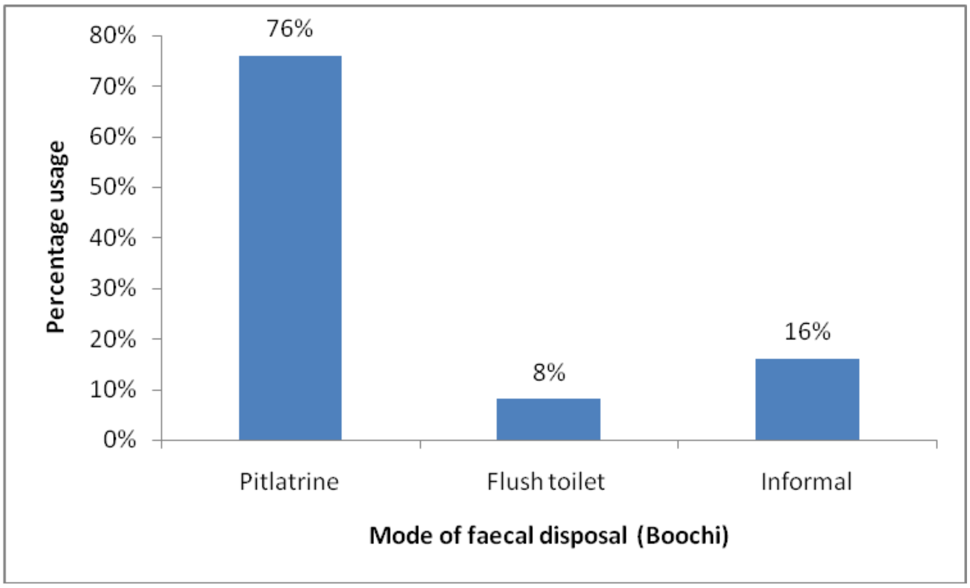


Figure 4.27 Percent usage of different modes of fecal disposal in Boochi area

4.3.5 Bomachoge – Borabu sub county area

Results show that the fecal coliforms count (cfu/100 ml) decreased as the horizontal distance between pit latrines and hand dug wells increased. There was a significant (P<0.05) relationship between horizontal distance between wells and pit latrines and fecal coliform count (Appendix 9) and a minimum horizontal distance is about 60 meters beyond which no fecal coliform was observed in Bomachoge area, R=48.9% (Figure 4.28).

Results also showed that the fecal coliforms count (cfu/100 ml) decreased as the vertical distance between depths of pit latrines and hand dug wells increased. There was a significant (P<0.05) relationship between vertical distance between wells and pit latrines and fecal coliform count (Appendix 8) and a minimum horizontal distance of about 46 inches beyond which no fecal coliform was observed generally in Bomachoge area, R=51.9% (Figure 4.29).

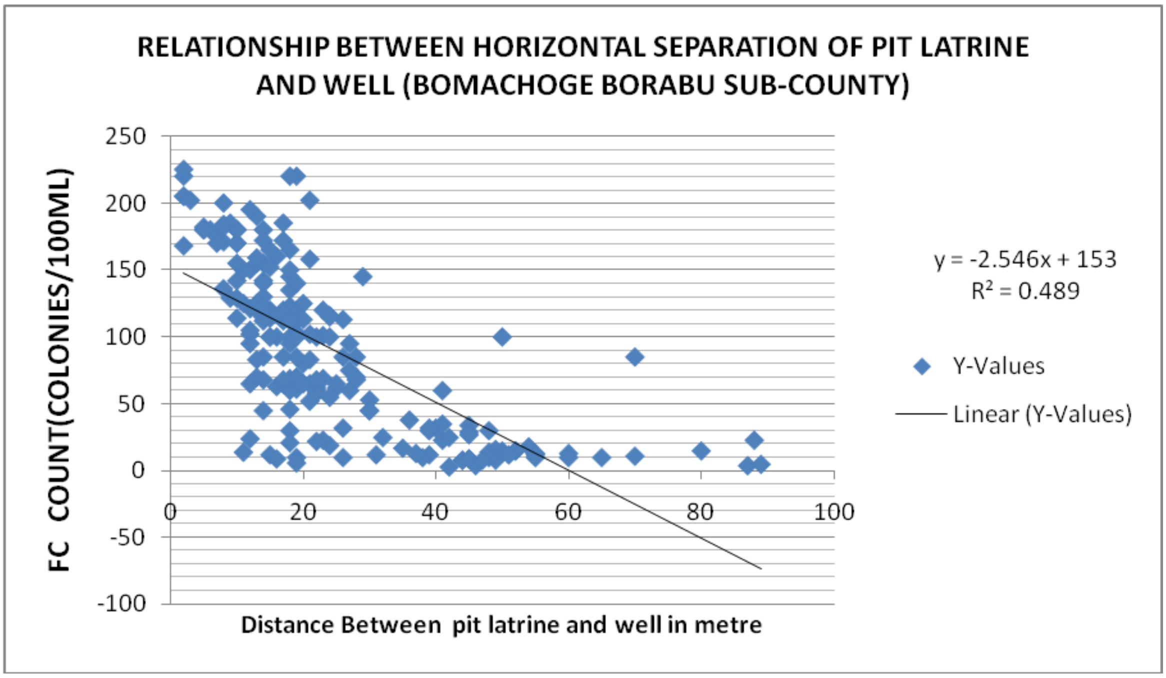


Figure 4.28 The relationship between horizontal distance of pit latrine, the well and levels of fecal coliforms in Bomachoge sub county

