LAND USE CHANGE, WATER AVAILABILITY AND ADAPTATION STRATEGIES IN CHANGING AND VARIABLE CLIMATE IN KAJIADO NORTH, KENYA

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DECLARATION

This thesis is my original work and has not been presented for award of a degree/research in any other university.

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

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DEDICATION

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ACRONYMS AND ABBREVIATIONS

ADB Asian Development Bank

ASALs Arid and Semi-Arid Lands

CWR Crop Water Requirement

DDP District Development Plan

FAO Food and Agriculture Organization

FGDs Focus Group Discussions

GDP Gross Domestic Product

GIS Geographic Information System

GoK Government of Kenya

GPS Global Positioning System

IPCC Inter-governmental Panel on Climate Change

PGIS Participatory GIS

RELMA Regional Land Management Unit

SSA Sub-Saharan Africa

TISDA Transparency and Integrity Service Delivery in Africa

TISDA Transparency and Integrity Service Delivery in Africa

UNDP United Nations Development Programme

UNEP United Nations Environmental Programme

UNICEF United Nations Children’s Fund

ABSTRACT

Water is a fundamental natural resource for all life on the planet, as both social and economic activities depend heavily on water. In Kenya like many other countries in sub Saharan Africa, water resources are becoming scarce due to climate change, change in land use and high population growth. The study was conducted in Kajiado North with principal objectives of (a) determining the magnitude and pattern of land use changes that have occurred in the past 20 years in Kajiado North (b) assessing the effect of climate change and variability on water resources and (c) assessing the perception of rainwater harvesting as a coping strategy to climate change and variability. A semi-structured questionnaire was administered to 220 respondents chosen randomly in Isinya and Ngong' sub-counties to explore the perceptions about rainwater harvesting and the data analyzed using the Statistical Package for Social Scientists (SPSS). To determine the magnitude and pattern of land use change, Participatory GIS (PGIS) and focus group discussions were conducted from 4 sub locations within the study area and the PGIS maps subjected to Arc view software and Map info for analysis. Results from PGIS maps revealed significant increase in settlement of 3.75% from 1990-2000 and 6.5% from 2000 to 2010 and a significant decrease in grassland of 4.6% from 1990 to 2000 and 7.2% from 2000 to 2010. The main sources of water are boreholes (33.7%), followed by piped water (25.5%) and rainwater harvesting was 15.8%. Climate change has affected water resources through drought (30%), runoff and erosion (21%) and increased evaporation (20%). 100% of the respondents have heard about rain water harvesting in one way or the other. 87% of the respondents harvest water. Some harvest it on their households storing it in containers which take less than a month to finish. Majority of the respondents (80.2%) use the harvested water for domestic use, (5.8%) of the harvested water from the tanks is used for irrigating crops and the least (1.4%) is used for

livestock. There was no significant difference on the involvement in rainwater harvesting for both men and women. Only 13% of the residents do not harvest water at all. This is because of lack of equipments and storage facilities. In addition, there is lack of involvement of government and other institutions in rain water harvesting. Based on the results, it was concluded that there is a significant change in land use which has affected the communities both positively and negatively. Climate change has a significant negative impact on agriculture activities in the area as it leads to reduction in crop yields and increased food prices. People are aware of rainwater harvesting but it is not being utilized to its full potential. However the level of income is the major factor that influences the adoption of rain water harvesting at a large scale. The study recommends that there is need for a constant monitoring of land use change for planning purposes, with the change in climate appropriate adaptation are essential as the prices of agricultural commodities are projected to increase in both domestic and world markets. Forming associations on water harvesting and constructing dams at local level as a group can be used as a solution to the water storage problems to improve Agriculture production. However, involvement of institutions, especially for technical expertise would enhance the group water harvesting interventions.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Water is a precious resource that needs to be protected and properly managed so that an adequate supply and acceptable quality of water can satisfy the increasing need for economic production (World Bank, 2006). Water contributes tremendously to development and social well-being of the human population as both social and economic activities rely heavily on the quantity and quality of water. Water is crucial to plant life. Plants are 90% water and to survive plants require water. To grow daily food needs; people require 3000 liters of water per person per day (Mati *et al.*, 2007). However, the agriculture sector is often criticized for high wastage and inefficient use of water at the point of consumption encouraged by subsidized low charges for water use or low energy tariffs for pumping, (FAO, 2004).

Change in land use and climate change has resulted in continuous pressure on the world's water resources (Asian Development Bank, 2002). The world is expected to reach between 7.5 and 10.5 billion people by 2050, (United Nations, 2009). The total usable freshwater supply for ecosystems and humans is about 200 000 km^3 of water, less than 1% of all fresh water resources, (Diop *et al.,* 2002). The United Nations Environmental Programme estimates that by 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under stress conditions, (Alder *et al.,* 2007). Climate change would deeply modify future patterns of both water availability and use, thereby increasing levels of water stress and insecurity, both at the global scale and in sectors that depend on water, (Saunders *et al.,* 2009). Adaptation to climate change and variability is important in agriculture for impact and vulnerability assessment and for the development of climate change and variability policy (Smit and Skinner, 2001).

The Intergovernmental Panel on Climate Change (IPCC) defines climate change as changes in the mean and/or the variability of its properties that persists for an extended period, typically, decades or longer. It is statistically significant decadal variation in either the mean state of the climate or in its variability (IPCC, 2007). Climate variability refers to short-term fluctuations around the mean climate state within an averaging period, typically, 30 years (Hare, 1985).

Kenya is described by the United Nations as a water scarce country where by the water demand exceeds renewable fresh water sources and currently ranks 21st for the worst levels of access to potable water in the world (United Nations, 2009). Climate change, increase in population and change in land use has resulted in water resources degradation which has made people food insecure. Agriculture is the mainstay of the country's economy contributing 29% of Kenya's GDP and about 80% of Kenya's population is employed in the sector, (UNICEF, 2008). About 84% of the country is arid and semi-arid (GoK, 2010). Kenyan vision 2030 strategy aims to conserve water sources and start new ways of harvesting and using rain and underground water (Kenya Vision 2030, 2007).

Rainwater harvesting has been proved to be a sufficient water supply during water restrictions for household needs in Kenya despite climate change, it is a form of managing risks during weather variability, (Aroka, 2010). A 2006 report by the UNEP and World Agro-forestry Centre found that in Africa the rainfall distribution is more than adequate to meet the needs of the current population, and that water crisis is more of an economic problem from lack of investment.

Kajiado North is one of the peri-urban areas of Kenya in desperate need of clean and safe water for agricultural production. In recent years there have been long periods of drought when there has been little or no rain and pressure on water resources by people migrating to this area. This hampers efforts to encourage agriculture as an alternative to livestock production, (Bouwer, 2000).

1.2 Statement of the problem

Land use change and climate change brought about by drought has led to reduced availability of water resources especially the permanent rivers in the area (UNDP, 2007). Kajiado is a semi-arid area of Kenya and therefore access to water has remained a challenge, over the last 50 years, the county has experienced drought which have had a negative impact on the standards of living of the communities (Government of Kenya, 2007). Its population has increased rapidly over the years with an estimated growth of 4.5% due to migration from other parts of Kenya and the bordering areas of Tanzania, (Kajiado DDP 2002). The government of Kenya does not have the sufficient funds to maintain strong piping systems, and about 80% of Kenya’s water resources are completely unprotected (UNDP, 2007). The pressure brought about by population continues to increase while the economy and resources struggle to keep up putting pressure on water resources through agriculture, land and energy uses.

1.3 Justification of the study

The changes in land use and the variability of weather patterns has reduced the agricultural yield in Kajiado North because it is putting pressure on the available natural resources including water. The growing concern on food security is that water resources are being degrades due to climate change, leading to a reduction in both quality and quantity of water. With the increase in population doubling every year, if the water problem is not addressed there is going to be a tremendous decrease in agriculture production and other income generating activities. Although many programs and projects in Kenya aim to modernize agriculture and double the food supply by emphasizing on different mechanisms, most of the technologies are often not customized to meet the needs and present conditions of smallholder farmers who are the majority of the population.

However many future impacts of climate change can be reduced or avoided if the necessary adaptation and coping strategies are implemented. Collecting rainwater for example is an established practice in Africa. Rainwater is an increasingly promising complement to other sources of household water, especially in the face of rising demand and drought. Although there has been progress in achieving some of the water-related Millennium Development Goals (MDGs) in certain counties and regions including Kenya, much work remains, particularly to address the special needs of most vulnerable members of society, women and children who bear the brunt of poverty worldwide.

This study will point out the potential water sources, the magnitude of land use change and analyze the potential of water harvesting as a coping and adaptation strategy to climate change and variability in Kajiado north district. The community has different demands from land and water resources that result into conflicts, this study will help in creating awareness to the policy makers on the main sources of water in Kajiado and how they can use it.

1.4 Research objectives

1.4.1 Overall objective

To contribute towards alleviating water scarcity through promoting rainwater harvesting and sustainable water conservation measures in Kajiado North, Kenya

1.4.2 Specific objectives

1. To determine the magnitude and pattern of land use changes that have occurred in the past 20 years
2. To assess the effect of climate change and variability on water resources
3. To assess the perception of rainwater harvesting as a coping strategy to climate change and variability

1.5 Research questions

1. How has the land use changed in Kajiado north in the last 20 years?
2. What are the effects of land use change, and climate change and variability on water resources?
3. What is the perception of rainwater harvesting in the area?
4. How is rainwater harvesting used to cope to climate change?

CHAPTER TWO: LITERATURE REVIEW

2.1 Global climate change

Models of climate change (GCMs) predict U.S. annual- mean temperatures to generally rise by 2° C to 3° C over the next 100 years, with greater increases in northern regions (5° C), and northern Alaska (10° C). Numerous other climatic effects are also expected. For example, U.S. precipitation, which increased by 5 to 10% over the 20th century, is predicted to continue to increase overall. More specifically, an ensemble of GCMs predicts a 20% increase for northern North America, a 15% increase in winter precipitation for northwestern regions, and a general increase in winter precipitation for central and eastern regions (Chase *et al.,* 2003).

Despite predictions of increased precipitation in most regions, net decreases in water availability are expected in those areas, due to offsetting increases in evaporation (Boko *et al.*, 2007). A 20% decrease in summer precipitation, for example, is projected for southwestern regions, and a general decrease in summer precipitation is projected for southern areas. Although projected regional impacts of climate change are highly variable between models, the above impacts are consistent across models. In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans (Falkenmark, 2003). Evidence of climate-change impacts is strongest and most comprehensive for natural systems. Some impacts on human systems have also been attributed to climate change, with a major or minor contribution of climate change distinguishable from other influences (Kabat *et al.,* 2003).

Some studies showing positive impacts relate mainly to high latitude regions, though it is not yet clear whether the balance of impacts has been negative or positive in these regions. Climate change has negatively affected wheat and maize yields for many regions and in the global aggregate. Effects on rice and soybean yield have been smaller in major production regions and globally, with a median change of zero across all available data (Houghton and Skole, 1990). Observed impacts relate mainly to production aspects of food security rather than access or other components of food security. Several periods of rapid food and cereal price increases following climate extremes in key producing regions indicate a sensitivity of current markets to climate extremes among other factors (IPCC, 2001).

2.2 Climate change in sub-Saharan Africa

Approximately 80 percent of poor people in Sub-Saharan Africa continue to depend on the agricultural sector for their livelihoods (Kurukulasuriya *et al.*, 2006)). However unlike in other regions of the world, agriculture in Sub-Saharan Africa is characterized by very low yields due to agro-ecological features, poor access to services, lack of knowledge and inputs, and low levels of investment in infrastructure and irrigation. In addition, high population growth rates, especially in rural areas, intensify pressure on agricultural production and natural resources and further complicate the challenge of reducing poverty (Loveland *et al.*, 1990). Against this background, potential climate change poses a significant additional challenge to the future of agriculture in the region. Climate change could cause serious deterioration of rural livelihoods and increase food insecurity in Sub-Saharan Africa. Given these multiple challenges, the region's smallholders and pastoralists must adapt, in particular by adopting technologies to increase productivity and the stability and resilience of their production systems (Olomoda, 2003).

The Fourth Assessment Report of the IPCC highlighted the vulnerability of African agriculture and all who depend on it for food security and livelihoods (IPCC 2007). Agriculture will be affected by reduced growing seasons and higher temperatures. The IPCC predicted that rain-fed crop yields in some countries will decrease by 50 percent, and that an estimated 50-250 million Africans will face increased water stress by 2020. With only about 6 percent of African crop lands irrigated, the impacts on smallholders could be catastrophic. These direct effects on agricultural production and food security will be exacerbated by greater exposure to malaria and other climate-influenced diseases that reduce labor productivity and employment opportunities. According to FAO (2007), agricultural production and the biophysical, political and social systems that determine food security in Africa are expected to be placed under considerable additional stress by climate change (FAO, 2007). It is anticipated that adverse impacts on agriculture sector will exacerbate the incidence of rural poverty (Dinar *et al.* 2008) Africa has done the least to contribute to climate change, but will be hit hard by its impacts. Africa already has a highly variable and unpredictable climate, and many countries are ill-equipped to respond to existing climate pressures, such as periodic floods and drought. In 2002, 13 million people in southern Africa needed food relief due to drought (Pielke *et al.,* 2002). The frequency and intensity of extreme weather in Africa is predicted to increase as a result of climate change. The impacts on a continent in which 333 million people already live in extreme poverty threaten to be devastating. Agricultural production, on which two out of three Africans rely for their living, is projected to be severely compromised by climate change (Ramankutty, 1999).

More frequent floods and drought could reduce agricultural yields, affecting food supplies. Climate change will also affect the supply and quality of water in Africa (Pitman *et al.*, 2004). Around 300 million people more than 40% of sub-Saharan Africa’s population currently lack access to safe drinking water. By 2020, an additional 75-250 million people could find water supplies are more unreliable (Climate change could also change patterns of disease, increasing pressure on underdeveloped health systems). If no action is taken to help developing countries adapt and plan for the future, climate change threatens to undermine development gains made over the past few decades (Saunders *et al.*, 2009).

