UNIVERSITY OF NAIROBI

RAINFALL AND TEMPERATURE TRENDS, FARMING PATTERNS AND RAINWATER HARVESTING TECHNOLOGIES IN KIENI SUB-COUNTY

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DECLARATION

I declare that this thesis is my original work and has not been submitted elsewhere for research. Where other people's work has been used, this has properly been acknowledged and referenced in accordance with the requirements of the University of Nairobi.

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DEDICATION

This work is dedicated to the Almighty God for His grace. It is also dedicated to my family for the financial and emotional encouragement and support they have given me throughout this academic journey.

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ABSTRACT

The study area was in Tigithi Sub-location of Kieni constituency in Nyeri County which is an Arid and Semi-Arid zone with unreliable rainfall and high temperatures. The area experiences a bimodal rainfall pattern. The study analysed seasonal average rainfall (1984-2013) and seasonal average maximum temperature (1983-2012) trends to detect the presence of climate change. To investigate changing farming patterns from 1987 to 2017, a sectional survey was conducted in 2017 in which 400 households participated. The percentage change detection in land use and land cover in the area was accomplished with the use of remote sensing and GIS. The study engaged the community in harvesting rain water which was used to grow Kale as supplemental irrigation whose results were compared to the same crop grown depending fully on the rains. Kale was grown in three seasons whereby each season produced a rain-fed and supplemental irrigated Kale. The growing of Kale involved farmer 1 and farmer 2

Analysis of seasonal average rainfall and average maximum temperature trends was calculated by the Mann-Kendall test together with Sen's slope Estimator application using the MAKESENS template in Excel from the Finish Meteorological Institute. The March April May (MAM) rainfall season had positive average Mann-Kendall test value of 0.33 and positive Sen's slope average value of 0.32 which was upward rainfall trend. The OND rainfall season had an average Mann-Kendall test value of -0.06 and an average Sen's slope value of 0.02. The OND average rainfall results showed a decreasing rainfall trend. The highest mean rainfall for both seasons was experienced in April with over 115mm.

The MAM and OND seasonal maximum temperature returned positive Man-Kendall test and Sen's slope values. The average Mann-Kendal test for MAM season was 1.09 while the average Sen's slope for the season was 0.016. The same tests for OND returned the values of 1.55 and 0.025 as the results for Mann-Kendall and Sen's slope respectively. The MAM and OND average maximum temperature trend analysis showed an upward trend. The highest mean temperature recorded for both MAM and OND season was in March with maximum temperature of 26.5^{0}C.

The investigation of the changing farming practices in the study area as a result of declining average seasonal rainfall and increasing seasonal temperature, a sectional survey was conducted through administration of questionnaires and the collected data analysed with SPSS Statistics Version 23 program. The survey established that more than 70% of the farmers settled in the area from the 1990s and about 70% of them own farms of size of between 1 and 5 acres. Maize, potatoes and beans were the crops grown in the 1980s at 100%, 93% and 67.7% of the respondents respectively but reported to have declined in 2017 by 10.2%, 4.5% and 26.2% respectively. There was a significant rise in the growing of horticultural crops at about 30% from a low of 2% in the 1980s. The farming of Napier grass increased by almost 22% from low of 4%.

Land use land cover changes in the study area for the 1987-2017 period involved downloading and processing Landsat images of 1987, 1995, 2002, 2010 and 2017. Land use and land cover in the area was categorised into the following six classes: bare areas, bushlands, farmlands, forest, grasslands and water bodies. The percentage cover of farmlands classification increased significantly by over 160% in 2017 from 1987. The forest percentage cover declined by almost 50% over the same period. Farming practices have been changing due to climate change from growing wholly rain-fed crops like maize and beans to growing horticultural crops and Napier grass.

Brassica oleracea (1000 headed kale) was grown both as rain-fed and under supplemental irrigation for three seasons each comprising of 14 weeks. The rain-fed and supplemental irrigated total Kale yields were analysed using Analysis of Variance (ANOVA) with a set significant level of 5%. The famer 1's rain-fed Kale had a total yield of 18.5t /ha and the Kale grown under supplemental irrigation had total yields of 25t/ha an increase of 35%. Famer 2's both rain-fed and supplemental irrigated Kale had total yields of 16.4t/ha and 26.4t/ha a 62% increase in yields.

The increasing seasonal temperature and decreasing rainfall in Kieni as a result of climate change and climate variability occasioned changes on how farming was conducted. Horticultural crops farming was being practiced by more farmers. More farmers were getting involved with zero grazing as evidenced by the increase in growing of Napier grass.

Local farmers can increase resilience in the face of climate change by adapting rainwater harvesting for supplemental irrigation which will increase crop yields by as much as 60% as in this study. The crops grown with supplemental irrigation will also provide soil cover reducing soil erosion and the dead foliage providing humus to the soil.

Key words: Climate Change, GIS, MAKESENS, Land Use Land Cover, Water Harvesting

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ACRONYMS AND ABBREVIATIONS

%	Percentage
^0C	Degrees Centigrade
ANOVA	Analysis of Variance
ASAL	Arid and Semi-Arid Lands
C	Carbon
Ca	Calcium
cm	Centimetres
cmol/Kg	Centi moles per Kilogram
CO_2	Carbon Dioxide
DEM	Digital Elevation Model
DN	Digital Number
FAO	Food and Agriculture Organisation
GCM	Global Circulation Model
GDP	Gross Domestic Product
GIS	Geographical Information Systems
GoK	Government of Kenya
GPS	Global Positioning System
IEBC	Independent Electoral and Boundaries Commission
IPCC	Intergovernmental Panel in Climate Change
K	Potassium
Kgs	Kilograms
Kgs/ha	Kilograms per Hectare
KIPPRA	Kenya Institute for Public Policy Research and Analysis
Km	Kilometres
Km^2	Kilometre squared
KMD	Kenya Meteorological Department
Kshs	Kenya Shillings
LULC	Land Use/Land cover
LULCC	Land Use and Land Cover Change
m	Meters
M^2	Meter squared
M^3	Meter cubed

MAM	March April May
MDGs	Millennium Development Goals
Mg	Magnesium
mm	Millimetres
Mt	Metric tonnes
MWI	Ministry of Water and Irrigation
NCCRS	National Climate Change Response Strategy
NGOs	Non-Governmental Organisations
NPK	Nitrogen Phosphorous Potassium
OC	Organic Carbon
OECD-DAC	Organisation for Economic Co-operation and Development's Assistance Committee
OND	October November December
P	Phosphorous
PCEA	Protestant Church of East Africa
pH	Potential of Hydrogen
ppm	Parts Per Million
RCMRD	Regional Centre for Mapping of Resources for Development
RWH	Rainwater-Harvesting
RWHM	Rain Water Harvesting Management
SI	Supplemental Irrigation
SMC	Soil Moisture Content
SPSS	Statistical Package for the Social Science
SSA	Sub-Saharan Africa
t/ha	Tonnes per hectare
UNCCD	United Nations Convention to Combat Desertification
USD$	US Dollar

CHAPTER 1: INTRODUCTION

1.1 Introduction

This thesis presents findings from analysis of seasonal rainfall and temperature trends, examination of changing farming patterns and experimenting with rainwater harvesting technologies in Kieni to enhance rural agriculture.

This thesis is divided into seven chapters. The problem statement, research questions, aims and objectives, research justification and scope and overview of the research approach as well as the conceptual framework are contained in chapter 1. Chapter 2 is the review of the related literature, theory and professional literature. The main aspects reviewed include climate change and adaptation, climate change effect on agriculture, how changes in climate influences soil moisture and plant growth and the collection and use of rainwater as a coping mechanism to climate change and rainwater-harvesting technologies. Other aspects reviewed in this chapter include irrigation systems and role of irrigation in food production.

The research methods are found in chapter 3, which includes all the aspects of the study area and materials and methods. Chapter 4 has results and discussion on the seasonal average rainfall and seasonal mean maximum temperature trends in the area of study for a 30-year period. Chapter 5 has results and discussion on the changing farming patterns, which include the questionnaire survey as well as the effects of variations in land use and land cover. Chapter 6 has the results and discussion on working with the Kieni sub-county community to improve rural agriculture in the study area. The conclusion and recommendation are in chapter 7.

1.2 Background to the Study

Temperatures in Africa are rising and "by the end of this century they are likely to have gone up by 2^0C relative to 20^{th} century," according to the IPCC Fifth Assessment report (IPCC, 2014). Surface temperatures will continue to rise, due to climate change according to Global Circulation Models (GCM) simulations (Matzarakis and Amelung, 2008). Global models show that if nothing is done to bring down the worldwide carbon emissions, the global surface temperature is likely to exceed 2^0C relative to the 1850-1900 period by the end of this century (Murphy and Tembo, 2014).

The Intergovernmental Panel on Climate Change (IPCC) communicated that majority of the countries will see an increase in mean temperatures resulting in more stressed water resources while precipitation remains unreliable (IPCC, 2014; Parry *et al*., 2007). Susceptibility of a country to climate change is related to how developed it is as shown by various effects of climate change on different sectors of a country's economy (Richards, 2003; Smit and Pilifosova, 2003). Agriculture is one of the key economic sectors that are highly vulnerable to impacts of climate change (Pearson *et al*., 2011). Therefore, any major adverse climate change impact on agriculture would significantly affect economy of a country.

According to Kulshreshtha (2011), changes in temperature, rainfall and concentration of CO_2 in the atmosphere will directly affect the quantity and quality of agricultural produce. Kenya's central region, which is a good contributor of the food consumed in the country, has recorded significant changes in temperature and rainfall patterns. Recent research in Nyeri County demonstrates that rainfall received has been decreasing every 3 to 4 years (Karienye *et al*., 2012). From the 1960s, the area's minimum and maximum temperatures have been in the extent of 0.8-2.0^{0}C and 0.1-0.7^{0}C, in that order (GOK,2010). Nderitu *et al*., (2016) reported reducing long rains that are experienced from March to May between 1985 and 2015.

Four fifth of the land in Kenya is made up of arid and semi-arid areas with unreliable annual rainfall ranging between 100mm and 600mm (Kaluli, *et al*., 2013). This makes water management a vital part of agriculture for a country that has agriculture as the main export and revenue source and earns 60% of Kenya's export income (Ngigi *et al.,* 2010*).* As reported by the Economic Survey Report Highlight of 2014, growth in Kenya's agricultural sector decreased from 4.2% in 2012 to 2.9% in 2013, which was attributed to inadequate rainfall received in some grain growing areas (GoK, 2014). According to the Economic Survey (2018), the "real gross value added in the agricultural sector grew at a decelerated rate of 1.6% from Kshs 879.6 billion in 2016 to Kshs 893.3 billion in 2017 occasioned by drought, pests and disease incidence which resulted in reduced crop and livestock production". Therefore, effective water management in the arid and semi-arid areas of Kenya can improve crop yields and quality that would eventually improve the economy of the country. This would enhance the natural environment and improve the living conditions of farmers (Ngigi *et al.,* 2010).

Rainfall patterns as well as surface temperature changes directly affect the status of soil moisture, which in turn impacts on plant growth and the various stages of plant development (Leuzinger *et* *al*., 2015; Tietjen *et al*., 2017). With a projected rise in minimum surface temperatures as well as decrease in seasonal rainfall under climate change (Knowles *et al*., 2006), local conditions, especially the amount of water present in the soil, may decrease significantly as a result of evaporation loss. Responses to moisture stress by different types of crops change as they grow from one phase to the next. For every particular crop grown, there is a defined range of highest and lowest soil moisture condition forming the boundaries of observable development. A rise in moisture stress past a certain level negatively distresses the growth, pollination and reproduction purposes of plants (Sacks and Kucharik, 2011). Climate controls the population and species of crop insect pests influencing their development, reproduction and dispersal. Every species of insect pests has a particular "threshold temperature" above which development can occur and below which development ceases (Garrick and Liburd, 2018).

Climate change and variability will, therefore, affect the growing of some crops due to increased temperatures and declining rainfall, reduced soil moisture and increased population of crop pests, hence the reason why different farming practises are evolving in order for farmers to adapt to climate change and variability. IPCC (2001) defines adaptation as the manmade changes aimed at coping with climatic changes and at reducing negative effects. Changes in land use, location, restoration tolerance, as well as prevention are some of the adaptation measures (Adele *et al*., 2015; Smith *et al*., 2016). Adaptation to climatic change and variability can be effected with rainwater harvesting for Supplemental Irrigation (SI) to reduce increasing trends in crop failure that happens under rain-fed agriculture.

Rainwater-harvesting (RWH) is among the interventions proposed by the National Climate Change Response Strategy (NCCRS) for agricultural sector in Kenya (GoK, 2010). Others include support for community-based adaptation strategies, enhanced technical and financial support, addressing land degradation, promoting conservation agriculture, diversifying rural economies, among others. RWH technologies include but not limited to: rooftop rainwater-harvesting, terracing, ponds and pans, earth dams, sand dams, Zai pits and half-moon pits as well as harnessing of storm and flood water for farming. Rainwater harvesting technologies can be used as coping strategies for unreliable and poorly distributed rainfall in many countries especially in Sub-Saharan Africa (SSA) though the acceptance rate is low. Researchers predict that there will be an upsurge of rainfall variability and evaporation as a consequence of climate change while a rise in population will raise the need for ecosystems services and in particular water. Therefore, to increase resilience, knowledge of harvesting rainwater will be very crucial (Barron, 2009).

RWH and conservation can effectively help alleviate water scarcity and food shortages as well as prevent soil erosion. Lack of water for agriculture in SSA where most crops are rain-fed is largely due to erratic rainfall (Pachpute *et al.*, 2009; Wuta *et al*., 2018). Therefore, rainwater harvesting and conservation technologies and systems are important in improving the effectiveness of water use and enhancing rain-fed agriculture in the study area.

In Kenya the more predominant rainwater harvesting methods are the small scale and in-situ methods compared to large-scale systems (GoK, 2010). Water harvested from rainfall if used correctly can improve crop rooting area by about 30% although this is subject to the regional soil condition and rainfall distribution (Biazin *et al*., 2012; Oweis and Hachum, 2006). The RWH systems employed depend on the irrigation technology available such as drip irrigation, sprinkler and flooding systems (Biazin *et al.*, 2012).

1.3 Problem Statement

In Iran, field trials showed an increase in wheat and barley yields from 2.2-3.4t/ha; in Syria from1.25-3t/ha; and 4.6-5.8t/ha in Morocco, with small quantities of SI (Nangia *et al*., 2018). Worldwide, produce from rain-fed cereal crop at 2.2 t/ha is about two thirds of the irrigated yield (Oweis and Hachum, 2009).

Kieni sub-county is an Arid and Semi-Arid Land (ASAL) area located in the greater Nyeri County. The area experiences low and unpredictable rainfall, recurrent dry spells and dust storms and as a result reduced crop yields, which subsequently affect the livelihoods of the community (Macharia *et al*., 2012). ASAL areas normally experience lower rate of precipitation compared to the rate of water loss from evaporation due to high maximum temperatures (Oweis and Hachum, 2009) Therefore, to increase crops yields in the face of declining rainfall and rising temperatures, affordable rainwater harvesting technologies are needed for use for supplemental irrigation. The application of the harvested rainwater to the crops besides increasing crop yields provides ground cover, therefore a reduction in dust storms and soil water evaporation. Consequently, there would be more fodder for livestock and health issues associated food security would likely decrease.

Research Questions

1. Have there been any changes in the recorded seasonal average annual rainfall in the 1984-2013 period and seasonal average annual maximum temperature in the 1983-2012 period in Kieni sub-county?
2. To what extent are farming patterns changing in response to rainfall and temperature trends in the study area?
3. Can rainwater-harvesting technologies improve rural agriculture in Kieni sub-county?

1.4 Aims and Objectives

Overall Objective

Rainfall and temperature trends, examining farming patterns and enhancing rainwater harvesting technologies in rural agriculture in Kieni.

Specific Objectives:

1. Analysis of seasonal average annual rainfall (1984-2013) and seasonal average annual maximum temperature (1983-2012) records in Kieni sub-county to establish trends;
2. Examination of evolving farming patterns in response to rainfall and temperature trends in Kieni sub-county;
3. Working with Kieni sub-county farmers to enhance rainwater-harvesting technologies to improve agriculture.

1.5 Research Justification

In 2013, of the 1.5 billion hectares of cropland worldwide, more than four fifth of the land depend on rainfall yet it contributes at minimum two-thirds of the total global food production (Mekdaschi and Liniger, 2013). It is estimated that produce from rain-fed agriculture may fall by up to 50% in some areas. Should this occur, agricultural production, including access to food, may be severely affected in the near future (Ammar *et al.,* 2016).

The study was informed by the fact that rainwater harvesting in rural agriculture is one way of enhancing crop yields. Crops performance is affected by reduced precipitation leading to water stress especially as the limited available water in the rivers in Kieni is over abstracted for domestic and livestock use. Enhanced crop yields would bring socio-economic and ecological benefits to the community. The socio-economic benefits include improved food security, fodder for livestock, reduction of food deficiency related diseases, adaptation to low and erratic rainfall and improved livelihoods. The ecological benefits include increased land productivity, introduction of crops that could adapt to climate variability and reduction of soil erosion due to increased vegetation cover (Kahane *et al*., 2013).

Rainwater harvesting is promoted by NGOs globally. It is one of the practices recommended by the United Nations Convention to Combat Desertification (UNCCD) to combat desertification though its uptake remains slow. It has been reported that a twofold or threefold harvest can be realised if an additional 10-25% of collected rainfall run-off is made accessible to the crop at its acute stages of growth (Liniger *et al*., 2011). New farming skills being employed including the rainwater harvesting are looking for ways to lessen the consequences of recurrent dry spells in drought prone region of Sub-Saharan Africa (Mutekwa and Kusangaya, 2006). Therefore, for continuity and protection of water sources from contamination, innovative technologies should be applied and indigenous ones improved to include management of the sources (Hatibu and Mahoo, 1999).

1.6 Scope of Research and Overview of the Research Methodology

The principal focus of this research was the analyses of seasonal rainfall and temperature trends; examine the farming patterns; and utilize rainwater harvesting technologies to enhance agriculture among Kieni sub-county farmers. Several factors were considered before deciding on the two most sustainable technologies to be employed in the area for this study. The first consideration was the acceptability on which the sustainability of the method employed depended on. The farmers in the area were used to getting government support inform of free relief food and fertilisers therefore for them to understand the reasons for the study the research was able to gain access to the farmers through the use of focus group discussions, local leaders as well as opinion leaders who explained the role of the research to the community.

The second factor considered was the cost of the technology. The technology needed to be affordable and of low maintenance. Rooftop harvesting was a good example since almost every farmer has a roof top which can be used to harvest rainfall. Other factors were the topography of the land and the soil type; the type ofcrops to be grown; and the type of local materials available to develop the technology. The overall underlying factor was the willingness of the government to have supportive policies that could help farmers with the knowledge to implement these technologies.

The study approach involved in-depth understanding of the study community's culture and agricultural practices including existing rainwater-harvesting technology used and how SI can be applied to enhance crop yields in the study area.

The study methodology consisted of acquisition of rainfall and temperature data records for the for the 1984-2013 and 1983-2012 periods respectively from the Kenya Meteorological Department and subsequent analysis of seasonal data to establish trends. The research used questionnaires to collect data on how farming practices have changed in response to the established rainfall trends in the study area a 30year period from 1987-2017. The questionnaires had a random sample size of 400 and the data collected was analysed with SPSS Statistics Version 23 program.

The changing land covers were determined by the use of downloaded remote sensing imagery covering the same period of 30 years. These were remote sensing images for the years 1987, 1995, 2002, 2010 and 2017, which were analysed by categorising the land cover and land use characteristics of forest cover, water bodies, grasslands, bushlands, farmlands and bare lands. This was combined with a visit to the study area to record prominent physical features as well as ground truthing of the remote sensing imagery.

The methodological approach employed in the enhancement of rainwater harvesting technologies to improve rural agriculture through SI was the pilot farm method. The rainwater harvesting technologies employed were the water pan and roof rainwater harvesting, which were employed on two pilot farms. The crop grown was *Brassica oleracea L.* (1000 Headed Kale), which was rain-fed and SI during the rainy seasons of March-April-May (MAM) and October-November-December (OND). The soil wetness and its chemical composition were monitored throughout the growing season. On crop maturity, harvesting was done once a week and crop yields recorded for further analysis.

1.7 Conceptual Framework

Fig. 1 is the conceptual framework of the study, which demonstrates the effects climate change and variability have on the adaptive capacity of the community. The effects of climate change and variability as a result of increasing mean maximum temperatures and depressed rainfall calls for farmers to apply adaptation measures to counter their impacts. Some of the adaptation methods applied include rainwater-harvesting on the farms through various methods including roof rainwater harvesting and water pans. This harvested rainwater is then applied to the crops when they are about to encounter water stress through SI through drip irrigation, to economically use the water. Rainwater harvesting coupled with SI at the appropriate stage of the crop growth ensures that the crop does not wither, hence improved crop yields. Enhanced crop yields in the rural areas where the majority of the communities rely on agriculture for their sustenance brings about sustainable food production and improved livelihoods to the farmers, hence increased resilience in the face of climate change and climate variability.

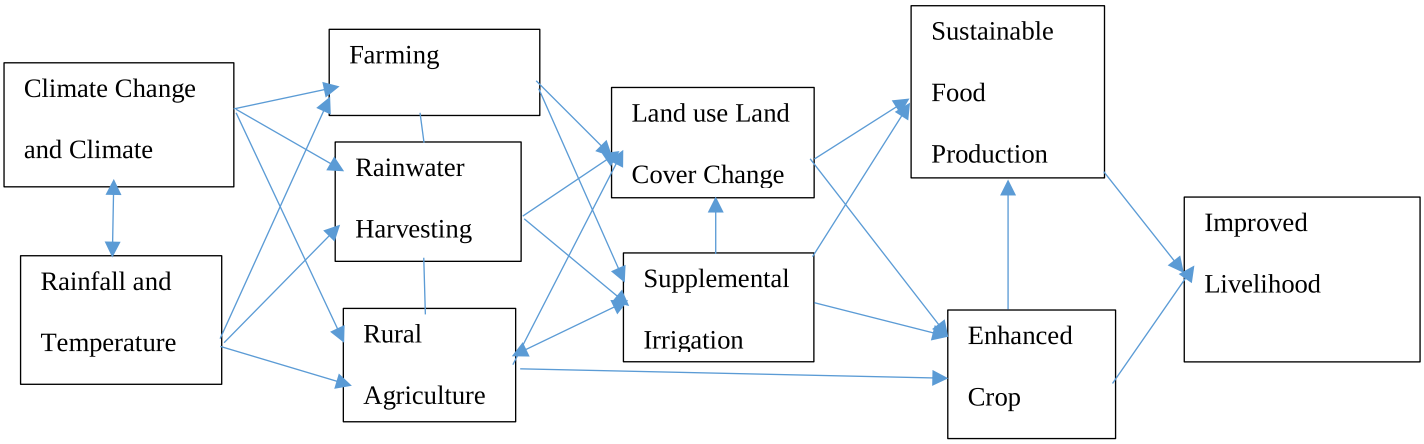


Figure 1: Conceptual Framework

CHAPTER 2: LITERATURE REVIEW

2.1 Climate Change and Adaptation

The global climate change has received attention since 1990 when the first assessment report of the IPCC was published (IPCC, 1990). Susceptibility of a country to climate change is linked to its state of development as indicated by the contrasting effects of climate change on different sectors of a country's economy (Richards, 2003; Smit and Pilifosova, 2003). Agriculture is one of the key economic sectors that are highly vulnerable to the impacts of climate change (Pearson *et al.*, 2011). Things to do with agriculture in the tropics occur very near the heat tolerance thresholds and moisture availability, meaning that the impact of climate change is likely to be unfavourable (Zhao *et al.*, 2005). Unreliable rainfall coupled with severe dry spells are the most sizeable risks facing Kenya's agricultural sector, and have major impact on crop production (D'Alessandro *et al.*, 2015).

Temperature and rainfall trends in Central Kenya have undergone major changes considering the region is one of the country's high food producer (Nderitu *et al.*, 2016). Since the 1960s, the region's maximum temperature has been in the range of 0.1-0.7^{0}C (GoK, 2010). Research done in 2012 in Nyeri County indicated that rainfall received in the locality has been on a declining in about every 3 to 4 years (Karienye *et al.*, 2012). In Kieni area, Nderitu *et al*. (2016) reported that long rains were on a downward trend between the years 1985 – 2015. These variations in climate coupled with other anthropogenic stresses will increase food insecurity as crop production could be severely impacted.

According to IPCC (2001), adaptation refers to the anthropogenic adjustments aimed at coping with climatic changes and at lowering their adverse effects. It is also defined as "activities that aim to reduce the vulnerability of human or natural systems to the impacts of climate change and climate-related risks, by maintaining or increasing adaptive capacity and systems resilience" (OECD-DAC, 2011). These coping needs vary across geographical and temporal scales and must be addressed in complex and uncertain circumstances requiring different areas of skills at the international and local level (Parry *et al.*, 2005). Adaptation strategies aimed at increasing crop production need to be formulated at local and regional scales, and considering differences in land-use and ecology of the targeted crop (IPCC, 2014).

There are various adaptation measures to climate change and variability. These include land use change; location; reduction of soil erosion and land degradation; improvement of water use efficiency, changing the lay of the land to enhance water uptake; as well as varying how farming is done in order to conserve moisture, organic matter and nutrients (FAO, 2012). Conventional approaches to climate change adaptation have focused on future climate change scenarios using the General Circulation Models (GCM), which help to identify and quantify potential impacts on different ecosystems and economic sectors (Parry *et al.*, 2005). However, these approaches fail to depict the regional and local impacts of climate change nor represent the local communities' ability to adapt to climate change at the local level. The best approach to climate change adaptation is the bottom-up participatory approach that involves the communities' adapting strategies, which may or may not need any modification. According to Mimura (2006), design of adaptation measures is based on concepts of risk avoidance, sharing and acceptance as well as reduction of negative impacts and exploitation of opportunities.

2.2 Impact of Climate Change on The Agricultural Sector

Based on observed climate trends, Lobell and Field (2007) estimated that the effects of rising temperatures since 1981 had brought about combined annual losses of yields of wheat, maize and barley, which are among the six most grown crops in the world, representing 40MT or US$5 billion per year. According to IPCC 2014, it is predicted that by 2050 temperate regions will experience increased crops yields associated with anticipated mean temperature rise of 1-3^{0}C, whereas water constrained tropical regions will undergo yield decreases. It is predicted that by the end of the 21st century, mean growing season temperatures are likely to equal the current extremes in temperate areas and the same will happen in the tropics and subtropics, resulting in major impacts on food production (Vermeulen *et al.*, 2012).

In Kenya, the agriculture gives rise to approximately a third of Kenya's GDP and employs more than fourty per cent of the country's population directly (KIPPRA, 2017). However, the agricultural sector is particularly vulnerable to variations in climate change and variability: rising temperature, fluctuating rainfall distribution and amount. It is predicted that majority of the countries will experience a rise in average temperature, overstretched water resources, and erratic precipitation (IPCC, 2014; Parry *et al.*, 2007). According to Kulshreshtha (2011), changes in temperature, rainfall and the concentration of CO_2 in the atmosphere will directly affect the quantity and quality of produce.

