An assessment of climate variability and change and its effects on millet yields in Paicho sub county, Gulu District

BY

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A dissertation submitted to the directorate of research and graduate training in partial fulfillment of the requirements for the award of a degree of masters of arts in geography of Makerere University
DECLARATION

I George Oriangi hereby declare that the views in this dissertation are mine except the citations made therein.

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DEDICATION

I dedicate this piece of work from my hands to my beloved parents Mr. Olajor Raphael and the late Ms. Kafuko Federes, My dear wife Akello Mary together with my guardian Mr.Obbo Gideon and his wife Ms. Theresa Mary Obbo for the great and tireless sacrifice they have made to see me reach this height of my Education. May the Almighty God bless them.
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TABLE OF CONTENTS

DECLARATION................................................................................................................................. iii
APPROVAL ........................................................................................................................................... iii
DEDICATION......................................................................................................................................... iii
ACKNOWLEDGEMENTS ................................................................................................................ iv
TABLE OF CONTENTS ....................................................................................................................... iv
LIST OF TABLES .............................................................................................................................. xiv
LIST OF FIGURES ............................................................................................................................ ix
LIST OF ACRONYMS ....................................................................................................................... xv
ABSTRACT ........................................................................................................................................... xviii

CHAPTER ONE: INTRODUCTION ................................................................................................. 1

1.1: Background of the study ........................................................................................................... 1

1.2: Statement of the problem ......................................................................................................... 2

1.3: General objective ....................................................................................................................... 43

1.4: Specific objectives .................................................................................................................... 3
1.5: Hypotheses tested ................................................................. 54
1.6: Justification of the study ...................................................... 54
1.7: Scope of the study: ............................................................. 75
CHAPTER TWO: LITERATURE REVIEW ................................................................. 87
2.0: Introduction ........................................................................................................ 82
2.1: Climate patterns and trends in variability and change ...................................... 87
2.2: The effects of climate variability and change on crop yields .............................. 10
2.3: Coping mechanisms to climate variability and climate change ......................... 17
2.4: Adaptation strategies to climate variability and change ................................... 18
2.5: The role of Institutions in community adaptation to climate variability and change. 21

vii
CHAPTER THREE: RESEARCH METHODOLOGY ..............................................................

3.0: Introduction ................................................................................................. 24

3.1: Study area .................................................................................................. 24

3.1.1: Location ................................................................................................ 24

3.1.2: Climate .................................................................................................. 25

3.1.3: Vegetation ............................................................................................. 27

3.1.4: Soils ...................................................................................................... 28

3.1.5: Topography .......................................................................................... 23

3.1.6: Land use types ..................................................................................... 29

3.1.7: Population ............................................................................................ 30

3.2: Research design ........................................................................................ 25

3.2.1: Target population and unit of analysis .............................................. 31

3.2.2: Sample size and sample selection ..................................................... 31

3.2.3: Selection of respondents ..................................................................... 33

3.3: Data collection methods ........................................................................... 33

3.3.1: Interviews ............................................................................................ 34

3.3.2: Climatic data collection ...................................................................... 34

3.3.3: Soil sampling technique ...................................................................... 35

3.3.4: Document analysis .............................................................................. 35

3.4: Data processing ........................................................................................ 36

3.4.1: Projecting future climate change ....................................................... 36

3.4.2: Millet yield modeling ......................................................................... 37

3.5: Data analysis ............................................................................................. 40
CHAPTER FOUR: PRESENTATION OF FINDINGS

4.0: Introduction

4.1: Variability and changes in rainfall and temperature in Paicho Sub County

4.1.1: Variability in rainfall

4.1.2: Variability in temperature

4.1.3: The perception of households on climate variability and change

4.2: Projected changes in climate

4.2.1: Projected changes in rainfall

4.2.2: Projected changes in maximum and minimum temperature

4.3: Effects of climate change on millet yields

4.4: Households coping mechanisms to climate stressors

4.5: Households adaptation strategies to climate stressors

4.6: The role of institutions in community adaptation to climate variability and change

CHAPTER FIVE: DISCUSSION OF FINDINGS

5.0: Introduction

5.1: Variability and changes in rainfall and temperature in Paicho Sub County

5.1.1: Variability in rainfall

5.1.2: Variability in temperature

5.2: Projected changes in climate
5.2.1: Projected changes in rainfall ................................................................. 72
5.2.2: Projected changes in maximum and minimum temperature .................. 73
5.2.3: Household perceptions on climate change ............................................. 74
5.3: Effects of climate change on millet yields............................................... 75
5.4: Coping mechanisms to climate stressors ............................................... 76
5.5: Adaptation strategies to climate stressors ............................................... 76
5.6: Evaluation of the role of institutions in community adaptation to climate stressors 77

CHAPTER SIX: SUMMARY OF RESEARCH FINDINGS, RECOMMENDATIONS AND CONCLUSIONS ..................................................................................................................... 81
6.1: Summary of research findings.................................................................... 78
6.2: Conclusions................................................................................................ 79
6.3: Recommendations....................................................................................... 79

REFERENCES ................................................................................................... 80
APPENDICES ..................................................................................................... 106
Appendix A ....................................................................................................... 106
APPENDIX B ..................................................................................................... 105
Questionnaire .................................................................................................... 105
LIST OF TABLES

xi
Table 1: Observed millet yields for Paicho Sub County..................................................24
Table 2: Sample size for the study ..................................................................................33
Table 3: Weeks of onset of rainfall for Paicho S/C, 1980-2012 .........................................50
Table 4: Decadal maximum temperature variations for the periods 1990-1999 and 2000-2010
........................................................................................................................................54
Table 5: Decadal variations in minimum temperature for the periods 1990-1999 and 2000-2009
........................................................................................................................................58
Table 6: Factors influencing adaptation mechanisms in Paicho Sub County ..................70
Table 7: Institutional roles in community adaptation to climate stressors .......................65
Table 8: Variation in annual rainfall amounts for the period 1980-2010, Gulu station........106
Gulu station .......................................................................................................................108
Table 10: Long term seasonal variations in rainfall amounts for Gulu station for the period 1980-
2010 ..................................................................................................................................109
Table 11: Simulated millet yields with net moisture gain/loss, observed millet yields and rainfall
amounts for the period 1980-2012 in Paicho Sub County in Gulu district .....................110
Table 12: Simulated millet yields for the period 2013-2033 ..............................................112
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Impact of climate on food in Africa</td>
<td>151512</td>
</tr>
<tr>
<td>2</td>
<td>Location of the study area</td>
<td>252521</td>
</tr>
<tr>
<td>3</td>
<td>Annual rainfall and maximum temperature variability for Gulu station</td>
<td>272222</td>
</tr>
<tr>
<td>4</td>
<td>Variations in annual rainfall amount between 1980 and 2010</td>
<td>434235</td>
</tr>
<tr>
<td>5</td>
<td>Deviations of annual rainfall amounts of Paicho S/C from the long term mean (1460mm) indicated as 0 in the figure for the period 1980-2010</td>
<td>444336</td>
</tr>
<tr>
<td>6</td>
<td>Decadal variations in monthly rainfall amounts for Gulu station, 1980-1990</td>
<td>454437</td>
</tr>
<tr>
<td>7</td>
<td>Decadal variations in monthly rainfall amounts for Gulu station, 1991-2000</td>
<td>464537</td>
</tr>
<tr>
<td>8</td>
<td>Decadal variations in monthly rainfall amounts for Gulu station, 2001-2010</td>
<td>464538</td>
</tr>
<tr>
<td>9</td>
<td>Variations in seasonal rainfall amounts for Paicho S/C, 1980-2012</td>
<td>474639</td>
</tr>
<tr>
<td>10</td>
<td>Variations in the length of the growing season for the period 1980-2012</td>
<td>484740</td>
</tr>
<tr>
<td>11</td>
<td>Mean annual maximum temperature trend for Gulu, 1990-2009</td>
<td>535243</td>
</tr>
<tr>
<td>12</td>
<td>Variations in the highest long term mean monthly maximum temperature for the 2 decades 1990-1999 and 2000-2009</td>
<td>565545</td>
</tr>
<tr>
<td>13</td>
<td>Mean annual minimum temperature trend for Gulu, 1990-2009</td>
<td>575646</td>
</tr>
<tr>
<td>14</td>
<td>The highest mean monthly minimum temperature for 2 decades 1990-1999 and 2000-2000</td>
<td>595848</td>
</tr>
<tr>
<td>15</td>
<td>Household perception on climate change in the last 30 years</td>
<td>605949</td>
</tr>
</tbody>
</table>
Figure 16: Household’s responses on climate parameters that have changed ranking from the most changed to the least Changed ................................................................. 616050
Figure 17: Households responses on the season which have changed most .................. 626451
Figure 18: Predictability of the onset of rainfall now as compared to 15 or 30 years ago ... 636252
Figure 19: Projected trend of rainfall for Paicho, 2013-2033 ........................................ 646353
Figure 20: Projected trend of mean annual maximum temperature for Paicho S/C, 2013-2033 ................................................................. 656454
Figure 21: Projected trend of mean annual minimum temperature for Paicho S/C, 2013-2033 ................................................................. 666555
Figure 22: Simulated millet yields for Paicho S/C, 2013-2033 ...................................... 676656
Figure 23: Household coping mechanisms to climate stressors ................................. 686257
Figure 24: Household adaptation strategies to climate stressors .................................. 696858
Figure 25: Household’s responses on whether there are any institutions that involve in community coping and adaptation to climatic stressors ..................................... 727160

xiv
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACRRA</td>
<td>African Climate Change Resilience Alliance</td>
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<tr>
<td>CBO's</td>
<td>Community Based Organization’s</td>
</tr>
<tr>
<td>CFSVA</td>
<td>Comprehensive Food Security and Vulnerability Analysis</td>
</tr>
<tr>
<td>CV</td>
<td>Coefficient of Variation</td>
</tr>
<tr>
<td>°C</td>
<td>Degrees centigrade</td>
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<tr>
<td>FAO</td>
<td>Food and Agriculture Organization</td>
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<tr>
<td>GCM</td>
<td>General Circulation Model</td>
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<td>Ha</td>
<td>Hectare</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<tr>
<td>Kg</td>
<td>Kilogram</td>
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<tr>
<td>Km</td>
<td>Kilometers</td>
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<tr>
<td>LGP</td>
<td>Length of Growing Period</td>
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<td>LGS</td>
<td>Length of Growing Season</td>
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<tr>
<td>LTM</td>
<td>Long Term Mean</td>
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<td>Mm</td>
<td>Millimeters</td>
</tr>
</tbody>
</table>
NDP: National Development Plan
NAPA: National Adaptation Plan of Action
NEMA: National Environment Management Authority
PEAP: Poverty Alleviation Action Plan
RCM: Regional Circulation Model
SE: Standard Error of the Proportion
S/C: Sub County
SSA: Sub Saharan Africa
SST: Sea Surface Temperature
UBOS: Uganda Bureau of Statistics
UNDP: United Nations Development Program
UK: United Kingdom
UNFCCC: United Nations Framework Convention on Climate Change
WMO: World Meteorology Organization
WFP: World Food Program
%: Percentage
NGO’s: Non Governmental Organizations
ABSTRACT

Climate variability and change are generally expected to adversely affect crop yields and livelihoods of agro-dependent societies especially in Sub Saharan Africa (SSA). However, there remain gaps on the dynamics of the expected regional climatic changes and impacts on key food security crops. In this study, an assessment of historical and projected climatic conditions and expected changes in millet yields for Paicho S/C up to the year 2033 was undertaken. Also assessed were the coping, adaptive and institutional roles with respect to climate change threats in the region. The study adopted a cross sectional survey design and engaged a compendium of methods to realize the formulated objectives. To determine historic climatic trends, rainfall and temperature data for 32 years and 19 years respectively was obtained from the Department of Meteorology of Uganda and subjected to trend analysis. For future climate, the PRECIS (Providing Regional Climates for Impact Studies) model was used based on projected conditions at a 50 km spatial resolution. The projected climate outputs from the PRECIS model were input in the Penman Grindley model to simulate future millet yields under changed climatic regimes. To elicit coping and adaptation measures, household interviews based on a statistically determined sample of 147 respondents were conducted. This was subjected to a range of statistical analysis techniques including regression analysis and cross tabulations to generate relationships as well as descriptive statistics. Differences in means were detected at a 95% confidence level. The results indicate seasonal and decadal variations in rainfall amounts while annual rainfall amount remained quasi uniform (P>0.05) for the period 1980-2010) implying that the area is currently contending more with climate variability rather than climate change. In
general, the area receives adequate annual rainfall amount of over 1150mm which should be supportive to crop growth and abundant yields. However, the rainfall is distributed in one long season spanning from March to October and characterized with inconsistencies in amounts. Both mean annual maximum and minimum temperature trends show a statistically strong and significant increase (p<0.05). Comparatively, the minimum temperatures have varied more than the maximum temperatures. PRECIS projected changes for 2033 reveal a strong and significant decrease in rainfall (p< 0.05). This is likely to decrease millet yields by 2.6% below the average current yields of 1.8t/ha/yr under the business as usual scenario. The current coping mechanisms to climate variability and change in the community include buying food (27%), exchange of labor for food (25%), and getting food help (21%). The major adaptation strategies to climate change include; getting jobs outside agriculture (20%), adjusting planting dates and diversifying production (19%) and mixed cropping (15%). Existing institutions include; Local councils, clan/elders networks, family networks, religious institutions, NGO’s and CBO’s. Their major roles include; governing entitlements to key resources, decision on planting dates, limiting tree cutting and bush burning, access to credit and relevant information regarding climate variability and change.
CHAPTER ONE: INTRODUCTION

1.1: Background of the study

Climate variability and change are major factors redefining the world food equation through their adverse effects on yields particularly in the heavily dependent agro-based livelihoods (Brown, 2007; David et al., 2008; Cline, 2008; Popular & Tek, 2012; Lobell et al., 2013). Climate variability has always been fatal to crops in rain fed agricultural systems often resulting into crop destruction, crop failure and reduction in yields (Cynthia, et al., 2002; MacCarthy et al., 2008; Evenbergen & Pondorfer, 2011; Keith et al, 2012; Jawoo, 2013). A compelling number of studies globally indicate that yields of most crops grown under rain fed conditions are likely to be negatively affected by climate change severely affecting the poor due to their limited adaptive capacities and systems manifested by limited education, limited technology, limited supporting institutions and limited access to financial assets (FAO, 2008; Hepworth and Gouden, 2007; IPCC, 2007; Kilembe, et al., 2012 & Sultan et al., 2013) and in many parts of the world, the link between failed crops and changing weather patterns is not even made (Ziervogel et al., 2008).