2.3 Climate change in Kenya

Kenya is an agricultural based economy, with majority of her people deriving their livelihood from various forms of agriculture, (Smith and Karuga, 2004). As a result, different communities practice various forms of land use based on their social-economic needs and cultural practices and determined mainly by weather patterns, soil fertility, ecology and level of social development.

The increase in population has also resulted in massive land sub divisions in the high and medium potential areas, population pressures and the increased pace and scale of human activities in watersheds are straining water supplies (Republic of Kenya, 2004).

2.3.1 Impact of climate change on water resources

Climate change impacts add to already difficult water management challenges in the arid and semi-arid regions (Alder *et al.,* 2007). More recently technological innovations especially deep tube wells and high-powered pumps significantly altered water management behaviors. Deep tube wells allowed continual, unsustainable drawdown of aquifers as well as access to fossil water, wherever available. Pumps allowed faster abstraction from canals and rivers than previously possible, disrupting historical patterns of consumption (Andares, 2000). As a consequence, the possibility that water resources will limit the socio-economic development of many arid and semi-arid regions has gained credence. Climate change will impact several sectors of the economy and have worldwide ramifications (Bates *et al.,* 2008).

The changes in other parts of the world will impact the economy of arid and semi-arid regions too. Many countries in these regions depend on river flows originating in tropical or temperate regions. The overall water stress will increase (Bouwer, 2000). Climate change is expected to lead to declining precipitation in most parts of the world. But projected temperature increase will imply higher evaporation and drier conditions. Rain is also expected to reduce in frequency but increase in intensity; all these will result in frequent droughts and floods (Dinar *et al.,* 2008).

Additional effects of climate change that have important implications for water resources include increased evaporation rates, a higher proportion of precipitation received as rain, rather than snow, earlier and shorter runoff seasons, increased water temperatures, and decreased water quality in both inland and coastal areas (Diop *et al.*, 2002). Increased evaporation rates are expected to reduce water supplies in many regions. The greatest deficits are expected to occur in the summer, leading to decreased soil moisture levels and more frequent and severe agricultural drought.

Agricultural producers and urban areas are particularly vulnerable, by 2020; yields from rain-fed agriculture could be reduced by as much as 50 percent in some countries (IPCC 2007). This will adversely affect food security and further exacerbate malnutrition and poverty, especially in SSA. The vulnerabilities and anticipated impacts of climate change will be observed at different scales in different countries (IPCC 2001). These heterogeneous and inconsistent data impose serious limitations in constructing scenarios of water resources in response to climate change and land use change.

Several studies on water assessment and impact of climate change have been undertaken in Africa (Kabat *et al.*, 2003, Olomoda 2002, Gyau-Boakye and Tumbulto 2000, Falkenmark 2003 and Gleick 1998). The IPCC (2001) indicates that extreme events, including floods and droughts, are becoming increasingly frequent and severe. Even countries that previously did not experience floods, such as Burkina Faso, have recently reported severe flooding, notably in 2007. IPCC (2001) noted that these challenges include population pressure, problems associated with land use such as erosion/siltation and possible ecological consequences of land use change on the hydrological cycle (Boko *et al*., 2007).

2.3.2 Coping strategies to climate change

Water resource users can reduce the negative effects of water shortages brought by climate change and land use change through a number of strategies. These include revising water storage and release programs for reservoirs, adopting crops and cropping practices that are robust over a wider spectrum of water availability, expanding and adjusting crop insurance programs, adjusting water prices to encourage conservation and the expansion of water supply infrastructure, and supporting water transfer opportunities (Eriksen *et al.,* 2008) The ability to anticipate and efficiently prepare for future water resource management challenges is currently limited, in part, by imprecise regional climate change models and long-term weather forecasts. Uncertainty about future climate conditions makes it more difficult to optimally prepare for and adapt to associated changes in water resource availability and quality (FAO, 2012).

Communities in Sub-Saharan Africa are already experiencing the impacts of climate change in a very real way. These impacts, including rising temperatures, more erratic rainfall and increasing frequency of droughts and floods, have critical consequences for livelihoods, particularly for the poorest households in rural areas (Gleick, 1998). Despite this, vulnerable people across the region are taking action to manage the risks that climate change poses to their livelihoods, and are demanding right action by governments and other actors to support them in these efforts (Kalnay and Cai, 2003).

Developing countries have very different individual circumstances and the specific impacts of climate change on a country depend on the climate it experiences as well as its geographical, social, cultural, economic and political situations (Liniger, 1995). As a result, countries require a diversity of adaptation measures very much depending on individual circumstances. However there are cross cutting issues which apply across countries and regions (Sala *et al.,* 2000). The same sectors are affected by climate change, albeit to differing degrees. These main sectors include: agriculture, water resources, human health, terrestrial ecosystems and biodiversity and coastal zones (Smit and Skinner, 2002).

2.4 Global land use change

Land-use and land-cover changes are so pervasive that, when aggregated globally they affect the key aspects of the Earth System functioning. They directly impact biotic diversity worldwide (Sala *et al*., 2000); contribute to local and regional climate change as well as to global climate warming (Houghton *et al*., 1999); are the primary source of soil degradation (Tolba *et al.*, 1992); and, by altering ecosystem services, affect the ability of biological systems to support human needs (Vitousek *et al.*, 1997).

Such changes also determine, in part, the vulnerability of places and people to climatic, economic or socio-political perturbations (Kasperson *et al*., 1995). Despite improvements in land-cover characterization made possible by earth observing satellites (Loveland *et al.,* 1999), global and regional land covers and, in particular, land uses are poorly enumerated (IPCC, 2000). Scientists recognize, however, that the magnitude of change is large. One estimate, for example, holds that the global expansion of croplands since 1850 has converted some 6millionkm^2 of forests/woodlands and 4.7millionkm^2 of savannas/grasslands/steppes. Within these categories, respectively, 1.5 and 0.6 million km^2 of cropland has been abandoned (Ramankutty and Foley, 1999).

2.5 Land use change in sub Saharan Africa

With the continued growth of the human population, competition for limited land resources has steadily increased over recent years and most countries in sub-Saharan Africa have experienced a progressive expansion of their agriculture and rural settlement, putting so much pressure on water resources (FAO, 2011). Change in land use by humans and the resulting alterations in surface features are major but poorly recognized drivers of long-term global climate patterns (Pielke, 2002). The earth's surface is altered through different ways like urbanization and deforestation. Kalnay and Cai, (2003) estimated 40% of the global temperature rises is coming from land use changes which affect agriculture production in the long run (Kalnary and Cai, 2003).

Many of the water problems worldwide can be traced to land use activities. Change in land use affects water quality, the hydrologic regime, volume of surface runoff and decreasing ground water recharge (UNEP, 1996). This can induce increased flooding and lowered groundwater levels. Large-scale increases in some rural land uses can change the way water moves through the landscape by intercepting water before it reaches waterways, reservoirs and aquifers (The state of Victoria Department of Sustainability and Environment, 2011).

2.6 Land use change in Kenya

The significance of land use change to emissions of Green House Gases is well recognized, with approximately one-third of anthropogenic carbon dioxide emissions since 1850 attributed to land use activities (IPCC, 1997). Likewise, extensive deforestation has been associated with reduced rainfall, reduced cloud formation, and enhanced temperature (Pitman *et al.*, 2004).

According to the Government of Kenya National Water Development Report of 2006, Kenya's water resources have been mismanaged through unsustainable water and land use policies among others. It was added that while proper land use management is central to conserving water resources, it is also a lever for combating global climate change. Reports by Moraa *et al.*, 2012 confirmed that many water problems in Kenya, Kajiado inclusive are caused by lack of a comprehensive land policy: the owning of land in water catchment areas presents the many challenges in the sector as such areas become degraded as the land owner develops the piece of land leading to decreased water flows in rivers (Moraa *et al.*, 2012).

2.7 Land use change in Kajiado

Land use is escalating in Kajiado North District, of Kenya. In the 1960s and 1970s, land used communally by the Maasai was divided into group ranches with title held collectively by ranch members (Behnke, 2011). Some ranches have since been divided into parcels owned by individual members. Other sources of land use intensification include human population growth and immigration, more intensive livestock management and a rapid diversification of livelihood strategies (Western and Nightingale, 2006).

According to the study conducted by Boone Livestock keeping remains the dominant livelihood strategy in the area, even though things are changing because of water scarcity and increase in population. With the changes taking place farmers are now shifting to crop production to sustain their livelihood (Boone *et al.*, 2005).

Rapid human population growth and immigration have amplified food insecurity in Kajiado North district (Kajiado District Strategic Plan, 2005-2010). Land tenure changes have reduced livestock mobility in subdivided areas. Other sources of land use intensification include human population growth and immigration by both Maasai and non-Maasai (Boone, 2005).

Land use is intensifying in southern Kajiado District, Kenya. In the 1960s and 1970s, land used communally by Maasai was divided into group ranches with title held collectively by ranch members (Moraa, 2012). Some ranches have since been divided into parcels owned by individual members. Other sources of land use intensification include human population growth and immigration, more intensive livestock management, and a rapid diversification of livelihood strategies (Munale, 2000).

Livestock keeping remains the dominant livelihood strategy, but many practice rain-fed agriculture, do intensive irrigated agriculture in the swamps, earn wages, or own businesses (Ngigi, 2003). Land use intensification may be an inevitable or even desirable process in Kajiado. However, there are many pathways to intensified use. Pathways will have deleterious effects for some and positive effects for others. Other sources of land use intensification include human population growth and immigration by both Maasai and non-Maasai (Thornton *et al*., 2006).

2.7.1 Impact of land use changes on water resources

Land use changes have potentially large impacts on water resources (Stonestrom et al., 2009). Rapid socio-economic development drives land use changes, which include changes of land use classes, e.g., conversion of cropland to urban area due to urbanization, as well as changes within classes such as a change of crops or crop rotations. Particularly in regions here water availability is limited, land use changes could result in an increase of water scarcity and thus contribute to a deterioration of living conditions. DeFries and Eshleman (2004) underline the importance of understanding the impact of land use change on water resources, which they identify as a key research topic for the decades ahead.

2.8 The use of Participatory GIS in determining land use change

Participatory GIS is a practice in which local communities share their knowledge and opinions to help generate maps to inform management and decision-making (Carver *et al.*, 2001). Participatory GIS fosters discussion and collaboration among stakeholders and can capture important knowledge from underrepresented groups (Elwood, 2002). Due to the changes of land use and the effect it has on water resources, it is necessary to take a look at the present water situation in the area and to conduct scientific studies towards water resource utilization and management (Barndt, 2002). However, critical to this is the need for good information that describes the condition, trend, spatial location, and variability of water resources in the given area (Adjomah, 2010).

Forrester and Cinderby (2000) described Participatory GIS as the practice of gathering data using traditional methods such as interviews, questions, focus groups, all using some form of paper maps to allow participants to record spatial details (Cinderby, 2000). This information is then digitalized so that it can be analyzed and interrogated using the power of the computer GIS software. PGIS is described as 'qualitative data' as it is based on people's knowledge, opinions and perceptions (Al-kodmany, 2000). Also, the location and boundaries of areas that people draw on the community maps may be of varying accuracy levels. PGIS practice is usually geared towards community empowerment through measured, demand-driven, and user-friendly where maps become a major conduit in the process (Chrisman, 1987).

Participatory GIS uses Geographic Information System (GIS) to involve people in planning and design decisions using their spatial knowledge and discussion of virtual or physical, two or three-dimensional maps and visualization aides (Haklay, 2003). The use of Participatory GIS often promotes better integration of social issues with the ecological and technical land use issues (Haining, 1990).

A good PGIS practice is embedded into long-lasting spatial decision-making processes, is flexible, adapts to different socio-cultural and bio-physical environments, depends on multidisciplinary facilitation and skills and builds essentially on visual language (Lake, 1993). The practice integrates several tools and methods, it promotes interactive participation of stakeholders in generating and managing spatial information and it uses information about specific landscapes to facilitate broadly-based decision making processes that support effective communication and community advocacy (Loukaitou-sideris, 1999). PGIS practice could protect traditional knowledge and wisdom from external exploitation.

PGIS studies by several researchers have proved that PGIS has been adopted to protect indigenous land rights (Jarvis and Stearman, 1995; Nietschmann, 1995), mitigate resource conflicts (Kyem 2006), and to assess local needs (Craig and Elwood 1998; Ghose, 2001). Other community-based GIS applications have sought to increase community access to information and resources like water (Elwood 2002; Laituri, 2002) and enable a broader and more effective participation of marginalized groups in the decision making process (Smith and Craglia, 2003; Sawicki and Craig, 1996). GIS and related spatial technologies have therefore become invaluable tools for creating access to information, natural resources, political access and legitimacy to underrepresented groups in the society. Mapping is any method where people are encouraged to use a map or maps in order to communicate their knowledge and ideas more clearly (Smith and Craglia, 2003).

Geographic Information Systems (GIS) are increasingly used for the identification of forestry/wildlife conflicts (Brown *et al.*, 1994); land use conflicts (Carr and Zwick 2007) and local government decision-making (O'Looney 2003). Participatory GIS (PGIS) techniques are also used to capture local community and stakeholder opinions. This application of PGIS is also used in the identification of land use conflicts on a vulnerable coast with a high density of urban settlement.

In African including Kenyan geographic research GIS approaches are also contributing significantly to participatory planning and research as well as urban, environment, population, climatic, land use and natural resource management studies (Kyem, 1999; NRC, 2002; Ottichilo *et al.*, 2002; Wafula 1994). As a tool for measuring change GIS is also enhancing African as well as Kenyan urban studies and research.