Much of the horticultural practice in Kenya is carried out in arid and semi-arid lands (ASALs), resulting in the sub-sector being prone to the effects of climate variability and change (GoK, 2010). Climate change and variability affects crops through heat and water stress, water logging from flooding and increase or decrease of particular pests and diseases (Challinor *et al.*, 2009, Chakraborty and Newton, 2011, Bender and Weigel, 2011). Climate controls the populations of crop pests by influencing their development, reproduction and dispersal. For example, every species of insect pest has a particular 'threshold temperature' above which development can occur, and below which development ceases (Garrick and Liburd, 2018). The projected increase in temperatures in the tropics may increase the population and diversity of pests and potentially increase the costs of controlling them.

2.3 Effect of Climate Change on Soil Moisture and Plant Growth

Current evaluations of the impact of climate change have focused on the changes in rainfall and temperature patterns which have direct impact on soil moisture status, that in-turn affects plant growth and phenology (Leuzinger *et al.*, 2015; Tietjen *et al.*, 2017). With the projected increase in minimum air temperatures and scarce rainfall under climate change,(Knowles *et al.*, 2006), local conditions especially soil water content may fall significantly due to evapotranspiration (Alfaro *et al.*, 2006). According to Parry *et al.*, (2007) and FAO, (2008b) it is expected that low latitude countries with less water available will generally be at risk of reduced crop yields at even 1-2^0C warming due to an increased evapotranspiration and levels of moisture going down (Bals *et al*., 2008). Should the above happen some of the agricultural lands in SSA will become unsuitable for growing crops while some grassland regions will become unfit for pasture though the extent of these yields declines are still unknown (Bals *et al*., 2008). According to Gachene *et al*., (2015), in SSA, calculated and simulated analyses show crop yields will decline by more than 10% by 2055.

Climate change caused by change in rainfall amounts and patterns will result in the tropics becoming drier while the temperate regions become wetter (FAO, 2008b). According to Bals *et al*., (2008) and Chijioke *et al*., (2011), temperature rise coupled with diminishing volume of rainfall in SSA may cause loss of farming acreage owing to soil dryness, soil erosion, increase in drought and salinity as well as exhaustion of groundwater.

Climate change poses the greatest challenge to agriculture and food security in Sub-Saharan Africa (SSA) because farmers in this region depend almost wholly on rain-fed agriculture for their livelihoods. Food production and access in many African countries in these SSA regions would be severely compromised by climate variability and change (IPCC, 2007; Shah *et al*., 2008 and Nellemann *et al*., 2009). This means that areas suitable for agriculture would be negatively affected by climatic change and the yield potentials of many high profile crops produced in the region, particularly along the margins of semiarid, arid and coastal areas, are expected to decrease (Chijioke *et al*., 2011).

In Kenya, regions where changing climate is expected to cause reduction in rainfall, crop destruction by floods or where irrigation is not practiced, crop failure is likely to occur compared to regions receiving sufficient rainfall or where farmers are practicing irrigation.

Responses to moisture stress are not the same within different plant types throughout their growth phases. Each crop has a precise array of highest and lowest soil dampness condition forming the boundaries of observable growth, beyond which points, plant growth, pollination, and reproductive processes are affected (Sacks and Kucharik, 2011). Hatfield and Prueger (2011) reported that the chances for biomass accumulation and crop yield to decrease as a result of soil moisture stress.

2.4 Rainwater Harvesting as an Adaptation Measure to Climate Change

Continued increase in ambient temperature and variability of rainfall due to changing climate has contributed to the increasing trends of crop failure under rain fed agricultural systems in SSA. This has aggravated agricultural water scarcity in Kenya because of the long dry spells that continues to be witnessed (GoK, 2010). Nyeri County has not been spared from experiencing these long dry spells. In this county, private holdings land is dedicated to horticultural farming for both local and international markets. However, agricultural water scarcity due to spatial and temporal variability of rainfall is threatening crop production (Karienye *et al.*, 2012; Nderitu *et al.*, 2016). Rain water harvesting is an important intervention proposed by the National Climate Change Response Strategy (NCCRS) for the agricultural sector in Kenya (GoK, 2010). Rainwater harvesting can effectively help reduce water scarcity and food shortages as well as prevent soil erosion. Hence, rainwater harvesting and management (RWHM) innovations are important in crop farming as they complement the unreliable rainfall.

2.4.1 Rainwater harvesting technologies

Pachpute *et al.*, (2009) and Wuta *et al.*, (2018) projected that shortage of water for farming in the SSA region which employs mostly rain-fed agricultural system, is due to the unpredictability of rainfall and non-productive waste in the period of crop development. It is reported that less than 15% of the terrestrial precipitation is utilized for crop production purposes (Oweis and Hachum, 2006). Therefore, to support rain fed agriculture in the region and increased efficacy in the use of rainwater harvesting (RWH) skills and methods are very important. Crop yields can increase 2-3 fold because of the incorporation of RWH systems together with good farming practices to avoid on-farm water losses, which are likely to reduce the yields to only 10-20% of the farm potential (Falkenmark *et al.*, 2001).

Evidence from elsewhere revealed that rainfall coupled with application of supplemental irrigation (SI) increased both yields and water use efficiency, and in one season rain fed wheat yields increased from 2.16 t/ha to 4.61 t/ha by using only 68mm of irrigation water (Adary *et al.*, 2002).With inadequate rainfall more water is required by the crops as they respond better with a notable surge in yields even with rainfall amounts of 500 mm (Oweis and Hachum, 2012).The amount of soil water in the rooting zone could be enhanced by up to 30% with proper use of in-situ and micro-catchment methods subject to the local area rainfall patterns and soil types (Biazin *et al.*, 2012; Oweis and Hachum, 2006).

Rain water harvesting systems consist of a catchment area, runoff channel, sediment tank, storage vessel or area and SI system (Rockström *et al.*, 2002). It involves the transfer of rainwater from a catchment area to supplement the rainfall received on a cultivated area. Common water harvesting systems in Kenya include roof catchments, runoff harvesting from ground surfaces and floodwater harvesting from water courses. The technologies are cheap, simple and environmentally friendly and can be easily managed with limited technical skills. The RWH technologies can also be integrated in many land-use systems making it appropriate for local social-cultural, economic and biophysical conditions (Ngigi, 2003).

The RWH systems employed depend on the irrigation technology available including drip, sprinkler and flood irrigation methods (Biazin *et al.*, 2012). Mate *et al.*, (2006) reported that rainwater harvesting technologies can be classified as:

1. Macro-catchment. These technologies involve diverting big runoff flows from surfaces such as roads and pastures. The structures are at a considerable distance from where water collected is being applied. Use of hillside sheet/rill runoff, rock catchments, sand and earth dams are examples.

2. Micro-catchment. These harness runoffs near the growing crop root zone replenishing the soil wetness. For crop growth, the soil or reservoirs situated within the farm are the crucial water storage devices that would offer additional water for crop growth. Micro-catchment technologies, such as zai pits, strip catchment tillage, contour bunds, and semi-circular bunds. are largely used for growing crops whose water-demand is average such as maize, sorghum, groundnuts and millet.
3. Rooftop harvesting. Can be implemented wherever there is the presence of a roof as catchment to collect rainwater. Rural agricultural famers have dwellings whose rooftops can be used as catchment for harvesting rainfall.

Roof water harvesting

This system is among the most popular water harnessing practices embraced by separate households both in urban and rural areas to meet their various water supply needs in many dry regions of Kenya. Rooftop catchment is a system inside the household compound comprising of gutters secured to the roof channeling the rainwater into a storage tank with the roof acting as the catchment surface.

Water harvested via the roof top may be utilized for (a) domestic purposes; (b) supplementary irrigation in ASAL and areas experiencing dry spells; (c) reclamation soils from alkalinity and salinity; and (d) groundwater recharge (Biswas, 1991; Kamra *et al.*, 1986; Kumar, 2004). Storage tanks for roof catchments are built in connection to roofed buildings with rainwater flowing in via gutters. The tanks come in different shapes, sizes and are made from different materials, for instance cement, brick, iron sheet and plastic. The rooftop catchment systems have the advantage of collecting relatively clean water.

Rooftop rainwater harvesting is greatly dependable particularly for those families that have capitalized on big storage structures (Kimani *et al*., 2015). Households with enough storage facilities use the stored water for irrigating kitchen/back yard gardens and livestock. However, this practice is not reliable in some instances where families do not have enough volume water storage tanks.

Water pans

Water pans, also known as earth dams, are becoming popular in ASALs for collecting runoff water during the rainy season. Runoff harvesting techniques involve the use of contour earth ridges/bunds and contour stone bunds. In Kenya, they are sometimes used for supplemental irrigation in Kitui, Laikipia, Machakos, and Nakuru Counties (Nega and Kimeu, 2002), and are common in horticulture growing zones. The structure is established by digging up the pan or from a natural depression with the capacity not exceeding 20,000 m^3(MWI, 2015). Recently, lined pans with volumes of up to 70,000 m^3 are becoming prevalent with horticultural growers (MWI, 2015).

Earth dams do not have a long useful life span as they are affected by high rates of evaporation and siltation. Substantial water loss through seepage and evaporation is one of the major drawbacks affecting the adoption and up-scaling of on-farm water storage systems, as the losses may account for approximately 30–50% of the stored runoff (Ngigi *et al.*, 2005). Falkenmark *et al*., (2001) also pointed out that in ASALs, evaporation alone can result to water loss amounting approximately to 0.9 - 1.4 m within 6 months. However, Rockstrom *et al*., (2002) reported promising results in a feasibility study which focused on the use of earth dams for SI of maize in Machakos. Similar initiatives in Kitui and Laikipia were discouraging as the loss of water through seepage was identified as a major drawback (Kihara, 2002). Various remedies like concrete sealing, polythene lining and rubble stones or clay, are being implemented to reduce seepage losses. Optimal benefits of using water pans could be realized if appropriate water lifting and application technologies such as treadle pump and drip irrigation are incorporated. For example, a 50 m^3 water pan coupled with a drip irrigation system was reported adequate to meet SI requirement for a garden of 300–600 m^2 planted with cabbages (Ngigi *et al.*, 2005).

2.5 Irrigation Systems

Irrigation is an artificial method of supplying water to the soil or crop root zone in areas where there is insufficient or unreliable rainfall or when crops are grown in the dry season. Irrigation systems normally consist of a water pumping system, conveyance system and water application system. Pumping system is used where the topography does not allow water to flow to the cropping area by gravity and the conveyance system is for transporting the pumped water. The pumped water is conveyed to the application system which delivers water for irrigation to the soil or the crop root zone through sprays in case of sprinkler irrigation, drips (drip irrigation), watering cans (manual irrigation) or furrows (surface irrigation). Some of the common types of irrigation systems in Kenya are: surface irrigation, drip irrigation, sprinkler irrigation and manual irrigation.

2.5.1 Drip irrigation

This is commonly used in dry areas where groundwater is limited due to its efficiency in conserving water. Further, the system is suitable for high valued widely-spaced row crops cropping systems planted on individual plots (Kumar, 2008). Drip irrigation is widely regarded as the most promising irrigation system in combination with RWH as it uses harvested rainwater efficiently. The drip irrigation kit consists of a network of plastic pipes, water emitters (or drippers), and a set of valves and filters. Automatic drip irrigation system is considered expensive hence inaccessible to small-scale farmers.

The introduction of low-cost kits for smallholder farmers in Kenya in 1996 (Kulecho and Weatherhead, 2005) made the kits affordable for smallholder farmers, hence are playing a considerable role in the horticultural production sub-sector in Kenya. The systems vary with the mode of water lifting/pumping, size of drip line and containers. The efficiency of drip irrigation is affected by factors such as the use of saline water which is reported to corrode the metallic parts of the drip kit; and secondly, where water is harvested, physical substances in water clog the drip line leading to discontinuation of drip kit irrigation (Kulecho and Weatherhead, 2005).

Cheap drip irrigation kits like the Chapin bucket kit are increasingly being adopted by farmers in Kenya as they do not require a pump or running water, and reduce water requirements by up to 70% by supplying water at the root zone and in the required amounts (Ngigi *et al*., 2000). In Kenya, smallholder farmers prefer supplemental irrigation for cash crops as opposed to food crops (Jurdell and Svensson, 1998). Research shows that a well-managed drip irrigation systems may increase water-use efficiency up to 100% (Sivanappan, 1994). Increased crop yields and higher fertilizer-use efficiency have also been reported (Hou *et al*., 2016; Ngigi *et al*., 2000). Additionally, problems associated with surface methods of irrigation such as waterlogging and salinity are significantly reduced when drip irrigation system is employed (Valipour, 2014).

2.5.2 Role of irrigation in food production

According to FAO (2009) reported irrigation raises crop yields by between 100 and 400 per cent and that by 2029 irrigated land is projected to increase by 27%, while only a 12% rise in the amount of water due for farming will be realised (FAO, 2009). In Kenya, only 1.8% of crop land is irrigated compared to 4.0% in Sub-Saharan Africa and while 20% of the land is appropriate for rain fed farming, irrigation is likely to increase accessible land by 10% (FAO, 2009). In Kenya and especially in Kieni ASAL lands can be made to be more crop productive through the development of rainwater harvesting and irrigation.

However, the uptake is slow due to technological limitations, and farmers lacking sufficient funds and capacity for operator managed irrigation schemes. To guarantee food security, the accessible acreage suitable for irrigation must be used optimally through suitable expertise of better seeds, fertilizers and procedures that are friendly to the grower. Even though this optimal use of suitable irrigable land may seem like standard knowledge, unfortunately it has not reached a critical mass of growers as to realise reliable outcomes. Therefore, Kenya continues to suffer perpetual food deficiencies and lack.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Area

The study was conducted in Tigithi sub-location, which was located in Kiamathaga location, Kieni Constituency, Nyeri County and lies between 0^{o} 7' 0.4" - 0^{o} 10' 27.5" South and 37^{o} 1' 14.2" - 37^{o} 5'25.2" Eastas shown in Figure 2. The sub-location had a population of 2194during the period of this study in 2017according to the 2009 Kenya Population and Housing Census (GoK, 2010) (Table 1). On average the sub-county is approximately 180km from Nairobi, 40km from Nyeri, 25km from Nanyuki, and 50km from Karatina, which has probably the largest open air market in East Africa. The Kenya Meteorological Department has weather stations in Nyeri and Nanyuki whose rainfall and temperature data were used. The researcher worked with officers on the ground from the various government ministries including agriculture, education and devolution and the local farmers.

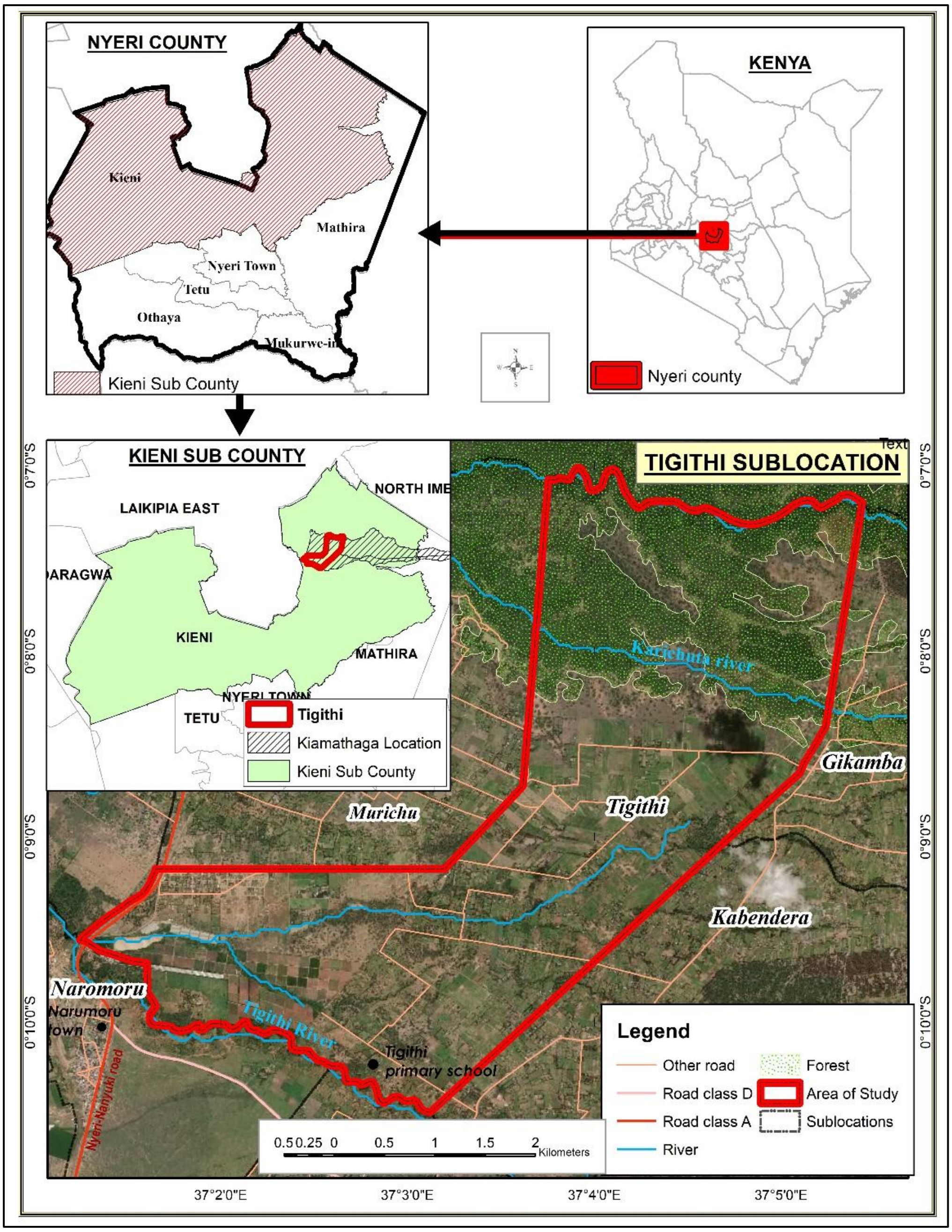


Figure 2: Tigithi Sub-location in Kieni Sub-County, Nyeri County (Source: Author, 2017)

3.1.1 Location and description

Kieni sub-county is divided administratively into Kieni East and Kieni West. The area of study (Figure 2above), was in Tigithi sub-location in Naromoru, Kiamathaga location, Kieni East. From the 2009 National Population Census it was reported that Kieni's population was 175,812 people and covering an area of about 1,378.10 Km^2. Naromoru/Kiamathaga location has four sub-locations (Table 1). The household population Tigithi sub-location was 666 as per 2009 Kenya Population and Housing Census.

Table 1: Population of Kiamathaga Location According to Gender, Households and Density

Sub location	Male	Female	Total	Households	Area (Km^2)	Density (Population/Km^2)
Tigithi	**1,175**	**1,019**	**2,194**	**666**	**21.1**	**104**
Murichu	1,353	1,321	2,674	762	11.3	237
Gikamba	2,183	2,001	4,184	1,098	66.4	63
Kabendera	1,419	1,472	2,891	830	11.3	256
Total	**6,130**	**5,813**	**11,943**	**3,356**	**110.1**	**108**

Source: 2009 Kenya Population and Housing Census

3.1.2 Biophysical setting

(a) Climate

The quantity of rainfall experienced in Kieni is influenced by the presence of Mt. Kenya, which rises more than 4,000m from the sea level and lies to the east while the Aberdare Ranges are to the west with an altitude of about 3,000m above sea level. Driest parts of Kieni are found in Kiganjo and Naromoru (Wamicha, 1993) which receive 500-850mm of rainfall per year. The amount of rainfall received rises to 2300mm close to the slopes of Mt Kenya and 3100mm close to the areas surrounding the Aberdare Ranges. Kieni East where the study was carried out experience a yearly precipitation of about 500mm. Therefore, the region is classified as an arid and semi-arid area (ASAL). These ASALs where Kieni sub-county is located are characterised mostly by a scorching dry climate with low unreliable rainfall which is poorly distributed. The area experiences bimodal rainfall pattern with long rains being received around March/April and short rains experienced in October/November.

(b) Vegetation

The study area map (Figure 2) shows some forest cover along and to the north of Karichuta River. To the north of the river is Mt Kenya which had forest cover which thinned out with decreasing altitude. In the lower regions of Kieni, the vegetation is grassland and shrubs that dry out with declining rainfall. Most farmers in the region grow seasonal crops such as maize and beans on their farms. Some farmers practice horticultural production and some apply supplemental irrigation to the crops. With declining rainfall land degradation may occur as the land may remain bare lands causing soil erosion and loss.

(c) Physiography and Drainage

The study area is surrounded by Mt Kenya located to the east and the Aberdare Ranges appearing to the west which have forest cover in the upper parts and grassland in the lower regions. The major rivers are Tigithi River and its tributaries to the South and Karichuta River to the North. The nearest river to the study area is Tigithi River.

(d)Water Resources

The study area experiences drought from low and unreliable rainfall and some farmers have resulted to harvesting runoff rain water and storing it water pans for domestic use. Some farmers also harvest the rainfall from their rooftops and store in plastic tanks. The harvested rainfall is applied to the crops through sprinklers which is not an efficient method of irrigation. The section on physiography and drainage mentions the two rivers found in the area. However, the Tigithi, and Karichuta rivers provide water for domestic use as well as for small irrigation projects which are discontinued immediately the flow volumes. The decrease of the river flow could be due to declining rainfall, evaporation due to high temperatures as well as over consumption. Table 2 that indicates the main sources of water in Nyeri North (where Kieni Sub county is located) and Nyeri South for various households.

Table 2: Number of Households Served by Various Sources of Water in Nyeri County

Nyeri	Pond/Dam	Lake	Stream	Spring well/ Borehole	Piped into Dwelling	Piped	Harvested Rain	Water Vendor	other	Total
North	**674**	**19**	**26,699**	**10,471**	**6,698**	**32,705**	**2,692**	**1,256**	**93**	**81,307**
South	344	28	22,930	7,154	6,264	23,782	5,068	432	26	66,028

Source: 2009 Kenya Population and Housing Census

(e) Biophysical Vulnerabilities

Climate change refers to significant changes in temperature, precipitation, wind patterns and other measures of climate. Climate change occurs when there is an increase, in this case, of average temperatures over an extended period of time, normally decades or longer (IPCC, 2007). There are also extremes in the climatic conditions occasioned by heavy torrential rains of very high intensity, which does not give soil enough time to be percolated. Consequently, most of it is lost as runoff. This runoff carries away the top soil, leading to soil loss due to soil erosion. The other climate extreme is the prolonged dry spells that affect the crop yields as well. The prolonged drought is usually accompanied by winds which blow away the top soil because it is light as it lacks of soil moisture.

The area is also affected by a high population density leading to subdivision of farms that are over-cropped. The high population means larger built up areas so that more rainwater is lost as runoff. The area being arid and semi-arid with low vegetation cover exacerbates the problem of soil erosion. The soil is lost through water and wind erosion. The other negative impacts are from other land uses such as overgrazing of livestock occasioning bare lands which are vulnerable to soil loss from wind and other forms of soil erosion.

3.1.3 Socio-economic setting

(i) Political and Administrative Context

Kieni sub-county has eight assembly wards as (Table 3). The study area of Tigithi sub-location falls within Naromoru/Kiamathaga ward with a population of 26,291 and an area of 176.2Km^2.

Table 3: Kieni Administrative Wards, Population and Area

Item	Assembly Wards	Population 2009 census	Area (Km^2)
1.	Mega	17,264	69.40
2.	**Naromoru/Kiamathaga**	**26,291**	**176.2**
3.	Mwiyogo/Endrasha	19,446	132.9
4.	Mugunda	23,712	261.0
5.	Gatarakwa	18,890	97.5
6.	Thegu River	21,804	185.9
7.	Kabaru	22,084	203.7
8.	Gakawa	26,321	251.5

Source: Independent Electoral and Boundaries Commission (2012)

(ii) National/ Regional /Local Economic Setting

Livelihoods of the inhabitants of arid and semi-arid areas are affected due to the crop failure from lack of enough rainfall and rising temperatures and floods from extreme weather events. Kieni sub-county is usually affected by declining rainfall, strong winds and high temperatures which result in low crop yields. Local farmers in the area practise subsistence farming on small acreage with low crop yields.

(iii) Social Setting

The population of Kieni is 175,812 as per the 2009 Kenya Population and Housing Census (GoK, 2010). Table 4 shows the demographic profile for the rural population of the host Nyeri North District.

Table 4: Nyeri North Rural Population by Age and Gender

Age	Male	Female	Total
0-4	16,304	15,414	31,721
5-9	17,266	16,754	34,020
10-14	17,194	16,510	33,704
15-19	14,494	13,342	27839
20-24	12,010	11,251	23,261
25-29	10,739	11,347	22,086
30-34	9,979	10,541	20,520
35-39	9,043	9,739	18,782
40-44	7,630	8,197	15,827
45-49	6,804	6,967	13,771
50-54	4,255	4,979	9,234
55-59	3,700	4,139	7,839
60-64	3,817	4,121	7,938
65-69	2,501	3,208	5,709
70-74	2,197	2,567	4,766
75-79	1,272	1,531	2,803
Age Not Stated	29	20	49
Total	**141,423**	**143,971**	**285,394**

Source: 2009 Kenya Population and Housing Census

(iv) Health Setting

Kieni sub-county is in the greater Nyeri County which boasts several major health facilities including the Nyeri Provincial General Hospital which is the largest in the County. The County has a district hospital based in Karatina which is not very far off from Kieni. There are several sub-district hospitals including Mukurwe-ini and Othaya, and faith-run hospitals including

Consolata Hospital, PCEA Tumutumu and Mary Immaculate Hospital in Mweiga. Within the sub-county there are various government dispensaries which are located closer to the people, especially in the rural areas.

3.2 Rainfall and Temperature Time Series

Introduction

This study analysed historical secondary rainfall and temperature data procured from the Kenya Meteorological Department (KMD). Meteorological data includes precipitation, temperature, humidity, wind direction and pressure, among other atmospheric parameters. The data is very important in many industries including aviation and agricultural industries.

Rainfall and Temperature data

The 12-month average accumulative data on average rainfall was procured from the Nanyuki Weather Station. The data for this study was for the 1984-2013 period and measured in millimetres. Similarly, average maximum temperature data for 12-month cumulative was obtained from the Nyeri Weather Station recorded in the period of 1981-2012 and measured in degrees Celsius.

3.2.1 Rainfall and temperature trends

Trend analysis of a time series consists of the magnitude of the trend or pattern and its statistical significance. Detecting trends of rainfall and temperature was done by Mann-Kendall test (Gilbert, 1987) and Sen's slope estimates Application (MAKESENS), an Excel template by Finish meteorological institute (MAKESENS, 2002).

Mann-Kendall Test

Mann Kendal test (Mann, 1945 and Kendall, 1975) is a statistical test commonly applied to analyses time series data including climatological data such as rainfall and temperature. The test is advantageous because it is non-parametric which means the data does not have to be distributed normally and the test is not very sensitive to inhomogeneous data. It is fit for the data series where the trend may be assumed to be monotonic and noncyclic. Depending on the total number of data values, MAKESENS performs two types of statistics. The first statistic is that S-statistics used if the number of values is less than 10 while the second Z- statistics is for data values equal to or greater than 10 as shown in equation (i).