Global mean surface temperatures are projected to rise between 1.0°C to 6°C by 2100, with tropical regions experiencing the largest increments (Schmidhuber & Tubiello, 2007; Bello et al., 2012; Scott et al., 2013). In Uganda, temperatures are projected to rise by between 1.5° and 4.3° by the year 2100 depending on the location. The projected rise in mean surface temperatures are likely to have significant negative effects on crop yields (Wasige, 2009; Kilembe, 2012;
Mohamed et al., 2002; Bello et al., 2012; Alexander, 2013). The intensity of precipitation events is on average expected to increase particularly in tropical and high latitude regions (Alexander, 2013). In Uganda, annual rainfall amounts are generally expected to increase by 10% and 20% by the year 2050 and 2100 respectively (Wasige, 2009). These projected changes will obviously vary by region as a function of the biophysical conditions as well as the local and global climate control conditions. Irrespective of the direction and magnitude of the change in climate, crop yields and food security is likely to be negatively affected.

Variations and changes in climate have a profound and unavoidable effect on crop production as increasing temperatures, shifting rain patterns and extreme weather events reduce crop yields (MacCathy et al., 2008; Brown, 2007). Changes in climate will lead to reduced agricultural productivity of most crops in tropical regions due to increased evapotranspiration, lower soil moisture and prolonged drought (Parry et al., 1999). Consequently, some areas under rain fed conditions will become unsuitable for cropping affecting livelihoods which are heavily dependent on agriculture (Droogers, 2003; Houden et al., 2007). For example, Mohamed et al., (2002) projected a 13% reduction in millet yields by 2025, while Kilembe (2012) estimates a 26% yield reduction in the same crop by 2080.

The major challenge now is how to adapt food systems and livelihoods to the expected variability and change in climate (Ziervogel & Eriksen, 2010), especially in Sub Saharan Africa where crop production is highly dependent on intra-seasonal and inter-annual variation in rainfall (Schulze et al., 1993). Realizing this requires understanding site specific variability and expected changes in climate to facilitate quantification of expected impacts on crop yields (Sultan et al., 2013). Although, knowledge on climate change has substantially increased over the last 10 years, there is still a dearth on local specific expected changes and the expected effects on crop
yields and productivity in general. In some cases, divergence in estimations by coarse models warrants detailed studies to elicit site specific variations and expected changes. The need for information and knowledge on climate variability and change and its effects on crop yields thus exists, more so in Gulu District which suffered neglect in the scientific domain during the 1986-2006 conflict period. Cognizant of these scientific gaps and knowledgeable of the fact that over 90% of the populations in Gulu attain their livelihoods from agriculture (WFP, 2009) which is almost entirely dependent on climate, the study therefore addressed the variability and changes in climate and assessed the effects on yields of millet which is a staple and key food security crop in the region (WFP, 2009). This information is vital in formulating sustainable adaptation strategies to the adverse effects of climate variability and change.

1.2: Statement of the problem

It is generally known that the effects of climate change on crop yields will vary due to geography (Wasige, 2009), level of preparedness, institutional set up, technological development and financial capabilities (Hepworth & Gouden, 2007). Aggregate studies and isolated reports indicate that climate in Uganda will change with temperatures increasing by 1.5°C by 2050 and by 4.3°C by 2100. This will increase the rate of soil moisture loss and affecting crop growth and the resultant yields. Rainfall will increase by 10% by 2050 and by 20% by 2100 (Wasige, 2009). However, available meteorological data reveals that rainfall in the country has decreased (McSweeney et al., 2008) this is likely to affect crop production many folds due to reduced soil moisture. Although this is likely to affect agriculture production, it is not clearly known how it will affect millet yields in Paicho Sub County in Gulu district. Currently, millet grain yield data from the office of the district production officer shows declining yields. Also many households
have abandoned growing millet because of declining yields. Therefore, there is a need to establish what historic and current climate change trends have occurred at the local scale in Gulu district? What future trends are likely to occur? How will these trends affect millet yields? What coping and adaptive measures are in play? What institutions exist and what is their role in community adaptation to climate variability and change? The gist of this study was to determine the variations and changes in climate and their effects on millet yields establish coping and adaptation strategies to climate variability and change in Paicho Sub County, Gulu district.

1.3: General objective

To contribute to improved coping and adaptation of communities owing to the adverse impacts of climate variability and change

1.4: Specific objectives

1. To determine the variability and changes in climate

2. To assess the effect of climate change on millet grain yields on a medium time scale in Paicho Sub County, Gulu District.

3. To assess the coping and adaptive strategies to climatic stressors in Paicho Sub county.

4. To determine the role of institutions on community adaptation strategies to climatic stressors
1.5: Hypotheses tested

- H1 Temperature rather than rainfall has significantly increased for the period 1980-2010
- H2 Rainfall rather than temperature is likely to decrease significantly by 2033
- H3 Climate change will lead to a 20% reduction of millet yields by 2033.
- H4 Household income rather than education level significantly influences adaptation to climate stressors.

1.6: Justification of the study

The government of Uganda is a signatory to the United Nations Framework Convention on Climate Change and the Kyoto Protocol (UNFCCC, 2003) making it to prioritise measure to improve adaptation strategies in order to address the adverse effects of climate variability and change since this will help communities to be resilient to the climate change stressor and be able to improve crop productivity. The government of Uganda has also embossed the National Adaptation Plan of Action (NAPA, 2007) whose agenda is to improve adaptive capacities of the people. Further more, the United Nations Millenium Development goal number one prioritises
eradicating extreme poverty and hunger (UNDP, 2012) of which climate variability and change are major contributors. Climate variability and change are gradual and incremental, continually affecting people’s agricultural productivity and if there are no location specific investigation and realization of its negative effects then mitigation and adaptation would be delayed and the future effects on crop yields would be disastrous.

Uganda’s economy is dependent on rain fed agriculture for food supply; agriculture employs over 80% of the work force, and contributes 23.9% of the gross domestic product (World Bank, 2013). This agriculture is likely to be affected by climate variability and change. Therefore investigations on the magnitude and intensity of these changes will help inform policy to enable agricultural systems adapt to create resilient communities to future climate variability and change.

A better understanding of climate variability and change together with farmers’ perceptions, ongoing coping and adaptation measures, and institutional roles are important to inform policies aimed at promoting successful adaptation strategies for the agricultural sector. It was also important in identifying gaps that exist in adaptation and recommendations made on other geographically suitable adaptation strategies being undertaken by communities elsewhere. All together these would help the community to reduce climate variability and change effects in the region thereby creating resilient communities.
1.7: Scope of the study:

In scientific terms, the study focused on determining the historic, current and future trends of rainfall and temperature and how these affect millet yields. Millet was chosen because it is a staple food crop forming an important element of food security and resilience in the region but at the same time being abandoned by many households due to reduced yields exacerbated by climate variability and change. The study established household coping and adaptation strategies to climate change and evaluated the role of institutions in community coping and adaptation to climate variability and change. In spatial terms, the study focused on Paicho Sub County (S/C), Gulu district in northern Uganda. Paicho Sub County was purposively chosen because of its fragility and sensitivity to climate change and climate variability, was one of the Sub Counties which was so much affected by war and is also easily accessible. In temporal terms, the study assessed climate variability and change and their effects on millet yields for the period 1980 to 2033.
CHAPTER TWO: LITERATURE REVIEW

2.0: Introduction

In this chapter, relevant literature to the issues which the study addressed are synthesized and presented. It covers; (a) climate patterns and trends in variability and change (b) effects of climate variability and change on millet yields (c) coping mechanisms to climate stressors (d) adaptation strategies to climate stressors and (e) the role of Institutions in community adaptation to climate change.

2.1: Climate patterns and trends in variability and change

According to IPCC (2001), climate change is a change in the state of climate identified using statistical tests by changes in the mean and/or the variability of its properties persisting for an extended period typically decades or longer while climate variability refers to the variations in the mean state and other statistics such as standard deviation or occurrence of extreme events of climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural processes within the climate system (internal variability) or as a result of variations in natural or anthropogenic external forcing (external variability).

Studies indicate that global mean surface temperatures are projected to rise between 1.0°C to 6.0°C by 2100 (Xiaodong et al., 2006; IPCC, 2007; Schmidhuber & Tubiello, 2007; NRC, 2001; ACCRA, 2012). Analysis done by (IPCC, 2007) projected an increase by 1.8°C to 4.0°C by 2100.
with tropical regions experiencing the largest increments because of prolonged droughts, dry
spells, and direct exposure of the region to the sun’s rays throughout the year. However,
McSweeney et al., (2008) reported higher temperature projections by 1.5°C by 2050 and by
4.3°C by 2100, ACCRA (2012) projected a rise in temperature by 1.0°C to 3.1°C by 2060’s and
1.4°C to 4.9°C by 2090’s while Alexander (2013) projects even a much higher rise by 4-6°C by
2080 which is even above the global increase. Some studies indicate that a 1.5°C change in
temperature is critical for crop yields (Kilembe, 2012; Mohamed et al., 2002; Eschenback, 2013).

All projections indicate increase in the frequency of hot days and nights in current climate
change; annual projections report that ‘hot’ days will occur on 15-43% of days by 2060’s and 18-
73% of days by the 2090’s; all projections indicate a decrease in the frequency of days and
nights that are considered ‘cold’ in current climate. These events are expected to become
extremely rare and may not occur at all by the 2090’s in any projections under the highest
emissions scenario (A_2 & A_1b) (ACCRA, 2012; Wasige, 2009). These temperature observations
indicate variable results and underpin the need to understand the projected changes at a local
level.

An evaluation of the projected changes in rainfall is inconclusive and gives mixed results. Many
studies indicate an increase in rainfall by 5% to 40% by 2100 (NRC, 2001; Cynthia, 2002; IPCC,
2007; Schmidhuber & Tubiello, 2007; Alexander, 2013) while others indicate a decrease on
average by 10% to 40% (Some & Kone, 2000; Worishima & Akasaka, 2010). The intensity of
precipitation events are likely to increase on average by -8% to +46% by 2090’s and this will be
particularly pronounced in tropical and high-latitude regions which are also expected to
experience overall increase in precipitation because of high evapotranspiration (IPCC, 2007). In
general, rainfall is projected to increase over the African continent (Mohamed et al., 2002;
Druyan, 2010; Sultan, et al., 2013) with the exceptions of southern Africa and parts of the Horn of Africa where rainfall is projected to decline by about 10% by 2050 (Worishima & Akasaka, 2010) and in the semi-arid and sub humid zones of West Africa where rainfall during the period 1968-2000 has been on average 15% to 40% lower than during the period 1931 to 1960 (Some & Kone, 2000). Projected increases in rainfall are largest in short rain season (-8 to +35%); model consistently project overall increase in the proportion of rainfall that falls in heavy events and the increase ranges from 1% to 15% in annual rainfall by 2090’s (ACCRA, 2012; Bashaasha et al., 2012).

Rainfall model results are not consistent and tend to vary from region to region or even in the same region. It is thus apparent that expected changes in rainfall are spatially constrained; particularly in Africa where a large natural variability exists necessitating more studies which are location specific to understand climatic dynamics and probable effects on crop yields.

Available outputs from General Circulation Models (GCMs) and Regional Climate Models (RCMs) point to significant climate variability events (Wouter et al., 2006; Hepworth and Gouden et al, 2008; Wheeler & Harry, 2009; Todd; et al., 2013). Global and regional weather conditions are expected to become more variable than at present characterized by increased frequency and severity of extreme events such as floods and hail storms, changes in the onset dates of rainfall, delayed or even failed rains and these are likely to have negative effects on crop yields (Harper et al., 2005; Ziervogel et al., 2008; Wimalasuriya et al., 2008; Vreiling, et al., 2013). In Sub Saharan Africa, climate variability is evident indicated by shifting rain patterns, sudden rain spells, heat waves, prolonged droughts; sudden drought spells hitting regions when it
is supposed to be a rainy season (McCathy et al., 2008; Ziervogel & Eriksen, 2010; Miller, 2012; Lobel et al., 2013).