2.9 Overview of water resources in the World

Water resources are sources of water that are useful or potentially useful. Uses of water include agricultural, industrial, household, recreational and environmental activities (World Bank, 2009). Rapid population growth, combined with industrialization, urbanization, and agricultural intensification and water intensive lifestyles is resulting in a global water crisis. In 2000, at least 1.1 billion of the world's people about one in five did not have access to safe water. 39 percent of the world's population lives without access to safe water (Tolba and El-Kholy, 1992. Due to rapid population growth, the number of urban dwellers lacking access to safe water increasing (Tumbulto, 2005).

Falling water tables are widespread and cause serious problems, both because they lead to water shortages and, in coastal areas, to salt intrusion (Vitousek *et al.*, 1997). The world supply of freshwater cannot be increased (Wafula, 2010). More and more people are becoming dependent on limited supplies of freshwater that are becoming more polluted. Water security, like food security, is becoming a major national and regional priority in many areas of the world (Wheater and Evans, 2010).

Throughout the world, water resource management will be one of the most important economic and social issues of this century (World Bank 1993). In total, about a quarter of the continent's entire population lives in water-stressed regions (UNEP 1999). Because the amount of available fresh water is relatively finite, increases in population result in corresponding decreases in the per capita water supply, while rising temperatures exacerbate an already alarming situation in Africa (Human Impact Report 2009). In terms of fresh water, annual run-off and water availability are projected to increase by 10-40 percent at high latitudes but to decrease by 10-30 percent over some dry regions at mid-latitudes and in the dry tropics (Falkenmark 2007). This means that agricultural production is projected to be severely compromised in many regions by these trends (UNFCC 2008). According to projections, there will be increasing challenges in terms of increased water stress and areas suitable for agriculture along the margins of semi-arid and arid areas are expected to decrease significantly (Falkenmark 2007).

2.10 Overview of water resources in sub-Saharan Africa

In Sub-Saharan Africa, the amount of water withdrawn for agricultural use amounts to about 3 percent of the internal renewable resources, and only 6 percent of agricultural land is under irrigation (World Bank 2006). This may reflect a low level of development and use of water resources in the continent (AWDR 2006). Annual freshwater withdrawals in East Africa are a small percentage of the total available, ranging from less than 3 percent of the total resources available in Burundi to 12 percent in Rwanda (UNEP 2002). However, despite the low utilization of its renewable freshwater resources (WRI *et al.,* 2000), water is becoming one of the most critical natural resource issues in Africa, and the continent is one of the two regions in the world facing serious water shortages (Hopkins, 1998).

Nearly two thirds of Africans rely on limited water sources prone to high yearly variability (Vörösmarty et al., 2000). Africa's extreme variability of rainfall is reflected in an uneven distribution of surface and groundwater resources, from areas of severe aridity with limited freshwater resources such as the Sahara and Kalahari deserts, to the tropical belt of mid-Africa typified by abundant freshwater resources (UNEP 2008). The availability of water varies considerably, even within countries, and the situation is further complicated by frequent droughts and inappropriate water management programs. The demand for water is increasing rapidly in most countries due to population growth and economic development (AWDR, 2006). Most rivers in Africa traverse semi-arid to arid lands on their way to the coast from the tropics, hence; evaporative losses also are high in comparison to rivers in temperate regions (IPCC, 2001).

There is a significant poor management of water in Africa. Water management can be defined as the planned development, distribution, and use of water resources in accordance with predetermined objectives while respecting both the quantity and quality of water resources (ICID, 2001). Arnell (1999) shows that the greatest reduction in run-off by 2050 will affect the SSA's water withdrawals for agriculture amount to only 3 percent of its total renewable water resources despite the highly spatial and temporal variability of rainfall and resultant low land productivity and crop failures (UNECA, 2001; UNEP, 1999).

2.11 Overview of water resources in Kenya

Kenya as a country is facing a number of serious challenges related to water resources management, some of the challenges include water borne or sanitation diseases and lack of water resources mapping and management, (Pruss-Ustun *et al.*, 2008). There are about 40 million people living in Kenya, of which about 17 million (43 percent) do not have access to clean water (World Bank, 2010) Due to continued population growth, it has been estimated that by the year 2025, Kenya's per capita water availability will be 235 cubic meters per year, about two-thirds less than the current 650 cubic meters (Wafula, 2010).

A number of these challenges are as a result of factors both within and outside the water sector. According to the third United Nations development report, it stated that climate variability and increasing demand for water as a result of development and population pressure are some of the causes of water stress (Ngigi, 2003) Surface and ground water resources in Kenya are increasingly becoming polluted from both point and non-point sources caused by the activities of agriculture and industries, all of which increase catchment degradation and reduce the quantity and quality of water for agriculture production (UNEP, 2002).

Floods, droughts and landslides create severe stress on the people, the economy and on already over-stretched water resources (UNESCO, 2004). According to the Kenyan Ministry of Water and Irrigation, the 1998-2000 droughts in Kenya was classified as the third worst ever and affected all sectors of the economy including energy and agriculture sectors (Mati *et al.*, 2007).

Sustainable access to safe water is around 60% in the urban setting and drops to as low as 20% in the settlements of the urban poor where half of the urban population lives (KIHBS 2005/2006/7). Over 50% of Kenya's households do not have access to safe drinking water and the pro- portion is higher for the poor (Marshall, 2011). In urban areas, large populations living in informal settlements within the towns and cities have no access to safe water. In rural areas, there are large disparities between geographic areas where in North Eastern and Eastern Provinces less than 30% of the poor have access to safe water compared to some 60% in Western Province (Social Policy in Kenya Report).

A case study conducted in Kangemi area by TISDA (Transparency and Integrity Service Delivery in Africa) in 2011 revealed that many families in informal settlements such as Kangemi suffer acute shortages of water because some landlords have illegally continued to control access as well as the cost of water without approval from the water service provider or the regulator. Such landlords determine when their tenants get water, how much water they get, and how much money they pay for the water. This they have made certain by locking the yard taps which is the main source of water for their tenants (TISDA, 2011).

2.12 Overview of water resources in Kajiado

Out of Kenya's population of approximately 38 million, a considerable portion (75 %) is living in rural areas including Kajiado where rain-fed farming and livestock keeping are the main livelihoods (UI, 1999). Moreover, the population is increasing at a rate of 2.6 % per year (World Bank, 2010). Kajiado has no permanent rivers and it is considered as a dry area.

There is a high level of dependability on the seasonal rains. Kenya is classified as a water scarce country with annual water supplies below 1000 m^3 per person (UNEP, 2002). The situation is predicted to worsen drastically within the near future. Kajiado as one of the semi-arid regions of Kenya, temperatures are projected to increase and precipitation decline by 2030 due to climate change (Malesu *et al.,* 2007). Some figures estimate annual available freshwater at around 250

m^3 per capita in 2025 (Malesu *et al.,* 2007). This would be detrimental to the development of agricultural activities in Kajiado and in Kenya as a country.

2.13 Rainwater harvesting in Sub-Saharan Africa

Water harvesting is the accumulation and deposition of rainwater for reuse before it reaches the aquifer. Uses include water garden, water for livestock, water for irrigation (Kirk, 2009). Rainwater harvesting provides the long-term answers to the problem of water scarcity, it offers an ideal solution in areas where there is sufficient rain but inadequate ground water supply and surface water resources are either lacking or are insufficient. There are a number of ways in which water harvesting can benefit a community; water harvesting enables efficient collection and storage of rainwater, makes it accessible and substitutes for poor quality water, helps smooth out variation in water availability by collecting the rain and storing it more efficiently in closed stores or in sandy riverbeds. In doing so, water harvesting assures a continuous and reliable access to water (Mandloi *et al.,* 2005).

The harvested water can be used as drinking water as well as for storage. Water harvesting system is a complete system with a catchment, water collecting facilities and storage facilities. However no system is best suited for a particular area, for example different area have different soils, climate and topography therefore it is necessary to establish a system that best suits the areas' characteristics (Mandloi *et al.,* 2005).

Based on a report done by Frasier and Myers in 1983, water harvesting is believed to have developed in ancient Iraq, 4,000 to 6,000 years ago, for supplying water to trade caravans. There is evidence that similar systems were used 500 years ago by the Indians in the Southwestern United States, (Frasier and Myers, 1983). Collecting rain water from roofs of buildings and storing them in containers is still being used today as a means of storing water for domestic purposes, (UNDP, 2007).

Harvested water is used to provide for domestic and stock water, concentration of runoff for crops, fodder and tree production and less frequently water supply for fish and duck ponds (Ngigi, 2003). Rain water harvesting improves access to relatively safe, clean water, sustained water demands in times of drought, reduces pressure on surface and groundwater and also contributes to the replenishment of groundwater, (Aroka, 2010). In addition it promotes gender equity and female empowerment as it relieves the chore of collecting water from afar for many rural women. Rainwater harvesting can be done in single households or as a joint community venture (Clay, 2009). Water harvesting embraces a variety of different techniques, ranging from the collection of runoff from roofs, rock catchments, artificial surfaces at ground level, land surfaces and ephemeral streams (Hogg, 2008).

Water harvesting reduces the runoff volume and the peak flow, hence mitigating floods and conserving the top soil, (Wheater and Evans, 2009). When the runoff is reduces water travels slowly and ground water aquifers are recharged, mainly water harvesting reduces the cost per liter of water since a large amount of power that is consumed while pumping water from subsurface aquifers can be saved, (Munale, 2000).

In Africa to enhance resilience to future periods of drought stress it is essential to improve in present rain fed farming systems through improvements in the physical infrastructure including water harvesting, (Bates *et al.,* 2008). The importance of building on traditional knowledge related to water harvesting and use has been highlighted as one of the most important adaptation requirements to cope with climate change, indicating the need for its incorporation into climate change policies to ensure the development of effective adaptation strategies that are cost-effective, participatory and sustainable, (Sivanappan, 2006).

Around the globe there is a need to revive the traditional technologies blending them with modern methods to achieve the required present and future water need. Countries like Germany, Japan, United States, and Singapore are also adopting rainwater harvesting with modern methods (Kirk, 2009).

2.14 Rainwater harvesting in Kenya

Rainwater is a free source of nearly pure water and rainwater harvesting refers to collection and storage of rainwater and other activities aimed at harvesting surface and ground water (Langat, 2000). It also includes prevention of losses through evaporation and seepage and all other hydrological and engineering interventions, aimed at conservation and efficient utilization of the limited water. There are many water harvesting opportunities on developed sites and it can easily be planned into a new landscape during the design phase (Munale, 2000).

In Kenya today the key players in rainwater harvesting include the following government ministries: Ministry of Water Resources Management and Development, Ministry of Environment, Natural Resources and Wildlife and Ministry of Agriculture. Several NGOs and other Community-Based Organizations at national and local levels have played a major role in putting rainwater harvesting in the limelight. Through Southern and Eastern Africa Rainwater Network (SearNet) established with the assistance of International Rainwater Catchment System Association and the support of the Regional Land Management Unit of UNEP, Kenya has been able to exchange information on rainwater harvesting with other countries in the east and southern Africa sub-regions. At the local levels, church organizations and women Groups have been very active in this field (Government of the Republic of Kenya, 2006).

Due to variability in rainfall a myriad of rainwater harvesting schemes have sprouted in recent years, both in Kenya and in other water-stressed nations, with the aim to abate drought and water shortages. Rainwater harvesting is simple, low-cost techniques that involve the capture and storing of rainwater and/or groundwater (Hai, 1998). Such systems have been used all over the world for long time periods and go under different names such as small-scale water system innovations and rainwater catchment systems (Frasier and Myers, 1983). UNEP and other UN agencies have conducted pilot projects and workshops in Kenya to promote rainwater harvesting at national and local levels. Some bilateral development partners have also supported the use of this technology. The private sector has been instrumental through manufacture of components needed to implement rainwater harvesting projects such as gutters, roofing material, and concrete and water tanks (UNEP, 2006).

2.15 Rainwater harvesting in Kajiado and the ASALS of Kenya

The Arid and semi-arid Lands (ASALs) make up more than 40% of the earth's surface and provide livelihoods to more than one billion people. In Kenya, the ASALs occupy more than 80% of the country and are home to about 10 million people and approximately 70% of the national livestock herd. The ASALs in Kenya have the lowest development indicators and the highest incidence of poverty in the country (Ministry of Northern Kenya and other Arid Lands, 2009). The lack of water resources in Kajiado is a frequent problem, the access to safe drinking water is difficult and becomes even more difficult during droughts, as only the urban population is connected to the public water supply (Hauschild and Döll, 2000).

The costs of dealing with pressures have important implications in economic development. The problem of having a limited water supply together with a gradually increasing water demand implies that unless governments applies adequate policies, inadequacy in the quantity and quality of water supply could reach a calamity level within a few years (Ragab and Hamdy, 2004). In Kajiado, different types of rainwater harvesting management systems have been implemented throughout as a strategy to secure water resources in rural areas (Langat, 2000). The selling point for rainwater harvesting is that the methods are simple enough to organize and maintain at individual or community level with little training from specialists or technicians, (Aroka, 2010). The most common methods are the collection of rainwater falling on rooftops and the collection of floodwater from watercourses for domestic use (Hai, 1998).

Most of the people in Kajiado rely on underground water sources which are more permanent and boreholes have been drilled and fitted with equipment to pump water for both domestic and livestock use. Some of these water infrastructures are 20-30 km away from households and date as far back as the colonial era, often breaking down when overused, particularly during prolonged dry spells or during drought. Different types of rainwater harvesting management systems have been implemented throughout Kenya and in Kajiado as a strategy to secure water resources in rural areas (Kenya Rainwater Association, 2010). Many reports have been written on the potential benefits of rainwater harvesting for rural communities but there are few studies describing the detailed effects of the schemes on water availability, demands, and vulnerability in the case of climatic variations (RELMA, 2009).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of the study area

The study was conducted in Kajiado County. It borders Nairobi to the north and the Republic of Tanzania to the Southwest, Taita-Taveta County to the southeast, Machakos and Makueni counties to the east, Kiambu County to the north and Narok County to the west. It lies between longitudes 36º 5’ and latitudes 37º 5’ E and 1º 0’ and 3º 0’ S. It covers an area approximately 21,909.9 square kilometers with a population of 406, 054 (Government of Kenya, 2009).