The mathematical equation for calculating Mann-Kendall test.

$$S = \sum_{k=1}^{n-1} \sum_{h=k+1}^{n} sgn\ (x_h - x_k) \qquad \text{(i)}$$

Where:

x_h and x_k are annual in values 'h'and 'k'(chronologically) and h>k respectively

n=number of data points

$sgn(x_h - x_k)$ is calculated using equation (ii) below

$$sgn(x_h - x_k) = \begin{cases} 1\ if x_h - x_k > 0 \\ 0\ if\ x_h - x_k = 0 \\ -1\ if x_h - x_k < 0 \end{cases} \qquad \text{(ii)}$$

A positive value of S is an indicator of an upward trend while a negative value shows that the trend is decreasing. The S – statistics react as normally distributed if the data values are less than 10 and the test is performed with normal distribution with variation as given by the equation (iii) below.

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right] \qquad \text{(iii)}$$

Where;

q = number of tied values (equal value groups)

t_p= the number of ties in p^{th} value

The standard normal distribution (Z – statistics) is computed using equation (iv).

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} if S > 0 \\ 0\ if S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} if S < 0 \end{cases} \qquad \text{(iv)}$$

The test of trend is:

H_0: No trend

H_1: Monotonic increasing or decreasing trend (upward or downward trend)

H_0: Rejected if $Z > Z_{1-\alpha/2}$

Significance of trend is assessed statistically by using Z-value. A positive Z value shows an inclining trend while a negative Z-value is an indicator of a declining trend. MAKESENS performs calculations at four different significance levels which are: α=0.001, 0.01, 0.05 and 0.1.

The significance level of, for instance, 0.1 means that there is a 10% probability that we may make a mistake when rejecting H_0 (null hypothesis).

The MAKESENS template uses the following symbols the four tested significance levels:

***	if trend at α = 0.001 level of significance
**	if trend at α = 0.01 level of significance
*	if trend at α = 0.05 level of significance
+	if trend at α = 0.1 level of significance
Blank	if α>0.1 level of significance

Sen's Estimator (Slope) Method

Sen's non-parametric estimator method has been used for predicting the magnitude or true slope of various time series data such as the climatological data and it uses a linear model for trend analysis. This is the measure of change per unit time period, in this case a year. This means that f(t) in equation (v) is equal to

$$f(t) = Qt + B \qquad \text{(v)}$$

where Q is a slope and B is a constant.

To get the slope Q in equation (v) the slopes of all the data value pairs are calculated

$$Q_i = \frac{x_h - x_k}{h-k} \; for\; k = 1,2,3, \ldots\ldots n \qquad \text{(vi)}$$

where h and k are data values at time h and k (h>k)

Q_i values for each data pair are calculated and median value is taken as final Sen's slope of estimation (trend) which is calculated using equation (vi).

$$Q=\begin{cases} Q_{(n+1)/2}\; for\; n\; is\; odd \\ \frac{1}{2}\left(Q_{\frac{n}{2}} + Q_{(n+2)/2}\right. for\; n\; is\; even \end{cases} \qquad \text{(vii)}$$

The median (Q_{median}) is calculated using 100(1-α) % confidence interval and a non-parametric test depending on normal distribution which is calculated differently depending whether n is odd or even (equation vii). A positive value of Q is indicative of an upward trend while a negative value is a sign of a downward trend. MAKESENS computes the confidence interval at two different confidence levels; α = 0.01 and α = 0.05, resulting in two different confidence intervals. To obtain B in equation (v) n values of differences x_i-Qt_i are calculated and the median gives an estimate of B.

3.3 Evolving Farming Patterns in Response to Rainfall Trends

3.3.1 Questionnaire interviews

This section illustrates the methodology employed to accomplish the study. This section considers the data collection methods that were used for the primary data. It also considers the research design which was adopted by the researcher and the population size.

Research Design

Campbell and Katona (1953) similarly argue that the ability for extensive use and all-encompassing coverage provides the survey technique its unlimited effectiveness. According to Doyle (2004), "a survey research refers to a body of techniques for collecting data on human characteristics, attitudes, thoughts and behavior by obtaining responses from individuals to a set of prepared questions".

According to Kothari (2004), "a research design is an order of ways in collecting data and analyzing facts so as to compile important facts". Kothari (2004) additionally stresses that research designs, by necessity, must safeguard against prejudice and capitalize on dependability with bigger apprehensions on cost-effective conclusion of the study.

A cross-sectional survey design was applied in this study as it was the most acceptable since it made sure that the collected data gave relevant answers to research questions. Additionally, it was a comprehensive way of comparing the past and the present farming practices employed by each household interviewed. It is meant to establish the relationship between farming patterns practiced by residents of Tigithi sub-location in response to the change in climate and climate variability.

Population of the Study

Population of the study is the entire assembly of fundamentals which are required to create some implications or suggestions, according to Kothari (2004). Similarly, Mugenda and Mugenda (2003) "define a population as the total respondents under the focus of the study and which can help the researcher achieve the intended research purpose".

The population of the study was all the households in Tigithi sub-location. There were a total of 666 households (Table 1) in this sub-location according to the 2009 census. Using the research advisors sample size estimation table (https://www.research-advisors.com/tools/SampleSize.htm), a total of 400 households were randomly selected for the study. The selection was done using a 95% confidence interval, meaning if the study was to be repeated several times, then it is certain that 95% of the times the same findings would be obtained. The randomness guaranteed the validity of the study. A 2.5% margin of error used ensured the highest level of accuracy of the findings from the study.

Household heads were the respondents of the study. The researcher was convinced that household heads had clear views and experience in how they adapted to climate change and variability in their farming systems.

Data Collection

The primary data used in this study was collected by way of a questionnaire (Appendix 5). The questionnaires were delivered to the respondents through hired enumerators. The enumerators were hired from the locality. These were identified from among college students who were on vacation. The researcher trained the enumerators on how to apply the questionnaire This enumerator training was conducted at the Ministry of Agriculture, Kieni East District Offices located in Naromoru town. The data was collected for a period of two weeks in September 2017.

This method was used to reduce the non- responses rate as the enumerators could make a follow-up visit whenever the head of the household was missing at the time of the interview. To give a clearer picture and a valid comparison of the past and present farming patterns, established households were mostly selected for the study. The questionnaire (Appendix 5) was divided into two parts. The first section helped to collect general demographic data on the household. The other section collected data on the farming patterns across the years and the challenges faced by the farmers across the years, and how they respond to them.

Data Analysis

Cresswell (2005) avers that data processing includes the interpretation of questionnaire responses into form that can effortlessly be manipulated to yield reasonable statistics. This includes the stages involved in bringing together data into a rational system out of which inferences are created (Zikmund and Babin, 2007). It involves assigning data distinct codes, capturing it into applicable software, editing to completeness as well as observing and checking the entire process.

Completeness and consistency of data was done by editing the raw data first before the responses were processed. The edited data was then summarized, coded and tabulated. Descriptive statistics was used to analyze the data and establish the measures of central tendency such as means, proportions, mode and median, to show the key findings of the study. Percentages and proportions were used to quantify the main challenges identified by the farmers. The sum and average metrics were used to determine the yields of agricultural produce. The findings were presented in the form of tables, pie charts, area graphs and bar graphs for clarity and ease of interpretation. SPSS Statistics Version 23 program was used to carry out the data analysis.

3.3.2 Land use land cover change (LULCC) in the study area

Introduction

Multi-temporal investigation of satellite pictures is successful in revealing change only because of the presence of a high connection between imagery spectral variation and the land-cover change (Green *et al.*, 1994). Land cover is a major variable that affects and joins several parts of human and physical environment. Frequently updated land use land cover information is important to many socio-economic and environmental applications. These include urban and regional planning, natural resources conservation and management.

Remote sensing imagery of a large geographic area with high temporal frequency, offers a unique opportunity for deriving land use and land cover information through the process of image interpretation and classification. Land-change science has emerged as a foundational element of global environment change and sustainability science.

The main aim of the land use and land cover detection was to carry out land use and land cover analysis of Tigithi sub-location in Kieni sub-county. Specifically, the image interpretation and classification, Land Use Land Cover Change (LULCC) analysis and accuracy assessment. This was to aid in the analysis of changes in the land cover for the years between 1987 and 2017, a period of 30 years as a result of climate change and variability.

Data collection, image pre-processing, image processing (image classification), accuracy assessment and change analysis were the main components of this study. Image rectification and radiometric correction were done by the Regional Centre for Mapping of Resources for Development (RCMRD). The summary of the methodology is shown in Figure 3.

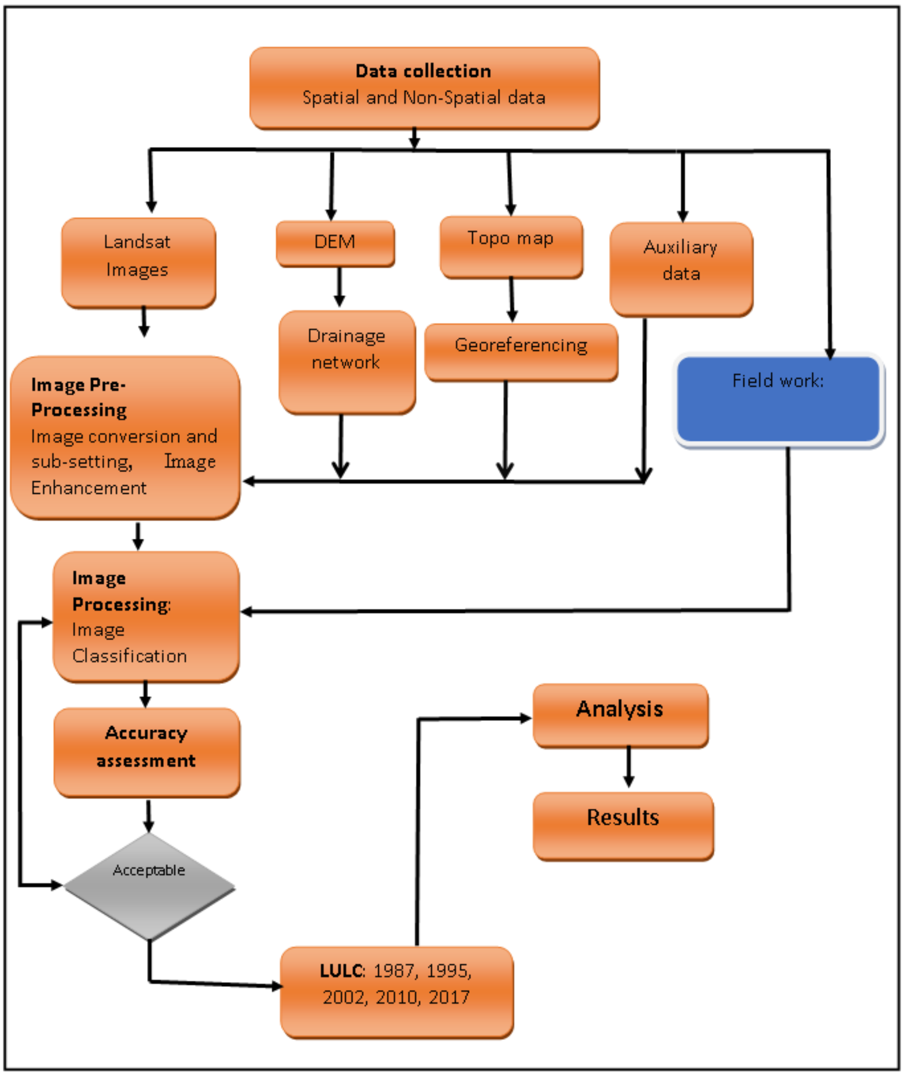


Figure 3: Land Use Land Cover Change Detection Methodology

Data collection

The primary datasets used for this research was the Landsat satellite Imagery with a 30-meter spatial resolution. The path and row of the scene was P168 and R060 and the images were acquired from the Regional Centre for Resource Mapping for Development (RCMRD), Nairobi. Five cloud free Landsat satellite images were selected for these dates: 25th February 1987, 30th January 1995, 10thFebruary 2002, 8th February 2010, and 11thFebruary 2017. The images for 1987, 1995, and 2010 were Landsat 5 which carries Thematic mapper sensor, while those for 2002 was Landsat 7 Enhanced thematic mapper and 2017 Landsat 8 Operational land Imager and Thermal Infrared sensor.

The other dataset used was the auxiliary data which included digital topographic map sheet No. 121/1 at a scale of 1: 50,000 obtained from Survey of Kenya, Nairobi. The topographic(topo) map was used for geo-referencing and acted as a guide for image interpretation as well as providing the geographical names of various features. Digital elevation model (DEM) at 30-meters spatial resolution obtained from RCMRD was used to generate the river network. Administrative boundaries were obtained from the Independent Electoral Boundaries Commission (IEBC) (GoK, 2012) while road maps of the area were obtained from the Kenya Roads Board.

Fieldwork data was collected using Garmin GPS in September 2017 to be used for image classification and ground verification to assess the overall accuracy of the classification results. Digital image processing was analysed with the use of Idris Selva 17.0 software for image processing and analysis.

Image preprocessing

Image preprocessing involved three main procedures: image format conversion, sub-setting and image enhancement.

Image conversion: The process aims at making the images readable in a specific software. The rectified Landsat images obtained from RCMRD were in geotiff format, therefore it needed to be converted and imported into Idrisi Selva software format to enable display and exploration of the images.

Image sub-setting: The Landsat image scene is usually 185km^{2}therefore the study area which was only 21.1km^2 (Table 1), was extracted from the bigger imagery. This was to speed up subsequent processing and analysis. Tigithi sub-location boundary was used to define and subset this area of study.

Image enhancement: This process was performed to improve the quality of the images. It improves the visual interpretability of an image by enhancing the evident distinction among features (Shalaby and Tateishi, 2007). The process of visually interpreting enhanced imagery attempts to optimize the complementary abilities of the human mind and the computer. The mind is excellent at interpreting spatial attributes on an image and is capable of identifying obscure or subtle features (Lillesand and Kiefer, 1994).

Contrast enhancement and band combination were the two techniques employed in this study. The techniques are adequate in expanding the range of brightness of values in an image so that it can be displayed efficiently in the desired manner (Hasmadi *et al.*, 2009). The effect of these enhancements was to increase the visual contrast between two areas of different uniform densities.

Different band combinations of the Landsat images were tested and displayed to create different composite effects and increased interpretation of LULC. In this research, the two most common composites that were used included true color composite and false color composite.

Image classification

This is a procedure through which various classes land covers are typically mapped out from digital data that has been remotely sensed (Foody, 2002) and whose overall objective is to categorize all pixels into those classes (Lillesand and Kiefer, 1994). The process is accomplished based on the Digital Number (DN) values of the pixel, which represent the spectral properties of the ground surface. In short, it is a quantitative aspect in which decisions are made on the basis of data present in the image and grouping its pixels or regions into classes representing different types of ground cover.

There are various classification approaches that range from supervised to unsupervised; parametric to nonparametric, or hard and soft (fuzzy) classification, or per-pixel, sub-pixel, and pre-field (Al-Duski *et al*., 2013). “Image classification may be attained both by either visual or computer-aided examination. It may be one that strives to bring together cases by their relative spectral similarity (unsupervised) or that aims to allocate the cases on the basis of their similarity to a set of predefined classes that have been characterized spectrally” (supervised) (Foody,2002).

The study utilized supervised classification for 2017 and unsupervised for 1987, 1995, 2002 and 2010.The algorithm used for the supervised classification was Maximum Likelihood Classifier while the supervised method used was Iterative Self-organizing Data Analysis technique (ISODATA). The methodology was used to analyse all the image bands and thereafter pick out pixel clusters with similar values without any user intervention. Picked pixel clusters were then allotted to their respective classes at the user's discretion. These methods were then complemented with ground truthing, Google earth and topographical map to assign clusters to their classes.

The study area was classified into six main information classes: forests, bare areas, farmlands, grassland, bushland and waterbody, as shown in Table 4.

Table 5: Description of Land Use Land Cover Classes

Land use/cover	Description
Forests	These include areas that have trees growing in their natural state and also tree plantations
Bare areas	These are exposed areas covered with bare soil
Bushland	These include areas with shrubs and bushes.
Farmlands	These cover areas that are usually cultivated with crops.
Grassland	This includes open areas covered with short grass that may be mixed with other land cover for example shrubs.
Waterbody	These include areas covered by open waters; it has slightly increased due to creation of dams/ water pans in the area for purposes of water harvesting.

Accuracy assessment using ground verification data

Accuracy assessment of a land cover classification allows users to evaluate the usefulness of a thematic map for their intended applications. It was done using error/confusion matrix which is the most common method (Congalton, 1991). A confusion matrix contains information about actual and predicted classifications as computed by a classification process (Hamsadi *et al.*, 2009). This means that the pixels that have been categorized from the satellite image were compared to the same site in the field. Typically, the assessment proves the accuracy of the analyst against the overall accuracy of the thematic map and for each class in the map.

Ground verification was conducted using simple random sampling ensuring that all classes were collected and the samples are well-distributed within the area of study to assess the reliability of the classification. Basic sampling designs, such as simple random sampling, can be suitable if the sample size is sufficient to confirm that all classes are effectively represented (Foody, 2002).

This data set was created by collecting land cover type information for a stratified random sample of 240 points with 40 points per class; 182 from the field using a handheld Garmin GPS; 40 from Google earth and 18 from topographic map. These sample points were used to generate a reference image that was compared with the 2017 classification results. The confusion matrix abstracted assisted in computing four measures of accuracy namely: overall accuracy, user's and producer's accuracies plus the overall Kappa.

Post-classification analysis

This was the method that was used for the discovery of change, and it required the comparison of independently produced classified images (Singh, 1988). By correctly coding the classification outcomes for the various epochs, change maps could be produced to show a complete matrix of change. Colwell and Weber (1981) and Weismiller *et al*., (1977) have exploited post-classification comparison.

3.4 Working with Farmers to Enhance Rainwater Harvesting Technologies for Increased Crop Production

Introduction

The first visit to the study area was to scope and get familiar with the area and plan for the best approach. The visit included holding preliminary talks with the sub-county ministry of agriculture administrators in Naromoru who requested that we get clearance from the county headquarters in Nyeri. The written clearance to conduct research was duly given by the county executive for agriculture for the research to commence in the field in 2017.

The sub-county agricultural officers who are well versed in the area helped in conducting various meetings and holding discussions with the farmers. The farmers were notified to attend the meetings through written notices in churches and announcements in women groups and through the word of mouth.

Three meetings were held. The first being held on 22^{nd} August 2017 in the nearby Tigithi primary school (latitude -0^{0} 10^{1} 11.54^{11}, longitude of 37^{0} 2^{1} 49.23^{11}). A combined group of men, women and youth attended. The second meeting was held on 25^{th} August 2017 at Tigithi secondary school which shares a boundary with the primary school. The third meeting was held on 29^{th} August 2017 at Mr. Mbare's home (latitude of -0^{0} 9^{1} 59.88^{11} and longitude of 37^{0} 3^{1} 21.23^{11}) with women from various women groups. The discussions held at the various meetings were mostly about weather conditions in the area, types of crops being grown presently and back in the 1980s, the rainfall patterns as they remember them, and challenges farmers are currently facing and coping strategies. The fora were also used to inform the audience about the benefits of harvesting rain water and how it could be applied for supplemental irrigation to enhance crop yields, hence improve their livelihoods in the face of decreasing precipitation due to climate change and climate variability.

The meetings held were also used as fora to choose representatives to participate as focus group members. The focus group was composed of the researcher, four farmers and the agricultural extension officers who met to delve deeper into issues discussed in the meetings. The focus group also discussed how to go about choosing the pilot farms and which rainwater harvesting technologies to employ in the farms. Focus group discussions were held at the agricultural offices in Naromoru town (latitude -0^{0} 9^{1} 44.94^{11} and longitude of 37^{0} 1^{1} 23.13^{11}).

Sampling Farms for Pilot Study

The meetings that were held discussed rainwater harvesting technologies and their benefits to farmers considering the area is an ASAL region. The meetings included participants from the county administration (Assistant Chief), county representatives from the ministry of agriculture and a representative from the local primary school. The rainwater harvesting technologies were to be applied as a pilot project. From the meetings and focus group discussions we were, therefore, able to select the famers whose farms could be used as pilot plots.

Pilot plots belonged to Farmer 1 and Farmer 2 (Figure 4). Farmer 1 was selected because he is an opinion leader. Farmer 2 was chosen because he is among the small scale famers who could harvest rainwater from their house rooftops and his 2-acre farm was a good representation of many farm in the area.

The focus group discussions concluded that two types of rainwater harvesting technologies be employed on the pilot farms. These were the harvesting and storage of rainwater in a water pan (farmer 1), and roof water harvesting and storage in a plastic tank (farmer 2). These technologies were to be used together with a drip irrigation system for water use efficiency. The farmers in the area were applying irrigation water using sprinklers systems. To conserve the rainwater harvested, it was decided that drip irrigation was the better option. The farmers were to irrigate the crops only partially when there are no rains and to stop irrigation when it rained. This method of irrigation is the supplemental irrigation.

The water pan method of harvesting rainwater was applied on Farmer 1's farm, which had an existing one**.** The collected rainfall in the water pan was delivered through a series of pipes including stop valves and non-return valves to the farm through gravity to a 2,300 liters' storage tank placed at an elevation of 1.5 meters above the ground. Rooftop rainwater harvesting method was applied on Farmer 2's farm where the harnessed rainwater from the roof was stored in a plastic tank then conveyed through pipes onward to the drip irrigation system, which delivered the water to the crops. The tank was placed on a raised platform to make sure the irrigation water had enough pressure to reach all the crops through drip irrigation.

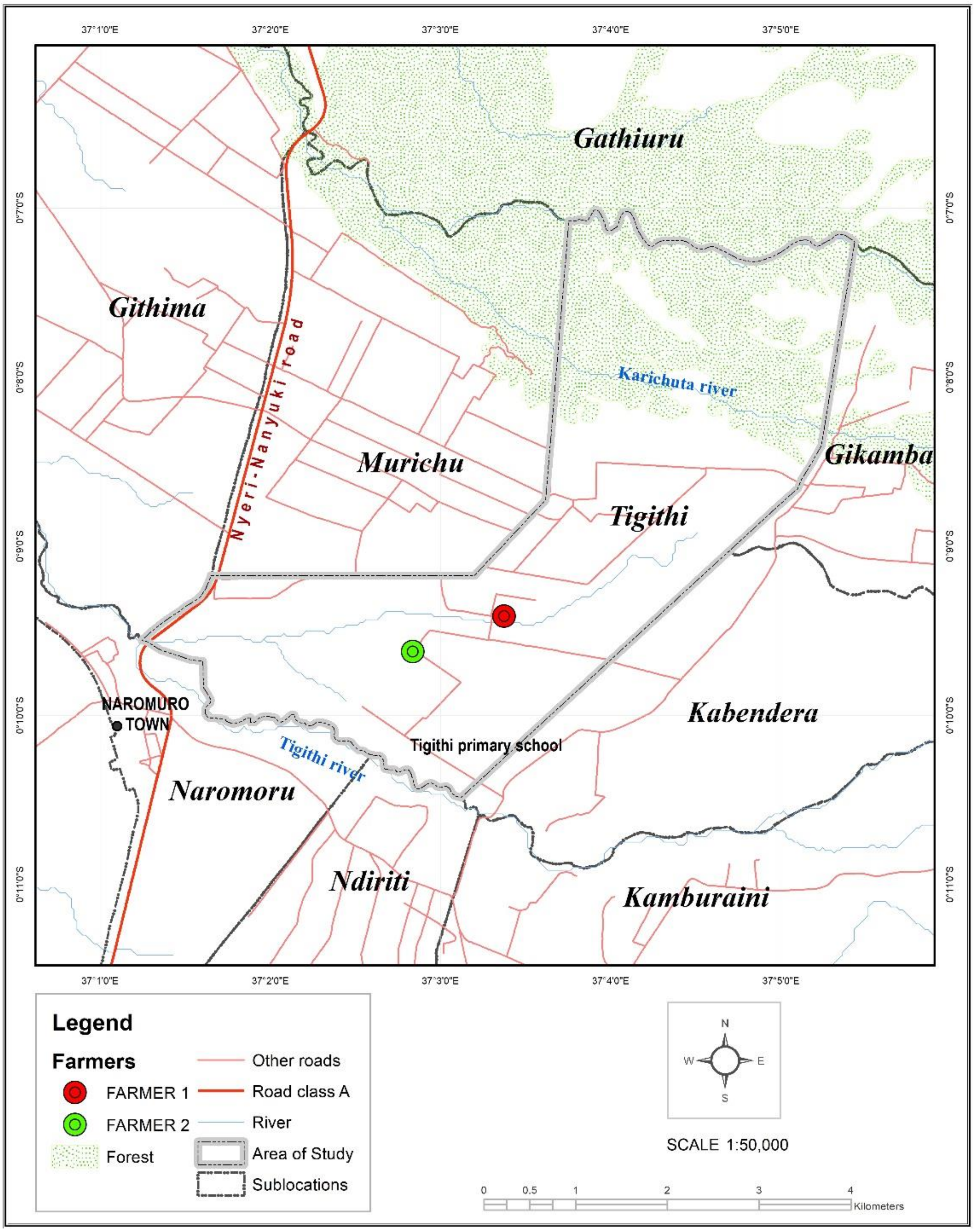


Figure 4: Pilot Farms (Source: Author, 2017)

Kale production

Kale (*Brassica oleracea* L. var. acephala)locally known as 'sukumawiki' belongs to the Brassica family, and it generally does well in cooler climates (Inzaule, 1990). It is the most commonly used leafy vegetable in Kenya with very high demand due to its nutritional value and its accessibility. In Kenya, the vegetable is grown at altitudes of 800-2200m above sea level with of 1500 mm of rainfall per annum (ishamba.com, 2020). It has an extensive environmental flexibility although it favours well-drained productive soil rich in organic matter and an ideal pH of 6.0 - 7.5 (Board, 2004; Das, 1997). Kale can tolerate drought, but prefers consistent moisture (Trend, 2016). In the other parts of the country, the vegetable is intercropped with other local vegetables. The main varieties currently grown across the country include Thousand Headed; Collards Southern Georgia, which are drought tolerant; Collard Mfalme F1; *Sukuma Siku Hybrid*; and Marrow stem, which prefers cool climates. Thousand Headed variety was chosen for this study due to its high vigor, ability to tolerate drought, and high yield potential of 20 t/ha.

Soil Moisture and Methods of Measuring Soil Moisture in the Field

Water found within the unsaturated soil surface of the earth is termed as soil moisture. In the tropics soil wetness is as a result of rainfall or by capillary pull from groundwater. Soil moisture content (SMC) is exceedingly inconsistent both in time and space, particularly at the soil surface (Verstraeten *et al.*, 2008). Research has demonstrated that *in-situ* SMC is as a result of a combination of more than one environmental factors such as: landscape, soil characteristics, species and density of plants, distance of the water table from the surface, rainfall, land practice, and some meteorological factors such as solar radiation (Famiglietti *et al.*, 1998; Verstraeten *et al.*, 2008; Zhao *et al.*, 2011).

Measurement of the amount of water in the soil ranges from the method of feeling the soil texture by hand to the electronic tools usage. The gravimetric method is the oldest, cheapest and most widely used method for measuring soil moisture (Huang *et al.*, 2011). It involves the measurement of soil water content by determining the difference in mass between a sample of the soil before and after oven drying at 105^0C for 24 hours (Reynolds, 1970). The gravimetric method is used for calibrating equipment used in the other methods such as the neutron probe. Hand augers and core samplers are among the sampling equipment used in the field.