Although more rainfall projections tend to emphasize changes in annual amount, it is imperative to distill the seasonal changes such as changes in length of the growing season, changes in the onset of the rain which may have more significant implication on productivity of rain fed agriculture. Studies by (Krishnamurthy & Shuka, 2000; Sultan and Serge, 2000; Barchuk et al., 2005; Gobin, 2011; Todd et al., 2013) reported variability in seasonal and intra-seasonal variability of rainfall caused mainly by abrupt shift of the inter-tropical convergence zone. Rowel et al., (2007) noted that global sea surface temperature variations are indeed responsible for most of the variability of seasonal rainfall, the possible effects of land-surface-moisture feedback and the influence of internal atmospheric variations.

Studies indicate that the length of the growing periods (LGP) vary depending on region and such analysis provides useful information for mapping of farming systems, and the effects on crop yields (Xiaodong et al., 2006; Hans et al., 2006; Lawal-Adebowale, 2006; Cline, 2007; Vreiling et al., 2013). The spatial distribution of crops and farming systems is determined by the duration of the period during which crop and livestock water requirements are met. The length of the growing season is increasingly expanding in the temperate regions at a rate of 20 days per century since 1900 due to warming temperatures with positive effects on crop yields because of warming temperatures which reduce the length of winter periods and increases the length of the crop growing season compared to about 6 days in the tropics (Hans et al., 2006). Variability in the LGP is dominant in the tropical areas, and is indicative of crop failure risk (Loning, 2009; Vreiling et al., 2013). The length of the growing period has been defined in many ways;
Mugalarai et al., (2008) define the length of growing season as the difference between cessation and onset of a particular year; Vrieling et al., (2013), define the length of growing season as the period where there are favorable weather conditions for crop emergence, vegetative growth, and ripening. However, this study adopts the definition by Cline (2007) who noted that the length of the growing season is the number of days per year when both water availability and temperature permits crop growth.

More still, the onset of rain is also an important seasonal characteristic that has reflected variability over time (Todros et al., 2005; Ziervogel, et al., 2008; Loux et al., 2008; Seth et al., 2013; Moron and Robertson, 2013), rainy seasons in most cases begin later or earlier than normal and this is fatal to crops often resulting to crop destruction, crop failure and low yields. The onset of rains according to Subash et al. (2010) was found to have a significant delayed trend at a rate of 2.8% of the mean/30 years with an increasing trend in the seasons. Moron and Robertson (2013) notes that the variations in the inter-quartile range of onset of rain varies from less than 2 weeks over the monsoon zone and Western Ghats to about a month over the northwestern desert. These relationships are found to be weak and geographically confined. Pierre and Diop, (2003) define the onset of rain as the first week receiving at least 15mm of rainfall after a given date determined by local climatology and agricultural practices; provided that no two weeks dry spell occurs in the next four weeks.

It is clear from the foregoing synthesis that although climate variability and change are generally expected, the expected changes are diverse in terms of magnitude, direction and are geographic specific. Therefore this study will establish the historic, current and future variations and changes
that have and will occur in precipitation and temperature in Paicho Sub County, Gulu district in northern Uganda.

2.2: The effects of climate variability and change on crop yields.

Substantial literature converges on the notion that climate change will variously impact on agriculture, notably on crop yields under rain fed agricultural systems (Parry et al., 2004; Wolfram & Michael, 2009; Mathew & Reynolds, 2010; Lobell et al., 2013; Jawoo, 2013). The impacts will be felt through reduction of suitable areas for agriculture, altering the length of growing season and reducing the yield potential (Hans et al., 2006; Cline, 2007; Lawal et al., 2006; Vreiling, 2013). Generally, a 4°C warming is expected to reduce crop yields by 15-80% (IPCC, 2010). Although some regions like the temperate may agriculturally benefit from climate change because of increase in the length of the growing season, expansion of agricultural land and increase in warm temperatures (Parry et al., 1999; Xiaodong et al., 2006; Eschenback, 2013), most areas and Africa especially is projected to be negatively affected (Mearns et al., 1997; Marshall et al., 2009) moreover over 40% of the continent's population lives on less than 1 US$ /day, and 70% of these population largely dependent on agriculture for their livelihoods. This implies that adverse shifts in climate will cause devastating effects on agriculture necessitating increased attention to be paid to assessing risks to African agriculture under climate change. Finding from some studies have already projected moderate to severe effects on agricultural productivity occurring in as early as two decades depending on weather adaptation to climate change is taken into consideration (Lobel et al., 2013).
A summary of how climate change will affect crop yields in different parts of Africa is illustrated in Figure 1.
The use of simulation and regression models show mixed results on how crop yields will be affected by climate change (Wheeler et al., 2000; Rosenzweig et al., 2001; IPCC, 2007; Wasige, 2009; Muhamed and Azam, 2012; Kilembe et al., 2012; Sultan et al., 2013). On average yields of maize, soya beans and cotton are predicted to decrease by 30–46% before the end of the 21st century under the slowest (B$_1$) warming scenario and a decrease by 63–82% under the most rapid
warming scenario (A$_1$F$_1$) under the Hadley III mod (Wolfram & Michael, 2009) while, Knox et al., (2012) reports increase in maize yields by 10% in 2020’s-2030 and by 60% by 2050’s-2080; beans output will reduce by 19 to 57% without carbon fertilization and mixed results with carbon fertilization (Rosenzweig & Iglesias, 1994), sorghum yields are projected to more than triple (Bashaasha et al., 2012). Increase in temperature by 1.5°C by 2050 and by 4.3°C by 2100 and an increase in rainfall by 10% by 2050 and 20% by 2100 will affect crop production differently depending on region. This synthesis shows that model predictions of crop yields tend to vary even with the same crop in the same region hence need for more studies. However, this study focuses on the effect of climate variability and change on millet yields.

One of the key food security crops in Uganda and Africa in general is millet. Millet is one of the crops which historically have been resilient to climate variability (Mohamed et al., 2002; Philips, 2002; Hari et al., 2005; Sultan et al., 2013). But this is likely to change in future due to elevated temperatures (Muhammed & Azam, 2002 and Kilembe et al., 2012). When warming exceeds +2°C, negative impacts caused by temperature rise cannot be counteracted by any rainfall change. Sub-Saharan region is a vulnerable region where a better quantification and understanding of site specific effects of climate variability and change on crop yields is urgently needed (Sultan et al., 2013), his studies also reveal that the potential future climate impacts on millet yields are very different from those recorded in the past because of the increasingly adverse role of higher temperatures in reducing crop yields. Mohamed et al., (2002) reported that by 2025 production of millet is estimated to reduce by 13% as a result of a reduction of the total amount of rainfall
and increase in temperature while (Kilembe et al., 2012) projected a decrease in millet yields by 26% by 2080’s.

The intensity of the negative and positive effects of climate variability and change on agriculture varies from location to location and divergence in estimations by coarse models warrants detailed studies to elicit site specific variations and expected changes. The need for information and knowledge on climate variability and change and its effects on crop yields thus exists, more so in Gulu District which suffered neglect in the scientific domain during the conflict period (1986-2006) creating a need for location specific effects.

2.3: Coping mechanisms to climate variability and climate change

Communities in many parts of the world have often tried to use a range of coping mechanisms as a way of responding to an experienced impact with a short term vision in order to reduce the effects of the variations and changes in climate on yield reduction (UNFCCC, 2003; UNDP, 2005; Morton, 2007; Alejandro, 2013). Traditional coping methods are often based on experience accumulated over the years and transmitted from generation to generation (Cooper et al., 2008). Coping mechanisms in reaction to the stress caused by climate variability and change are obtained from a number of studies (Quay 2008; Osbahr et al., 2010; Fana & Snake, 2012; Kyekyeku, 2012; Bardege et al., 2013). These studies indicated the following coping mechanisms; collection of wild foods, purchasing food from the market, in-kind (food) payment, Support from relatives and friends, sales from livestock and household valuables, migration and wage labor in exchange for food, reduction in the number of meals served each day, reduction in
the portions/sizes of meals and consumption of less preferred foods. Farmers have also managed to cope up by water rationing during periods of drought, rain water harvesting, re-use of water for example water from washing clothes or utensils to irrigate crops in the backyard gardens and nurseries, carry out mixed cropping, adjustment in land and crop management (Kabat et al., 2012 and Gyampoh et al., 2008). Furthermore, communities have also employed coping mechanisms such as reliance on social networks i.e. sharing of information, emotional support, cash loans, petty trade, temporary migration; women making handicrafts to sell in nearby markets and relying on friends for support (Osbarhr et al., 2010)

According to FAO (2007); Kumar et al. (2008) and Cooper et al. (2008), people can cope up with climate variability effects through getting jobs outside agriculture, pasture preservation, reducing the herd, asking for food aid and resorting to fruit trees as a strategy to cope with the famine period. According to Carmenza et al., (2011), communities can also cope up to climate variability and change by accessing alternative natural resources from forests such as charcoal burning and selling. These findings are generic and the study had to establish the coping mechanisms that households in Paicho Sub County employ in response to experienced effects of climate variability and change.

2.4: Adaptation strategies to climate variability and change

Strong trends in climate variability are already evident, the likelihood of further changes are occurring, and the increasing scale of potential climate effects give urgency to addressing agricultural adaptation more coherently (Howden et al., 2007; IPCC, 2007; UNFCCC, 2003;
Camenza et al., 2011; Nielson & Anette, 2009; Bardege et al., 2013). This has prompted government policies and international agreements to focus towards climate change adaptation in order to promote adaptive capacity Neil et al., (2003). Adaptation to climate change are adjustments or interventions which take place in order to manage the losses or take advantage of the opportunities presented by a changing climate. Agriculture is a major land use across the globe and currently ≈1.2–1.5 billion hectares of land are under crops. Importantly, agriculture in its many different facets in various localities remains highly sensitive to climate variations and change (Vermoulen et al, 2008; Bello et al., 2012; Eschenbach, 2013). Hence, it has become critical to identify and evaluate options for adaptation to climate stressors in specific places to effectively manage potential climate risks over the coming decades and enable communities to withstand the stress. Finally, it should be recognized that “adaptation” is an ongoing process that is part of good risk management whereby drivers of risk are identified and their likely effects on systems under alternative management are assessed. In this respect, adaptation to climate change is similar to adaptation to climate variability (Smit & McCathy, 2001).

Furthermore, the means and capacity in developing countries to adapt to variations and changes in climate are limited due to low levels of human and economic development which include low levels of technology, low education levels, limited supporting institutions and limited access to financial assets. These conditions combine to create a state of high vulnerability to climate variability and change in much of the developing world and greatly affecting food production (IPCC, 2007; Hepworth and Gouden, 2007; FAO, 2008).
The changes that are likely to occur in climate require farmers to alter their agricultural practices; Sorghum, for instance is more heat resistant and therefore does better than maize in places where rainfall decreases. However, the question is whether communities that are used to and have a preference to maize will switch to sorghum or another more suitable staple crop (Ziervogel et al., 2008; Badege, 2013). Ziervogel asserts that the major challenge is how to adapt to climate stressors (Ziervogel and Eriksen, 2010) and accomplishing this task needs a multidisciplinary strategy which should be adapted to location specific circumstances (IPCC, 2007).

According to (IPCC, 2007; Ellina and Tirpark, 2006; Bardege et al., 2013), a rapid, coordinated and multidisciplinary response is needed to respond to climate variability and change and its emerging risks for agriculture, various forms of adaptation strategies to climate variability and change exist and these include; anticipatory adaptation which involves improved land management; autonomous adaptation involving growth and diversification of production, change in market demands and food supply practices (McKinney, 2009); technological adaptation involving introduction or modification of irrigation techniques (Ludi, 2009); introducing new crop hybrids and making better use of scarce water (Ziervogel & Eriksen, 2010); planned adaptation involving introduction and growing of new crop varieties, improved water management, change in planting dates, integration of crop, livestock, forestry and fishery sectors at farm and catchment levels (Ludi, 2009; Marshal et al., 2009); public adaptation which involves early warnings on floods and droughts and improved institutional settings (Vermoulen et al, 2008); private adaptation which constitutes migrating from water stressed areas and semi-arid areas, and going for off farm employment opportunities (UNDP, 2005); main streaming
adaptation which involves creation of enabling policies, research and dissemination of crop varieties and breeds adapted to changing climatic conditions.

The major challenge is how to adapt to climate variability and change without threatening sensitive livelihood systems. This will require analyzing and changing farming and food systems, learning from community based approaches, generation and use of technology, overcoming biotic stress in crops through crop breeding, targeting investments in understanding where different biotic stress dominate and matching crops to future climate in a way that accounts for uncertainties (Smit & Wandel, 2006). According to Schneider et al., (2007), there is evidence of an adaptation deficit, and acting now to narrow the deficit can yield immediate benefits (Nail et al., 2008). Uganda is labeled as one of the most unprepared and most vulnerable countries in the world, yet among the most vulnerable countries, Uganda has the least adaptive capacity, making location specific adaptation the most immediate priority for the country (Hepworth & Gouden, 2007).

2.5: The role of Institutions in community adaptation to climate variability and change.

Institutions are structures and mechanisms of social order and cooperation governing the behavior of a set of individuals within a given human collectivity (Amaru & Netra, 2013). Institutions may help society to interpret scientific knowledge and devise improved adaptation strategies. Institutional roles in influencing coping and adaptation to climate change and variability include but not limited to information gathering and dissemination, resource
mobilization and allocation, skills development and capacity building, providing leadership skills, and relating with other decision makers and institutions (Amaru & Netra, 2013).