The Kajiado County is divided into seven sub-counties - Central, Isinya, Loitokitok, Magadi, Mashuru, Namanga, and Ngong’. The study was conducted in Isinya and Ngong’ sub-counties which are in Kajiado North. Two locations were selected in each of the two sub-counties; Isinya and Kitengela locations for Isinya sub-county and Ongata Rongai and South Keekonyoike locations for Ngong’ sub-county.

There are no permanent natural sources of surface water in the study area. Mean annual rainfall ranges from 300 to 800 mm. Rainfall is bimodal, with "short rains" from October to December and "long rains" from March to May. The distribution of rainfall between the two seasons changes gradually from east to west across Kajiado County. Kajiado is one of the semi arid areas in Kenya, in recent years there have been long periods of drought when there has been little or no rains (Hallberg, 2011).

The lack of permanent sources of surface water led to the construction of several small dams and the drilling of a large number of boreholes. Many dams have silted up or have been washed away; the location of others have been forgotten (Dietz *et al*, 1986). Most of the older boreholes have broken down. Within the county also a number of individually owned boreholes are operating, but it seems obvious that the existing and functioning water facilities are far too few to serve the population and their livestock. Running costs and maintenance are major problems. Most boreholes are equipped with an electric or a diesel pumps and, thus, have high running costs.

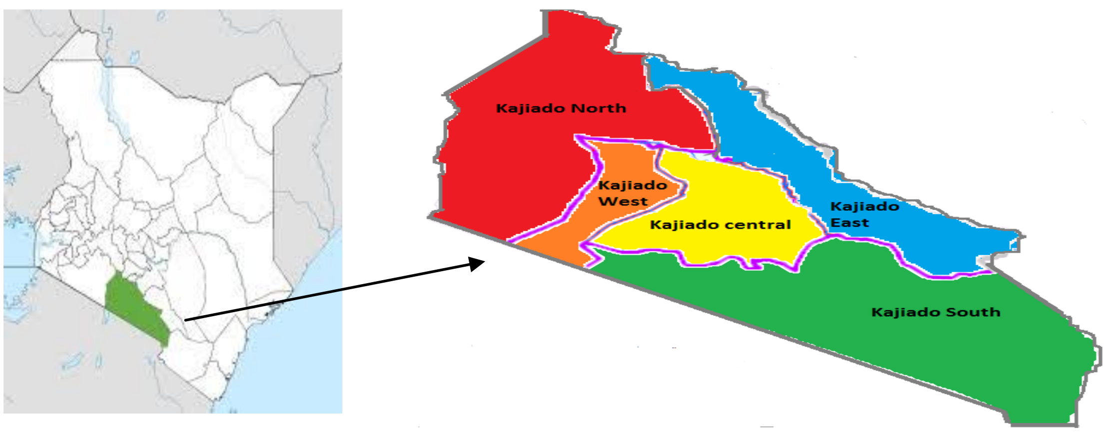


Figure 1: Map of Kajiado County showing Kajiado North where the study was carried out (*Source; ThingLink*).

Crops grown in the area are tomatoes, okra, kales, cabbages, bananas and maize. Most of the residents in Kajiado are pastoralists in which the majorities are small scale livestock farmers and they face perennial livestock losses during drought and this has increased the number of people facing extreme poverty and hunger.

3.2 Determining the magnitude and pattern of land use changes in the past 20 years

Participatory GIS fosters discussion and collaboration among stakeholders and can capture important knowledge from underrepresented groups (Elwood, 2002). Due to the changes of land use and the effect it has on water resources, it is necessary to take a look at the present water situation in the area and to conduct scientific studies towards water resource utilization and management (Barndt, 2002). PGIS practice is usually geared towards community empowerment through measured, demand-driven, and user-friendly where maps become a major conduit in the process (Chrisman, 1987).

Participatory GIS was used to assess the changes and pattern in land use change in the past 20 years. Four (4) sub locations were randomly picked to participate in the Participatory GIS meetings. Kisaju sub location in Kitengela, Nkoroi Kadisi sub location in Ongata Rongai, Oloosidan sub location in Isinya, and Oloika/Matali sub location in Isinya.

In each of the four selected sub-locations, twenty (20) respondents were purposively selected to participate in the participatory GIS. The selection was based on gender and age. The group consisted of five elderly men (above 50 years), five elderly women (above 50 years), five young women (18 to 35 years) and five young men (18 to 35 years), to get an idea of the area for the past 20 years.

The participants drew maps showing their location and the extent of land resources (water sources, settlements, grass lands, roads, and farm lands) for years 1990, 2000 and 2010. These years were chosen because they are also the ones that the government of Kenya published the census so it was done on purpose to compare with the changes in population.

The participants selected the best three (3) PGIS maps (that is for 1990, 2000 and 2010) that best describes their area properly. Then Focus Group Discussions were conducted to discuss the changes that have taken place based on the maps they drew. The checklist consisted of the following questions;

- Main land use/land cover changes that have occurred in the area
- Causes of the change
- Positive effects of the change
- Negative effects of the change
- Coping strategies
- Recommendations based on the undesirable effects

Photos of the maps were taken using a digital camera. The photos were exported to Arc GIS 9.3 software for geo-referencing. Areas under settlements, farming, grass lands and wetlands were examined and analyzed using Map info professional v12.5 software. MapInfo is a versatile Windows-based application that visualizes information on digital maps by linking data to geography. It creates maps that present information for analysis and decision making. The maps were analyzed for land use and land cover area changes and their percentage changes for the period between 1990-2000 and 2000-2010 calculated.

3.3 Climate change effect on water resources and the perception of rainwater harvesting as a coping strategy to climate change and variability

A semi structured questionnaire (Appendix 1) was used to collect information on the effects of climate variability and change on agricultural activities, the coping and adaptation mechanisms to climate change and variability, the current water sources and the rainwater harvesting technologies in the area.

The method of using a questionnaire provided quantitative data required to determine impacts and outcome indicators. In addition it helped to provide quantitative gender disaggregated data while complementing the other qualitative methods by highlighting how different gender, age, cultural and socio-economic groups' livelihoods impact on decision making.

3.3.1 Sampling size and sampling technique

Simple random sampling was used since the communities are spacely distributed, each individual was chosen randomly and entirely by chance.

The questionnaire was administered to 220 respondents from the two sub-locations (Isinya and Ngong'), one hundred and twenty (120) in Isinya and one hundred (100) in Ngong'.

In Ngong' sub-location two divisions were selected (Ongata Rongai and South Keekonyoke and fifty respondents were administered in each. In Isinya sub-location two divisions were selected as well (Isinya and Kitengela divisions) and sixty respondents were interviewed in each, making the total of 220.

Data collected from the questionnaires was analyzed using the Statistical Package for Social Scientists (SPSS). Descriptive statistics such as means, frequencies, percentages and cross tabulations was used in the analysis.

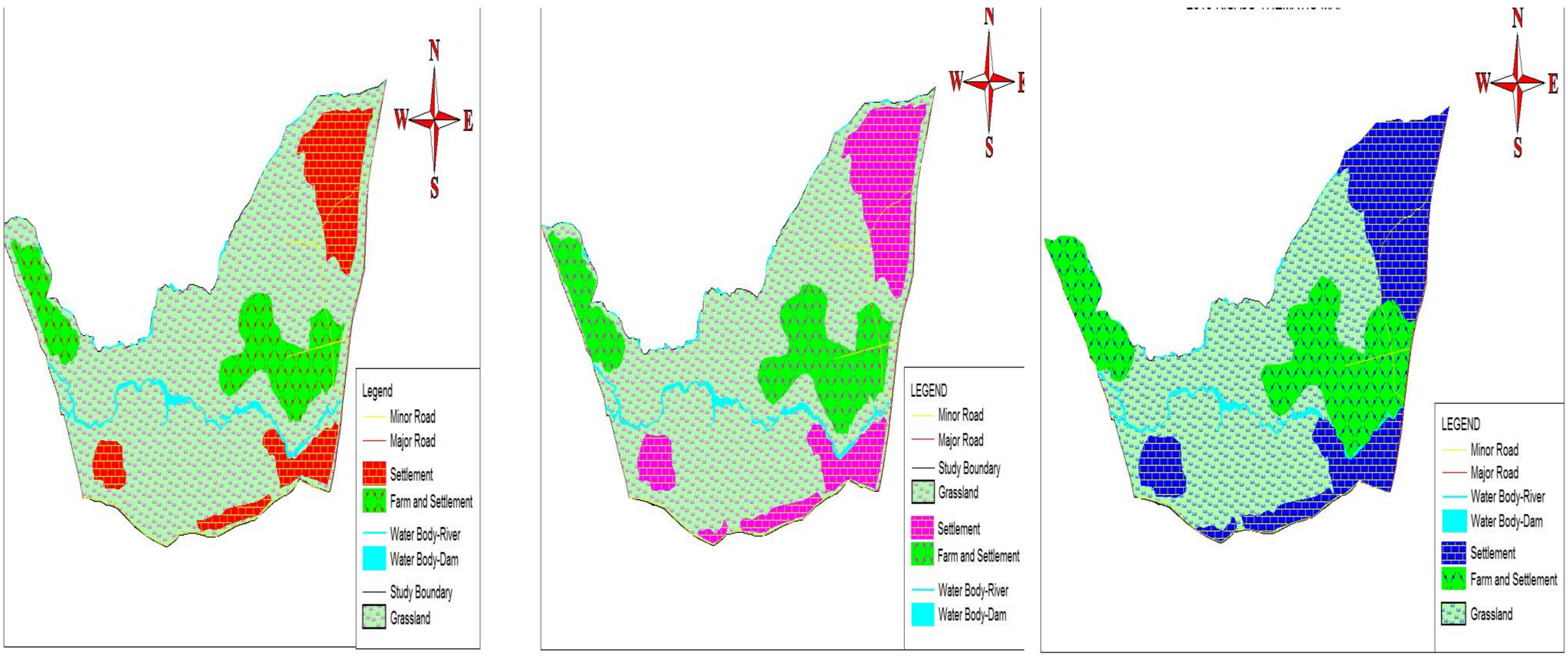
CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Magnitude and pattern of land use change in the past 20 years

This section presents the results from the PGIS analysis of the four sub-locations namely Kisaju, Matali, Nkoroi and Oloosidan showing changes in land use/cover from year 1990, 2000 and 2010.

4.1.1 Changes in land use/cover in Kisaju sub-location

As shown in the figure 2, Kisaju sub-location settlements and farmland their total area have increased significantly ($p<0.05$) in 1990 to 2000 and 2000 to 2010 by 4.8% and 8.5% for settlements respectively, and 3.1% and 5.9% for farmland respectively. There is a significant ($p<0.05$) decrease in the grassland total area of 8% and 14.2% for 1990-2000 and 2000-2010 respectively.

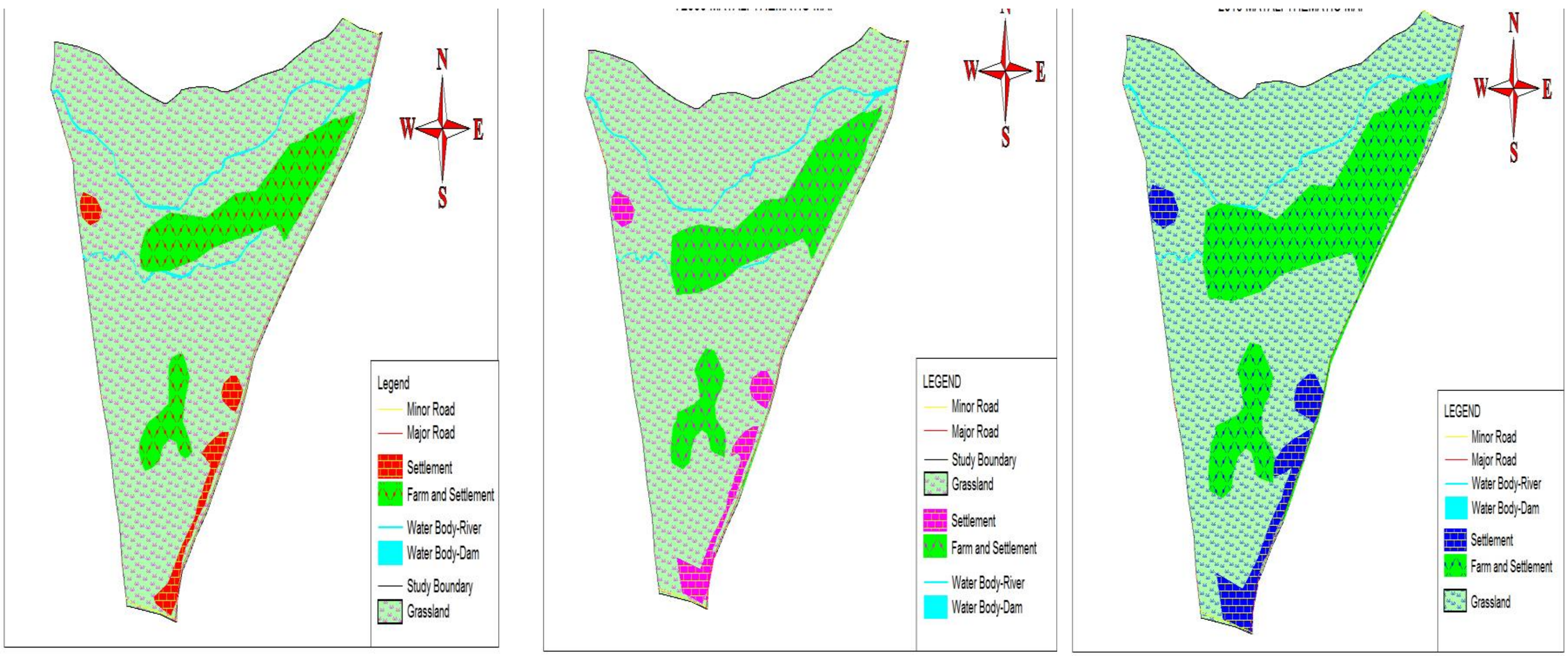


(a) (b) (c)

Figure 2: Map of Kisaju sub location showing changes in land use (a) 1990, (b) 2000 and (c) 2010.