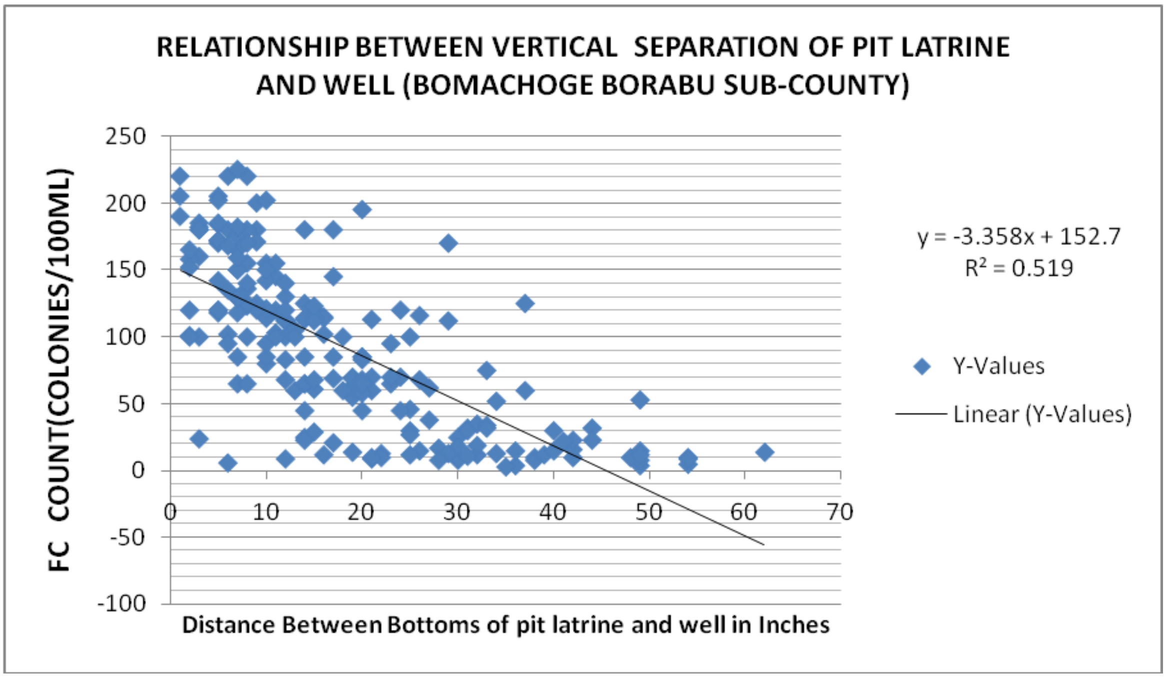


Figure 4.29.The relationship of the distance between the bottoms of pit latrines and wells and to fecal coliform count in Bomachoge-Borabu sub-county

The ratio of fecal coliforms and fecal *Streptococcus* from calculated means was 0.87 (Table 4.5) and the value lies between 0.7 and 4.

Table 4.5 Fecal coliforms (FC) and fecal *Streptococcus* (FS) ratio

Parameter	FC and FS means in the reservoir (cfu/100mls)	FC:FS ratio
FC	308.00	0.87
FS	352.00	

CHAPTER FIVE

DISCUSSION

5.1 Effects of constructed wetlands with sand filters on bacteriological and physicochemical parameters of water

5.1.1 Microbiological parameters

Discharge of wastewater into water bodies alters the bacteriological and chemical levels negatively affecting human and aquatic life. When an ecosystem gets polluted, the natural environment is disturbed and this affects organisms in different ways and can potentially reduce biodiversity of organisms (Soper, 2002). It is therefore important to remove pollutants from water since pollution of water causes abnormal conditions in ecosystems (Zacharia and Shordt, 2004).

Chemicals such as nitrates, phosphates and bacteria, affect water conditions greatly for example excessive nutrients leads to eutrophication which could directly destroy populations of organisms dependent on water bodies for their survival (Zacharia and Shordt, 2004). The main damage caused by water pollution is that it kills life that depends on this water bodies. Dead of fish, crabs, birds, sea gulls, dolphin and many other animals often wind up on beaches, killed by pollutants in their habitats (Tebbut, 1992).

Constructed wetlands and sand filters have been used effectively in the removal of pollutants from polluted water. Boutilier *et al* (2010) using cattails plant in wetlands reported average *E. coli* removal efficiency of 95% and Kadlec and Knight (1996) reported removal efficiencies of 90% and 80% for fecal coliforms and 80% *E. coli* respectively in a wetland vegetated with reed beds. All these studies demonstrated the ability of constructed wetland system using various plant species in treating polluted water hence preventing pollution problems. These plants are commonly known as biological filters because they provide protection for water sources. Stauber., (2008) reported 98.9% removal efficiency of *E. coli* by sand filters alone similar findings were echoed by Wheelis (2008) who revealed interesting trends in bacterial removal by sand filters. He reported 98%, 74% and 85% fecal *Streptococcus,* fecal coliforms and total coliforms count removal respectively at sand bed depth of 0.5m. Therefore, it is worth assuming that combining plants and sand filters may improve efficiency due to presumed synergy. In the current study *Colocasia esculenta*, *Cyperus esculentus* together with sand filters were investigated to establish efficacy in filtering pollutants from contaminated water.

The test for significant change in the pollutant load in the current study showed that both plants species as well as the combination of the two plant species resulted in a significant reduction of most pollutants (P<0.05). Plant type and sand grain sizes significantly reduced the levels total coliforms, fecal coliforms, *E.coli,* fecal *Streptococcus,* biological oxygen demand, dissolved oxygen, nitrates, phosphates, temperature, pH, conductivity and turbidity.

The interactions between plant type and sand grain size also had significant effects on the six bacteriological parameters.

Colocasia esculenta reduced total coliforms, fecal coliforms, *E. coli* and fecal *Streptococcus* by approximately 98%. Further filtration of water by sand filters did not significantly reduced the number of these bacterial groups. These reductions in the number of bacterial groups by plants in the current study are similar to those observed by Torrens *et al.,* (2009) in monocultural systems, whereby the findings indicated that the wetlands planted with canna achieved a removal efficiency of 97.1%, 98.3%, 99.98% and 100% for fecal coliforms, total coliforms, fecal *Streptococcus* and *E. coli* respectively. The results in the current study also found out that the range of bacterial removals by constructed wetlands was similar to those reported by Reinoso *et al* (2008). Though there was no significant difference detected in bacterial removal within sand grain sizes of sand filters together with *C. esculenta* in the present study. The average percentage removal of bacterial groups in this study is consistent with previous studies done on efficiencies of sand filters as reported by Stauber *et al* (2006).

The excellent removal of these bacterial groups by wetlands vegetated with *C. esculenta* may involve several factors such as amount of plant coverage, hydraulic retention time and settling of bacteria. These factors may account for variability in reduction the bacteria groups especially in other plant species (Shutes, 2001). Interestingly, this study showed substantial differences in bacterial groups reductions when *C. esculentus* alone and a combination of *C. esculenta* and *C. esculentus* together with sand filters. A monoculture of *C. esculentus* reduced total coliforms and fecal *Streptococcus* by 21% and 9% respectively. Similarly, fecal coliforms and *E. coli* decreased by 3% and 11% respectively this could be probably because conditions around the root mat of the *C. esculentus* not being suitable for removal of this particular group of bacteria. However, subsequent filtration through the sand filters generally reduced total coliforms, fecal coliforms, fecal *Streptococcus* and *E. coli* by approximately 70%.

The sand filters (0.5, 1 and 2mm) did not significantly differ in reduction of total coliforms. The performance of *C. esculentus* alone in reduction of bacterial groups was significantly lower than that of *C. esculenta*. However, the increase in its performance was achieved after it was combined with sand filters presumably this could be associated with filtration by the sand grains. Sand filters are more efficient than constructed wetlands vegetated with *C. esculentus*, if designed and operated well they can remove bacterial groups within a range of 90-99% (Vymazal, 2006).

