NITROGEN LOADING AND GROUNDWATER CONTAMINATION: COMPARISON AMONG DIFFERENT FARM SIZES IN AINABKOI SUB-COUNTY, UASIN GISHU COUNTY, KENYA

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DECLARATION AND RECOMMENDATION

Declaration

I declare that this thesis is my original work and has not been submitted for an award of a degree in any other University.

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Recommendation

This thesis has been submitted with our approval as University supervisors.

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DEDICATION

Dedicated to God the Fount of every blessing

and

To my Husband Richard, and Children Stevie and Neema

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ABSTRACT

The mobility of nitrate-N (NO_3-N), nitrite-N (NO_2-N) and ammonium-N (NH_4-N) down the soil profile and its ultimate presence in groundwater is aggravated by predisposing conditions such as farm agricultural activities and nitrogen fertilizer management, rainfall, seasons and well sanitary conditions. The main objective of the study was to assess the groundwater nitrogen loading compared in different farm sizes. The study was conducted in three agro-ecological wards of Ainabkoi sub-county. Each ward was identified as a homogenous stratum of same size-ranged farms. Farms in Ainabkoi ward were large, family-generations-owned mixed farm sizes and ranged 40-71 acres (16-29 ha) with an average farm acreage of 56 acres (23 ha). In Kaptagat ward farms were medium sized mixed farms on purchased settlement farms and ranged from 10-35 acres (4-14 ha). The small mixed farm sizes were located in Olare ward and ranged 2-10 acres (0.8-4 ha) in size. Farms in each ward were purposively selected such that only accessible farms that had access to either a privately owned or communal wells were selected. The study was carried out between 2012 and 2013. Onsite sanitary survey of the wells and the homesteads was carried out in each farm. A questionnaire was used to obtain general information on farm production and management, farm sizes, crops grown, crop acreage, cropping calendars, types and number of livestock animals kept, type and amount of fertilizer applied and well characteristics. The nitrate-N, nitrite-N and ammonium-N concentrations did not exceed the recommended maximum concentration by Kenya and WHO of 10mg/l, 3mg/l and 0.5mg/l respectively. The physico-chemical parameters were within the acceptable limits set by WHO except for turbidity. There was a positive linear relationship between the average fertilizer N amount at top dressing and the groundwater nitrate ($Y = 0.0836x - 165.18 \quad R^2 = 0.31$), hence N pollution is closely related to the amount and timing of fertilizer application. There were highly significant differences between precipitation and the N concentration although the trends were not clearly recognizable. There was a highly significant positive linear relationship between the monthly rainfall amount and NO_3-N concentration in well water ($Y = 0.1759x + 22.07 \quad R^2 = 0.23^{***}$). There were highly significant differences between the farm sizes in the sanitary contamination risk scores mainly due to individual farm endowments, well site environmental factors and ownership. Conclusively, precipitation, season and timing of fertilizer application were common significant predictors of the concentration levels of N in well water. The absence of any significant N contamination of groundwater in this study does not preclude it occurring in the future. Best nitrogen fertilizer management strategies should be adopted in order to synchronize N supply with crop seasonal demand such as timing and splitting of fertilizer N application and real-time monitoring of nitrogen in soil, plants and groundwater. Well conformity requirements with regard to the parameters of well construction and its vicinities are necessary.

Keywords: Groundwater, Farm Sizes, wells, Fertilizers, Precipitation, Nitrogen.

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ABBREVIATIONS AND ACRONYMS

ADI	Acceptance Daily intake
AEZ	Agro-Ecological Zone
ANOVA	Analysis of Variance
BNF	Biological Nitrogen Fixation
C	Concentration
CAN	Calcium Ammonium Nitrate
CRS	Contamination Risk Factor
DAP	Di-Ammonium Phosphate
DAO	District Agricultural Officer
DLAO	District Ward Agricultural officers
DS	Dry Season
EPA	Environmental Protection Agency
GAP	Good Agricultural Practices
GDP	Gross Domestic Product
GV	Guideline Value
INI	International Nitrogen Initiative's
JECFA	Joint Expert Committee on Food Additives
kg N ha^{-1}	Kilograms Nitrogen per Hectare
kg/ha/year	Kilograms per Hectare per Year
MAC	Maximum Allowable Concentration
MGD	Millennium Development Goals
mg/L	milligrams per litre
N	Nitrogen
NH_4-N	Ammonium-Nitrogen
NO_3-N	Nitrate-Nitrogen
NO_2-N	Nitrite-Nitrogen
NH_4^+	Ammonium ion
NO_3^-	Nitrate ion
NO_2^-	Nitrite ion
ppm	Parts per million
ROK	Republic of Kenya
SDG	Sustainable Development Goals
SRF	Sanitary risk Factor

UN	United Nations
WHO	World Health Organization
WRMA	Water Resources Management Authority
WS	Wet Season

CHAPTER ONE
INTRODUCTION

1.1 Background Information

Environmental policies have changed over the years from policies on concentration of harmful substances in the various environmental media to policies on sustainable development. Sustainability within agricultural systems has been discussed in international fora as necessary for the achievement of global sustainable development (Binder, Feola, and Steinberger 2010). In view of this, the worldwide market has set up requirements for agricultural and horticultural produce to meet high standards of quality and also be produced using environmentally sound practices which support the principles of sustainable development (Carey, Benge, & Haynes, 2009).

Today, fertilizer use is directly responsible for most of the world's food production and will be a more significant factor in future yield increases. Inputs of nutrients, such as nitrogen and phosphorus, are essential to agricultural production, and integral to increasing productivity. Nitrogen (N) is an essential plant macro-nutrient and is a constituent of chlorophyll and proteins which are vital for plant growth (Jalali, 2005; Mwanza, Swiader & Mulwa 2011). Nitrogen influences plant yields and is most often the limiting nutrient in plant growth. To overcome this limitation, excessive fertilizer application is therefore a common practice. Despite the foregoing benefits of nitrogen, the excessive fertilizer application makes it the major contributor of non-point source pollution of groundwater, because plant uptake and microbial immobilization cannot remove the entire nitrate ion from solution (Davies, 2000 & Jalali, 2005). It is listed as the second greatest threat to surface and groundwater in the world after pesticides (Akoto & Adiyiah, 2008).

Groundwater pollution with nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N) and ammonium-nitrogen (NH_4-N) occurs through leaching of N fertilizer from the fertilizer N application rates that exceed crop demand in agricultural management practices such as intensive farming in horticulture and cropping practices designed to achieve optimum grain yields but with low nitrogen use efficiency (Strebel, Duynisveld, & Bottcher, 1989, Rass, Rithie, Peterson., Loudn, & Martin, 1999 & Granstedt, 2000). However, renewed and increasing focus on the negative environmental consequences of over- or mismanaged fertilization, particularly regarding nitrate (NO_3^-) pollution of surface water and ground water, has provided impetus for more careful and introspective N management.

Groundwater is a major source of water for drinking and significantly contributes to surface water bodies when aquifers intersect the earth's surface and is a main component of the terrestrial hydrological cycle (Egboka, Nwankwor, Orajaka, & Ejiofor, 1989; Owens and Kaelen, 2013). However, pollution of this vital resource is a documented worldwide problem that has economic, ecosystem and human health impacts (Goolsby, 2000 and Kraft and Stites, 2003). Groundwater is being increasingly contaminated by nitrates from anthropogenic activities such as modern farming systems, and other domestic and industrial activities (Egboka *et al*. 1989; Spalding and Exner, 1993). Excessive rainfall or irrigation, and the free flow of water in the soil profile coupled with high nitrate accumulation are pre-conditions for nitrate leaching below the plant's root zone, into the subsoil and may eventually reach groundwater. Residual nitrate can move continuously downwards and be lost even if it is not leached during the season of application. The vulnerability of aquifers to nitrogen pollution depends on the climate, the soil, the crop and farming systems (Liu, Wu, & Zhang, 2005).

Nitrate and nitrite levels in drinking water should not exceed the threshold recommended by the World Health Organization of 50 mg NO_3^-/L nitrate-nitrogen and 1 mg/L (or 1 ppm) nitrite-nitrogen (World Health Organization (WHO), 2008). This is critical because excessive concentrations in drinking water can be hazardous to health, causing methaemoglobinaemia or blue baby syndrome in infants; (Spalding and Exner, 1993, Hudak, 1999 and USEPA, 2002) and development of cancers such as digestive tract cancers, non-Hodgkin's lymphoma, bladder and ovarian cancers (Johnson *et al*., 1987, Addiscott *et al*., 1992; Knobeloch, Krenz, Anderson, & Hovell, 1992; Ward, Zahm, & Blair,. 1994). This danger is enhanced by the fact that these compounds are undetectable without testing because they are odourless, colourless and tasteless (USEPA, 2002).

Ainabkoi sub-county in Uasin Gishu County, is a high-potential maize growing agro-ecological zone of Kenya, with high levels of fertilizer consumption and the dosage rates seem to be increasing (Wanzala, 2001; Ariga, Jayne, Kibaara, and Nyoro, 2008). There has also been an increasing trend towards the intensive production of horticultural crops such as vegetables, fruits and flowers in Ainabkoi Sub-county of Uasin Gishu County alongside the extensive growing of maize and wheat.

Groundwater is inherently a local regional resource and access is by individual land owners. Groundwater quality can be easily affected by pollution such as from agricultural activities at the farm level. There has been limited monitoring of groundwater quality hence the impact of above ground activities that may deteriorate the water quality have largely gone unnoticed. In this regard it is important to carry out an assessment of the impact and extent of agricultural activities on the groundwater well supplies with regard to farm activities and subsequently contribute to the development of a comprehensive management strategy to protect groundwater quality.

1.2 Statement of the Problem

The mobility of nitrogen in form of nitrates (NO_3-N), nitrites (NO_2-N) and ammonium (NH_4-N) down the soil profile and its ultimate presence and pollution in groundwater is enhanced by the extensiveness of agricultural production and the nitrogen fertilizer usage associated with agricultural production. Other predisposing conditions that aggravate the nitrogen mobility include high rainfall amounts or irrigation, relatively shallow well depths and well proximity to agricultural land and pit latrines. The foregoing are N groundwater pollution predisposing conditions that are characteristic of Ainabkoi Sub-County. The impact of nitrogen fertilizer use and other agricultural practices on groundwater quality is of concern because of the fact that the majority of the population in Ainabkoi rely on the farm wells for drinking water supply. The general or broad fertilizer application rates for maize in Ainabkoi sub-county averaged 150 kg DAP/ha at planting and 143 kg CAN/ha or 227 kg ASN/ha. These rates are expected to increase as accessibility to fertilizers improves and farmers shift to the intensive horticultural farming. In view of the negative health impact of nitrogen ions in drinking water, it is important to have evaluation or systematic studies comparing the impact of agricultural production on the groundwater nitrogen loading in Ainabkoi Sub-County, Uasin Gishu County.

The nitrogen loading in groundwater in Ainabkoi sub-county needs to be assessed and the contamination explained in terms of farm sizes, rainfall amount, temporal trends and variations and well construction and on-site sanitary evaluation.

1.3 Objectives

1.3.1 Broad Objective

To determine the quality of groundwater through the evaluation and comparison of nitrogen loading and groundwater nitrate-N, nitrite-N and ammonium-N accumulation in different farm sizes in Ainabkoi Sub-County of Uasin Gishu County, Kenya.

1.3.2 Specific objectives

1. To characterize the farm sizes in the Ainabkoi, Olare and Kaptagat wards of Ainabkoi Sub-County.
2. To determine the physico-chemical characteristics of groundwater among the different farm sizes in Ainabkoi Sub-County.
3. To evaluate the relationship between nitrogen fertilizer input levels and the nitrate-nitrogen, nitrite-nitrogen and ammonium-nitrogen concentrations in groundwater among the different farm sizes.
4. To evaluate the impact of temporal and precipitation variation on nitrate-N, nitrite-N, and ammonium-N loading in groundwater among the different farm
5. To assess the relationship between the sanitary characteristics of the well and the groundwater nitrates-N, nitrite-N and ammonium-N concentration among the different farm sizes.

1.4 Research Questions

1. Which are the dominant farm sizes in the Ainabkoi, Olare and Kaptagat wards of Ainabkoi Sub-County?
2. What are the physico-chemical characteristics of groundwater in the different farm sizes in Ainabkoi Sub-County?
3. What is the relationship between nitrogen fertilizer input levels and the nitrate-N, nitrite-N and ammonium-N concentrations in groundwater among the different farm sizes?
4. What is the impact of the temporal and precipitation variations on nitrate-N, nitrite-N and ammonium-N loading in groundwater in three different farm sizes?
5. Is there a relationship between the sanitary characteristics of the wells and the nitrate-nitrogen, nitrite-N and ammonium-N concentrations in groundwater in the different farm sizes?

1.5 Justification of the Study

The information that has been generated from the research is important for risk assessment of the nitrate-nitrogen, nitrite-nitrogen and ammonium-nitrogen levels in groundwater and to impress on policy makers to make decisions on controlling agriculture-derived non-point source pollution of groundwater through the adoption of

Good Agricultural Practices (GAP) for the protection of groundwater. In order to sustain steadily growing rural and urban populations and to maintain agriculture as the major economic sector in Kenya with a Gross Domestic Product (GDP contribution of 6% (Economic Review, 1999), agricultural production must grow at rates of 6% (Maatman, Wopereis, Debrah, & Groot, 2007; New Partnership for Agricultural Development (NEPAD), 2003). One of the most plausible options for increasing agricultural production per hectare and subsequently address the rising food demands (intensification) is an increased use of external inputs especially fertilizers. This is why the average annual application rate of nitrogen in Kenya has progressively risen from a mean of 180,000 tons during the 1980's, to 250,000 tons during the early 1990's and to over 400,000 tons in the 2004/2006 season (Olwande, Sikei, and Mathenge, 2009). The research has set the agenda in achieving synchrony between N supply, crop demand and environmental protection through the quantitative evaluation of the nitrogen levels leached into groundwater. The information has brought to awareness the importance of soil nitrogen analysis in order to develop specific nitrogen application rates. Proper fertilizer nitrogen application strategies will be developed for specific farms. The sanitary evaluation of wells has highlighted the need for proper construction of wells to protect them from pollution.

In a global perspective, the research has highlighted the overall goal of the International Nitrogen Initiative's (INI) of optimizing the beneficial role of nitrogen in sustainable food production while at the same time minimizing nitrogen's negative effects on human health and the environment (Bekunda, Galloway, Syers & Scholes, 2007). Kenya's vision 2030 for water and sanitation was to ensure that improved water and sanitation are available and accessible to all. The information generated through this research is important in realising the national policy on Kenya's groundwater resources of providing a common framework to protect its quality by minimising the risks posed by pollution (Republic of Kenya (ROK). 2013). The research output provides continuous and timely data on water quality and an evaluation of the effects of activities that may affect its quality in an agricultural setup.

The recently commissioned Sustainable Development Goals (SDG) seeks to build on the (Millennium Development Goals) MDG and complete what they did not achieve by balancing the dimensions of sustainable development of the environment, economic, social aspects (Osborn, Cutter, & Ullah, 2015; United Nations (U.N.) 2015). The SDGs have set focus on ending hunger, achieving food security and improving nutrition (2nd SDG) while promoting sustainable agriculture and ensuring availability, accessibility and sustainable management of safe water for all by 2030 (6th SDG) (Osborn *et al*., 2015; UN., 2015). In view of this, the study has initiated a quest into building sustainable food production systems and implementation of resilient agricultural practices that increase productivity and production while maintaining ecosystems which progressively improve land and soil quality. The study has addressed the SDG requirement of improving the water quality by reducing pollution and minimizing release of hazardous chemicals and materials and the information generated can be applied in the development of policies at the national and international level for sustainable food production. In general the research has provided information on improvement of agricultural productivity through the use of inputs such as nitrogen fertilizers in a sustainable way that protects groundwater quality. If hunger and poverty are to be reduced, this agricultural intensification must be ecologically, socially and economically sustainable. It is important to establish the relationship between well water quality and predisposing contamination indicators such as agricultural activities, precipitation amounts, well attributes and farm sizes. This will reinforce the enforcement of nutrient management policies as fertilizer application rates increase.

There are also health concerns with elevated levels of nitrates due to the formation of methaemoglobinaemia or ‘blue-baby’ syndrome in humans. This is as a consequence of the reaction of nitrite with iron (III) haemoglobin in the red blood cells to form methaemoglobin, which binds oxygen tightly hence blocking oxygen transport. Infants are susceptible because the bacteria found in their intestinal tract can convert nitrate to the highly toxic nitrite (Spellman, 2008) and low acidity in the stomach of infants, allows the growth of nitrite-reducing microorganisms (Zatar, 1999). The risk of methaemoglobinaemia is primarily increased in the presence of simultaneous gastrointestinal infections (World Health Organisation (WHO) 2008) notably associated with private wells that also have a high probability of microbial contamination and predominantly anaerobic water. High levels of nitrates in drinking water have the potential role in the development of cancers of the digestive tract, non-Hodgkin’s lymphoma and other types of cancers such as bladder and ovarian cancers (Johnson *et al*., 1987, Addiscott & Powlson, 1992; Knobeloch, Krenz, Anderson & Hovell 1992 and Ward *et al*., 1994). There are also concerns with the notable upsurge of chronic diseases such as cancer reported within the county in the recent past with a total of total of 5,137 various cancer cases documented between 2004 and 2012 (Kirumba, 2014). The data emanating from the study has set the stage for further work on the possible correlation between the prevalent cancers and the groundwater nitrogen levels.

1.6 Scope

The study covered farmers within three wards, namely, Ainabkoi, Olare and Kaptagat in Ainabkoi Sub-county of Uasin Gishu County. The study focused on evaluation of the impact of nitrogen variation in groundwater within the limits of an extensive mixed farm system of more than 40 acres, medium sized extending 20-40 acres and small farms of less than 20 acres as the dominant mixed agricultural land use farm sizes. The research was conducted within the span of the three important influxes of nitrogen, immobilization and mineralization that take place mainly within the soil and are in a dynamic equilibrium in an agricultural system.

Five farms of more than 40 acres, five farms of 20-40 acres and five small farms of less than 20 acres were identified for sampling of their water wells. In total 15 wells were sampled during the wet and dry seasons of the year for a period of two years. The sampled water was analysed for nitrate-N, nitrite-N and ammonium-N.

1.7 Assumptions and limitations

The project upheld the assumption that nitrate-N, nitrite-N levels and ammonium-nitrate concentrations in groundwater were more closely related to the specific agricultural system management such as N fertilizer application rates and that there was no water flow from one well to another. It was also assumed that the investigated pollution effects of nitrogen fertiliser are external to the farmer, meaning that the farmer did not take into account the potentially damaging effects of the nitrogen applied in the farm. This did not however mean that farmers are not concerned about the environmental consequences of their actions. It was assumed that the possible variations due to the unpredictable cause-effect impact chain of the agro-ecosystems and the environment were negligible and that the interaction between farm sizes and year has no agronomic meaning and is therefore less important than the interaction between farm sizes and season. Therefore repetition over seasons was preferred to repetition over years. It was assumed that the farmers were being truthful in the amount of fertilizer that they applied. There was the possibility that they would understate the amounts applied in fear of any possible repercussions.

1.8 Operational definitions

Domestic withdrawals Water used for normal household purposes, such a drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and watering lawns and gardens. The water may be obtained from a public supplier or may be self-supplied.

Farming System farming system is defined as a population of farm households, often a mix of small and large farms that as a group have broadly similar patterns of livelihood and consumption patterns, and constraints and opportunities, and for which similar development strategies and interventions would be appropriate. Often, such systems share similar agro-ecological and market access conditions.

Farm System: This is an individual farm with its own specific characteristics arising from variations in resource endowments and family circumstances which are translated into productive activities, and household consumption and decision making activities. The functioning of any individual farm system is strongly influenced by the local external rural environment, including local institutions, land, labour and input markets and information linkages.

Land use: The predominant land use on the property where the well was located which was determined by the examination of the site and discussed with well owner.

Large Mixed Farm Size: Refers to large scale farm sizes where farms were >40 acres in size with privately owned wells.

Medium Mixed Farm Size: Refers to medium scale farm sizes where farms size was greater than 20 but less than with privately owned wells.

Mixed Farm sizes: Refers to the individual farms whereby the crop production is dominated by maize production complemented with some vegetables, fruit, legumes and other cereals production and cattle, goats, sheep and poultry rearing. The mixed farm sizes were based on apparent variation with regard to the extensiveness of production such that the large scale farm sizes were farms (>40 acres) mixed farm system with privately owned wells in Ainabkoi ward and medium scale (10-40 acres) mixed farm system with privately owned wells in Kaptagat and to the mixed farm system of less than 10 acres with communally owned wells in Olare. Farmers commonly keep small gardens beside their homes that contain a variety of vegetables and fruit crops.

Non-biodegradable Substances that do not break down easily in the environment.

Non-Point Source: Diffuse (or nonpoint) sources of water contamination are those that originate from a broad area (such as leaching of agricultural chemicals from crop land) or generally where the origin of the contamination cannot be accurately traced to a single polluter, or where the contamination arises from a number of closely-spaced similar activities and enters the water resource diffusely over a large area.

Nutrient Any inorganic or organic compound needed to sustain plant life.

Point Source: Point sources of pollution are those where the origin of contamination can be identified.

Small Mixed: Farm Size: Refers to small scale farm sizes where farms were <10 acres in size with communally owned

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CHAPTER TWO
GENERAL LITERATURE REVIEW

2.1 Introduction

Nitrogen is a common and abundant element in nature with approximately 79% of the earth’s atmosphere consisting of Nitrogen gas (N_2) (Canter, 1997, Spellman, 2008). Nitrogen (N) is an essential plant nutrient required for normal growth and development of plants. It is an integral component in many essential plant compounds such as chlorophyll (Taiz and Zeiger, 1991) and is a major part of all amino acids, the building blocks of all proteins and nucleic acids. Human activity has doubled the supply of reactive N to the global terrestrial system (Galloway, 1998). This additional increase has not only caused an increase in productivity, but has also damaged components of terrestrial and aquatic ecosystems, and has changed the atmosphere and projections indicate that anthropogenic N inputs will continue to grow.

Most of the nitrogen in a highly productive soil is in organic matter, which includes plant and animal residues ranging from newly added material, through those that are well decomposed to soil humus, the end product of decay. Organic matter is the only form in which large amounts of nitrogen can be stored in the soil because N is an elusive element (Weil & Brady, 2016). Inorganic nitrogen, which occurs as Nitrate-N, nitrite-N and ammonium-N, seldom accounts for more than 1 to 2% of the total nitrogen in the soil except where large amounts of chemical fertilizers have been applied. Unlike most of the organic nitrogen, the inorganic forms of nitrogen are mostly quite soluble in water and may be easily lost from soils through leaching. This characteristic greatly influences the way in which nitrogen must be managed for efficient crop production and explains why nitrates leach out of crop-rooting zone into surface and groundwater.

The hydrological cycle is represented as a closed system comprising of major storage components such as the atmosphere, oceans, ice-caps, soil, groundwater and streams (Galloway, 1998). In the context of agricultural impacts, however, attention is focused upon a limited part of this cycle, referred to rather loosely as the terrestrial hydrological cycle. This consists of four main components namely, the soil, groundwater, streams, and seas linked by various transfers such as drainage, through flow, runoff and seepage. The main losses occur by evaporation and to a much lesser extent by deep percolation (Galloway, 1998). This part of the hydrological cycle is of great concern because it is most vulnerable to the effects of agriculture. Agricultural impacts upon water quality are possibly the most serious of the hydrological effects of farming. In recent years, agricultural chemicals have been implicated in the pollution of surface and groundwater sources with sometimes, direct threats to human health (Ma and Qian, 1987; Lu, Tong, & Sun, 1998 and Liu, Lei, Zhang, Y., Zhang, W. & Lin, 2001).

Nitrogen (N) has different biologically induced oxidation states. The "reactive" forms of N include ammonia (NH_3), ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), nitrogen oxides (NO and NO_2), and nitrous oxide (N_2O_5 and N_2O) (Brady 1990; Stevens, Sullivan and Cogger, 1993; Canter, 1997;). the nitrogen forms of significance in the soil-water environment are ammonia (NH_3), ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-) and Nitrogen gas (N_2) (Lamb, Fernandez, & Kaiser, 2014). N compounds can be transformed through several mechanisms, which include fixation, ammonification, synthesis, nitrification and denitrification (Canter, 1987; Spellman, 2008). Nitrogen transformations in the soil are predominantly brought about by living soil microorganisms such as bacteria and fungi. The greater bulk (95 to 99%) of the soil nitrogen is in organic compounds that protect it from loss but leave it largely unavailable to higher plants. Soil microbes break down these compounds present as amines groups, largely in proteins and humic compounds into simple amino compounds. Mineralisation is the conversion of soil organic nitrogen organically bound nitrogen into inorganic forms of nitrogen (NH_4^+ and NO_3^-) by aerobic organisms via ammonification and nitrification (Canter 1997, Brady, 1990). Nitrification is the oxidation, by microorganisms, of the ammonium ion, first to nitrite (NO_2^-) and then to nitrate (NO_3^-) while ammonification is the release of nitrogen fixed in plant material and bacteria, as ammonia (NH_3), which is subsequently available for uptake by plants and oxidized to nitrate (Stevens *et al*. 1993). Studies have shown that only about 1.5 to 3.5% of organic nitrogen of a soil mineralizes annually and this rate of mineralization provides sufficient mineral nitrogen for normal growth of natural vegetation in most soils except those with low organic matter, such as the desert soils (Brady, 1990). Nitrogen fixation refers to the incorporation of atmospheric N to organic nitrogen by special microorganisms. It is not available for use by plants or other microorganisms until it is released by the bacteria (Canter, 1997).

The opposite of mineralization is immobilization which is the conversion of inorganic nitrogen ions into organic forms. As microorganisms decompose carbonaceous organic residues in the soil, they may require more nitrogen than is contained in the residues themselves. The microorganisms then incorporate mineral nitrogen ions into their cellular components such as proteins. Mineralization and immobilization occur simultaneously in the soil and whether the net effect is an increase or decrease in the mineral nitrogen available depends primarily on the carbon to nitrogen ratio in the organic residues undergoing decomposition (Brady, 1990). Nitrification is important in relation to nitrogen losses from the soil environment as the reaction transforms the relatively immobile ammonium ion into a very mobile species. Given sufficient recharge and soil permeability, nitrate migration to soil and groundwater may be rapid. Adsorption of ammonium ions may be important in holding ammonium on the exchange sites until nitrification occurs.

Denitrification is the biological reduction of nitrate to atmospheric nitrogen (Canter, 1997; Brady, 1990; Lamb, Fernandez & Kaiser 2014). Apart from plant uptake, which will only occur within the root zone of plants, denitrification is the only means by which nitrate can be removed from soil or groundwater. There is inadequate air in the rooting zone and therefore microbes thrive there by using the oxygen in nitrate (NO_3^-) in the soil. This process converts the nitrate into gaseous forms of nitrogen and also nitrous oxide (N_2O) or nitric oxide (NO). The conditions that favour denitrification within the rooting zone are soils with slow internal drainage (fine textured soil), a readily available supply of utilisable organic compounds (food for the microbes) and saturated soils from shallow groundwater or heavy rainfall. Although anaerobic conditions, high organic carbon content and low redox potentials favour denitrification in groundwater, such conditions are not common in the unsaturated zone above the water-table and therefore over time, any nitrate load below the root zone is likely to reach the water table (Bolger and Stevens, 1999). Denitrification can also occur in the groundwater and surface water environments and sometimes can result in the complete conversion of nitrate to dissolved nitrogen gas which is not harmful to human health and aquatic ecosystems. However denitrification cannot be counted on to eliminate all the nitrogen leaching to groundwater or running off to surface water. Although from a farmer’s stand point, denitrification is undesirable because it loses nitrogen that would otherwise be available to the crop, it is advantageous because it reduces the amount of nitrate that potentially reaches surface and groundwater (Brady, 1990).

The behaviour of the ammonium (NH_4^+) and the nitrate ions (NO_3^-) differs greatly within the soil and this difference is crucial in assessing the possible accumulation of excess nitrate in groundwater (Brady, 1990; Lamb, *et al*., 2014). The NH_4^+ has a positive electrical charge, while the nitrate (NO_3^-) and nitrite (NO_2^-) ions are negatively charged has a negative charge (Stevens *et al*. 1993). The clay particles and organic matter within the soil play key roles in the movement of these ions in the soil. The clay particles carry negative charges on their surfaces and therefore the positively charged ammonium ions are attracted and held against leaching or moving about in the soil as water moves up, down and sideways (Brady, 1990; Lamb, *et al*., 2014). Due to the large size of the ammonium ion it can become entrapped within cavities in the crystal structure of certain clays such as the ones with a 2:1 type structure. The ammonium fixed by clay minerals is held in a nonexchangeable form, from which it is release only slowly to higher plants and microorganisms (Brady, 1990). The concentration of ammonium in soil is generally quite low (less than 1 mg/kg), because it is quickly converted to nitrate under conditions that are favourable for mineralization. Ammonium fixation is greater in subsoil than in topsoil due to the higher clay content of subsoil. The exception is where high rates of an ammonium fertilizer (anhydrous ammonia, urea or ammonium sulphate) or high rate of manure are applied. Occasionally heavy rainfall washes this concentrated ammonium from the field into surface water.

On the other hand, the nitrate ions because of their negative charges are repelled from the soil surface. Being totally soluble they are free to move in whatever direction water moves through the soil (Brady, 1990). Nitrate may therefore leach into groundwater sources. The nitrogen portion of urea (NH_2) carries no charge and is therefore like nitrate not held by clay and humus (Stevens *et al*. 1993; Canter, 1997 and Brady, 1990. However it is converted to ammonia and then to ammonium ion within a day or two by the enzyme urease and then behaves like ammonium (Stevens *et al*. 1993; Brady, 1990). Nitrate is the final oxidation product of the nitrogen cycle in natural waters and is considered to be the only thermodynamically stable nitrogen compound in aerobic waters.

Nitrite (NO_2^-) is produced naturally as part of the process of converting ammonium into nitrate called nitrification and in this process, ammonium ions are enzymatically oxidized by autotrophic bacteria, nitrosomonas and nitrobacter, to yield first nitrites and then nitrates (Brady, 1990). Nitrites seldom accumulate in the soil since the conversion of nitrite to nitrate is generally much faster than the conversion from ammonium to nitrite. This is advantageous because even at low concentrations of just a few parts per million, nitrite is quite toxic to most plants and animals. The World Health Organization (WHO) and the United States Environmental Protection Agency (USEPA) have adopted the 1 mg/L (or 1 ppm) nitrite-nitrogen for regulated public water systems (WHO, 2003).

The main sources of nitrogen to the soil environment include; human and animal wastes, plant residues, applied fertilisers, and fixation of atmospheric nitrogen (Canter, 1997). The organic sources such as animal wastes and plant residues must undergo decomposition before nitrification can occur. Nitrate can enter groundwater from either diffuse (non-point) or point sources of nitrogen. Point sources of pollution are those where the origin of contamination can be identified (Egboka *et al*. 1989 and Bolger & Stevens, 1999). Examples of point sources of nitrate pollution include direct injection of effluent into soils and aquifers such as sewage disposal systems, barnyards/feedlots, pit latrines, landfills or garbage dumps (Egboka *et al* 1989; Bolger and Stevens, 1999). Diffuse or distributed sources of pollution (nonpoint) are generally those where the origin of the contamination cannot be accurately traced to a single polluter, or where the contamination arises from a number of closely-spaced similar activities. These sources are widespread and maybe introduced from various directions and sources and enhanced by other environmental factors such as precipitation (Egboka, 1989).

According to Bolger and Stevens (1999), there are three categories of nitrate sources which vary in their spatial distribution and loads to the groundwater system which are;

a) Broad area sources, such as grazing, dairying and fertiliser applications which have the potential to affect large areas with widespread nitrate loads;
b) Multiple point sources, such as animal husbandry, effluent disposal and septic tanks which form single point sources or broad scale sources when their effects are aggregated; and
c) Naturally occurring nitrate sources such as termite mounds and nitrogen fixing native vegetation.

According to Brady, (1990) there is no difference in behaviour of the nitrate ions from different sources such as fertilizers, humus, animal manures or plant residues. Differences among these sources are mainly in the time needed for the nitrogen to convert to ammonium and nitrate. Nitrogen in plant residues is released only after the residues decompose. Animal manures contain a portion of the nitrogen in solution and the remainder is tied up in organic matter. In contrast most fertilizers are chemically formulated to be available immediately or shortly after being applied. Once converted the nitrate ions behave identically. Once nitrate has been generated and passes below the plant root zone, it typically behaves as a conservative contaminant. The significance of this concept is that it is the total amount of available nitrogen from all sources rather than the amount added in fertilizer or any other specific source that determines whether the amount in water will be excessive (Raven *et al*., 1995). The agricultural practices of high input farming have resulted in a number of environmental problems. According to the United

States Environmental Protection Agency (USEPA) fertilizers and pesticides are the single largest causes of water pollution. Ammonium-N that is adsorbed can be is easily converted to nitrates and leached to groundwater (Canter 1989).

Nitrogen influences the yields and quality of arable and horticultural plants and is most often the limiting nutrient in plant growth. To overcome this limitation, N fertilizers are used to increase crop yields. In as much as N provides large responses in crop yields and is an extremely valuable nutrient, it is the major nutrient of concern in groundwater pollution (Davies, 2000 and Groffman, 2000). Arguably one of the most widespread and damaging impacts of agricultural over application of nitrogen fertilizers is the degradation of groundwater quality and contamination of drinking water supplies, which can pose immediate risks to human health (Schroeder *et al*., 2004).