4.1.2 Changes in land use/cover in Matali sub-location

Figure 3 shows Matali sub-location settlements area has increased significantly ($p<0.05$) by 2.4% and 3.6% for 1990-2000 and 2000-2010 respectively, farmland has increased significantly ($p<0.05$) by 2.5% and 5.5% for 1990-2000 and 2000-2010 respectively, and grassland decreased significantly ($p<0.05$) by 4.9% and 9.1% for 1990-2000 and 2000-2010 respectively.



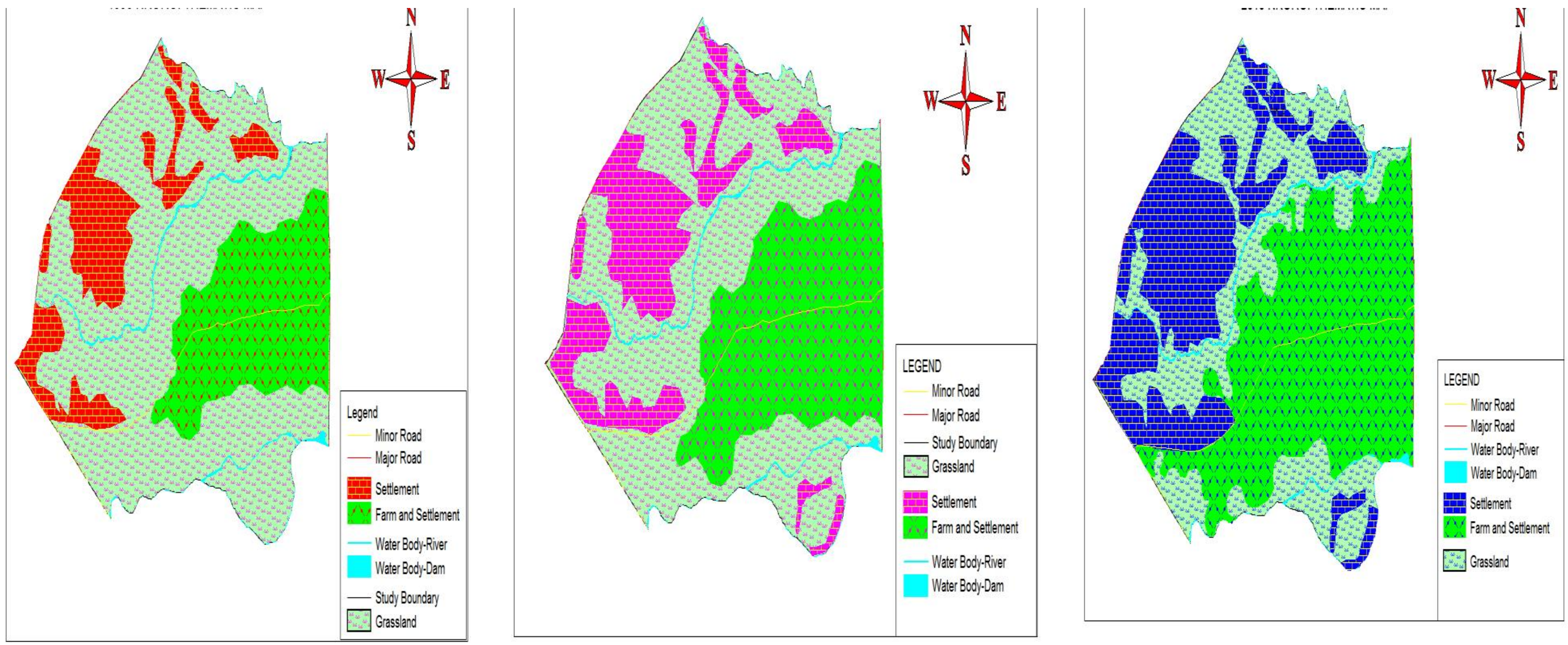
(a) (b) (c)

Figure 3: Map of Matali sub location showing changes in land use (a) 1990, (b) 2000 and (c) 2010.

4.1.3 Changes in land use/cover in Nkoroi sub-location

Figure 4 shows Nkoroi sub-location settlements area have increased significantly ($p<0.05$) by 5.7% and 9.5% for 1990-2000 and 2000-2010 respectively, farmland has increased significantly ($p<0.05$) by 6.7% and 10% for 1990-2000 and 2000-2010 respectively, and grassland had a significant decrease ($p<0.05$) by 12.3% and 19.6% for 1990-2000 and 2000-2010 respectively.

The highest increase in settlement and farmland area was observed in Nkoroi sublocation for both 1990-2000 and 2000-2010. This was the same with the changes in grassland in which Nkoroi showed the highest change. This can be because Nkoroi is close to the main road therefore more people are moving to that area unlike the other sub-locations.



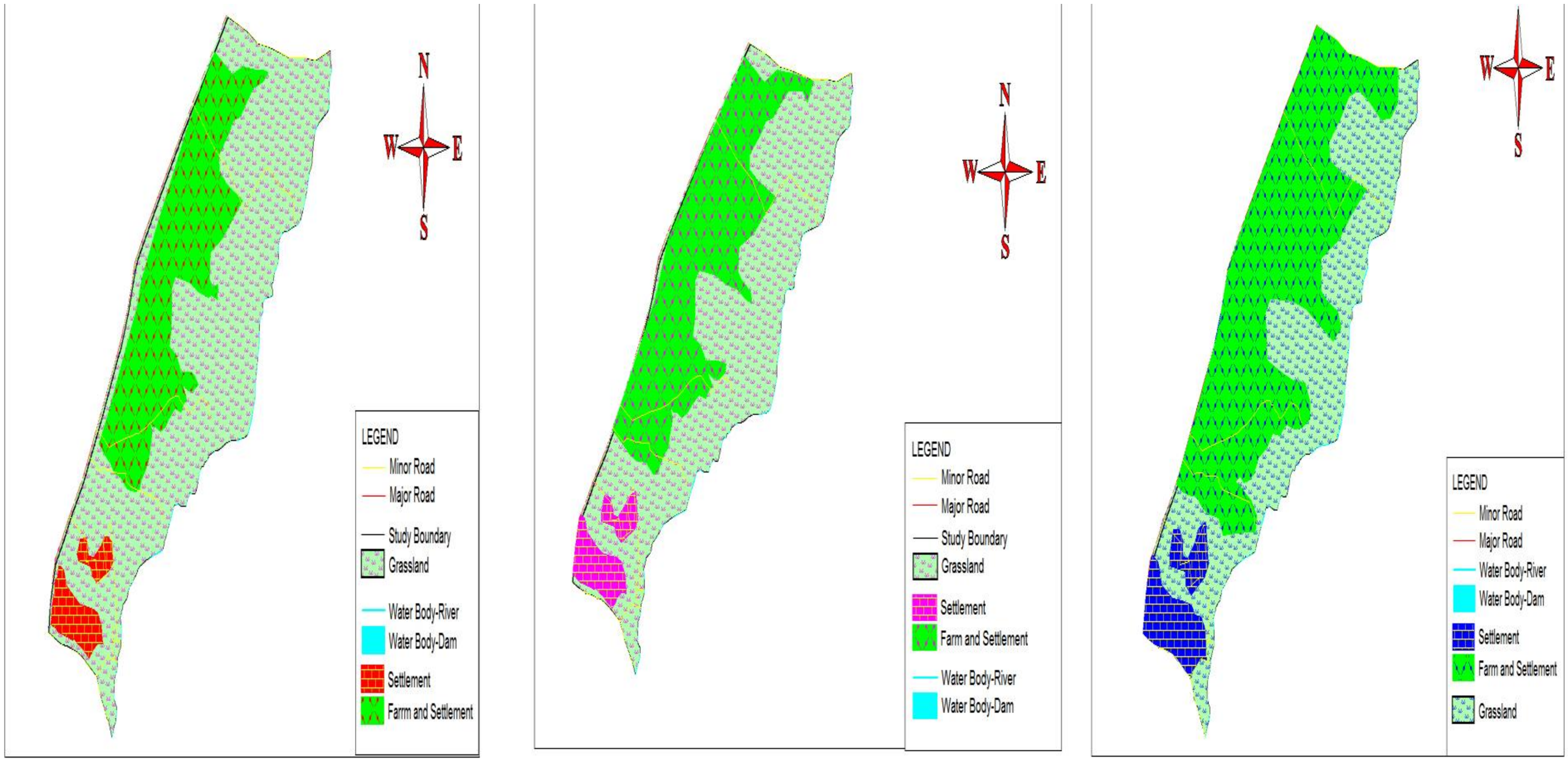
(a) (b) (c)

Figure 4: Map of Nkoroi sub location showing changes in land use (a) 1990, (b) 2000 and (c) 2010.

4.1.4 Changes in land use/cover in Oloosidan sub-location

Figure 5 shows Oloosidan sub-location settlements area have increased significantly ($p<0.05$) by 2.1% and 4.1% for 1990-2000 and 2000-2010 respectively, farmland has increased significantly ($p<0.05$) by 7% and 14.1% for 1990-2000 and 2000-2010 respectively, and grassland decreased significantly ($p<0.05$) by 9.1% and 18.2% for 1990-2000 and 2000-2010 respectively.

The lowest increase in settlement and farmland area was observed in Oloosidan. This is because the area is far away from the main road.



(a) **(b)** **(c)**

Figure 5: Map of Oloosidan sub location showing changes in land use (a) 1990, (b) 2000 and (c) 2010.

There was significant decrease in grassland for all the 4 sub-locations in years 1990-2000 and 2000 -2010 (P = 0.000) [See appendix 2]. There was also a significant increase in settlement and farmland. However there was no significant land use change in water bodies (P >0.05) for all the 4 sub-locations. This is because the respondents did not observe the changes in the volume of the water bodies but their main focus was on the level of the water. The increase in settlement and the decrease in grassland are brought by the increase in population in the area in which there in a high migration of people from Nairobi and the surrounding areas to Kajiado. This has also resulted in many grasslands being converted to farm lands.

The results show that land use/cover is changing from grassland to settlements and farmland, as the pastoralists community people are now combining livestock with crop production as shown by the increase in the farmland area. This agrees with a report by the Government of Kenya in 2011 and the United Nations Environmental Programme (2009) which stated that over the last 30 years, human settlement and farmland has taken a complex pattern in Kenya due to rapid rural-urban migration and rising occupation of the arid and semi-arid lands (ASALs). The rapid rural-urban migration has led to unplanned informal settlements (slums) in the major urban areas.

The drift to the marginal areas has led to degradation of the fragile ASAL ecosystems, increased human-wildlife conflicts as well as land use conflicts between agriculturalists and pastoralists (GoK, 2011; UNEP, 2009). This agreed with report by the United Nations Environmental Programme (1997) in which it was reported that the major land-cover types in Kenya are grasslands, wetlands, fresh and saline water bodies, and deserts. These are used for agriculture, pastoralism, water catchments, nature reserves, urban and rural settlements, industry, mining, transport and communications, tourism, recreation (UNEP 1997).

In addition to this a study conducted by Boone (2005) reported that livestock keeping remains the dominant livelihood strategy in Kajiado, even though things are changing because of water scarcity and increase in population. With the changes taking place, farmers are now shifting to crop production to sustain their livelihood therefore clearing the grassland (Boone *et al.*, 2005). Different land uses such as pastoralism and sedentary farming in ASALs compete. The people living in a specific area usually consist of different groups with divergent interests in land and its resources (Mwichabe *et al.*, 2000).