The lower removal percentage of bacterial groups by *C. esculentus* contrasts the high percentage removal of bacterial groups reported in other studies demonstrated by wetland plant (Shutes, 2001). In many constructed wetland studies, removal efficiencies of total coliforms and fecal coliforms have been reported to be slightly greater than 90% while, *E. coli* and fecal *Streptococcus* percentage removal greater than 80% (Jenkins *et al.*, 2009). Sand filters provide a synergy that improves the efficiency of the removal of bacterial groups (Torrens *et al*., 2009). The association between wetland plants and sand filters in the current study shows the importance of the plant and sand filter systems in removing bacterial groups. This could be due to sedimentation, chemical reactions, natural die offs mechanical filtration and predation by zooplanktons, lytic bacteria and attack by bacteriophages (Kadlec and Knight 1996; USEPA, 2000; Pant *et al.*, 2001).

A combination of *C. esculenta* and *C. esculentus* plant species alone in a wetland reduced total coliforms, fecal coliforms and *E. coli* by approximately 26%, 36% and 31% respectively. Fecal streptococci decreased by9% as revealed by the current study. This results show that combined plant species did not improve the performance of *C. esculenta* plant species in terms of removal of investigated bacterial groups. In addition, conditions for multiplication of fecal *Streptococcus* were maintained. Interestingly, favorable conditions for multiplication of *E .coli* were probably withdrawn by the introduction of *C. esculenta* and this explains why percentage removal of *E. coli* increased.

Generally, the current study revealed that *C. esculenta* plant is more superior in removing pollutants from contaminated water as compared to *C. esculentus* alone and even their combination did not reduce bacterial groups in water. The plants *C. esculenta* and *C. esculentus* together with 0.5mm sand filter reduced the number of bacterial groups such as fecal coliforms, total coliforms and fecal *Streptococcus* by 76%, 78% and 79% respectively. However, the two plants combined with the 1mm and 2mm sand filters did not significantly increase performance bacterial reduction from water. Though there was slight increase in removal efficiency of approximately 10% on average. These findings are not in tandem with those reported by Barret (1989) that sand filters using finer sand grain sizes performed better in terms of bacteria removal than sand filters using coarser sand.

Logan *et al*. (2001) also reported that intermittent sand filter column of 0.6mm sand grains effectively removed bacteria than coarse grain sand media regardless of the conditions. The results in the current study could probably be attributed to easy attachment of bacteria groups to the coarse sand grains and reduction of die-off rates due good aeration in coarse sand than fine sand grains.

Biological oxygen demand, Phosphates and nitrates levels in the reservoir of the current study were higher as compared to the WHO recommended levels (WHO, 2007) probably due to contamination by the water resource users. Conversely, the dissolved oxygen quantity in the reservoir was lower than levels recorded in outflows from plants and sand filters. However, the values of other parameters were reduced as water passed through *C. esculenta, Cyperus esculentus* and a polyculture of the two plants in the current study. The reduction percentages of BOD, PO_4 and NO_3 were much lower when water passed through *C. esculentus* and a polyculture of *C. esculenta* and *C. esculentus* compared a monoculture of *C. esculenta* alone. Kivaisi (2001) working on morphologically similar plants as those used in the current study, he reported approximately 81% efficiency in removing bacterial groups using surface flow constructed wetland system with water hyacinth species. Likewise, Ismail *et al* (2008) found removal efficiency of up to approximately 85% of these parameters by *Phragmites* of constructed wetlands in Egypt. These reports are similar to the results of the current study on the performance of *C. esculenta* in which BOD, DO, NO_3, PO_4 reduced by 62%, 67%,86% and 95% respectively.

The possible reason for lower removal percentage bacteriological and physico-chemical parameters from water by *C. esculentus* and a polyculture of *C. esculentus* and *C. esculenta* in the current as compared to other reports may be due to low levels of degradable organic matter entering the reservoir as such much of it might have been reduced on entering the wetlands. Watson *et al* (1989) pointed out that the oxygen is obtained through diffusion, convection and oxygen leakages from macrophyte roots into rhizophore. Hence, treatment efficiency for removal of BOD depends on availability of oxygen.

Reduction of nutrients such as PO_4 and NO_3in the current study may be due to sedimentation and much of it may be used while others still bound in organic matter at the root mat (Weisner *et al.*, 1994). The phosphate removal mechanisms include chemical adsorption, precipitation in substrate, biological transformations and to lower percentage plant uptake as observed by Kadlec and Knight (1996). The removal mechanisms of nitrates include uptake by plants and microorganisms, ammonification, nitrification, denitrification, ammonia volatilization and cation exchange for ammonium as reported by Vymazal (2006).

Generally, use of wetlands jointly with sand filters had significant effects on nutrients, BOD and dissolved oxygen. The results obtained in the current study showed that plants played a role in removal of phosphates and nitrates from water and removal efficiency was most probably enhanced when the wetlands were combined to sand filters. This was probably due to the fact that the phosphates and nitrates were filtered out mechanically by adsorption.

5.1.2 Physico-chemical parameters

The interactions between plant type and sand grain size had significant ($p \leq 0.05$) effects on all physico-chemical parameters except pH. Conductivity was significantly reduced by plant types and sand grain sizes during filtration process probably due to evapo-transpiration or movement of substrate by plant roots accumulated this effect (Hench *et al.*, 2003). The decrease in conductivity despite significant water losses is explained by uptake of micro and macro elements and ions by plants and bacteria, and their removal through adsorption to plant roots (Hench *et al.*, 2003).

Reduction of conductivity by sand filters is probably due to adsorption in the sand and action by bacteria communities. In addition, results from this study indicated that sand filters reduced conductivity significantly although their sand grain sizes did not significantly affect the reduction levels. These findings are similar to those observed by Bellamy *et al* (1985) who reported that increase in the effective sand grain size did not necessarily result in reduced sand filter performance.

Efficiency of constructed wetlands together with sand filters in removal of turbidity in this study may have probably depended on size of sand granules, the finer the sand the higher the removal levels. This system of plant types together with sand filters acted as a mechanical and biological filter and removed suspended particles from water and thus decreased turbidity. Similar results were reported by Matagi *et al* (1998) who observed in his findings that sand granules and plant roots mechanically sieve water removing particles and hence reduction in turbidity. It is also worth mentioning that the plant type alone had lower performance in reduction of turbidity as compared to plant species together with sand filters. This is presumably due to large spaces between the roots of wetland plants that allow particles to pass through unlike sand grains.