Institutions are of different forms i.e. command and control institutions which are historically the most common strategy for regulating domestic environmental problems through direct regulations and economic instruments such as charges and taxes, persuasive/educational/information institutions such as mass media and market based institutions dealing with exchanges and trade (Parvin, 2012; Davison, 2003). This study focuses on the role of institutions in adaptation to climate variability and change because impacts will affect disadvantaged social groups significantly, and that local institutions centrally influence how different social groups gain access to and are able to use assets and resources. It suggests that adaptation to climate change is inevitably local and that institutions influence adaptation by structuring impacts and vulnerability, mediating between individual and collective responses to climate impacts and thereby shape outcomes of adaptation, and they also act as the means of delivery of external resources to facilitate adaptation, and thus govern access to such resources (Agrawal, 2008).

In understanding how people adapt to the shocks and stresses in climate change and variability, it is important to recognize the role of institutions in influencing behavior. In rural Uganda, institutions are formal and informal and take a number of different forms e.g. local councils, religious institutions, family networks and clan/elders networks African Climate Change Resilience Alliance (ACCRA) (2012). Each of these has its own internal rules, structures and norms that shape individual behavior. Institutions are important in the context of climate
variability and change because of their significant role in influencing adaptation responses because livelihood decisions and activities are based on past practices e.g. traditional seasonal calendars dictate on when crops are planted. Institutions may stop people from deviating from common practices, certain institutions and norms can prevent people from adapting to more appropriate practices and livelihoods and often govern entitlements to key natural resources (Jones & Boyd, 2011).

According to Agrawal (2008), local government actors were identified in playing practical roles in adaptation practices and such roles included; tree planting and reforestation, selection of appropriate crop varieties, better implementation of forest laws, soil and water conservation, controlled burning, logging ban, information sharing, development of water sources, research and capacity building. The capacity of communities to respond to climate stressors depends on knowledge flow through a broad range of institutions and the ability of institutions to act collectively at multiple scales (Hepworth & Gouden, 2007).

The above synthesis of literature reveals that the expected variations and changes in climate are diverse and geographic specific, affecting agriculture particularly rain fed agriculture in various ways. Both simulation and regression models indicate mixed results on how climate variability and change affects crop yields and communities have responded variously to climate stressor in order to cope and adapt. This study therefore was intended to determine variability and changes in climate and assess the effects on millet yields, determine coping and adaptation strategies and evaluate the role of institutions in community adaptation in Paicho Sub County, Gulu district.
CHAPTER THREE: RESEARCH METHODOLOGY

3.0: Introduction

In this chapter, the background information of the study area is given. The background information entails: location, climate, vegetation, soils, land use and the population. The chapter also covers the research methodology employed to undertake the study including; the research design data collection methods and data processing and analysis techniques.

3.1: Study area

3.1.1: Location

The study was conducted in Paicho Sub county, Gulu district in northern Uganda (Figure 2). Paicho Sub County geographically lies between latitudes 2°52’-2°55’ N and longitudes 32°27’-32°29’ E. The total area covered by the Sub County is 592.7 square kilometers (UBOS, 2011). Paicho Sub County is bordered by Awach Sub County in the north, Atanga Sub County in the north east, Awer and Puranga in the east, Odek Sub County in the south east, Lalogi and Koro Sub Counties in the south and Bungatira Sub County in the west (Okello, 2010).
3.1.2: Climate

Paicho Sub County experiences tropical type of climate (wet and dry) (NEMA, 2009). The average total annual rainfall received is 1500 mm with the monthly average rainfall varying...
between 1.4 mm in January and 230 mm in August. Normally the wet season extends from April to October with the highest peaks during May, August and October, while the dry season begins in November and extends up to March. Rainfall is mainly convectional characterized by afternoon and evening occurrences. Occasionally the area experiences long droughts and irregular rains which are recently becoming more frequent (WFP, 2009) with negative effects on crop yields. The average maximum temperature is $30^\circ$C and the average minimum temperature is $18^\circ$C. Relative humidity is high during the wet season and low in the dry season (UBOS, 2011). Although the annual rainfall totals are theoretically good enough to support crop growth, its temporal distribution appears to be constraining since the rains come in one season consequently, there is one crop growing season coupled with occasional experiences of long droughts and irregular rains (WFP, 2009; NEMA, 2009) hence threatening crop production and affecting the yield potential of the area.

Generally, the annual variations in total rainfall amounts and average annual maximum temperature for the period 1990 to 2009 for Paicho Sub County, Gulu district are illustrated in Figure 3.
3.1.3: Vegetation

Paicho Sub County is mostly covered by intermediate savannah grasslands characterized by open canopy of trees of 10-12 meters high and underlying grasses of 80 centimeters high, the trees are fire resistant, regenerate after being burnt and the most common tree species are the acacia trees, Ficus Nantalensis, Combretum and Borasusan aethiopum while common grasses include imperatum cylindrical, hyperhania rufa and digitaria scalsria (Nkuuhe at al., 2000). The author also continues to say that herbs like Bideu pilosa, Ageratum Coinzolds, Amaranthus species, and Lantana camara exist. However, in areas that have been cleared for agriculture and other human activities secondary savannah vegetation has emerged. Savannah grass lands commonly grow in areas of moderate soil fertility which are less productive agriculturally unless modern farming
methods such as addition of fertilizers are employed and in the harvest time of the year such areas occasionally suffer from low agricultural output (FAO, 2008).

3.1.4: Soils

Paicho Sub County contains Leptosol soils characterized by high percentage of sand (NEMA, 2009). These soils are susceptible to erosion, have low water retention capacity, high rate of water infiltration and moderate fertility (UBOS, 2011) hence may require addition of fertilizers for maximum output of crop yields but given the low incomes of the population in Paicho Sub County (UNDP, 2012), purchase of fertilizers and other modern agricultural inputs is limited for most households resulting to low crop yields.

3.1.5: Topography

The Sub County consists of complex landscape with relatively uniform topography marked with a sharp contrast of Aswa River which was formed as a result of up warp and down warp of underground rocks accompanied by faulting. Generally, the altitude ranges from 1000 to 1200 Meters above sea level (Gulu Lancashire Local Agenda 21, N.D.)
3.1.6: Land use types

There are various land use types in Paicho Sub County, namely, agriculture which is rain fed, dominated by subsistence farmers and is the dominant land use employing over 90% of the total population. The major crops grown include finger millet with the observed yields indicated in Table 1, maize, sorghum, beans, peas, sesame, ground nuts, cassava and potatoes. The major crops that contribute to household income include; groundnuts, beans, cassava, and sesame (WFP, 2009). Other land use types include a forestation, fishing in swamps and streams, settlements, transport and communication and small scale lumbering (UNDP, 2012).

Table 1: Observed millet yields for Paicho Sub County

<table>
<thead>
<tr>
<th>Years</th>
<th>Observed millet yields (Kg/ha/yr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>1607</td>
</tr>
<tr>
<td>2008</td>
<td>1400</td>
</tr>
<tr>
<td>2009</td>
<td>1600</td>
</tr>
<tr>
<td>2010</td>
<td>1000</td>
</tr>
<tr>
<td>2011</td>
<td>1300</td>
</tr>
<tr>
<td>2012</td>
<td>1500</td>
</tr>
</tbody>
</table>
3.1.7: Population

The total population of Paicho Sub County in 2002 was 24,876 people for 5242 households according UBOS (2002). In 2011, the population was estimated to have grown to 32,100 of which 15,900 were male and 16,200 were female with 5,779 households (Okello, 2010). The sub county has a low social economic status with 62% of the population living below the poverty line (UNDP, 2012) and this has a negative implication to crop production. The main option for income is the sale of crops and others include casual labor and sale of forest products. However, a smaller proportion of the population are involved in petty trade activities such as selling of crop produce, brewing and selling alcohol, selling local consumable goods, handcrafts and foodstuffs which are mainly sold in the shift/village markets (WFP, 2009).

3.2: Research design

The study employed a cross sectional survey research design as described by Lyberg et al. (1997) to capture a sample of the population as representative to the population. Using this design, the study was able to derive insights on the opinions, attitudes, perceptions, and knowledge pertaining to climate variability, climate change, coping mechanisms, adaptation strategies and the role of institutions in community adaptation to climate change. The elements of the research design of the study i.e. target population; sample size and sampling procedures are described below.
3.2.1: Target population and unit of analysis

Because the study issues were focused on climate variability, climate change and their effects on millet yield, coping mechanisms, adaptation strategies and institutional roles in community adaptation aspects, the main target population of the study constituted of farmers in the study area. Farmers also pre-dominate the study area since agriculture is the major livelihood activity employing over 90% of the people (WFP, 2009). The unit of analysis for the study was the household since it enables to capture and implicate a range of socio-economic characteristics at that level.

3.2.2: Sample size and sample selection

The sample size was determined on the basis of household population. To capture an appropriate sample, there was need to obtain the current household population data. Although population data for the previous census of 2002 was readily available, this was deemed outdated. Thus a reconnaissance was undertaken in Paicho sub county headquarters to obtain current population data. The reconnaissance yielded population and household data for each parish for the year 2011. Although the data was based on estimated projections, it was certainly more realistic than the UBOS census data of 2002. The total sample size of the study was 147 households obtained from two parishes; Kalumu parish (87 households) and Kal-ali Parish (60 households). Although, Paicho Sub County is constituted of four parishes covering Kalumu, Kal-ali, Pagik and Omel, only two parishes deemed to be representative of the entire population were selected taking into
consideration accessibility, population characteristics and cost implications. The sample size for the study was statistically determined using the equation given by Allyn and Bacon (2010) as:

$$n = \frac{p \times N}{(SE)^2 \times p \times q}$$

Equation 1

- **n** = sample size,
- **SE** = standard error of the proportion,
- **p** = proportion of households engaged in farming
- **q** = 1-p and
- **N** = total population of households.

$$SE = \frac{1.96}{2.83}$$

At 99% confidence level=0.04, N=2470, p=0.5, q=1-0.5=0.5

$$n = \frac{0.5 \times 0.5 \times 2470}{(0.04)^2 \times 2470 + 0.5 \times 0.5}$$

Therefore n=147

The household based data and the determined sample size collapsed for the two parishes are given in Table 2.
Table 2: Sample size for the study

<table>
<thead>
<tr>
<th>Parish</th>
<th>Number of households</th>
<th>Sampled households</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kalumu</td>
<td>1456</td>
<td>87</td>
</tr>
<tr>
<td>Kal-ali</td>
<td>1014</td>
<td>60</td>
</tr>
<tr>
<td>Total</td>
<td>2470</td>
<td>147</td>
</tr>
</tbody>
</table>

3.2.3: Selection of respondents

The selection of respondents was based on random sampling procedures as described by Dillman et al., (2001). Random sampling was deemed appropriate due to the rural set up of Paicho Sub County where over 90% of the households are engaged in agriculture (WFP, 2009) and assumed to be uniform and selecting any household would be representative of the total population.

3.3: Data collection methods
A wealth of data on socio-economic and biophysical, qualitative and quantitative was required to address the objectives of the study. The data was obtained from primary and secondary sources. Details of how the data was collected are given in sections 3.3.1 to 3.3.4.

### 3.3.1: Interviews

Structured household interviews were used to collect the socio-economic data of the study. The data obtained using this method included demographic characteristics of households, perceptions of households on variations and changes in climate parameters, the coping mechanisms, adaptation strategies to climate variability and change and the role of institutions in community adaptation to climate stressors. Structured household interviews were administered to the target respondents using a questionnaire/interview instrument. The questionnaire consisting 11 closed and 5 open ended questions (Appendix 1) was administered to respondents in their homes. Each interview with the respondent took approximately one hour. This data served to address objective two, three and part of objective one of the study.

### 3.3.2: Climatic data collection

Historical climatic data for the study area was required to determine the past trends and facilitate projections of future climate changes. The data was obtained from the Department of Meteorology of Uganda. The climate data used in the study consisted of rainfall and temperature
spanning for a period of 32 years from 1980 to 2012 and 19 years from 1990 to 2009 respectively. The obtained rainfall data was on daily, monthly and annual temporal scales. The temperature data obtained consisted of minimum temperature, average temperature and maximum temperature. The time scale of the obtained temperature data was decadal, annual and monthly. These data contributed to addressing objective one of the study.

### 3.3.3: Soil sampling

Soil data was required to determine some parameters required in the Penman-Grindley soil moisture balance model, which was used to simulate the effects of climate change on millet yields. The study adopted the gravimetric sampling technique which involves collecting soil samples from representative sites in the study area at a depth of 0-30 cm, considered for root penetration according to FAO (2013). Three sites were visited and at each site, three points were selected and three soil cores taken from each point. The soil cores of approximately 200g were collected in a plastic bag and taken for laboratory analysis in the Soil science Laboratory in the Department of Agricultural Production, Makerere University. The parameters which were determined include; soil moisture deficit, wilting point, drying point and root constant.

### 3.3.4: Document analysis

35
Data on millet yield patterns for previous years was required to facilitate calibration of the model to simulate future changes owing to climate change. Millet yield data for Paicho Sub County was obtained from the Production Office, Gulu District. The obtained data covers a period of 6 years, from 2007 to 2012. This data contributed to addressing objective one of the study.