Nitrate has been reported in groundwater worldwide and it has been identified to be the most common and widespread chemical contaminant in groundwater (Spalding and Exner, 1993). Nitrates remain soluble and are easily transported to groundwater, though the levels of nitrate (as N) in natural groundwater is typically low. Concentrations between 0.45 and 2.0 mg/L have been reported in groundwaters in Europe and the USA (Hallberg, 1989) and from 1.15 to 2.3 mg/L in Australia (Lawrence, 1983). Well water nitrate concentration exceeding WHO recommendations has been found in Ghana (Anim-Gyampo *et al*. 2014; Nigeria (Oloruntoba, Sridhar, Alabi, & Adebowale, 2013 and Adekunle, Adetunji, Gbadebo and Banjoko, 2007). According to Spalding and Exner (1993), the first comprehensive evaluation of the extent of nitrate contamination of groundwater in the USA was done by Madison and Burnett in 1985, who sampled more than 87,000 wells over a period of 25 years and reported that the level of nitrate in aquifers was greater than 3 mg/L (NO_3–N) in 15 USA states. Significant levels of nitrate contamination of drinking water supplies in Europe has been noted since the 1980s prompting the development of thirty Nitrate Sensitive areas in which compensation is provided for farmers who undertake improved management practices (Thorburn *et al*., 2003). In addition, groundwater management in the United Kingdom (UK) includes identification of groundwater protection zones around well heads to minimise groundwater contamination by nitrate and other contaminants, particularly those associated with agricultural practices. Due to the continued increase in drinking water nitrate contamination European countries have had to legislate against the problem, with legal requirements of activities such as compulsory nitrogen balance sheets for individual farms, regulated fallow management and ‘nitrate protection areas’ around individual wells

(Keating *et al*., 1996; Canter, 1997; Iversen *et al*., 1998). There are reports of high groundwater nitrate concentrations of above 50 mg/L in wells in all states and territories, and across differing land-uses in Australia (Keating *et al*., 1996). This includes the North-eastern coast of Australia, the Eastern Darling Downs which has extensive cereal cropping and the Callide Valley where irrigated pasture, cotton and grain production is done; the irrigated areas of Northern Victoria, the horticultural areas overlying the coastal aquifers near Perth and under irrigated and dryland pastures and vineyards of the south-eastern region of South Australia. The nitrate water concentrations in many areas are greater than the Australian Drinking Water Guidelines (National Health and Medical Research Council-Agricultural and Resource Management Council of Australia and New Zealand (NHMRC–ARMCANZ), 1996) recommended maximum concentration of 10 mg/L and makes the groundwater resource in these areas unfit for drinking.

It is often difficult to pinpoint sources of nitrate because there are so many possibilities. Sources of nitrogen and nitrate may include runoff or seepage from fertilized agricultural lands, municipal and industrial waste water, refuse dumps, animal feedlots, septic tanks and private sewage disposal systems, urban drainage and decaying plant debris. Geologic formations and direction of ground water flow may also influence nitrate concentration (Nas and Berktay, 2006). The impact of nitrogen load on groundwater quality is affected by many factors, including soil type, topography, precipitation, evaporation, and the structure of geological layers (Inoue, 2012). Evidently, where a source of nitrogen exists there is the potential for nitrate to reach the groundwater beneath the source and the concentration of leachate which reaches the groundwater depends on local conditions at the source. The relationships between N fertilizer applied to the soil and the concentration of N in the soil or in soil solution have been the main focus of studies concerning the evaluation of fertilizer N contribution to groundwater NO_3-N.

The ultimate nitrate load to the groundwater is influenced by several key factors which include, manure management, crop cultivation practices, soil texture and excess precipitation (Fraters *et al*., 1998; Boumans, Fraters & Van Drecht, 2001; Elmi, Madramootoo, Egeh, Liu, & Hamel, 2002; Salo and Turtola 2006; Rankinen, Salo, Granlund & Rita 2007) have been found to influence the extent of agricultural nitrate leaching. When the soil is near saturation, there is maximum downward movement of nitrate. However there are other critical factors such as soil type, climate and tillage methods, as well as fertilizer type, timing and application rates will influence nitrate transport (Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA, 1994). A major factor controlling solute losses is the solubility of the compound. Nitrates tend to be very soluble and are therefore readily lost from the soil. The quantity of nitrate nitrogen lost in drainage water depends on two basic factors; the rate of water leaching through the soil and the concentration of nitrates in the drainage water. Other predisposing factors include amount of precipitation, and the soil texture (Nas and Berktay, 2006). The most appropriate means of minimising nitrate loads to groundwater is to carefully manage the application rates taking the local site factors into account. While there is a general understanding of the nitrate contamination processes in soil and groundwater, for any specific study or land management situation the characteristics of both the groundwater system and the unsaturated zone need to be carefully understood to evaluate nitrate contamination and its future impacts.

Nitrate is listed as the second greatest chemical threat after pesticides, to surface and groundwater in the world (Akoto & Adiyiah, 2008). Nitrogen pollution especially nitrate contamination of ground and surface water in the world has been a subject of concern since the 1960's due to the association between elevated nitrate levels in well water and Methaemoglobinaemia in infants (Kumazawa, 2002 & Liu, Wu, & Zhang, 2005). Nitrite is the toxic form of nitrogen, and its toxicity is as a result of its change in the blood stream to ferrous iron, which is capable of transporting and releasing oxygen, to ferric iron, which is incapable of supplying oxygen (WHO, 2008). The human health risk associated with consumption of water containing nitrate is due to the reduction of nitrate to nitrite in the human gut. When present at high concentration in blood, nitrite can react with iron (III) of the haemoglobin, forming methaemoglobin which has no oxygen-carrying ability. Therefore, methaemoglobinaemia in humans forms as a consequence of the reaction of nitrite with haemoglobin in the red blood cells to form methaemoglobin, which binds oxygen tightly and does not release it, thereby blocking oxygen transport. Ultimately most of the absorbed nitrite is oxidized to nitrate in the blood. However any residual nitrite reacts with haemoglobin and high levels of methaemoglobin (greater than 10%) formation can give rise to cyanosis or 'blue-baby' syndrome. The symptoms of methaemoglobin include blood losing its bright red colour, and becoming more chocolate in colour, lips and fingernails having a bluish cast, hence the description term "blue baby". Human infants who drink water containing excess nitrate develop the "blue-baby" syndrome (Spalding and Exner 1993, Hudak 1999, EPA 2002 and WHO, 2008). Young infants, pregnant women and the elderly are more susceptible to methaemoglobinaemia than adults. Infants are susceptible because the bacteria found in their intestinal tract can convert nitrate to the highly toxic nitrite (Spellman, 2008). Evidence has shown that the risk of methaemoglobinaemia is primarily increased in the presence of simultaneous gastrointestinal infections (World Health Organisation (WHO) 2008). This is notably so because most of the cases of methaemoglobinaemia reported are associated with contaminated private wells that also have a high probability of microbial contamination and predominantly when the drinking-water is anaerobic. The reduction of nitrate to nitrite is possible in the stomach of infants, because the low acidity allows the growth of nitrite-reducing microorganisms (Zatar, 1999). In the natural environment system of nitrogen transformations, nitrite is an intermediate step from ammonia to nitrate and since the enzyme that carries out the final step is omnipresent the transformation is usually highly effective. Nitrites and nitrates are also capable of reacting with nitrosatable compounds mainly amines and proteins in the body, food and tobacco to form N~nitroso compounds (related nitrogen-containing compounds) such as nitrosamine that are documented carcinogens (Tricker and Preussmann, 1991 and WHO, 2008). Ingestion of high nitrate concentrations is thought to competitively inhibit iodine uptake with the likely hood of the adverse effect on the thyroid (WHO, 2008),

Studies in laboratory animals have not indicated that nitrate or nitrite are directly carcinogenic. However there is evidence that they may react in the stomach with foods containing secondary amines to produce N-nitroso compounds which are known to be carcinogenic in animals (NHMRC-ARMCANZ, 1996). However, epidemiological studies have reported several suggestions of associations between nitrate intake and incidences of gastric cancers, congenital malformations, childhood diabetes mellitus and competitive inhibition of iodine uptake, subsequently causing adverse effects on the thyroid reference. However, the epidemiological data is considered to be inadequate to allow definitive conclusions to be drawn. High levels of nitrates in drinking water have the potential role in the development of cancers of the digestive tract, non-Hodgkin’s lymphoma and other types of cancers such as bladder and ovarian cancers (Johnson *et al*., 1987, Addiscott & Powlson, 1992; Knobeloch, Krenz, Anderson & Hovell 1992 and Ward *et al*., 1994). The beneficial effect of nitrate uptake is in its role in protecting the gastrointestinal tract against a variety of gastrointestinal pathogens, since nitrous oxide and acidified nitrite have antibacterial properties (World Health Organisation (WHO, 2008). Unlike nitrate and nitrite, ammonia is not a human health concern in drinking water at levels typically observed in the environment.

The guideline for nitrite of 3 mg/L is based on human data showing that doses of nitrite that cause methaemoglobinaemia in infants range from 0.4 to more than 200 mg/kg of body weight. By applying the lowest level of the range (0.4 mg/kg of body weight), a body weight of 5 kg for an infant and a drinking-water consumption of 0.75 litre, a guideline value of 3 mg/litre (rounded figure) can be derived (Thomson and Mitchell, 2004). Due to the often simultaneous presence of nitrate and nitrite in drinking-water, the sum of the ratios of the Concentration (C) of each to its Guideline Value (GV) should not exceed one (1), as shown below;

$$\mathbf{C_{Nitrate}/GV_{Nitrate} + C_{Nitrite}/GV_{Nitrite} < 1} \qquad \text{(WHO, 2008)}$$

For chronic exposure, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) has proposed an Acceptance Daily intake (ADI) for nitrate of 0–3.7 mg/kg of body weight and an ADI of 0–0.07 mg/kg of body weight for nitrite, expressed as nitrite ion (Thomson & Mitchell,. 2004). Using JECFA’s ADI of 0–0.07 mg/kg of body weight, assuming a 60-kg adult ingesting 2 litres of drinking-water per day, and allocating 10% of the ADI to drinking-water, a guideline value of 0.2 mg of nitrite ion per litre (rounded figure) can be calculated. However, owing to the uncertainty surrounding the susceptibility of humans compared with animals, this guideline value should be considered provisional. The recommended maximum allowable concentrations by WHO and Government of Kenya of Nitrate-Nitrogen, Nitrite-Nitrogen and Ammonium-Nitrogen in drinking water are 10 mg/L, 3 mg/L and 0.5 mg/L respectively (Republic of Kenya (ROK, 2006) & WHO, 2008). Different countries have slightly varying Maximum Allowable Concentration (MAC) of Nutrients for Portable Water as shown in Table 1 below.

Table 1: Maximum Allowable Concentration (MAC) of Nutrients for Portable Water in Different Countries.

Country/ Organization	**Nutrient Concentration**			
	NO_3^--N	**NO_2^--N**	**NH_4-N**	**Reference**
WHO	10 mg/L	3 mg/L 0.2mg/L (LTE)		WHO, 2008
KENYA	10 mg/L	3 mg/L	0.5 mg/L	ROK, 2006
EUROPE	11.3 mg/L			Spalding and Exner, 1993
USA	10mg/L	1 mg/L (1ppm)		Liu *et al.*, 2005; USEPA 2002
JAPAN	10 mg/L			Kumazawa,2002
CANADA	0.06 mg/L; 10 mg L^{-1}			Terraqua, 1997
AUSTRALIA	50 mg/l (11.3 mg/l N)	3 mg/l (0.9 mg/l N)	0.5 mg/l	NHMRC-ARMCANZ). 1996(1996)

LTE= Long Term Exposure

2.2 Conceptual Framework

Agri-environmental relationships are often complex, site specific and non-linear with a wide range of bio-physical conditions which reflect variations in climate, rainfall patterns, soils and land use patterns. The basic rule is that, where there is a source of N, there is the potential for nitrate to reach the groundwater beneath the source. The main sources of nitrogen to the soil environment include, applied fertilizers, atmospheric nitrogen fixation, organic sources, pit latrines, septic tanks, and agricultural farm activities. The impact and magnitude of N leaching as either NO_3-N,

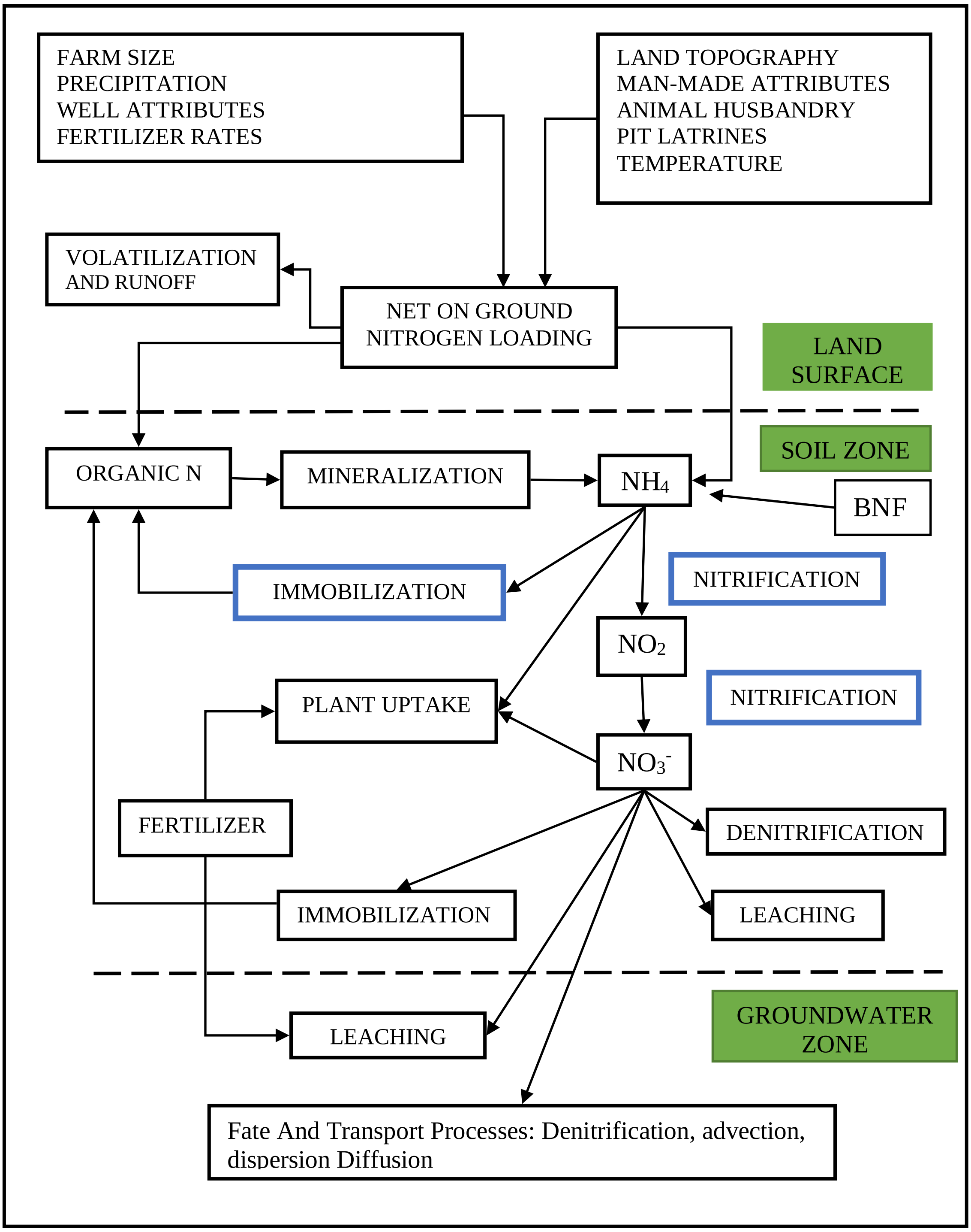

Figure 1: Conceptualization of the interacting processes that govern nitrate occurrence in groundwater.
(Adapted and modified from Almasri, 2007).

NO_2-N or NH_4-N into groundwater is a complex interactive of many factors namely farm sizes, agricultural activities, precipitation amounts, seasonality and distribution, amount of N fertilizer applied and well characteristics. There are many factors and variabilities that affect both the conversion of nitrogen to nitrate and its consequent migration into groundwater. Several potential explanatory variables or intervening variables increase the migration of nitrogen into groundwater. These variables include land topography, animal husbandry, man-made attributes, organic matter/manure, soil N dynamics, soil characteristics, depth of well, water table and plant uptake (Figure 1).

Nitrate enters the groundwater after it is oxidised from other forms of nitrogen, a process that may occur as a result of human activity or naturally. Nitrate is soluble and negatively charged and thus has a high mobility and potential for loss from the unsaturated zone by leaching. Fertilizers especially nitrogenous fertilizers are considered to be a main non-point source of NO_3 that leaches to groundwater. The extensive and intensive use of fertilizers that is common in agricultural systems leads to high N accumulation in the soil profile which is not taken up by plants. This high N accumulation and free flow of water down the soil profile are preconditions for N leaching into the subsoil and groundwater. The free flow of water is enhanced by heavy and frequent rainfall, low evaporation rates due to low temperatures, coarse sandy soil and amount of nitrogen fertilizer applied.

Mineralization is the collective term for the conversion of soil organic nitrogen to inorganic forms of nitrogen by aerobic organisms through ammonification and nitrification. Ammonification is the release of inorganic N, as ammonium, by microbial breakdown of plant residues, and soil organic matter while nitrification is the oxidation by microorganisms of the ammonium ion, first to nitrite (NO_2-N) and then nitrate (NO_3-N). These transformations are important in relation to nitrogen losses from the soil environment because the reaction transforms the relatively immobile ammonium (NH_4^+) into the very mobile species (NO_3^-). With the external factors such a humid weather conditions, soil characteristics and agricultural farm activities and the free flow of water leaches the N into the groundwater.

Nitrogen is removed from soil or groundwater through plants uptake which only occurs within the root zone of plants and through denitrifcation. N is also lost through volatilization and runoff from the soil surface. Nitrates and Ammonium can be biologically reduced to atmospheric nitrogen through the process of denitrification (Spellman, 2008). Anaerobic conditions and high organic matter content favour the denitrifcation process in groundwater. Nitrogen is released slowly from soil organic matter, but more rapidly from some crop residues, and animal manures and compost. Many commercial fertilizers contain ammonium, which plants can use directly. Microorganisms also use ammonium or nitrate when they digest plant residues with little N.

Soil characteristics also dictate the N kinetics because it controls the lagtime between the on-ground application of fertilizer N and nitrogen leaching ultimately affecting the amount of nitrates leached to groundwater. The well integrity also affects the nitrate loading of groundwater. Wells that are either shallow and/or in close proximity to the farms, and pit latrines/septic tanks are susceptible to nitrogen pollution.

The conceptual framework (Figure 1) shows that there exists a relationship between the quantity of N in the soil environment and its concentration in groundwater. This conceptual framework allows forecast on potential nitrate contamination of groundwater.

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CHAPTER THREE

GENERAL METHODOLOGY

3.1 Description of the Study Site

Uasin Gishu County lies between longitudes 34^0 50´ East and 35^0 37´ West, and latitudes 0^0 03´South and 0^0 55´ North covering a total area coverage of 3,345.2 km^2 (Uasin Gishu County Integrated Development Plan 2013-2018 (UGCIDP, 2013). The county shares common borders with Trans Nzoia County to the North, Elgeyo Marakwet County to the East, Baringo County to the South East, Kericho County to the South, Nandi County to the South West and Kakamega County to the North West (UGCIDP, 2013). The county is a highland plateau with a terrain that varies greatly with altitude, ranging between 1500m-2700m above sea level. According to the 2009 population and housing census the total population of the county was at 894,179 and 202,000 households with a projection of growth to about 1.22 million 2017. The population density was projected to increase from about 270 persons/Km^2 to 362 persons/Km^2 by 2017 and this is expected to have significant implications on the average size of land holdings.

The County is physiographically divided into three zones: the upper highlands, upper midlands and lower highlands and these zone significantly influence land use patterns since they determine the climatic conditions (UGCIDP, 2013). Geologically, the county is dominated by tertiary volcanic rock that has not been found to have any minerals that can be exploited commercially (UGCIDP 2013). Uasin Gishu is endowed with good land resources and varied agro-ecological potential and is commonly referred to as the bread basket of the country due to the predominant production of rain-fed maize production. The county produces slightly more than 14% of the national output of maize (Kamau and Otieno, 2013).

Uasin Gishu County is divided into six sub-counties namely Turbo, Soy, Ainabkoi, Moiben, Kessess and Kapseret and the sub-counties are further subdivided into fifty one wards and ninety seven sub-wards (Figure 2).

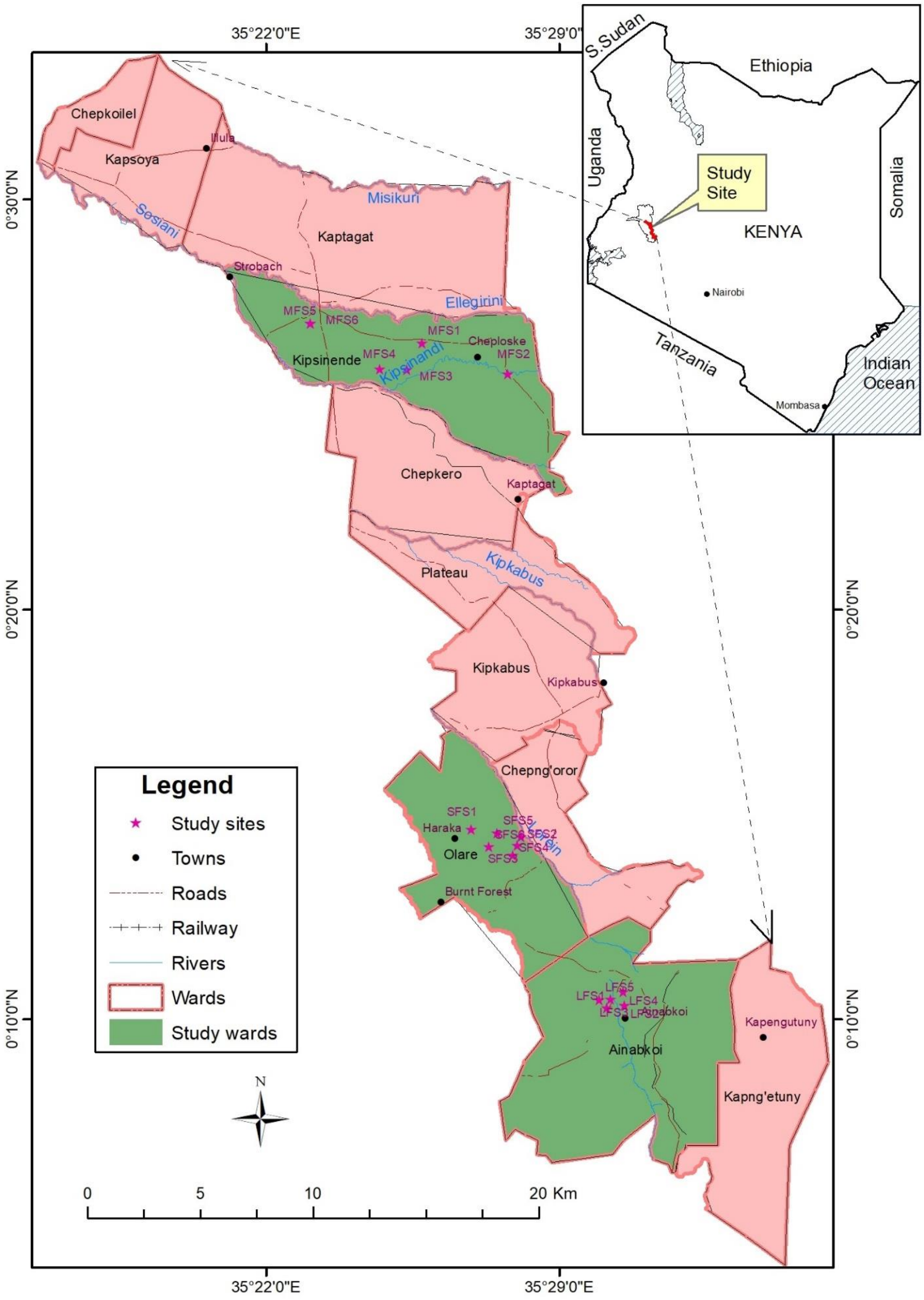

Figure 2: Map of Ainabkoi Sub-County showing the sampling sites.
Source: Extracted from Topographic Maps of Kenya (Scale 1:50,000).

3.1.2 Ainabkoi Sub-County

The study was conducted in 2012 and 2013 in Ainabkoi sub-county of Uasin Gishu County. Ainabkoi sub-county is divided into several wards namely Ainabkoi, Olare, Kaptagat ward and Kapsoya Ward. The research was conducted in several locations within

Ainabkoi, Olare and Kaptagat wards which have which have extensive agricultural activities. Ainabkoi and Olare Wards cover an area of 479km^2 with a population of about 38,563 people (UGCIDP, 2013). Kaptagat Ward covers 68.5km^2 with a population of 41,105 people.

The sub-county has a long cropping season between March and October and intermediate rains which can be divided into two variable cropping seasons. The first rains normally start at the end of March and the second at the end of June. Average rainfall amounts are sufficiently high and range between 624.9 mm to 1,560.4 mm with two distinct bimodal peaks occurring between March and September; and May and August and a dry spell occurring between November and February. Temperatures are relatively low due to the high altitude with a mean maximum temperature of 25^{0}C and mean minimum temperature of 8.8^{0}C, and a moderate humidity of 50% (UGCIDP, 2013). For the purpose of this study, the rain or wet season was noted as from March to August and denoted as the wet season (WS), while the dry season (DS) was regarded as being from November to February

3.1.3 Agricultural Activities in Uasin Gishu

Most of the sub-county has soils of unit 61 L (rhodic ferrasols) which are well drained, and moderately deep, dark red to brown, friable clay that are underlain with murram with inclusions of small bottomlands of unit 339 B (mollic gleysols) which are poorly drained, moderately deep dark grey to grey soils (Jaetzold and Schmidt, 1983).

Since Uasin Gishu County is a highland plateau the terrain varies greatly with altitude. Ainabkoi sub-county is located at the highest part of the highland plateau county with an altitude range between 1826m to 2100m above sea level. Due to the favourable topography and climatic conditions the sub-county has a high potential for agricultural and livestock activities. The main food crops include maize, wheat and potatoes. Agriculture is therefore a significant source of household income and food security for over 80% of the rural population although the county's agricultural potential has not been realized (UGCIDP, 2013). Mixed farming (food crops and livestock) and mixed farming (commercial crops and livestock-dairy) are the main forms of agricultural livelihood. However, the characteristics of the agricultural sector varies widely from predominantly small scale farms with low input levels to highly mechanized large scale farming with higher levels of external inputs. All households have kitchen gardens that supply the family's vegetable requirements such as carrots, onions, indigenous vegetables, potatoes and kales. The declining soil fertility due to continuous tilling of the same land coupled with overuse of fertilizers and chemicals and the increasing land fragmentation with the resultant decreased land sizes are among the key factors leading to low crop production in the County. The soils which comprise of red loam soils, red clay soils, brown clay soils and brown loam soils mainly support maize, sunflower, wheat, pyrethrum, potatoes and barley farming. They also support livestock rearing and forestry.

Ainaibkoi sub-county is considered an intensive and extensive agricultural area. It has an area of 893 km^2 under farming and 30% of the land is under high value crops. The main crops produced in the small farm sectors include maize, beans, wheat, vegetables, pyrethrum and flowers. Livestock production, in the form of cattle, sheep, goats and chicken is also a major resource exploited in the area. Most of the land in the sub-county is privately owned, acquired either through purchase or inherited within the family. Most of the purchased land sizes are relatively smaller compared with the inherited farms.

3.1.4 Water Resources

Uasin Gishu county lies within the Lake Victoria catchment zone hence all its rivers drain into the Lake with main rivers such as Sosiani, Kipkaren, Kerita, Nderugut, Ndaragwa and Sambu. The rivers in the southern parts of the county receive water from Ainabkoi.

There are several water resources in form of dams, rivers, boreholes, shallow wells and springs. There are about 250 boreholes in the county of which 170 are registered. However, most homes have shallow wells as their source of water for domestic use. The main challenges facing these various water sources include reduced water tables due to the destruction of water catchment areas of Kaptagat, Timboroa and Kapchemutwo forests (UGCIDP, 2013). There is increased water pollution due to poor sanitation and effluent discharge. The leaching of chemical fertilizers is reported as an emerging major source of river pollution ((UGCIDP, 2013). There are also several dams constructed during the colonial times and farmers use them for both domestic and Livestock purposes. However the existing dams are increasingly silted and putrefied due to mismanagement and neglect.

Uasin Gishu County has set objectives and concomitant strategies for attaining these objectives in the Uasin Gishu Integrated development plan, 2013-2018. The county has set an objective to increase agricultural production and productivity by promoting Good agricultural Practices (GAP) in all aspects of farming. The proposed strategies involve reducing the cost of farm inputs which includes fertilizers. Cheaper fertilizer sources may mean higher application rates of fertilizer and subsequent groundwater pollution. Accessibility to clean and potable water is of significance is one of the objectives set by the county government of Uasin Gishu. The county has proposed tapping groundwater in order to increase the water volumes through establishment of community water sources (UGCIDP, 2013).

In the recent past there has been an upsurge of chronic diseases such as cancer and the county needs to develop effective strategies to combat these diseases (UGCIDP, 2013). There is need to study and evaluate the environment in an effort to identify any cancer causing agents in the environment especially water. This is especially important because nitrate has been linked to several gastrointestinal cancers.

3.2 Study Design

The research involved a combination of various study designs: longitudinal survey, diagnostic and observational/descriptive.

i. A longitudinal survey was carried out over a period of two years (2011-2013) that involved selection of farms to be evaluated for sampling of groundwater wells at different times throughout the crop production cycle.
ii. A diagnostic study design was employed in analysis of the groundwater samples in the laboratory for nitrate-N, nitrite-N and ammonium-N concentrations and the physico-chemical characteristics. The farm acreage under production, the rates of N fertilizer applied and the agricultural activities within each farm were recorded.
iii. Descriptive research design was used to obtain information to determine the well vulnerability to contamination and describe the existing condition with respect to variables and conditions in the situation (University of Southern California (USC, n.d.).

3.3 Farm Survey and Selection

Ainabkoi sub-ward was selected for the study because of its extensive agricultural activities accompanied by the high rainfall amounts it receives. Prior to the start of the baseline survey, consultations were done with the Sub-County Agricultural Officer (SCAO), whereby the purpose of the survey was explained and discussed. During further consultative meetings it was decided that three wards within Ainabkoi sub-county namely

Ainabkoi, Olare and Kaptagat were representative of the Ainabkoi sub-county agricultural activities and for the purposes of the research. The selection and characterization of farms within each of the three wards was thereafter carried out with the guidance of the Ward Agriculture Officers.

During the survey, it was identified that farmers predominantly practiced mixed farming. In general all the farmers grew maize, kept some farm animals, and grew a variety of vegetables and fruit crops in small gardens beside their homes. Further to this each farm had its own unique characteristics with regard to the size, the number and types of domestic animals kept, the maize acreage, variety of vegetable and fruit crops grown, and the homestead/property development (landscaping, housing, toilet construction, well construction). In order to conceptualize and establish effective comparison between farms it was necessary to conceive a working typology that captured a common characteristic within farms. According to Ojiem, Ridder, Vanlauwe, & Giller, (2006) the heterogeneity of farming size is created by several biophysical and socio-economic factors. However official farm typologies in Africa are almost nonexistence due to general state withdrawal in agricultural public policies (Matus, Cimpoies & Ronzon, 2013). The selection of factors that define farm typology varies greatly from study to study and may be governed by the purpose of research (Goswami, Chatterjee & Prasad, 2014). For purposes of this study different farm sizes were determined as a working farm typology because it captured a common characteristic within farms in each ward in Ainabkoi Sub-county. In this regard it was identified that farms in Ainabkoi ward were mainly large, family-generations-owned mixed farming size and ranged more than 40 acres in size (>40 acres) with privately owned wells. In Kaptagat ward, farms were medium sized (10-40 acres) mixed farming size with privately owned wells. The farms in Olare ward were small mixed farm size which ranged 2-10 acres in size and with communally owned wells. In view of the foregoing, the three wards were identified as non-overlapping strata and farms were stratified on the basis of farm sizes into three farm typologies. Each ward was considered as a stratum of homogenous farms characterised by individual farm sizes with the same extensiveness or size in terms of acreage and accessibility to a well. Purposive random sampling technique was applied in selection of the representative farms within each ward whereby only accessible farms that had access to a well for evaluation of the groundwater sources were selected. Five farms in each ward were therefore identified for well water sampling. Hence a total of 15 wells were sampled during the wet and dry seasons of the year for a period of two years. The Magellan Global Positioning System (GPS) 315 meridian was used to determine the geographical extent and coordinates of each ward. The well coordinates in Ainabkoi ward were within the latitude range of 0^{o}10’19.4”N to 0^{o}10’33.9”N and longitudes 35^{o}30’03.9”E to 35^{o}30’34.9” E. In Kaptagat ward the well coordinates ranged from 0^{o} 25’ 45’’N to 0^{o} 26’ 59’’N and 35^{o} 23’ 4’’E to 35^{o} 27’ 47’’E and in Olare from 0^{o} 14’ 8’’N to 0^{o} 14’ 38’’N and 35^{o} 26’ 55’’E to 35^{o} 28’ 6’’E.

The rain or wet season (WS) usually occurs as from March to August while the dry season (DS) is from September to February. It was assumed that the possible variations due to the unpredictable cause-effect impact chain of the agro-ecosystems and the environment were negligible and that the interaction between farm sizes and year has no agronomic meaning and is therefore less important than the interaction between farm sizes and season. Therefore repetition over seasons was preferred to repetition over years.