Laboratory equipment used for gravimetric moisture determination include drying ovens and balances. Collection of soil samples from the filed should use techniques and equipment such that there is no moisture loss or gain, or become altered or contaminated during sampling and transportation. The disadvantage of the gravimetric method is that it is destructive and timeconsuming especially when samples are to be collected from several depths, and it is difficult to use in rocky environments (Dobriyal *et al.*, 2012).

Effect of Soil Moisture Stress On the Quality and Biomass of Leafy Vegetables

The farmers' paramount fear is insufficient water which is most obvious in the crop yields as a result of soil moisture stress. Kale contains essential minerals such as; potassium (K), calcium (Ca), and magnesium (Mg) which are important, though lack of enough water in the soil can affect the presence of these nutrients (Pathirana *et al*., 2017). Despite kale being a hardy crop that tolerates heat, persistent dryness and trauma due to high temperature lessen kale yields (Pathirana *et al*., 2017). Generally, kale varieties grown under optimum temperature and moisture conditions are sweet, crunchy superior leaf with a high production of biomass yield. Comparatively, the crop grown under drought and limited moisture is bitter with low biomass yield (Hatfield and Prueger, 2011).

Growing

With the help of the agricultural extension officers who were also members of the focus group, it was decided that the pilot project would be better off growing a fast growing horticultural crop. The group settled on one Thousand Headed Kale (*Brassica oleracea, variety acephala*). The first growing season was September-December 2017; The second growing season was March–May 2018; while the third season was September-December 2018.

The nursery bed which was 20cm high 1m width and 2m length was made ready by first digging a depth of about 20cm into the soil thus loosening it. This was followed by thoroughly mixing two buckets of organic manure with the soil and levelling the bed to make a flat surface ideal for watering. Rows with a spacing of 20cm and a depth of 0.5cm were made on the bed with the help of a stick and seeds were planted 1 hour after watering. To decrease evaporation rate and prevent running off the seeds during watering, the nursery bed was carefully covered with clean dry grass. Watering of the seed bed was carried out twice a day, in the morning and evening hours. Seeds started germinating after 7 days whereby the dry grass covering was removed but raised to about 60cm above the seed bed to provide shade to the growing seedlings. However, watering continued twice a day as usual for a further two weeks thereafter gradually reduced to once a week until the seedlings were ready to be transplanting at 6 weeks.

Growing of the Kale crop was divided into two parts: The rain-fed and Supplemental irrigation crops. Planting of the rain-fed crop was done at the beginning of the rains when all the other farmers were also planting. The crop that received supplemental irrigation from the harvested rainwater was planted in the mid rainy season so that the crop would utilize the rains for the first six weeks or so depending on the length of the rainy season. Drip irrigation was later introduced at the end of the rains when the soil wetness decreased and the crop needed to be watered. Crops under supplemental irrigation were watered after every three days for an average of 30 minutes in the evenings when the temperatures were cooler, therefore, the rate of evaporation was reduced.

The rain-fed Kale was planted in three blocks each measuring 10m x1m at a spacing of 30cm between plants and 45cm between rows of plants. NPK 17:17:17 was applied at 10 grams per plant during planting. The procedure was same for the crops under supplemental irrigation as well. Beds were weeded whenever the weeds were big enough to be uprooted by hand to minimize soil disturbance and also reduce the soil moisture loss. Harvesting was done on a weekly basis over a period of 14 weeks in each season. The average weekly yields were subjected to two-way ANOVA (Analysis of Variance) with replication to determine whether the average yields from rain-fed and supplemental irrigated crops were statistically different as well as comparing the means of the two conditions by fixing a statistical level of significance at 5%. The ANOVA analysis was applied to the average yields harvested in a week for each of the two farmers.

Soil Moisture and Soil Chemical Analysis

The supplemental irrigated crop moisture and chemical soil analysis was done on the first day of transplanting. Measurement of moisture content was only done for the vegetables under supplemental irrigation. Soil moisture content analysis was to indicate the soil wetness and the chemical analysis was done to determine the pH, Carbon content, Phosphorous, Potassium and Nitrogen composition of the soil. It was also to determine the soil texture. Soil moisture analysis was done once a week while soil chemical analysis was done at the planting stage and the middle of the season.

The soil samples were picked per block from several random locations using an augur so as not to disturb the soil and then packed in a tightly closed container to reduce loss of moisture through evaporation before it reached the laboratory for analysis. The samples were transported to University of Nairobi’s soil laboratory located at Kabete campus and the moisture content measured as a percentage of water in the soil. Nitrogen and Organic Carbon were measured as a percentage content in the soil, Phosphorous as parts per million while Potassium was in cmol/Kg. The measurement of the soil moisture content was to monitor the soil moisture content per block in case there were plants not receiving adequate irrigation water either because the drips were clogged or the irrigation for one reason or the other was not done correctly. On the days that it rained, crops were not irrigated and had to wait until they showed water stress.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Rainfall Seasonal Time Series Analysis

Time series analysis was done for the rainy season in the Kieni sub-county covering the months of March April May (MAM) and October November December (OND) to establish trends. MAM and OND average rainfall data was for 1984-2013 (Appendix 1) period, while the average maximum temperature seasonal data used was for the 1983-2012 (Appendix 2) period.

Central tendency parameters of mean, standard deviation were analysed together with the maximum and minimum seasonal rainfall for the MAM (Table 6) and OND seasons (Table 7). Further analysis of the two seasonal rainfall was graphically illustrated from the data in appendix 3and figures generated (Figures 5-10). The Sen's Slope was calculated and displayed in the graphs at both 95% and 99% maximum and minimum significant levels. The seasonal M-K tests showing the trends movement were calculated at more than 0.1significant level.

4.1.1 MAM seasonal average rainfall time series analysis (1984-2013)

The highest mean rainfall for MAM season was recorded in April with 115.2(55.6) mm with a standard deviation of 55.6mm (Table 6). The average mean for the season was 75.9(44.2). April recorded the highest rainfall of over almost 250mm and March recorded no rainfall. M-K tests for the season were positive with a seasonal average of 0.33 which showed an upward trend at a more than 0.1 significance level (α). Sen's slope for the season was an average of 0.32 which was the magnitude of positive change of 0.32mm/year for the season.

Table 6: MAM Statistical Analysis of Rainfall Data with Mann-Kendall Test and Sen's Slope (1984-2013)

Time	M (SD)(mm)	Max (mm)	Min (mm)	M-K Test	α	Slope
March	46.4 (38.5)	162.8	0	0.25		0.25
April	115.2(55.6)	242.1	35.4	0.52		0.56
May	66.1(38.4)	145.1	11.8	0.21		0.14
Average	**75.9(44.2)**	**183.3**	**15.7**	**0.33**		**0.32**

Notes: M=Mean, Max= Maximum, Min=Minimum, SD=Standard Deviation, M-K=Mann-Kendall, α = Significance level and Slope=Sen's Slope Estimator at α>0.1

March monthly seasonal average rainfall trend analysis

The 1984-2013 rainfall data series in Table 6 shows M-K test value for the months of March of 0.25 at more than 0.1 significant level and Sen's slope 0.25 and both values were positive. The rainfall trend was increasing at 0.25mm/year. Figure 5 illustrates Sen's slope for the months of March over the 30-year period.

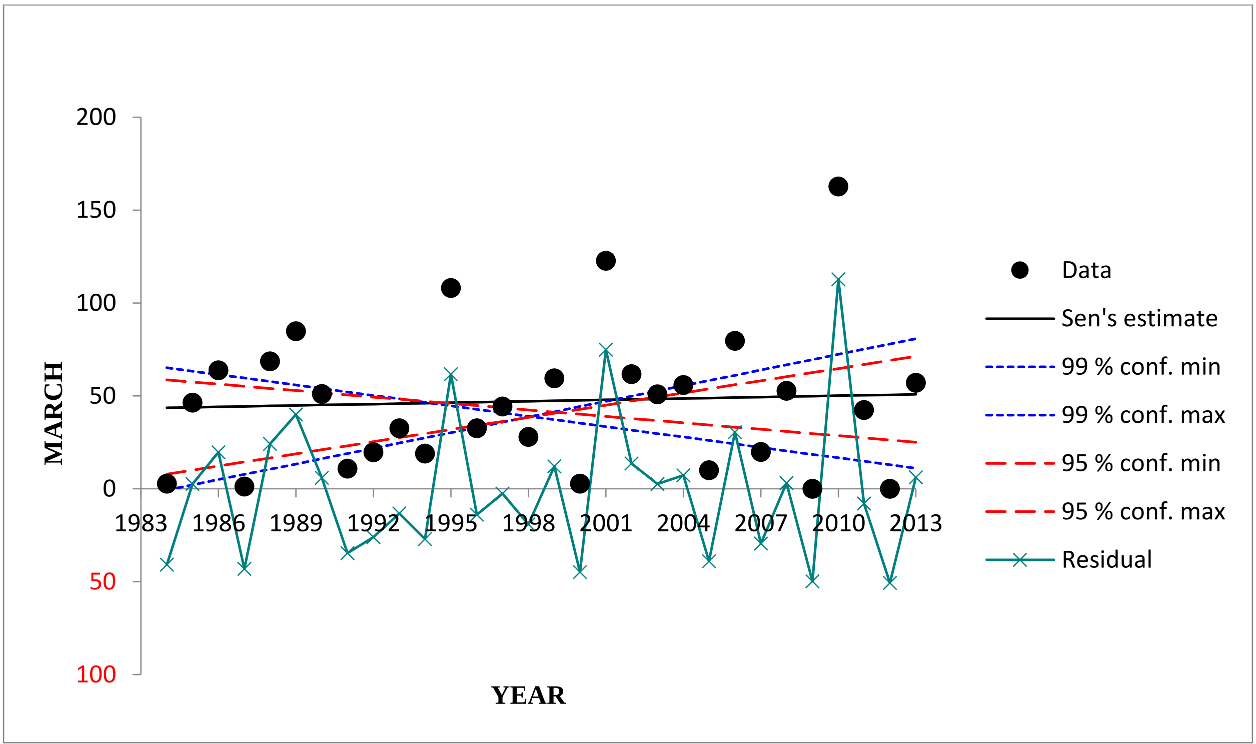


Figure 5: March Average Rainfall Specific Trend (1984-2013)

April monthly seasonal average rainfall trend analysis

Figure 6 shows April Sen's slope for the 1984-2013-time series. M-K test value for the months of April was 0.52(α>0.1) and Sen's slope was 0.56 respectively (Table 6). Both values being positive determined that the trend was increasing at 0.56mm/year.

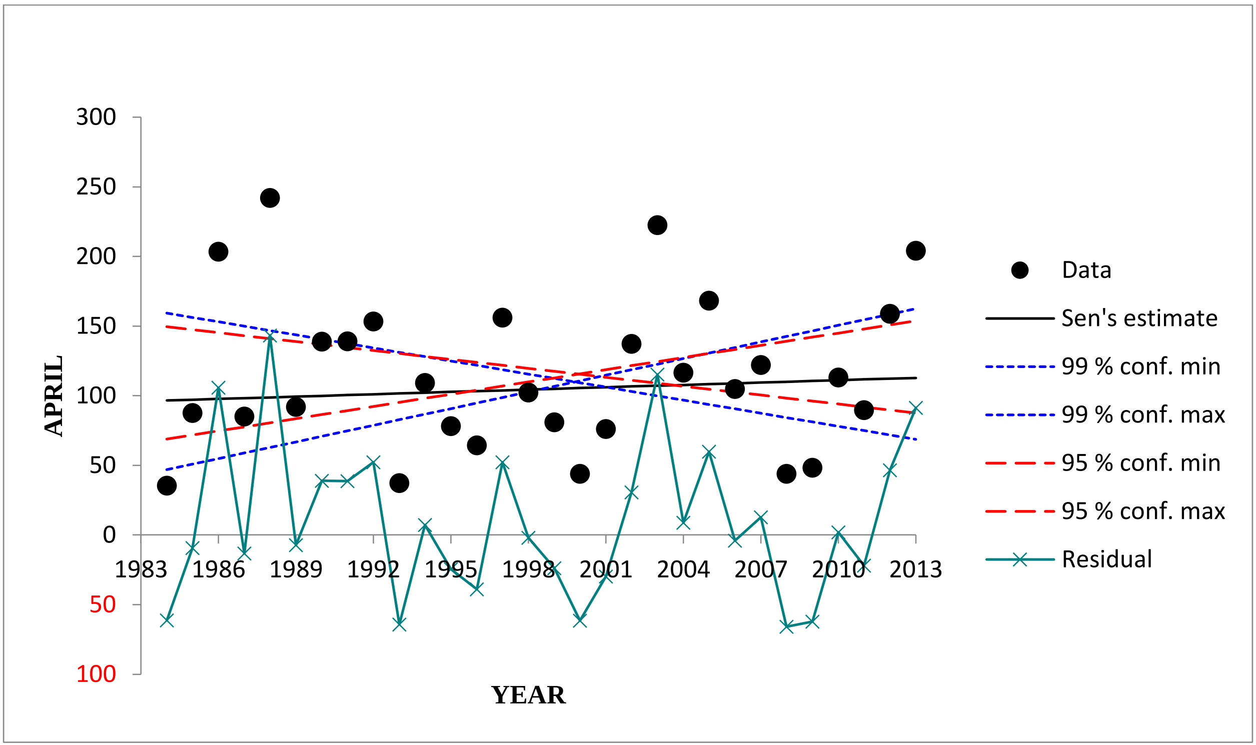


Figure 6: April Rainfall Specific Trend (1984-2013)

May monthly seasonal average rainfall trend analysis

Sen's slope for May in for the 1984-2013 period is graphically illustrated in Figure 7. M-K test value for the months of May was 0.21 (α>0.1) and Sen's slope was 0.14 (Table 6). The seasonal rainfall during these months was therefore showed an increasing trend at 0.25mm/year.

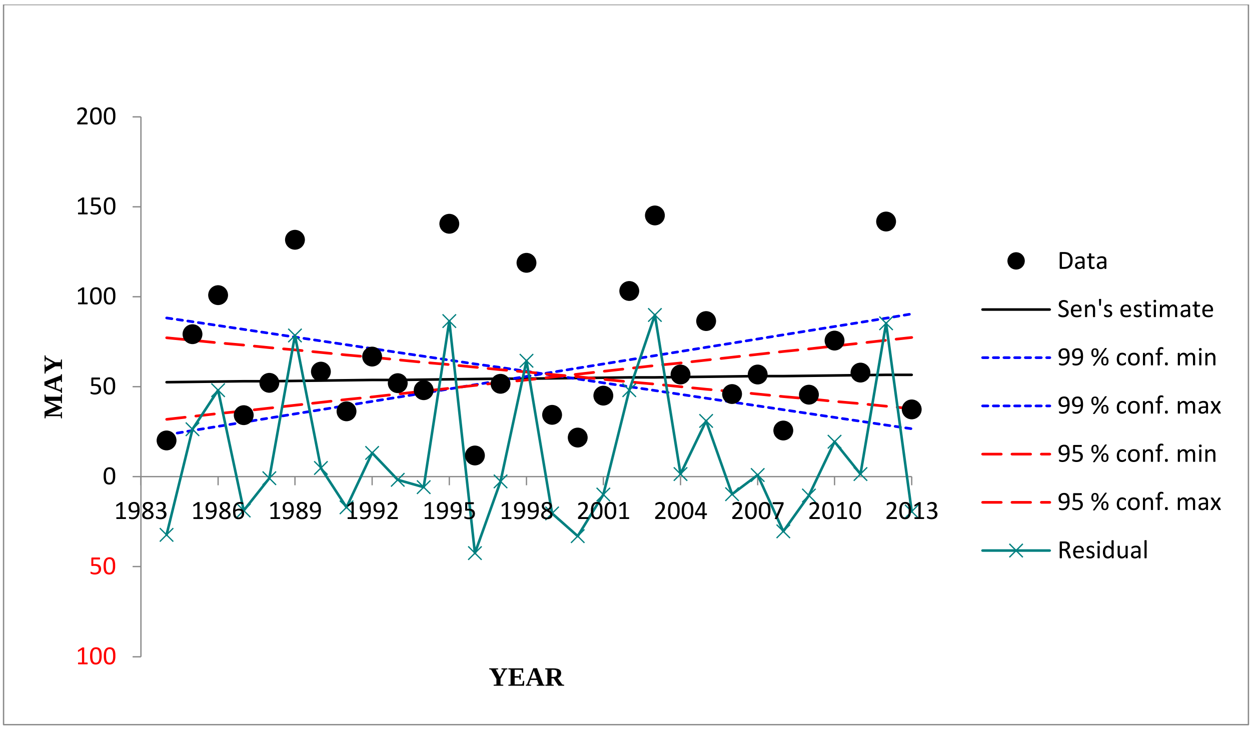


Figure 7: May Rainfall Specific Trend (1984-2013)

4.1.2 OND seasonal average rainfall time series analysis (1984-2013)

The highest mean rainfall for this season was recorded in April with 80.5(40.8) mm with highest seasonal standard deviation of 40.8mm. The season recorded average rainfall of 62.3(33.5). Maximum rainfall of over 200mm was recorded in October and the minimum of slightly more than 3mm fell in December. The Table 7 shows average M-K test of -0.06 at more than 0.1 significant level (α) determining a downward trend decreasing at 0.021mm/year.

Table 7: OND Statistical Analysis of Rainfall data with Mann-Kendall Test and Sen's Slope (1984-2013)

Time	M(SD)(mm)	Max (mm)	Min (mm)	M-K Test	α	Slope
October	70.2(35.0)	211.1	18.9	-0.04		-0.023
November	80.5(40.8)	181.8	14.8	0.43		0.332
December	36.1(24.6)	109.6	3.7	-0.57		-0.247
Average	**62.3(33.5)**	**167.5**	**12.5**	**-0.06**		**0.021**

Notes: M=Mean, Max= Maximum, Min=Minimum, SD=Standard Deviation, M-K=Mann-Kendall, α = Significance level and Slope=Sen's Slope Estimator, ** α=0.01

October monthly seasonal average rainfall trend analysis

Figure 8 is an illustration of the months of October Sen's slope for the rainfall for the period of 30 years from 1984 to 2013. From Table 7 M-K test for these months was -0.4 (α>0.1) a downward trend. The slope from the same table was decreasing at -0.023mm per year.

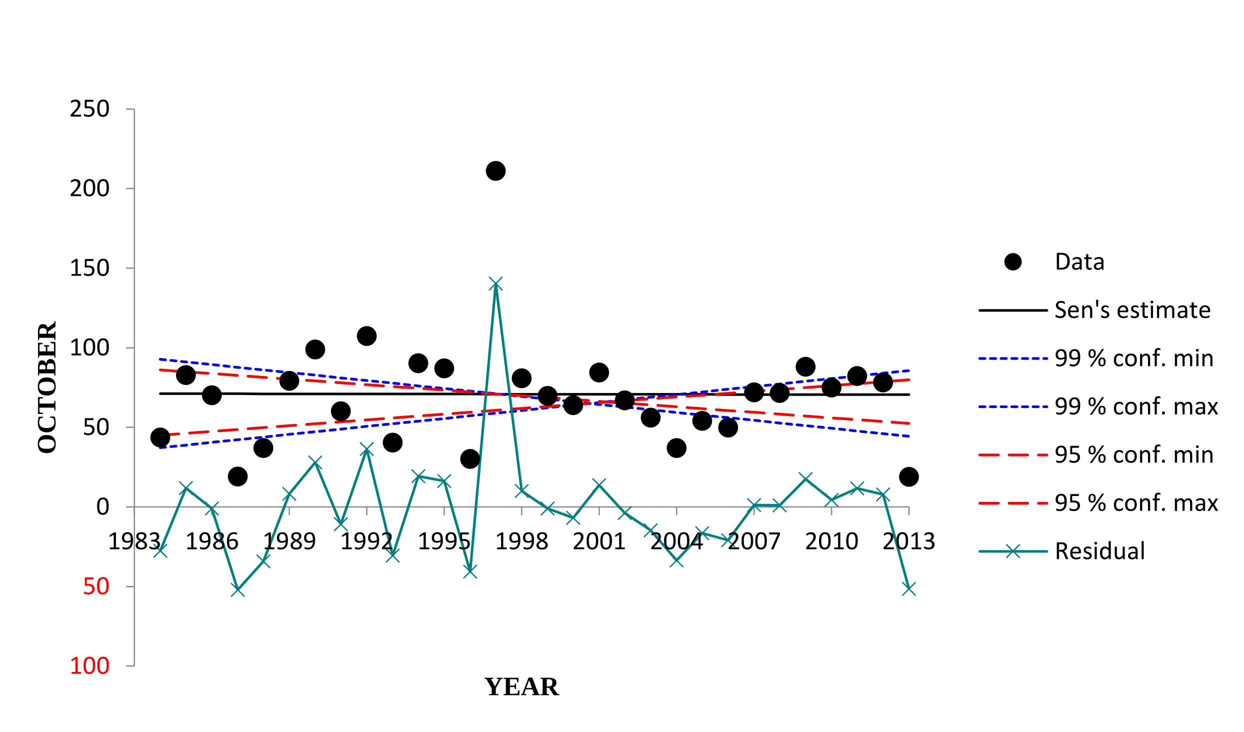


Figure 8: October Rainfall Specific Trend (1984-2013)

November monthly seasonal average rainfall trend analysis

The M-K test for November at more than 0.1 significant level was a positive value of 0.43 and Sen's slope value of 0.33(Table 7) for the 1984-2013 period. The slope is graphically illustrated in Figure 9. This was an upward rainfall trend at 0.33mm/year.

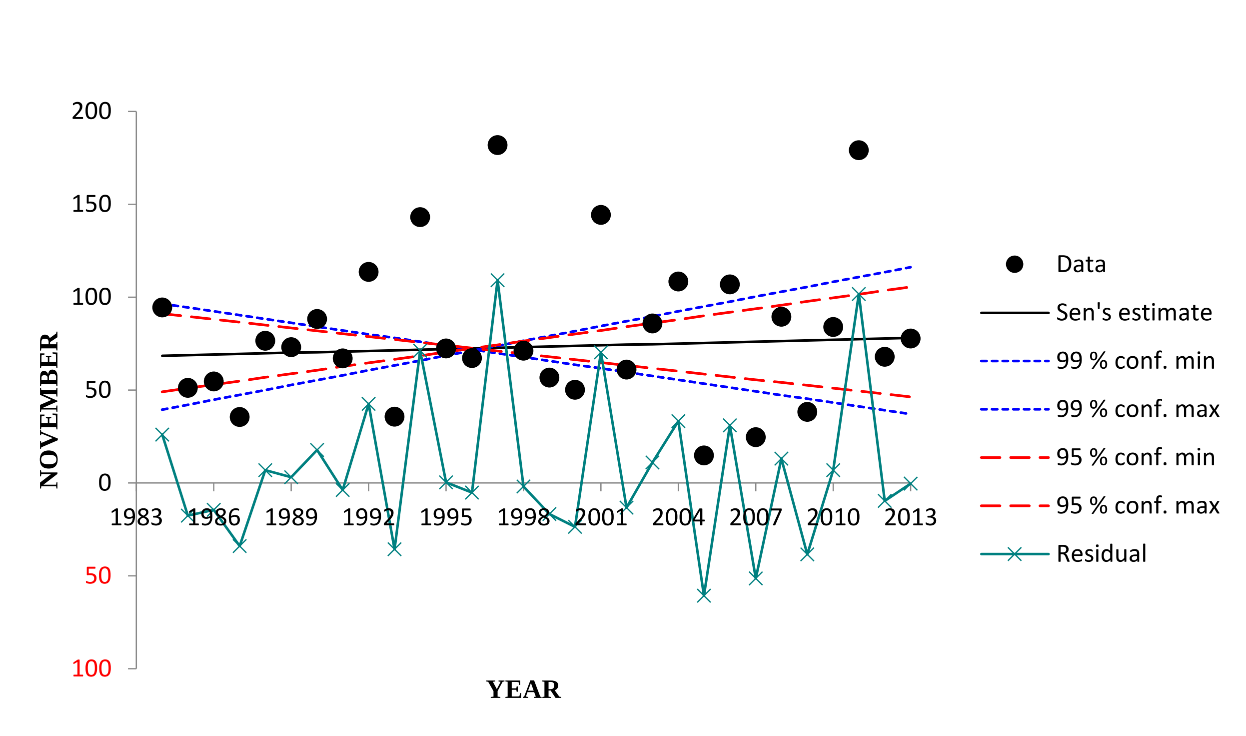


Figure 9: November Rainfall Specific Trend (1984-2013)

December monthly seasonal average rainfall trend analysis

The months of December M-K test calculated at more than 0.1 significance level had a value of -0.57 and a Sen's slope of -0.25 as shown in Table 7. Sen's slope is illustrated in Figure 10 at the two significant levels. The overall trend for these months was a general downward rainfall trend decreasing at 0.25mm/year.

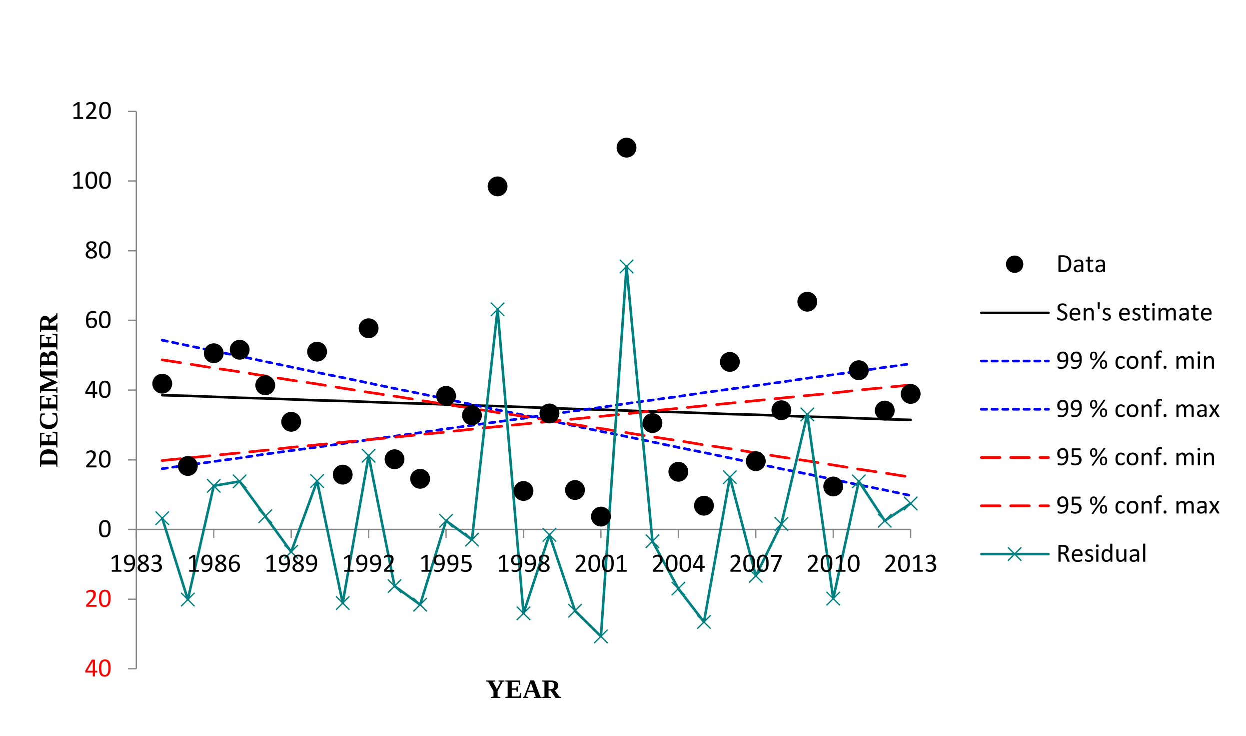


Figure 10: December Rainfall Specific Trend (1984-2013)

4.2 Temperature Seasonal Time Series Analysis

Time series temperature data analysis was done for the rainy season in the Kieni sub-county covering the months of March April May (MAM) and October November December (OND) to establish temperature trends. MAM and OND average temperature data was for 1983-2012 (Appendix 2) period.