3.4: Data processing

3.4.1: Projecting future climate change

This component served two related purposes of the study; (a) understanding the future climate conditions at a relatively finer resolution using downscaled data and (b) using the projected climatic conditions to simulate effects on yields of millet. Future climatic conditions were obtained using the PRECIS model (Providing Regional Climates for Impact Studies). Details of the PRECIS model are widely available in Kumar et al. (2008), Yong et al. (2006), Marengo et al. (2009) and Urrutai and Mathias (2009), among others. In brief, PRECIS is a Regional Climate Modeling (RCM) system based on the third generation of the UK’s Hadley center’s regional climate model. PRECIS downscales climate up to a spatial resolution of 25 km. RCMs represent an effective method of adding fine-scale detail to simulated patterns of climate variability and change as they resolve better the local land-surface properties such as orography, coasts and vegetation and the internal regional climate variability through their better resolution of atmospheric dynamics and processes (Marengo et al., 2009). PRECIS downscaled data for most parts of Uganda are readily available and were for this study obtained from the Meteorology
Unit, Department of Geography, Geo-Informatics and Climatic Sciences, Makerere University, which has for a longtime worked on climate downscaling in collaboration with University of Reading, ICPAC and University of Nairobi. The PRECIS model was calibrated using historical climatic data. The obtained PRECIS data was downscaled to a resolution of 50km. For this study; projections of future climatic conditions were confined to a medium temporal scale (year 2033) to obviate the uncertainty associated with long timescale projections.

3.4.2: Millet yield modeling

Modeling using the Penman Grindley soil moisture balance model was done to test whether climate variability and change will lead to a 20% decrease in millet yield by the year 2033, this model was first developed by Penman (1950), and later revised by Grindley (1967) and Lerner et al. (1990). The model was considered suitable, putting soil moisture at the center and has variously been used under African conditions by several researchers e.g. Mileham et al. (2009), Houston (1990), Howard and Karundu (1992) and Taylor and Howard (1999). Millet was chosen because it is a staple food crop forming an important element of food security in the region but at the same time being abandoned by many households due to reduced yields exsacerbated by climate variability and change.

The basic structure of the model is represented by two equations as follows;

\[ R = (P - RO) - E_t \quad \text{when SMD} = 0 \]  \hspace{1cm} \text{Equation 2}

\[ R = 0 \quad \text{when SMD} > 0 \]  \hspace{1cm} \text{Equation 3}
According to the model represented in Equation (2) and (3), direct recharge \((R)\) occurs when incoming precipitation \((P)\), less surface runoff \((RO)\), exceeds evapotranspiration \((Et)\) and raises soil-moisture content beyond field capacity, a condition at which any additional net influx of water is not stored within the soil but drains to underlying strata. When the water content of the soil is less than field capacity, a soil-moisture deficit \((SMD)\) is said to exist and direct recharge prevented. Soil-moisture balance models provide estimates of direct groundwater recharge (i.e. from the infiltration of rainfall based on changes in the moisture content of soil (Penman, 1950; Grindley, 1967; Lerner et al., 1990).

The major inputs of the model are climatic, soil and land use data, while the major output is the net change (gain or loss) of soil moisture (mm). The climate Parameters were precipitation, runoff, pan evaporation, and potential evapotranspiration. Data for pan evapotranspiration for Gulu station which also facilitates derivation of potential evapotranspiration data was not available. However, data for the nearest station (Lira) was considered since the two stations lie in the same agro-climatic zone. The soil parameters cover the root constant, wilting point and soil moisture deficit. The land use type considered was agriculture (Mileham et al., 2009).

The soil samples were analyzed using standard procedures according to (Penman, 1949; Allen, 1998; Howard, FAO, 2013) to determine the soil moisture deficit, the wilting point and drying point as depicted in appendices A and Climatic data for the future conditions was obtained from PRECIS modeling as explained in section 3.4.1 and in appendices A.

Equation 4 indicates the resulting output of the soil moisture balance model
SM g/l = f (C, D, F, RO, SMD, P, PEₜ, Eₒ) ................................................. Equation (4)

Where, SM g/l is the net gain/loss of soil moisture,

C is the root constant,

D is the wilting point,

F is the drying point,

RO is runoff,

SMD is soil moisture deficit,

P is Precipitation

PEₜ is potential evapotranspiration,

Eₒ is pan evaporation.

Equation 5 was used to simulate millet yields for the period 2013-2033

\[ \mu = \beta/\infty \times \alpha \] ................................................................. Equation (5)

Where;

\( \mu \) is the simulated millet yields,

\( \beta \) is maximum yield if all conditions are favorable,

\( \infty \) is moisture requirement for millet,
α is the net moisture

3.5: Data analysis

The study obtained a range of both biophysical and socio-economic data which was subjected to a range of statistical analysis techniques. To analyze the interview data and the following analytical tools were employed: (a) Regression model was used to determine whether household income rather than education level significantly influenced adaptation strategies to climate variability and change. Other household characteristics analyzed using this model included household income, household type, gender, household access to credit, size of land and access to extension service these formed independent variables while a range of adaptation strategies to climate variability and change formed the dependent variables. Significance in relationships were determined at P<0.05. This covered the analysis needed for objective two; (b) Descriptive statistics involved i) Cross tabulation to establish the relationship between institutions, their roles in community adaptation to climate variability and climate change and their distribution in terms of Parishes where they exist and ii) Percentages and frequencies to quantify household perceptions on variability and changes in climate. This constituted the analysis required by objective one and three.
Trend analysis was performed on rainfall, maximum temperature and minimum temperature data. In addition, quartiles, standard deviation, coefficient of variation, means, minimum, maximum, percentages, frequencies and ranges were computed for the period 1980-2033 for rainfall and the period 1990-2033 for maximum and minimum temperature. This was performed in Statistical Package for Social Scientists (SPSS) version 16.0 and Excel software. This constituted the analysis required by objective one of the study.
CHAPTER FOUR: PRESENTATION OF FINDINGS

4.0: Introduction

In this chapter, the findings of the study are presented. It presents findings on (a) variability in rainfall and temperature (b) projected changes in climate (c) effects of climate change on millet yields (d) coping mechanisms (e) adaptation strategies and (f) the role of institutions in community adaptation to climate stressors.

4.1: Variability and changes in climate parameters in Paicho Sub County

4.1.1: Variability in rainfall

The trend observed in annual rainfall amounts for the period 1980 to 2010 is illustrated in Figure 4 and appendix A. Results revealed a decreasing trend, the annual rainfall amounts received in Paicho S/C varied from 1160mm-1808mm averaging to 1460mm. A linear trend tilted on the data shows that the decrease is not strong ($R^2 < 0.5$) and is insignificant ($P>0.05$). The annual coefficients of variation (C.V) in rainfall amounts for the period 1980-2010 ranged from 55% to 97% and this implied a high coefficient of variation. Generally, from 1980-1996 oscillations in
annual rainfall amounts were above 1300mm and from 1997-2010 oscillations were below 1300mm.

Figure 4: Variations in annual rainfall amount between 1980 and 2010

Deviations in annual rainfall amounts from the Long term mean (LTM) (1460mm) are illustrated in Figure 5. Results revealed that the deviation of annual rainfall amounts from the long term mean ranged from -300mm to +348mm giving a range of 648. A visual inspection of the graph generally shows that rain fall amounts for the period 1980-1997 were below the long term mean,
for the period 1988-1996 the annual rainfall amounts were above the long term mean and for the period 1997-2009 the annual rainfall amounts were far much below the long term mean. This implies that rainfall is generally oscillating over time coupled with wide deviations from the long term mean.

Figure 5: Deviations of annual rainfall amounts of Paicho S/C from the long term mean (1460mm) indicated as 0 in the figure for the period 1980-2010
Decadal variability in rainfall for the periods 1980-1990, 1991-2000 and 2001-2010 is illustrated in Figures 6, 7, 8 and appendices A. Results showed variability of decadal rainfall amounts for the period 1980-2010. For the period 1980-1990 the annual coefficients of variation (C.V) ranged from 19% to 128%; for 1991-2000 the C.V ranged from 15%-189% and for the period 2001-2010, the C.V ranged from 32%-108%, all these coefficients of variations are considered high variance according to Reed et al., (2000). Decadal variability of rainfall is also revealed by varying minimum, maximum, quartiles, and high standard deviations (STDEV). To compare variations in the maximum rainfall received in the three decades, the months of September for example received different amounts of rainfall for the three decades. For the period 1980-1990 it was 327, for 1991-2000 it was 234 and for 2001-2010 it was 282. These results therefore imply high variance in intra-decadal and inter-decadal rainfall amounts for Paicho S/C.

![Decadal variations in monthly rainfall amounts for Gulu station, 1980-1990](image-url)
Figure 7: Decadal variations in monthly rainfall amounts for Gulu station, 1991-2000

Figure 8: Decadal variations in monthly rainfall amounts for Gulu station, 2001-2010
Variability in seasonal rainfall amounts for the period 1980-2012 is illustrated in Figure 9. The area receives one long rainy season that stretches from March to October (WPF, 2009). Results reveal that the seasonal rainfall amounts varied from 985mm to 1624mm averaging to 1305mm and when subjected to statistical analysis results reveals that the coefficient of variation in seasonal rainfall ranges from 48%-96%. This implies a high variance in seasonal rainfall amounts. This seasonal rainfall amounts are enough to favor crop production and abundant crop yields however, there is inconsistency in seasonal amounts depicted by a high variance.

Figure 9: Variations in seasonal rainfall amounts for Paicho S/C, 1980-2012
A variation in the length of the growing season for the period 1980-2012 is illustrated in Figure 10. The length of the growing season has been defined variously by scholars. Mugalarai et al. (2008) define the length of growing season as the difference between cessation and onset of a particular year; Vrieling et al., (2013), defines it as the period where there are favorable weather conditions for crop emergence, vegetative growth, and ripening. However this study adopted the definition by Cline (2007) who defines the length of the growing season as the number of days per year when both water availability and temperature permits crop growth. Results revealed that the number of rain days during the growing season for the period 1980-2012 ranged from 94 rain days to 158 rain days averaging to 126 rain days. This implies a wide range of variation in the length of the growing season for the period 1980-2012.

Figure 10: Variations in the length of the growing season for the period 1980-2012
Variations in the onset of rains for the period 1980-2012 are illustrated in table 2. The onset of rain has been defined in many ways. Ati et al., (2000) define the onset of rain as a date during the period determined by local climatology and agricultural practices when rainfall accumulated over three consecutive days is at least 20 millimeters (mm) provided no dry spell occurs within the next 30 days; According to Benoit (1977), the onset date is when accumulated daily rainfall exceeds 0.5 of the accumulated potential evapotranspiration for the remainder of the season, provided no dry spell longer than 5 days occurs immediately after that date; Kowal and Knabe (1972) define the onset date as the 10 days in which rainfall is equal to or greater than 25mm but where the subsequent 10-day rainfall total is greater than 0.5 of the potential evapotranspiration; Loux et al., (2008) defines it as the total of at least 25mm of rain observed within a 5-day period followed by no dry period of seven on more consecutive days occurring in the following 30 days. Raes et al., (2004) define the onset of rain as a cumulative rainfall depth that will bring the top 0.25 meters of the soil to field capacity during a maximum of 4 days. However, this study adopts the definition by Pierre and Diop, (2003) who define the onset of rain as the first week receiving at least 15mm of rainfall after a given date determined by local climatology and agricultural practices; provided that no two weeks dry spell occurs in the next four weeks.

Findings revealed that the onsets of rain have been varying from 1\textsuperscript{st} March for the earliest rains to 10\textsuperscript{th} April for late rains. An inspection of the onset dates reveals that in the 1980’s and 1990’s, the onset of rain was generally being experienced within the first week and second week of March but between 2003-2012, the onset of rain has generally been experienced in the third to
fifth week of March or even in early April. This implies that the onset of rain has been varying and indicates a shift from early March to late March or early April.