A questionnaire was developed for interviewing farmers during characterization of the individual farms (Appendix 1). The main purpose of the questionnaire was to obtain general information on farm sizes, crops grown, crop acreage, cropping calendars, type and amount of fertilizer applied.

3.4 Groundwater sampling

For each farm size, Large mixed, Medium mixed or Small mixed farm systems, five farms were selected such that each had access to a well within the farm or a centrally communal well. Groundwater samples were collected at least every week from just before planting, in January to March, during planting in April and through to two weeks after topdressing in June-July and thereafter at least once a month until after harvesting in October December in 2012 and 2013. Sampling of groundwater was also done at least once a month during off production season in the months of November to January in 2013. The purpose of the sampling times were aimed at monitoring any possible temporal changes in groundwater characteristics throughout the production cycle and during off season. Groundwater sampling was done in triplicates at each sampling time, directly into clean high density 150 ml polyethylene bottles, sealed and stored in an icebox in the field and transported to the laboratory within the same day. Samples transported immediately to Kenya Marine Fisheries research institute, (KMFRI) laboratories and kept frozen prior to analysis. It was expected that the nutrient levels in the water samples would not be significantly changed through freezing since it is considered an effective means of nutrient preservation in water samples (Fellman, D'Amore, & Hood, 2008). Unstable hydrochemical parameters such as pH, Electrical Conductivity (EC) and Total Dissolved

Solids (TDS) were measured in situ (in the field) immediately after collection of samples while the others were analysed in the laboratory as described by the American Public Health Association (APHA, 1995).

3.5 Nutrient Analysis

3.5.1 Nitrate-N (NO_3-N) and Nitrite-N (NO_2-N) Analysis

Nitrate-nitrogen (NO_3-N) and Nitrite-Nitrogen ($N0_2$-N) were quantitatively determined by the colorimetric cadmium reduction-diazotization automated segmented flow. Nitrate was reduced to nitrite by cadmium metal and the resulting nitrite determined by formation of an azo dye (Zhang, Ortner, and Fischer, 1997). In the laboratory, the water samples were prepared for analysis by first thawing them at room temperature. In this procedure samples were passed through a copper-coated cadmium reduction column. The nitrate in water was reduced almost quantitatively to nitrite by running a sample through a column containing cadmium filings coated with metallic copper (Cu). The nitrite thus produced was quantified by diazotising and coupling with N- (1- napthyl) ethylene to form a highly colored azo dye. For the analysis 50ml containing water sample was run through the column. The first 25 mls was wasted and the final 25 ml was saved for analysis. 1ml Sulphanilamide was added to the 25 mls and shaken thoroughly and the reagents allowed to stand for 2-8 minutes. Then 1ml of N-1-Napthyl ethylene diamine dihydrochloride was added and mixed completely. After 10 minutes to 2 hours, the extinction of the solution was measured against distilled water at a wavelength of 540 nm. The absorbance value was converted to the equivalent concentration of nitrate against a standard curve. Nitrate concentration was determined by subtracting the nitrite values separately determined with the cadmium reduction procedure.

3.5.2 Ammonium-N Analysis (NH_4-N)

The method used for the ammonium analysis was the common indophenol blue photometric determination (APHA. 1995). Ammonium reacts with phenol and hypochlorite under alkaline conditions to form indophenol blue. The colour development is proportional to the concentration of ammonium within a given range (0-1000 µg NH_4-N l^{-1}). The blue colour-forming reaction, called the Berthelot reaction, did not proceed rapidly enough to achieve adequate colour formation, therefore samples are stored at ambient temperatures in the dark for one day after addition of the reagents and the final complex remained stable for over 24 hours. The absorbance was measured at a wavelength of 630 nm on a spectrophotometer.

3.6 Data Analysis

Data was analysed using the Statistical Analysis System (SAS Institute Inc., Cary N.C.). The primary data was summarized and organized using descriptive statistics and presented in tables and graphs.

Data analysis of variance (PROC GLM) with stepwise elimination of non-significant independent variables was used to identify significant effects at 5% level of significance. When significant main effects were detected ($P \leq 0.05$), means were separated by the least significant difference procedures (LSD) at ($P \leq 0.05$).

Multiple linear regression analysis was used to determine how the independent variables in the environment predict the nitrogen concentrations in the well water.

The model for the linear multiple regression analysis was:

$Yi = Bo + B_1x_1 + B_2x_2 + \ldots . B_nx_n + A$

Where Yi = the dependent variable (Nitrate-N, Nitrite-N and Ammonium-N concentration in well water)

A = Constant

B = the non-standardized coefficient

X = Independent variables (Rainfall amount, fertilizer rates,

3.7 References

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CHAPTER 4

CHARACTERIZATION OF FARMS IN AINABKOI SUB-LOCATION

Abstract

Categorization of the African small holder farmer can be on the basis of the agro-ecological zones, the type and composition of the farm portfolio, land size and on the basis of the annual income generated from farm activities. There is no unique and unambiguous definition of small holders, however they are often those who farm less than a threshold size of 2 hectares. Agricultural typologies are considerably large, diverse and can be constructed for one-time measurements and give a snapshot of farm situations at a certain period of time for a specific research objective. The study was conducted in 3 wards of Ainabkoi sub-county namely, Ainabkoi, Olare and Kaptagat. Each ward was identified as a homogenous stratum of same size-ranged farms classified as Large, Medium and Small farm sizes in Ainabkoi, Olare and Kaptagat wards respectively. Within each ward farms were purposively and randomly selected such that only accessible farms that had access to either a privately owned or communal wells were selected. The study was carried out between 2012 and 2013. In Ainabkoi ward the farms were mainly large, family-generations-owned mixed farm sizes and ranged 40-71 acres (16-29 ha) with an average farm acreage of 56 acres (23 ha). The medium sized mixed farm sizes were mainly located in Kaptagat ward which were relatively newer purchased settlement farms (about 10 years old) of varying sizes ranging from 10-35 acres (4-14 ha). The small mixed farm sizes were located in Olare ward. The farms in this study were generally small farm sizes which range 2-10 acres (0.8-4 ha) in size. Analysis of Variance (ANOVA) showed highly significant differences between the farm sizes in total farm acreage, acreage under maize production, size of the homestead, and numbers of different livestock on the farm. The land was predominantly utilized for maize production. However these farmers also had small kitchen gardens for their vegetables whereby tomatoes, Kales, spinach, carrots, spring onions; and potatoes are grown in a mixed cropping. Farmers also grew some fruit crops such as passion fruits, tree tomatoes, bananas, oranges and lemons.

Keywords: Ainabkoi; Typologies; Farm sizes.

4.1 Introduction

Agriculture is the backbone of the economy of Kenya and is mainly dominated by small holder farmers who occupy the land and produce most of the crop and livestock products (Salami *et al*. 2010). Agriculture provides 80% of the total rural household income and food security as maize, wheat, beans, horticultural produce, chicken as the key commodities in the value chain.

Matus, Cimpoies & Ronzon, (2013) defined an agricultural holding as 'an economic unit of agricultural production under single management comprising all livestock kept and all land used wholly or partly for agricultural production purposes without regard to title, legal form or size. These small holder farms or agricultural holdings can be catergorized according to the agro-ecological zones, the type and composition of the farm and the annual revenue generated from farming activities (Salami *et al*. 2010). However, agricultural typologies are considerably large, diverse and differ by their focus on the research question. According to Alvarez, Pass, Descheemaeker, Tittonell & Groot, (2014) typologies can be constructed for a specific research objective. In such cases the type of typologies are on-time measurements and give a snapshot of farm situations at a certain period of time. In East Africa the small holder is not well understood especially with regard to farm management knowledge and practices (Jaleta, Gebremedhin and Hoekstra, 2009).

Uasin Gishu County is referred to as the breadbasket of Kenya has high and reliable rainfall, relatively large farm sizes, and highly mechanized farming. Ainabkoi sub-county is largely agricultural. The main farm practice in the sub-county is mainly largely maize-mixed farming whereby farmers grow maize and other food crops and keep livestock (sheep and dairy cattle). Agriculture is mainly rain-fed and production costs are high due to high costs of inputs especially fertilizer, poor and long marketing chains, low levels of mechanization and high transportation costs.

4.2 Literature Review

There are over 570 million farms worldwide and most are small and family operated with about 12% agricultural land being small farms of less than 2ha. The average farm size has been decreasing in most low and lower middle income countries whereas it has increased in some upper-middle and high-income countries (Lowder, Skoet, & Raney, 2016). Farmland distribution in 14 African countries, indicated that 80% of farmholdings are smaller than 2 ha and operate about 25% of the agricultural land while in the European

Union (EU) 50% of the farms are smaller than 2ha but operate about 2.4% of the agricultural land (High Level Panel of Experts (HLPE, 2013). From a global perspective 84% of farms are smaller than 2 ha and they operate about 12% of the farmland. This translates to smaller farms operating a greater share of farmland in lower income countries than smaller farms in higher income countries (Lowder, Skoet, & Raney, 2016).

According to Salami, Kamara & Brixiova (2010) categorization of the African small holder farmer can be on the basis of the agro-ecological zones in which they exist; the type and composition of the farm portfolio and land size and on the basis of the annual income generated from farm activities. Smallholdings of less than 1ha are found in areas with high population densities and increases to 10 ha or more in sparsely populated areas in combination with livestock of up to 10 animals (Dixon, Tanyeri-Abur & Wattenbach, 2003). According to FAO (2017) there is no unique and unambiguous definition of small holders. Small holders are often those who farm less than a threshold size of 2 hectares. However the distribution of farm size depends on a number of agroecologocal and demographic conditions together with economic and technological factors. The farm size and land is the land operated by the household including land left fallow (FAO, (2017). FAO has developed a farmers' data portrait that captures several attributes with the aim of providing a clear picture of small holder agriculture with regard to its scale, productivity, technology, commercialization and wellbeing. Farm size is a significant indicator and refers to the average land operated by the household for crop production in hectares. In Kenya the weighted median threshold of operated land identified at national level in Kenya is 1.21 Ha. Another indicator, the Tropical Livestock Units (TLU) is for all livestock in the farm and reports the number of animals owned in TLU (which is taken to be an animal of 250kg live weight).

Family farms are the dominant type of farms in agricultural development. In developing countries such as Kenya, families usually farm small plots of land with most of the labour being family. This motivation to work in their own farms is thought to give a productive advantage over large farms. This is in contrast with some regions such as Latin America and East Europe, whereby family farms coexist with large corporate farms. The farming system in the highlands of East Africa is the mixed crop-livestock farming. There are variations in the intensification of the crop-livestock system due to different land fragmentation, economic opportunities, and cultural preferences, lack of capital to purchase crop and livestock inputs and labour constraints (Kindu *et al*. 2014). Masters *et al*. (2013) indicated that the average farm sizes have been decreasing for Africa and Asia since the 1950s but in recent years they have begun increasing for Asia as a whole while they continue to decrease in Africa.

Farmers often diversify the source of income to contribute to the purchase of both crop and livestock needs. Increases in farm-household income generate as much as two to four times additional income in the rural non-farm economy. The main challenge faced by smallholder farmers is low productivity which stems from the lack of credit, expensive inputs, and the unstable food and energy prices.

4.3 Methodology

The selection and characterization of farms within each of the three wards was carried out with the guidance of the Ward Agriculture Officers as discussed in Chapter 3.

A questionnaire was used to interview the farmers during characterization of the individual farms and during the production cycle (Appendix 1). The main purpose of the questionnaire was to obtain general information on farm sizes, crops grown, crop acreage, cropping calendars, types and number of livestock animals kept, type and amount of fertilizer applied and well depth. The interviews took place on the farmers’ sites and involved asking open-ended questions in ‘Kiswahili’ for ease of communication.

4.4 Results

The baseline survey captured a common characteristic of size within farms in each ward in the sub-county. In this regard it was identified that farms in Ainabkoi ward were mainly large, family-generations-owned mixed farming size and ranged more than 40 acres in size (>40 acres) and had privately owned wells. In Kaptagat ward, farms were medium sized (10-40 acres) mixed farms with privately owned wells. The farms in Olare ward were small mixed farms which ranged 2-10 acres in size and with communally owned wells. The results of the survey and characterization of farm sizes in Ainabkoi Sub-County are presented in Table 2.

Table: 2 Characteristics of selected farms in different Farm sizes.

	Farm Size				
Farm Characteristic	Large	Medium	Small	$LSD_{0.05}$	Significance $P \leq 0.05$
Total Farm Size (Acres)	55.67a	18.2b	4.8c	2.25	***
Homestead size(Acres)	3.67a	3.4b	0.6c	0.16	***
Maize Acreage (Acres)	34.17a	10.70b	3.50c	1.89	***
Well Depth (m)	36.67a	26.00b	7.6c	2.28	***
Main Livestock types (No.)					
Cattle	10.67a	10.72a	2.4b	1.003	***
Goats and Sheep	11.33a	8.03b	3.4c	1.44	***
Poultry	17.3a	8.03b	7.6b	1.37	***

^{x}Mean separation across rows by LSD, $P \leq 0.05$; means followed by the same letter are not significantly different.
*** Highly significant at $P \leq 0.05$

Analysis of Variance (ANOVA) showed highly significant differences between the farm sizes in total farm acreage, acreage under maize production, size of the homestead, and numbers of different livestock on the farm (Table 2). Overall ANOVA tables for the farm sizes are shown in Appendix II.

In Ainabkoi ward the farms were mainly large, family-generations-owned mixed farm sizes and ranged 40-71 acres (16-29 ha) with an average farm acreage of 56 acres (23 ha). The farms were therefore characterised as large mixed family farms because they are expansive, well organized and developed in terms of modern stone houses, landscaped and partitioned into utility areas. The land was predominantly utilized for maize production for both home consumption and as a source of income, pasture, woodlots and the homestead. Farm animals such as cattle, sheep and free ranging chicken are a major part of all farms. The wells in these farms were privately owned, relatively old (>20 years old) and deep (mean 37m). The well water usually fluctuated between rains such that the water level rapidly went down once the rainy season subsided. This could be an indicator that the well water was not stagnant but there was continuous groundwater flow.

The medium sized mixed farm sizes were mainly located in Kaptagat ward which were relatively newer purchased settlement farms (about 10 years old) of varying sizes ranging from 10-35 acres (4-14 ha). These farms had modern stone houses, with wellmanicured large landscapes, privately owned wells and organized farm planning into utility areas. Maize production is a major agricultural activity in both the large and medium farm sizes. However these farmers also had small kitchen gardens for their vegetables whereby tomatoes, Kales, spinach, carrots, spring onions; and potatoes are grown in a mixed cropping. Farmers also grew some fruit crops such as passion fruits, tree tomatoes, bananas, oranges and lemons. The organization characteristic of these medium sized farms was identified with the division of the fields into grazing paddocks for the livestock, kitchen gardens, and fruit trees growing such as loquats, guavas, passion fruits, citrus fruits, bananas, and mulberry and well landscaped family homestead. The farmers in this farm sizes are generally better endowed in terms of resources since most were either retired civil servants or work away from home. The higher income levels were translated into production activities and decision making activities. Farmers therefore increase their fertilizer application rates to double the rates recommended by agriculture extension officers.

The small mixed farm sizes were located in Olare ward. The farms in this study were generally small farm sizes which range 2-10 acres (0.8-4 ha) in size. Burnt Forest is the major urban trading centre in the ward. The wells are shallow and communally shared for household water needs and for watering animals. The infrastructure facilities are mostly weather roads which are impassable during the wet season. Most houses within the small mixed farm sizes were constructed using materials such as mud or wood as the main walling material. Farm households were closer to each other due to the smaller land sizes. The farmers in the ward are mainly small scale farmers and practice multi–cropping on their farms for household vegetables. Farmers did not apply more than the recommended fertilizer rates and several fields show N deficiency of yellowing leaves.

4.5 Discussion

Lowder, *et al* (2016) noted that the term family farm is often used interchangeably with smallholder farm and that there is no universally agreed definition of family farms. However they discoursed that although there is a degree of overlap between the two categories they are not the same. According to the most commonly used definitions, 84% of all farms are small farms of less than 2ha while more than 90% of the world's farms are considered family farms. Most of the world's agricultural land (about 75%) is operated by family farms while only about 15% is operated by the small farms of below 2 ha.

The survey showed that the farms in the three wards in Ainabkoi Sub County were characterised by significantly different farm sizes, homestead sizes and development, number of different livestock in the farm and family resource endowment. This concurs with Kindu *et al*., 2014, who reported that small-scale crop-livestock farms are representative of the farms in the East African highlands and the level of intensification varies between villages and farms. They attributed the variations in the level of intensification to factors such as different rates of population increase, economic opportunities, cultural preferences, and capital constraints such that they cannot purchase farm inputs. Likewise Thornton *et al*., (2010), reported that East African farms are spatially heterogenous and are characterized by changing socio-economic circumstances and rapidly expanding population.

In Ainabkoi ward, farms were inherited down generations, hence the larger farm sizes, old deep wells and developed homesteads. The farmers grow significantly large acreages of maize and keep more livestock than other farms. This implies that the farmers do not sell portions of their land and depend on a large scale farming of mostly maize as a source of income. The long distance between farms, the livestock water needs and the larger extended family size are probably factors that have led the farms to have privately owned wells. These farms can be defined as family farms as compared to smallholder farms which are about 2ha in size.

The farms in Kaptagat were relatively smaller in size probably because they were newly purchased pieces of land by new settlers. The well landscaped homesteads and modern stone farm houses can be attributed to the fact that the farm owners mostly worked away from home as a major source of income hence they had considerably more income and resources. Jayne *et al*, (2001) reported that most farm households in Kenya generate 50% of their income off-farm. According to Sindi, (2008), there has been a general increase in horticultural production in farming systems in Kenya because of the proximity to input and output markets, access to credit, availability of seed and adequate rainfall.

Farms in Olare ward were owned by people who had been displaced during the post-election violence of 2007-2008 and had been resettled through a government programme. The area also had people who had settled there since 1950's while they worked in European farms. The farmers in the small mixed farm sizes were small-scale farmers who are financially constrains. The financial limitation subsequently limited their access to farm inputs such fertilizers, farm animals and pesticides. The N deficiency noted on the maize crops could be due to the N leaching and also due to lack of adequate application of adequate N fertilizer. Farmers often apply fertilizers as a one-time application, which subjects the fertilizer to leaching loss down the soil profile. According to Kindu *et al*., (2014) agricultural land fragmentation and the conversion of land use from grazing and forest to agriculture has been done to cater for rapid population increase This was evident in mostly the medium and small scale farm sizes.

4.6 Conclusion

All the farm sizes had livestock which include cattle, free ranging chicken, sheep and goats. However, farmers within the large and medium mixed farm sizes had at least more than five dairy cows unlike the small mixed farm system farms with 1-2 cows. The farms were also involved in cereal production predominantly maize, and some vegetables in a kitchen garden for home consumption. The farm sizes are crop production environments that can be manipulated and managed in order to realize sustainable, profitable and environmentally sound way of crop production. However it is apparent that only farmers able to be eco-efficient in use of inputs such as fertilizers will be able to reach productivity level for staple crops.

4.7 Recommendation

In order to realize sustainable, profitable and environmentally sound way of crop production there is need to enhance the farmers' knowledge base. This can be achieved through various activities such as field visits, agricultural shows, farmer exchange visits, farmers' trainings, workshops, demonstrations and extension services. There is need to institute conversion of agricultural land in order to control land fragmentation and change of land use.

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CHAPTER FIVE

ASSESSMENT OF PHYSICO-CHEMICAL CHARACTERISTICS OF GROUNDWATER AMONG DIFFERENT FARM SIZES IN AINABKOI SUB-COUNTY.

Abstract

Access to quality drinking water is of major concern for sustainable development in developing countries with regard to physico-chemical properties. Groundwater from shallow wells is the main source of domestic water supply for the community of Ainabkoi Sub-county. This study aimed to assess the seasonal physico-chemical parameters in shallow wells among different farm sizes in three wards within Ainabkoi sub-county. Each ward was a homogenous stratum of same size-ranged farms classified as Large, Medium and Small farm sizes in Ainabkoi, Olare and Kaptagat (Kipsinende) wards respectively. Within each ward farms were purposively selected such that only accessible farms that had access to either a privately owned or communal wells were selected. Wells were sampled during the wet and dry seasons of the year for a period of two years. The seasonal levels of physico-chemical parameters pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Total Suspended Solids (TSS), turbidity and temperature were determined. There were non-significant differences between the farm sizes in the groundwater pH, EC, DO, turbidity and temperature. The pH values were within the WHO standards range of 6.3 to 8.5 and the EC values were below the recommended limits of potable water of 250 μccm^{-1}. Wells within the small mixed farm sizes had significantly high TDS levels ranging from 30-250 mgl^{-1}. TSS values were significantly higher during the wet season by about 90% and highest in wells within the large sized farms. The turbidity levels were higher than the recommended limits by WHO of at least 5.0 NTU. The groundwater in Ainabkoi sub-county can conservatively be categorized as safe for domestic use with regard to physico-chemical parameters.

Keywords: Farm Sizes, Groundwater, Season; Physico-chemical properties.

5.1 Introduction

Potable or drinking water is defined as having acceptable quality in terms of its physical, chemical, and bacteriological parameters so that it can be safely used for drinking and cooking (Gadgil, 1998). Drinking water quality is of major concern in developing countries with regard to microbiological, inorganic contaminants and physico-chemical properties which deteriorate water quality (Sorlini, Palazzini, Sieliechi & Ngassoum 2003). Communities should have access to safe drinking water as a basic need to health and sustainable development as outlined in the Sustainable Development Goals (SDGs) which focus on ensuring universal and equitable accessibility of safe water for all by 2030 (6th SDG) (Osborn, Cutter, & Ullah, 2015). However, the chemical and biological quality of water is often overlooked in comparison with the quantity view point of water for drinking, domestic and agriculture use (Falowo, Akindureni, & Ojo, 2017). Groundwater is mainly contaminated and polluted by anthropogenic activities such as modern farming and other domestic and industrial activities. Since groundwater is a major source of water for domestic water supply, its quality should therefore be of major concern especially in agricultural settings. World Health Organisation (WHO, 2011) recommends regular physical assessment of water quality especially after heavy rains to monitor any temporal changes in important physical characteristics such as colour, odour, turbidity, taste, temperature, solids and chemical characteristics such as acidity, alkalinity and hardness.

The study was carried within Ainabkoi Sub-county of Uasin Gishu County in Kenya. Groundwater is the main source of domestic water supply for the community and is exploited through shallow wells (Uasin Gishu Integrated Development Plan (UGCIDP), 2013). Groundwater is considered to be more stable in quality hence requiring no treatment unlike surface waters, is conveniently available and accessible for the family and wells can be developed at comparatively low costs. However the groundwater resource in Ainabkoi is exposed to possible pollution from agricultural production activities which may make it unfit for consumption. Mixed farming agriculture (food/commercial crops and livestock-dairy) characterised by different farm sizes is the predominant economic activity for the rural community of Ainabkoi subcounty with farmers gradually shifting to intensive horticultural farming (UGCIDP, 2013).

In view of the foregoing and in line with the county objectives and concomitant strategies aimed at improving access to clean and potable water to the community it became imperative to access the seasonal quality of ground water. This will provide base data and information which is largely non-existent, on the water quality status to policy makers for future management and planning. The study therefore examined the seasonal levels of Physico-chemical parameters of the well water among different farm sizes in Ainabkoi Sub-County, Uasin Gishu County, Kenya.

5.2 Materials and Methods

5.2.1 Water sample collection

Groundwater samples were collected at least every week from just before planting, in January to March, during planting in April and through to two weeks after topdressing in June-July and thereafter at least once a month until after harvesting in October in 2012 and 2013. Sampling of groundwater was also done at least once a month during off production season in the months of November to January. The purpose of the sampling times were aimed at monitoring any possible temporal changes in groundwater characteristics throughout the production cycle and during off season. Groundwater sampling was done in triplicates at each sampling time, directly into clean high density 150 ml polyethylene bottles, sealed and stored in an icebox in the field and transported to the laboratory within the same day. Samples transported immediately to Kenya Marine Fisheries research institute, (KMFRI) laboratories and kept frozen prior to analysis.

It was expected that the nutrient levels in the water samples would not be significantly changed through freezing since it is considered an effective means of nutrient preservation in water samples (Fellman, D'Amore, & Hood, 2008). Unstable hydrochemical parameters such as pH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were measured in situ (in the field) immediately after collection of samples while the others were analysed in the laboratory as described by the American Public Health Association (APHA, 1995).

5.2.1 Determination of pH, Electrical Conductivity and Total Dissolved Solids.

The pH, EC and TDS parameters were measured in-situ using a combined pH/EC/TDS combo (Hanna instruments) Model HI 98130 by selecting the target mode. The probe was submerged into the sampled water and reading taken when they stabilised. Any electromagnetic interference was minimised by using the plastic bottles to hold the water samples. TDS was then determined by the method of O'wen (1979), by multiplying the EC value of the water sample by 0.65.

5.2.2 Dissolved Oxygen

Dissoloved oxygen was determined by using the Winkler's method according to APHA, (1995).

5.2.3 Total suspended solids (TSS)

The concentration of total suspended solids was estimated gravimetrically on glass-fibre filters (Whatman GFC, or Ederol BM/C filters) after drying to constant weight at 95°C (APHA, 1995).

5.2.4 Turbidity

Turbidity was measured using a Hatch Turbidimeter 2100 P (APHA, 1995). Turbidity is the cloudiness of water as a result of suspended material such as clay, silt, organic/soluble organic, planktonic, microscopic organism thereby inhibiting light transmission by scattering and absorption rather than being transmitted in a straight line (APHA, 1995).

5.3 Results

The comparison of the mean values for the physico-chemical characteristics of groundwater in the different farm size in 2012 and 2013 are shown in Table 3. There were non-significant differences between the farm size in the water pH, DO, EC, turbidity and temperature. However there were highly significant differences between the farm sizes in the TDS and the TSS. The small farm size had significantly the highest TDS compared with the large and medium mixed farm size. The TSS levels were significantly highest in the large farms size and least in the small mixed farm size. Turbidity was the only physico-chemical characteristic in the wells that exceeded the permissible levels by World Health organisation (WHO, 2011) of at least less than 5 NTU in rural supplies. The average turbidity levels in the sampled well water were 86.67 NTU.

Table 3: Comparison of average of physico-chemical analysis of water samples in different farm sizes in Ainabkoi Sub-County

Physico-chemical characteristics	**Farm Size**					
	Large	**Medium**	**Small**	**lsd**	**Significance P≤0.05**	**WHO (2008)**
pH	7.42^{a}	7.48^{a}	7.44^{a}	0.99	ns	6.5-9.5
Dissolved Oxygen(mgl^{-1})	6.56^{a}	6.69^{a}	6.78^{a}	0.45	ns	N.A
Electrical Conductivity(μScm^{-1})	87.58^{a}	92.44^{a}	88.45^{a}	8.52	ns	250
Total Suspended Solids (mgl^{-1})	76.44^{a}	60.89^{ab}	40.91^{b}	23.87	**	N.A
Total Dissolved Solids (mgl^{-1})	80.31^{ab}	65.44^{b}	106.10^{a}	26.29	***	1000
Turbidity (NTU)	85.98^{a}	85.69^{a}	88.35^{a}	13.06	ns	24.5
Temperature (^{o}C)	24.42^{a}	24.81^{a}	24.48^{a}	0.57	ns	

Means followed by the same superscript within a row are not significantly different at 5% significance level according to Fisher's protected LSD test.
^{ns}, *, **, ***, Non-significant, significant at P≤ 0.05, 0.01, 0.001, respectively

The average values of the groundwater physiochemical characteristics were determined and compared for the wet and dry seasons of 2012 and 2013 (Table 4). There were no significant seasonal differences between the wet and dry seasons in the pH, EC, TDS and Turbidity in the groundwater.

Table 4: Groundwater physico-chemical characteristics during the wet and dry seasons of 2012 and 2013.

Physico-chemical characteristics (Mean)	**SEASON**					
	Wet	**sd**	**Dry**	**sd**	**t-test**	**sed**
pH	7.43	0.53	7.87	4.95	-1.12ns	0.40
Dissolved Oxygen (mgl^{-1})	6.75	0.90	6.51	1.13	0.04*	0.12
Electrical Conductivity (μScm^{-1})	88.21	24.13	91.35	35.44	0.92ns	3.43
Total Suspended Solids (mgl^{-1})	74.38	104.85	39.20	56.38	3.69***	9.53
Total Dissolved Solids (mgl^{-1})	90.75	121.01	78.28	58.25	1.16ns	10.75
Turbidity (NTU)	83.56	49.14	89.99	43.32	1.23ns	-5.24

^{ns}, *, **, ***, Non-significant, significant at P≤ 0.05, 0.01, 0.001, respectively

5.3.1 pH

The average pH of the groundwater samples in all the farm size ranged from 5.94 to 8.96 in 2012 with a mean of 7.41 and 6.6 to 8.96 with a mean of 7.49 in 2013. The pH of the groundwater samples ranged from 5.94 to 8.66 during the wet season with a seasonal average pH of 7.43 and from 6.46 to 8.96 with a mean value of 7.87 in the dry season (Table 4). However, it was observed that the pH fluctuated considerably within each individual well throughout the production cycle. The general trend observed was that most wells had a pH level averaging about 7.5 with a few wells within the medium and small mixed farm size that had pH levels of 8.0 during the wet and dry season.

5.3.2 Dissolved Oxygen (DO)

The Dissolved Oxygen (DO) levels in the groundwater samples ranged from 3.01 to 8.79 mgl^{-1}. There were no significant differences in the dissolved oxygen levels between the wells in the different farm sizes (Table 3). However there were significant differences in the DO levels in the wet and dry seasons (Table 4). The DO ranged from 3.90 to 8.72 mgl^{-1} with a mean of 6.75 mgl^{-1} during the wet season and from 3.01 to 8.79 mgl^{-1} in the dry season with a mean of 6.51 mgl^{-1}. These results indicate that the DO levels were higher during the wet season than the dry season by a margin of 3.7%.

5.3.3 Electrical Conductivity (EC)

The EC values in the groundwater samples ranged from 5.32 to 290 µc cm^{-1}. The ANOVA showed that there were no significant differences in EC values between the farm size (Table 3) and also non-significant seasonal variations in the EC values (Table 4). The conductivity of the water samples varied from 38.77-146 µScm^{-1} with a seasonal average of 88.21 µScm^{-1} during the wet season, while it varied from 5.32-290 µScm^{-1} during the dry season and a seasonal average of 91.35 µScm^{-1}.

5.3.4 Total Suspended Solids (TSS)

There were highly significant differences in TSS between the wells in the different farm sizes (Table 3). The TSS were highest in wells within the large farm size with values varying from 8.67-247.1mgl^{-1}. The TSS values in well water on average ranged from 12.2-273.5mg/l in the medium farm size and 9.2-150.3 in the small farm size. The TSS values were significantly higher during the wet season than during the dry season by about 90%

(Table 4). The TSS concentration during the wet season was highest in wells within the large farm size, and lowest in wells in the small farm size (Figure 3).

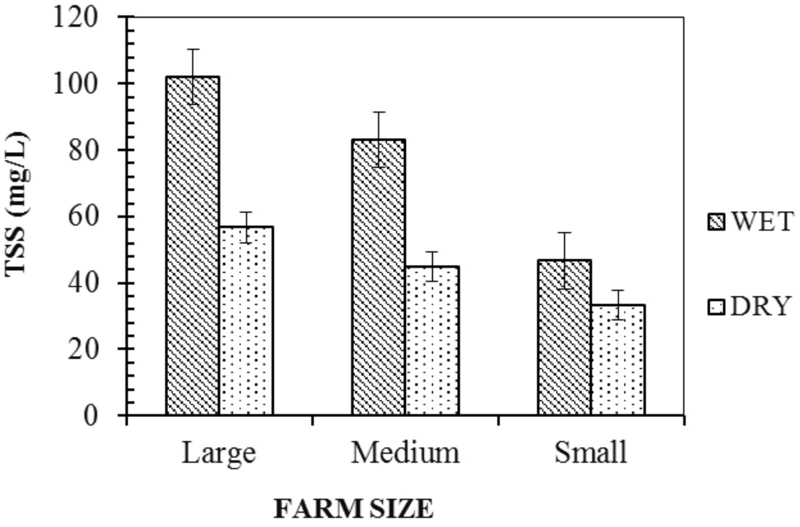

Figure 3: **Seasonal variation of TSS in three different farming size**

5.3.5 Total Dissolved Solids (TDS)

Analysis of variance showed highly significant differences between well water samples in the different farm sizes (Table 3). Wells within the small mixed farm size had significantly the highest levels of TDS ranging from 30-250 mgl^{-1} and averaging 119 mgl^{-1} (Figure 4 and Figure 5).