Plant type and sand grains did not significantly ($P \geq 0.05$) affect pH in water. This observation in this study was probably due to CO_2 production from decomposing organic matter in water and other water components trapped in water in their root mat and also nitrification process (APHA, 1998). In addition, when compared to WHO standards, the pH effluent in the study area remained with a range of 6.5 to 8.5 and these are acceptable limits for drinking water and survival of aquatic life (APHA, 1998).

Temperature measured in this study had values within a range of 15 and 26 ^{0}C. This shows that there was no temperature uniformity of the water at different stages during filtration process by plant types and sand filters. This obviously shows that the values do not meet WHO/UNICEF standards for drinking water of between 22 to 29^{0}C (WHO/UNICEF, 2004). Low water temperatures are not recommended mainly because they make drinking difficult. Low temperatures in the water as observed in the current study could be due to the canopy created by plant leaves which prevent light from reaching the water in the constructed wetlands and sand filters placed in areas without direct sunlight.

5.2 Sanitation survey

The major domestic water sources in Bomachoge Borabu sub county are hand dug wells and natural springs, the study revealed that the hand dug wells were located between 5 to 90 meters and majority ranged from 5 to 30 meters horizontal separation distance. In addition, the vertical separation distance between depths of pit latrines and hand dug wells range was 0 to 62 inches and many cases ranged from 0 to 20 inches which is about 0.508metre.

According to Sugden (2004) pit latrines should always be above the water table during all seasons and 1.5 meters below the surface is the minimum depth necessary to ensure the pit latrine contents remain dry and allow pathogens to die off naturally before reaching the water table. In comparison to the current study, this exposed the hand-dug wells to the risk of bacteriological contamination through inflow and seepage of fecal bacteria from the pit latrines.

Results of the current study indicated that hand dug wells were generally the most accessed among domestic water sources. Many of the hand dug wells did not have a cemented cover slaps and, in some cases, the inner walls of the hand dug wells were not fitted with concrete walls or impermeable materials. Responses from residents indicated that the hand-dug wells were used for multiple domestic purposes including drinking, bathing, watering livestock and washing clothes. Reports from other studies indicated that the hand-dug wells were the most utilized water resources (Kabogo and Kabiswa, 2008; Kabede, 1978). Therefore utilization of well water in other areas is similar to that observed in the present study.

The preference in utilization of hand dug well water in Bomachoge Borabu sub county was based on their proximity within the homestead which made it convenient to fetch and in addition, the water resource utilization does not attract any cost. Findings of the current study also indicate that preference of wells was quite varied among study areas. Hand-dug well water accessibility was highest across the Bomachoge sub county compared to the natural springs. Similar preference has been previously reported by other researchers (Dzwairo *et al.,* 2006). The report identified several factors including topography of the area as the driving force towards accessibility of hand-dug well water.

The higher preference of well water was probably due to the topography of its sub county that is hilly. The natural springs are located on the lower side that means that the population would carry the water up-hill, hence reduces its preference. Since wells are mostly contaminated due to frequent usage coupled with poor sanitary practices (Gakukia *et al*., 2010) other than domestic water sources, it is possible that the sanitary practices of a particular population could be responsible for the magnitude of its groundwater contamination.

The usage of natural springs in Bomachoge Borabu sub county was notably low than hand-dug wells. As indicated in the local development plan (Kisii Development Plan, 2008) most residents would travel long distances of up to 1.5km on average to reach natural spring after negotiating corners and hills. These factors reduced the usage of the spring as a source of domestic water. Dzwairo, *et al*., (2006) noted that the degree of contamination is complex and must be approached from several dimensions if contamination of domestic water sources is to be tackled effectively. The present study demonstrated that domestic the water sources were contaminated by bacteria. With well water being the most contaminated while spring water was the least contaminated. The results showed that domestic water sources were potential sources of human illnesses and dead of aquatic life (Bartram and Balance, 1996).

Although water pollution indicator organisms may be presumed to be harmless, the presence of fecal coliforms is an indication of the likely presence of other pathogenic organisms (Bartram and Balance, 1996; Olivieri *et al*., 1977). Also the intensity of fecal coliforms in water is usually taken as a measure of degree of contamination of water sources (Cheesbrough, 2006).Different modes of human fecal disposal contribute variously to the contamination of different water sources (Howard *et al*., 2003).

Contamination of domestic water sources is more serious in developing than in developed countries as was noted in Tanzania (Kauzeni, 1981; Norconsult,1981) and Java (Lloyd,1990).In these two studies, domestic water sources were heavily contaminated with fecal bacteria. Whereas, in developed countries, on-site sanitation facilities were properly sited, designed, constructed and maintained in settlement areas (Lerner, 1996). These conditions presumably limited the risk of groundwater contamination by human fecal materials.

Fecal disposal management in the study areas (Magenche, Bokimonge, Bombaba and Boochi) involved use of pit latrines and informal methods. The main mode of human fecal matter disposal in the four areas was pit latrines with over 60% of the residents using the facility. This mode of human fecal disposal was reported to be also common in many developing countries (Esrey *et al.*, 2001; Gakukia *et al*., 2010).Pit latrines were the most preferred structures due to their affordability in terms of construction and utilization. They also work under the principle of “drop and store“(Esrey *et al*., 2001) as compared to flush toilets that are more expensive to install (Lenton *et al*., 2005).The later also requires a lot of water to operate. Despite the numerous merits, pit latrines contribute to the highest risk of contaminating domestic water sources. Improper construction, design and unhygienic management of pit latrines in rural and urban areas may lead to environmental degradation expressed by contamination of surface and ground water through seepage and direct fecal contact with the soils (Obabori, 2009).

Pit latrines easily contaminate underground water sources through seepage and infiltration of it is contents. In addition, contamination worsens when the pit latrines are poorly designed, constructed and maintained. Probably this is the main source of high level of fecal bacteria count found in the drinking water sources of Bomachoge Borabu sub county. If the design and infrastructure are poor the clean disposable facilities may not function to the expected levels in terms of hygiene. The economic power of an area may not play a major role in hygiene if the culture of residents is unfriendly to hygiene and human fecal disposal structures are not properly designed and maintained (Shannon, 2003).

Informal methods of human fecal disposal are important sources of domestic water contamination in Bomachoge sub county. This was especially true for the main domestic water source like hand dug wells (Dzwairo *et al*., 2006). The situation may be complicated by the fact that there is no order or regularity in the way disposals are made, thus making the existing safe disposal policies implementation impractical.

Use of informal disposal methods is a worldwide issue House *et al.,* (2004) reported that in Bangladesh a large population used informal fecal matter disposal methods. A similar situation was reported in Kenya by Guardian Development Network (2010) revealing that 10% of Kenyan population used informal methods for fecal matter disposal especially in slum areas. Yeager *et al.,* (1999) also noted that majority of young children defecate informally on soil and their mothers use grass for anal cleaning thus contaminating the ground with feces through water runoffs.