Table 3: Weeks of onset of rainfall for Paicho S/C, 1980-2012

<table>
<thead>
<tr>
<th>Year of rain</th>
<th>Expected onset of Rain</th>
<th>Observed onset of Rain</th>
<th>Rainfall amount in the onset week (mm)</th>
<th>Remark</th>
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</thead>
<tbody>
<tr>
<td>1980</td>
<td>1st.-2nd. week</td>
<td>1st. March, 1st. week</td>
<td>32</td>
<td>Normal</td>
</tr>
<tr>
<td>1981</td>
<td>1st.-2nd. week</td>
<td>11th. March, 2nd. week</td>
<td>52.2</td>
<td>Normal</td>
</tr>
<tr>
<td>1982</td>
<td>1st.-2nd. week</td>
<td>1st.March, 1st. week</td>
<td>16.4</td>
<td>Normal</td>
</tr>
<tr>
<td>1983</td>
<td>1st.-2nd. week</td>
<td>4th.April, 1st. week</td>
<td>37.5</td>
<td>*Deviation</td>
</tr>
<tr>
<td>1984</td>
<td>1st.-2nd. week</td>
<td>12th.March, 2nd. week</td>
<td>39.9</td>
<td>Normal</td>
</tr>
<tr>
<td>1985</td>
<td>1st.-2nd. week</td>
<td>18th.March, 3rd. week</td>
<td>69.5</td>
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<tr>
<td>1986</td>
<td>1st.-2nd. week</td>
<td>12th.March, 2nd. week</td>
<td>100.4</td>
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<tr>
<td>1987</td>
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<td>9th.March, 2nd. week</td>
<td>68.6</td>
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<td>4th.March, 1st. week</td>
<td>67.5</td>
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<td>25th.March, 4th. week</td>
<td>41.7</td>
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<tr>
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<td>5th.March, 1st. week</td>
<td>26.2</td>
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</tr>
<tr>
<td>1992</td>
<td>1st.-2nd. week</td>
<td>2nd.April, 1st. week</td>
<td>29.2</td>
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</tr>
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<td>Year</td>
<td>Month, Week</td>
<td>Date</td>
<td>Days from Normal</td>
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<td>------</td>
<td>------------------</td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>6th March, 1st week</td>
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<td>1996</td>
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<td>1997</td>
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<td>62.4</td>
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<td>16.6</td>
<td>*Deviation</td>
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<td>2005</td>
<td>15th March, 3rd week</td>
<td>54.9</td>
<td>*Deviation</td>
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<td>102.6</td>
<td>*Deviation</td>
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<td>24.6</td>
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<tr>
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<tr>
<td>2012</td>
<td>1st April, 1st week</td>
<td>15</td>
<td>*Deviation</td>
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*Deviation of onset of rain from expected
4.1.2: Variability in temperature

The trend of mean annual maximum temperature for the period 1990-2009 is illustrated in Figure 11. The area experiences a linear increase in annual maximum temperatures which is strong ($R^2 \geq 0.5$) and significant ($P < 0.05$). It ranged from $27^\circ C$ to $35^\circ C$ averaging to $31^\circ C$. A visual inspection into the temperature maximum graph reveals that maximum temperatures have been oscillating in an increasing progression indicating increasing trend for the two decades.

Figure 11: Mean annual maximum temperature trend for Gulu, 1990-2009
Decadal variations in mean monthly maximum temperature for the periods 1990-1999 and 2000-2009 are illustrated in table 3. Results revealed that in the period 1990-1999, the coefficients of variation ranged from 2.4% and for the period 2000-2009, the coefficient of variation ranged from 1.4%. This implies high variance in decadal mean monthly maximum temperature.

The highest maximum temperature for the period 1990-1999 was 35.0°C and was experienced in the months of February while in the period 2000-2009 the highest maximum temperatures increased to 35.5°C in the same months of February.

Table 4: Decadal maximum temperature variations for the periods 1990-1999 and 2000-2010

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| 2000-2009 |  |  |  |  |  |  |  |  |  |  |  |
| Temperature |  |  |  |  |  |  |  |  |  |  |  |

54
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</table>

C.V Coefficient of variation, STD Standard deviation, MIN Minimum, MAX Maximum

Variations in the highest mean monthly maximum temperatures for the two decades i.e.1990-1999 and 2000-2009 are illustrated in Figure 12. Findings revealed that there have been variations in the highest mean monthly maximum temperatures for the 2 decades with the highest temperatures of above 30°C registered during the dry months of January, February and December and the lowest mean monthly maximum temperatures registered during the rainy seasons ranging from March to November.
Figure 12: Variations in the highest long term mean monthly maximum temperature for the 2 decades 1990-1999 and 2000-2009

The trend of mean annual minimum temperature for the period 1990-2009 is illustrated in Figure 13. The minimum temperature also increased linearly with time. It varied from $17^0C$ to $21^0C$ averaging to $19^0C$ and statistical analysis reveals that the increase was statistically strong ($R^2 > 0.5$) and significant ($P < 0.05$). A visual inspection into the temperature minimum graph for the period 1990-2009 reveal that minimum temperatures have been varying in an increasing progression indicating increasing regime for the two decades.
Decadal variations in mean monthly minimum temperature for the periods 1990-1999 and 2000-2009 are illustrated in table 4. The coefficients of variation ranged from 2-4% and 1-5% for the period 1990-1999 and 2000-2009 respectively. This implies high variance in mean monthly minimum temperatures.
Table 5: Decadal variations in minimum temperature for the periods 1990-1999 and 2000-2009

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<tr>
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<tr>
<td></td>
<td>Temperature</td>
<td>minimum</td>
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</tr>
<tr>
<td></td>
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<td>January</td>
<td>February</td>
</tr>
<tr>
<td>QUARTILE(1)</td>
<td>17</td>
<td>18</td>
<td>19</td>
</tr>
<tr>
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<td>17</td>
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<td>19</td>
<td>20</td>
</tr>
<tr>
<td>STDEV</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>C.V</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

58
Variations in the highest mean monthly minimum temperatures for the two decades i.e. 1990-1999 and 2000-2009 are illustrated in Figure 14. There have been variations in the highest mean monthly minimum temperatures for the 2 decades with the highest mean monthly minimum temperatures experienced from mid-January to mid-June and the lowest mean monthly minimum temperatures experienced from mid-June to mid-January.

Figure 14: The highest mean monthly minimum temperature for 2 decades 1990-1999 and 2000-2009
4.1.3: The perception of households on climate variability and change

The household perceptions on climate change are given in figure 15. Most respondents (67%) perceived that there is climate change taking place.

![Bar chart showing household perception on climate change in the last 30 years]

Figure 15: Household perception on climate change in the last 30 years

Household’s responses on climate parameters that have changed ranking from the most changed to the least Changed are illustrated in Figure 16. Findings reveal that rainfall has changed most
represented by 26% of the responses followed by temperature represented by 25% of the responses and wind speed and direction represented by 21% of the households responses. However this findings contrast with statistically analyzed meteorology data which shows that rainfall has not changed significantly ($P>0.05$) over the period 1980-2010 rather, it is temperature both maximum and minimum that have changed significantly ($P>0.05$) for the period 1990-2009. Wind speed and direction, Sun shine hours, humidity and cloud cover could not be validated because data on them was not collected from meteorology.

Figure 16: Household’s responses on climate parameters that have changed ranking from the most changed to the least Changed
Perceptions on seasons that have changed most are illustrated in Figure 17. Findings revealed that 54% of the households perceived that the rainy season has changed most and 46% responded that the dry season has changed most.

![Bar chart showing percentage of households per season](chart)

**Figure 17: Households responses on the season which have changed most**

Perceptions on predictability of the onset of rains are illustrated in Figure 18. The onset of rainfall now as compared to 15 or 30 years ago is largely un-predictable this was represented by 48% of household responses. The perception that rainfall is now un-predictable rimes with analyzed meteorology data which indicates that the occurrence of the onset of rain for the period 1980-2012 ranges from first week of March to second week of April hence difficult to predict because of the wide variation.
4.2: Projected changes in climate

4.2.1: Projected changes in rainfall

The trends observed in projected annual rainfall amounts for the period 2013-2033 are illustrated in Figure 19. Projected annual rainfall amounts are likely to have no strong but significant decrease \((R^2 < 0.5)\) and \((P > 0.05)\) respectively for the period 2013-2033. This implies that changes in rainfall are likely to occur in Paicho Sub County by 2033.
4.2.2: Projected changes in maximum and minimum temperature

The trends observed in projected mean annual maximum temperature for the period 2013-2033 are illustrated in Figure 20. Annual maximum temperature is likely to remain quasi uniform ($R^2 < 0.5$) and ($P > 0.05$) for the period 2013-2033. This implies that mean annual maximum temperature is likely to vary but not change by 2033 characterized by slight oscillations.
Figure 20: Projected trend of mean annual maximum temperature for Paicho Sub County, 2013-2033

The trend observed in projected mean annual minimum temperature for the period 2013-2033 is illustrated in Figure 21. Annual minimum temperature is likely to remain quasi uniform for the period 2013-2033 ($R^2 < 0.5$) and ($P > 0.05$). This implies that mean annual minimum temperature for Paicho Sub County is likely to vary rather than change by 2033 characterized by oscillations.
4.3: Effects of climate change on millet yields

Millet simulation results for Paicho Sub County for the period 2013-2033 are illustrated in figure 22 and in the appendices A. Annual millet yields for the period 2013-2033 are expected to oscillate from 1800 to 2189 kilograms per hectare per year. However, in the years 2019 and 2027 there will be drastic increases in millet yields as a result of increase in the net gain of soil moisture. Generally, a decrease in millet yields of 2.6% is expected for the period 2013-2033.
Figure 22: Simulated millet yields per Kilogram (Kg) per hectare (ha) per year (yr.) for Paicho Sub County for 2013-2033

4.4: Households coping mechanisms to climate stressors

Results on the coping mechanisms to climate stressors adopted by households in Paicho Sub County are given in Figure 23. The major coping mechanisms undertaken include; buying food from the market (27%), exchange of labor for food (25%), getting food help from relatives, community and food agencies (21%).
4.5: Households adaptation strategies to climate stressors

Results on adaptation strategies to climatic stressors undertaken by households are given in figure 24. The major adaptation mechanisms include; getting other jobs outside agriculture (20%), adjustment of planting dates and diversification of production (19%), carrying out mixed cropping (15%), growing improved crop varieties (11%), rearing improved animal breeds (10%), and growing first season crops in second season and second season crops in first season (10%).
Household characteristics that determine adaptation to climatic stressors were studied and these are illustrated in the table 5. Household income (P>0.05) and level of education of household head (P>0.05) did not significantly influences adaptation strategies. However, it was the gender (P<0.05), the size of land (P<0.05) and the age of household head (P<0.05) that were found to be the most significant factors influencing adaptation mechanisms in Paicho Sub County.
Table 6: Factors influencing adaptation mechanisms in Paicho Sub County

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Estimated coefficient</th>
<th>SE of coefficient</th>
<th>P</th>
</tr>
</thead>
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<tr>
<td>Age of household head</td>
<td>-0.393</td>
<td>0.271</td>
<td>0.05</td>
</tr>
<tr>
<td>Education level of household head</td>
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<td>0.406</td>
<td>0.479</td>
</tr>
<tr>
<td>Household type</td>
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<td>0.806</td>
<td>0.485</td>
</tr>
<tr>
<td>Gender</td>
<td>1.902</td>
<td>0.809</td>
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</tr>
<tr>
<td>Average weekly income</td>
<td>-0.121</td>
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</tr>
<tr>
<td>Size of land in acres</td>
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<td>0.005</td>
<td>0.07</td>
</tr>
<tr>
<td>Household access to extension service</td>
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<td>0.428</td>
</tr>
<tr>
<td>Household access to credit</td>
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<td>0.692</td>
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</tr>
<tr>
<td>Constant</td>
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<td>1.981</td>
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</tr>
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<td>R Square</td>
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<td>Standard error of the estimate</td>
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</tr>
<tr>
<td>Regression significant</td>
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<td></td>
</tr>
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</table>
4.6: The role of institutions in community adaptation to climate variability and change

Findings on existence of institutions that involve in community adaptation to climatic stressors in Kal-ali and Kalumu parishes in Paicho Sub County are illustrated in Figure 25. 34% of the households indicated existences of institutions while 66% responded that there are no institutions that involve in community adaptation to climate stressors.
The institutions that exist in Kalamu and Kalali Parishes in Paicho Sub County and their role in community adaptation to climate stressors are illustrated in Table 6. Institutions that exist in Kalamu include; local councils, farmers groups, NGO’s/CBO’s, clan/elder networks, family networks, and religious institutions. Those in Kalali include; Local councils, NGO’s/CBO’s, clan/elder networks and religious institutions. Generally, more institutions exist in Kalamu Parish than in Kalali Parish. The roles of these institutions in the two Parishes are related i.e. Local councils advice on avoiding tree cutting, avoiding bush burning and providing access to information relevant to coping and adaptation. Farmers groups also avoid bush burning, make
decision on planting time and access to information. NGO’s provide access to credit and access to information relevant to adaptation and capacity building. Clan/elders networks make decision on when farmers should plant crops and govern entitlements to key natural resources. Family networks give access to information and also govern entitlements to key resources. Religious institutions also give access to information relevant to climate change adaptation and capacity building.
Table 7: Institutional roles in community adaptation to climate stressors

<table>
<thead>
<tr>
<th>Institution</th>
<th>Avoiding tree cutting</th>
<th>Avoiding bush burning</th>
<th>Government to key resources</th>
<th>Decision on when farmers should plant crops</th>
<th>Access to credit</th>
<th>Access to information</th>
<th>Capacity building</th>
</tr>
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<tbody>
<tr>
<td>Local councils</td>
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<td>26</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>48</td>
<td>0</td>
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<td>Farmers' groups</td>
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<td>0</td>
<td>33</td>
<td>0</td>
<td>53</td>
<td>0</td>
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<td>NGO's/C-BO's</td>
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<td>0</td>
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<td>48</td>
<td>31</td>
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<td>45</td>
<td>36</td>
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<td>10</td>
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<td>0</td>
<td>0</td>
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<td>12</td>
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<tr>
<td>Clan/Elder-s</td>
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<td>39</td>
<td>35</td>
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<td>26</td>
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<tr>
<td>Religious institutions</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>88</td>
<td>12</td>
</tr>
</tbody>
</table>
CHAPTER FIVE: DISCUSSION OF FINDINGS

5.0: Introduction

In this chapter, the discussion of the study findings is presented. It presents the discussion of findings on (a) variability and changes that occur in climate (b) effects of climate change on millet grain yields (c) coping mechanisms (d) adaptation strategies and (e) the role of institutions in community coping and adaptation to climate stressors.