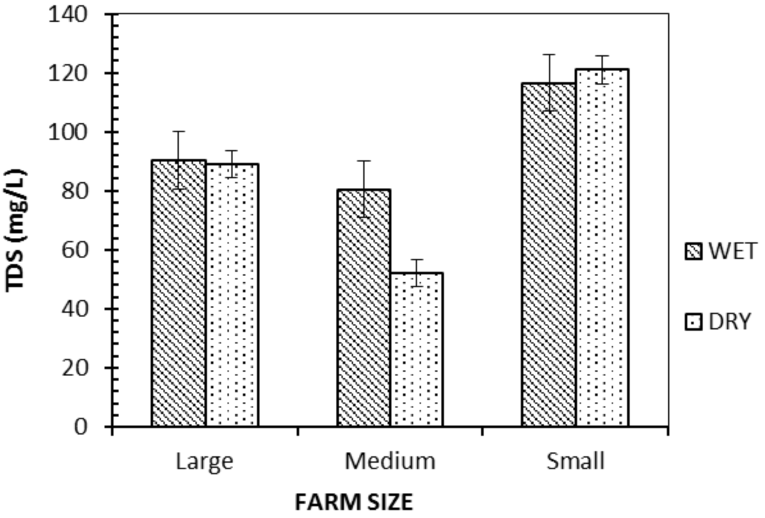

Figure 4: **Seasonal Variation in the TDS in different Farm Size.**

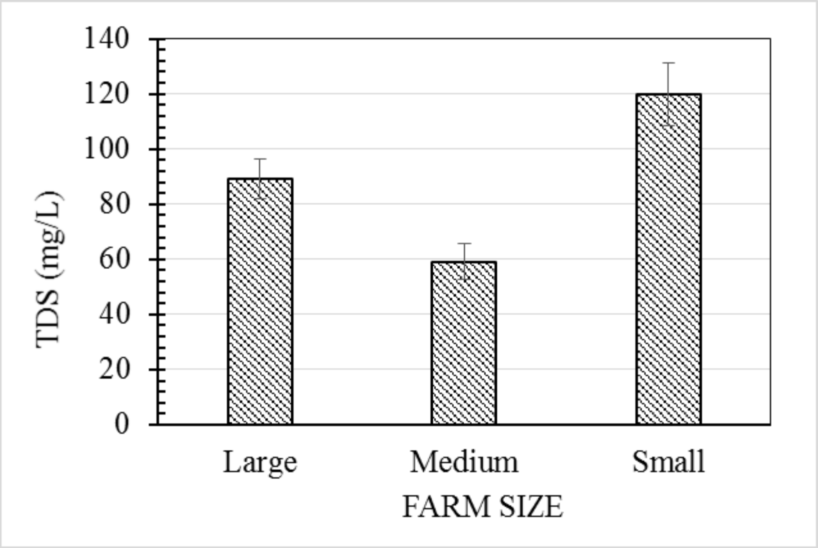

Figure 5: Variation in the TDS in different Farming Size.

The content of TDS in well water in the large farm size ranged from 33-168 mgl^{-1} with an average of about 90 mgl^{-1}, while in the medium farm size TDS concentration ranged from 10-188 mgl^{-1} with an average of 66 mgl^{-1}. There were non-significant seasonal differences in TDS levels in well water (Table 4). The seasonal TDS values ranged from 32-202 mgl^{-1} during the wet season and 58-136mgl^{-1} during the dry season. The TDS in the well water did not exceed the maximum allowed limit of 1000 mgl^{-1}.

5.3.6 Turbidity

There were no significant differences in turbidity between the farm sizes (Table 3). The turbidity averaged across the farm size varied from the lowest value of 22.5 to the highest record of 119.9NTU. There were non-significant seasonal differences in the turbidity level of the sampled well water. The average turbidity levels ranged from 22.7-119.9 NTU with a mean of 70 NTU and 20.4-113 NTU with a mean of 76 NTU were during the wet and dry seasons respectively.

5.4 Discussion

The pH values in the sampled groundwater were within the WHO standards of 6.5 to 8.5 (WHO, 2011). The optimum pH required will vary in different supplies according to the composition of the water and the nature of the construction materials used in the distribution system, but it is usually in the range 6.5–8.5. Anim-Gyampo, Zango & Ampadu (2014) reported closely similar results whereby borehole water pH ranged between 5.77 and 8.3. These results therefore indicate that the well water samples represented satisfactory water pH values for drinking and domestic water use. Seasonal pH variations showed that the average pH values were slightly lower during the wet season (pH 7.4) than during the dry season (pH 7.5). These results concur with those reported by Olutona. Akintunde, Otolorin, & Ajisekola, (2012) who reported lower pH of 7.25 during the wet season and 8.08 during the dry season, an indication of lower levels of hydrogen ions. According to Hounslow's classification of wells, (Hounslow, 1995) as being either moderately acidic (4-6.5), neutral (pH 6.55-7.8) or alkaline (pH 7.8-9), 71% of the wells in 2012 and 54% in 2013, can be classifed as being neutral pH (pH 6.5-7.8). According to the classification, on average only 4.5% and 4% of the wells were moderately acidic (pH 4-6.5) during the wet and dry seasons respectively. Although there are no health-based drinking water standards for pH, an optimum pH of 6.5-9.5 is recommended (WHO, 2008). The united States of America Environemental Protection Agency (USEPA) has established a secondary standard for pH range of 6.5 – 8.5, because pH within this range can produce aesthetic effects such as staining and scaling of eqipment and lead to dissolved concentrations of some metals associated with health effects (Fisher, Davidson, & Goodmann. (2004).

The level of DO in the wells was relatively higher compared with DO (3.56-5.13mgl^{-1}) in wells in Nigeria (Imoisi, Ayesanmi, & Uwumarongie-IIori, 2012). The DO seasonal variations were similar to results of groundwater quality assessment of boreholes in Nigeria whereby wells had slightly higher DO during the wet season than during the dry season (Ornguga, 2014). This can be attributed to the mixing caused by rapid flow of excess rain water. There are no health-based guideline values for dissolved oxygen in water (WHO, 2008). However since depletion of DO encourages microbial conversion of nitrates into nitrite, which is harmful, it is considered advantageous to have higher levels of DO in the water, (WHO, 2008).

The Specific electrical conductivity or EC values in the sampled well water were below the recommended limit of 900 μScm^{-1} acceptable for drinking water (WHO, 2008). Conductivity does not directly indicate water quality and therefore there are no health or water-use standards based on this parameter. However conductivity indicates the presence of dissolved solids and contaminants especially electrolytes but does not give inspiration about specific chemicals. Conductivity measures the capacity of water to pass an electric current, and will therefore increase with increase in presence of inorganic dissolved solids such as nitrate, sulphate and phosphate anions and ammonium, sodium, magnesium, calcium, iron and aluminium cations (Spellman, 2008). The slightly higher values obtained during the wet season could be ascribed to the surface run-off of leachates into the ground water. Similar results were reported in groundwater in Bunkpurugu-Yunyo, Ghana, with an average EC of 413.46 μScm^{-1} during the wet season and 356.88 μScm^{-1} during the dry season (Anim-Gyampo *et al*., 2014).

Total Suspended Solids (TSS) are the suspended particulate material in water. There are no internationally set health or cosmetic standards for TSS in water. However the maximum allowable value by the government of Kenya for domestic water is 30 mgl^{-1} Republic of Kenya (ROK, 2005). The TSS values in the study area were often higher than the maximum allowable and were significantly higher during the wet season and in wells within the large farm size. The higher values during the wet season can be attributed to the increased water flow that may carry more suspended solids. Water high in TSS may also contain high amounts of metals that may have health or safety implications because some metals are preferentially sorbed onto the matrix of suspended material (WHO, 2008). Some water quality monitoring groups such as the Kentucky Pollution Discharge elimination size recommends that TSS levels be less than 35 mgl^{-1} (Fisher, *et al*. 2004). Suspended solids also provide surfaces on which pathogens often adhere to in water (WHO, 2008) and can therefore increase water contamination.

Total Dissolved Solids (TDS) is a measure of all dissolved substances in water, including organic and suspended particles that can pass through a very small filter and inorganic salts mainly calcium, magnesium, potassium, sodium, hydro-carbonates, chlorides and sulphates (WHO, 2008). The TDS values obtained in all the wells did not exceed the recommended maximum limit of drinking water by the WHO (2008) of 1000 mgl^{-1} for drinking water and also by United States EPA drinking water standard of 500 mg/L total dissolved solids (Fisher, *et al*. 2004). Similar seasonal variations were recorded from a study on the quality of drinking water in Ghana, where the TDS of the samples ranged from 34.8 to 502 mgl^{-1} averaging 248.86 during the wet season and ranging from 23.9 to 355 mgl^{-1} with an average of 178.51 mgl^{-1} during the dry season (Anim-Gyampo *et al*., 2014).. Similarly, groundwater assessment in a typical urban settlement in South Nigeria indicated that the water was fit for consumption with TDS values ranging between 74 to 260 mgl^{-1} (Imoisi, *et al*. 2012). Freeze and Chery (1979), classified groundwater on the basis of TDS as fresh water when values range 0-1000 mgl^{-1}. In this study all the groundwater samples analysed had TDS values below 1000 mgl^{-1} baseline for fresh water, hence, according to the classification of groundwater by Freeze and Chery (1979), these wells have fresh water. TDS and EC values are general indicators of the suitability of groundwater for various uses. According to Mazor (1991), potable water can have up to 500 mgl^{-1} of TDS and be slightly saline water which is adequate for drinking while irrigation can have 500 to 1,000 mgl^{-1} TDS. Water that has TDS values greater than 500 mgl^{-1} has an unpleasant taste and may stain objects or precipitate scale.

Turbidity is a relative qualitative measurement of the amount of light that is scattered or absorbed by either organic or inorganic matter or a combination of the two (WHO, 2011). Since turbidity measures the light scattering combined effect of the suspended particles in water samples, it is a simple indicator of water quality and serves as a surrogate for other factors or conditions. It is therefore important in determining the quality of water because pathogenic organisms can hide on the tiny colloidal particles and cause gastroenteritis (USEPA, 1999). High turbidity can therefore be an indicator of higher concentrations of bacteria, nutrient, pesticides or metals. The colloidal materials in turbid water provide adsorption site for chemicals that may be harmful to health or cause undesirable taste or odour in drinking water (WHO, 2011). Metals, semi-volatile organic compounds (SVOCs), petroleum hydrocarbons and polychlorinated biphenyls (PCBs) easily adsorb to suspended solids. The turbidity levels in the groundwater samples were largely higher than the recommended values by WHO (2011) of less than 5 NTU. The groundwater appeared to be slightly more turbid during the dry season than during the wet season. Turbidity could have been as a result of contamination of the shallow and unprotected wells from surface runoff during rains, bringing in suspended matter or solids, silt or clay, organic compounds such as animal dung, plankton and other microscopic organisms or from groundwater flow from other areas. These seasonal differences were also reported in Bunkpurugu-Yunyo, Ghana with turbidity values averaging 8.81 and 13.24NTU during the wet and dry seasons respectively (Anim-Gyampo *et al*. 2014). The highest value of 96 NTU was recorded during the dry season and 73 scored during the wet season which were extremely higher than the recommended maximum value by World Health Organization of 5 NTU. High turbidity values of 34 NTU were also reported by (Adekunle, Adetunji, Gbadebo & Banjoko, 2007), in Abeokuta, Nigeria, while Imoisi *et al*., (2012), recorded low turbidity values range between 1.05 and 1.35NTU. According to WHO, (2011), a properly constructed well should have water with a turbidity of 5 NTUs or less which is acceptable to many consumers although this may vary with localities. At this level of turbidity, suspended solids cannot be seen by the naked eye, a stable drawdown is attained (avoids turbulence); and microbial activity is minimal.

5.5 Conclusion

The groundwater in Ainabkoi can conservatively be categorised as safe for domestic use with regard to physico-chemical parameters. The electrical conductivity and turbidity levels are the basic parameters that should be regularly monitored because of the characteristic relationship between dissolved ions and suspended matter with EC.

5.6 Recommendation

There is need to develop health-based guidelines on possible health effects associated with ingestion of water with levels of TDS, TSS, turbidity and EC. However in order to check overflow into wells, it would be recommended to construct walls around the wells. Further research into building the dataset on the wider water quality status such as bacterial contamination is necessary for sustainability.

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CHAPTER SIX

RELATIONSHIP BETWEEN NITROGEN FERTILIZER APPLICATION AND NITROGEN CONCENTRATION IN GROUNDWATER.

Abstract

Great losses may come from agricultural systems through leaching into groundwater of unutilized nitrogen fertilizer. Ainabkoi sub-county is predominantly agricultural and groundwater from shallow wells are the main source of water for communities. Hence it was deemed paramount to evaluate the relationship between fertilizer input and the groundwater N levels with regard to different farm sizes. Each ward was a homogenous stratum of same size-ranged farms classified as Large, Medium and Small farm sizes in Ainabkoi, Olare and Kaptagat (Kaptagat) wards respectively. Within each ward five farms were purposively selected such that only accessible farms that had access to either a privately owned or communal wells were selected. Wells were sampled weekly from just before planting, during planting and through to two weeks after topdressing and thereafter once a month until after harvesting in 2012 and 2013. Samples were kept frozen prior to analysis of Ammonium–Nitrogen, Nitrate-N Analysis and Nitrite-N at the Kenya Marine Fisheries Research Institute, (KMFRI) laboratories. Fertilizer application recommendation rates were 22 kg N/ha DAP (18%) at planting and 32 kg N/ha CAN (26%) at top dressing. There were no significant differences between the farm sizes in the nitrogen concentrations. The nitrate-N, nitrite-N and ammonium-N concentrations after topdressing did not exceed the recommended limit of 10 mg/l, 3 mg/L and 0.5mg/L respectively. Regression analysis of average fertilizer N at top dressing and nitrate-N concentration showed a positive linear relationship ($Y = 0.0836x - 165.18$ $R^2 = 0.31$ indicating potential water pollution. Regression analysis for NO_2-N and NH_4-N were weak but positive linear relationships. Split N fertilizer application at topdressing and Real-time N determination procedures in groundwater and plant tissue nutrient status may prove resourceful in N fertilizer management.

Keywords: Farm Sizes, Groundwater, Season; Fertilizer Rates.

6.1 Introduction

Throughout history the increase and intensive use of nitrogen-based fertilizers to achieve higher yields or productivity in agricultural systems has been well documented in Japan (Kumazawa, 2002 and Inoue, 2012), in China (Liu, Wu & Zhang, 2005; Ju, Kou, Zhang, & Christie, 2006). USA (Kraft and Stites, 2003), Australia (Keating, *et al*. (1996) and New Zealand (McLay, 2001). When N fertilizer application rates exceed the plant demand and the denitrification capacity of the soil, the nitrogen leaches out into groundwater usually as nitrate-N. Today the focus worldwide is on sustainable agriculture which aims at developing environmentally friendly, ecologically sound and economically profitable agricultural management systems. Arguably one of the most widespread and damaging impacts of over application of nitrogen fertilizers is the degradation of groundwater quality and contamination of drinking water supplies, which can pose immediate risks to human health (Lord and Anthony, 2002 and Schroeder, 2004). It is accepted that the use of fertilizer nitrogen is expanding globally in order to meet the needs for food, fiber, and fuel for a growing world population (Zhang, Tian, Zhang & Li, 1996; Snyder, 2009). Therefore fertilizer N management is paramount in achieving protection of water resources, minimize greenhouse gas emissions, sustaining soil resources and providing a healthy economy. This means that fertilizer management practices must be geared towards achieving high yields and high-quality crops with the efficient use of water, fertilizers, agrochemicals and energy with minimal environmental impact.

One of the major sources of N in groundwater is the nonpoint source from excessive use of nitrogen based fertilizers. In addition other nitrogenous compounds from agricultural and livestock production systems are also major sources of nitrate and nitrite ions in groundwater (Kumazawa, 2002). Great losses often occur in which inputs of nitrogen regularly exceed the amounts removed by plant uptake and harvest. This is because nitrates are soluble, highly mobile and loosely bound therefore leach out of the soil with percolating water making it unavailable for plant uptake. In agricultural systems, nitrogen is one of the most limiting plant nutrients because it is not mineral bound in the rocks from which soil is derived and is removed from the soil by the plants, hence new available N must be supplied from outside the plant-soil systems using inorganic fertilizers, if high yields are to be realised. However many producers tend to apply N fertilizer in excess of the recommended rates. According to Daberkow, Taylor, Gollenhon, & Moravek (2001) the recommended N fertilizer rate is usually based on the amount of N required to meet the expected yield minus the amount of nitrogen in the soil, irrigation water and previous legume crop. The average recommendation can be increased due to lower soil N level or when a farmer has higher expected yields. However, when supplied in excess of plant uptake N fertilizers can result in the pollution of water. Crop producers, therefore, need to match nitrogen applications to crop uptake to minimize nitrate leaching and maximize efficiency. Several authors have reported that the application of natural and commercial fertilizers make agricultural fields the main diffuse sources of nitrate contamination of groundwater (Novotny and Chesters, 1981; Spalding and Exner, 1993; and Hill, 1996). High nitrogen fertilization that exceeds what the plants are able to utilize such as is common in vegetables, corn/maize and cash crops, can be a major cause of excessive nitrate leaching (Ju *et al*., 2006). Manure can also be a significant source of groundwater pollution especially when in combination with high fertilizer nitrogen applications. This has caused shallow groundwater under some farm conditions to contain nitrate in excess of 50 mg/L of NO_3^- (10 mg/l NO_3-N) which is the recommended threshold by WHO for drinking water (World Health Organization (WHO), 2008). In addition, large one-off applications of soluble fertilizer in excess of immediate crop needs can lead to substantial nutrient losses leaching (Crush, Catheart, Singleton, Longhurst, & Bake, 1997). Nitrate contamination of groundwater usually exceeds the standard for drinking water in the regions where N fertilizer application rates are above 500 N ha^{-1} and N use efficiency is less than 40% (Zhang *et al*., 1996).

6.2 N fertilizer consumption in Kenya

Agriculture continues to be a fundamental instrument for sustainable development, poverty reduction and enhanced food security in developing countries. It was a vital development tool for achieving the Millennium Development Goals (MDG), one of which was to halve the share of people suffering from extreme poverty and hunger by 2015 (World Bank, 2008). The rapid population growth has changed the view of Africa from a land-abundant region, where food crop supply could be increased by expansion of land used in agriculture, to increasingly marginal for agriculture and arable land becoming scarce in many African countries (Jayne, Chamberlin & Headey, 2014). This makes the need for intensification of land use through use of productivity enhancing technologies such as fertilizer application critical for achieving food security. Yet, the rate of increase in fertilizer use has been substantially lower in Africa than in Asia and Latin America (Ariga *et al*., 2006). Nitrogen fertilizers have contributed to a 40% increase in per capita food production over the past 50 years, tripling cereal grain production from 631 million tonnes in 1950 to 1,840 million tonnes in 2000 (Mosier, Syers & Freney, 2004).

Fertilizer use in Sub-Saharan countries is generally lower than in other developing regions. However, Kenya has a relatively higher fertilizer use compared with other Sub-Saharan countries. There has been a growing trend in fertilizer use intensity at more than 25 kgs/ha during the 1996-2002 period, and a greater than 30% increase in fertilizer use per cultivated hectare between the 1990-95 and 1996-2002 periods (Ariga, Jayne, & Nyoro, 2006). Kenya has achieved more than a 30% increase in fertilizer use intensity between 1990 and 2002, with a continuous increase in fertilizer consumption/use from an average of approximately 180,000 tons per year in the 1980s, to 250,000 tons per year in the early 1990s, to over 325,000 tons between 1996 and 2003. In 2004/05, Kenyan farmers consumed 351,776 metric tons of fertilizer (Ariga, *et al*. 2006). About 87% of small-scale farmers in the high-potential maize zones of Western Kenya use fertilizer. Those that use fertilizer apply roughly 163 kgs per hectare on maize, higher than mean levels obtained in South and East Asia (Ariga, *et al*. 2006). Moreover, Kenya's growth in fertilizer consumption is a phenomenon covering both food crops (mainly maize and domestic horticulture) as well as export. This increase is attributed to the liberalization of the fertilizer market was liberalized in the early 1990's.

In Kenya the fertilizer dose rates applied on maize fields during the main season has increased from 160 kg/ha (65 kg/acre) in 1997 to 185 kg/ha (75 kg/acre) in 2007 and the intensity of fertilizer application has increased dramatically on the intercropped fields (Ariga, Jayne, Kibaara, & Nyoro, 2008). The general or broad fertilizer application rates for maize in Uasin Gishu county, Kenya is about 128.5-173 kg DAP/ha (52-70 kg DAP/acre) at planting and 143 kg CAN/ha or 227 kg ASN/ha (58 kg of CAN or 92 kg ASN/acre) at top dressing. In this regard it was considered important to evaluate any plausible relationships between the amount of N fertilizer application and the groundwater nitrate-N, nitrite-N and Ammonium-N concentrations.

6.3 Agricultural farming and nitrogen contamination of groundwater.

Farm nutrient management has always been a critical component of the economic and social sustainability of agriculture. Sustainable agricultural intensification has been and is still the major factor in achieving food security. It is notable that fertilizer consumption in Sub-Saharan Africa (SSA) has stagnated at only 8-12 kg/ha/yr and by 2010 none of the SSA countries had reached the 50kg/ha/year target set at the Abuja fertilizer summit of 2006. This low demand for fertilizers by farmers is due to inaccessibility of fertilizer, high costs of fertilizers and poor access to credit for farmers. According to Sommer *et al* (2013), the often too low benefit-cost ratio, coupled with the relatively high fertilizer prices, the low market value of maize, and the high year to year variability of the agronomic efficiency of the fertilizer applied significantly discourages the use of fertilizers especially by small scale farmers. In addition the fertilizer recommendations often ignore the differences between soils and the small scale farmer resources.

Nitrate contamination of groundwater has been shown to be a function of present and past land use practices. A common assumption is that groundwater is at risk of contamination due to land use or management activity on the overlying (Ledgard, Clarke, Sprosen, Brier, & Nemaia, 1996). Lee, (2003) reported low and weak correlation results between NO_3–N concentration and land uses. It is the farmers' target to achieve high-yielding and high-quality crop production as well as efficient use of water, agrochemicals and energy with minimal environmental impacts.

Nitrate contamination of groundwater has been closely related to the corresponding agricultural management practices (Keeney and Follet, 1991; Spalding and Exner, 1993; Hill, 1996; Townsend, Sleezer, & Macko, 1996; Rass, Rithie, Peterson, Loudn, & Martin, 1999). In Shandong Province, North china, agricultural over-fertilization is common (Ju *et al*., 2006). Studies on the annual nitrogen balance and groundwater NO_3-N concentration in three major cropping systems namely, greenhouse vegetable, wheat-maize and apple orchard, showed that there were significant differences among the systems in the annual fertilizer N inputs with the vegetable greenhouse system having the highest fertilizer input amount. Although the annual fertilizer N input in all three intensive cropping systems were higher than the recommended rates, the crop yields in the three cropping systems did not increase significantly with increasing N application rates. The soil N surpluses were significantly correlated with N application rates which were a recipe for leaching losses, ammonia volatilization, denitrification or storage in various soil fractions, especially in greenhouses producing vegetable. Nitrate accumulation in the 0-90cm soil profile showed high variance among individual fields in each cropping system with vegetable greenhouse cropping system having the highest accumulation. Vegetable crops have shallow root systems and are sensitive to water and nutrient supply; therefore farmers readily apply large amounts of fertilizer and frequently irrigate the fields, leading to leaching of NO_3-N out of the root zone and into the subsoil or shallow groundwater. Some studies have reported amounts of N leached into groundwater from vegetable fields in the range of 200-500 kg N ha^{-1} (Kraft and Stites, 2003 & Zhu, Zhang, Zhao, Cheng, & Li. 2005). China has had a strongly increasing trend towards the growth of crops of high economic value mainly vegetables and fruits over the last twenty years (Ju *et al* 2006). The annual fertilizer application has risen gradually from 2.4 N kg/ha in the 1950s' through to 211 N kg/ha in the 1990s' in order to meet increasing food requirement by an ever increasing population and reducing arable land (Zhang *et al*., 1996). A study in Shandong province found that the average N fertilizer rate was 280 kg N ha^{-1} in 952 winter wheat fields, 280 kg N ha^{-1} in 896 summer maize fields, 1700 kg N ha^{-1} per crop in 147 protected vegetable fields (plastic film greenhouses) and 848 kg N ha^{-1} in 217 apple orchards (Ma & Qian, 1987). The increased N fertilizer consumption is the main cause of increase in nitrate content in groundwater.

Research indicates maize (corn) production as a significant contributor to nitrate in groundwater. In a study to evaluate the potential risk of agricultural land use on nitrate contamination in the city of Waterloo, corn systems had a total loading of 127.6 kg/ha/year which was categorised as a high risk (100-150 kg/ha/year individual land use application rates (Kerr-Upal, van Seters, Whitehead, Price, & Stone, 1999). Nitrate accumulation in the soil profile showed high variation among individual fields in each cropping system such that nitrate accumulation in the 0-90 cm and 90-180 cm soil layer was highest in vegetable greenhouses, followed by apple orchard field, maize fields and least in wheat fields. These large amounts of nitrate accumulation especially in the 90-180 cm soil layer point to substantial leaching of nitrate in the vegetable greenhouses. The annual N applied in fertilizers and organic manures and the total N inputs in the greenhouse vegetable systems were all significantly higher than (more than two times) in the wheat-maize and apple orchards.

In Japan, nitrate-nitrogen (NO_3-N) concentrations in groundwater have increased steadily due to the development of intensive agriculture (Kumazawa, 2002). In some areas the NO_3-N have reached or even exceeded the unacceptable level for drinking water with some wells containing 100 mg/L. NO_3-N pollution of groundwater has been widely observed in regions of vegetable growing, livestock farming and orchards. In the east district of Kagamighara city, the NO_3-N levels in groundwater have increased over the years due to intensive cultivation of carrots. This was resolved by decreasing the nitrogen fertilizer remarkably from 266 kg ha^{-1} to 153 kg ha^{-1}, which corresponded with a steady decline in groundwater NO_3-N. The nitrate pollution problem of groundwater wells in small scale farming systems of the Niayes region of Senegal was assessed and explained in terms of well characteristics and land use properties (Sall and Vanclooster, 2009). The study showed that the rate of application of fertilizer was highly variable as the farmers sought to enhance their performance by the intensification of the small fields and subsequently nitrate threshold levels were exceeded, especially in areas under vegetable production.

McLay, (2001) carried out an investigative study to determine whether nitrate-N (NO_3-N) concentrations of shallow groundwater (<30m from the land surface) in a region of intensive agriculture of Waikato in New Zealand could be predicted on the basis of land use information. The results showed that there was considerable variation in groundwater NO_3-N concentration and it increased as the proportion of area used for dairy farming increased. This suggests that that non-point source groundwater NO_3-N contamination in the region is a reflection of the localised intensive agricultural practices. Further to this, market gardening had significantly larger NO_3-N concentrations in underlying groundwater than drystock/sheep grazing which had less intensive farming practices than the other land uses. While it is difficult to distinguish between nitrate contributions from variable sources, evidence from studies on groundwater quality indicates that animal wastes from active or abandoned feed lots may be a significant source of nitrates to groundwater (Kirder, 1987).

In Central Pennsylvania, the nitrate-nitrogen concentration in leachate below a corn field supplied with the economic optimum N fertilizer rate of about 180 kg/Ha was generally in the range of 15-20 mg/l leading to the conclusion that this was probably because corn is an inefficient absorber of nitrate from the soil (Fox, 2001). Baker and Laflen (1983) noted that a linear relationship between nitrate-N losses below the root zone and nitrogen application rates occurs at annual rates above 50 kg/ha. This brings the conclusion that the major factors contributing to groundwater nitrate contamination on a regional scale are the application of nitrogen-based fertilizers to agricultural land, and the potential of soils to leach nitrate to groundwater.

Today, fertilizer use is directly responsible for most of the world’s food production and will be a more significant factor in future yield increases. A major drawback of fertilizer use, particularly in the case of N, is the excessive use beyond the crops needs which leads to negative implications for the environment, especially groundwater pollution (Li, 2005). Groundwater contamination by nitrates is a worldwide problem mainly related to the excessive use of fertilizers in intensive agriculture (WHO, 2003). The loss of N from the farmer's field, regardless of the quantity used, is a potential contributor to environmental pollution (Ersahin 2001; Jalali, 2005). It is from soil that water picks up the majority of the agricultural pollutants and therefore it is here that attention needs to be focused, if pollution processes are to be understood at source. Researchers have identified several factors affecting nitrate groundwater contamination, such as fertilizer levels and build-up of soil organic matter, which can result in a large mineral nitrogen pool and thus in a higher risk of nitrate leaching (Korsaeth and Eltun, 2000; Sieling and Kage, 2006). The application of natural and commercial fertilizers combined with livestock wastes, septic tank and atmospheric inputs make agricultural fields the main diffuse sources of nitrate contamination of groundwater, (Spalding and Exner, 1993 and Hill, 1996).

Great losses may come from agricultural systems in which inputs of nitrogen regularly exceed the amounts removed by plant uptake and harvest. Heavy nitrogen fertilization, especially common in vegetables, corn and other cash crops, exceeds what the plants are able to utilize and can be a major cause of excessive nitrate leaching (Ju *et al*., 2006). The most severely contaminated groundwaters that are reported in agricultural areas are often associated with vegetable production, orchards and floriculture land uses due to the greater amount of N fertiliser used than other agricultural land uses, and also with land uses where wastes are frequently applied to soils. Using ^{15}N tracer technique, Townsend *et al*. (1996) found that high nitrate-N concentrations ranging between 12-60mg N L^{-1} in groundwater in the southwest of Kansas resulted from high application rates of N fertilizer to sugar beet fields. Similarly, Thornburn *et al*. (2003) found that up to 21% of the wells in the intensive agricultural areas of northeast Australia were contaminated with nitrate-N which was traced back to the N fertilizer applied by using ^{15}N. In china there has been a strongly increasing trend towards the growth of crops of high economic value such as vegetables and fruit trees over the last 20 years. In order to maximize yields farmers usually apply large amounts of N fertilizers and organic manures, with some applications as high as 1700 kg N ha-1 per crop in vegetable fields (Ma, 1999). A survey of groundwater nitrate-N concentrations in the Chinese provinces of Beijing, Tianjin, Hebei, Shandong and Shanxi showed that about 45% of 600 groundwater samples exceeded the WHO and European limit for nitrate in drinking water of 11.3 mg NO_3-N (50 mg NO_3^{-1} L^{-1}), with the highest nitrate-N concentration reaching 113 mg L^{-1} (Zhang, Wu, Ji, & Kolbe, 2004). The proportion of samples above the limit was much higher in intensive vegetable farming regions than in other cropping systems. A study in Shandong province found that the average N fertilizer rate was 280 kg N ha^{-1} in winter wheat and summer maize fields, 1700 kg N ha^{-1} per crop in 147 protected vegetable fields (plastic film greenhouses) and 848 kg N ha^{-1} in 217 apple orchards (Ma, 1999). In a review by Baker and Laflen (1983), a linear relationship between nitrate-N losses below the root zone and nitrogen application rates was found to occur at annual rates above 50 kilograms per hectare.

Timing of nitrogen inputs is also critical. The concentration of nitrates in the drainage water depends on the balance and timing of nitrogen inputs and outputs to and from the soil and on the rates of nitrification and removal of nitrates from the soil solution (Weil & Brady, 2014). Large one-off applications of soluble fertilizer in excess of immediate crop needs can lead to substantial nutrient losses through leaching (Crush *et al* 1997). The poor development of rational fertilizer recommendations with rapidly expanding production systems results in farmers applying large amounts of N fertilizers and organic manures in order to ensure high yields. Therefore excessive N fertilizer application is very common and may cause groundwater pollution. Fertilizer dose rates applied on maize fields in Kenya during the main season has increased from 65 kg/acre in 1997 to 75 kg/acre in 2007 (Ariga *et al*., 2008). The intensity of fertilizer application has increased dramatically on the intercropped fields

Notably the, the causal relationship between nitrogen fertiliser and pollution is obscure and uncertain because of the unknown processes of transportation from non-point source to specific monitoring points as well as uncertain (Inoue, 2012). This means that most changes occurring on farmland surface cannot be directly related to the concurrent status of groundwater, but can be related to past changes on farmland, (Inoue, 2012) because it can take a few years to a few decades for chemicals to reach the nearest groundwater layer.

6.4 Methodology

6.4.1 Farm preparation and fertilization

A questionnaire was used to collect information about farm operations from land preparations to planting time, timing of fertilizer application, types of fertilizers used, and fertilizer application rates. The questionnaires were administered at the beginning of the season and during the season.

6.4.2 Groundwater Sampling and Nutrient Analysis

Groundwater sampling was carried out as described in Chapter 3. Samples were be moved to the laboratory and kept frozen prior to analysis. Ammonium-N, Nitrate-N, and Nitrite-N analysis were quantitatively determined as described in Chapter 3.

6.4.3 Data Analysis

The data collected was subjected to the analysis of variance using SAS statistical package (SAS Version 6.12, 1997) and mean values were compared by least significant difference (LSD) at the 5% level. Analysis of Variance was carried out between the total N fertilizer applied annually, at planting and at topdressing in the different farm sizes and subsequent mean separation done. The results were presented in table forms and graphs. The groundwater N concentration at planting and topdressing in the different farm sizes was presented graphically. Regression analysis was done to determine the relationship between fertilizer N applied at top-dressing and concentrations of nitrate-N, nitrite-N and ammonium-N and presented graphically.

6.5 Results

Maize was the most commonly cultivated crop in Ainabkoi Sub-County and was therefore predominantly the crop fertilized with inorganic nitrogen. It was characteristic for farms to have home gardens for family vegetable needs. The planting season begins in the months of March-April with the exact timing determined by the onset of the long rains season. Field preparation includes several ploughings, harrowing and basal fertilizer application as broadcast. Farmers normally broadcast Di-ammonium Phosphate (DAP 18%) fertilizer at the rate of one 50 kg DAP bag /Acre, which is equivalent to 22 kg N/ha (9 kg N/Acre) during the last field harrowing procedure. Maize planting was done between March-April in 2012 and 2013 at the onset of the long rains. Top dressing was done when the crop was knee high or 45-60cm high, with Calcium Ammonium Nitrate (CAN 26%) at the rate of one 50 kg CAN bag /Acre which translates to 32 kg N/ha (13 kg N/Acre) as recommended by the Agriculture Extension officers. Although these were the general recommendations from the Agricultural Extension services to all famers, it was noted that some farmers tended to increase the recommended rate by 1½ to 2 times with the aim of increasing crop yields. Therefore the range of fertilizer application was 22-44 kg N/ha at planting and ranged from 32-48 Kg N/ha at topdressing in both 2012 and 2013. The average amount of N fertilizer applied as total N (kg N) in each farm system at planting and at top-dressing during the study period of 2012-2013 is shown in Table 5.