In the current study it was also found that children feces were commonly disposed on open ground in most homesteads among the four study areas of Bomachoge Borabu sub county. This was presumed to be the cause of contamination of domestic water sources, through surface runoffs that carry the feces and polluted soils into the water sources. Apart from disposal methods, physical factors have also been implicated in contamination of domestic water sources by fecal bacteria (Sugden, 2004; Kimani and Ngindu, 2007).The distance between pit latrine and hand dug wells at which there are no fecal bacteria count found has been defined by several authors (Cave and Kolsky, 1999); Morgan, 1990; Kimani and Ngindu, 2007; WHO, 2007).

As evidenced in the current study the distance between well and pit latrine affects fecal contamination of well water. Contamination at various distances may depend upon soil types and hydraulic gradient or slope of an area. The depths of both well and pit latrine also influenced well water contamination. Bomachoge Borabu sub county generally has a low water table of about 60 inches for hand-dug wells while pit latrines depths are on average 35 inches (KDDP, 2008). According to Sugden (2004) the pit latrines should always be above the water table during all seasons and 1.5 meters below the surface is the minimum depth necessary to ensure the pit latrine contents remain dry and allow pathogens to die off naturally before reaching the water table.

In comparison with the current study it was found that the water table was generally close from the pit latrine depth, explaining why vertical separation between bottom of pit latrine and water influenced drinking water contamination by fecal bacteria. Probably, informal fecal disposition was quite rampant in these areas of study and this seems to be the main source of spring water contamination. This may occur at the surface or through subterranean means. It seems that surface runoff is one of the predominant mechanisms through which spring water source is fecally contaminated (Dhaneshwar *et al.*, 1985; Nordberg and Winblad, 1990).

Topography of the area may also influence fecal bacteria contamination on spring water. It is expected that hilly areas contribute more to fecal bacteria contamination of spring water than flat areas. Moreover, hilly topography increases water flow compared to flat topography. Cave and Kolsky (1999) explained that as the water flow rate increases, microorganisms penetrate deeper and infiltration increases into the ground. This influences natural spring water contamination since spring water originates from the underground.

The outcomes of the physico-chemical examination of the water samples from 96 and 98 hand-dug wells and springs respectively, show that the pH of collected water samples ranged from about 6 to 8. Obtained pH values from the results indicate that majority of the samples deviated significantly from the recommended World Health Organization standards for drinking water of 7.0 and this deviation may cause pose health implications. The measured temperature values of springs and hand dug wells collected water samples ranged from 10 to 25^0C. This shows a wide range of temperatures in ground water samples and this can be attributed to difference in levels of contamination and associated microbial activities. Generally high water temperatures are not suitable since they lower the quality of water and its palatability for resource users.

Water becomes turbid when substances like organic matter and soils are present. Mean turbidity for springs and wells was about 15 NTU and 35 NTU respectively, indicating that the wells were more turbid than springs. Generally, the level of turbidity in both springs and wells is higher than the recommended safe drinking water level of 0.5 to 1.0 NTU. These high levels of turbidity in well water could probably be the major cause of high bacteria counts in wells. The values recorded exceeded the WHO recommended levels of turbidity in drinking water, indicating that well water was unsafe for human consumption in Bomachoge Borabu sub county. Majority of hand-dug wells from which samples were collected were not covered with concrete slabs and the surrounding was bare.

These conditions might have combined to increase the inflow through water runoffs or infiltration into the hand dug wells of the study area. Mishra *et al.*, (2009) confirmed that high turbidity is caused by surface runoffs where soils are bare and wells not lined or covered. Hence the soil becomes loose during the rainy season or when drawing water from the wells. It was also observed that during water withdrawal a rope tied on a dirty container was used for drawing water and was abandoned on a dirty ground and later reintroduced during the next water withdrawal. This probably was another reason for high turbidity in hand-dug wells in the study area. Turbidity is also considered as a surrogate microbiological condition because it was closely associated to bacteria safety of drinking water and may also indicate that water could be contaminated with pathogens presenting human health risks (Olson, 2004; Mishra *et al.*, 2009).

The current study assessed the concentration of phosphates in the water samples from wells and springs. The concentrations of phosphates recorded in the collected samples were 1.1 to 1.4 mg/l and 0.9 to 2.0mg/l in springs and wells respectively. The high concentration of phosphorous in hand-dug well in the study areas might be due to the sanitary practices of the users and the proximity between wells and disposal points (Kabogo and Kabiswa, 2008). It is established that high phosphorous levels has no human health implications (WHO, 2004). From the results phosphate levels in the springs and wells reveals that the wells were highly contaminated than springs indicating that well water was unsafe for drinking.

The study revealed that all the collected samples from springs and wells had high concentrations of nitrates. Springs recorded arrange of 4.2 to 7.5mg/l whereas hand dug wells recorded 2.1 to 9.0 and the difference was insignificant. The high concentrations of nitrates in these sources could be attributed to farming practices in the surrounding areas and seepage of pit latrine contents to ground water. Drinking water report concluded that the nitrate concentration in ground water and surface water is normally low but can reach high levels as a result of leaching or run-off from agricultural activities or contamination from animal wastes (Dzwairo *et al*., 1985).

The results in this study show that conductivity was within acceptable levels in both springs and wells. There was a significant difference among springs of Bokimonge and Bombaba compared to those of Boochi and Magenche. Conductivity within springs and wells ranged from 1.6 to 2.2µs/cm and 1.9 to 2.2µs/cm. This reveals that conductivity cannot be used explain contamination of water among wells and springs of the study area. De-ionized water has conductivity range of 0.5 to 3µs/cm, while most streams range between 50 to 1500µs/cm. This shows that the recorded conductivity in this study was within acceptable standards.

In the current study results show that average BOD concentration was 0.7mg/l in water samples collected from springs and 2.4mg/l in samples collected from wells. From these results well water had a significantly high BOD than springs of Bomachoge Borabu sub county. This situation might be associated with contamination levels of the wells that were higher than springs. The high level of BOD can also be explained by the microbial activities in the hand-dug wells that results to high oxygen demands. High BOD is associated with presence of contaminants in sample; it is clear that hand-dug well water was not safe for drinking. Incubating water samples for 5 days is likely to show significantly high BOD and 2.4mg/l indicates a highly contaminated water source.