Central tendency parameters of mean, standard deviation were calculated as well as the maximum and minimum MAM temperatures (Table 8) and OND seasons (Table 9). This was graphically illustrated in Figures 11-16 generated from the data in appendix 4. The Sen's Slope was calculated and displayed in the graphs at both 95% and 99% maximum and minimum significant levels. The seasonal M-K tests showing the temperature trends movement were calculated at various significant levels.

4.1.1 MAM seasonal average temperature time series analysis (1983-2012)

The MAM season recorded the highest mean temperature in March with 26.8(1.00)^{0}C while the overall season average temperature was 25.0(0.77)^{0}C (Table 8). The maximum temperature occurred in March with over 28^{0}C and the minimum in May with slightly over 21^{0}C.M-K tests and Sen's slope values were both negative for months of March at -0.23 and -0.001. M-K tests for March and April were calculated at more than 0.1 significant level while May's test was calculated at α=0.01. The general temperature trend for this season was upward with an average M-K test value of 1.09 and increasing at 0.016^{0}C.

Table 8: Statistical Analysis of Temperature data with Mann-Kendall Test and Sen's Slope (MAM)

Month	M/SD(^{0}C)	Max (^{0}C)	Min (^{0}C)	M-K Test	α	Slope
March	26.8(1.00)	28.4	24.5	-0.23		-0.001
April	24.8(0.73)	26.0	23.0	0.75		0.017
May	23.3(0.57)	24.1	21.8	2.75	**	0.032
Average	**25.0(0.77)**	**26.2**	**23.1**	**1.09**		**0.016**

Notes: M=Mean, Max= Maximum, Min=Minimum, SD=Standard Deviation, M-K=Mann-Kendall, α = Significance level and Slope=Sen's Slope Estimator, ** α=0.01

March monthly seasonal average temperature trend analysis

The 1983-2012 temperature data series in Table 8 shows March M-K test value of -0.23 calculated at more than 0.1 significant level. Figure 11 shows the slope value for March with a value which had a value of -0.001(Table 7) with a negative trend decreasing at -0.001^{0}C/year.

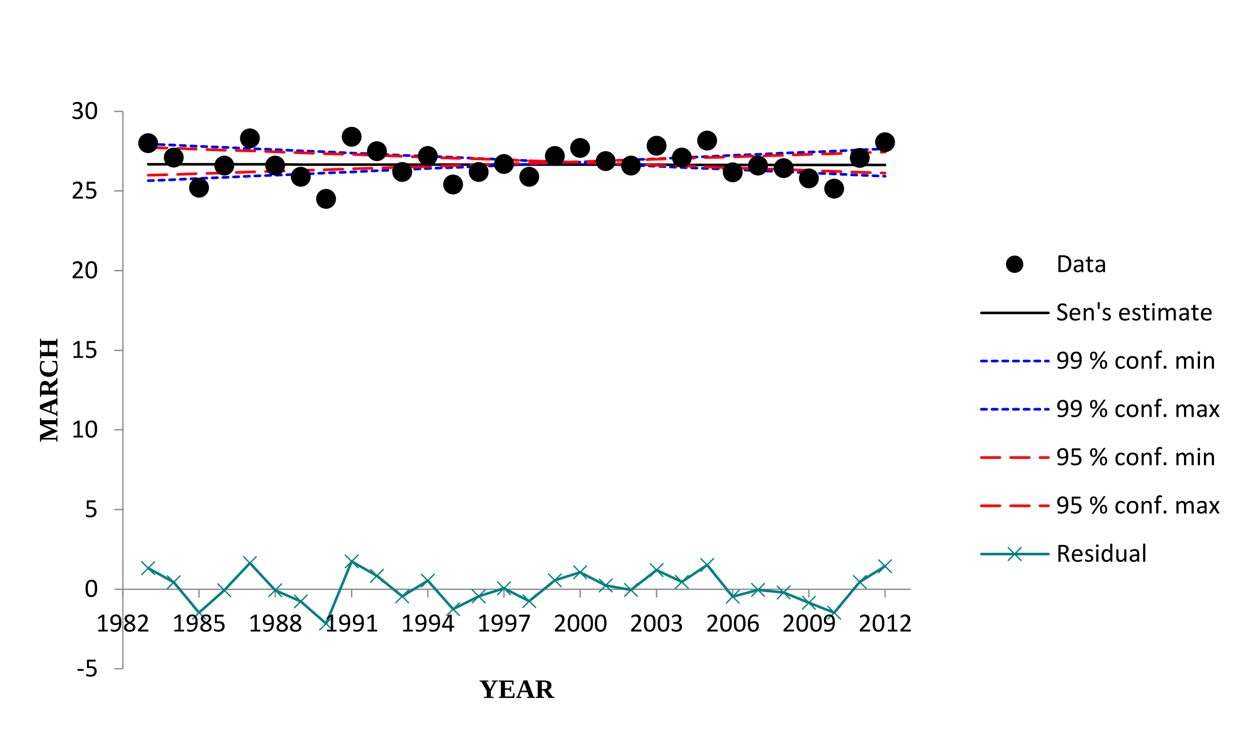


Figure 11: March Maximum Temperature Specific Trend (1983-2012)

April monthly seasonal average temperature trend analysis

Figure 12 shows the slope at 95% and 99% significant levels for the April seasonal rainfall computation. Table 8 shows the calculated M-K test (α>0.1) of 0.75 and Sen's slope of 0.017 for the month over the 1983-2012 period. The temperature trend was moving upwards with a magnitude of 0.017^{0}C.

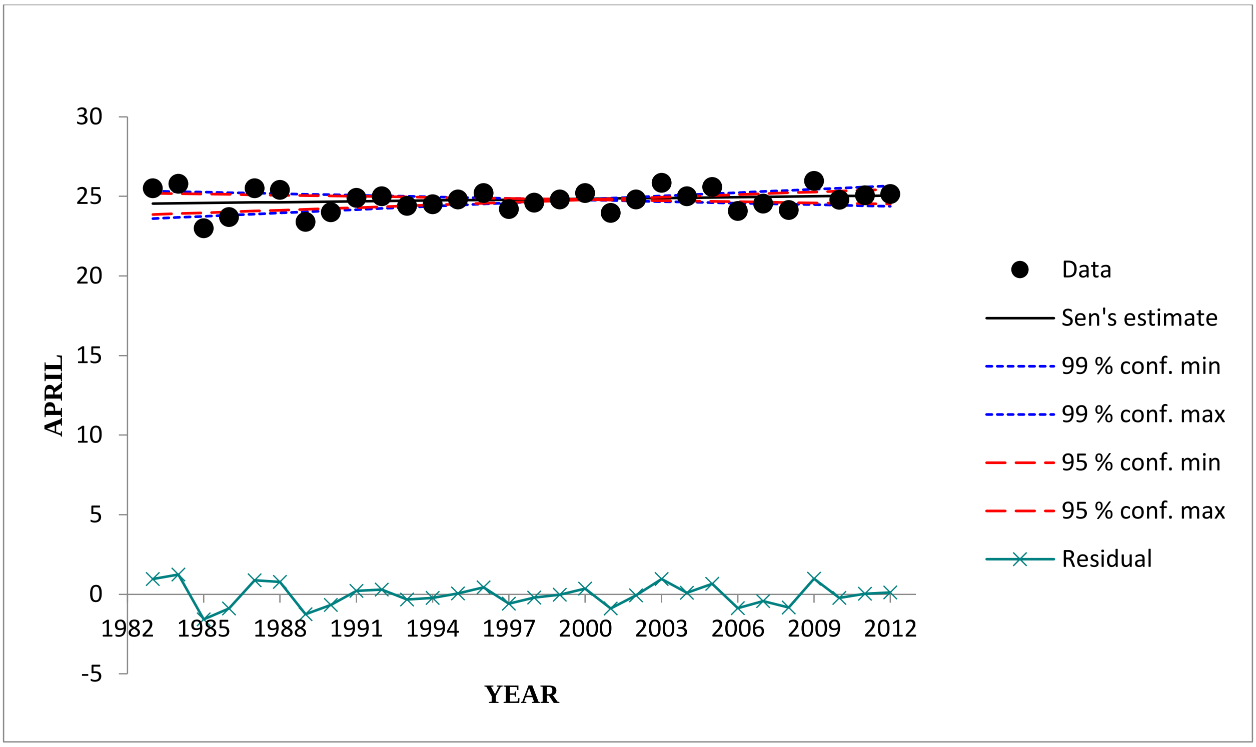


Figure 12: April Maximum Temperature Specific Trend (1983-2012)

May monthly seasonal average temperature trend analysis

In Table 8 the months of May's M-K test was calculated at α=0.01 and had a value of 2.75 showing that the temperature trend was increasing during these months. The Sen's slope for 1983-2012 period is illustrated in Figure13 showing that temperature for these months was increasing at 0.017^{0}C/year (Table 8).

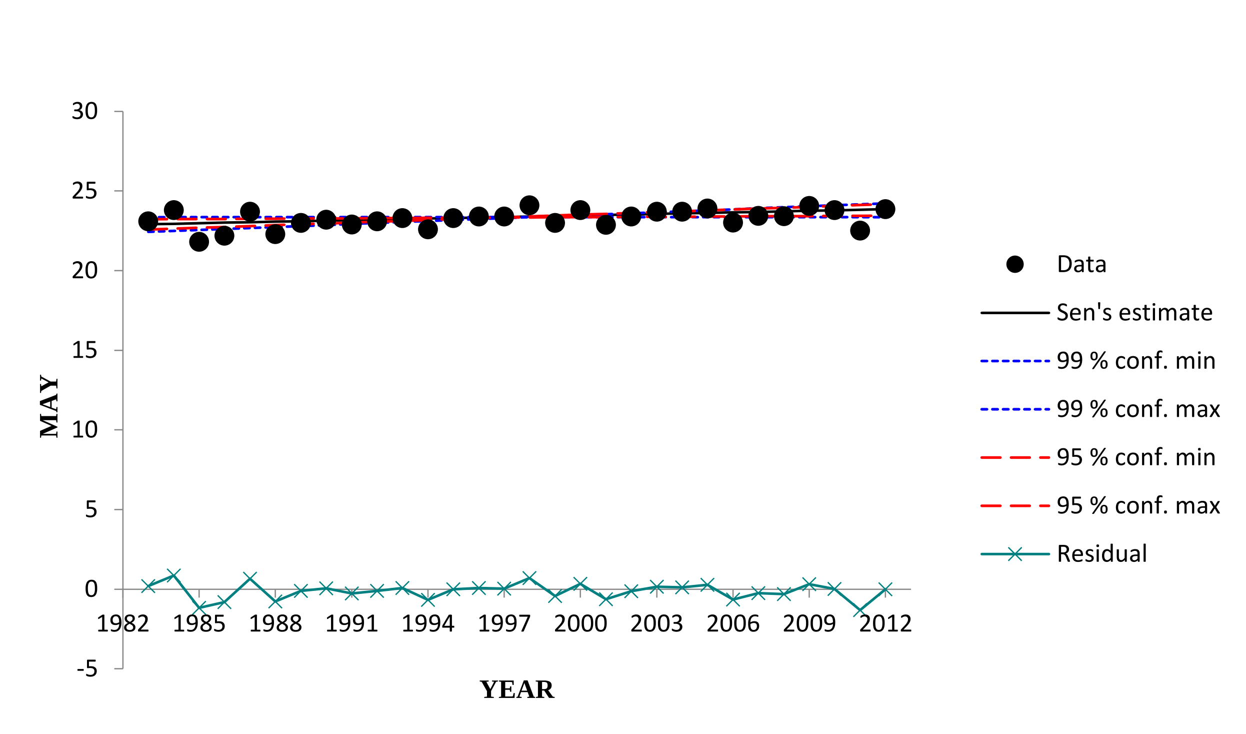


Figure 13: May Maximum Temperature Specific Trend (1983-2012)

The trend analysis for May resulted into a Z-statistic value of 2.75 and Sen's slope of 0.032 as seen in Figure 13, both values being positive. During this month most of the data records lay just below the 25^0C mark.

4.1.2 OND seasonal average temperature time series analysis (1983-2012)

Table 8 shows the statistical analysis of OND temperature data from 1983 to 2012 which had an average mean of $24.1(0.78)^0$C and the highest mean in October with 24.5^0C. The maximum temperature was in October with over 260C and minimum temperature was in November with slightly over 20^0C. M-K test for the season was calculated at α>0.1 in October and α=0.1 in November and December. The average M-K test for the season was 1.55 which determined that the temperature trend was increasing with a magnitude of 0.03^0C/year as portrayed by the slope in Table 8.

Table 9: Statistical Analysis of Temperature data with Mann-Kendall Test and Sen's Slope (OND)

Month	M/SD(^{0}C)	Max (^{0}C)	Min (^{0}C)	M-K Test	α	Slope
October	24.5(0.85)	26.5	22.4	1.09		0.021
November	23.6(0.69)	24.8	21.5	1.89	+	0.026
December	24.3(0.81)	26.4	22.9	1.66	+	0.029
Average	**24.1(0.78)**	**25.9**	**22.3**	**1.55**		**0.03**

Notes: M=Mean, Max= Maximum, Min=Minimum, SD=Standard Deviation, M-K=Mann-Kendall, α = Significance level and Slope=Sen's Slope Estimator, ** α=0.01

October monthly seasonal average temperature trend analysis

The months of October Sen's slopes at 95% and 99% for 1983-2012 period are illustrated in Figure 14. Table 9 shows that M-K test (α>0.1) for these months of OND season showed an increasing temperature trend with a value of 1.09. Table 9 also shows that this trend was increasing with 0.021^{0}C/year as shown by the slope.

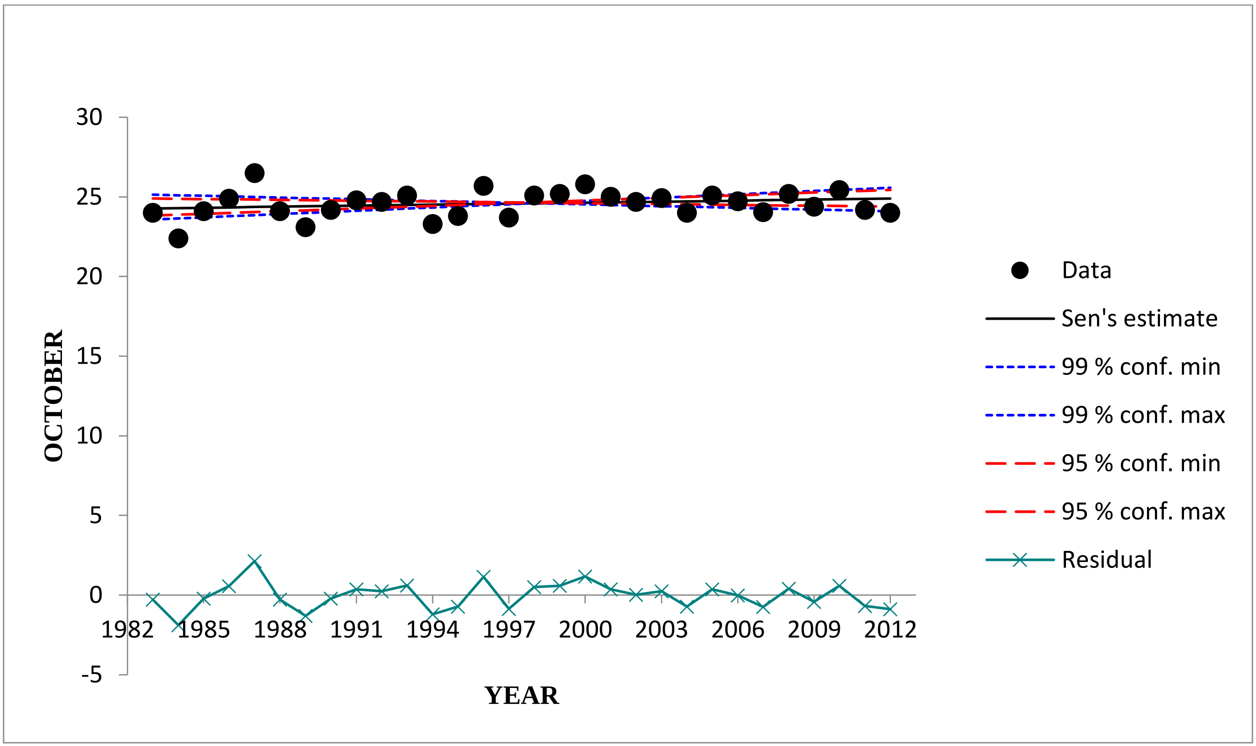


Figure 14: October Maximum Temperature Specific Trend (1984-2012)

November monthly seasonal average temperature trend analysis

Sen's slope for the months of November during the 1983-2012 temperature analysis period at both 95% and 99% significant levels are shown in Figure 15. Table 9 shows that M-K test for these months was calculated at α=0.1 and resulted an upward trend with a value of 1.89. This trend was increasing at 0.026^{0}C/year as shown by the slope in Table 8.

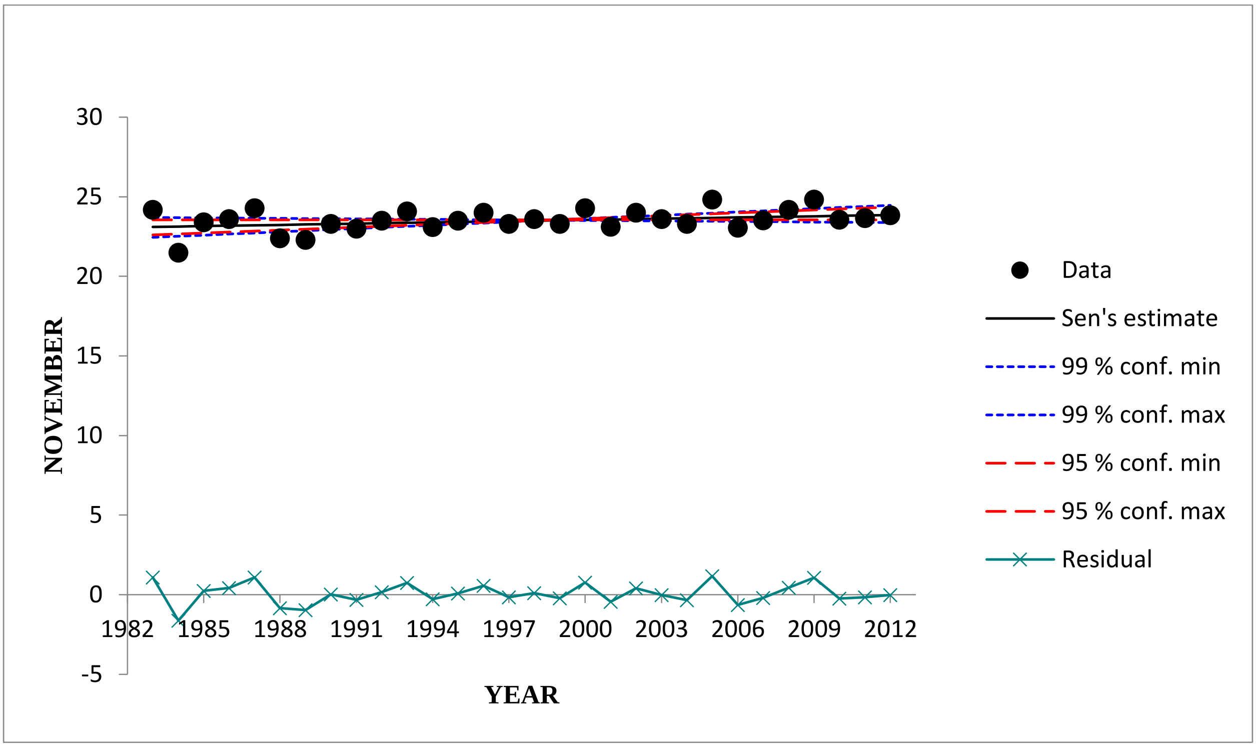


Figure 15: November Maximum Temperature Specific Trend (1983-2012)

December monthly seasonal average temperature trend analysis

Sen's slope for the December temperature for the 1983-2012 period is illustrated in Figure 16 which were calculated at both 95% and 99% significant levels. The M-K test for months calculated at α=0.1 had a value of 1.66 (Table 9) which was an upward trend increasing at 0.029^{0}C/year (Table 8).

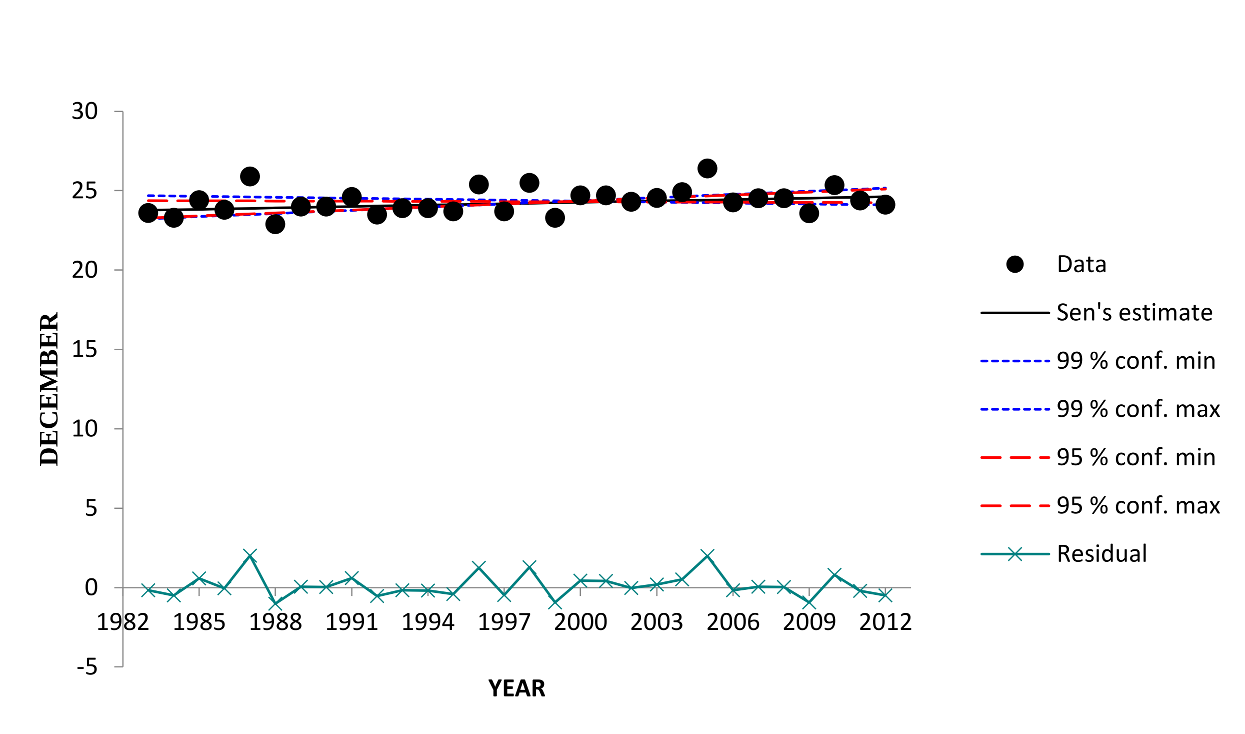


Figure 16: December Maximum Temperature Trend (1983-2012)

The trend analysis for December showed both Z-statistics and Sen's slope values to be positive with 1.66 and 0.029, respectively.

Discussion

The findings from this study suggest that the MAM rainfall in Kieni sub-county had marginally increased and the OND seasonal rainfall had an upward trend in the 1984-2013 period. The study findings also suggest MAM and OND temperature in the study area to have an increasing trend for the 1983-2012 period.

(Pearson *et al.*, 2011) projected that agriculture being among the major economic sectors which are susceptible to climate change impacts it is important to therefore to analyse rainfall and temperature trends of a region and in our case Kieni sub-county. The MAM seasonal mean rainfall for 1984-2013 had an upward trend as shown by the Mann-Kendall test for the season of 0.33 calculated at α>0.1. This trend was changing at the rate of 0.32mm/year as indicated by the Sen's slope. The area's OND rainfall was shown to decrease with a Mann-Kendal test value of -0.06 (α>0.1) at a rate of 0.021mm/year for the 1983-2012 period.

MAM seasonal temperature trend for 1983-2012 period had an average Mann-Kendall test of 1.09 calculated at α>0.1(March and April) and α=0.01 (May). It seasonal trend was increasing at 0.016^0C as shown by Sen's slope. The OND temperature for the same period showed an upward rise with a positive average Mann-Kendall test value of 1.55 at α>0.1 (October) and α=0.1 (November and December). The seasonal trend was changing at an average of temperature of 0.03^0C.

Karienye *et al*., (2012) reported that rainfall received in Nyeri was declining every 3 to 4 years though Nderitu *et al*., 2016 reported long rains in a reducing mode in the years between 1985 and 2015. From our time series trend analysis, long rains that fall between March and May (MAM) were increasing while the short rains were decreasing (OND). However, the MAM rainfall season trend upward movement could have been due the months of April recording the highest rainfall of over 240mm which is almost a halve of the areas annual rainfall of about 500mm (Wamicha, 1993).

With a projected rise in minimum surface temperatures and decrease in seasonal rainfall under climate change (Knowles *et al*., 2006), local conditions, especially the amount of water present in the soil, may be reduced significantly due to loss from evaporation. The decreasing seasonal rainfall and increasing seasonal maximum temperatures in the Kieni sub-county would affect the status of soil moisture and in turn plant growth (Tietjen *et al*., 2017). Pathirana *et al*., (2017) projected that persistent dryness due to high temperatures reduce Kale yields. The MAM and OND seasonal temperature trends were in upward movement which means the rate of evapotranspiration is increased and the loss of soil moisture could also be increasing due to the high temperatures experienced in the area.