5.1: Variability and changes in rainfall and temperature in Paicho Sub County

5.1.1: Variability in rainfall

The trend observed in annual rainfall amounts for Paicho S/C is decreasing for the period 1980-2010. The rain fall amounts varied from 1160mm-1808mm averaging to 1460mm. A statistical analysis found out that the decrease was insignificant but depicted a high coefficient of variation implying that the area is currently contending more with rainfall variability rather than change. This was further supported by household perceptions that rainfall is a climatic variable that varies most. In general, the area receives adequate annual rainfall amount of over 1150mm which
should be supportive to crop growth and abundant yields. However, the rainfall is distributed in one season spanning from March to October characterized with high level of variability. This finding is in line with findings by Some and Kone, (2000) in the semi-arid and sub humid zones of West Africa. Similarly, Worishima and Akasaka (2010) reported that rainfall in southern Africa and parts of the Horn of Africa is decreasing. However, most studies have found out an increasing trend of rainfall (Cynthia et al., 2002; IPCC, 2007; Schmidhuber & Tubiello, 2007; Alexander, 2013)

Furthermore, the study found out deviations of annual rainfall amounts from the long term annual average ranging from -300 to +348mm for the period 1980-2010. Generally, the deviation was below the long term average for the period 1980-1987, above the long term average for the period 1988-1996 and far much below the long term average for the period 1997-2009. The causes of deviation of annual rainfall from the long term annual average in Paicho Sub County is likely to be a result of: early onset followed by a delay in cessation and increased intensity of seasonal rainfall. These can cause an increase in annual rainfall amounts above the long term average while dry spells, prolonged droughts, delayed onset followed by early cessation and reduced intensity of seasonal rainfall can cause a fall in annual rainfall amounts below the long term average. The deviation of annual rainfall amounts in Paicho Sub County is coupled with decadal variations in rainfall amounts and Statistical data analyzed reveals high variance in intra-decadal and inter-decadal rainfall amounts for decades 1980-1990, 1991-2000 and 2001-2010.
In terms of seasonality, Paicho S/C receives one long rainy season that stretches from March to October. The seasonal rainfall amounts over the period 1980-2012 varied from 985mm to 1624mm averaging to 1305mm and this depicted a wide variation. Statistical analysis revealed a high coefficient of variation in seasonal rainfall amounts for the area. This seasonal rainfall amounts are enough to favor crop production and abundant crop yields however, the limitation lies in the inconsistency in seasonal amounts depicted by a high variance. Similarly, studies by Krishnamurthy and Shuka (2000); Sultan and Serge (2000); Barchuk et al.(2005); Gobin (2011) and Todd et al. (2013) found out variability in seasonal rainfall amount in the tropics mainly caused by abrupt shift of the inter-tropical convergence zone. Rowel et al. (2007) reported that global Sea Surface Temperature (SST) variations, the possible effects of land-surface-moisture feedback and the influence of internal atmospheric variations are indeed responsible for most of the variability of seasonal rainfall. These are likely to be the probable causes of seasonal variability of rainfall amounts in Paicho S/C.

The study also investigated the variations in the length of the growing season and results found out that the number of rain days during the growing season for the period 1980-2012 ranged from 94 rain days to 158 rain days averaging to 126 rain days for Paicho Sub County. This is a wide range of variation in the length of the growing seasons and yet this is responsible for determining the spatial distribution of crops and the farming system (Xiaodong et al., 2006; Hans et al., 2006; Lawal et al, 2006; Cline, 2007; Vreiling et al., 2013) hence indicative of crop risk. This finding rimes with findings by Vreiling et al. (2013) who reported variability in length of growing season in arid and semi-arid areas, significant negative trends in Tanzania, Mozambique and for short rains in Eastern Kenya, positive trends occurring across West Africa, South Africa and Eastern Kenya for the long rains. In the temperate regions, studies indicate a positive trend in
the length of the growing season (LGS) (Abu-Asab et al., 2001; Menzel et al., 2001; Ahas et al., 2002; Penuelas et al., 2002). Similar findings on variations in LGS have been observed when climatological growing season was studied for large parts of the northern hemisphere (Frich et al., 2002). Menzel et al. (2003) reported an increase in the length of growing season by 1-3 weeks in Germany. Linderholm (2006) and ACIA (2004) assert that variations that occur in the LGS are associated with global warming.

The onset of rain for Paicho Sub County is expected within the first and second week of the month of March according to local agriculturalists and also NEMA (2009). Findings revealed variations in the onset of rainfall for the period 1980-2012. The variations range from 1st March for the earliest rains to 10th April for the late rains generally, in the period 1980’s and 1990’s, the onset of rain was being experienced within the first week and second week of March but between 2003-2012, the onset of rain has been experienced in the third to fifth week of March or even in early April implying that the onset of rain is widely variable ranging from one week to 7 weeks with an indication of a shift from early March to late March and early April. This was supported by household perception that the onset of rainfall now as compared to 15 or 30 years ago is largely un-predictable. The fact that agricultural production in Paicho Sub County is largely dependent on rainfall suggests that it is largely affected since farmers cannot easily predict the onset of rain hence negatively affecting their planning of farm activities and the resultant yields. This finding is in line with the assertion that the onset of rain is an important seasonal characteristic that has reflected variability over time (Todros, 2005; Ziervogel, et al., 2008; Loux et al., 2008; Mileham et al., 2009; Seth et al., 2013; Moron and Robertson, 2013). A study done in Moroto and Nakapiripirit by Mubiru et al, (2010) found out that the onset of rain is
largely unpredictable, in most cases beginning later or earlier than normal. The onset of rains according to Subash et al. (2010) was found to have a significant delayed trend. Moron and Robertson, (2013) reported that the onset of rain varied from 2 weeks over the monsoon zone and Western Ghats to about a month over the northwestern desert. The relationships in the onset of rains between regions are weak and geographic specific.

5.1.2 Variability in temperature

Mean annual maximum and minimum temperature for Paicho Sub County for the period 1990-2009 were linearly increasing though at different rates. This statistical finding was supported by household perceptions and is in line with the assertion that annual temperatures are generally increasing in the region (Schmidhuber & Tubiello, 2007; NRC, 2001; ACCRA, 2012).

High variances in the inter-decadal and intra-decadal temperature were also observed for the period 1990-1999 and 2000-2009. Similarly, there have been variations in the highest decadal mean monthly maximum temperatures for the 2 decades with the highest temperatures of above $30^\circ$C registered during the dry months of January, February and December and the lowest mean monthly maximum temperatures registered during the rainy seasons ranging from March to November. The increasing progression in decadal, annual, and monthly maximum temperature is one of the most serious climatic hazards that affects agricultural production and crop yields.
(Bates et al., 2008) because it leads to reduction of soil moisture, water shortage, favors multiplication of some pests and diseases which affect crop production resulting to low crop yields (Sarkar, 1997). This finding is related to the finding of Nandozi et al. (2012) in Uganda; Subas (2012) in India who reported that the seasonal changes in environmental temperatures are large and imposing serious effects on agriculture. It is also in line with findings by Schmidhuber & Tubiello (2007) and IPCC (2007) which assert an increase in global atmospheric temperature.

The trends observed for mean annual minimum temperature for Paicho S/C for the period 1990-2009 was found to be increasing and the increase was statistically significant. For decadal mean monthly minimum temperature, findings revealed an inter-decadal and intra-decadal variation for the periods 1990-1999 and 2000-2009. Statistical analysis indicates high coefficients of variation in the inter-decadal and intra-decadal minimum temperature for the two decades for Paicho S/C. Similarly, findings also revealed variations in the highest mean monthly minimum temperatures for the 2 decades with the highest mean monthly minimum temperatures experienced from mid-January to mid-June and the lowest mean monthly minimum temperatures experienced from mid-June to mid-January.

The causes of increasing minimum and maximum temperatures in different regions in most cases are not location specific but derived mostly by the interconnected effect of global human activities and natural factors. A study by Makokha and Shisanya (2010) in Nairobi, Kenya reported increasing maximum and minimum temperature due to air pollution resulting from
increasing energy consumption and alteration of the natural landscape by human activities. Adger and Brown (1994) reported the effect of land use change resulting from deforestation, agriculture, and urbanization to be a cause of global warming. Nantalia et al. (2000) and Crowley (2000) asserted that global temperature changes are caused by the ‘external’ factors of anthropogenic activities, volcanoes, variations in the irradiance of the sun and the ‘internal’ factor of natural variability.

5.2: Projected changes in climate

5.2.1: Projected changes in rainfall

The trends in projected annual rainfall amounts for Paicho S/C was found to be decreasing for the period 2013-2033 and statistical analysis reveals that the decrease is statistically significant. This is likely to affect agricultural production because the population of the S/C largely depends on rain fed agriculture for their livelihood. The study finding relate to the findings of Nandozi et al., (2012); Worishima & Akasaka (2010) who found out that rainfall in South Africa and parts of the Horn of Africa is projected to decline by about 10% by 2050. Similarly, Some & Kone, (2000) reported that rainfall in the semi-arid and sub-humid zones of West Africa was decreasing. However, this findings deviates from the general notion that rainfall in the coming decades is likely to increase (NRC, 2001; Cynthia et al., 2002; Schmidhuber and Tubielllos, 2007; Alexander, 2013). A study by IPCC (2007) reported that the intensity of precipitation events are likely to increase on average and this will be particularly pronounced in tropical and high-
latitude regions which are also expected to experience overall increase in precipitation because of high evapotranspiration. Mohamed et al. (2002); Druyan, (2010) and Sultan, et al. (2013) reported that rainfall is projected to increase over the African continent. ACCRA (2012) and Bashaasha et al. (2010) reported that the increases in rainfall in Uganda are largest in short rain season and in the heavy rainfall events. Although climate change is generally expected, the expected changes are diverse in terms of magnitude, direction and are geographic specific.

5.2.2: Projected changes in maximum and minimum temperature

The trends in both projected mean annual maximum and minimum temperature for Paicho S/C for the period 2013-2033 shows an increasing trend and statistical analysis reveals that the increase is statistically insignificant. This finding agrees with other study findings on the notion that mean surface temperature will increase (Xiaodong et al., 2006; IPCC, 2007; Schmidhuber and Tubiello, 2007; NRC, 2001; ACCRA, 2012). However variations exist in the magnitude and the temporal extent of their predictions. IPCC (2007) projects an increase in mean surface temperature between 1.8°C to 4.0°C by 2100 with tropical regions experiencing the largest increments likely because of prolonged droughts, dry spells, and direct exposure of the region to the sun’s rays throughout the year. McSweeney et al. (2008) reported temperature increase by 1.5°C by 2050 and by 4.3°C by 2100 in Uganda. ACCRA (2012) reported a rise in temperature by 1.0°C to 3.1°C by 2060’s and 1.4°C to 4.9°C by 2090’s still in Uganda while Alexander (2013) projects even a much higher rise by 4-6°C by 2080 in Mekong region in Asia which is even above the global increase. Studies indicate that even a 1.5°C change is critical for crop yields
(Kilembe, 2012; Mohamed et al., 2002; Eschenback, 2013). All projections indicate increase in the frequency of hot days and nights, and a decrease in the frequency of days and nights that are considered ‘cold’ in current climate (ACCRA, 2012; Wasige, 2009).

5.2.3: Household perceptions on climate change

Results from household perception indicated that there is climate change taking place. This perception agrees with the general notion that climate is changing (Orindi and Eriksen, 2005; IPCC, 2007; Mac Cathy et al., 2008; Brown, 2007; Lobell et al., 2013 and Alexander, 2013). However, it contrasts with statistically analyzed meteorology data which indicates more of variability in climate than change. Because out of the two major elements (rainfall and temperature) that drive the climate of the tropical regions, the projected increase in both maximum and minimum temperature was found to be insignificant by 2033. Much as the decrease in rainfall was found to be significant; change in only one property of weather will not qualify climate to change because according to IPCC (2001) definition, climate change is a change in the state of climate identified using statistical tests by changes in the mean and/or the variability of its properties/parameters persisting for an extended period typically decades. Therefore the perceived change in climate according to the households is likely to be driven by information disseminated on radios and other media on rainfall predictions. The likely effects of variations and changes that will occur in climate should not be underestimated, more so that the analyzed meteorological data reveals a significant reduction of rainfall by 2033. This can affect
Paicho Sub County whose livelihoods are agro-dependent by reduction of crop yields and food security if no appropriate adaptation strategies by both the community and government actors are undertaken.

5.3: Effects of climate change on millet yields

Millet simulation results for Paicho Sub County for the period 2013-2033 reveal oscillations in annual yields ranging from 1810-2189. However, millet yields are likely to decrease by 2.6% but the decrease is insignificant. The projected decrease is likely to occur due to the projected increase in maximum and minimum temperature and the projected decrease in rain fall by 2033 as established by the study. One of the key food security crops in Uganda and Africa in general is millet and has been resilient to climate variability (Philips, 2002; Hari et al., 2005; Sultan at al., 2013). But this is likely to change in future due to elevated temperatures and change in rainfall. When warming exceeds +2°C, negative impacts caused by temperature rise cannot be counteracted by any rainfall change Kilembe et al. (2012). The study finding conforms to the findings by Mohamed et al., (2002) in the Sahel region and Kilembe et al. (2012) in the east African region who reported that climate change will lead to a reduction of millet yields in the coming decades. However variations occur in the percentage change, the models used and the period projected. Mohamed and his colleagues found out a change in millet yields by 13% by the year 2025 while Kilembe and his colleagues projects a decrease by 26% by 2080’s.