4.2 Assessing the effect of climate change and variability on water resources

4.2.1 Establishing the available water resources

The following were listed as the available water sources in Kajiado North. 33.7% of the respondents get their water from boreholes followed by piped water which is about 25.5%. The third source of water is from rain water through water harvesting which is 15.8%, followed by wells (9.2%) and the least is 7.6% from rivers. Most people choose bores as their main source of water because once they are installed on the household they don't need to walk long distances to fetch water, they are cheap and reliable. Piped water is also preferred because it is safe to drink unlike borehole water which is usually saline. Rainwater is the third source of water because it is seasonal and with the changes in climate it is unpredictable. Rivers are the least because there are no permanent rivers in the area; soon after the rains it takes less than 2 months for the rivers to start dry up. (See Figure 6)

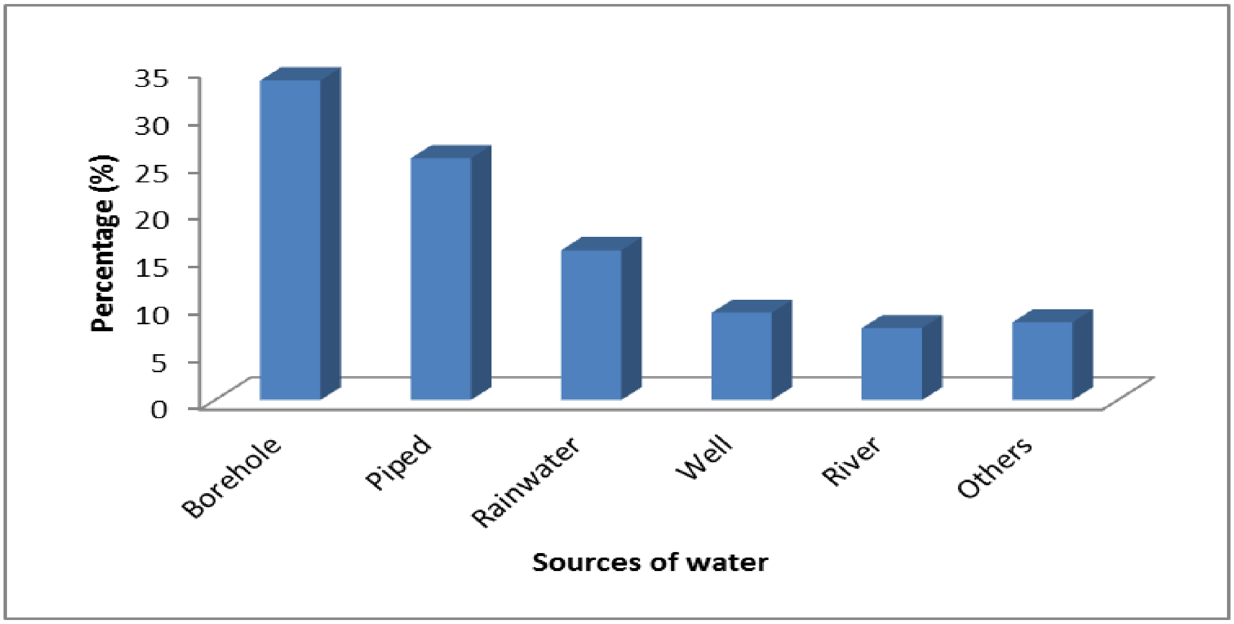


Figure 6: The main sources of water in Kajiado North.

These results agree with those by the Kenya National Water Development report, 2006 which reported that more than 40% of people in Kenya use borehole water, (Kenya National water development report, 2006). A high percentage of Kenyans including Kajiado north residents use unprotected sources of water mainly ponds, dams and streams. In some areas of the country mostly arid areas in which Kajiado is part of, conflicts have risen amongst the various competing sectors and users of water (ASAL Development Policy, 2002).

The lack of water resources is a frequent problem in semi-arid regions, where there is not enough water to sustain agricultural production, for rural population, For rural population, the access to safe drinking water is difficult and becomes even more difficult during droughts, as only the urban population (or most part of it) is connected to the public water supply (Hauschild and Döll, 2000). The rainfall is erratic and sometimes falls in storms only a few days, making surface water difficult to find unless, pans and dams have been constructed. In many cases most communities in the ASALs have to rely on underground water sources which are more permanent and boreholes have been drilled and fitted with equipment to pump water for both domestic and livestock use. A study by Mvungi (2005) also reported that the majority of people in the area use boreholes (Mvungi, 2005). Mwangi (1999) also reported that another reason for the increase in boreholes in Kajiado District is political, especially at the end of the 1970s when Stanley Oloitiptip, a Maasai minister, was at the height of his power, large amounts of money were transferred to the Kajiado water sector in his constituency where a number of boreholes were constructed later on 20 Other Maasai politicians, like former Vice President Saitoti, followed his example (Mwangi, 1999).

4.2.2 Effect of climate change and variability on water resources

The following were listed as the effects of climate change and variability on water resources. 30% of the respondents reported that drought is the major effect of climate change, followed by run off and erosion (21%), the third one is increased evaporation (20%), then changing in water levels (17%) and the least impact is increased water temperature (12%). (See Figure 7)

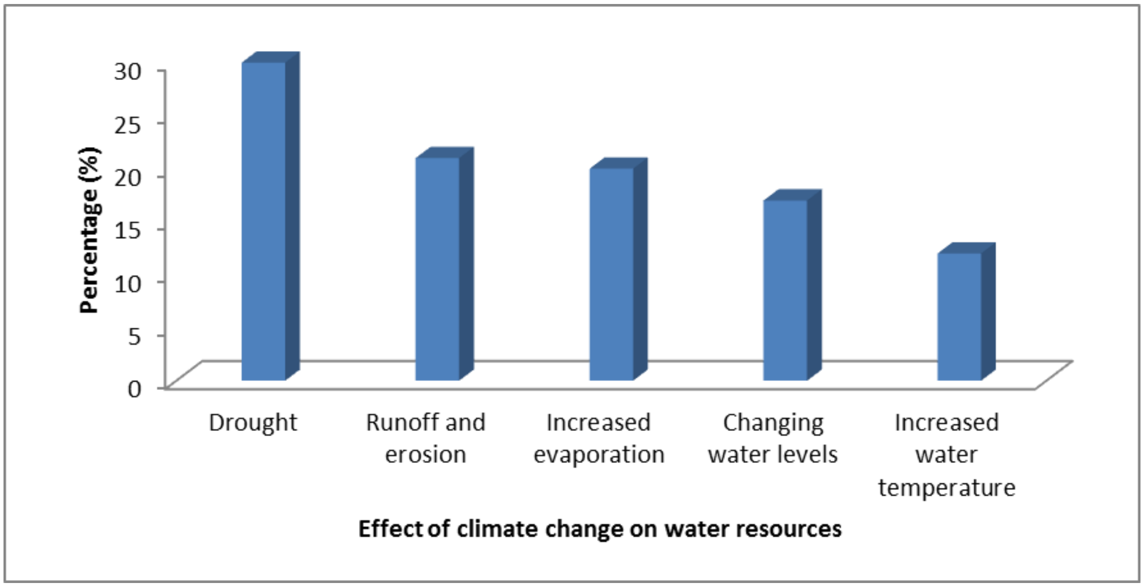


Figure 7: The effects of climate change on water resources in Kajiado North.

These results are in line with the global aspect since at the global scale, there is also evidence of a broadly coherent pattern of change in annual runoff, with some regions experiencing an increase (Allan *et al.*, 2005) particularly at higher latitudes, and others a decrease, for example in parts of West Africa, southern Europe and southern Latin America (Beamish and Mahnken, 2001). The effects of climate change on river ecosystems are no longer just speculations Rivers and lakes have been sensitive to consequences of climate change (Ormerod, 2009).

Droughts have become more common, especially in the tropics and sub-tropics, since the 1970s. Decreased land precipitation and increased temperatures, which enhance evapotranspiration and Reduce soil moisture, are important factors that have contributed to more regions experiencing droughts, as measured by the Palmer Drought Severity Index (PDSI) (Bunnell and Squires, K.A. 2005).

4.3 Assessing the perception of rainwater harvesting as a coping strategy to climate change and variability

4.3.1 Awareness on water harvesting

According to the survey conducted 100% of the respondents have heard about water harvesting technologies and are very much aware of the procedures and the requirements for water harvesting. However 87% of the respondents harvest water and 13% of the respondents do not harvest water in their households (Figure 8).

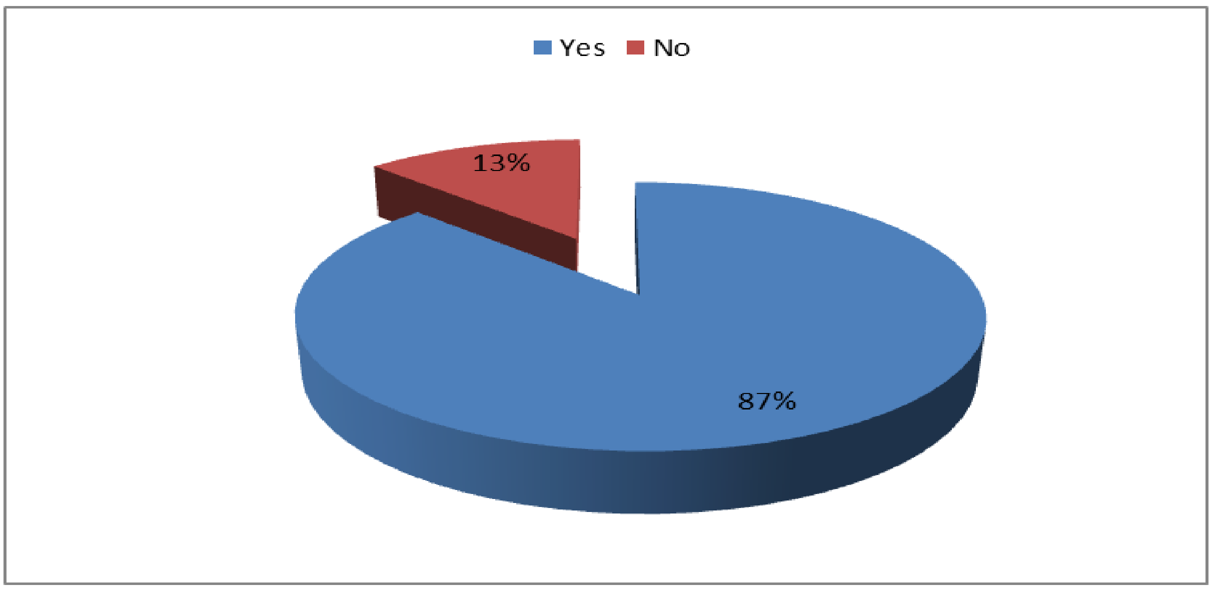


Figure 8: The percentages of households who harvest water in Kajiado North

The majority of the respondents harvest water because Kajiado is a dry area therefore water harvesting is essential in the area for domestic and livestock use. Some harvest in ponds for the livestock and from house and farm structures roofs. The 86% of the respondents that harvest water all owned a water tank. The respondents reported that they prefer water tanks than digging a ditch or using buckets, this could be because tanks are reliable, easy to manage and do not require a lot of human labor to extract water from unlike a ditch which also requires a household to have enough land and it is very expensive since it needs continuous maintenance.

Kenya's water policy takes into account all the relevant issues including water conservation and preservation of its quality. In this regard, mainstreaming of rainwater harvesting is very prominent. In Kenya today the key players in rainwater harvesting include the following government ministries: Ministry of Water Resources Management and Development, Ministry of Environment, Natural Resources and Wildlife and Ministry of Agriculture. Several NGOs and other Community-Based Organizations at national and local levels have played a major role in putting rainwater harvesting in the limelight (GoK, 2006).

Through Southern and Eastern Africa Rainwater Network (SearNet) established with the assistance of International Rainwater Catchment System Association and the support of the Regional Land Management Unit of UNEP, Kenya has been able to exchange information on rainwater harvesting with other countries in the east and southern Africa sub-regions. At the local levels, church organizations and women Groups have been very active in this field (GoK, 2011). Therefore this is in agreement with the results, there are a lot of awareness campaigns in promoting water harvesting therefore more people are aware of the technology.

4.3.2 Rainwater harvesting technologies existing in the area

The results showed that 76.9% of the respondents harvest water from the rooftop, most respondents had multiple responses and some were harvesting from both rooftop and infield surface storage. The second type of water harvesting used was runoff (8.1%) in which they dig a ditch either on the household or at the farm to collect runoff, most of this water is the one used to feed the livestock. Household and infield water harvesting were 6.5% each. The harvested water from households was mostly recycled for other uses like irrigating their gardens. The least water harvesting practice used was surface storage which was only 2%. (See Figure 9.

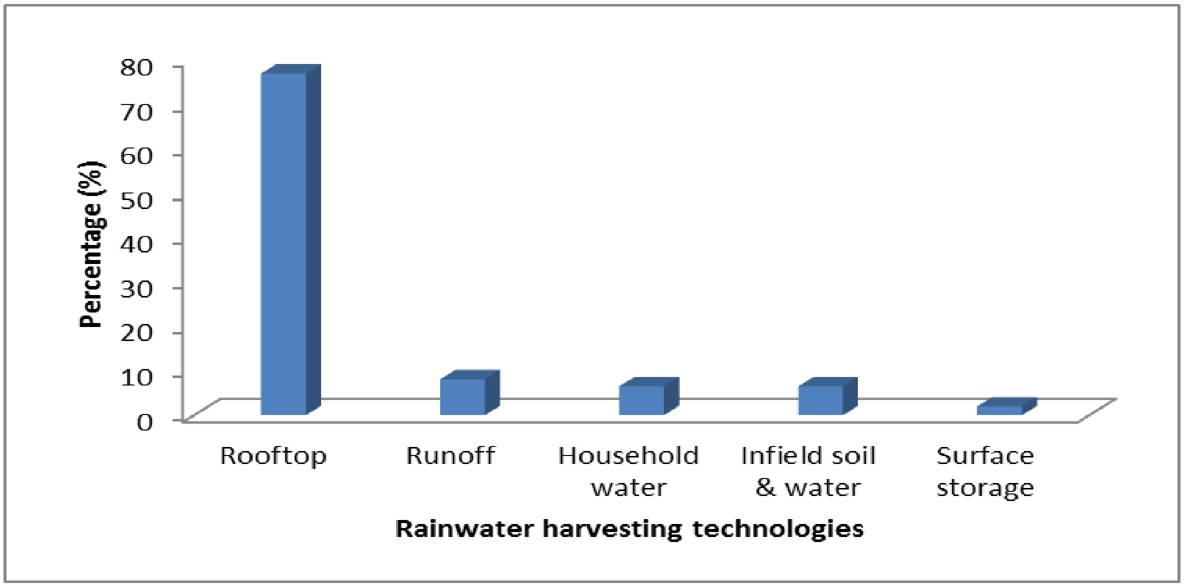


Figure 9: The rainwater harvesting technologies practiced in Kajiado North.

Rooftop harvesting is preferred because it is easy to use and they just use buckets to collect water from the roof; it does not require a lot of labour and equipments and the water is safe to drink unlike infield and surface storage. Rooftop harvesting also provides safe and clean water which can be used for different activities around the household unlike runoff. The other types of water harvesting like infield and runoff were not preferred by the respondents because they require the household to have land and install appropriate mechanism to harvest the water.