CHAPTER 5: RESULTS AND DISUSSION

5.1 Changing Farming Patterns in Response to Rainfall and Temperature Trends in Kieni Sub-County

5.1.1 Questionnaires survey results

Introduction

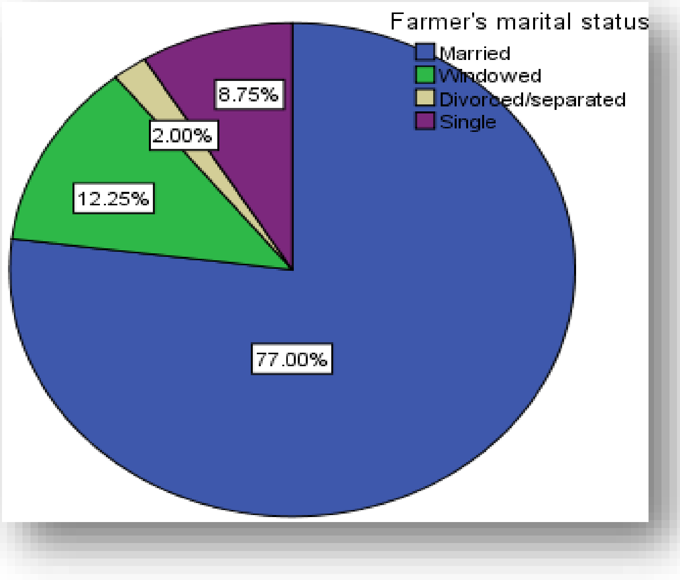
The study targeted households who were primarily farmers in Tigithi sub-location Nyeri County. The response rate was 100%. A total of 400 respondents participated in the study in 2017. This response rate was made possible by the researcher who engaged research assistants to assist interviewing and following up the respondents. Another contributing factor was the fact that the target community was also very welcoming and cooperative.

Farmers' Demographic Information

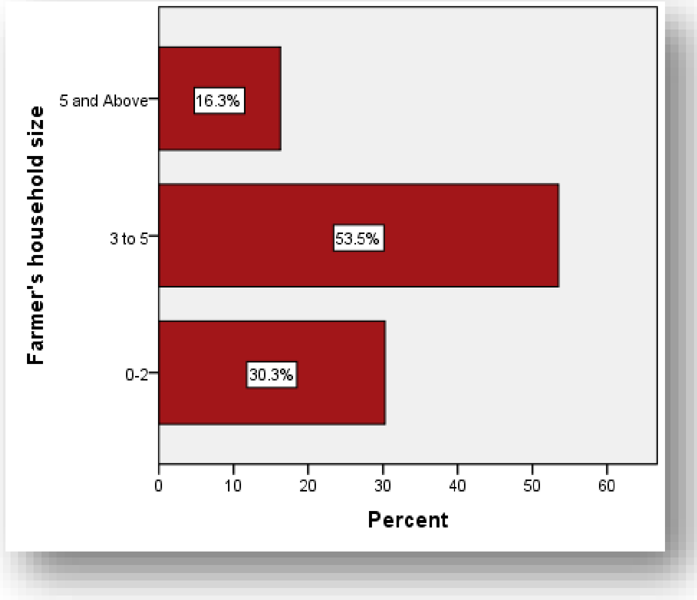
Section A of the questionnaire (Appendix 5) sought to find out some demographic information about the farmers in Tigithi area. This information helped the researcher to understand the respondent's background. in order to determine the credibility of the responses given in the questionnaire.

(i) Marital Status and Household Size

Figure 17(a) shows had almost 80% of the farmers participating in the survey in the study area were married with only 2% of the farmers were single.



Marital Status (a)



Household size (b).

Figure 17: Demographic Information of Marital Status (a) and Household Size (b) (2017)

Figure 17(b) shows the analysis of the survey had more than half (50%) of the participating farmers with household sizes of between 3–5 in 2017. Slightly over 30% of the participants had household sizes of between 0-2.

(ii) Farmers' Farm size, Farmer 'Age, Year Farming Started and who Works on the Farm

More than 70% of the participants reported to own farms of sizes 1-5 acres and only a quarter of them had farms with acreage of more than 5 acres (Table 10) as at 2017.

Table 10: Percentages of Farmers' Farm size in Acres (2017)

	Responses	Percent
Less than 1 acre	100	25.0
1-5 acres	281	70.2
More than 5 acres	19	4.8
Total	400	100.0

More than 70% of the farmers working on the farms in 2017 were aged 40 years and above (Figure 18). Less than 10% of the farmers working on the farms were below 30 years of age while the rest of the famers were in the 30-39-years age bracket.

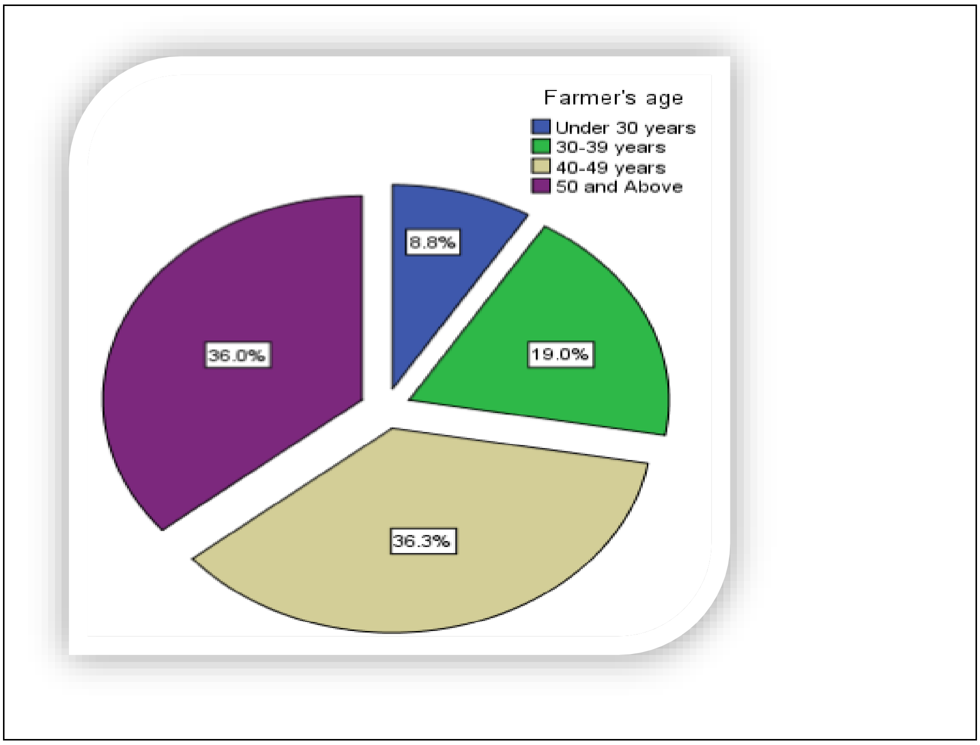


Figure 18: Farmer's Age in 2017

The households survey conducted in Tigithi sub-location asked the participants to state the year when they started farming. About a quarter (25%) (Figure 19) reported to have started farming before 1990 and another quarter started farming between 1990 and 1999. Almost 80% of the farming community had settled in the area by 2009.

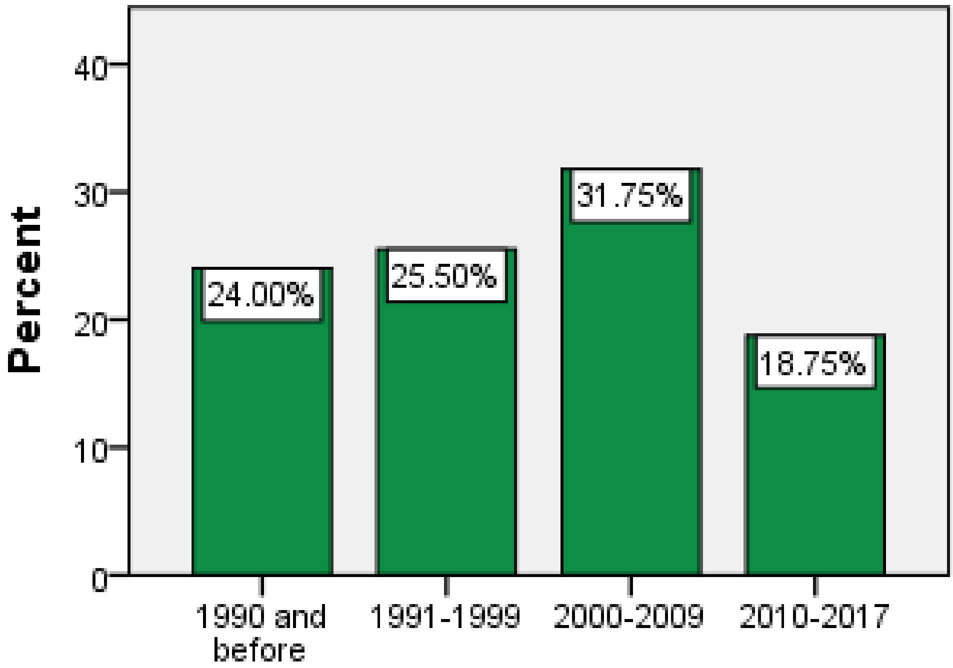


Figure 19: When did you start Farming in Tigithi (2017)

Table 11 shows that most of the activities on the farm as of 2017 were being carried out by both husbands and wives almost at equal measure at about 40% as compared to the combined children and hired labour at approximately 25%.

Table 11: Frequencies of who Works on the Farm

	Responses	Percent
Husband	142	35.5
Wife	155	38.8
Children	53	13.2
Hired Labour	50	12.5
Total	400	100.0

Comparison of Crops Grown and Livestock Reared in the Tigithi sub-location in the 1980s and 2017

The survey conducted among the 400 participating households compared the crops that were being grown in the 1980s and to the ones being grown in 2017. About 95% of the participants grew maize and potatoes in the 1980s (Table 12). There were crops being grown in 2017 but were reported not being grown in the 1980s such as the spinach, carrots, bananas, star grass, pumpkins and sweet potatoes. Some crops such as pyrethrum were reported not to be grown in 2017.

Growing of horticultural crops that included cabbages, spinach, kales, carrots, beetroots, bananas and coriander went up exponentially from about 10% of the respondents growing them in the 1980s to about 30% in 2017. There was also a marked upward movement in growing of Napier grass whereby the percentage of respondents growing the crop rose to more than 25% in 2017 from about 4% in the 1980s.

Table 12: Comparison of Crops Grown in the 1980s and 2017

	1980s	2017
	Percentages (%)	Percentages (%)
Maize	100.0	89.8
Potatoes	93.8	89.3
Beans	67.7	41.5
Napier Grass	4.2	26.0
Cabbages	7.5	13.8
Spinach	-	5.5
Carrots	-	5.0
Kales	1.0	2.8
Wheat	15.6	1.8
Bananas	-	1.5
Star Grass	-	1.0
Pumpkins	-	0.8
Sweet Potatoes	-	0.5
Arrow roots		0.5
Beetroots	1.0	0.5
Mangoes	-	0.3
Coriander	-	0.3
Pyrethrum	2.1	-

The farmer participating in the study were asked to recall the kind of domestic animals that they were rearing in the 1980s and in 2017 and responses analysed. More than 50% (Table 13) of the famers were rearing cows, sheep and chicken in the 1980s which was still the case in the 2017. However, about 1% of the farmers had started rearing pigs and geese which were not being reared in the 1980s.

Table 13: Comparison of Livestock Reared in the 1980s and 2017

	1980s	2017
	Percentages (%)	Percentages (%)
Cows	94.7	85.6
Sheep	67.0	55.9
Chicken	55.3	52.1
Goats	23.4	14.4
Rabbits	2.1	3.3
Pigs	-	1.3
Goose	-	0.8

In the survey the study did a comparison of the breed of cows that were being reared in the 1980s and compared them to the cow breeds in 2017. The study shows in Table 14that more than 50% of the famers in the survey reared Friesian cows and more than 60% reared Zebu breed of cows. The rearing of Friesian cows however rose to more than 60% of the famers and those rearing Zebu considerably declined to about 20% in 2017.

Table 14: Comparison of Breed of Cows Reared in the 19080s and 2017

	1980s	2017
	Percentages (%)	Percentages (%)
Friesian	51.1	60.6
Zebu	64.4	23.6
Ayrshire	10.0	14.4
Jersey	4.4	8.9
Guernsey	12.8	5.8

The survey conducted set out to determine the breeds of sheep and goats reared in the 1980s as compared to the ones the farmers were rearing in 2017. Table 15 shows that Merino and Doper breeds of sheep were being reared by more than 50% of the famers in the survey. The 2017 analyses in Table 14 shows that rearing of Merino breed of sheep quickly fell to about 20% of the farmers while more than 25% of the farmers were rearing black headed sheep in 2017.

Table 15: Comparison of Breeds of Sheep and Goats Reared in 1980s and 2017

Sheep	1980s	2017
	Percentages (%)	Percentages (%)
Merino	51.2	18.8
Dorper	48.2	62.5
Blackheaded	6.1	25.0
Goats		
Anglo Nubian	37.5	65.5
Boer	62.5	41.4
Saanen	12.5	-

In the 1980s Table 14 shows that about 40% and 60% of the farmers in the survey were rearing Anglo Nubian and Boer breeds of goats respectively. In 2017 rearing of the Anglo Nubian had a marginal increase to slightly over 60% and rearing of the Boer breed had a decreased to about 40%. The Saanen breed of goats which was being reared by about slightly more than 10% of the respondents in the 1980s was no longer being reared in 2017.

Comparison of Weather and Challenges Experienced by Famers in the 1980s and 2017

The study needed to know whether there was enough rainfall to grow crops in the 1980s as compared the year of study of 2017. Almost all the farmers taking part in the survey reported that rainfall was enough in the 1980s (Figure 20(a)) and almost the same percentage of famers responded that it was not enough in 2017 when the study was being conducted (Figure 20(b)).

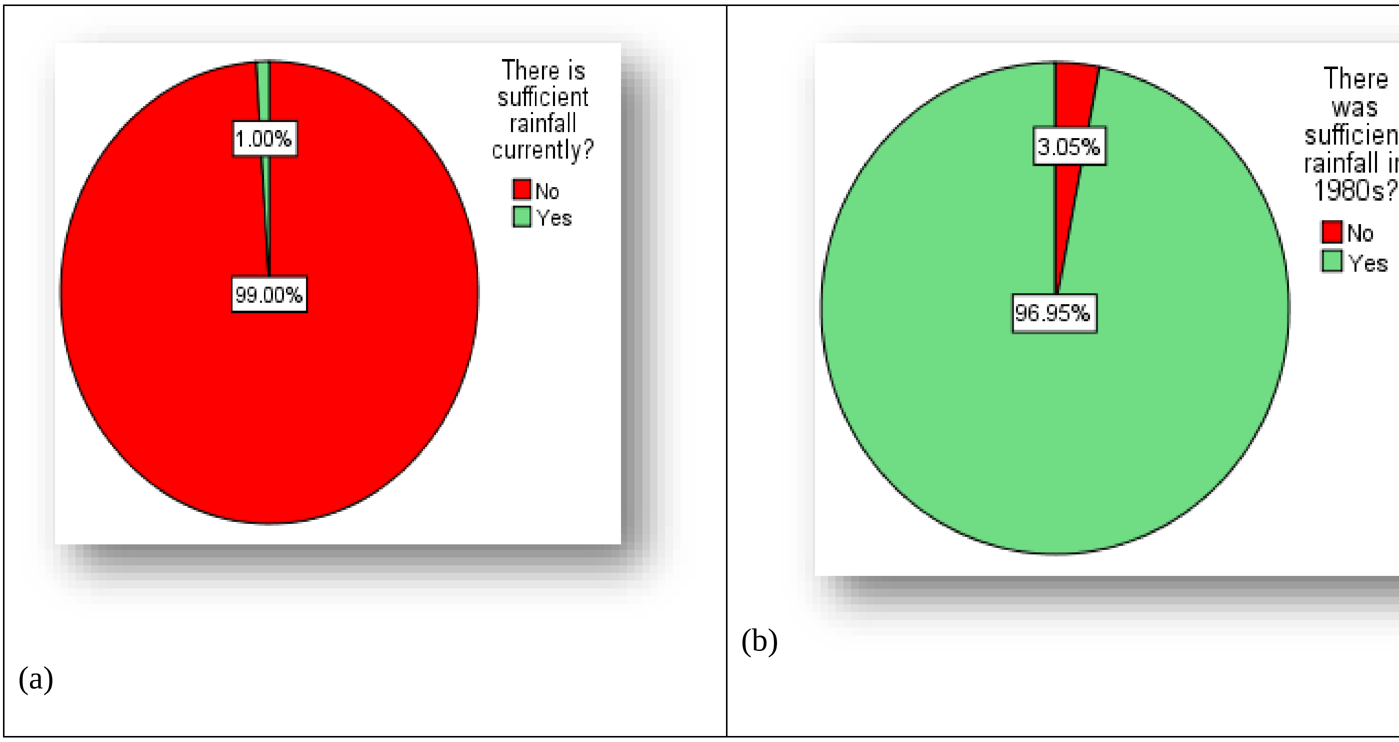


Figure 20: Comparison of whether there was Enough Rainfall in the 1980s (a) and 2017 (b).

Table 15 shows the analyses of the responses that the survey got from asking the participants when could recall experiencing the heaviest rainfall and severest famine. The highest rainfall was experienced in 1997 according to about 30% of the participants (Table 16). The year that the study area experienced the severest famine was year 2000 as reported by slightly more than 20% of the participants.

Table 16: Percentages of the Most Common Year of Heaviest and Severest Famine

	Mode	Percentage (%)
The year the heaviest rainfall was experienced	1997	27.0
The year of Severest Famine	2000	24.0

The participating household heads in the study were asked to state the challenges they were facing as they continued to farm in 2017. The three biggest challenges in the order of magnitude were; shortage of rainfall by 389 participants, pests and diseases by 330 participants and lastly the lack of capital to buy inputs and labour by 291 participants out of the 400 participating (Figure 21).

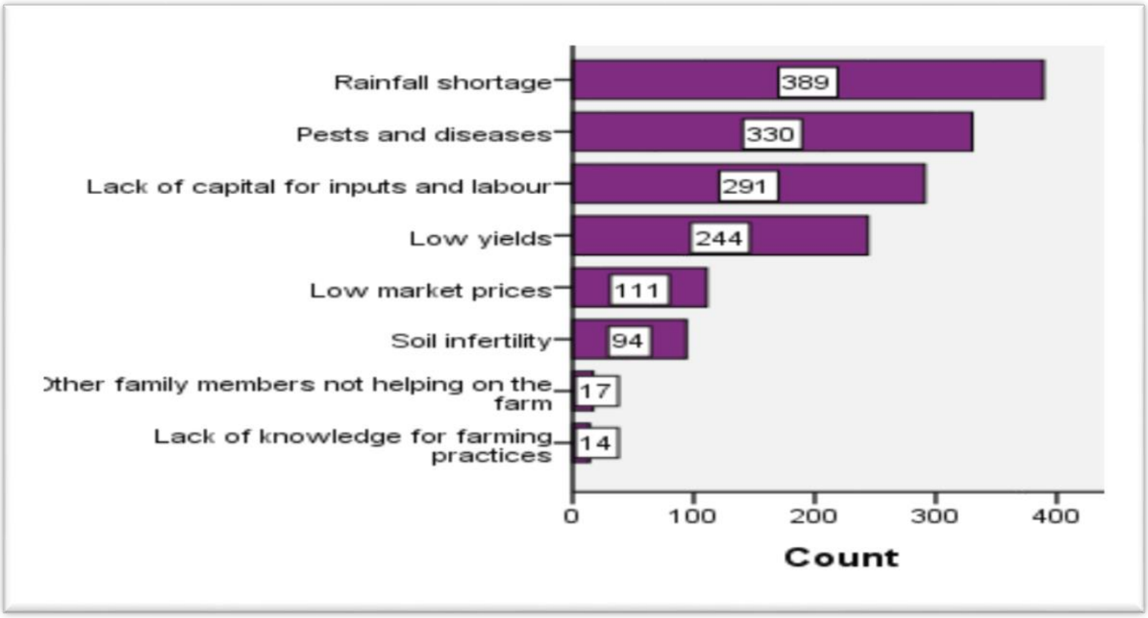


Figure 21: Challenges facing Farmers in 2017

5.1.2 Land use and land cover analysis

Introduction

This study conducted in 2017 processed and analysed the Landsat images for 1987, 1995, 2002, 2010 and 2017, a 30-year period for the detection of land use and land cover change in the study area.

LULC Image Classification and Change Analysis

The analysis of land use land cover change in Tigithi sub-location was divided into six classifications. These were; bare areas, bushlands, farmlands, forest, grasslands and water bodies. Landsat images for 1987, 1995, 2002, 2010 and 2017 were processed into those classes in order to detect change.

Land use land cover analysis for 1987 showed forest cover being dominant at almost 40% cover but decreased to about 30% in 1995 (Table17). In 2002 bare areas almost doubled from slightly above 10% in 1987 to more than 20% in 2017. In 2002 bushlands nearly halved from nearly 25% cover in 1987 to slightly over 10%. Land cover for water bodies classification increased from 0.1% in 1987 to 0.3% in 2017. Forest cover decreased from almost 40% in 1987 to about 20% in 2017. Grassland cover slightly decreased by about 5% from 1987 to 2017.

Table 17: LULC Percentage Cover Change for the Classes (1987-2017)

	Year (%) Cover				
Classification	1987	1995	2002	2010	2017
Bare areas	13.2	20.8	24.3	10.9	22.9
Bushland	24.5	17.6	12.8	19.1	15.0
Farmlands	12.5	18.0	28.7	31.0	32.6
Forest	35.5	31.1	23.0	25.7	19.2
Grassland	14.2	12.5	10.9	13.0	10.0
Water body	0.1	0.0	0.3	0.3	0.3
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Notes: LULC=Land Use and Land Cover

Land Use Land Cover Classifications for 1987

Figure 22 is a map showing visually the different land use land cover categories in the study area as represented by the six classifications for 1987. Forest cover was predominant on the upper part of the study area near Karichuta river and towards Gathiuru sub-location. Most of the forest cover had bushland cover in the vicinity. Figure 22 shows that the areas immediately below Karichuta River and those along Tigithi river to have plenty of farmlands cover. Most of the bare areas were shown to be towards Murichu sub location and near the Nyeri-Nanyuki highway. The dominant classification in1987was the forest cover with an almost 40% as shown in Table 16.

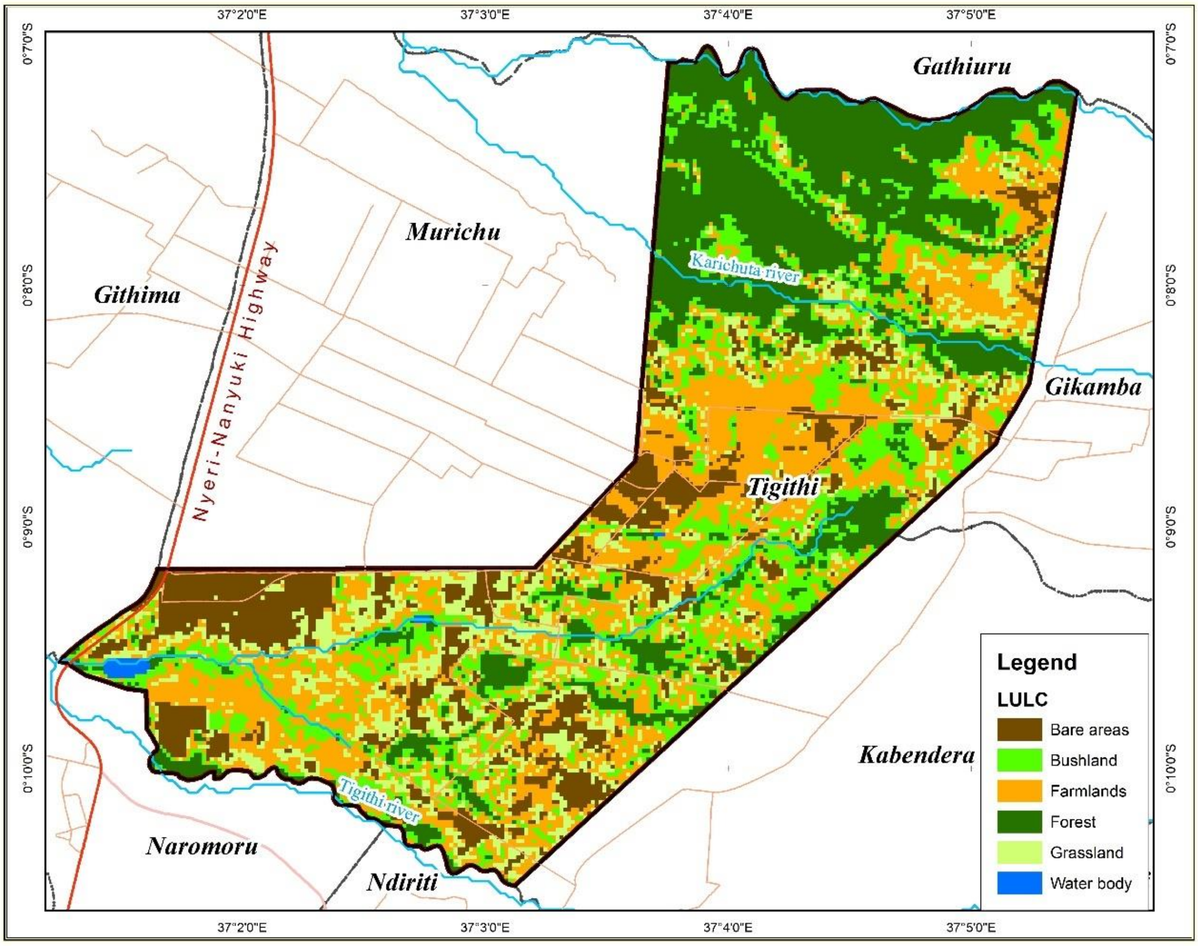


Figure 22: 1987 Map of LULC Classes in Tigithi Sub-location

Land Use Land Cover Classifications for 1995

1995 Landsat images were analysed to six land use and land cover classifications as shown in Figure 23map of Tigithi sub-location. The forest cover seemed to increase in the area above Karichuta River as compared to the 1997 land use and land cover while the farmlands cover increased in the areas on the lower parts of the river. The figure shows more bushland cover along Tigithi River and more patches of bare areas especially around Tigithi and Karichuta Rivers that were not visible in the 1987 LULC map. From Table 14 the bare areas and forest covers were the most prevalent with a combined cover of more than 50%.