Analysis of variance (ANOVA) was done to determine if there were any significant differences in fertilizer N application between the farm sizes at both planting and at top-dressing during the maize production season. Results showed that there were highly significant differences between the farm sizes on the total fertilizer N applied at planting and at top-dressing in 2012 and 2013 (Table 5). Significantly more N fertilizer was applied in the large mixed farm sizes than in the medium and the least was applied to the small farm sizes. This significant difference is attributed to the larger area under maize production in the large farm sizes compared with the other two farm sizes. Most of the farmers adhere to the recommended N fertilizer application rate, with the limiting factor being the high cost of fertilizer. In general, the application rate ranged from 22-44 kg N/ha at planting in 2012 and 2013. It was however noted from interview responses, that farmers in the medium sized farms often applied more than the recommended fertilizer rates in order to boost the yields. These farmers had more disposable income and could afford to apply even up to twice the recommended rate hence they applied 30-45 Kg N /ha (or 75-100 kg of DAP/Acre). The small mixed farms generally adhered to the recommended rate of fertilizer application. It was however noted from interview responses, that farmers in the medium sized farms often applied more than the recommended fertilizer rates in order to boost the yields. These farmers had more disposable income and could afford to apply even up to twice the recommended rate hence they applied 30-45 Kg N /ha (or 75-100 kg of DAP/Acre). The small mixed farms generally adhered to the recommended rate of fertilizer application.

Table 5: The average total amount of inorganic nitrogen fertilizer (kg N) applied in the different farm sizes at planting and top-dressing in 2012 and 2013.

		Average Total N Fertilizer (kg N)/Year			
		2012		2013	
Farm System	Average Total Maize Acreage	Planting	Top-dressing	Planting	Top-Dressing
Large Mixed	34.2[†]a	276a	598a	303a	656.5a
Medium Mixed	10.7b	144.9b	176.7b	175.5b	213.2b
Small Mixed	3.5c	31.5c	45.5c	31.5c	45.5c
Significance (P≤0.05)	***	***	***	***	***
CV(%)		65.4	52.7	74.9	67.3
LSD	2.28	34.3	46.97	44.7	67.4

[†] Means followed by the same superscript within a columns are not significantly different at 5% significance level according to Fishers' protected LSD test.

*** Significant at P≤0.001%

Top-dressing of maize was done in mid-July when the plants were about 45-60 cm high, with Calcium Ammonium Nitrate (CAN 26%) at the recommended rate of 32 Kg N/ha (125 Kg CAN/ha or 50 kg CAN/acre). The average total amount of N fertilizer applied during top dressing in the large farm sizes ranged from 390 N kg to 1053 N kg in 2012 and 2013 which averaged to 598 N kg in 2012 and 657 N kg in 2013 (Table 6).

The average total amount of N fertilizer applied during top dressing in the medium farm sizes ranged from 39 N kg to 487 N kg in 2012 and 2013 which averaged to 177 N kg in 2012 and 213 N kg in 2013. The small mixed farms generally kept to the recommended rate of fertilizer application rates at top dressing with total amounts ranging from 32-48 Kg N in both 2012 and 2013 an average of 45.5 N Kg.

Table 6: The average total amount of inorganic nitrogen fertilizer (kg N) applied in all the studied farm sizes in 2012 and 2013.

	Average Annual Total N Fertilizer (Kg)					
	Farm sizes					
Year	Large	Medium	Small	Significance (P<0.05)	LSD	CV (%)
2012	874[†]a	321.7b	77.0c	***	80.18	56.63
2013	959.5a	388.7b	77.0c	***	110.29	69.05

[†]Means followed by the same superscript within a row are not significantly different at 5% significance level according to Fishers protected LSD test.
*** Significant at $P \leq 0.001$

The groundwater nitrogen ions concentrations (NH_4-N, NO_3-N and NO_2-N) were determined at the time of planting in the months of March and April and at the time of topdressing in the months of June-August 2012 and 2013 in the different farm sizes. Analysis of variance (ANOVA) between the nitrogen ion concentrations in groundwater and the time of fertilizer N application, at planting and at topdressing was determined. There were no significant differences between the farm sizes when the

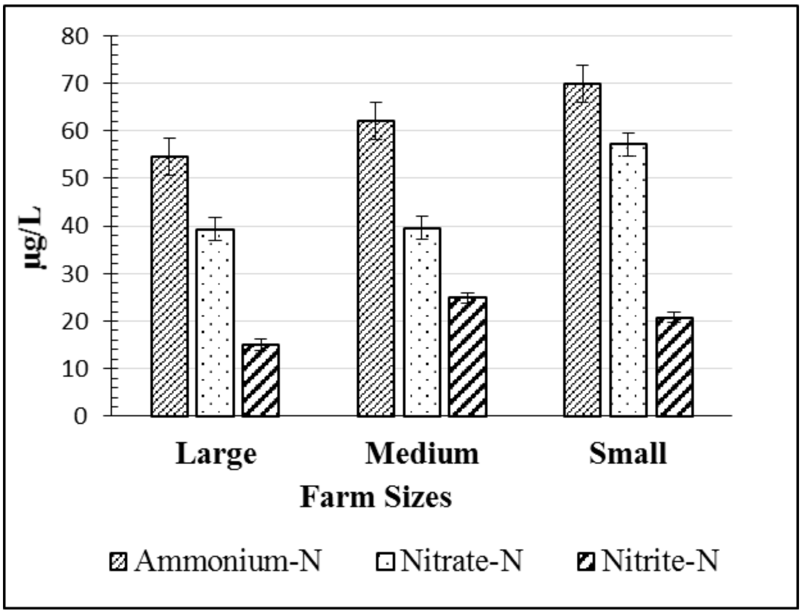

Figure 6: Average Groundwater concentration of Ammonium-N, nitrate-N and nitrite-N at planting time (March and April) in different farm sizes in 2012 and 2013.

NH_4-N, NO_3-N and NO_2-N groundwater concentrations were compared at planting (Figure 6). The small farm sizes generally seemed to have higher Ammonium and nitrate concentrations than the other farm sizes. The highest levels of ammonium, nitrate and nitrite at planting were 183.92, 116.66 and 64.65 respectively.

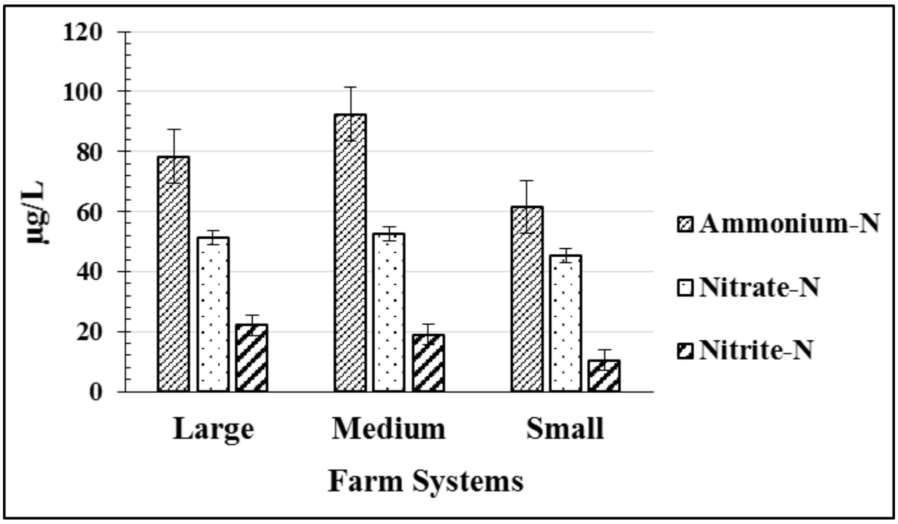

Figure 7: Averaged Groundwater concentration of Ammonium-N, nitrate-N and nitrite-N at top-dressing (June, July and August) in different farm sizes in 2012 and 2013

At top-dressing, the levels of ammonium-N, nitrate-N and nitrite-N were not significantly different between the different farm sizes. Figure 7 shows the concentrations of the different ions of nitrogen (NO_2-N, NO_3-N and NH_4-N) in groundwater at the time of topdressing (June-July-August) in the different farm sizes.in 2012 and 2013. Ammonium-N was generally the nutrient in highest levels in the groundwater followed by nitrate-N and nitrites.

A regression analysis at top dressing with CAN fertilizer, was done to determine if there was any relationship between the timing of application of fertilizer nitrogen and the loading of N in groundwater.

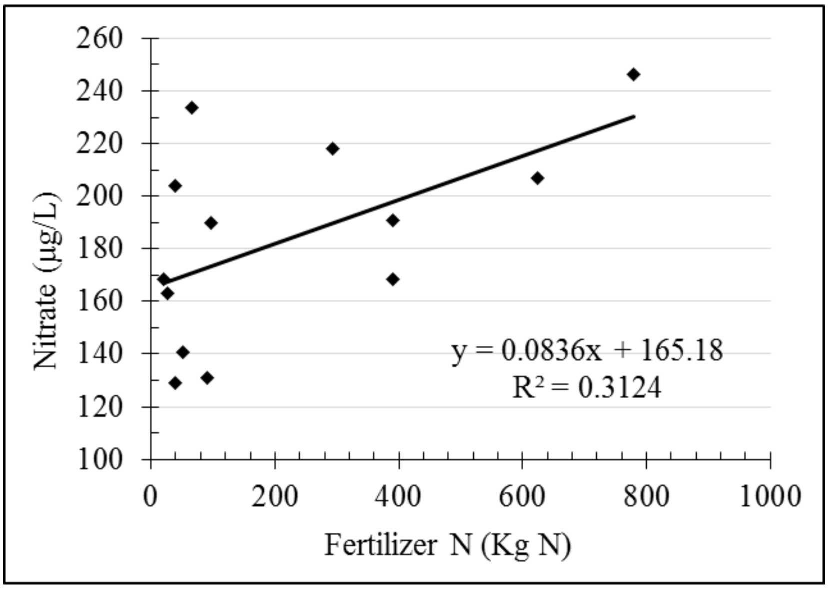

Figure 8: Relationship between Nitrate Concentration in Groundwater and Fertilizer N at Top Dressing in July 2012.

The regression analysis of fertilizer N amount at top dressing and the groundwater nitrate concentration showed a positive linear relationship ($Y = 0.0836x – 165.18 \quad R^2 = 0.31$), indicating the potential impact of nitrogen load from fertilizer N on NO_3-N in groundwater (Figure 8).

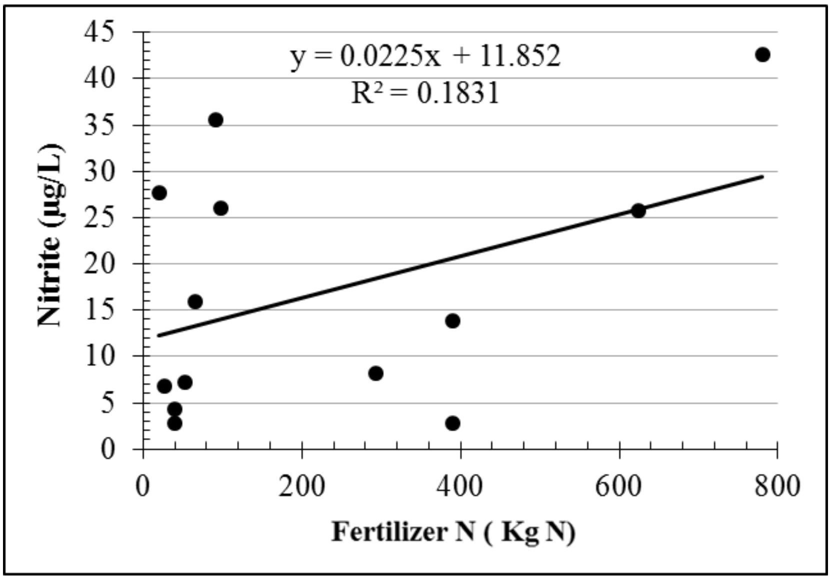

Figure 9: Relationship between nitrite Concentration in Groundwater and Fertilizer N at Top Dressing in July 2012

Similarly regression analysis for NO_2-N and NH_4-N also returned positive linear relationships although the relationships were weak, as shown in Figures 9 and 10 respectively.

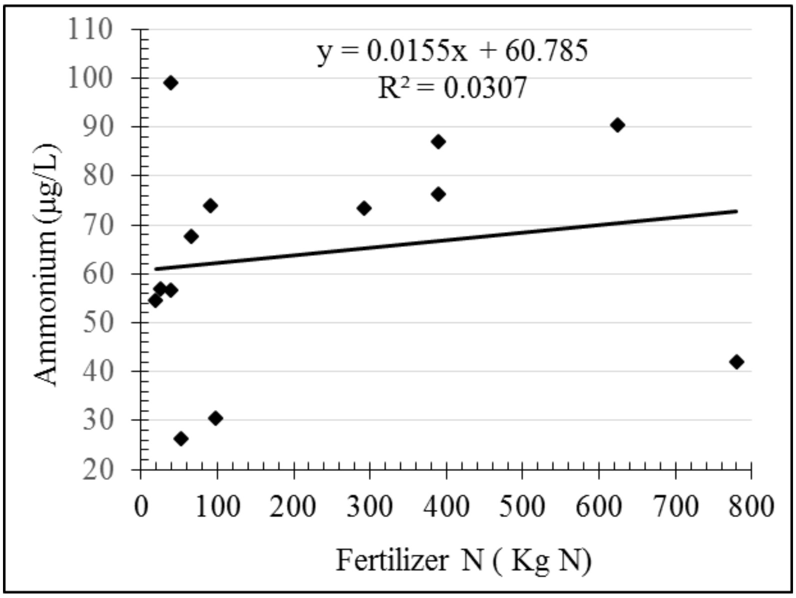

Figure 10: Relationship between Ammonium concentration in groundwater and fertilizer N at top dressing in July 2012.

Regression analysis did not show a significant positive regression between the N kg/ha applied at planting time and the concentration of N-compounds in groundwater in all the three farm sizes. The nitrate-N concentration in groundwater in the different farm sizes ranged from a minimum of 0.129 mg/L to a maximum of 0.246 mg/L. The Nitrite concentrations in groundwater ranged from 2.75 µg/L to 42.55 µg/L (0.003 mg /L to 0.043

mg/L) while ammonium concentration ranged from 26.43µg/L to 90 µg/L (0.026mg/L to 0.09 mg/L)

6.6 Discussion

The groundwater nitrate-N, nitrite-N and ammonium-N concentrations after topdressing of the fields did not exceed the recommended maximum allowable limit of 10 mg/l, 3 mg/L and 500µg/L (ROK, 2006) respectively. Maize production is the most important agronomic crop in Uasin Gishu, Kenya. The Agricultural Extension officers and Kenya Seed Company recommend fertilizer application rates for the region of 124 kg DAP/ha (22 kg N/ha) at planting and 124-185 kg/ha CAN (32-48 kg N/ha) at topdressing. However, some farmers apply one and a half to twice the recommended rate of DAP and CAN. This results in the application of 185-247 Kg DAP/ha (33.36-44.48kg N/ha) at planting and 185 kg CAN/ha (32.12 kg N/ha) at topdressing. This higher application rate is driven by farmer accessibility to higher disposable income that is common with the medium and the large farm sizes. At the recommended rate of N fertilizer application at planting and topdressing, the average application rate of N fertilizer during the production season was within the range of 54-92 Kg N/ha. However the total N applied during the maize production season varied significantly with the farm sizes. This is because the area under crop production varied in the different farms systems such that the large farm sizes had crop acreage ranging from 8-21 ha, the medium sized from 1.2-10.1 ha and the small farm sizes ranging from 0.6-2.8 ha during the study period of 2012 and 2013. These N-fertilizer rates are much lower than those reported in several parts of the world’s farm production areas. In several regions of China the optimal fertilizer rates for maize production ranged 150-250 kg N ha^{-1} (Zhang *et al*., 1996).

The fertilizer application rate in Ainabkoi county closely compares with that of sweet corn production in the state of Illinois, United States (US) which ranges from 84-336 kg N/ha depending on the soil fertility (Mwanza *et al*. 2011) and in Lithuania where the N fertilization rate for cereals and annual grasses was 90 and 180 kg/ha. The practice of farmers exceeding recommended fertilizer application seems to be a common practice with farmers in other parts of the world. The fertilizer recommendation rate for sweet corn was 168 kg N/ha and for potato was 258 kg N/ha in Wisconsin, USA, but farmers generally apply 250 kg N /ha and 297-357 kg N/ha for sweet corn and potato respectively (Kraft and Stites, 2003). In view of the forgoing, the essential goal of N fertilizer application is to achieve high grain yields and completely utilize the applied soil N in order to minimize N surpluses that increase the potential for groundwater contamination through possible leaching into groundwater. The poor development of rational fertilizer recommendations with rapidly expanding production systems and farmers better endowed financially has resulted in farmers in the study area of Ainabkoi applying larger amounts of N fertilizers and organic manures in order to ensure higher yields. Reports have shown that between 1997 and 2007 fertilizer consumption in the area during the main season has increased by 65% (Ariga *et al*., 2008). This increase in fertilizer use has correlated with an increase in maize yields even though the total area under maize has remained largely constant over decades. At the time of the study the rates had increase to 92 kg N /ha and the farmers express a desire to have more fertile fields through application of more fertilizer.

Research has linked the evolution of increasing nitrates in groundwater to increasing fertilizer use in many parts of the agricultural world such as in Central Lithuania (Adomaitis, 2008); Vietnam (Kurosawa, 2008), China (Ju *et al*., 2006), Australia (Thorburn, 2003); USA (Hallberg *et al*., 1989 and Kraft and Stites, 2003), Japan (Kumazawa, 2002). Several research outputs have also confirmed that groundwater N pollution generally increases with the amount of N-fertilizer application (Zhang *et al*., 1996; Owens *et al*. 1999; Kuo *et al*., 2001; Thorburn, 2003; & Liu *et al*., 2005). In Central Lithuania, the nitrate concentration in lysimeter water depended mainly on the nitrate fertilizers application rate (Adomaitis, 2008). On average, fertilization of agricultural crops with 112 kg N/Ha increased nitrate concentration in lysimeter water at 40-cm depth by 67.1 mg /L to 112.1 mg /L and an N-fertilization rate of 224 kg N /ha increased nitrate concentrations by 139.1 mg/L to 187.2 mg/L. In contrast, the results from this study did not indicate such significant increases in N concentration in groundwater increase with increase in fertilizer nitrogen application which could be due to the fact that fertilizer input levels of range of 54-92 Kg N/ha are still low in comparison with an N application range of 112 kg N/Ha -224 kg N/ha. It is therefore reasonable to expect that a similar phenomenon may occur in Ainabkoi, which is a predominantly an agricultural area. This is because fertilizer marketing costs have declined substantially in Kenya since the liberalization of the fertilizer market in the early 1990's (Ariga *et al*. 2008). This has led to increased rural stockists and hence reduction in the distance between farms and fertilizer stockists. This has led and will continue to contribute to growth in fertilizer use. It is documented that nitrate concentration in groundwater is normally low, and can reach high levels due to agricultural runoff and infiltration (WHO 2008).

With the fore knowledge of increased fertilizer rates for more yields, it can be deduced that with increased population, farmers will increase the field outputs by improving on their fertilizer application rates and there is also a change to the more profitable per unit area intensive horticultural production. This potential exists in Ainabkoi as farmers chose to shift to horticultural production and increase in N fertilizer application in cereal production. Several studies have reported that the rapid increase in nitrogen fertilizer application in order to achieve higher yields and profits in intensive farming is the main cause of increased nitrate concentration in groundwater such as in Japan (Kumazawa, 2002), in Platte Valley of Nebraska, USA (Daberkow, *et al*., 2001) and in Northern China. (Zhang, *et al*., (1996). Japan has recorded a steady increase in NO_3-N in groundwater due to the development of intensive agriculture, with some well nitrate concentrations reaching 100 mg l^{-1}.

Timing of nitrogen inputs in agricultural land is critical because the concentration of nitrogen in the groundwater depends on the balance and timing of nitrogen inputs as outputs to and from the soil and the rates of nitrification. At planting time (March-April), and at top dressing time (July-August) when the farmers in the study area apply DAP and CAN fertilizer respectively, high rainfall conditions are prevalent and this increases the mobility of the highly soluble NO_3^- and NO_2^- anions down the soil profile and are therefore easily transported with filtrating water fronts into groundwater. The NH_4^+ that is relatively immobile but is also carried down the soil profile. The concentration of NH_4-N concentration levels in the groundwater seemed to be higher compared with the levels of NO_3-N, and NO_2-N. This has also been reported in several studies (Kurosawa, 2008). In farming villages in northern Vietnam (2002-2006), 380-420 Kg N/ha of inorganic N fertilizer application resulted in high NH_4-N concentration in drinking water and low NO_3-N concentrations (Kurosawa, 2008). These results from this study showed that although the N concentration in groundwater did not exceed the recommended maximum concentration, but the application of fertilizer nitrogen has the potential to pollute groundwater systems.

The potential impact of fertilizer nitrogen application on the concentration of nitrate in groundwater brings into perspective the importance of timing and splitting of N fertilizer application. Timing of nitrogen inputs is critical because the concentration of nitrates in the drainage water depends on the balance and timing of nitrogen inputs and outputs to and from the soil and on the rates of nitrification and removal of nitrates from the soil solution (Weil and Brady, 2016). Farmers in Ainabkoi sub-county normally do a once application top dress during the peak rainfall period of the production season, which is usually in July. This exposes the nutrients to runoff and leaching especially nitrogen due to its high solubility. This is a common practice in rain fed agriculture in several parts of the country such as Nandi South District tea plantations which is done during the rainy seasons in May and October and causes river eutrophication and nitrate pollution (Maghanga, Kituyi, Kisinyo, & Ng'etich, 2013). In the city of Kagamigahara in Japan the N fertilizer input in carrot production reduced from 266 kg /ha to 153 kg /ha and helped to reduce the nitrate concentration in groundwater, whereby the main source of nitrate pollution in groundwater was identified as carrot cultivation. It is therefore important to note that reduction of fertilizer may reduce the N concentration in groundwater. It is important to note that reduction of fertilizer may reduce the N concentration in groundwater.

Without any well thought out policies to control groundwater pollution, the nitrate levels in the water can therefore be expected to steadily increase as it has happened in other parts of the world. Currently the benefit–cost is too low to encourage farmers to apply more fertilizers because of the relatively high fertilizer price at farm gate, the low market price of food crops like maize and the high year-to-year variability of the agronomic efficiency of fertilizer applied. Lack of enabling policies for the private industry, poor infrastructure (access to fertilizer), and low demand by fertilizer consumers, especially in rural areas of Sub-Saharan Africa (SSA), are three major causes of low consumption (Ariga *et al*., 2006). Notably maize yields have increased progressively over the years (1997-2007) even though the total area under maize has remained largely constant which is related with the rise in fertilizer use. In concurrence with the results in this research which showed a weak positive correlation the concentration of NH_4-N and NO_2-N in lysimeter water was minimal and the influence of mineral fertilizers negligible. Inoue, (2012) reported a linear impact of nitrogen laod from fertilizer on groundwater NO_3-N over a four year period (2000-2004) and attributed the large differential over the regression line to non-fertiliser sources of nitrogen, such as the livestock industry and human sewage. In this research this can be attributed to the same sources of livestock waste, pit latrines and decomposing plant organic matter in the vicinity of the wells.

One driver for over fertilization is the poor development of rational fertilizer recommendations with rapidly expanding production systems results in farmers applying large amounts of N fertilizers and organic manures in order to ensure high yields. If, as it has been discussed that in order for Africa to meet its food need, South-Sahara African

(SSA) countries must increase their consumption of fertilizers which has stagnated at 8-12 kg/ha/yr for the last twelve years. In 2010, none of the SSA countries reached the 50 kg/ha/yr target set by the Abuja Fertilizer Summit in 2006 to be attained by (Sommer, 2013). An overestimation of the risk of failure to break even when applying fertilizer by farmers adds to the dilemma. Furthermore, fertilizer recommendations developed in the past often ignore differences between soils and are highly incompatible with smallholders' resources. Notably the, the causal relationship between nitrogen fertiliser and pollution is obscure and uncertain because of the unknown processes of transportation from non-point source to specific monitoring points as well as uncertain (Inoue, 2012). This means that most changes occurring on farmland surface cannot be directly related to the concurrent status of groundwater, but that can be related to past changes on farmland. Ammonium in the soil is transformed in the process of nitrification into nitrites and rapidly into nitrates by soil bacteria. Nitrate is highly soluble and easily leaches down the soil profile into groundwater. However, the low concentrations of nitrites could be due to the fact that nitrification of ammonium to nitrites and nitrates is rapid process.

Therefore, although the farmers in Ainabkoi sub-county occassionaly increase the fertilizer application rates to booster yields, it is controlled to avoid compromising the yields and therefore the amount that would leach into the groundwater systems is controlled.

6.7 Conclusion

The results from this research showed that none of the wells in Ainabkoi have NH_4-N, NO_3-N and NO_2-N concentration in groundwater greater than the Kenya Maximum allowable limits for drinking water of 0.5 mg/l, 10 mg/L and 3 mg/l respectively. However the variability in N concentrations indicates these wells are vulnerable to impacts of fertilizer N rates and farm sizes. The NH_4-N concentration in groundwater was in the range of 3.25-382 µg/l and 1.85-542.38 µg/l in 2012 and 2013 respectively. The highest NH_4-N concentration in groundwater was in wells in the large farm sizes with an average of 464 µg/l in 2012 and 2013. Ammonium is short-lived in most soils and is rapidly transformed to nitrites and nitrates. The NO_3-N concentration in groundwater was in the range of 1.61-246.18 µg/l and 2.56-177.56 µg/l in 2012 and 2013 respectively. The groundwater NO_3-N concentration was highest in the large farm sizes with an average of 211.87 µg/l in 2012 and 2013. The concentration of NO_2-N was generally low in all the farms except for an unexpected spike in the medium sized farm probably due to the rapid nitrification of ammonium to nitrites and then nitrates. The NO_2-N concentration in groundwater was in the range of 0.19-119.77 µg/l and 0.46-80.6 µg/l in 2012 and 2013 respectively.

It was apparently realized that farmers exhibited a tendency to apply N fertilizer in excess of the recommended N fertilizer rate in the large and medium farm sizes. The recommended fertilizer N rate was 53 kg N/Ha, but farmers increased the rate to 93 kg N/Ha which was dependent on farmer income. However the results indicate that changes in N fertilizer application rate can result in relative modest changes in groundwater N concentration, although the N concentration in groundwater did not exceed the recommended maximum concentration. Therefore the application of fertilizer nitrogen has the potential to pollute groundwater systems at different times of application. The results from this research showed that there exists a significant regression between the timing of fertilizer application and the groundwater N concentration, hence the N pollution in an area is closely related to the amount of fertilizer applied in the area. With increasing population and reduction of arable land to urban development it is inevitable that the N fertilizer rates will go up if regional food security is to be realised.

6.8 Recommendation

Agriculture must co-exist with environmental concerns hence there is need to quantify the leaching losses of N from a range of fertiliser practices over several seasons in order to develop environmentally and economical fertilizer application rates. The absence of any significant contamination of groundwater in this study does not preclude it occurring in the future. There is also a gradual shift to more intensive agriculture with the production of cut-flowers and vegetables for local and export markets, along with increased N-fertilizer application rates. Since these are known prerequisite conditions for groundwater pollution, farmers should be trained on the Best Management Practices (BMP) for N nutrient proposed by Goulding, (2000). This includes aspects such as timing fertilizer N application to when the crop is growing rapidly and soil analyses to determine the soil N content and hence the N application rate. Therefore there is need to advocated for fertilizer management strategies, such as split N fertilizer application in order to synchronize N supply with crop seasonal demand. There is need to develop procedures for determining real-time nitrates-N concentrations in groundwater. This will be instrumental in monitoring and documenting the N concentrations continuously during the production season and subsequent development of fertilizer N management.

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CHAPTER SEVEN

IMPACT OF TEMPORAL AND RAINFALL VARIATIONS ON NITROGEN CONCENTRATIONS IN GROUNDWATER IN DIFFERENT FARM SIZES IN AINABKOI SUB-COUNTY.

Abstract

Precipitation plays an important role, in explaining variations in groundwater nitrogen concentration which readily leaches down the soil profile. In this regard the study aimed to assess the nitrate-N, nitrite-N and ammonium-N in shallow wells among different farm sizes in three wards within Ainabkoi sub-county. Each ward was identified as a homogenous stratum of same size-ranged farms classified as Large, Medium and Small farm sizes in Ainabkoi, Olare and Kaptagat (Kaptagat) wards respectively. Farms in each ward were purposively and randomly selected such that only accessible farms that had access to either a privately owned or communal wells were selected. Wells were sampled during the wet and dry seasons of 2012 and 2013 and samples kept frozen prior to analysis. There were non-significant differences between the farm sizes but there were highly significant effects of rainfall on the nitrogen concentration in groundwater. Although the temporal change followed a non-distinct bimodal pattern, generally higher precipitation amounts coincided with higher nitrate-N, ammonium-N and nitrite-N concentrations. There was a highly significant positive linear relationship ($Y = 0.1759x + 22.07 \quad R^2 = 0.23^{***}$) between the monthly rainfall amount and nitrate concentration and highly significant seasonal differences in ammonium-N. Although NO_3-N, NO_2-N and NH_4-N, concentrations did not exceed the recommended maximum concentration by Kenya and WHO of 10mg/l, 3mg/l and 0.5mg/l respectively, precipitation has a highly significant impact on their groundwater concentration. Hence nitrogen fertilizer application rates, timing and split application should be adopted to increase crop nitrogen uptake and reduce nitrogen leaching.

Keywords: Farm Sizes, Groundwater, Season; precipitation.

7.1 Introduction

Groundwater contamination by nitrates is a worldwide problem mainly related to the excessive use of fertilizers in intensive agriculture (World Health Organization, (WHO) 2008; USEPA, 1993). The ultimate nitrate load to the groundwater is influenced by several key factors which include variations in precipitation or irrigation, evaporation, soil type, topography, recharge rate and the structure of geological layers (Goulding, Jarvis, & Whitmore, 2008 and Inoue, 2012). Leaching is the natural process of movement of dissolved materials especially plant nutrients through soil in water (Zhang, Tian, Zhang & Li, 1996,). It is an important process for plant growth and health because without leaching, the soil would gradually accumulate nutrients which are mostly salts and subsequently negatively affect plant growth. However leaching has been identified as a major contributor to groundwater contamination which occurs when excess amounts of soluble nutrients leach below the root zone and into groundwater (Zhang *et al*., 1996). Evidently then, where a source of nitrogen exists there is the potential for nitrogen such as nitrates to reach the groundwater beneath the source and the concentration of leachate depends on local conditions at the source.

High application rates of N fertilizer combined with flood irrigation on high fertility soils seem to have greater potential for nitrate leaching (Agrawal, Lunkad, & Malkhed, 1999). According to Ju, Liu, & Zhang, (2003), accumulated nitrate is prone to leaching into the subsoil after high irrigation rates or heavy rainfall. Temporal variation in nitrate-N concentration in shallow groundwater wells can be caused by a combination of influences such as groundwater depths, rainfall, irrigation, crop growth conditions, and strong seasonal effects. Several researches have reported that observed pollution may be the consequence of farming practices many years earlier rather than current practices (Singh and Skelon, 1978 and Mutch, 1998). This means that the pollutant source may not spatially and temporally coincide with the polluted site. A case in point is in the vegetable production region in Shunyi, Beijing, whereby nitrate concentration in groundwater was unexpectedly high though land use type and N application rate were similar to other adjacent regions. This inconsistency was attributed to the hydrographical conditions (Liu, Lei, Zhang, Zhang, & Lin, 2001). It is a known fact that the overlying land use or management activity influences groundwater quality because it commonly influences nitrogen flow in the soil hence making groundwater to be at risk of contamination (Ledgard, Clarke, Sprosen, Brier, & Nemaia, 1996). Mixed land use such as grazing, animal husbandry, cropping pattern and effluent disposal have been associated with groundwater nitrate problems. A case study of South-East South Australia, which is predominantly pasture, mixed agriculture and forestry, found that the nitrate concentrations in groundwater were above 10 mg/L occur under grazing and dry-land dairy pastures, field cropping and irrigated cropping with a significant source of the nitrate being from urea from cattle urine in paddocks. However monitoring over ten years (1972–1982) did not show any apparent increase in nitrate in groundwater (Bolger, and Stevens 1999).

Studies have shown that agricultural areas involved in vegetable, fruit and floricultural production have more N contamination of groundwater due to the large amounts of N fertilizer used compared with cereal production (Townsend, Sleezer, & Macko, 1996; Zhang *et al*., 1996; Liu *et al*., 2001 and Thorburn *et al*., 2003). However, groundwater N concentration is not always positively correlated with intensive agricultural production. Highest N concentrations in groundwater were recorded in groundwater beneath cotton fields which received 182.6 kg N/ha of fertilizer compared vegetable production fields which received 884 kg N/ha and a wheat-corn rotational cropping system that received 633.7 Kg N/ha (Liu and Zhang, 2005). Therefore nitrate-N concentration in groundwater should be related to the geographical ward and not only fertilizer regimes.