The results that were obtained agreed with those by Bharadwaj (2001) and Thomas and Martinson (2007) that roof top water harvesting is the most preferred method of water harvesting compared to other methods.

4.3.3 Institutions dealing with rainwater harvesting

The results show that the only institution working in the area on the issue of rainwater harvesting is the extension services provided by the government, even though some don't have access to the extension services. 65% of the respondents said they have had some sort of contact with the extension officers on the issues of rain water harvesting and 35% said they have never had any contact with the extension officers on the issue of rain water harvesting. (See Figure 10).

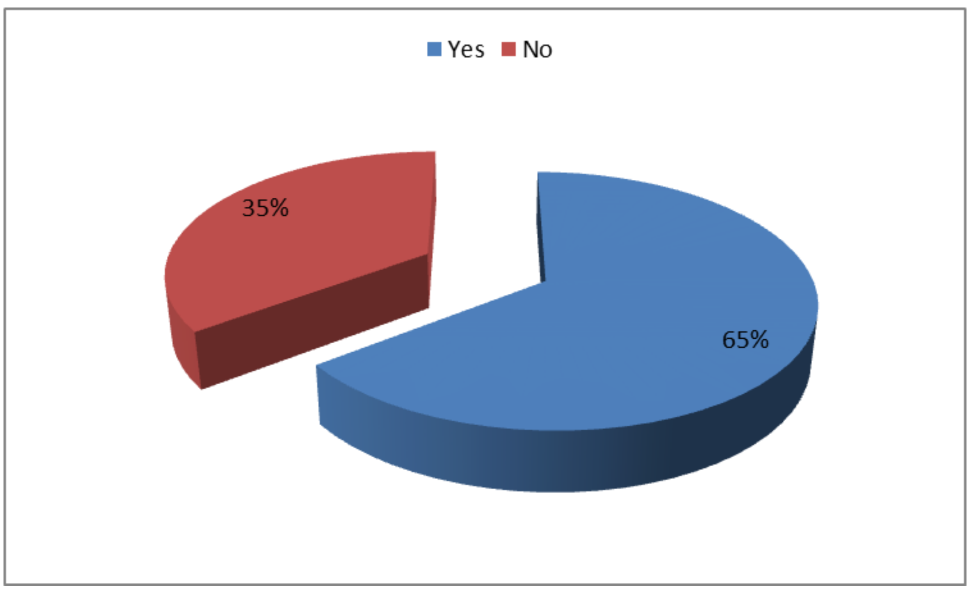


Figure 10: The percentage of people who had contact with the extension officers in Kajiado North.

Although Kenya has a long tradition of rainwater harvesting, policies and interventions are lacking behind as there are no enough capacity building interventions on rainwater harvesting for agriculture (Berger, 2011). Therefore there is still need to explore the potentials for new Kenyan policies on rainwater harvesting to ensure that farmers are benefiting.

4.3.4 Gender and rainwater harvesting

The respondents said both men and women are involved in water harvesting, they argued that men take part in the construction of the water harvesting equipment and women are mostly involved in collected the water. 30% of the respondents said that women are the mostly involved than men, 23% said the men are the ones who are involved. (See Figure 11)

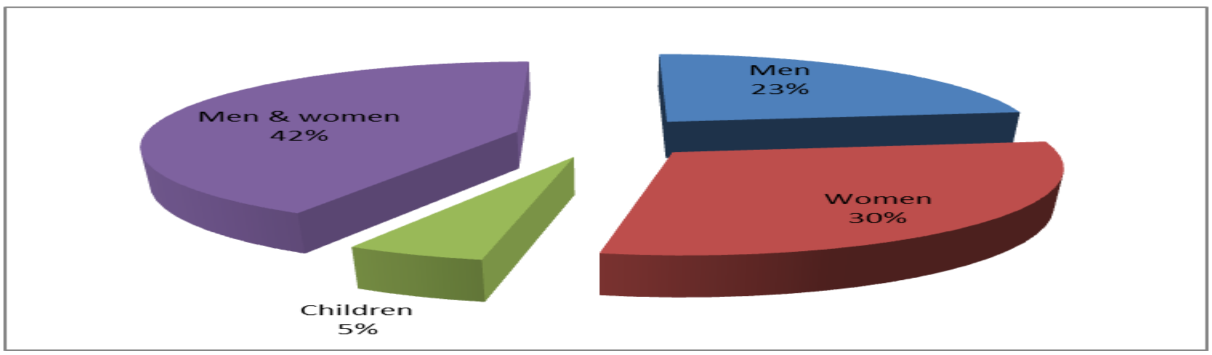


Figure 11: Involvement of men, women and children in rainwater harvesting in Kajiado North.

There was no significant difference on who is more involved in water harvesting between men and women. However previous studies show that women play a major role and take on a range of other agricultural tasks to ensure food production for household sustenance as women are more likely to invest the additional income in children and family therefore more involved in making sure there is water in the household.

Therefore these consequences need to be addressed where the women have become increasingly central in agricultural production and rainwater harvesting as men engage in migratory labour. Even at local levels, church organizations and women groups have been very active in rainwater harvesting (Baiphethi *et al.*, 2009)

4.3.5 Basis for not harvesting water

It was reported that 14% of the respondents do not harvest water based on a number of reasons, 60.4% of the people that do not harvest water reported that they do not harvest water because it is expensive, 24.6% said there is lack of information from experts like extension workers. Only 15% of the interviewed population said they do not harvest water because of lack of interest. (See Figure 12)

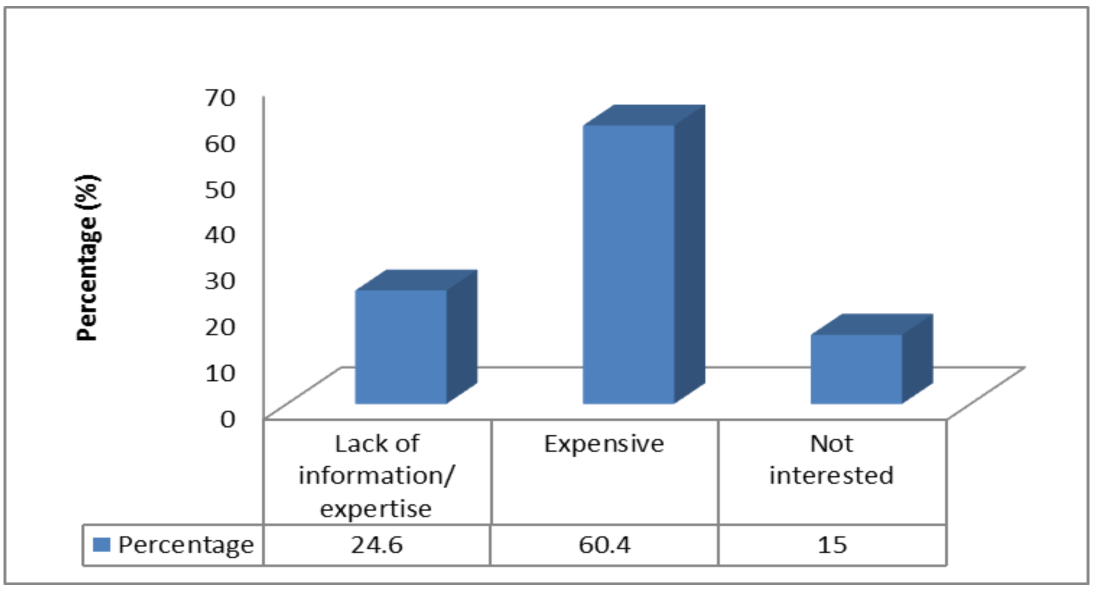


Figure 12: Reasons for not harvesting water in Kajiado North.

Most people consider harvesting water expensive because of the equipments like gutters, pipes and a tank that needs to be installed on the household. According to studies by the World Bank, most of the urban poor Kenyans only have access to polluted water because of the high costs associated with accessing water which has caused multiple problems that affect health and livelihoods. Despite the critical shortage of clean water in Kenya's urban slums, there also is a large rural to urban discrepancy in access to clean water in Kenya (World Bank, 2010).

4.3.6 Duration of the harvested water

The respondents who harvest water using different methods were asked on the time the harvested water last. The harvested water mostly last for 2 to 3 months after the rains for the 35.4% of the respondents who harvest water. Depending on the size of the tank or the size of the family the harvested water may sometimes last for 6 months or even the whole year. Unfortunately only 16.3% of the respondents can have their harvested water for the whole year and 18.3% still have their harvested water for 6 months. Lastly 30% of the total respondents interviewed can only have the harvested water for less than a month, and the remaining time they have to source water from other sources. (See Figure 13)

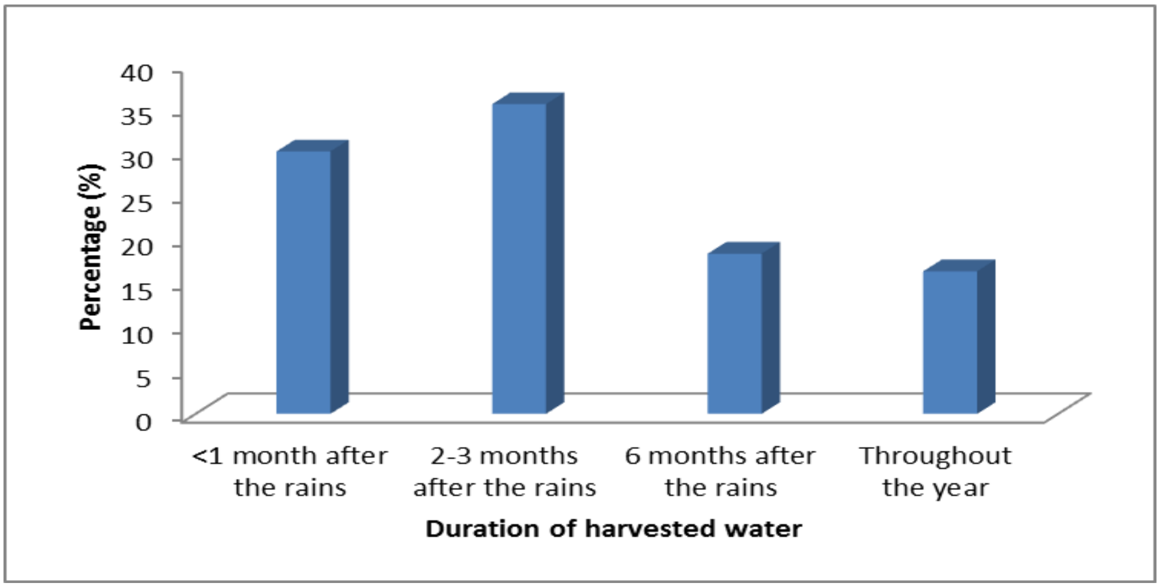


Figure 13: The amount of time that harvested water lasts.

During every prolonged dry spell or prolonged drought, pans dry out, shallow wells are not recharged and the underground storage tanks empty quicker than normal (Aklilu and Wekesa, 2002). However results showed that due to this problem most households have the desire to harvest water because of the water situation in the area. However they do not have enough storage facilities that can enable them to harvest enough water to be used all year round. From the 1970s onwards, individual Maasai have pointed at falling water levels in the rivers in Kajiado District. Indeed, when comparing a list of rivers in the 1930s with the current situation we have to conclude that more rivers nowadays should be labelled as ‘perennial’ and fewer as ‘permanent’. It is hard to know the exact reason for this development but one could point at causes such as increased demand, irrigated agriculture, deforestation and the loss of storing capacity in the rivers because of sand mining (Wagura and Kanyanjua, 1992).

4.3.7 Uses of the harvested water

A high percentage of the harvested water around the household is used for domestic purposes (80.2%). The domestic uses include bathing, washing dishes, washing clothes and cleaning the house, 12.6% was not applicable as some did not have the tank or did not harvest water. A small percentage (5.8%) of the harvested water from the tanks is used for irrigating crops and the least (1.4%) is used for livestock. Domestic use was the main reason for harvesting water because most households did not have the equipments to use the water for irrigation. (See Figure 14).

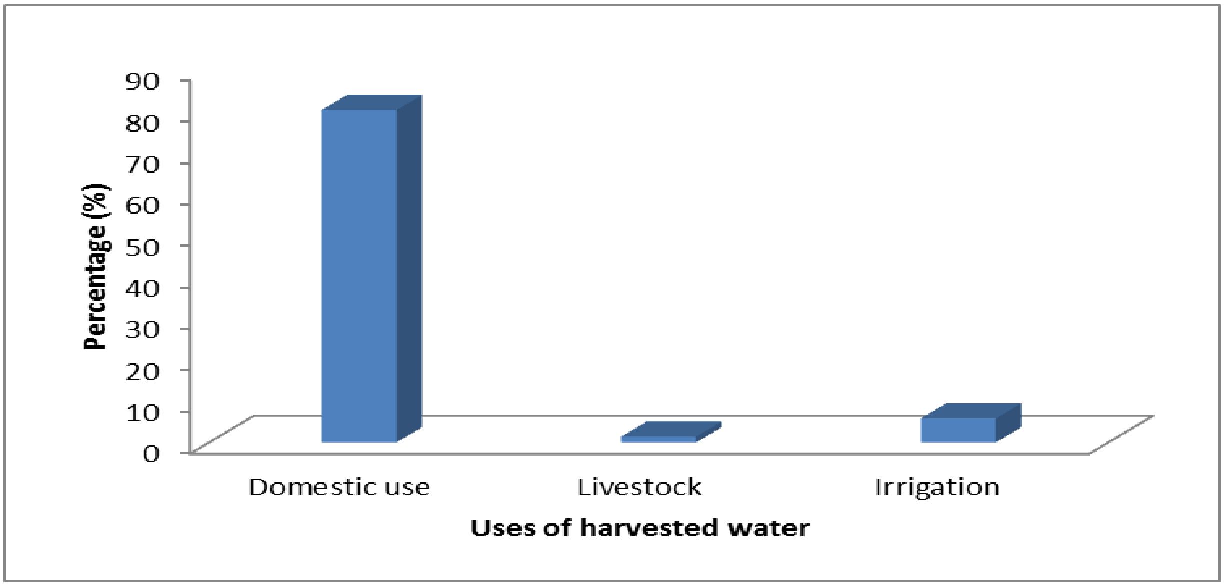


Figure 14: The uses of the harvested water.