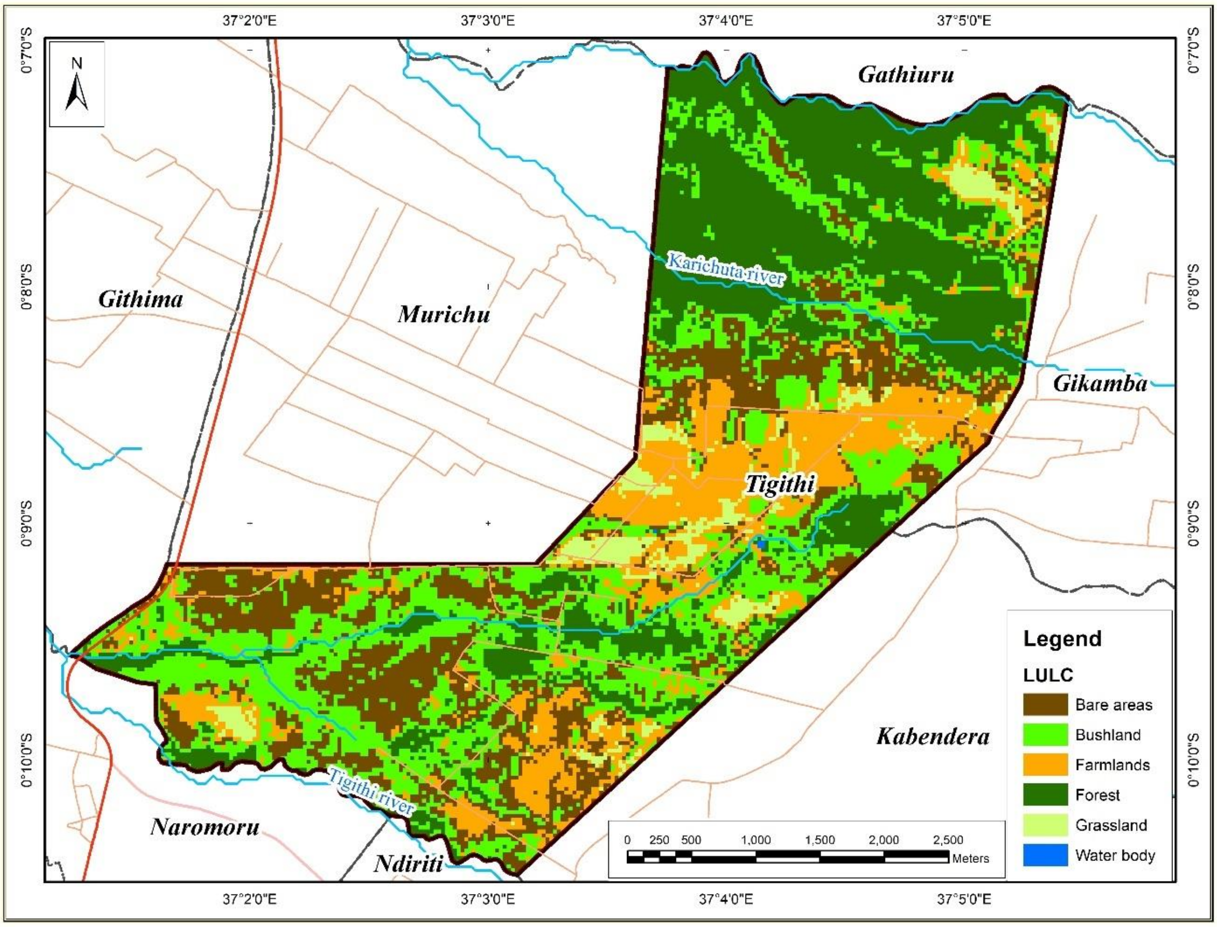


Figure 23: 1995 Map of LULC Classes in Tigithi Sub-location

Land Use Land Cover for 2002

Land use and land cover change for 2002 was determined by processing and analysis of the 2002 Landsat image. The map shows more farmlands even in areas that were not there in 1995 such above Karichuta river (Figure 24). From Figure 25 there seen more farmlands along Tigithi and Karichuta Rivers in 2002 and a presence of a water body at the corner where Tigithi sub-location meets Githima and Naromoru sub-locations and near the Nyeri-Nanyuki Road (Figure 2). Table 16shows land use and land cover percentage of farmlands and bare areas had steadily increased to a combined cover of slightly more than 50%.

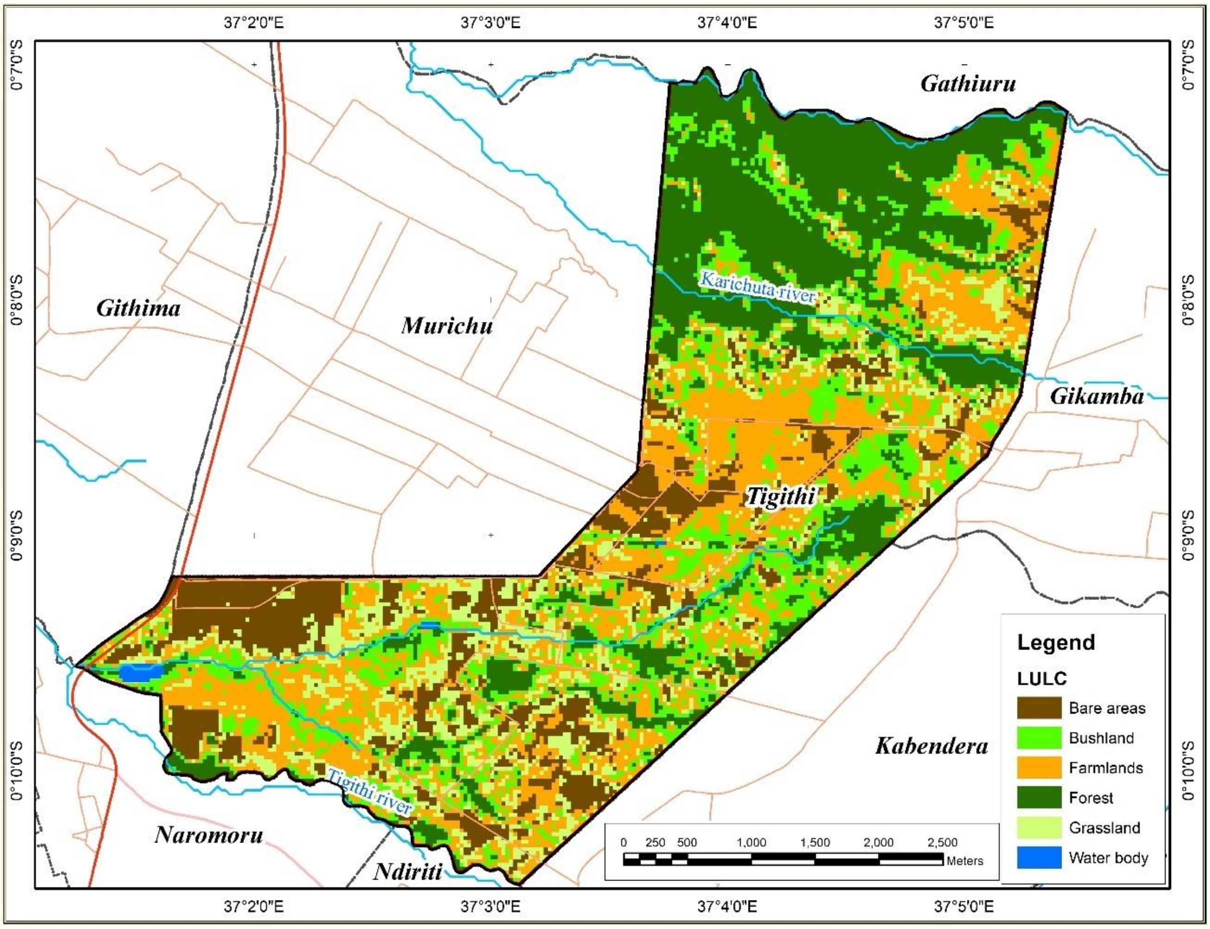


Figure 24: 2002 Map of LULC Classes in Tigithi Sub-location

Land Use Land Cover for 2010

The study analysed the land use land cover images in 2010 to detect any changes in the six classifications. The forest cover which was predominant in 1987 (Figure 22), 1995 (Figure 23) and 2002 (figure 24) had been overtaken by farmlands in 2010(Figure 25) land use land cover analysis. Figure 26 shows the areas on the lower parts of Tigithi sub-location to have more bushlands and grassland during in 2010. The 2010 land use and land cover changes shown in Table 16 have bushlands and farm lands having the combined cover of about 50% of the study area.

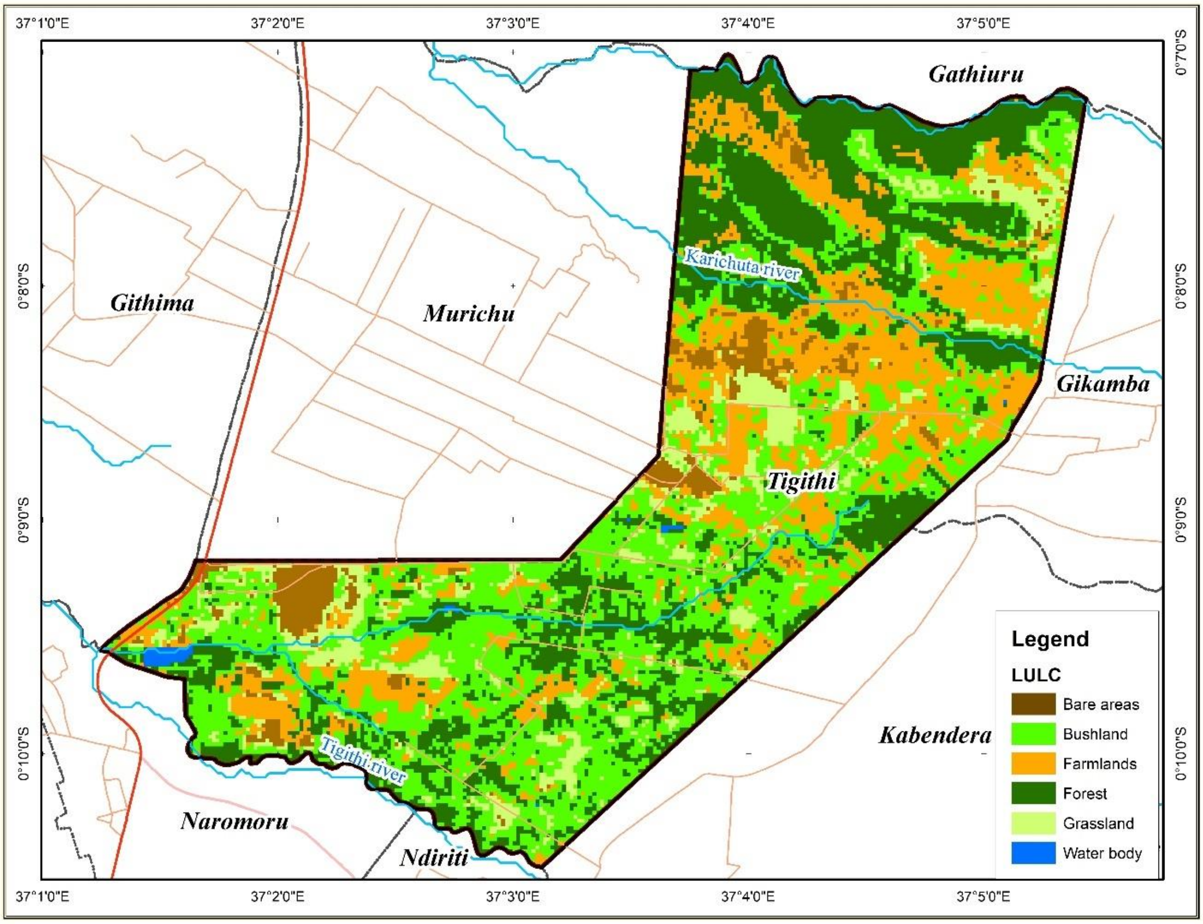


Figure 25: 2010 Map of LULC Classes in Tigithi Sub-location

Land Use Land Cover for 2017

The study was involved in classification and analysis of Landsat images from 1987, 1995, 2002, 2010 and lastly 2017 to detect any land use land cover changes in Tabitha sub-location. The analysis for the 2017 land use land cover changes in Figure 26 shows farmlands to be spread all over the study area. Bare areas cover seemed to have increased in the lower part of the study area and the areas to the north of Karichuta River. Table 16 shows that the farmlands land use land cover classification had increased from around 10% in 1987 to over 30% in 2017.

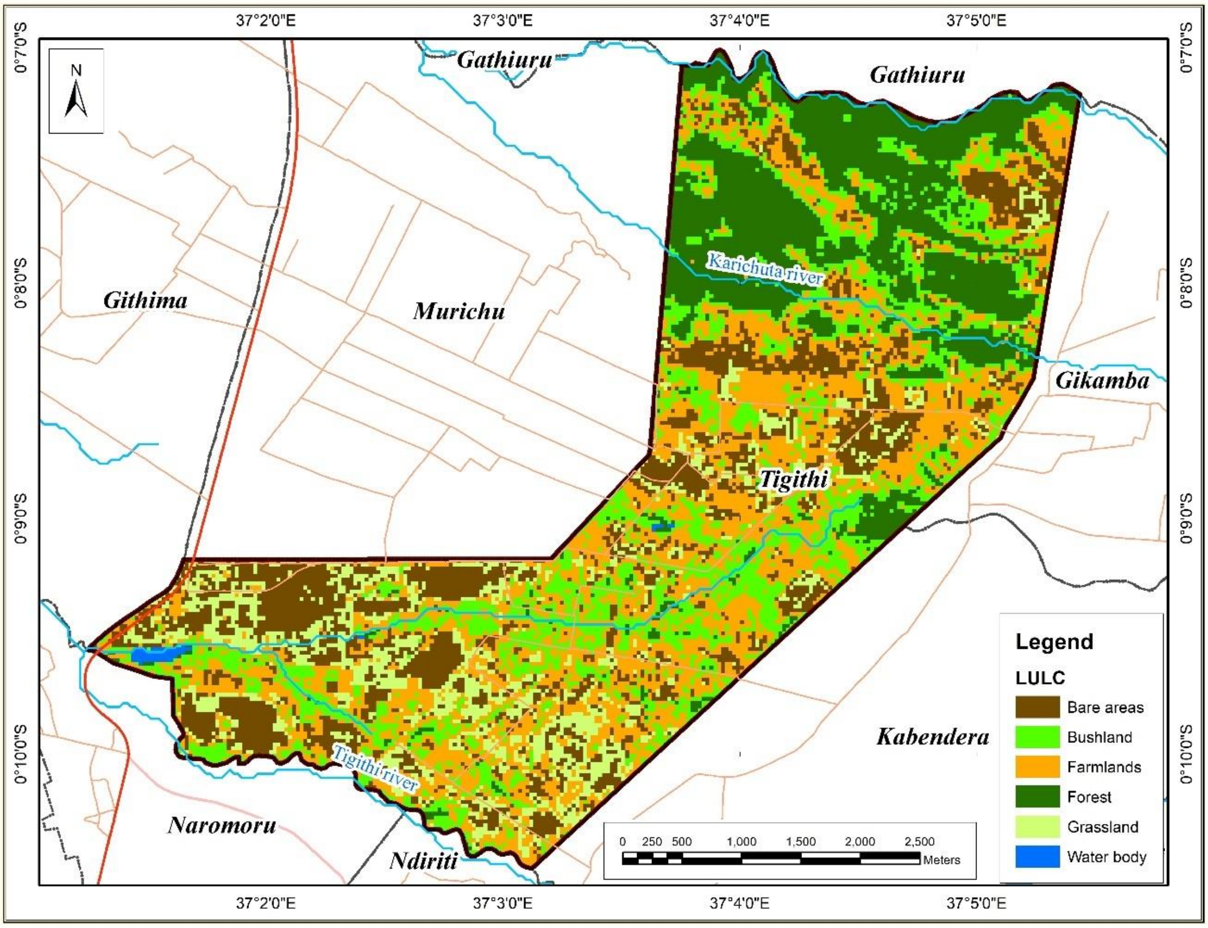


Figure 26: 2017 Map of LULC Classes in Tigithi Sub-location

Combined Land Use Land Cover Classes in Tigithi Sub-location (1987-2017)

The study analysed land use land cover in the study area by processing Landsat images covering 30 years from 1987 to 2017 by selecting 1987, 1995, 2002, 2010 and 2017 as the years of study. The analyses produced maps whose results are shown in Figures 22, 23, 24, 25, 26. Figure 27 is a composite map combing those showing land use and land covers in 1987, 1995, 2002, 2010 and 2017 side by side. Figure 27 shows the forest, bushlands and grass lands covers to dominate in the 1987 gradually decrease towards 2017. Farm lands and bare areas in Figure 27 are seen to increase from 1987 to 2017. Table 14 shows that in 2017 farmlands and bare areas covers to gradually increase to a combined cover of almost 60% from a low of about 25% cover in 1987.

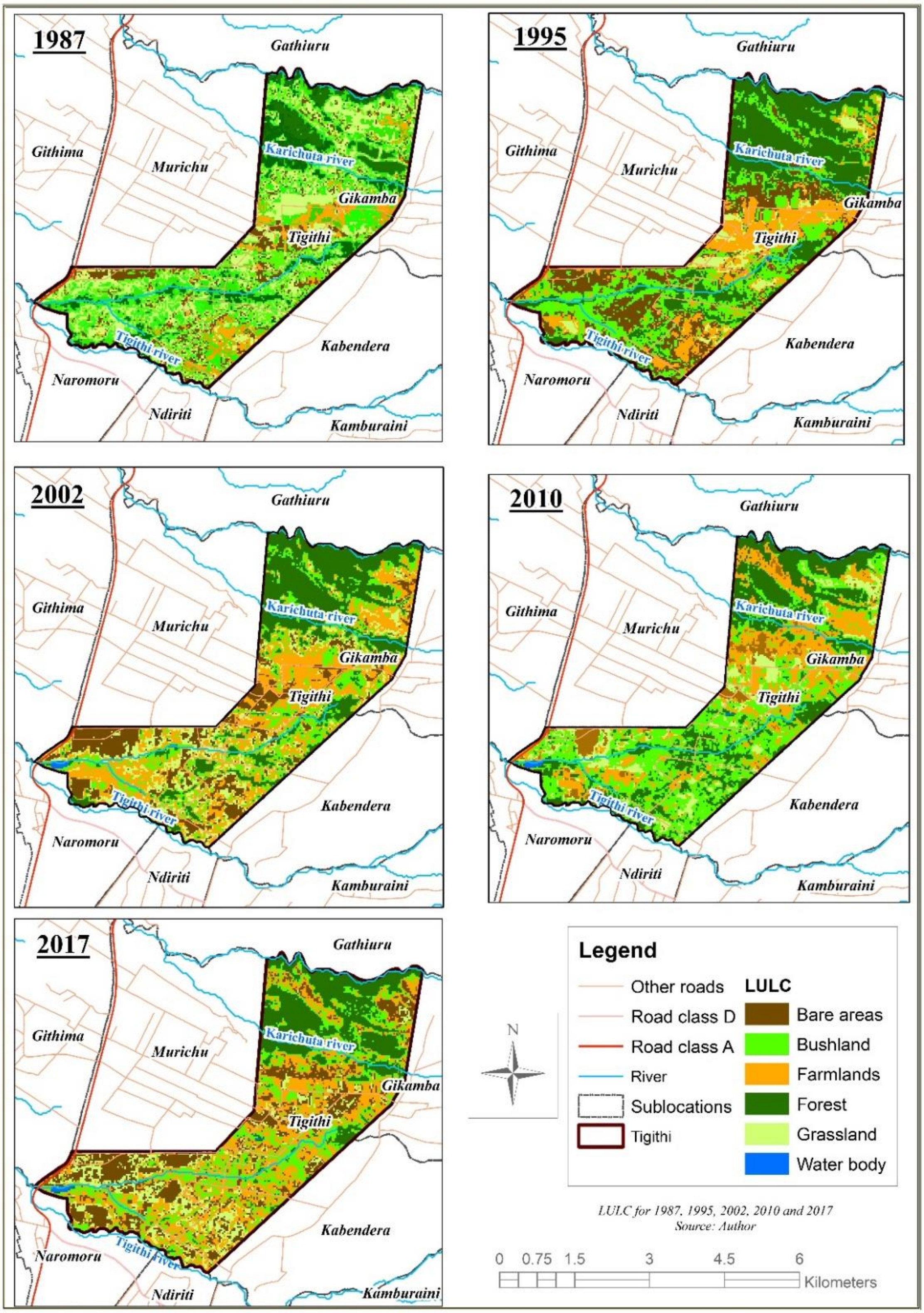


Figure 27: Composite Map (1987, 1995, 2002, 2010 and 2017) in Tigithi Sub-location

To comprehend the percentage changes of the land use and land cover classifications a comparison was done between land covers in 1987 and the same in 2017. Table 18 shows farmlands increased by more than 160% and the bare areas by more than 70% from 1987 to 2017. Water bodies category also increased by more than 300% over the same period. The study determined that almost 50% and 40% of the forest and bushlands were lost by 2017 whereas there was a marginal decrease in grassland cover as shown in Table 18.

Table 18: Percentage Land Cover Change for all classes (1987-2017)

	% Change	% Change	% Difference	% of Change
Classification	1987	2017	2017-1987	{(2017-1987)/1987}x100
Bare Areas	13.2	22.86	9.66	73.18
Bushlands	24.5	15.01	-9.49	-38.73
Farmlands	12.54	32.66	20.12	160.45
Forest	35.46	19.17	-16.29	-45.94
Grassland	14.23	10.01	-4.22	-29.66
Water Bodies	0.07	0.29	0.22	314.86

Accuracy Assessment and Ground Truthing

Accuracy assessment and ground truthing were conducted to assess the overall, user's and producer's accuracies. Table 19 shows user's accuracy for bushlands had low accuracy assessment of about 40% and the producer's accuracy for bushland to be 40% also. The user's accuracy for forest cover was higher than 95%. The overall accuracy was over 75% as shown in Table 16.

Table 19: Confusion matrix Analysis of the 2017 Supervised Classification Image

Classified data	Reference data: Water body	Forest	Bushland	Farmlands	Bare areas	grassland	Total	UA(%)
Water body	18	0	0	0	0	0	18	**100**
Forest	0	88	2	0	0	0	91	**96.7**
Bushland	0	0	10	9	7	11	26	**38.46**
Farmlands	0	0	7	49	6	9	73	**67.12**
Bare areas	0	0	0	24	99	9	132	**75**
grassland	0	0	0	0	1	5	6	**83.33**
TOTAL	18	88	24	82	114	30	356	
PA(%)	**100**	**100**	**41.66**	**59.76**	**86.84**	**16.67**		**OA75.56%**

Notes: PA=Producer's Accuracy, UA= User's Accuracy and OA=Overall accuracy

Discussion

The study main aim was to investigate the extent to which farming patterns are changing as a result of rainfall and temperature trends in Kieni sub-county from 1987-2017 period. The findings of the study suggest that the farming patterns were changing in the study area as rainfall declined and temperature increased in the study area. In chapter 4, the OND seasonal rainfall (1984-2013) in the study area showed that rainfall was declining while the temperature trends analysis showed an upward trend for both OND and MAM seasons (1983-2012).

The sectional survey results conducted in 2017 showed that almost 80% of the respondents settled in the area from the 1990s and over 70% of them owned land of sizes between one and five acres. Production of maize and potatoes were the predominantly grown in the 1980s decreased by about10% and 5% of the participants respectively. Horticultural and Napier grass farming increased by almost 30% and over 20% of the respondents in that order. The percentage land use land cover change (table 17) for 1987 to 2017 shows that farmlands increased by over 160% and at the same time forest cover decreasing by almost 50%.

Steffen and Tyson, (2001) reported that population growth and land scarcity and expansion of agricultural land are among the drivers of land use land cover change in the world. Masek *et al.*, (2000) projected that land use and land cove changes respond to forces largely associated with high human population as is the case with our study area. The study findings suggest that Kieni sub-county population increased substantially from the 1990s. This increase in population increased the demand for farming land resulting to the clearing of some forest cover to pave way for more settlement and farming. Local farmers were growing more Napier grass in 2017 unlike in 1987 pointing to the fact that the farmers could have been practicing zero grazing considering the average acreage of the farms.

Climate change and climate variability affect growing of some crops due to declining rainfall and increased temperature which reduce soil moisture and encourage the increase of some crop pests and diseases hence the change in farming patterns (IPCC, 2001). Changes in land use is one of the measures of adaptation in the face of climate change and climate variability (Adenle *et al*., 2015: Smith *et al*., 2016). Lobell and Field (2007) estimated that the effects of rising temperatures since 1981had brought about annual losses in wheat maize and barley. Crop yields potential of many crops grown in SSA region especially the semi-arid areas are expected to decrease Chijioke *et al*., 2011).

The study determined that as more farmer settled in Kieni sub-county from the 1990s, percentage forest cover decreased paving way for farmlands. The growing of maize, potatoes and beans has changed to farming of horticultural crops and Napier grass though was not clear from the study why there was an increase in the farming of horticultural crops.

CHAPTER 6: RESULTS AND DISCUSSIONS

6.1 Working with Kieni Sub-County Farmers to Enhance Rainwater Harvesting Technologies for Improved Rural Agriculture.

Growing of Kales was done in three seasons; October November and December 2017, March April May 2018 and October November December 2018 each season comprised of 14 weeks (appendix 6 and 7). Two farmers were involved in the study: farmer 1 and 2. The yields were computed using Analysis of Variance (ANOVA) with two with replication at 5% confidence level. The analysis computed the sum of the squares (SS), mean sum (MS) degrees of freedom (df), f value, p-value, f-critical value.

6.1.1 Kale yields results

Farmer 1 Yields Statistical Analysis

A two-way ANOVA was run on rain-fed and supplemental irrigation Kales weekly yields (Table 20) at P=.05. There was no significant-statistical interaction between the weekly yields of both Kales for Farmer 1, F (13,56) =0.37, P=.975. It was evident from the analysis that there was a significant-statistical differences in weekly yields of the samples (rain-fed and supplemental irrigation) Kale, F (1, 56) = 6.68, P=.012.

Table 20: Two-way Analysis of Variance for Weekly rain-fed and SI Kale yields (Farmer 1)

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	0.51	1	0.51	6.68	0.012	4.01
Columns	9.49	13	0.73	9.58	$4.77*10^{-10}$	1.90
Interaction	0.36	13	0.03	0.37	0.975	1.90
Within	4.27	56	0.08			
Total	14.63	83				

Notes: SS=Sum of Squares, df=Degree of Freedom, MS=Mean of Squares, Fcrit=Fcritical, SI=Supplemental Irrigation.

The rain-fed and supplemental average weekly Kale yields for Famer 1 were analysed for their mean and standard deviation for the three seasons. The seasonal total yields for the rain-fed Kale was almost 19t/ha (Table 21). Rain-fed Kale yields increased from a mean of 0.83(0.39) in week one to a highest mean for the season in week four with 0.91(0.46). Week five saw the yields start a downward movement from a mean of 0.78(0.34) to week eleven with a mean of 0.04(-0.4) and thereafter there were no yields.

Table 21: Farmer 1 Kale Yield Statistical Analysis for 3 Three Seasons of 14 Weeks Each

Rain fed (t/ha)			SI (t/ha)	
Weeks	Sum	Mean(SD)	Sum	Mean(SD)
1	2.5	0.83(0.39)	2.9	0.98(0.38)
2	2.5	0.83(0.39)	2.8	0.94(0.35)
3	2.1	0.71(0.27)	2.7	0.91(0.31)
4	2.7	0.91(0.46)	4.0	1.32(0.72)
5	2.3	0.78(0.34)	2.4	0.81(0.21)
6	2.0	0.67(0.22)	1.8	0.61(0.01)
7	1.6	0.54(0.09)	1.6	0.52(-0.07)
8	1.2	0.41(-0.03)	1.3	0.43(-0.16)
9	0.9	0.30(-0.15)	1.8	0.59(-0.01)
10	0.6	0.19(-0.26)	1.4	0.48(-0.12)
11	0.1	0.04(-0.4)	0.9	0.31(-0.29)
12	0.0	0.00(-0.44)	0.7	0.22(-0.37)
13	0.0	0.00(-0.44)	0.4	0.14(-0.45)
14	0.0	0(-0.44)	0.2	0.08(-0.52)
Total	**18.5**		**25.0**	

Note: SD=Standard Deviation, t/ha=ton per hectare and SI=Supplemental irrigation

The SI Kale yields shown in Table 21had a total of 25t/ha. The first week of the season had a mean of 0.98(0.38) which was higher than yields for week two and three but peaked in week four with a mean of 1.32(0.72). The yields decreased steadily from week five with a mean of 0.81(0.21) up to the end of the season at week fourteen with a mean of 0.08(-0.52).