The dissolved oxygen is the amount of oxygen dissolved in water. The results indicate that DO 2.6 to 4.2mg/l and 2.3 to 3.4mg/l in samples collected from springs and wells. There many sources of oxygen for water, for instance the surrounding air, aeration of water that moves in the open and waste product of photosynthesis. Despite all these sources, oxygen levels in these samples were very low. This condition can be associated with the organic matter in the springs and wells that consumed oxygen during oxidation or microbial activities in the water. This confirms that the springs and wells of Bomachoge sub county were contaminated and therefore not safe for human consumption, numerous scientific studies suggest that 4-5 parts per million (ppm) of DO is the minimum amount that will support a large and diverse fish population. The DO concentration from the study area cannot support aquatic life. In addition, increase in temperature reduces the DO levels in water and this could be another reason for low oxygen levels in tested water samples.

Collected water samples from hand dug wells recorded a significant number of total coliforms ranging from 25 to 170 cfu/100 ml which far exceeded the WHO and Kenya standards of drinking water quality of o cfu/100 ml (WHO, 2004). The spring water samples also recorded 5 to 40 cfu/100 ml, levels which are equally unacceptable for drinking water. This could be due to sanitary practices around springs and hand dug wells that could have lead to the introduction of total coliforms by water users and water run-offs during rainy season (Howard *et al*., 2003).

Fecal coliforms in water samples collected from springs and wells ranged from 10 to 20 cfu/100 ml and 150 to 250 cfu/100 ml respectively. These results revealed that both spring and well water did not meet the WHO and Kenya drinking water standards of 0 cfu/100 ml (WHO, 2004). Howard *et al.*, (2007) reported that one of the major contributing factors of ground water pollution is pit latrines mostly located near water sources such as hand-dug wells and have been identified as a major source of contamination of wells by human fecal matter. A contamination level by fecal coliforms in springs and wells of the study area was significant.

The fact that *E. coli* bacteria were detected in both springs and wells in the present study area indicated recent fecal contamination (WHO, 2004). Results indicated that contamination of *E. coli* in springs and wells were 1 to 20 cfu/100ml and 25 to 100 cfu/100ml respectively. The wells recorded the highest number of cfu/100 ml. This trend was associated with sanitary practices around the hand-dug wells. Spring and hand-dug well water was unsuitable for human consumption. Presence of *E. coli* in water samples also gave an indication of the presence of other potentially harmful bacteria in the water (WHO, 2004). The figures of cfu/100 ml are unacceptable according to the drinking water standards of 0 cfu/100 ml (APHA, 1998).

Water samples collected from hand dug-wells recorded a smaller number of total feecal *Streptococcus* ranging from 3 to 25 cfu/100 ml when compared other bacteria strains. However, though low it exceeded the WHO and Kenya standards of drinking water quality (WHO, 2004). The spring water samples also recorded 2 to 14 cfu/100 ml levels, which were equally unacceptable for drinking water. This could be due to poor sanitary practices around springs and hand dug wells that presumably lead to the introduction of fecal *Streptococcus* by water users and water run-offs during rainy season (Howard *et al*., 2003).

The fecal coliforms and fecal *Streptococcus* ratio calculated from their mean values was 0.87. The ratio of 0.87 lies between 0.7 to 4 which indicated that the source of fecal pollution in water sources was presumably human and other warm blooded animals according to Coyne and Howell (1994). The prediction is consistent with the findings from the current study. Research tools like questionnaires and observations revealed that the main sources of fecal matter in the study area were human, dogs, cattle and poultry and could easily get into water sources through poor waste management.

Based on the results the main domestic water sources of Bomachoge Borabu sub county were hand-dug wells and natural springs. These water sources were highly contaminated with fecal matter due to poorly designed disposal systems and poor sanitary practices. The situation can potentially cause health impacts on water consumers if efforts are not made to improve the quality of water drawn from these sources. However, improving water quality requires heavy investment and that becomes a burden to water resource users. The results of the current study reveal further, that the use of native plant species (*C. esculenta*) together with sand filters proved to be cost effective and the best combination in removing water pollutants. Use of this native plant species and sand filters in purification of domestic water sources of the study area could be the most appropriate way of improving water quality and the venture is tenable.

CHAPTER SIX

CONCLUSION

Constructed wetlands vegetated with *Colocasia esculenta, Cyperus esculentus* and a combination of the two plants with sand filters was continually efficient in removal of bacteriological and physico- chemical parameters from polluted water. The system indicated significant differences among plant species and sand filters of various grain sizes. Suggesting that *C. esculenta, C. esculentus* together with sand filters significantly removed pollutants from water which affect the dissolved oxygen levels required by aquatic life.

The study revealed that all the bacteriological and physico-chemical parameters of water analyzed from various hand dug wells and springs within Bomachoge sub county did not meet WHO standards of drinking water and cannot sustain aquatic life. The high levels of fecal bacteria and turbidity make water unpleasant and unfit for human use.

All the hand dug wells and springs tested positive for fecal bacteria and the presence of fecal bacteria suggested that there was fecal contamination of the main domestic water sources from pit latrines due to poor sanitary practices and close proximity between pit latrines and hand dug wells. It was also observed that significant association existed between horizontal distances from hand dug wells and pit latrines and vertical separations between the bottoms of pit latrines and hand-dug wells. The mode of human fecal disposal had a great impact on contamination domestic water sources.

RECOMMENDATION

Based on the findings of the current study it was suggested that;

- Native plant *Colocasia esculenta* which was investigated in the current study is recommended for planting along river and stream banks to reduce contaminants in the lotic waters.
- Policy to be put in place by stakeholders on conservation of *Colocasia esculenta* plant species.
- The water managers and stakeholders should ensure that the distance between pit latrines and hand dug wells should meet the recommended distance of 60 meters as observed in the current study.
- The vertical distance between the pit latrine bottom depth and hand dug well depth should be not less than 1.10 meter as per the findings of this study.
- The government should ensure adequate personnel for implementation of public health policies as a way of reducing water contamination.
- Enhancement of awareness and education of residents on design, citing, construction and protection of fecal disposal points, springs and hand dug wells.

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APPENDICES

Appendix 1: Questionnaire and Measurement Information

Introduction

Greetings, All respondents were given sufficient time to respond to questionnaires and the information was treated confidential for each respondent.

INSTRUCTIONS FOR COMPLETION

Tick (√) wherever appropriate

Name of the household…………………………Location……………………………

Code of the area……………………………………………………………………

1. What is your main source of water?

A. ( ) Hand dug well B. ( ) Piped water. C. ( ) Natural spring. D ( ).River E ( ) Other sources. Specify…………………………………

2. How many people use the main source of drinking water?

A. ( ) 0-5 B. ( ) 6-10 C. ( ) 11-20 D ( ) >20

3. Which method do you use to dispose stool within the homestead?

A. ( ) Pit latrine B.( ) Flush toilets C. ( ) Informal (bush, open field and paper bag).

4. Do you experience pit latrine over flow?( ) Yes ( ) No.

5.What do you do when your pit latrine is full?