Excessive use of nitrogen fertilisers can lead to soil acidification and loss of nitrate by leaching to groundwater and surface water, particularly in humid environments (Heylar and Porter, 1989). Large amounts of N fertilizer application are commonly applied in order to obtain high yields resulting in a large accumulation of nitrates in the soil profile which is therefore readily leached down the soil profile especially during heavy rainfall (Zhang *et al*., 1996; Liu *et al*., 2005; Rutkoviene, 2005). High precipitation has also been associated with a decrease in nitrate concentration in groundwater. It has been established that increased rainfall supports crop growth and subsequent nitrogen uptake as well as dilutes soil nitrates. Wick, Heumesser, & Schmid, (2012) reported that municipals that experienced high average daily precipitation level subsequently experienced lower groundwater nitrate concentration. They put forward that a 1mm increase in average daily precipitation levels implies 0.84 mg/l decrease in observed average nitrate concentration in groundwater. The comparison of a region with an average daily rainfall of 2.78 mm with one that experiences a daily average of 10.8 mm implies that the nitrate concentration in the municipality with higher rainfall will be lower by 6.75 mg/l (Wick, Heumesser, & Schmid, 2012). However irrigation agriculture is known to cause increase in groundwater nitrate pollution (Pionke, 1990 and Guimera, 1998).

7.2 Impact of Rainfall Amounts on Groundwater Nitrogen Concentrations

Precipitation plays an important role, whether negative or positive, in explaining variations in groundwater nitrate concentration. Applied N not taken up by crop or immobilized in soil organic pools, is vulnerable to losses from volatilization, denitrification and leaching (Cassman, Dobermann, & Walters, 2000). Nitrate leaching to groundwater depends on climate such as excess rainfall or irrigation. The potential for groundwater contamination with nitrate is greatest where inputs of water (rainfall and irrigation) and nitrate are high and the removal of water and nitrates from the soil solution by evaporations and plant uptake are low (Diez, Caballero, Roman, Tarquis, Cartagena, Vallejo, 2000; Stites and Kraft, 2000 and Ju *et al*., 2003). Several studies have found that increasing precipitation leads to higher nitrate leaching and hence positively affect nitrate concentration in groundwater (Korsaeth and Eltun, 2000 and Rankinen, Salo, Granlund, & Rita, 2007). Deep drainage and NO_3-N leaching loss and subsequent groundwater contamination in China has been attributed to both excessive and inappropriate irrigation and N fertilization (Zhu, Zhang, Zhao, Cheng, & Li, 2005). This is also enhanced by heavy rainfall during the production season especially in vegetable production areas where N inputs greatly exceeded crop needs (Ju, Kou, Zhang, & Christie, 2006).

Results from a long term study (1998-2003), in Lithuania, Rutkoviene, (2005) showed a positive correlation between nitrate concentrations, precipitation level and air temperature. The highest nitrate concentrations were observed in spring and summer (March through August), during when precipitation levels are received are highest in summer thereby saturating the ground to the layers which feed the wells while in spring the melting spring water may carry the pollutants to the deeper layers of the soil and into the wells. These nitrate levels were explained by the fact that spring and summer are warm seasons with very active circulation of organic substances. The warm air temperature creates more favourable conditions for the conversion of ammonia nitrogen to nitrate nitrogen. Lower nitrate concentrations were recorded during the winter and autumn seasons (September through February). Equally higher mean precipitation may cause the uptake of nitrogen by crops (Sieling and Kage, 2006) or support the dilution of nitrates (Wick *et al*. 2012) and thus decrease potential nitrate leaching. Wick *et al*, (2012) noted that a 1mm increase in average daily precipitation levels implies, a 0.84mg/l decrease in observed average nitrate concentration in groundwater. This means that the nitrate concentration in groundwater is lower with higher rainfall. Similarly, Lee, (2003) and Nas and Berktay, (2006) have reported nitrate concentration in groundwater as weakly and inversely correlated to the precipitation amount. This was translated from NO_3–N concentrations in the rainy season being lower than those in the dry season which could be attributed to rainfall recharge and resulting dilution effects on the NO_3–N concentration.

Nitrate concentration in groundwater has been observed to fluctuate with seasons (Nas and Berktay, 2006) in which low concentrations were measured in the wet seasons and high concentrations during the dry seasons. Ibrikci, *et al.*, (2012) found that groundwater NO_3-N concentration was only greatest early in the season which is an indication of potential N leaching of unused N from the fields. However the groundwater NO_3-N concentrations decreased thereafter during the peak irrigation season because of crop uptake during spring and summer. Babiker *et al*, (2004) investigated nitrate contamination of groundwater by fertilizers in Central Japan and reported that nitrate concentration in groundwater was weakly and inversely correlated to the precipitation amount. Lee, (2003) analysed the characteristics of NO_3–N in groundwater according to rainfall distribution and reported that concentrations in the rainy season were lower than those in the dry season. This could be attributed to rainfall recharge and resulting dilution effects on the NO_3–N concentration.

Another important weather effect concerns average daily maximum temperature, which can have opposing effects on nitrate concentration in groundwater. Average daily maximum temperature also exhibits a negative effect on nitrate concentration, which suggests higher temperatures, higher rates of evapotranspiration and biomass production occur that in turn reduce nitrate leaching into groundwater. Schweigert *et al*. (2004) suggested that high average temperature can lead to higher soil mineralization rates, which could subsequently increase nitrate concentration in groundwater. On the other hand, they suggest that high temperatures favour evapotranspiration. At the same time, high temperatures often correlate with dryness, which slows the process of mineralization (Schweigert *et al*., 2004), hence both processes could thus reduce leaching of nitrates into groundwater.

7.3 Methodology

7.3.1 Rainfall data

The daily weather data for Ainabkoi sub-county was secondary data recorded and obtained from the Ainabkoi-Olare weather station. The daily rainfall amounts were recorded for the period 2012-2014 and summation of the daily rainfall gave the monthly total rainfall. Due to this absence of any predictable pattern, years were generally considered a random variable (Gomez and Gomez, 1988) and were therefore analysed separately.

7.3.2 Groundwater Sampling and Nutrient Analysis

Groundwater sampling was carried out as described in Chapter 3. Samples were be moved to the laboratory and kept frozen prior to analysis. Ammonium–Nitrogen (NH_4-N), Nitrate-N Analysis (NO_3-N) and Nitrite-N (NO_2-N) were analysed as described in Chapter 3.

7.3.3 Data Analysis

The data collected was subjected to the analysis of variance using Statistical Analysis Software (SAS (2002) and mean values were compared by least significant difference (LSD) at the 5% level. Analysis of Variance was carried out between the NH_4-N, NO_3-N and NO_2-N in the different farm sizes and the monthly precipitation amounts. The results were presented graphically for each nitrogen ion in 2012 and 2013. The seasonal variations in N concentrations were subjected to t-test.

The functional form of the linear relationship between the dependent and nindependent variable s is represented by the formular:

$Y = \alpha + \beta x$

Where α the intercept of the line on the Y axis and β the linear regression coefficient is the slope of the line or the amount of change in Y for each unit in x.

The environment is compounded by interdependence between factors hence there was need to use regression procedures that can simultaneously handle several independent variables. Stepwise multiple regression technique was used to determine the appropriate regression model between groundwater nitrogen concentration and independent variables. This was studied in order to predict the model that best predicts the variable or variables that may greatly influence the nitrogen concentration in groundwater.

The model statement for multiple regression was in the form:

$Y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_a x_a$

Where;

Y = The Dependent variables (Ammonium-N, Nitrate-N and Nitrite-N concentration)

x_1, x_2, x_a = Are the independent variables;

β = Regression Coefficient values

α = Constant

The results were presented in tables and graphs. The groundwater N concentration in the different farm sizes was presented graphically.

7.4 Results

7.4.1 Rainfall pattern and amounts in Ainabkoi Sub-County

The rainfall distribution in each month from 2012 to 2014 is depicted in Figure 11. The average annual rainfall received was 2,001 mm and 1,599 mm in 2012 and 2013 respectively (Figure 11). This was slightly more than the annual rainfall range of between 625 mm to 1,560 mm usually expected in the Uasin Gishu County (Uasin Gishu County Integrated Development Plan 2013-2018 (UGCIDP, 2013; Jaetzold and Schmidt, 1983). The rainfall amounts showed a bimodal pattern with two peaks in March-May and in June-September. The highest precipitation was recorded in July 2012 as 427.1 mm and August in 2013 as 251.1 mm. A drier spell was experienced between November and February with about 10-13% of the rainfall occurring during these months.

The months of January and February in both years had the lowest precipitation records of approximately 25 mm. The wet season occurs between March and August during when 76% and 68% of the total rainfall was experienced in 2012 and 2013 respectively. The variability between the years was characteristically observed in the rainfall pattern and amounts.

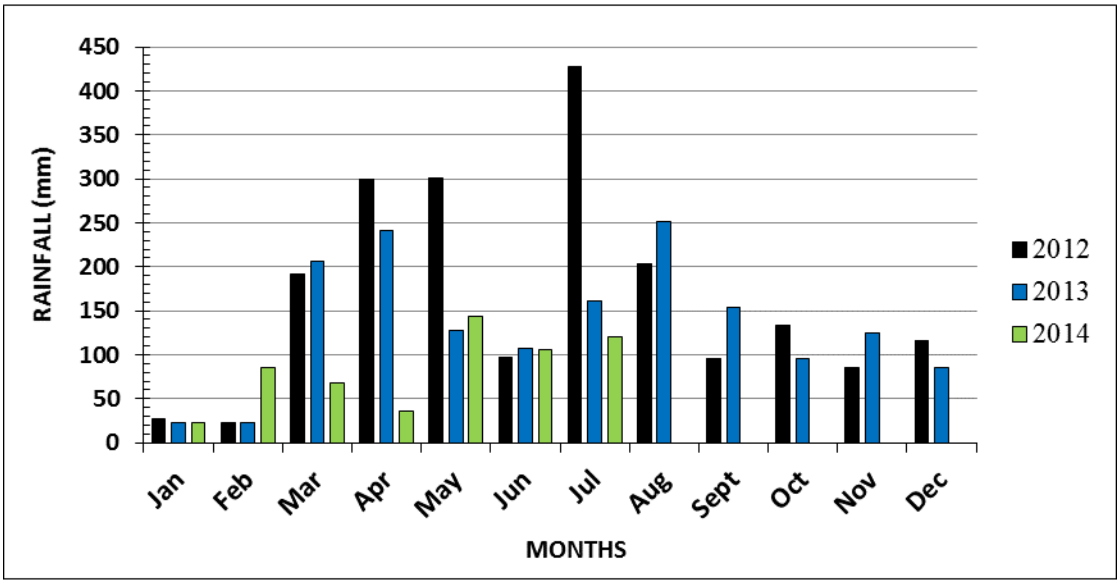

Figure 11: Average Rainfall amount between 2012 and 2014.
Source: Ainabkoi-Olare weather station.

7.4.2 Temporal and Rainfall Impact on groundwater Nitrate-N Concentration

Analysis of Variance (ANOVA) showed a highly significant (p = 0.0001) effect of the rainfall amount on the nitrate-N concentration in the groundwater (ANOVA Appendix II) in both 2012 and 2013. There were highly significant differences between years and months in the nitrate concentration in groundwater. However there were non-significant differences in nitrate levels in the different farm sizes.

Although there was a highly significant effect of rainfall on the nitrate the relationship, trends between rainfall and groundwater nitrate concentration were not very distinct and varied considerably year to year. In general, the trends in the precipitation amount and changes in the nitrate concentration were such that during periods of higher precipitation amounts, groundwater nitrate concentrations were higher, while during lower precipitation amounts the nitrate concentrations were lower (Figure 12 and Figure 13). In 2012, the first bimodal rainfall peak (March-June) occurred in May (301.4 mm) and the second bimodal peak (June-September) in July (427.1 mm), during which the average nitrate concentration in the farm sizes was 65.92 µg/l and 186.26 µg/l respectively (Figure 12).

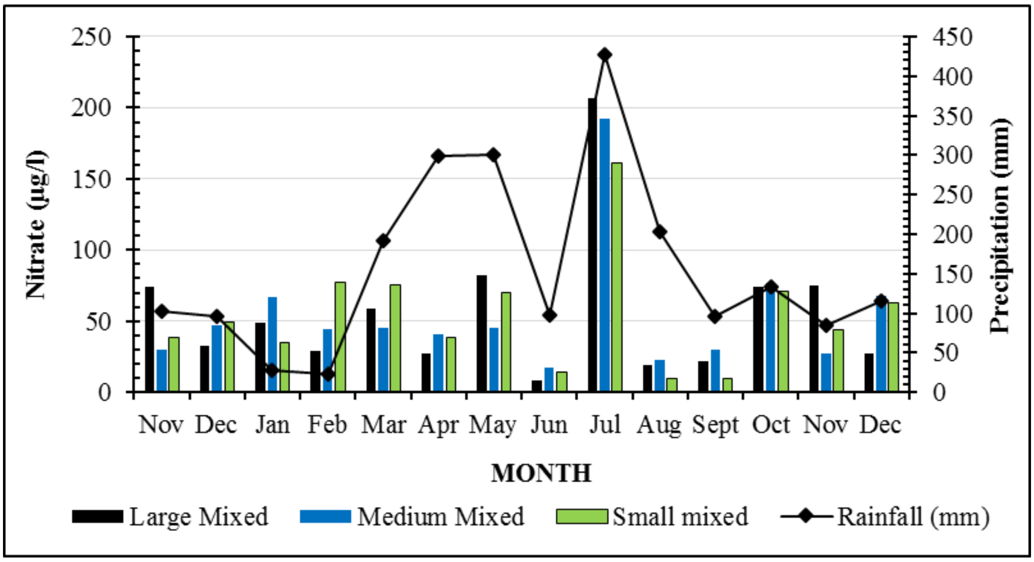

Figure 12: Comparison of Monthly Precipitation and Temporal Trends in Groundwater Nitrate-N Concentration in Different Farm sizes in 2012

During the highest rainfall amount in July 2012 (427.1mm), the highest groundwater nitrate concentrations of 207.06, 192.33 and 161.46 µg/l were recorded in the large, medium and small mixed farm sizes respectively.

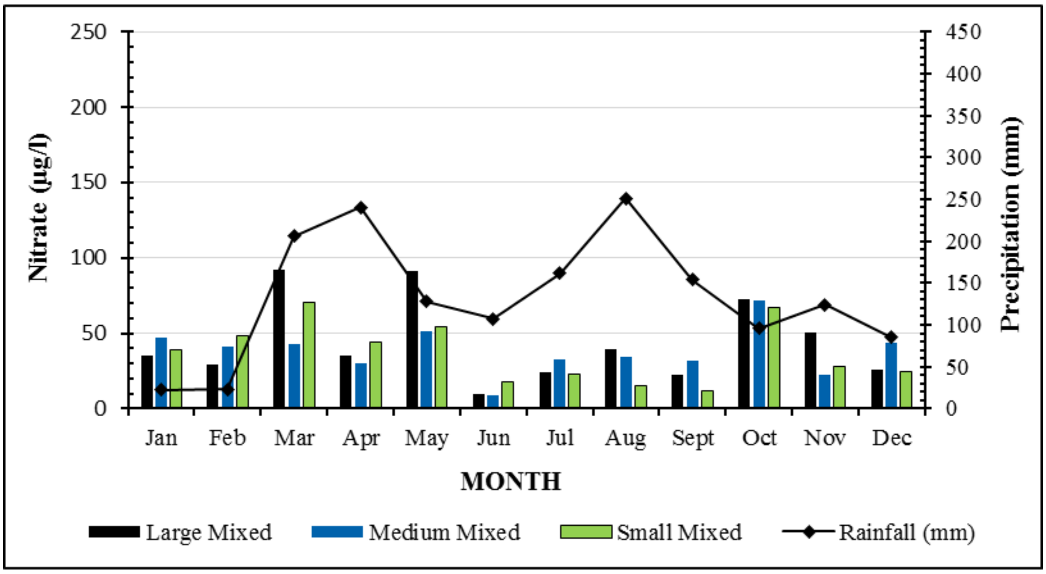

Figure 13: Comparison of monthly Precipitation and Temporal Trends in Groundwater Nitrate-N Concentration in Different Farm sizes in 2013

In 2013, the study area received less rainfall than in 2012 and the nitrate concentration in groundwater was also reduced. The first rainfall bimodal peak was in April (240.7 mm) and this corresponded to an average nitrate concentration of 36.65µg/l. The second bimodal peak was in August (251.1 mm) corresponding to an average nitrate concentration of 29.57 µg/l (Figure 13). In 2013, a mixed trend was observed whereby when the rainfall amounts were low in October-December and January to February the nitrate concentrations tended to be slightly higher. Lower rainfall amounts in the months of January and February 2013, (22.7 mm and 23.1 mm respectively), corresponded with lower average nitrate concentrations in the groundwater of 40.50 µg/l and 39.59 µg/l respectively. In contrast to the results observed in 2012, the nitrate concentration decreased in July-September as rainfall amounts increased. Thus the temporal change in nitrate concentration in groundwater seemed to follow a non-distinct bimodal pattern throughout the two years of sampling. In general, the nitrate-N concentrations somewhat peaked between the months of March and May and again between October and November in both 2012 and 2013.

There were non-significant differences between the effects of farm sizes in nitrate concentration levels in the groundwater. Although there were outliers that may have exerted considerable influence on the functional form of the relationship, it was deemed right not to eliminate them. However, the results showed that NO_3-N concentration in groundwater varied widely between farm sizes as shown in Figure 12 and Figure 13. The highest and lowest nitrate-N concentration in groundwater was recorded in the large farm system ranging from 8.87-104.7 µg/l. The nitrate-N concentration in the medium and small farm sizes ranged from 13.4-74 µg/l and 10.4-73 µg/l respectively. There were also variations between the farm sizes in when the lowest concentrations of nitrate-N in groundwater were recorded. This was such that the lowest concentrations in the large and small farm sizes were observed between the months of June and September with average concentrations of 18.76 µg/l and 17.56 µg/l respectively. However the lowest nitrate-N concentrations in the medium sized farm sizes were obtained in the months of June and July and averaged 18.13 µg/l.

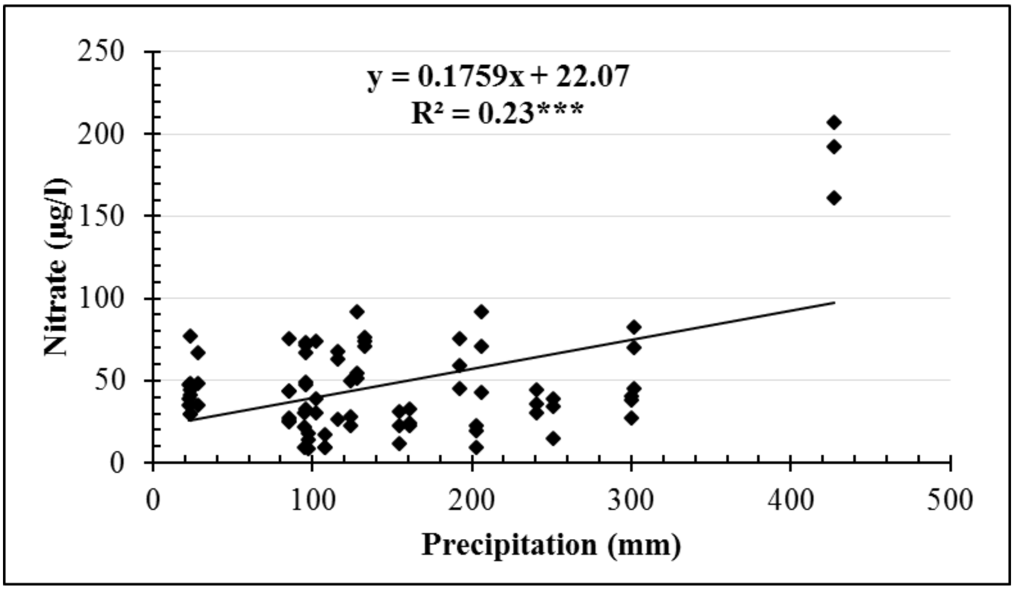

Figure 14: Linear Regression between nitrate-N at topdressing and precipitation amounts

The regression analysis of the monthly rainfall amount and nitrate concentration in groundwater returned a highly significant positive linear relationship (Y = 0.1759x + 22.07 R^2 = 0.23***), indicating the highly significant potential impact of precipitation amounts on NO_3-N concentration in groundwater (Figure 14).

Table 7: Seasonal Variation of nitrate-N in groundwater in 2012 and 2013 in different Farm sizes.

	2012		**2013**	
	WET	**DRY**	**WET**	**DRY**
LARGE MIXED	67.20	55.30	48.68	53.05
MEDIUM MIXED	60.63	50.74	33.42	48.66
SMALL MIXED	61.44	49.96	37.45	40.72
MEAN	62.46	49.86	40.91	39.63
SD	64.40	34.50	36.62	25.27
SE	7.29	3.91	4.5	2.86
t-value	-1.52		-0.25	
(P≤0.05)	0.13ns		0.80ns	

ns: Non-Significant at p≤0.05)

There were non-significant but notable seasonal variations in the groundwater nitrate concentration (Table 7). Nitrate concentrations in groundwater were slightly higher during the wet season (March-August) than during the dry season (September-February) in both 2012 and 2013.

7.4.3 Temporal and Rainfall impact on the groundwater Nitrite-N Concentration

The ANOVA returned highly significant differences between the effect of the amount of precipitation and the nitrite concentration in groundwater. Albeit this highly significant relationship, there were no clearly recognizable trends in the groundwater nitrite concentration and rainfall amounts in the different farm sizes. It was generally observed that the groundwater nitrite was on average higher during periods of higher precipitation. This was the case in 2012 whereby the highest concentration recorded in April (34.58 µg/l) and October (36.55 µg/l) corresponded with high rainfall amounts of 299.8mm and 133.4mm respectively (Figure 15). The lowest concentration in 2012 was recorded in February (3.21 µg/l) and in June (2.94 µg/l) which corresponded to rainfall amounts of 23.4mm and 97.6mm respectively. The variability in groundwater nitrite concentration versus the precipitation amount was also observed in 2013 (Figure 16). However, on average the highest nitrite concentrations were recorded in July (44.9 µg/l) and October (36.55 µg/l) with corresponding high precipitation amounts of 161.3mm and

95.8mm respectively (Figure 16). The lowest nitrite concentrations were also recorded in May (9.02 µg/l) and June (2.57 µg/l) when precipitation amounts were relatively high at 128.1mm and 107.5mm respectively. The groundwater nitrite concentrations were generally lower between January and June and thereafter increased between July and December as rain decreased from September to December.

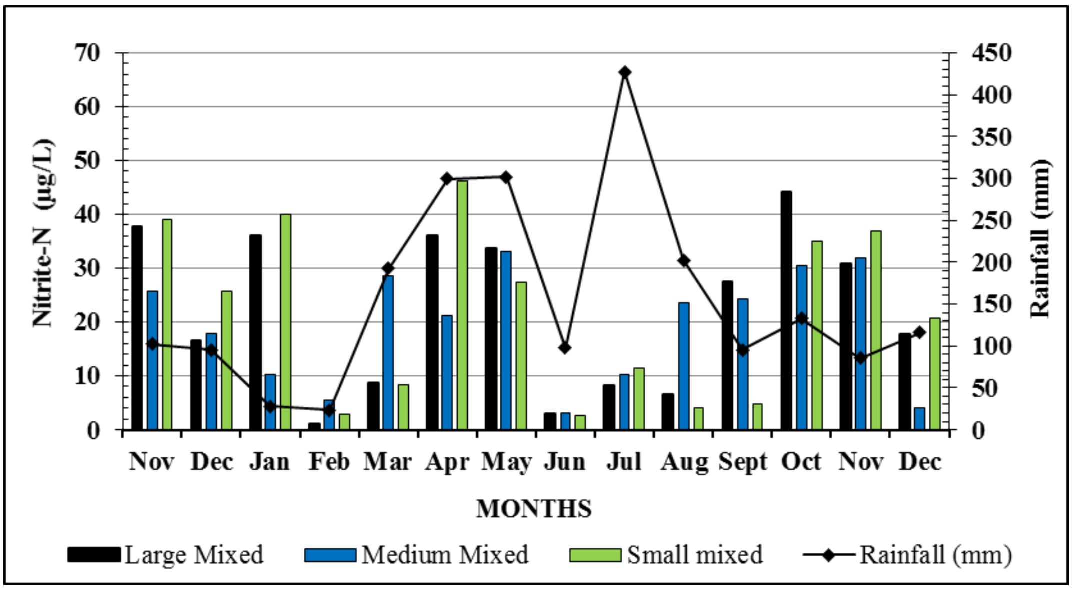

Figure 15: Comparison of Monthly Rainfall amount and Temporal Trends in Groundwater Nitrite-N Concentration in Different Farm sizes in 2012

However, the rainfall decline from April (240.7mm), May (128.1mm) and June (107.5mm) caused a gradual decrease in nitrite concentration from 20.97, 9.02, and 2.57µg/l respectively. Thereafter nitrites concentration in groundwater generally remained higher in July (44.9µg/l), August (17.38µg/l), September (22.11µg/l) and October (36.55µg/l) as the rain gradually decreased from 251.1 in August to 84.9mm.

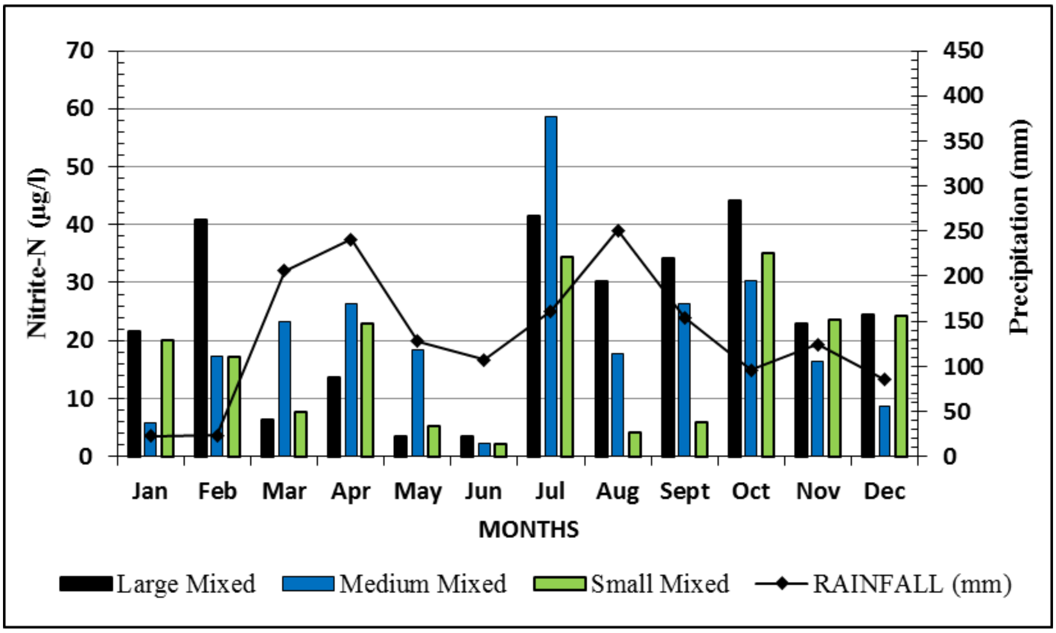

Figure 16: Comparison of Monthly Precipitation and Temporal trends in Groundwater Nitrite-N Concentration in Different Farm sizes in 2013.

ANOVA showed that there were no significant differences between the farm sizes in the nitrite concentration in the sampled groundwater. However, it was apparent that higher levels of nitrite-N concentration were most of the time recorded in the large and small mixed farm sizes with an average of 23.3µg/l and 20.42 µg/l respectively.

The students T-test on the seasonal difference in groundwater nitrite concentrations resulted in a non-significant difference between the wet and dry season nitrite concentration in groundwater.

7.4.4 Temporal and Rainfall impact on the groundwater Ammonium-N Concentration

Analysis of Variance was such that there were highly significant differences in the groundwater ammonium-N concentration and rainfall amount. In general the concentration of Ammonium in groundwater seemed to follow a unimodal pattern, peaking during the months of May-June, in 2012 and 2013. In 2012, the highest average concentration of ammonium in groundwater was 138.08µg/L with corresponding rainfall of 97.6mm (Figure 17). The peak ammonium-N concentration coincided with the time of topdressing.

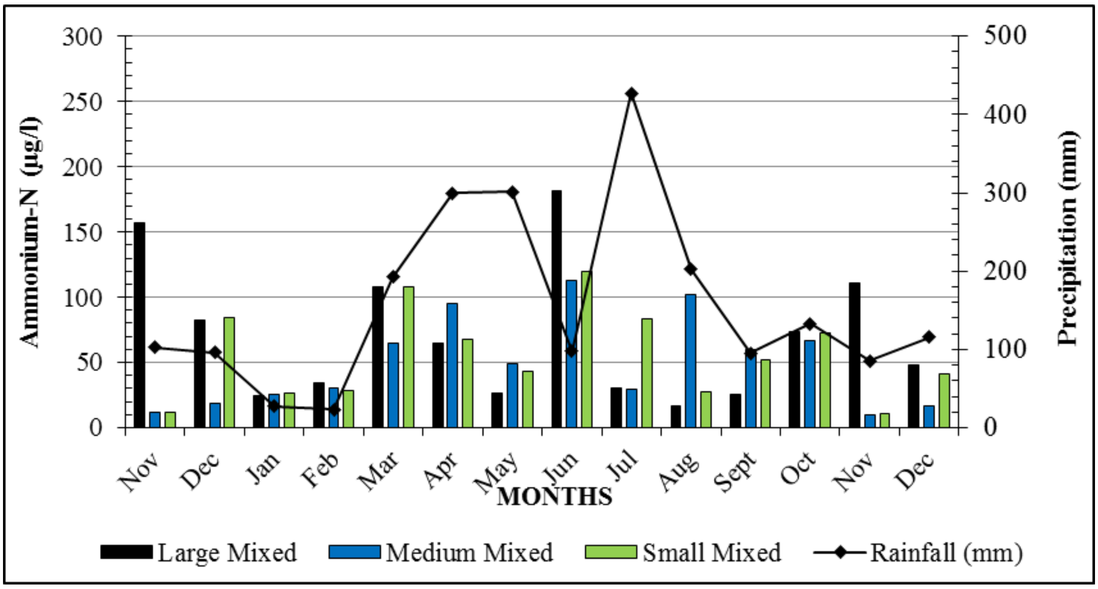

Figure 17: Comparison of Monthly Precipitation and Temporal Trends in Groundwater Ammonium-N Concentration in Different Farm sizes in 2012

The trend was similar in 2013, as depicted in Figure 18, with the ammonium concentration rising sharply to 119.43µg/L in May with rainfall levels at 250mm. Ammonium concentration was generally low between the months of November and February ranging within 30µg/l and 70µg/l. The ammonium levels increased gradually with the onset of the rain season in March in both years. It is notable that the high increase in ammonium concentration in June 2012 and in May 2013 occurred soon after heavy rainfall in the previous months of May (301.4mm) and April (240.7mm).

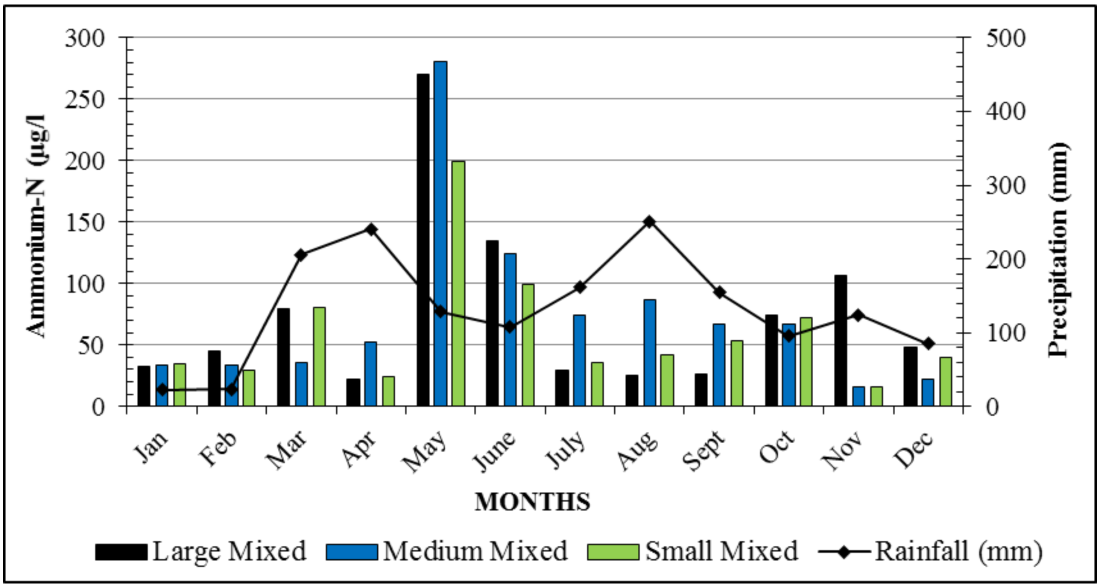

Figure 18: Comparison of Monthly Precipitation and Temporal Trends in Groundwater Ammonium-N Concentration in Different Farm sizes in 2013

There were no significant differences between farm sizes in the level of ammonium-N. Ammonium-N concentration in wells within the large mixed farm ranged from 20.77-158.48µg/l. The lowest ammonium-N contamination of groundwater occurred during different times in the production season in the different farm sizes such that it was lowest in August (20.77 µg/l) in the large farm sizes and in November in the medium and small farm sizes (13 µg/l).