The standard deviation for both rain-fed Kale changed from being a positive value deviation from the mean on the eighth week with a mean of 0.41(-0.03) and on the seventh week for the SI Kale with mean was 0.52(-0.07).

Farmer 2 Yields Statistical Analysis

Farmer 2's weekly rain-fed and supplemental irrigation Kale yields had a two-way ANOVA run (Table 22) at P=.05. There was no significant-statistical interaction between the weekly yields of both treatments for Farmer 2, F (13,56) = 0.42, P=.96. From the analysis it was shown that there was a significant-statistical differences in weekly yields in the samples (rain-fed and supplemental irrigation) Kale, F (1, 56) = 17.94, $P=.9x10^{-5}$.

Table 22: Two-way Analysis of Variance for Weekly Rain-fed and SI Kale yields (Farmer 2)

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	1.21	1	1.21	17.94	$9*10^{-5}$	4.01
Columns	11.10	13	0.85	12.61	$2.8*10^{-12}$	1.90
Interaction	0.37	13	0.03	0.42	0.96	1.90
Within	3.79	56	0.07			
Total	16.47	83				

Notes: SS=Sum of Squares, df=Degrees of Freedom, MS=Mean of Squares, F crit=Fcritical, SI=Supplemental Irrigation

The mean and standard deviation of the weekly rain-fed and supplemental irrigation Kale yields for farmer 2 were analysed and an average total yields of over 16t/ha (Table 23). Rain-fed Kale yields had a gradual decrease from a mean of 0.89(0.50) in week one of the seasons to the lowest yields in week 10 of the season with a mean of 0.22(-0.17) and then thereafter there were no yields.

Table 23: Farmer 2 Kale Weekly Yield Statistical Analysis for Rain-fed and SI Kale

Rain fed (t/ha)			SI (t/ha)	
Weeks	Sum	Mean(SD)	Sum	Mean (SD)
1	2.7	0.89(0.50)	3.6	1.19(0.56)
2	2.4	0.81(0.42)	3.4	1.14(0.51)
3	2.3	0.75(0.37)	3.4	1.13(0.50)
4	2.1	0.69(0.30)	3.6	1.2(0.57)
5	1.8	0.61(0.22)	2.9	0.98(0.35)
6	1.4	0.47(0.08)	2.3	0.78(0.15)
7	1.2	0.39(0.00)	2.1	0.69(0.06)
8	1.0	0.33(-0.06)	1.5	0.50(-0.13)
9	0.7	0.24(-0.14)	1.1	0.36(-0.27)
10	0.7	0.22(-0.17)	0.8	0.28(-0.35)
11	0.1	0.03(-0.36)	0.8	0.26(-0.37)
12	0.0	0.00(-0.39)	0.4	0.13(-0.50)
13	0.0	0.00(-0.39)	0.3	0.11(-0.52)
14	0.0	0.00(-0.39)	0.2	0.08(-0.55)
Yields	**16.4**		**26.4**	

Notes: SD= Standard Deviation, SI=Supplemental Irrigation, t/ha=Ton per hectare

Table 23 shows that the seasonal total yields for SI Kale was over 26t/ha while week one of the season had the highest mean of 1.19(0.56). The weekly mean yields continuously decreased after week one up to the last week of the season, week fourteen, with a mean of 0.14(-0.55).

The average weekly yields for both rain-fed and supplemental irrigated Kale had their standard deviation change from positive values after the seventh week. The rain-fed Kale mean and standard deviation at the middle of the season was 0.39(0.00) as compared to that of SI Kale in the same week 0.69(0.06).

6.1.2: Soil chemical and moisture content analysis results

Soil Analysis for Farmer 1

The seasonal soil and chemical analysis for famer 1's soil was analysed. The average pH ranged from approximately 6 in season three to about 7 in season two (Table 24). The Nitrogen content in the soil remained constant at 0.3%, and the Organic Carbon ranged from 2.7%-3.%. Potassium in the soil for the three seasons had a mean of about 2cmol/kg. Farmer 1's soil Phosphorous component was very high in the 3rd season with almost 80ppm and lowest in the 2nd season with a content of slightly over 30ppm as shown in Table 23.

Table 24: Seasonal Soil Chemical and Moisture Content Analysis (Farmer 1)

Season	pH	N(%)	OC(%)	K (cmol/kg)	P (ppm)	Sand (%)	Silt(%)	Clay (%)	Av. MC(%)
Season 1	6.9	0.3	3.3	2.3	40.4	56	18	26	29.6
Season 2	7.1	0.3	2.7	2.0	36.3				33.4
Season 3	6.4	0.3	3.6	1.5	79.0				35.0
Total Average	**6.8**	**0.3**	**3.2**	**1.9**	**51.9**				**32.7**

Notes: pH=Potential of Hydrogen, N=Nitrogen, K=Potassium, cmol/kg=centimes per kilogram, %=Percentage, Av. MC=Average Moisture Content

Table 23 shows that the soil comprised of over 50% sand and more than 20% clay while the rest was silt. Average moisture content in the soil was steadily maintained at about 30% during the growing season of Kales (appendix 6).

Soil Analysis for Farmer 2

The analysis for the soil chemical composition for farmer 2 was carried out during the three seasons as shown in Table 24. pH was measured at neutral in the second season while in the first and third seasons it was about 6.5. In Table 25 shows the soil had the highest Nitrogen, Organic Carbon and Phosphorous at about 0.3%, 4% and almost 80ppm respectively. The third season however had the least Potassium measured at just 1.5 cmol/kg.

Table 25: Seasonal Soil Chemical and Moisture Content Results (Farmer 2)

Season	pH	N(%)	OC(%)	K (cmol/kg)	P (ppm)	Sand(%)	Silt(%)	% clay	Av. MC(%)
Season 1	6.6	0.2	2.1	2.6	46.7	50	22	28	28.5
Season 2	7.0	0.2	2.2	2.1	41.1				31.3
Season 3	6.4	0.3	3.6	1.5	79.0				33.2
Total Average	**6.7**	**0.2**	**2.6**	**2.1**	**55.6**				**31.0**

Notes: pH=Potential of Hydrogen, N=Nitrogen, K=Potassium, cmol/kg=centimoles per kilogram, %=Percentage, Av. MC=Average Moisture Content

Soil composition was more than half as sand while the rest were almost silt and clay in equal measure. The soil moisture for the three seasons (appendix 7) was maintained at around of 30% (table 22) throughout the three seasons.

Discussion

The research we conducted in Kieni sub-county was to determine whether the application of the rainy season and applied as supplemental irrigation to one Kale crop while the other crop was planted as it was raining and grew as wholly rain-fed. The research involved two farmers (farmer 1 and farmer 2). The study findings suggest that Kale that received supplemental irrigation realised better harvest than the one that grown depending wholly on the rains.

Famer 1's Kale crop under supplemental irrigation yielded over 25t/ha and the rain-fed crop yields almost 20t/ha (Table 20). Farmer 2's supplemental irrigated crop yielded over 26t/ha and the rain-fed crop had yields of over 16t/ha. The crop that was wholly rain-fed and the one under supplemental irrigating for both farmers were grown under identical conditions.

Kulshreshtha (2011), projected that changes in temperature and rainfall will have a direct effect on the quantity and quality of the yields. Reports from Hatibu *et al*., (2006) in a pilot experiment in a period of severe dry spells that there were no grains harvested whereas yields of about 1.5t/ha were realised from the plots supplied with supplemental irrigation. Fox and Rochstrom (2003), reported an on the farm experiment conducted in SAHEL that the rain-fed crops resulted in yields of 455Kg/ha while the supplemental irrigated crops yields were 712Kgs/ha. According to Oweis (1997), in Syria, the average produce of wheat grown under rain-fed circumstances is only 1.25 t/ha while the grain yield with SI was 3t/ha. Oweis *et al*., (1999) projected that rain-fed wheat yields ranged from 0.9-2.5t/ha and from 3t/ha-4.5t/ha with SI in Turkey and elsewhere wheat yield improved in one season from 2.16t/ha to 4.61 t/ha, which is more than 100% (Adary *et al.*, 2002). this is because according to Oweis and Hachum (2012), when rains are inadequate, more water is needed for crop growth. However, the response is greater, and yield increases are significance even when rainfall is as much as 500mm.

The study area, Kieni sub-county, is a dry tropical area and, therefore, rain-fed Kale yields were expected to decrease as the above two farmers' crop yields indicated, hence the need for the farmers to practice supplemental irrigation with rainwater harvested during the rainy season. The study showed that rainwater-harvesting technologies would improve rural agriculture in Kieni sub-county by supplying the harvested rainfall to growing crops by supplementing rainfall. Considering the average annual rainfall is only 500mm (Wamicha, 1993) in the study area, the harvested rain water may not be enough to support crops grown during a non-rainy season but it would be interesting to compare the yields of a fully irrigated crop with those of crops which are wholly rain-fed.

CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

7.1 Rainfall and temperature trends in Kieni sub-county

Analysis of seasonal rainfall for the period of 1984-2013 and seasonal maximum temperature for 1983-2012 period was conducted to establish their trends in Kieni sub-county. The seasons were the MAM and OND since the area experiences a bimodal rainfall pattern. The MAM rainfall data analysis resulted to an upward trend which was found to increase at a rate of 0.318mm/year. The MAM maximum temperature trend analysis determined an upward trend which was increasing by 0.016^0C/year. The months of April has the highest mean rainfall of over 115mm as well as the highest recorded of over 240mm in a single month. Kieni sub-county's annual rainfall was 500mm which therefore means about a fifth of the annual rainfall was experienced in one month. The season's upward surge in rainfall could also have been reversed as moisture could have been lost through evapotranspiration from the increasing temperature. The highest temperatures were recorded in March with over 28^0C.

The OND season rainfall analysis resulted in decreasing trend at a magnitude of 0.02mm/year and the maximum temperature trend increased at 0.025^0C/year. October received the highest seasonal rainfall of over 200mm while November received the highest seasonal mean at over 80mm. Though October received the highest rainfall it recorded the highest seasonal mean and maximum temperature of 24.5^0C and 26^0C respectively. The seasonal rainfall and temperature trends were both rising. OND seasonal maximum temperature increased by more than 56% as compared to the MAM temperatures which means OND temperature trend was rising faster than in the MAM season.

As maximum temperature increases in Kieni sub-county during the crop growing season, there is need for the community to adapt methods aimed at minimizing crop yields. These methods include increasing soil cover as a way of reducing the loss of soil moisture through evaporation and soil erosion from wind and floods. Other adaptation methods include; harnessing and storing the excess water especially when the rainfall intensity is high and using it for irrigation and growing of crops that are drought resistant.

Climate change and climate variability which is as a result of change of climatic parameters over a prolonged time which include rainfall, temperature, wind, humidity among others. Temperature is a measure of how hot or cold a substance is which in our study was the measure of the thermal energy of air in the study area. Our study analysed only the maximum temperature normally recorded during the day. However, some crops are sensitive to minimum temperatures mostly experienced at night and therefore, the study recommends further study on the seasonal minimum temperature trends in the study area.

7.2 Evolving farming practices in response to rainfall trends in Kieni sub county

Climate change and climate variability being experienced in Kieni sub-county coupled with the population increase has resulted to changes in farming patterns as evident in the land use and land cover change analysis. Farming patterns changes are seen in the context of farmers' shift from predominantly growing of maize and beans which decreased by over 10% and 26% respectively. There was growth in the farming of horticulture and Napier grass which increased by about 28% and over 21% in that order. The local community settled in the area from the 1990s according to over 76% of the respondents which resulted to an increase in population. As more farmers settled in the study area there was need for more land for settlement and farming hence the reduction of forest land cover by almost 50% and an increase in farmlands by over 160% from 1987 to 2017 period.

Some of the drivers of land use and land cover change include increase in population and the methods of land utilization. Kieni sub-county experienced population increase from the 1990s who needed land for settlement and subsequently to farm. According to over 70% of the respondents, the average size of farms in Kieni sub-county was in the range of 1-5 acres and could be the reason why there was an increase in Napier grass production as farmers practiced zero grazing. The reasons for the rise in horticultural crop growing in the study area was not very clearly though the study would suggest the crops are fast growing and fetch fast market in the neighbouring towns of Nanyuki, Nyeri and Karatina as well as nearby secondary schools.

To increase resilience in the face of climate change and climate variability the farmers in Kieni sub-county were changing their farming patterns. Farmers were moving from growing the traditional crops like maize and beans to horticultural crops therefore introducing new crops in the area as an adaptation measure. The study was not able to delve into the reasons why the farmers have specifically moved to farming horticultural crops and recommends further study to be done as to the reasons why.

7.3 Working with Kieni Sub-County Farmers to enhance rainwater harvesting technologies to enhance rural Agriculture

Rainwater-harvesting technologies when applied coupled with irrigation can improve rural agriculture. This is evident in our study where two crops of Kale were grown in each season with one crop being wholly rain-fed and the other receiving supplemental irrigation for three seasons. The study involved two farmers in the growing of the Kale crop; Farmer 1 and Farmer 2. Both rain-fed and the supplemental irrigation Kales were grown under the same soil and crop husbandly conditions. During the rainy season rain water was collected, stored and later used to irrigate the Kale that was supposed to receive the supplemental irrigation.

The Kale average produce from both rain-fed and the supplemental irrigation crops were analysed and the mean yields were found to be significantly different. The analysis for farmer 1's supplemental irrigated crop resulted in the total yields of over 25t/ha as compared to the rain-fed Kale yields of 19t/ha. This was an increase of over 30% in yields.

Famer 2's yields from the Kale crop under supplemental irrigation was over 26t/ha while the rain-fed Kale realized a produce of about 16t/ha. The percentage increase of the Kale under supplemental irrigation for farmer 2 was over 60%. The percentage increase in Kale yields from the two farmers for the supplemental irrigation has a difference of almost double which means there could have been other factors at play other than supplying crops with some extra water when the rains stop. The general trend however is that both framers Kale average yields increased when the crop received supplemental irrigation from the harvested rainfall.

The findings of this study suggest the presence of climate change in Kieni sub-county where the study took place. Extreme weather events including drought and flooding experienced in the study area due to climate change can result in loss of crops and crop yields. To adapt to these weather extremes, the farmers could adopt rainwater harvesting technologies coupled with soil and water conservation measures to increase crop yields. The farmers could also grow more crops that are more resistant to drought. Rainwater harvesting should be adopted especially as the area receives only about 500mm per year with almost half of it falling in April as the study has shown. The uneven distribution of rainfall can cause floods and soil erosion in the study area.

The study was involved with the harvesting of rain water which was later used on the supplemental irrigation. This study therefore recommends further study to be done on the yields of crops grown depending fully on irrigation and compare with the yields from crops grown depending fully on the rains.

Climate change and climate variability being experienced in the Kieni sub-county due to increased seasonal temperature and OND seasonal rainfall has seen farming practices change in order to adapt. The adaptation measures that can will increase resilience in the area include harvesting rain water through various technologies and practicing supplemental irrigation to increase crop yields as has been illustrated by this study.

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APPENDICES

Appendix 1: MAM and OND Rainfall Data (1984-2013)

Year	March (mm)	April (mm)	May (mm)	October (mm)	November (mm)	December (mm)
1984	2.7	35.4	20.2	43.6	94.4	41.8
1985	46.4	87.7	79.1	82.9	51.2	18.2
1986	63.8	203.4	100.9	70.1	54.6	50.6
1987	1.3	85.1	34.1	19.0	35.5	51.6
1988	68.7	242.1	52.2	36.9	76.6	41.4
1989	84.9	92.0	131.7	79.2	73.1	30.9
1990	51.0	138.9	58.3	98.9	88.2	51.0
1991	10.8	139.1	36.4	60.1	67.0	15.7
1992	19.6	153.3	66.8	107.3	113.6	57.7
1993	32.6	37.3	52.0	40.4	35.7	20.1
1994	19.0	109.3	48.1	90.3	143.0	14.5
1995	108.0	78.3	140.6	87.1	72.4	38.3
1996	32.6	64.4	11.8	30.2	67.2	32.7
1997	44.3	156.1	51.7	211.1	181.8	98.5
1998	28.0	102.4	118.9	80.8	71.2	11.0
1999	59.5	81.1	34.3	69.8	56.7	33.3
2000	2.8	44.1	21.8	64.0	50.1	11.3
2001	122.7	76.2	45.0	84.4	144.3	3.7
2002	61.8	137.2	103.2	66.9	61.1	109.6
2003	50.9	222.5	145.1	56.1	85.8	30.5
2004	55.9	116.5	56.8	37.0	108.4	16.6
2005	10.0	168.2	86.5	54.1	14.8	6.8
2006	79.7	104.8	45.9	49.8	106.8	48.1
2007	19.9	122.1	56.7	71.9	24.7	19.6
2008	52.7	44.1	25.6	71.6	89.5	34.2
2009	0.0	48.3	45.6	88	38.3	65.4
2010	162.8	113.1	75.6	74.9	83.9	12.3
2011	42.4	89.7	57.8	82.2	179.0	45.7
2012	0.0	158.8	141.7	78.3	68.0	34.1
2013	57.0	204.2	37.3	18.9	77.7	38.9

Appendix 2: MAM and OND Maximum Temperature Data (1983-2012)

Year	March(^{0}C)	April (^{0}C)	May (^{0}C)	October (^{0}C)	November (^{0}C)	December (^{0}C)
1983	28.0	25.5	23.1	24	24.2	23.6
1984	27.1	25.8	23.8	22.4	21.5	23.3
1985	25.2	23.0	21.8	24.1	23.4	24.4
1986	26.6	23.7	22.2	24.9	23.6	23.8
1987	28.3	25.5	23.7	26.5	24.3	25.9
1988	26.6	25.4	22.3	24.1	22.4	22.9
1989	25.9	23.4	23.0	23.1	22.3	24.0
1990	24.5	24.0	23.2	24.2	23.3	24.0
1991	28.4	24.9	22.9	24.8	23.0	24.6
1992	27.5	25.0	23.1	24.7	23.5	23.5
1993	26.2	24.4	23.3	25.1	24.1	23.9
1994	27.2	24.5	22.6	23.3	23.1	23.9
1995	25.4	24.8	23.3	23.8	23.5	23.7
1996	26.2	25.2	23.4	25.7	24.0	25.4
1997	26.7	24.2	23.4	23.7	23.3	23.7
1998	25.9	24.6	24.1	25.1	23.6	25.5
1999	27.2	24.8	23.0	25.2	23.3	23.3
2000	27.7	25.2	23.8	25.8	24.3	24.7
2001	26.9	24.0	22.9	25.0	23.1	24.7
2002	26.6	24.8	23.4	24.7	24.0	24.3
2003	27.8	25.8	23.7	24.9	23.6	24.5
2004	27.1	25.0	23.7	24.0	23.3	24.9
2005	28.2	25.6	23.9	25.1	24.8	26.4
2006	26.2	24.1	23.0	24.7	23.6	24.3
2007	26.6	24.5	23.4	24.1	23.5	24.5
2008	26.4	24.1	23.4	25.2	24.2	24.5
2009	25.9	26.0	24.1	24.4	24.8	23.6
2010	25.2	24.8	23.8	25.4	23.6	25.4
2011	27.1	25.1	22.5	24.2	23.7	24.4
2012	28.1	25.2	23.9	24.0	23.8	24.1

Appendix 3: Rainfall Seasonal Trend Statistics (Mann-Kendall and Sen's slope Estimator)

RAINFALL (1984-2013)				**MK Trend**	**Sen's slope estimate**					**Constant B**				
Time series	**First year**	**Last Year**	**n**	**Test Z**	**Q**	**Qmin 99**	**Qmax 99**	**Qmin 95**	**Qmax 95**	**B**	**Bmin 99**	**Bmax 99**	**Bmin 95**	**Bmax 95**
March	*1984*	*2013*	*30*	0.25	0.250	-1.866	2.808	-1.158	2.187	43.60	65.17	-0.69	58.65	7.86
April	*1984*	*2013*	*30*	0.52	0.560	-3.126	3.985	-2.136	2.927	96.55	159.32	46.91	149.55	68.87
May	*1984*	*2013*	*30*	0.21	0.143	-2.123	2.317	-1.358	1.569	52.52	88.20	23.25	77.18	31.85
Oct	*1984*	*2013*	*30*	-0.04	-0.023	-1.667	1.669	-1.160	1.202	71.15	92.74	37.22	86.10	45.02
Nov	*1984*	*2013*	*30*	0.43	0.332	-2.046	2.643	-1.544	1.946	68.41	96.42	39.45	91.10	49.04
Dec	*1984*	*2013*	*30*	-0.57	-0.247	-1.537	1.038	-1.161	0.748	38.57	54.32	17.42	48.68	19.77

Appendix 4: Temperature Seasonal Trend Statistics (Mann-Kendall and Sen's Slope Estimator)

TEMPERATURE (1983-2012)				MK Trend		Sen's slope estimate					Constant B				
Time series	**First year**	**Last Year**	**n**	**Test Z**	**Sign**	**Q**	**Qmin99**	**Qmax99**	**Qmin95**	**Qmax95**	**B**	**Bmin99**	**Bmax99**	**Bmin95**	**Bmax95**
March	*1983*	*2012*	*30*	-0.23		-0.001	-0.069	0.069	-0.056	0.050	26.67	27.94	25.65	27.73	25.99
April	*1983*	*2012*	*30*	0.75		0.017	-0.033	0.071	-0.023	0.054	24.55	25.33	23.60	25.19	23.86
May	*1983*	*2012*	*30*	2.75	**	0.032	0.000	0.062	0.008	0.055	22.91	23.35	22.43	23.22	22.58
Oct	*1983*	*2012*	*30*	1.09		0.021	-0.036	0.069	-0.018	0.056	24.28	25.14	23.58	24.90	23.82
Nov	*1983*	*2012*	*30*	1.89	+	0.026	-0.011	0.069	0.000	0.060	23.11	23.70	22.45	23.55	22.61
Dec	*1983*	*2012*	*30*	1.66	+	0.029	-0.020	0.067	-0.004	0.063	23.77	24.69	23.23	24.37	23.28

Appendix 5: Questionnaire

Date:

Sub Location:

Name:

Gender:

Question 1: What is your age group?

a) Under 30yrs
b) 30-39yrs
c) 40-49yrs
d) 50+

Question 2: What is your marital status?

a) Married
b) Widowed
c) Divorced/separated
d) Single

Question 3: Number of children

a) 0-2
b) 3-5
c) 5+

Question 4: Farmer's level of education

a) Primary level
b) Secondary level
c) University level

Question 5: What is the size of your farm?

a) Less than 1 acre
b) 1-5 acres
c) 5+ acres

Question 6: Who works on the farm? (*you can mark more than one category*)

a) Husband
b) Wife
c) Children
d) Hired Labour

Question 7: When did you start farming in Tigithi?

a) 1990s and before
b) 1991-1999
c) 2000-2009
d) 2010-2017

Question 8: What crops were being grown in the 1980s and how many 90kgs sacks were harvested per acre? (*indicate yields against a particular crop*)

a) Maize
f) Onions

Appendix 5: Continued

b) Beans
g) Wheat
c) Potatoes
h) Animal fodder (specify)
d) Peas
i) Others (*specify*)
e) Cabbages

Question 9: What livestock were being reared in the 1980s?

a) Cows (*specify the type*)
d) Chicken
b) Sheep (*specify the type*)
e) Others (*specify*)
c) Goats (*specify the type*)

Question 10: In your opinion as a farmer was rainfall enough for farming in the 1980s?

a) Yes
b) No

Question 11: What crops are you growing now and how many 90kgs sacks are harvested per acre? (*indicate yields against a particular crop*)

a) Maize
f) Onions
b) Beans
g) Wheat
c) Potatoes
h) Animal fodder (specify)
d) Peas
i) Others (specify)
e) Cabbages

Question 12: What livestock are you rearing now?

a) Cows (*specify the type*)
d) Chicken
b) Sheep (*specify the type*)
e) Others (specify)
c) Goats (*specify the type*)

Question 13: In your opinion as a farmer is rainfall enough for farming now?

a) Yes
b) No

Question 14: Which year do you recall had the heaviest rainfall?

Question 15: Which year do you recall had the severest famine/drought?

Question 16: Why are you growing the crops you are growing now and the livestock you are keeping now? *Tick as many as the farmer indicates)*

a) Home consumption
b) Generate income
c) Favourable climate
d) Fast growing
e) Involves less labour which is good owing to my old age
f)) Less infestation by pests and diseases

Question 17: What major challenges are you facing now when farming? *(Tick as many as the farmer indicates)*

a) Soil infertility
b) Rainfall shortage
c) Lack of capital for inputs and labour
d) Pests and diseases
e) Lack of Knowledge of farming practices
f) Low yields
g) Low market prices
h) Other family members not helping on the farm

Appendix 6: Average Seasonal Soil Moisture Content for SI Kale (Farmer 1)

Season 1	% Moisture Content	Season 2	%Moisture Content	Season 3	%Moisture Content
27/11/2017	22.5	13/03/2018	33.9	05/09/2018	30.4
04/12/2017	30.0	21/03/2018	38.5	12/09/2018	28.1
13/12/2017	29.6	28/03/2018	34.0	19/09/2018	33.8
19/12/2017	33.9	04/04/2018	33.4	26/09/2018	55.3
04/01/2018	32.5	11/04/2018	35.4	03/10/2018	33.2
11/01/2018	29.2	25/05/2018	33.2	10/10/2018	35.8
		02/05/2018	36.7	16/10/2018	40.0
		09/05/2018	37.1	24/10/2018	37.8
		16/05/2018	37.1	31/10/2018	29.5
		23/05/2018	35.5	07/11/2018	33.5
		30/05/2018	27.8	04/12/2018	33.1
		07/06/2018	29.6	11/12/2018	34.7
		12/06/2018	25.6	18/12/2018	29.3
		18/06/2018	30.5		
Average	29.6		33.4		35.0

Appendix 7: Average Seasonal Soil Moisture Content for SI Kale (Farmer 2)

Season 1	% Moisture Content	Season 2	%Moisture Content	Season 3	%Moisture Content
27/11/2017	23.2	13/03/2018	21.12	05/09/2018	34.1
04/12/2017	28.2	21/03/2018	36.09	12/09/2018	30.9
13/12/2017	26.8	28/03/2018	33.68	19/09/2018	32.1
19/12/2017	34.8	04/04/2018	31.04	26/09/2018	57.5
04/01/2018	30.1	11/04/2018	36.16	03/10/2018	30.8
11/01/2018	27.8	25/04/2018	36.98	10/10/2018	30.7
		02/05/2018	35.49	16/10/2018	32.0
		09/05/2018	35.21	24/10/2018	36.3
		16/05/2018	34.80	31/10/2018	28.9
		23/05/2018	29.47	07/11/2018	29.2
		30/05/2018	22.48	04/12/2018	24.1
		07/06/2018	32.71	11/12/2018	31.3
		12/06/2018	19.73	18/12/2018	33.2
		18/06/2018	33.38		
Average	28.5		31.31		33.2