A. ( ) Continue using it B. ( ) Close it and dig another one C. ( ) Emptied by municipal council

6. How do you dispose faecal matter from children?

( ) Soil ( ) Dust bin ( ) Pit latrine.

7. How do you clean children after defecation?

( ) Use grass ( ) use papers ( ) Wash the with water ( ) None ,specify…………………………………………………………….………………

8. Are your pit latrine roofed and borehole covered with no leakages?

( ) Yes ( ) No

9. How is your well protected from contamination?

A. ( ) Fenced B. ( ) Sealed with wood C.( )sealed with cement D.( ) Storm water diversion trenches

10. How are springs protected from human fecal contamination?

A. ( ) Grass planted around the spring B.( ) Fenced C.( ) Covered reservoir D.( ) Storm water diversion trenches.

11. What is the main use of river water?

( ) Bathing ( ) Washing clothes ( ) Drinking ( ) Disposing feces.

12. Do you tame domestic animals?

( ). Yes ( ). No

13. Which method of grazing do you practice?

( ) Zero grazing ( ) Tethering ( ) Paddocking ( ) None specify…………………………………………..…………………

14. How do you dispose faeces from cows,dogs, poultry and any other animal within your homestead?

( ) Field ( ) Dust bin ( ) Pit latrine ( ) Garden.

Measurements

All measurements done in meters and inches.

a. The horizontal distance between pit latrine and shallow well……
………………………………………………………………………………
b. The depth of hand dug well ....meters.
c. Estimated depth of the pit latrine ....meters.
d. Location of pit latrine to that of hand dug well.......................upper side ( ) lower side ( )
e. Location of pit latrine to that of natural spring..............................upper( )lower ( )
f. Distance between animal shed and water source…………………meters.

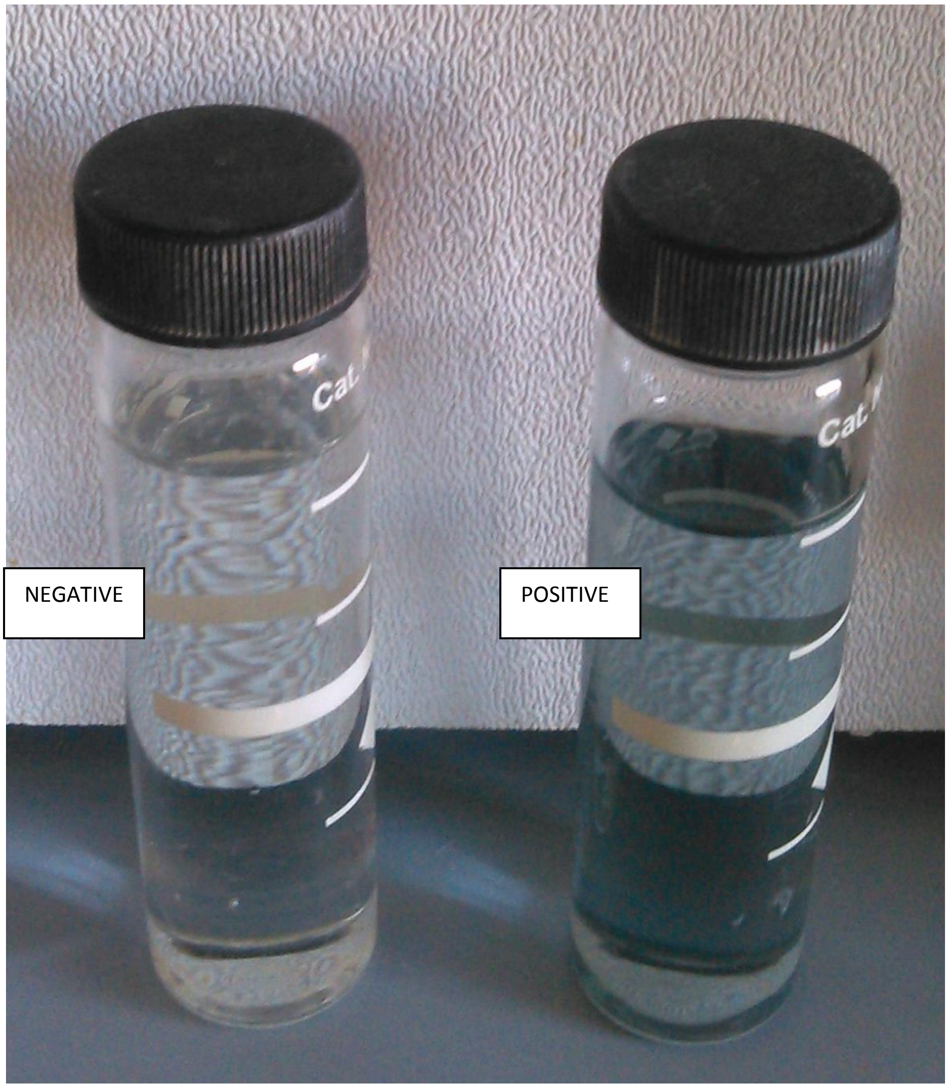
Appendix 2 Procedure for the preparation of M-Endo agar

Ingredients	Grams per liter
peptic digest (animal tissue)	10.0
lactose	10.0
dipotasium phosphate	3.50
sodium sulphate	2.50
basic fuchsm	0.50
agar	15.0