The student's T-test showed that there were highly significant differences between the wet and dry seasons in the concentration of ammonium-N in groundwater in both 2012 and 2013 (Table 6.2). The difference between the wet and dry seasons in Ammonium-N levels was by 34.74 and 50.05 in 2012 and 2013 respectively.

The seasonal differences were largest for wells in the large mixed farm system, with a groundwater ammonium concentration reduction from wet to dry season of 51% and 66% in 2012 and 2013 respectively. The concentration in the medium and small mixed farm sizes reduced by 46% and 22% respectively in 2012 and by 50% and 47% respectively in 2013.

Table 8: Comparison of Seasonal Variation of ammonium in groundwater in 2012 and 2013.

	2012		**2013**	
	WET	**DRY**	**WET**	**DRY**
Large Mixed	75.54	36.81	109.09	36.77
Medium Mixed	74.87	40.17	79.95	40.21
Small Mixed	71.21	55.82	93.60	49.20
Mean	75.51	40.77	94.07	44.02
SD	56.19	37.46	107	36.76
SE	6.36	4.24	12.12	4.16
t-value	-4.54		-3.91	
P≤0.05	***		***	

***Highly significant at P≤0.05

7.4.5 Determination of the best model of contributing variables to groundwater nitrogen concentration

Forward stepwise multiple linear regression was used to determine which factors or variables were best able to predict NO_3-N, NO_2-N and NH_4-N concentrations in well water. Although all the predictive factors were significant at ($p = 0.15$), they only explained less than 20% of the total variations in groundwater N concentrations. Precipitation amounts and season were common significant predictors of the concentration levels of ammonium-N, nitrate-N, and nitrite-N concentration in well water.

Model Equations of Best Fit were in the form below:

NO_3-N = 21.86 - 30.91*season + 0.28*precipitation

NO_2-N = 28.86 - 10.64*season + 0.05*precipitation – 0.08*DAP + 0.04*CAN – 1.29crs

NH_4-N = 54.52 + 72.02*season – 0.22*precipitation + 0.43*maize acreage

7.5 Discussions

Seasons are characterized by the amount of rainfall received, which distinguishes the wet and the dry seasons. Ainabkoi sub-county has two distinct seasons with the wet season starting in March through to August and the dry season starting in September through to February, with some rainfall still experienced during the dry seasons. In general, highest groundwater nitrate concentrations were recorded in March through to July, when rainfall was highest and the lowest concentration in September through February when rainfall was low. Several authors have reported varied seasonal fluctuations in groundwater nitrogen concentration (Rutkoviene *et al*, 2005 and Panahi and Moghaddam, 2012). Several studies have also reported similar direct relationship between rainfall amount and groundwater nitrate concentration (Rutkoviene, 2005 and Panahi and Moghaddam, 2012). Rutkoviene, (2005) reported that the highest nitrate concentrations were observed in spring and summer (March through August: wet season), while the lower concentrations were observed in the winter and autumn seasons (September through February; the dry season). A strong correlation between nitrate concentrations in summer was established and non-significant correlations in other seasons. They explained these tendencies by the fact that spring and summer are warm seasons with very active circulation of organic substances coupled with high rainfall in summer and the melting spring water which may easily transport pollutants to deeper soil layers and subsequently wells. The low nitrate concentration in autumn and winter was attributed to the possibility of wells being fed by water from deeper layers containing fewer organic substances, combined with the low temperatures in winter which slow chemical reactions. In another contrasting report Panahi and Moghaddam, (2012), reported that nitrate concentration was highest when rainfall was highest and subsequent infiltration quantity was large. This contrast may be explained by the contrasting conditions in the tropics which present dry summers and wet cooler seasons. During the rainy season (wet season) the nitrate concentrations are lower probably due to the dilution effect of water on the nitrate concentrations in the groundwater. Zhang *et al*., (1996) reported that excessive application rates of N dressing during the rainy season caused groundwater contamination as nitrates are leached into groundwater before it can be absorbed by crops concluding that nitrate concentration in groundwater corresponds to nitrogen fertilizer rates and the precipitation. (Srivastava1, 2012) also concluded that the high groundwater nitrate concentration in the Kheda district, Gujarat India, which is a heavily industrialized area with agricultural plains, and a subtropical monsoonal climate, was from both the fertilizer manufacturing industries and the high use of nitrogenous fertilizers in the agricultural fields. Rutkoviene, (2005) also reported that the months of highest precipitation (March-July) were also the months the highest nitrate levels (September-February) were recorded in groundwater in Lithuania. Several researchers agree that accumulated nitrate is prone to leaching into the subsoil after high irrigation rates or heavy rainfall (Diez *et al*., 2000; Stites and Kraft, 2000 and Ju, Liu, & Zhang, 2003). In particular, when the N application rate exceeds crop demand, considerable nitrate accumulation occurs in the soil profile (Granstedt, 2000 and Ju *et al*., 2004).

Several research findings contrast with this study on the impact of rainfall on the groundwater N contamination. According to Kaçaroglu, & Günay, (1997) low nitrate concentrations generally occurred in the wet seasons and high concentrations during the dry seasons which concurs with the groundwater analysis in this study. Liu *et al*, (2005), found that, nitrate concentration in groundwater was weakly and inversely correlated to the precipitation amount in two farmlands; Guojia and Lijia, in Northern China. Likewise research findings by Lee (2003) on the relationship between the concentration of NO_3–N in groundwater and rainfall distribution were similar to the findings in this study in which the NO_3–N concentrations during the rainy season were lower than those in the dry season.

This inverse relationship between precipitation and nitrate contamination of groundwater observed sometimes in 2012 and 2013 may be explained by the two counteracting effects of leaching and the dilution effect and has been evidenced in the variability of reported groundwater analysis. These two effects were reported by Wick *et al*., (2012), in preliminary results in which precipitation initially had a negative effect on the concentration of nitrate in groundwater in Austria. However as the amount of rainfall increased, the dilution effect weakened giving a positive correlation. Wick *et al*, (2012) noted that the effect of precipitation is influenced by differing soil qualities and soil humus content. Humus depressed the positive effect that rainfall has on nitrate concentration in groundwater.

Since nitrite is produced in the process of converting ammonium into nitrate, it is likely that the higher nitrite concentrations in groundwater during the dry season was produced in the process of nitrification when ammonium ions, that had accumulated during the rainy periods, were oxidized by the nitrosomonas and nitrobacter bacteria to yield nitrites. This conversion from ammonium to nitrites is slower than the conversion of nitrites to nitrates and is therefore advantageous because nitrite is quite toxic to most plants and animals. The World Health Organization (WHO) and the United States Environmental Protection Agency (USEPA) have adopted the 1 mg/L (or 1 ppm) nitrite-nitrogen for regulated public water systems (WHO, 2003). The nitrite values obtained in this research analysis were significantly low. However these measurements are time point analysis and the fact that nitrites seldom accumulate in the system, it can therefore be assumed that there is a likelihood of higher concentrations at some specific points of the season. The concentration of the forms of nitrogen in the groundwater in the different farm sizes did not exceed the maximum allowable limit of 10mg/l NO_3-N, 3 mg/l NO_2-N and 0.5 mg/l NH_4-N (WHO 1998).

Ammonium concentration significantly increased just after heavy rainfall. High ammonium concentration during the wet season may be attributed to the high precipitation that coincides with application of N fertilizers in the form of DAP and CAN, and therefore most of this N fertilizers leach down the soil profile and into groundwater. From the results observed in this study area, precipitation and high fertilizer N application predisposes groundwater to a high risk of nitrogen contamination.

Even though the total variation of N in groundwater explained by precipitation and seasons were low, they are the most important predictive variables that explain the variations in N concentration in well water. Several reports found that increasing precipitation may cause an increase in the nitrate concentration in groundwater (Korsaeth and Eltun, 2000; Rankinen, *et al*., 2007). Conversely high precipitation may cause the dilution of N concentration. It is apparent therefore that the impact of the various variables in the environment contribute to the N concentration into groundwater.

The groundwater Nitrate-N, Nitrite-N and Ammonium-N concentrations in groundwater did not exceed the maximum allowable limits 10ng/l, 3 mg/l and 0.5 mg/l (ROK, 2006 and WHO, 2008). However these results can be used as a predictor of the possibility of groundwater contamination depending on the prevailing environmental conditions. Precipitation and seasonal variations are common significant predictors of N levels in groundwater. Hence timing of N fertilizer application should be scheduled such that the leaching beyond the root zone is controlled.

7.6 Conclusion

The nitrate-N, ammonium-N and nitrite-N concentrations in the groundwater in all the farms did not exceed the recommended maximum concentration by Kenya and WHO of 10mg/l, 3mg/l and 0.5mg/l respectively (WHO, 2008 and ROK, 2006). Precipitation had a highly significant impact on the groundwater concentration on N forms, NO_3-N, NO_2-N and NH_4-N, even though concentrations did not exceed the recommended maximum concentrations. This implies that precipitation plays a significant role in the nitrogen concentration in groundwater.

The results showed that the best functional relationship between rainfall amounts and groundwater nitrogen concentration was just as variable and mixed as the variable environment in which they occur. This variability should be heeded as a warning of possible high nitrogen concentration in groundwater at any time. These seasonal variations can be explained by the agricultural activities such as top-dressing that is usually done during the wet season as well as movement of these pollutants as leachate down the soil profile. N accumulation and subsequent movement into groundwater is clearly unpredictable and factors such as soil type, precipitation, groundwater level fluctuation, and recharge conditions of the groundwater cannot be easily altered.

7.7 Recommendation

N fertilizer application should be near the root zone because this is generally more efficient than spreading fertilizer uniformly over a field and will reduce the amount washed down the soil profile and into groundwater especially during period of high precipitation. Sound agricultural management also referred to as Best Management Practices (BMPs), such as nitrogen application rate and timing, irrigation amount and timing, and crop management can be modified to increase crop nitrogen uptake and reduce nitrate leaching. Fertilizer application should be scheduled such that adequate N is available during peak plant demand. Split application is a common cropping system practice whereby N fertilizer is split into small applications at a time thereby reducing the loss of N into groundwater especially during the wet season and subsequently increases plant use of fertilizer N.

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CHAPTER EIGHT

SANITARY CHARACTERISTICS AND NITROGEN CONCENTRATION IN GROUNDWATER IN AINABKOI SUB-COUNTY.

Abstract

Sanitary survey is an on-site inspection of the physical environment of the water source to identify possible sources of environmental contamination. The the aim of this project was to identify and assess the sanitary risk factors associated with the wells and subsequently determine the Contamination Risk Score (CRS) as predictors of water nitrogen pollution. Onsite sanitary survey of the wells and the homesteads was carried out in each farm through visual inspection, observations and interviews whereby a score was allocated for a positive answer and no score for a negative answer. The CRS were categorized as Very High Risk (VHR) = 9-11; High Risk (HR) = 6-8; Intermediate Risk (IR) = 3-5; Low Risk (LR) = 0-2. There were 11 sanitary risk factors (SRF) used to assess the susceptibility of the well water to contamination. There were highly significant differences in well CRS within the different farm sizes. Wells within the large and medium mixed farm sizes had an Intermediate CRS because most wells are protected and the well vicinity was relatively clean. Wells within the small farm sizes were shallow communal water sources, did not have a wall protection and were located down slope. Therefore rain water flowed into these wells collecting any debris and waste into the wells. Although the NO_3-N, NO_2-N and NH_4-N concentrations in the wells did not exceed the statutory guiding limits of 10mg/l, 3 mg/l, and 0.5 mg/l respectively, well attributes increase the susceptibility of wells to pollution. Although the CRS could not adequately explain the nitrogen concentration in groundwater, it is a predictive factor of well contamination and the most important risk factors to the wells are the well protection construction and the activities within the well vicinity. There is need for local county initiatives to construct protective raised wall at the communal wells and educate farmers on aspects of water quality.

Keywords: Farm Sizes, Groundwater, Seasons; contamination Risk; Sanitary survey.

8.1 Introduction

Sanitary survey refers to an evaluation and on-site inspection of the physical environment of the water source to identify possible sources of environmental contamination (USEPA, 1999). Sanitary survey can be a complex technical task which involves the use of different questions to assess the key elements of a sanitary survey such as the water source itself, sources of contaminants and water handling (Lloyd and Helmer 1991 and USEPA, 1999). The information generated by a sanitary survey helps identify existing and potential sanitary risks to the water quality. Ground water contamination can be as a result of poor sanitation and subsequent leaching from site especially in the vicinity of the well (Abdulsalam and Zubairu, 2013). In view of this a sanitary surveillance method was developed by Lloyd and Helmer (1991) to assess the drinking water quality and the associated risks or hazards in the water supplies in rural areas.

The contamination of groundwater by N is associated with a wide range of nitrogen sources. The sources of N pollution in groundwater can either be from diffuse (non-point) or point sources of nitrogen (Bolger and Stevens, 1999). The origin of diffuse sources of pollution cannot be accurately traced to a single polluter and the polluters may also be those that arise from a number of closely spaced similar activities. Point sources of pollution are those where the origin of contamination can be identified such as localized agricultural practices that affect aquifers directly below the site (feedlots), septic tanks and landfills (Bolger and Stevens, 1999). Sources of nitrogen in groundwater may include runoff or seepage from fertilized agricultural lands, municipal and industrial waste water, refuse dumps, animal feedlots, septic tanks and private sewage disposal systems, urban drainage and decaying plant debris (Hudak, 1999 and Nas and Berktay, 2006). Non-point source pollution from agricultural activities such as animal farming and pit latrines have been reported to degrade groundwater quality and thereby threaten people’s health. The use of poorly protected groundwater sources has been linked to acute diarrhoea in developing countries (Nasinyama, 2000).

Under natural conditions, fresh water in shallow aquifers has a relatively short residence time, and its chemistry remains practically unchanged under the effect of a set of natural influences such as physical, geographical, geological and hydro-geological factors. However human economic activities, can distort this natural balance (Rutkoviene, Kusta, and Èesoniene, 2005). According to World Health Organization (WHO) (2008), N concentration in groundwater is normally low but can be increased to higher levels from agricultural activity such as excess application of inorganic nitrogenous fertilizer runoff, waste water disposal, refuse dump runoff or contamination with human and animal wastes. Well characteristics such as well depth, well age, type of well and its structural features, distance from vegetable gardens, and slope of the land, have been found to contribute to the level of nitrate pollution in the groundwater (Bruggeman *et al*., 1995). An inverse correlation has been observed between well depth and nitrate concentration (Clawges and Vowinkel 1996). Groundwater may become contaminated naturally or from numerous types of human activities, where nitrate pollution increases with anthropogenic activities in the vicinity of the well, as well as inappropriate ward of the well (Fawcett, 1992). Thus a poorly organized environment around the homestead, with poultry and livestock kept near the well will have an impact on N concentration in the water of shallow wells. According to Kutra, Kusta, & Rutkoviene, (2002) the distance at which the household premises, the cowsheds, greenhouses, vegetable gardens, pit latrines, dumps and other aggressive sources of pollution can be located and still have an impact on well water quality is 145 meters (Kutra *et al*. 2002). Animal wastes from active or abandoned feed lots may be a significant source of nitrates to groundwater (Kirder, 1987). When manure is stored in open lots for eight months, 7% nitrogen, 14% phosphorus and potassium enter the environment in the form of leachate, resulting in groundwater pollution from the leachate greatly exceeding the maximum allowable concentrations for the area (Kirder, 1987).

The direction of groundwater flow also has an important influence on the probability of contamination. A widely-held tenet of groundwater hydrology states that water flows down slope along the gradient of the groundwater surface or water table (Rutkoviene, *et al*., 2005). This gradient generally conforms to the surface contours. Thus, water quality in wells is highly influenced by pollutants moving from up-slope in the vicinity of the well (Rutkoviene, *et al*., 2005). Therefore an insufficiently dimensioned sanitary zone or a surface incline towards the well can lead to seeping of the surface water down into the well.

Groundwater is the main source of water for drinking and other domestic needs in Ainabkoi Sub-County. Therefore the aim of this project was to identify and assess the sanitary risk factors associated with the wells and subsequently determine the contamination risk score (CRS) as predictors of water nitrogen pollution.

8.2 Physical and Environmental Attributes of Wells

Contamination of groundwater has shown highly significant differences in nitrate concentrations as a function of well depth with nitrates from diffuse sources being commonly detected in aquifers less than 30 m deep (Hallberg, 1989). In addition to environmental influences, the type of well, its depth, age and structural features can also influence its water quality. Nitrate pollution is more common in old and shallow wells

Recently, many research projects have examined the relationship between nitrate levels and well depths (Hudak, 1999; Lake *et al*., 2003; & Lee., 2003). Nitrate contamination of groundwater has been reported to be higher in shallower wells than deeper ones in the Great Bend Prairie aquifer in south-central Kansas (Townsend and Young, 1995), in Shandong province, north China (Ju, Kou, Zhang, & Christie, 2006) and in southwest Victoria, Australia (Bolger and Stevens, 1999). Lee, (2003) reported that NO_3–N concentrations were higher in shallow wells (less than 40 m) than in deep wells (deeper than 40 m) in both the dry and rainy seasons although correlation results between NO_3–N concentration and land uses were generally low and weak. Groundwater in shallow wells (15 m depth) was significantly more contaminated with NO_3-N under a greenhouse vegetable system with levels as high levels of 270 mg L^{-1} (Ju *et al*., 2006). Nitrate-N concentrations in groundwater declined exponentially with well depth in the greenhouse areas (Ju *et al*., 2006). Nitrate-N concentrations in deep wells seldom exceeded the maximum standard in wheat-maize rotation areas. In the greenhouse vegetable production area, the total N inputs were much higher than crop requirements and the excessive fertilizer N inputs were only about 40% of total N inputs (Ju *et al*. 2006). Nitrate concentration versus depth in aquifers of southwest Victoria, Australia showed that elevated nitrate occurs in the shallower (<30 m) intervals of aquifers (Bolger and Stevens, 1999).

Private Wells in the agricultural areas of Pennsylvania State, USA, have NO_3-N concentration greater than the USEPA maximum contamination for drinking water with wells close to corn fields had significantly higher NO_3 concentration than those further from cornfields (Fox, 2001). In many areas across Australia, the concentration on nitrate in groundwater is greater than the recommended maximum concentration of Australian Drinking Water Guidelines of 10 mg/L making the groundwater resource unfit for drinking (Bolger and Stevens, 1999). The nitrate concentrations reached 100 ml/L in some areas and the highest concentrations were found in shallow unconfined aquifers which are most susceptible to contamination. However, there are also several wells contaminated at depths of 50 m or more due to the extent of mixing and local aquifer properties, the groundwater flow system characteristics and time.

8.3 Methodology

8.3.1 Groundwater Sampling and Nutrient Analysis and Data Analysis

Groundwater sampling was carried out as described in Chapter 3. Samples were be moved to the laboratory and kept frozen prior to analysis. Ammonium-N, Nitrate-N, and Nitrite-N analysis were quantitatively determined as described in Chapter 3.

8.3.2 Survey and Assessment of wells in relation to Sanitary risk factors.

Onsite sanitary survey of the wells and the homesteads was carried out in each farm in order to identify significant potential deficiencies, which could explain possible trends in the water quality with regard to the integrity of the whole system. This was done according to the guidance manual on conducting sanitary surveys (USEPA, 1999). Observations and interviews were used to collect information on the sanitary aspects of the wells. Visual inspection and observations of the wells and the immediate environments were conducted on each farm in the different farm sizes. For the purpose of the study, the sanitary survey encompassed the essential components of water source as described in the sanitary survey assessment form adapted from Lloyd and Helmer (1991) and modified in the context of the observations specific to the study area. Visual examination of each well at the time of groundwater sampling was done along with interviews with the landowner. Interviews were used to determine land ownership, well ownership and age, ward of septic tanks, toilets and cowshed. During the survey, farm owners ascertained their land/farm management practices which included the stock of animal farms and water use.

The field and well inspections were carried out to find out the proximity of the wells to latrines and other sources of pollution, nature of well surrounding, well construction such as lining of the well (parapet), and mode of water withdrawal. A positive response indicated the presence of a risk and a score was allocated for a positive answer and no score for a negative answer. The positive answer scores were added up to give an overall sanitary contamination risk score.

The Contamination Risk Score (CRS) was as follows:

i. Very High Risk (VHR) = 9-11
ii. High Risk (HR) = 6-8
iii. Intermediate Risk (IR) = 3-5
iv. Low Risk (LR) = 0-2

The average CRS was determined for the wells within each farm system. The average percentage of wells within each farm sizes that were exposed to each of the sanitary risk factors was determined.

8.3.3 Description of the Risk Assessment Factors

In the context of the study area there were 11 sanitary risk factors (SRF) used to assess the quality of the well water and were modified and described as follows:

1. Distance of Pit latrine from well. The question aimed at determining if the well was located at a safe distance from contamination by the pit-latrine. In this case a 10 m distance was used as a general guideline value. It was common for the homesteads to have a pit latrine near the main house and may therefore be near the well.
2. Position of Pit latrine on higher ground in relation to the well.
   The observation question was based on the assumption that water flows downwards and hence the potential to contaminate wells downhill because the land was generally undulating.
3. Is there any source(s) of possible pollution (man-made attributes, animal excreta, rubbish, Septic tanks, constructions, feedlot runoffs, cowshed runoffs) within 10m of the well?
   The aim of this question was to check for any sources of pollution that may wash into the well. It was common for animals to be tethered and graze within the well vicinity where green grass was common. Some cowsheds/barnyards were not far from the well. Disposal of rubbish was is done within the homestead.
4. Well Ownership: Wells were either privately or communally owned. This question focused on the assumption that communally owed wells may not be as well managed and protected like the privately owned one.
5. Was the well depth less than 15ft? This question was adapted because of the varied well depth in the different farm sizes. Deeper wells may indicate a lower water table and hence less likely to be polluted through leaching.

6. Does the general land terrain slope towards the well? This was an observation question of the land terrain to determine if it slopes towards the well. This was deemed important in sanitary risk determination because undulating land enhanced the likelihood of storm runoff into the well.
7. Do animals graze and water in the well vicinity? Livestock such as sheep were tethered and watered within a 10 m radius of the well vicinity. The excreta from these animals can be a source of nitrogen pollution of the wells.
8. Is the water extracted by use of a bucket and rope?

   This question was based on the probability of well water pollution when buckets and ropes left in unsanitary positions such as lying on the well surface or grounds around the well. This question was aimed at determining if the water abstraction means were left in such conditions that they contaminated or polluted the water source. Water extraction from wells was done manually by use of a metal or plastic container which was tied to a rope for deep wells. However some wells had windmill, and hand pumps were used for water extraction.
9. Is the well open (not constructed)? Wells either had a wall (parapet) constructed around them or not. Wells that were at the same level with the ground were deemed susceptible to pollution from runoff and other sources of pollution.
10. Is there likelihood of runoff entering the well? Runoff possibility into the well could be due to a wall (parapet) around the well that was not adequately high (more than 1m high) and other preferential pathways for the runoff to enter the well such as cracks on the wall. This observation question was aimed at determining if there was a wall (parapet) around the well that was adequately high (more than 1m high) to prevent surface water flow entering the well?
11. Is the maize garden less than 5m from the well? The question assumed the likelihood of ground water pollution through leaching of fertilizer N into groundwater.

8.3.4 Data Analysis

The data collected was subjected to the analysis of variance using SAS statistical package Version 6.12, (1997). ANOVA was done to determine if there were any significant differences between the farm sizes in the overall CRS and mean values were compared by least significant difference (LSD) at the 5% level. Regression analysis was done to determine the relationship between the CRS and the nitrate-N, nitrite-N and ammonium-N concentrations in well water.

8.4 Results

The results of the sanitary risk conditions of the wells in the different farm sizes in Ainabkoi ward are presented in Table 9. The sanitary survey revealed that there were highly significant differences between the farm sizes in the sanitary contamination

Table 9: Sanitary Risk Factors observed in wells in the different Farm sizes in Ainabkoi Sub-County.

Percentage of wells exposed to the sanitary Contamination Risk Factors				
	Sanitary Risk Factors (SRF)	Farm sizes		
		Large	Medium	Small
		Percentage observed		
1	Latrine within 10m of well	33	20	60
2	Latrine on higher ground than well	0	100	80
3	Any other source of possible pollution (animal excreta, rubbish, fertilizer)?	67	40	100
4	Is the well communally owned?	0	20	100
5	Is the well less than 15ft?	0	40	80
6	Does the general land terrain slope towards the well?	100	40	100
7	Is the well vicinity livestock grazing ground?	33	20	100
8	Is the water extracted by bucket and rope?	66	60	100
9	Is the well open (Not constructed)?	0	40	80
10	Is there likelihood of runoff entering the well	66	60	100
11	Is the garden less than 5m from the well?	33	80	80
	Average of Sanitary Risk Factors(out of 11)	4.0	4.2	9.65
	*Contamination Risk Score (CRS) Range	IR (36%)	IR (38%)	VHR (87%)
	Significance (p=0.05))		***	
	Least Significant Difference (LSD)		0.148	

Adapted and modified from Lloyd and Helmer (1991)

*Contamination Risk Score Range: 9-11 = Very High Risk (VHR); 6-8 = High Risk (HR);
3-5 = Intermediate Risk (IR); 0-2 = Low Risk (LR).

*** Highly significant at p≤0.05.

risk scores (Table 9). There were major differences between the farm sizes with regard to homestead organisation (Table 10). The homesteads within the large and medium farm sizes were well organized and landscaped whereby farm areas were subdivided into functional areas. These functional areas included grazing paddocks, the main house and homestead area, kitchen garden area, recreation/relaxing areas and the utility areas.

Table 10: Well and homestead Characteristics

Farm Size	**Approx Well Depth (ft)**	**Homestead Organization**	**Well Ownership**	**Construction type**	**Mode of Operation**	**Notable sanitary characteristic**
Large Mixed	40	Highly organized	Family	Protected	Pump	
	30	Moderately organized	Family	Semi-Protected	Bucket and Rope	
	40	Highly organized	Family	Semi-Protected	Bucket and Rope	
Medium Mixed	30	Moderately organized	Family	Semi-Protected	Bucket and Rope	
	12	Highly organized	Family	Semi-Protected	Bucket and Rope	
	45	Highly organized	Family	Protected	Pump	
	25	Highly organized	Family	Protected	Pump Windmill	
	18	Highly organized	Family	Semi-Protected	Bucket and Rope	
Small Mixed	18	Moderatly organized	Communal	Protected	Bucket and Rope	Old well
	7	Poorly organized	Communal	Unprotected	Bucket and Rope	
	5	Poorly organized	Communal	Unprotected	Bucket and Rope	Next to pit latrine
	3	Poorly organized	Communal	Unprotected	Bucket and Rope	
	5	Poorly organized	Communal	Unprotected	Bucket and Rope	

The medium sized farm sizes were visually well planned, organised and landscaped with modern houses. Functional areas, grazing paddocks, cow sheds and utility areas such as the toilets were located in the backhouse and isolated by use of live fences.

Most of the farms and homesteads within the small farm size, were visually poorly planned and organised. The houses were mostly semi-permanent and ranged from one house to about six houses within the homesteads.

The wells within the large farm sizes were privately owned, 30-40ft in depth and were either protected from runoff by a raised construction (parapet) or semi-protected with a concrete wall that was close to the ground surface and covered with iron sheets (Plate 1).

Plate 1: A protected well (parapet) with a hand pump (left) and a Semi-protected well showing the laundry activities and vegetable garden within the well vicinity a Large Farm Size

The wells within the medium farm sizes had both protected and semi-protected constructions around the well (Plate 2). Kaptagat ward, where the medium sized farms

Plate 2: Semi-protected wells within the medium farm system surrounded by a vegetable garden(left) and maize production(right) in the vicinity of the well.

were located was generally flat with gentle slopes in some parts hence pollution from runoff may not be a common occurrence.

Plate 3: Protected wells within the medium farm sizes showing modes of water extraction of a windmill (left) and bucket/rope extraction methods (right).

Wells within the small farm sizes were communally owned, shallow and unprotected making them vulnerable to pollution from runoff (Plate 4). Water extraction from the wells was done by use of hand buckets and cans because the water wells were very shallow and the water level was always high.

Plate 4: Shallow unprotected communal wells used for both home water consumption and also for watering cattle in the small mixed farm system

Within the small farm sizes the general terrain sloped towards the wells and livestock were tethered to graze and were also watered in the well vicinity. This consequently littered the area around the well with animal excreta (Plate 5).

Plate 5: A communal shallow well within the small farm system showing livestock grazing (left) and cow dung (right) within the vicinity of the well.

It was apparent that the water table in the region of the small mixed farm sizes of Olare ward was mostly high and therefore the wells were shallow and remained full throughout the wet and dry season (Plate 6).

Plate 6: Flooded fields (left) in a small mixed farm in Olare ward showing the visibly high water table (right).

These wells were located at the bottom of the terrains or slopes which facilitated drainage and runoff down slope into the wells. Observation of the maize crop around the area around the well showed significant N fertilizer deficiency as shown in Plate 7.

Plate 7: The road to a communal well in the small mixed farm system showing common N deficiency symptoms on the maize crop on the right.

The CRS did not significantly affect the nitrate-N and ammonium-N concentrations in groundwater but there were highly significant differences between the nitrite levels (Table 11). The regression analysis showed non-significant relationships between the well CRS and the nitrate-N and ammonium-N concentrations in the sampled groundwater but a significant relationship with nitrite-N (Table 11).

There were no clearly identifiable trends in nitrate-N, nitrite-N and ammonium-N concentration in groundwater in relation to the CRS. The N fertilizer application rates for the maize crop in the large, medium and small farm sizes were 917kg, 355kg and 77 kg N/year respectively. However the groundwater nitrate-N, nitrite-N and ammonium-N concentrations did not correspond significantly to neither the fertilizer amount applied nor the CRS (Table 12). It was however noted that nitrogen concentration in groundwater was generally higher in the small farm system than would be expected despite the lower fertilizer application.

Table 11: Relationship between the Contamination Risk Score of well water and Nitrogen concentration averaged across the different farm sizes

	Nitrogen Concentration in sampled well water		
Contamination Risk Score (CRS)	Nitrate-N (µg/l)	Nitrite-N (µg/l)	Ammonium-N (µg/l)
0	55.03ab	32.89a	50.58ab
1	47.35ab	28.96ab	56.16ab
2	37.01b	10.33c	55.89ab
5	54.81ab	20.03bc	63.10a
6	48.91ab	18.72bc	70.08ab
7	41.38ab	19.17bc	45.47b
8	41.78ab	18.49bc	74.92ab
9	63.25a	25.04ab	62.66ab
10	36.84b	12.69c	48.08ab
11	48.53ab	18.93bc	63.17b
LSD	22.82	10.23	36.28
P-Value (P ≤.0.05)	0.439ns	0.004***	0.43ns
R^2	0.03	0.08*	0.03

Means followed by the same superscript within a column are not significantly different.
^{ns}, *, ***, Non-significant, significant at P≤ 0.05, 0.001, respectively

Table 12: Summary Table of the average nitrogen concentration in groundwater, CRS and annual N fertilizer application in the three farm sizes in Ainabkoi.

Farm System	Nitrate-N (μg/l)	Nitrite-N (μg/l)	Ammonium-N (μg/l)	N fertilizer (Kg/year)	CRS
Large	50.27	23.73	71.33	917^a	IR^a
Medium	47.56	19.28	65.98	355^b	IR^a
Small	47.63	18.84	56.55	77^c	VHR^b
LSD	12.26	5.77	19.43	68.08	0.15
Significance (P≤0.05)	ns	ns	ns	***	***
R^2	0.00067	0.0092	0.0073	0.64	0.87

Means followed by the same superscript within a column are not significantly different.
^{ns}, ***, Non-significant, highly significant at P≤ 0.05

8.5 Discussion

The results showed that farm characteristics can influence the SRF associated with individual wells and consequently the CRS. The differences in well contamination risk in the different farm sizes could have been due to individual farm endowments and ownership of the wells. In the large and medium farm sizes wells were privately owned and therefore it was apparent that efforts were made to maintain the sanitary standards of the well. However wells within the small farm sizes were 100% communally owned and this may have contributed to the degradation of the area within the vicinity of the wells because the well was communally accessed by more people. This indicated that the people were either ignorant of the dangers associated with SRF or that the people/community could not control the use of communal property. The high percentage of wells located in positions where they are prone to pollution from the vicinity signifies that the well sanitary risk was not of importance in choice of its ward. Similar results were reported by Abdulsalam and Zubairu, (2013) who reported that 80% of the wells were within 10m of the latrines and 70% were very close to the source of pollution indicating the indiscriminate positioning of wells in relation to sanitary risk.

The raised construction on the wells reduced the likelihood of contamination from pollutants in the well vicinity however the semi-protected wells were subject to runoff such as during the rainy season even though they had lid covers that helped reduce entry of surface flow of water into the well. The fact that the wells were not protected and that the terrain slopes towards the wells were major predisposing factors to the sanitary risks of the wells. The Large and Medium mixed farm size wells have an Intermediate

Contamination Risk Score because most wells are protected and homesteads were moderately organised such that the well vicinity was relatively clean. This concurs with results by Llopis-Gonzalez, Sanchez, Marti-Requena & Suarez-Varela, (2014) who reported significant differences between percentages of protected and unprotected wells with regard to risk factors.