Kajiado is an area for pastoralists but the results show that water harvested to tanks is not used for livestock. When the respondents were asked why they reported that their livestock is free range and the water they use for it is not from water harvested from the tank. Therefore it can be concluded that agriculture is not a priority when it comes to harvesting water. The report by the Kenyan Mnistry of Water and Irrigation (2005) also indicated that the harvested water is mainly used for drinking and cooking because it is generally clean and safe.

According to reports by the United Nations World Water Development the primary use of water in most Kenyan households is for domestic use followed by public use, industry, agriculture, energy, livestock, wildlife, tourism, ecosystems and other water uses (United Nations Water Development Report, 2010).

4.3.8 Coping with the changing climate

On the coping strategies to climate change used, 49.8% reported that they plant trees, drought resistant crops (4.8%), irrigation (10.6%), rainwater harvesting (17.3%), early planting (1.4%), soil and water conservation (4.7%), application of fertilizer and organic inputs (9%), and changing from extensive to intensive farming (2.4%). This is because there are a lot of awareness campaigns on tree planting either on radios and field days, therefore most people prefer planting trees as the main coping strategy to climate change. The change from extensive to intensive farming was the least because of the climatic conditions of the area. Kajiado is a semi-arid area in which most of the crops do not do well. (See Figure 15)

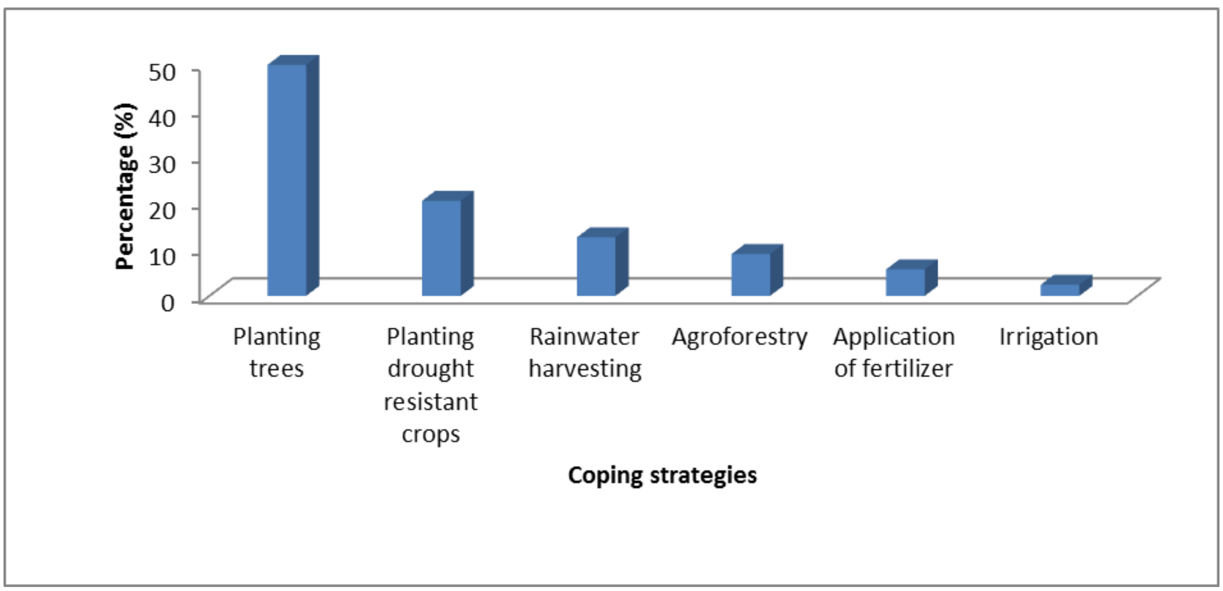


Figure 15: The coping strategies to climate change used in Kajiado North.

Just like in Kajiado County, many regions in the world are already taking actions that will help them manage the challenges of climate change like rainwater harvesting and irrigation. In Sub-Saharan Africa, irrigated area is projected to grow more than twice as fast as rain-fed area over the same period, (79 compared with 34 percent), but the share of irrigated area will be only 4.5 percent in 2050 compared with 3.4 percent in 2000 (IPCC, 2007). Factors like reduced rainfall over time, population growth and water scarcity combine to contribute to the region's considerable vulnerability to current climate variability and long-term climate change (Stern, 2006). As such, under a moderate climate change scenario without appropriate adaptation, the prices of agricultural commodities are projected to increase in both domestic and world markets (UNDP, 2004). Real commodity prices for all cereals are projected to rise by 2050 due to increased land and water scarcity, as well as the impacts of climate change, biofuel development, increased population, and income- and growth-driven demand for food diversification (IPCC, 2008).

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Land use/land covers have changed over time in Kajiado North. There has been a decrease in grassland and an increase in settlements, which means that more land is been used for cultivation. The demand for water has also increased and the pastoralist's are now combining livestock with crop production as shown by the increase in the farmland area. The maps revealed a significant increase in settlement of 3.75% from 1990-2000 and 6.5% from 2000 to 2010 and a significant decrease in grassland of 4.6% from 1990 to 2000 and 7.2% from 2000 to 2010.

Climate change has affected water resources in Kajiado North in terms of drought, runoff and increased evaporation leading to communities relying on ground water as evident by the majority of the respondents using boreholes as the main source of water. Vulnerability of rural Kenyans to climate change stems from increasingly uncertain rainfall patterns and rapid population growth as the agriculture in the area is purely rain-fed. Respondents in Kajiado are already taking actions that will help them manage the challenges of climate change like rainwater harvesting and planting trees.

Most of the respondents in the study area used unprotected sources of water mainly ponds, dams and ephemeral streams. There are a lot of awareness campaigns in promoting rainwater harvesting therefore more people are aware of the technology. The harvested water is mainly used for drinking and cooking because it is generally clean and safe. Most people consider harvesting water expensive because of lack of storage facilities and other equipments like gutters, pipes and a tank that needs to be installed on the household. The respondents were able to notice that water harvesting plays a vital role in promoting agriculture in the area. Most respondents prefer rooftop rainwater harvesting because it is easy to use and manage and do not require a lot of human labor to extract water unlike other rainwater harvesting technics like infield rainwater harvesting which requires a household to have land and it is very expensive since it needs continuous maintenance. The institutions that are working in the area on rainwater harvesting are the extension officers.

5.2 RECOMMENDATIONS

1. Appropriate governance and land use policy needs to be revised and implemented to ensure proper allocation and use of land for sustainable management of resources and risk management at community level.
2. There is need for the government to monitor land use change/cover. This will help in planning of future risks and uncertainties brought by the changes in land use
3. Efforts to increase the capacity of rural farmers to cope with and adapt to a greater prevalence of drought due to climate change requires a holistic approach that addresses their need for information, access to technology, capacity building, new livelihood opportunities and a supportive policy regime.
4. Different stakeholders under the Ministry of Agriculture need to promote rain water harvesting in their various programmes through awareness campaigns and field days in order to enhance agriculture production
5. Further research is required on the effects of land use change on water resources and to quantify the financial and other benefits of wider resilience building interventions such as rainwater harvesting.

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7.0 APPENDICES

7.1 Appendix 1: Questionnaire

Farmer and site identification

Name of the respondent [____]

District [__________________] Division [_______________] Location [_______________]

Date (dd/mm/yyyy) [__/__/____] Start time [________]

Year of settlement [______________]

0.0 Household characteristics

0.1 Age of the respondent [______]

0.2 Gender (1) female (2) male

0.3 Marital status (1) single (2) married (3)separated (4) widow/widower

0.4 Formal education level (years)

(1) None (2) primary (3) secondary (4) college/university (5) adult education

0.5 Total number of children [_____]

0.6 Source of income (1) formal employment (2) informal employment (3) formal business (4) informal business (5) Crop farming (6) Livestock production (7) Remittances (8) Other (specify)______________

1.0 Land use change

1.1 What was status of land cover by the time you settled?___________________

1.2 Are you aware of the land use changes that have occurred in the area in the last 20 years? (1) yes (2) no

1.3 If yes, what changes have taken place? ________________________________

1.4 Has the changes in land use affected you in any way? (1) yes (2) no

1.5 If yes are you better off now than you were before? (1) yes (2) no Explain____

1.6 What do you think can be done to adapt to the changes in land use?

2.0 Water availability

2.1 What is the main source of water for this household? (1) piped (2) river (3) well (4) rain water (5) bore hole (6) other (specify)

2.2 How much do you pay for water per month? _____________(KSh)

2.3 Do you own a water storage tank? (1) yes (2) no. If yes, how many liters does it hold? _________liters

2.4 If yes, what do you use the water it contains for? (1) domestic use (2) livestock (3) irrigation

2.5 If no question 2.3, how long does it take to collect water for use in the household? ______hours

2.6 Do you use the water to irrigate your crops? (1) yes (2) no

3.0 Climate Change and water availability

3.1 Have you ever heard of climate change? (1) yes (2) no

3.2 If yes what are the impacts of climate change on water resources in this area?

3.3 How do you cope with the changes mentioned above?

4.0 Rainwater harvesting

4.1 Have you ever heard of water harvesting? (1) yes (2) no

4.2 Do you harvest water in your household/farm? (1) yes (2) no

4.3 If the answer to part 4.2 is no, why do you not use rain-water harvesting? (1) lack of information/expertise (2) land constraint (3) laborious (4) expensive (5) not interested (6) other (specify)

4.4 If yes in question 4.2 above, what type of water harvesting do you practice? (1) rooftop harvesting (2) runoff harvesting (3) household water (4) in-field soil and water management (5) surface storage (6) other (specify)

4.5 What is the nature of the water source from which you harvest from? (1) rainfall (2) runoff (3) households (4) others (specify)

4.6 Who is mostly involved in water harvesting? (1) men (2) women (3) children (4) all

4.7 Where do you collect the harvested water? (1) containers (2) dam (3) on the farm (4) others (specify)

4.8 How do you conserve the harvested water? (1) polythene sheet lining (2) cemented pan/dam (3) covering the water (4) others (specify)

4.9 What is the main purpose for harvesting water? (1) irrigation (2) domestic use (3) livestock feeding (4) others (specify)

4.10 If the water harvested is used for irrigation, what type of irrigation do you use? (1) drip irrigation (2) sprinkler irrigation (3) furrow (4) piped-gravity flow (5) piped-motorized pump (6) bucket (7) other (specify)

5.0 **Institutions on water harvesting**

5.1 Have you ever had contact with any extension service? (1) no (2) yes

5.2 If yes, which organization(s)? ___________________________

5.3 Have you received any information on rain-water harvesting from any extension group?(1) Yes (2) No

5.4 If yes, what sort of information? ____________________________

5.5 Have you been trained on how to practice rain-water harvesting by any extension group? (1) no (2) yes

5.6 If yes, what method were you trained on? _______________________

5.7 Which of the trained method do you practice? ____________________________

5.8 Are you a member of any rain water harvesting farmers group? (1) no (2) yes

5.9 If yes, state the farmer group and its activities___________________

5.10 Are you satisfied with the implementations governing water harvesting groups (1) yes (2) no.

Explain your answer____

7.2. Appendix 2: Changes in settlements, farmland, water bodies and grassland in Kisaju, Matali, Nkoroi and Oloosidan sub locations

Sub-location	**Land use/cover**	**1990**		**2000**		**2010**		**Change (1990-2000)**	**Change (2000-2010)**	**Chi-square Test**	
		Area km^2	%	Area km^2	%	Area km^2	%	%	%	X^2	P-Value
Kisaju	Settlement	23.522	15.1	31.060	19.9	44.230	28.4	+4.8	+8.5	24.656	0.000
	Farmland	17.472	11.2	22.354	14.3	31.42	20.2	+3.1	+5.9	56.112	0.028
	Water bodies	0.005	0.003	0.005	0.003	0.005	0.003	0	0	76.798	0.488
	Grassland	114.904	73.7	102.484	65.7	80.247	51.5	-8	-14.2	24.834	0.000
Matali	Settlement	6.681	6.3	9.188	8.7	13.036	12.3	+2.4	+3.6	32.776	0.000
	Farmland	9.853	9.3	12.486	11.8	18.288	17.3	+2.5	+5.5	12.614	0.004
	Water bodies	1.279	1.2	1.279	1.2	1.279	1.2	0	0	76.409	0.335
	Grassland	87.988	83.2	82.846	78.3	73.198	69.2	-4.9	-9.1	24.732	0.000
Nkoroi	Settlement	1.650	17.2	2.193	22.9	3.112	32.4	+5.7	+9.5	12.665	0.000
	Farmland	1.939	20.2	2.577	26.9	3.539	36.9	+6.7	+10	34.910	0.006
	Water bodies	0.119	1.2	0.119	1.2	0.119	1.2	0	0	65.713	0.465
	Grassland	6.005	62.6	4.824	50.3	2.942	30.7	-12.3	-19.6	21.714	0.000
Oloosidan	Settlement	4.082	7.7	5.176	9.8	7.364	13.9	+2.1	+4.1	51.954	0.000
	Farmland	13.528	25.6	17.238	32.6	24.67	46.7	+7	+14.1	34.265	0.000
	Water bodies	0.044	0.1	0.044	0.1	0.044	0.1	0	0	47.232	0.654
	Grassland	35.240	66.7	30.436	57.6	20.81	39.4	-9.1	-18.2	38.321	0.000