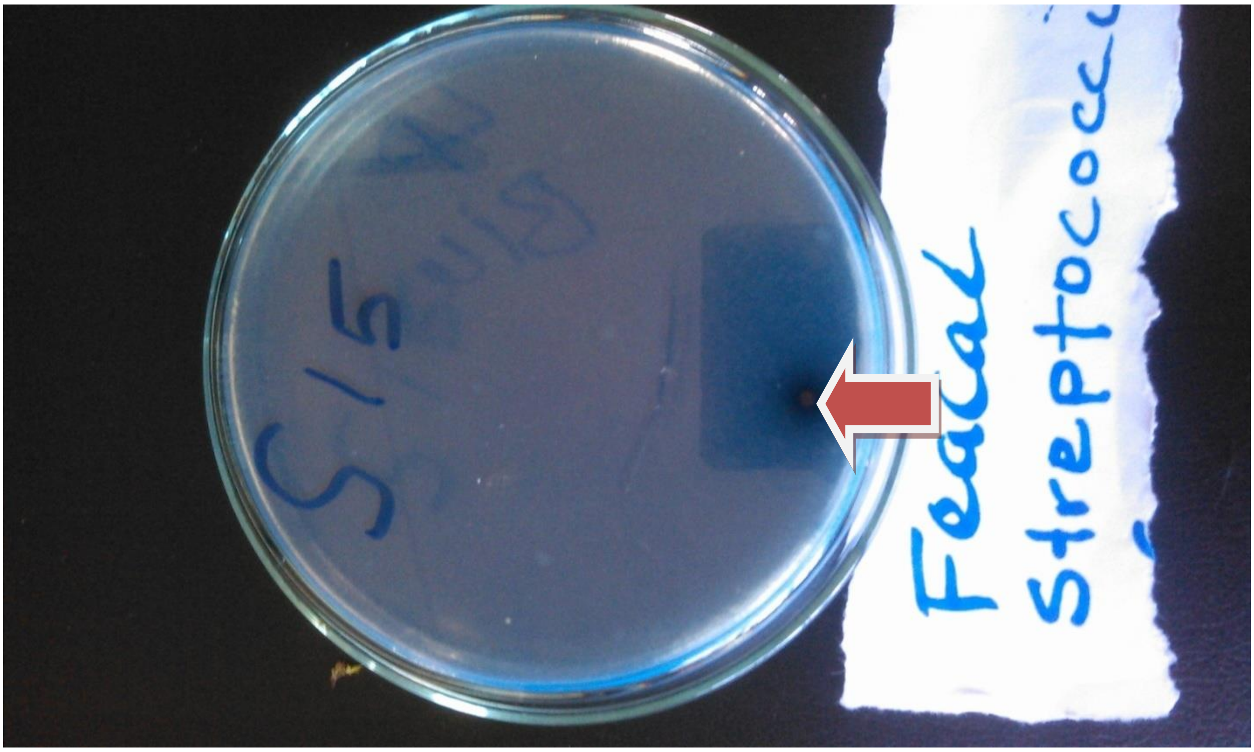
After mixing of the ingredients the final pH at 25^{O}C, was 7.5± 0.2. M-Endo agar was dissolved in distilled water and heated to mix completely and to kill any bacteria in the medium.

Appendix 3 Measurements of Water Samples in the Laboratory

Appendix 4: Positive and Negative Results for Nitrates



Appendix 5 Fecal *Streptococcus* colony



Appendix 6 Statistical Significance Levels and R - values

	F.C	**T.C**	**F.S**	**Cond**	**pH**	**Tem**	**BOD**	**DO**	**NO3**
T.C	0.529								
	0.000								
F.S	0.600	0.495							
	0.000	0.000							
Cond	0.523	0.393	0.686						
	0.000	0.000	0.000						
pH	0.456	0.443	0.595	0.443					
	0.000	0.000	0.000	0.000					
Temp	0.273	0.360	0.371	0.324	0.361				
	0.001	0.000	0.000	0.000	0.000				
BOD	0.571	0.525	0.501	0.366	0.528	0.325			
	0.000	0.000	0.000	0.000	0.000	0.000			
DO	-0.500	-0.605	-0.526	-0.492	-0.569	-0.307	-0.525		
	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
NO3	0.629	0.467	0.725	0.722	0.551	0.328	0.507	-0.650	
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
PO4	0.637	0.440	0.807	0.805	0.575	0.375	0.503	-0.595	0.840
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Appendix 7: Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients			95% Confidence Interval for B		Collinearity Statistics	
Model		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	153.003	5.463		28.005	.000	142.229	163.777		
	P.W	-2.546	.185	-.700	-13.779	.000	-2.911	-2.182	1.000	1.000

a. Dependent Variable: F.C

Appendix 8. Vertical distance between the pit latrine bases and well depth on fecal coliforms.

Study site			Value	Asymp. Std. Error^a	Approx. T^b	Approx. Sig.
Magenche	Interval by Interval	Pearson's R	-.855	.041	-11.308	.000^c
	Ordinal by Ordinal	Spearman Correlation	-.446	.143	-3.420	.001^c
	N of Valid Cases		49			
Mokimonge	Interval by Interval	Pearson's R	-.788	.048	-8.762	.000^c
	Ordinal by Ordinal	Spearman Correlation	-.818	.052	-9.733	.000^c
	N of Valid Cases		49			
Bombaba	Interval by Interval	Pearson's R	-.803	.030	-9.224	.000^c
	Ordinal by Ordinal	Spearman Correlation	-.887	.035	-13.181	.000^c
	N of Valid Cases		49			
Boochi	Interval by Interval	Pearson's R	-.877	.019	-12.519	.000^c
	Ordinal by Ordinal	Spearman Correlation	-.887	.040	-13.167	.000^c
	N of Valid Cases		49			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

The mean difference is significant at the $P \leq 0.05$ level.

Appendix 9. Symmetric Measures for horizontal distance between pit latrine and hand dug well on fecal coliforms

Site			Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Boochi	Interval by Interval	Pearson's R	-.783	.038	-8.641	.000[c]
	Ordinal by Ordinal	Spearman Correlation	-.886	.044	-13.083	.000[c]
	N of Valid Cases		49			
Bombaba	Interval by Interval	Pearson's R	-.803	.028	-9.241	.000[c]
	Ordinal by Ordinal	Spearman Correlation	-.963	.012	-24.402	.000[c]
	N of Valid Cases		49			
Bokimonge	Interval by Interval	Pearson's R	-.899	.016	-14.088	.000[c]
	Ordinal by Ordinal	Spearman Correlation	-.923	.034	-16.469	.000[c]
	N of Valid Cases		49			
Magenche	Interval by Interval	Pearson's R	-.864	.029	-11.790	.000[c]
	Ordinal by Ordinal	Spearman Correlation	-.764	.073	-8.111	.000[c]
	N of Valid Cases		49			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

c. Based on normal approximation.

The mean difference is significant at the $P \leq 0.05$ level.

Appendix 10. Multiple Comparisons on levels of fecal coliform counts among and within study sites of Bomachoge Borabu.

Dependent Variable	(I) site	(J) site	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
FC	boochi	bombaba	25.9184	13.94220	.249	-10.2153	62.0520
		bokimonge	10.3469	13.94220	.880	-25.7867	46.4806
		magenche	-22.1429	13.94220	.388	-58.2765	13.9908
	bombaba	boochi	-25.9184	13.94220	.249	-62.0520	10.2153
		bokimonge	-15.5714	13.94220	.680	-51.7051	20.5622
		magenche	-48.0612*	13.94220	**.004**	-84.1949	-11.9276
	bokimonge	boochi	-10.3469	13.94220	.880	-46.4806	25.7867
		bombaba	15.5714	13.94220	.680	-20.5622	51.7051
		magenche	-32.4898	13.94220	.095	-68.6234	3.6438
	magenche	boochi	22.1429	13.94220	.388	-13.9908	58.2765
		bombaba	48.0612*	13.94220	**.004**	11.9276	84.1949
		bokimonge	32.4898	13.94220	.095	-3.6438	68.6234

Based on observed means.

The error term is Mean Square (Error) = 384.088.

The mean difference is significant at the P ≤ 0.05 level.