The wells within the small farm sizes were shallow due to the high water table within the area of Olare unlike the low water table found in the large and medium farm system areas of Ainabkoi and Kaptagat. Llopis-Gonzallez *et al*., (2014), also reported that the depths of wells at high risk of contamination ranged from 0 to 300m and therefore making deeper wells have an increased ability to filter contaminants through different soil layers. Kibona, Mkoma, & Mjemah, (2011) observed a decrease in nitrates with increase in well depth, with high nitrate concentrations occurring mainly in wells with depths less than 41m. They attributed it to anoxic conditions in the deeper wells where the oxygen levels are depleted and reduction of other electron acceptors such as NO_3^- become energetically favorable. According to Hallberg (1989), groundwater nitrate contamination is often detected in aquifers less than 30m deep because the major nitrate sources occur at the surface and there is a delay in the migration of nitrates

The results showed that NO_3-N, NO_2-N and NH_4-N concentrations in the wells did not exceed the statutory Kenyan and WHO guiding limits of 10mg/l, 3 mg/l, and 0.5 mg/l respectively for drinking water (WHO, 2008; & Republic of Kenya (ROK 2006). Although the results showed highly significant differences in well CRS in the different farm sizes, the CRS could not adequately explain the nitrogen concentration in groundwater. This generally weak and non-significant relationships between CRS and nitrate-N, nitrite-N and ammonium-N concentrations in the sampled well water could be attributed to other factors that affect their concentration levels. Such factors include rainfall, fertilizer nitrogen application, and site specific factors such as, proximity of wells to pit latrines, other sources of pollution (livestock excreta, manure piles, livestock feed lots, farm wastes), well depth, sloping terrain in the well vicinity and the susceptibility to runoff. Notably, at zero (0) CRS there were nitrogen concentrations in groundwater wells. These results are different from those observed in a study of Nigerian wells (Oloruntoba, Sridhar, Alabi, & Adebowal, 2013) whereby the wells had high nitrate concentrations due to several sanitary risk factors (SRF), such as closeness to sources of pollution, septic tanks, lack of sanitary features such as cover, apron and well lining. Bolger and Steven, (1999) reported that nitrate contamination pattern suggest that there are high concentrations of nitrate are associated with grazing in the area. A common assumption is that groundwater is suggested to be at risk of contamination due to the overlying land use or management activity (Ledgard, Clarke, Sprosen, Brier, & Nemaia, 1996).

It would be expected that the contribution of the small mixed farm sizes to N contribution would significantly be the lowest. However the N concentration from these farms would sometimes exceed that of the medium and large farm sizes which is indicative that there are other sources of N concentration in groundwater or factors affecting the N concentration. It was observed that wells within the small mixed farm sizes were communal water sources, without any protection, were very shallow and located down slope. The water levels in these wells did not recede like in the other wells ever during the dry season. Rain water flowed into these wells collecting any debris and waste into the wells. These well characteristics would most certainly contribute to the higher N concentration levels even though total annual N fertilizer application in the farm sizes were generally low. These results are similar to findings by Ju *et al*, (2006) who also found that shallow wells were more severely polluted especially under vegetable cropping systems that have high N fertilizer application. According to Laftouhi *et al*. (2003) the nitrate concentration in groundwater is normally low but can reach very high levels as a result of leaching or runoff from agricultural land together with contamination from human or animal wastes. The maize crop close to the well in the small farm sizes showed N deficiency symptoms probably due to leaching down the soil profile and down the slope. However, these predisposing conditions did not increase N concentration in groundwater beyond the maximum allowed limit probably due to other geological conditions such as water flow, mixing and dilution. A widely held precept in groundwater hydrology is that water flows downslope along the gradient of the groundwater surface or water table and this gradient generally conforms to the surface contours (Rutkoviene, *et al*., 2005). Therefore, this affects well water because pollutants are carried down slope by runoff or general water flow. This tenet explains the high sanitary risk of wells found within the large and small farm sizes whereby the land slopes towards the well vicinity unlike in the medium farm sizes of Kaptagat ward where the farm lands are generally flat. Runoff down slope may introduce pollutants such as nitrates from fertilizers applied in the farms, animal excreta, organic waste, inorganic wastes. This explains why wells in the small farm sizes tended to have higher than expected nitrate levels despite the low fertilizer N application rates. These wells have a very high sanitary risk because they are found downslope and are not protected by raised construction. Livestock are often tethered and watered within the well vicinity, hence any animal wastes are washed into the wells from runoff down slope. Water quality in wells is highly influenced by pollutants moving from upslope in the vicinity of the well. The deeper wells of the large farm sizes tended to have relatively lower than expected nitrate concentration which may be attribute to the below surface groundwater flow. It was observed that the water level in these wells frequently fluctuated with rainfall amount received unlike in the shallow wells whose water level remained noticeably visible.

It is commonly accepted that nitrate generally behaves as a conservative solute. Once it enters the soil and groundwater system there is very limited potential for a reduction in the nitrogen concentration (Bolger and Stevens, 1999). Therefore, if current management of nitrogen sources continues, there is potential for increased increase of nitrate to aquifers and increases in both nitrate concentrations and in the extent of wells affected (Bolger and Stevens, 1999).

8.6 Conclusion

From this study it was apparent that there are multiple pollution point sources and risk factors that may determine the potential for environmental degradation on groundwater quality. Since there are so many possibilities of well water pollution it is difficult to pinpoint sources of nitrogen. Even though the N concentrations in groundwater did not exceed the maximum allowable limit, it may not indicate that there are no times when the N concentrations are high. It was concluded that the most important risk factors to the wells are the well protection and the activities within the well vicinity. The source of groundwater nitrate concentration pollution comes from a variety of factors including the fertilizer application rates, well protection, well depth, groundwater level fluctuations and recharge conditions of the groundwater.

8.7 Recommendations

The identification of areas or sources of nitrogen loading into groundwater from point and non-point sources is important for decision makers in implementing preventive or correctional measures to minimize the risk of nitrate leaching into groundwater. There is need for a local county initiative to construct protective raised wall at the communal wells and educate farmers on aspects of water quality.

8.8 References

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APPENDICES

Appendix I: Farmer Questionnaire

INTRODUCTORY LETTER

Dear Respondent,

I am a PhD Student at Egerton University. I am conducting a study on **NITROGEN LOADING AND GROUNDWATER CONTAMINATION: COMPARISON AMONG DIFFERENT FARM SIZES IN AINABKOI SUB-COUNTY.**

I therefore wish to request you to kindly spare some time and answer the questions below as honestly as possible by ticking or filling in the spaces provided.

The information given will be purely for academic purposes and will be treated confidentially. Ultimately, the findings of the study will make suitable recommendation to assist the farmers get insight into the well water quality.

Thank you for your cooperation.

Part 1: GENERAL INFORMATION

1. Farmer/Family name
(optional)____

2. Subward ____

3. What is the total acreage of the farm? (Tick the appropriate acreage range)
   a. Less than 5 acres
   b. 5-10 acres
   c. 10-15 acres
   d. More than 20 acre
4. Of the Total Acreage, about how much is under crop maize production?

____

5. How many years have you lived and farmed on the farm? Circle appropriately
   Less than 2 years 2-10 years more than 10 years

6. What is the approximate average size of your homestead? Tick the appropriate acreage range.

	Approximate Homestead acreage	**Tick**
1	Greater than 3 acres	
2	About 3 acres	
3	About 2 acres	
4	About 1 acre	
5	Less than 1acre	

Part II: WATER SOURCES

1). What is the **MAIN** source of water for your domestic use? (Circle the appropriate one)

Privately owned Well
Communally owned well
Municipal Tap Water
River
Roof Rain water catchment
Any Other (specify) ____

2). If your main water source is a well or borehole, is it within your farm?

Yes ☐
No ☐

3). If your main water source is not within your farm about how far is it?

____

5). Give a list of the various uses of the well water in your household.

____

____

____

6). If your water source is a well, please respond to the following questions.

i. How old is the well. _____________________
ii. Approximately how deep is the well? ________________________
iii. Give a list of the various uses of the well water in your household

____

____

____

Part III: **CROP PRODUCTION AND MANAGEMENT**

1). What crops do you grow? Make a complete list.

____

____

____

____

2). What do you consider to be the main crop that you grow?

____

3). Indicate the acreage for the crops and forage/pastures in your farm.

Crop/Forage/Pastures Types	Proportion (Acreage)	Any Remarks

4). Indicate the number of farm livestock in your farm at the moment.

Livestock	**Number**	**Any Remarks**
Cattle		
Goats and Sheep		
Poultry		
Others		

4). Indicate on the table below when you plant, fertilize, weed, control pests and harvest the crops that you grow.

Select from the following farm activities listed below:

CROP	**CROP HUSBANDRY BY MONTH**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**

i. Field Preparation ii. Planting iii. DAP fertilizer application iv. Topdressing with CAN v. Weeding vi. Harvesting

5) What fertilizer types do you use for each crop

Crop	Type of fertilizer applied	When fertilizer is applied (Month or Crop stage)

6). How do you handle crop and animal WASTE PRODUCTS on your farm?

FARM YARD MANURE(e.g cowdung, maize stocks, chicken waste, sheepdung, uprooted weeds etc)	**HANDLING OR DISPOSAL METHOD**

7). Please Rate the level of fertility of your farm according to your perception and experiences. Tick the appropriate answer.

Very fertile ☐

Moderately fertile ☐

Low fertility ☐

8. Any other comments? (Optional)

____
____
____
____
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____

Appendix II Analysis of Variance of Farm sizes

The GLM Procedure

```
Dependent Variable: Farm Acreage

                                           Sum of
   Source                      DF          Squares     Mean Square    F Value    Pr > F

   Model                        2      118812.0615      59406.0308     927.92    <.0001

   Error                      309       19782.4000         64.0207

   Corrected Total            311      138594.4615

                 R-Square     Coeff Var      Root MSE    Farmacreage Mean

                 0.857264      36.88540      8.001294            21.69231

   Source                      DF        Type I SS     Mean Square    F Value    Pr > F

   Farmsystem                   2      118812.0615      59406.0308     927.92    <.0001

   Source                      DF      Type III SS     Mean Square    F Value    Pr > F

   Farmsystem                   2      118812.0615      59406.0308     927.92    <.0001
```

```
Dependent Variable: maize Acreage

                                           Sum of
   Source                      DF          Squares     Mean Square    F Value    Pr > F

   Model                        2      43685.41538     21842.70769     483.23    <.0001

   Error                      309      13967.20000        45.20129

   Corrected Total            311      57652.61538

                R-Square     Coeff Var      Root MSE    maizeacreage Mean

                0.757735      50.37549      6.723191             13.34615

   Source                      DF        Type I SS     Mean Square    F Value    Pr > F

   Farmsystem                   2      43685.41538     21842.70769     483.23    <.0001

   Source                      DF      Type III SS     Mean Square    F Value    Pr > F

   Farmsystem                   2      43685.41538     21842.70769     483.23    <.0001
```

```
Dependent Variable: well depth

                                           Sum of
   Source                      DF          Squares     Mean Square    F Value    Pr > F

   Model                        2      42173.04615     21086.52308     320.20    <.0001

   Error                      309      20348.80000        65.85372

   Corrected Total            311      62521.84615
```

```
                  R-Square     Coeff Var      Root MSE    welldepth Mean

                  0.674533      37.94798      8.115031          21.38462


   Source                      DF       Type I SS     Mean Square    F Value    Pr > F

   Farmsystem                   2     42173.04615     21086.52308     320.20    <.0001


   Source                      DF     Type III SS     Mean Square    F Value    Pr > F

   Farmsystem                   2     42173.04615     21086.52308     320.20    <.0001
```

The GLM Procedure

Dependent Variable: Homestead Acreage

```
                                          Sum of
   Source                      DF         Squares     Mean Square    F Value    Pr > F

   Model                        2     624.2461538     312.1230769     988.18    <.0001

   Error                      309      97.6000000       0.3158576

   Corrected Total            311     721.8461538


              R-Square     Coeff Var      Root MSE    Homesteadacreage Mean

              0.864791      23.56825      0.562012                 2.384615


   Source                      DF       Type I SS     Mean Square    F Value    Pr > F

   Farmsystem                   2     624.2461538     312.1230769     988.18    <.0001


   Source                      DF     Type III SS     Mean Square    F Value    Pr > F

   Farmsystem                   2     624.2461538     312.1230769     988.18    <.0001
```

Dependent Variable: Cattle

```
                                          Sum of
   Source                      DF         Squares     Mean Square    F Value    Pr > F

   Model                        2     5084.820513     2542.410256     199.33    <.0001

   Error                      309     3941.166667       12.754585

   Corrected Total            311     9025.987179


                   R-Square     Coeff Var      Root MSE    Cattle Mean

                   0.563353      47.57742      3.571356       7.506410


   Source                      DF       Type I SS     Mean Square    F Value    Pr > F

   Farmsystem                   2     5084.820513     2542.410256     199.33    <.0001


   Source                      DF     Type III SS     Mean Square    F Value    Pr > F

   Farmsystem                   2     5084.820513     2542.410256     199.33    <.0001
```

Dependent Variable: Sheep and goats

```
                                          Sum of
   Source                      DF         Squares     Mean Square    F Value    Pr > F
```

```
   Model                        2      3035.28205      1517.64103      58.06    <.0001

   Error                      309      8076.66667        26.13808

   Corrected Total            311     11111.94872

                 R-Square     Coeff Var      Root MSE    Sheepgoats Mean

                 0.273155      72.90278      5.112541           7.012821

   Source                      DF       Type I SS     Mean Square    F Value    Pr > F

   Farmsystem                   2     3035.282051     1517.641026      58.06    <.0001

   Source                      DF     Type III SS     Mean Square    F Value    Pr > F

   Farmsystem                   2     3035.282051     1517.641026      58.06    <.0001
```

Dependent Variable: Poultry

```
                                           Sum of
   Source                      DF         Squares     Mean Square    F Value    Pr > F

   Model                        2      5027.28205      2513.64103     105.58    <.0001

   Error                      309      7356.66667        23.80798

   Corrected Total            311     12383.94872

                   R-Square     Coeff Var      Root MSE    Poultry Mean

                   0.405951      48.73095      4.879342        10.01282

   Source                      DF       Type I SS     Mean Square    F Value    Pr > F

   Farmsystem                   2     5027.282051     2513.641026     105.58    <.0001

   Source                      DF     Type III SS     Mean Square    F Value    Pr > F

   Farmsystem                   2     5027.282051     2513.641026     105.58    <.0001
```

Appendix III: Analysis of Variance of Farm sizes and Rainfall

```
The GLM Procedure
Class Level Information

Class         Levels  Values

PPT               12  23.4 27.8 85.3 95.3 97.6 115.7 133.1 192.2 202.6 299.8 301.4 427.1

Farmsystem         3  1 2 3


Number of observations    156

The GLM Procedure

Dependent Variable: Nitrate

                                        Sum of
   Source                      DF         Squares     Mean Square    F Value    Pr > F

   Model                       35     311047.5010       8887.0715      10.04    <.0001

   Error                      120     106172.0148        884.7668

   Corrected Total            155     417219.5158


                   R-Square     Coeff Var      Root MSE    Nitrate Mean

                   0.745525      52.96867      29.74503        56.15590


   Source                      DF       Type I SS     Mean Square    F Value    Pr > F

   PPT                         11     283808.7399      25800.7945      29.16    <.0001
   Farmsystem                   2         24.3000         12.1500       0.01    0.9864
   PPT*Farmsystem              22      27214.4611       1237.0210       1.40    0.1289


   Source                      DF     Type III SS     Mean Square    F Value    Pr > F

   PPT                         11     278811.1429      25346.4675      28.65    <.0001
   Farmsystem                   2         24.3000         12.1500       0.01    0.9864
   PPT*Farmsystem              22      27214.4611       1237.0210       1.40    0.1289

Dependent Variable: Ammonium

                                        Sum of
   Source                      DF         Squares     Mean Square    F Value    Pr > F

   Model                       35     181440.9083       5184.0260       2.87    <.0001

   Error                      120     216747.3066       1806.2276

   Corrected Total            155     398188.2149


                  R-Square     Coeff Var      Root MSE    Ammonium Mean

                  0.455666      73.10388      42.49974         58.13609


   Source                      DF       Type I SS     Mean Square    F Value    Pr > F

   PPT                         11     120628.5888      10966.2353       6.07    <.0001
   Farmsystem                   2       4661.1945       2330.5973       1.29    0.2790
   PPT*Farmsystem              22      56151.1249       2552.3239       1.41    0.1217


   Source                      DF     Type III SS     Mean Square    F Value    Pr > F
```

```
   PPT                        11     124613.5068      11328.5006       6.27    <.0001
   Farmsystem                  2       4661.1945       2330.5973       1.29    0.2790
   PPT*Farmsystem             22      56151.1249       2552.3239       1.41    0.1217
```

The GLM Procedure

Dependent Variable: Nitrite

```
                                          Sum of
   Source                     DF         Squares     Mean Square    F Value    Pr > F

   Model                      35     29423.66749       840.67621       2.13    0.0014

   Error                     120     47431.54736       395.26289

   Corrected Total           155     76855.21485


                   R-Square     Coeff Var      Root MSE    Nitrite Mean

                   0.382845      95.90288      19.88122        20.73058


   Source                     DF       Type I SS     Mean Square    F Value    Pr > F

   PPT                        11     19411.91002      1764.71909       4.46    <.0001
   Farmsystem                  2       503.35497       251.67748       0.64    0.5308
   PPT*Farmsystem             22      9508.40250       432.20011       1.09    0.3633


   Source                     DF     Type III SS     Mean Square    F Value    Pr > F

   PPT                        11     18248.39396      1658.94491       4.20    <.0001
   Farmsystem                  2       503.35497       251.67748       0.64    0.5308
   PPT*Farmsystem             22      9508.40250       432.20011       1.09    0.3633
```

t Tests (LSD) for Nitrate

```
  NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise
                                       error rate.


                          Alpha                              0.05
                          Error Degrees of Freedom            120
                          Error Mean Square              884.7668
                          Critical Value of t             1.97993
                          Least Significant Difference     23.1


              Means with the same letter are not significantly different.


                         t Grouping          Mean      N    PPT

                              A            183.86     13    427.1

                              B             73.81     13    133.1
                              B
                         C    B             63.39     13    301.4
                         C    B
                         C    B             59.90     13    192.2
                         C    B
                         C    B    D        56.34     13    115.7
                         C    B    D
                         C    B    D        53.52     13    23.4
                         C         D
                         C         D        50.53     13    27.8
                         C         D
                         C         D        44.64     13    85.3
                                   D
                              E    D        36.50     13    299.8
                              E
                              E             20.28     13    95.3
```

```
                           E
                           E              16.95     13    202.6
                           E
                           E              14.15     13    97.6
```

t Tests (LSD) for Ammonium

```
NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise
                                     error rate.


                        Alpha                            0.05
                        Error Degrees of Freedom          120
                        Error Mean Square            1806.228
                        Critical Value of t           1.97993
                        Least Significant Difference   33.005


              Means with the same letter are not significantly different.


                       t Grouping             Mean      N    PPT

                              A             124.98     13    97.6

                              B              91.58     13    192.2
                              B
                    C         B              77.68     13    299.8
                    C         B
                    C         B    D         67.10     13    133.1
                    C         B    D
                    C    E    B    D         64.26     13    427.1
                    C    E         D
                    C    E    F    D         55.20     13    202.6
                    C    E    F    D
                    C    E    F    D         49.10     13    95.3
                         E    F    D
                         E    F    D         39.34     13    301.4
                         E    F    D
                         E    F    D         34.42     13    23.4
                         E    F
                         E    F              33.69     13    85.3
                         E    F
                         E    F              33.43     13    115.7
                              F
                              F              26.85     13    27.8
```

t Tests (LSD) for Nitrite

```
NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise
                                     error rate.


                        Alpha                            0.05
                        Error Degrees of Freedom          120
                        Error Mean Square            395.2629
                        Critical Value of t           1.97993
                        Least Significant Difference    15.44


             Means with the same letter are not significantly different.


                      t Grouping           Mean      N    PPT

                           A             39.177     13    133.1
                           A
                           A             33.560     13    85.3
                           A
                      B    A             31.163     13    299.8
                      B    A
                      B    A             30.985     13    301.4
                      B    A
```

```
                      B    A    C        27.260     13    27.8
                      B         C
                      B    D    C        17.461     13    95.3
                      B    D    C
                      B    D    C        16.888     13    427.1
                      B    D    C
                      B    D    C        16.779     13    192.2
                           D    C
                           D    C        15.387     13    202.6
                           D    C
                           D    C        13.604     13    115.7
                           D
                           D              3.625     13    23.4
                           D
                           D              2.878     13    97.6
```

t Tests (LSD) for Nitrate

```
NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise
                                     error rate.


                        Alpha                            0.05
                        Error Degrees of Freedom          120
                        Error Mean Square            884.7668
                        Critical Value of t           1.97993
                        Least Significant Difference   11.887
                        Harmonic Mean of Cell Sizes  49.09091

                           NOTE: Cell sizes are not equal.


              Means with the same letter are not significantly different.


                t Grouping          Mean      N    Farmsystem

                         A        56.566     36    1
                         A
                         A        56.403     60    2
                         A
                         A        55.663     60    3


                              t Tests (LSD) for Ammonium

NOTE: This test controls the Type I comparison wise error rate, not the experiment wise
                                     error rate.


                        Alpha                            0.05
                        Error Degrees of Freedom          120
                        Error Mean Square            1806.228
                        Critical Value of t           1.97993
                        Least Significant Difference   16.984
                        Harmonic Mean of Cell Sizes  49.09091

                           NOTE: Cell sizes are not equal.


              Means with the same letter are not significantly different.


                t Grouping          Mean      N    Farmsystem

                         A        67.241     36    1
                         A
                         A        57.957     60    2
                         A
                         A        52.852     60    3
```

t Tests (LSD) for Nitrite

```
NOTE: This test controls the Type I comparison wise error rate, not the experiment wise
                                     error rate.


                        Alpha                            0.05
                        Error Degrees of Freedom          120
                        Error Mean Square            395.2629
                        Critical Value of t           1.97993
                        Least Significant Difference   7.9452
                        Harmonic Mean of Cell Sizes  49.09091

                           NOTE: Cell sizes are not equal.


                 Means with the same letter are not significantly different.


                  t Grouping          Mean      N    Farmsystem

                           A        23.342     36    1
                           A
                           A        21.186     60    3
                           A
                           A        18.708     60    2
```

Appendix IV: Sanitary Assessment Form

Sanitary Assessment Form

A. General Information

1. Ward:____
2. Farmer's Name/Farm Size:_______________________________________
3. Date of Assessment:____
4. Name of assessor:____

B. Identification of Sanitary Risk Factors

S/No.	Risk Factors	YES	NO
1	Latrine within 10m of well		
2	Latrine on higher ground than well		
3	Any other source of possible pollution (animal excreta, rubbish, fertilizer)?		
4	Is the well communally owned?		
5	Is the well less than 15ft?		
6	Does the general land terrain slope towards the well?		
7	Is the well vicinity livestock grazing ground?		
8	Is the water extracted by bucket and rope?		
9	Is the well open (Not constructed)?		
10	Is there likelihood of runoff entering the well		
11	Is the garden less than 5m from the well?		
	Total Sanitary Risk Factors Score		

Contamination Risk Score Range:

9-11 = Very High Risk (VHR)
6-8 = High Risk (HR)
3-5 = Intermediate Risk (IR)
0-2 = Low Risk (LR).

Appendix V: Description of Farms and Well characteristics

Farm Size	Approx. Well Depth (ft)	Homestead Organization	Well Ownership	Construction type	Mode of Operation	Notable sanitary characteristic
Large Mixed	40	Highly organized	Family	Protected	Pump	
	30	Moderately organized	Family	Semi-Protected	Bucket and Rope	
	40	Highly organized	Family	Semi-Protected	Bucket and Rope	
	35	Moderately organized	Family	Semi-Protected	Bucket and Rope	
	40	Moderately organized	Family	Semi-Protected	Bucket and Rope	
Medium Mixed	30	Moderately organized	Family	Semi-Protected	Bucket and Rope	
	12	Highly organized	Family	Semi-Protected	Bucket and Rope	
	45	Highly organized	Family	Protected	Pump	
	25	Highly organized	Family	Protected	Pump Windmill	
	18	Highly organized	Family	Semi-Protected	Bucket and Rope	
Small Mixed	18	Moderatly organized	Communal	Protected	Bucket and Rope	Old well
	7	Poorly organized	Communal	Unprotected	Bucket and Rope	
	5	Poorly organized	Communal	Unprotected	Bucket and Rope	Next to pit latrine
	3	Poorly organized	Communal	Unprotected	Bucket and Rope	
	5	Poorly organized	Communal	Unprotected	Bucket and Rope	

Appendix VI: Research Authorization

NATIONAL COMMISSION FOR SCIENCE,
TECHNOLOGY AND INNOVATION

Telephone:+254-20-2213471,
2241349,3310571,2219420
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When replying please quote

NACOSTI, Upper Kabete
Off Waiyaki Way
P.O. Box 30623-00100
NAIROBI-KENYA

Ref: No. **NACOSTI/P/18/48864/26417**

Date: **3rd November, 2018**

Lydia Lucy Mbula Kitonga
Egerton University
P.O. Box 536-20115
NJORO

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on **"*Nitrogen loading and groundwater contamination: Comparison among different farm sizes in Ainabkoi Sub-County, Uasin Gishu County, Kenya*"** I am pleased to inform you that you have been authorized to undertake research in **Uasin Gishu County** for the period ending **30th October, 2019.**

You are advised to report to **the County Commissioner and the County Director of Education, Uasin Gishu County** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

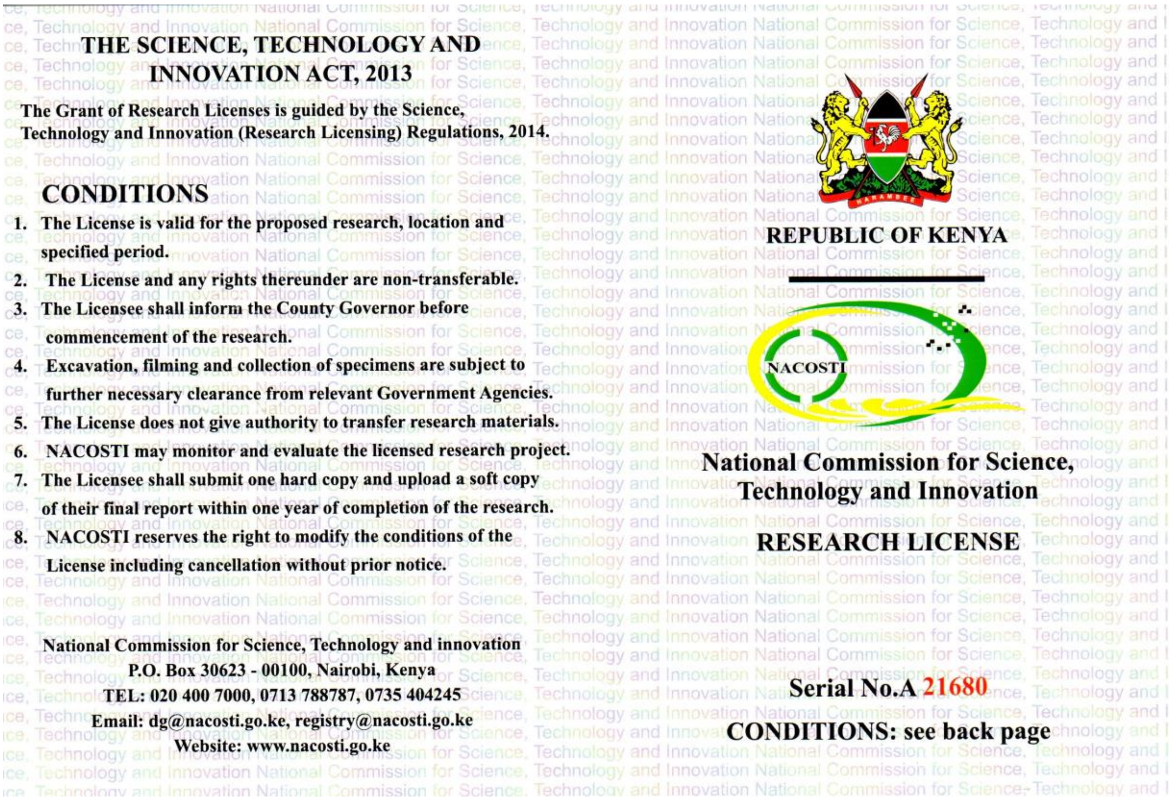
DR. STEPHEN K. KIBIRU, PhD.
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Uasin Gishu County.

The County Director of Education
Uasin Gishu County.

Appendix VII: Research License



THE SCIENCE, TECHNOLOGY AND INNOVATION ACT, 2013

The Grant of Research Licenses is guided by the Science, Technology and Innovation (Research Licensing) Regulations, 2014.

CONDITIONS

1. **The License is valid for the proposed research, location and specified period.**
2. **The License and any rights thereunder are non-transferable.**
3. **The Licensee shall inform the County Governor before commencement of the research.**
4. **Excavation, filming and collection of specimens are subject to further necessary clearance from relevant Government Agencies.**
5. **The License does not give authority to transfer research materials.**
6. **NACOSTI may monitor and evaluate the licensed research project.**
7. **The Licensee shall submit one hard copy and upload a soft copy of their final report within one year of completion of the research.**
8. **NACOSTI reserves the right to modify the conditions of the License including cancellation without prior notice.**

National Commission for Science, Technology and innovation
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REPUBLIC OF KENYA

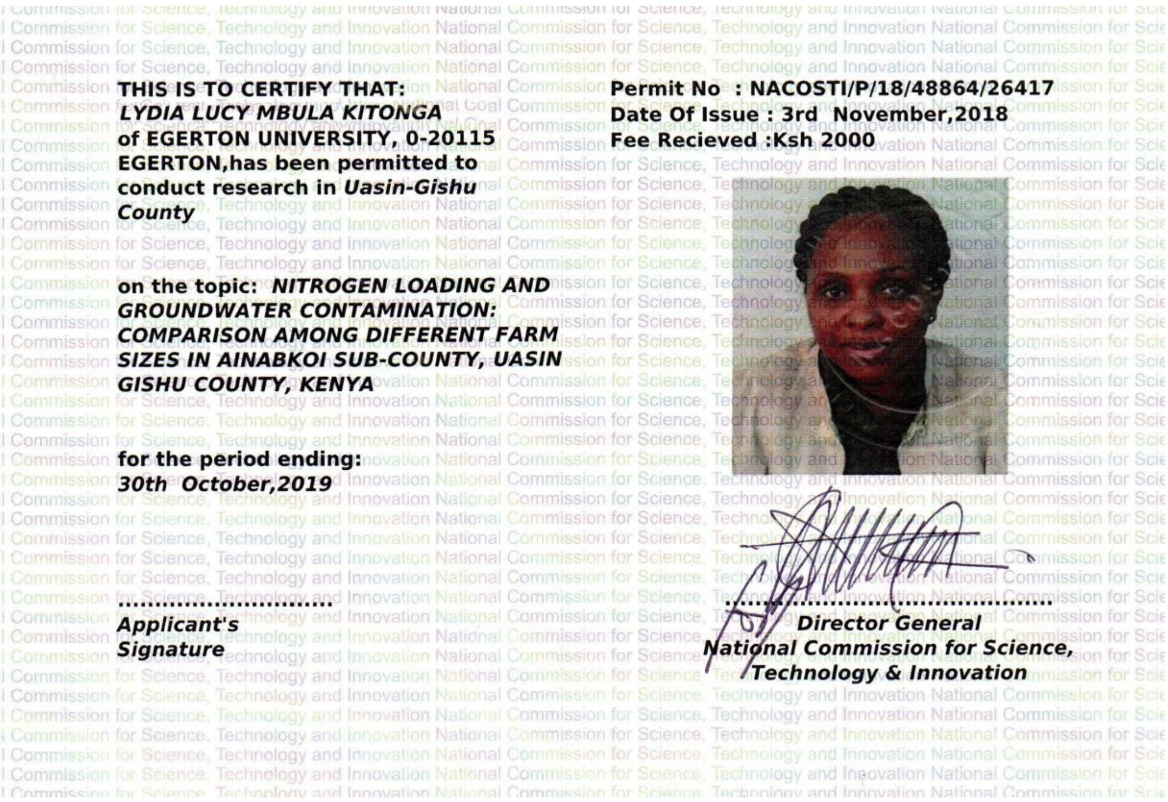
NACOSTI

National Commission for Science, Technology and Innovation

RESEARCH LICENSE

Serial No.A 21680

CONDITIONS: see back page



THIS IS TO CERTIFY THAT:
LYDIA LUCY MBULA KITONGA
of EGERTON UNIVERSITY, 0-20115 EGERTON,has been permitted to conduct research in *Uasin-Gishu County*

on the topic: *NITROGEN LOADING AND GROUNDWATER CONTAMINATION: COMPARISON AMONG DIFFERENT FARM SIZES IN AINABKOI SUB-COUNTY, UASIN GISHU COUNTY, KENYA*

for the period ending:
30th October,2019

Permit No : NACOSTI/P/18/48864/26417
Date Of Issue : 3rd November,2018
Fee Recieved :Ksh 2000

....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation

List of Publications

1. Kitonga, L.M.L, Moturi, W.N. and Mwonga, S.M. and Tabu, I. 2016. Impact of Nitrogen Fertilizer Application on Groundwater Nitrate and Ammonium concentration in different Farm Systems in Ainabkoi, Uasin Gishu County, Kenya. In: Edited by Wanjohi, W., Kyalo, D.W., Nguhiu, P & Gichaga, C. (EDs). *Proceedings of The 2nd Biennial International Conference On Enhancing Sustainable Agricultural Production and Marketing Systems Through Science, Technology and Innovations, pp*303-316. Kenyatta University Printing Press, Nairobi.

2. Kitonga, L.M., Moturi, W.N., Mwonga, S.M. & Taabu, I. 2018. Assessment of Physico-chemical characteristics of groundwater among different farm sizes in Ainabkoi sub-county, Uasin Gishu county, Kenya. *African Journal of Environmental Science and Technology*. 12:8.