5.4: Coping mechanisms to climate stressors
The major coping mechanisms to climatic stressors undertaken by households in Paicho Sub-County include; buying food from the market, exchange of labor for food, getting food help from relatives, community and food agencies. The probable reasons for this nature of coping mechanisms are likely to be the prevalence of high poverty rates and the effect of the civil war that dominated the region for the last two decades. Paicho Sub County has a low social economic status with 62% of the population living below poverty line (UNDP, 2012). The main option for income is the sale of crops, brewing and selling alcohol, selling local consumable goods, handicrafts and foodstuffs (WFP, 2009). Studies on coping mechanisms by Quay (2008) and Kyeyeku (2012) in Ghana; Fana and Snake (2012) in Ethiopia; Bardege et al. (2013) obtained various diversified coping mechanisms in response to climate stressors most of which relate to the coping mechanisms found in this study and they include; Collection of wild foods, purchasing food from the market, migration and wage labor in exchange for food , Support from relatives and friends, sales from livestock and household valuables, reduction in the number of meals served each day, reduction in the portions/sizes of meals and consumption of less preferred foods.

5.5: Adaptation strategies to climate stressors

Findings reveal that households in Paicho S/C have carried out several adaptation strategies in response to the effects of climatic stressors. The major adaptation strategies include; getting other jobs outside agriculture, adjusting of planting dates and diversification of production,
mixed cropping, rearing improved animal breeds, growing improved crop varieties and growing first season crops in second season and second season crops in first season. This implies that climate variability is not a new phenomenon to the people of Paicho S/C in Gulu district. The adoption of afore mentioned adaptation strategies is likely to be due to limited institutional capacity, low financial capability of the households and limited farm technology. These adaptation strategies are not strange but have a close relationship to those carried out elsewhere. A study by Rashid and Nhachena (2008) in 11 African countries found out diversified adaptation mechanisms to climate change e.g. diversifying production, using different improved varieties, changing planting dates, increased irrigation, use of insurance, water conservation, prayers, soil conservation etc; Kathleen et al. (2008) reported that in Ethiopia and South Africa, common adaptation strategies include use of different crop varieties, planting trees, soil conservation, changing planting dates and irrigation. Burton et al. (2002) reported the following adaptation strategies being carried out in Bangladesh, Netherland and USA; changing topography of land, changing farming practice, changing timing of farm operations, using different crop varieties, research into new technologies and change of government and institutional programs. The adaptation strategies adopted by communities in different regions depend on their level of economic development, technology, financial capacity, institutional support and traditions. However, most of the adaptation strategies adopted by communities in various regions tend to have a similarity.
The study investigated the influence of household characteristics on adaptation strategies in order to determine those that significantly influence adaptation. Gender, the size of land and age of household head were found to be the most significant household characteristics influencing adaptation strategies in Paicho S/C.

The influences of gender on adaptation strategies is because the male were more likely to adapt than their female counter parts since in many African traditions the females have less access to land, and other socio-economic resources constraining the adaptive capacity of female to adapt to climatic stressors. Gender studies by IFPRI (2001) and Meinzen-Dick et al., 2010) also reported unequal distribution of assets between male and female in rural households which was in favor of male. This finding from this study rimes with those found out by Tengen and Hella (2004) in West Usambara highlands in Tanzania, Nabikolo et al. (2012) in Eastern Uganda who found out a significant influence of gender on adaptation to climate stressors.

In addition, the size of land was also found to significantly influence adaptation mechanisms. Households that have more land are more likely to adapt than their counter parts that have small land holdings because they can open up large gardens, plant more crops and if the season is favorable they can be in position to reap a bumper harvest which can yield them high incomes. This can make them afford improved farm technologies like use of ox-ploughs, rearing improved livestock breeds, improved crop varieties, and addition of fertilizers. Nabikolo et al. (2012) asserted that people who own much land can rent out some of their land in order to generate more income for the household and be able to adapt more appropriately than those who have less land. A study by Advancing Capacity to Support Climate Change, (ACCCA, 2010), reported
that large farm size positively influenced adaptation strategies such as use of improved varieties of crops and livestock, growing trees and soil/water conservation practices. Knowler and Bradshaw (2010) asserted that land size indicates wealth an argument which was also reported by Bashaasha et al. (2012) in Uganda.

Furthermore, the age of household head significantly influenced adaptation mechanisms. This is likely to be that the young adults have higher level of motivation to act on perceived changes in order to cope up. They are energetic and able to get other jobs outside agriculture, can diversify agricultural production which can enable them get more income to adopt other adaptation mechanisms such as buying improved crop varieties, livestock varieties and fertilizers. A study by Bandura (1977) and Hines et al. (1987) reported that the ability to adapt depends on individual’s motivation to act. The elderly do not perceive themselves as able to act on perceived threats and therefore their adaptation ability is lower than that of the young adults. A study carried out by (Wolf et al., 2009) on elderly people’s perceptions on wave risks in the United Kingdom’s suggests that the old people do not perceive well their vulnerability and therefore do little to adapt.

5.6: Evaluation of the role of institutions in community adaptation to climate stressors

Findings reveal that there exist institutions that enhance community adaptation to climate stressors in Paicho Sub County in Gulu district. These institutions include; Local councils,
farmers groups, clan/elders networks, family networks, religious institutions, NGO’s and CBO’s. These findings have a relationship with the findings by ACCRA (2012) on institutions in Gulu, Kotido and Bundibujyo in Uganda. Reid and Vogel (2006) in South Africa reported the existence of three kinds of institutions which were critical in building adaptive capacity and to enhance resilience to environmental changes these included; farmers and local community groups, public and governmental institutions and local organization such as CBO’s.

Findings on institutional roles in community adaptation revealed that they avoid tree cutting and bush burning, provide access to relevant information regarding climate variability and change, making decision on when farmers should plant crops, providing access to credit, governing entitlements to key natural resources and capacity building. A study by African Climate Change Resilience Alliance (ACCRA), (2012) in the districts of Bundibujyo, Gulu and Kitgum reported that institutions dictate when farmers should plant crops, stop people from deviating from common practices and determine entitlements to key assets needed to cope and respond to climate change stressors. Agrawal (2008) found out that local government in the Philippines involved in tree planting and reforestation, better implementation of forest laws, soil and water conservation, construction of drainage, controlled burning, logging ban, information sharing, research and capacity building, provision of relief goods, creation of task forces, and infrastructure repair and construction. Neil and Adger (2001) assert that the role of institutions is much more eminent in post socialist countries where the ideology of social bonding is still strong. Institutions play diversified roles in enhancing community adaptation to climate stressors in various communities and the roles become rigorous when government institutions are greatly involved in enforcement.
CHAPTER SIX: SUMMARY OF RESEARCH FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

6.1: Summary of research findings
The historic annual rainfall amounts indicated insignificant decreasing trend for the period 1960-2012. However, annual rainfall projections for 2013-2033 revealed a decreasing trend which is likely to be significant.

Both historic mean annual maximum and minimum temperatures revealed a significant increasing trend for the period 1990-2009. However, annual maximum and minimum temperature projections for 2013-2033 revealed an insignificant increasing trend.

Millet simulation results for the period 2013-2033 reveal oscillations in annual yields ranging from 1810-2189. However, the yields are likely not to change significantly.

A range of coping and adaptation mechanisms to climate variability and change were applied. The most prominent coping mechanisms include: buying food from the market, exchange of labor for food, getting food help from relatives, community and food agencies while major adaptation strategies include; adjusting of planting dates and diversification of production, mixed cropping, getting other jobs outside agriculture, rearing improved animal breeds, growing improved crop varieties and changing crop growing seasons. Gender, the size of land and age of household head were found to be the most significant factors influencing adaptation mechanisms.

The institutions that enhance community adaptation to climate stressors include; Local councils, farmers groups, clan/elders networks, family networks, religious institutions, NGO’s and CBO’s and their roles include; avoiding tree cutting and bush burning, provide access to relevant information regarding climate variability and change, making decision on when farmers should plant crops, providing access to credit, governing entitlements to key natural resources and capacity building.
6.2: Conclusions

Rainfall variations are insignificant for the period 1980-2010, but temperature shows significant variations. Thus hypothesis 1 is not rejected.

Future projections show significant decrease in rainfall and insignificant increase in temperature. Thus hypothesis 2 was not rejected.

Millet yields will reduce by 2.6% by 2033. Thus hypothesis 3 was rejected.

Diversified coping and adaptation mechanisms are being undertaken.

Gender, size of land and age of household head are the significant determinants of adaptation. Thus hypothesis 4 was rejected.

6.3: Recommendations
There should be improved soil and water conservation.

Households need to enhance water harvesting techniques and also enhance crop production

There is a need to come out with better and new crop varieties by researchers that can survive under changed climate conditions

Institutions need to be strengthened to enhance adaptation to climate variability and change.

Long term investigations to determine the likely changes that would occur in climate and the likely effects on the major crops that form the agricultural livelihood of the region is still lacking.
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87


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APPENDICES

Appendix A

Table 8: Variation in annual rainfall amounts for the period 1980-2010, Gulu station.

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<th>Max</th>
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<td>393</td>
<td>197</td>
<td>108</td>
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<tr>
<td><strong>QUARTILE(3)</strong></td>
<td>32</td>
<td>18</td>
<td>87</td>
<td>173</td>
<td>253</td>
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<td>37</td>
<td>26</td>
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<td>71</td>
<td>44</td>
<td>54</td>
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<td>84</td>
<td>45</td>
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</tr>
<tr>
<td><strong>C.V</strong></td>
<td>90</td>
<td>189</td>
<td>67</td>
<td>15</td>
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<td>45</td>
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<td>26</td>
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<td>8</td>
<td>67</td>
<td>112</td>
<td>140</td>
<td>108</td>
<td>115</td>
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<td>16</td>
<td>15</td>
<td>86</td>
<td>65</td>
<td>79</td>
<td>85</td>
<td>36</td>
<td>68</td>
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<td>83</td>
<td>150</td>
<td>164</td>
<td>126</td>
<td>130</td>
<td>216</td>
<td>180</td>
<td>201</td>
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<td>32</td>
</tr>
<tr>
<td><strong>MAX</strong></td>
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<td>239</td>
<td>162</td>
<td>97</td>
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<tr>
<td><strong>QUARTILE(3)</strong></td>
<td>26</td>
<td>26</td>
<td>93</td>
<td>193</td>
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<td>162</td>
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<td>35</td>
<td>41</td>
<td>60</td>
<td>51</td>
<td>52</td>
<td>57</td>
<td>78</td>
<td>82</td>
<td>56</td>
<td>41</td>
<td>34</td>
</tr>
<tr>
<td><strong>C.V</strong></td>
<td>108</td>
<td>122</td>
<td>48</td>
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<td>39</td>
<td>35</td>
<td>50</td>
<td>32</td>
<td>40</td>
<td>92</td>
</tr>
</tbody>
</table>
Table 11: Simulated millet yields with net moisture gain/loss, observed millet yields and rainfall amounts for the period 1980-2012 in Paicho Sub County in Gulu district

<table>
<thead>
<tr>
<th>Years</th>
<th>Rainfall (mm)</th>
<th>Net moisture</th>
<th>Simulated millet yield (kg/ha/yr.)</th>
<th>Observed millet yield (Kg/ha/yr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>1475</td>
<td>3116</td>
<td>1816</td>
<td>1607</td>
</tr>
<tr>
<td>2008</td>
<td>1486</td>
<td>3121</td>
<td>1821</td>
<td>1400</td>
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<td>2009</td>
<td>1276</td>
<td>3131</td>
<td>1831</td>
<td>1600</td>
</tr>
<tr>
<td>2010</td>
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<td>2011</td>
<td>1704</td>
<td>3144</td>
<td>1844</td>
<td>1300</td>
</tr>
</tbody>
</table>
Table 12: Simulated millet yields for the period 2013-2033

<table>
<thead>
<tr>
<th>Years</th>
<th>Rainfall (mm)</th>
<th>Simulated millet yields (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>1622</td>
<td>1865</td>
</tr>
<tr>
<td>2014</td>
<td>1512</td>
<td>1822</td>
</tr>
<tr>
<td>2015</td>
<td>1547</td>
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<td>2017</td>
<td>1719</td>
<td>1844</td>
</tr>
<tr>
<td>2018</td>
<td>1626</td>
<td>1933</td>
</tr>
<tr>
<td>2019</td>
<td>1829</td>
<td>2189</td>
</tr>
<tr>
<td>2020</td>
<td>1715</td>
<td>1841</td>
</tr>
<tr>
<td>2021</td>
<td>1427</td>
<td>1844</td>
</tr>
<tr>
<td>2022</td>
<td>1524</td>
<td>1820</td>
</tr>
<tr>
<td>2023</td>
<td>1295</td>
<td>1810</td>
</tr>
<tr>
<td>2024</td>
<td>1521</td>
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<td>1819</td>
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<tr>
<td>2027</td>
<td>1665</td>
<td>2013</td>
</tr>
<tr>
<td>2028</td>
<td>1230</td>
<td>1844</td>
</tr>
<tr>
<td>2029</td>
<td>1517</td>
<td>1844</td>
</tr>
<tr>
<td>2030</td>
<td>1628</td>
<td>1918</td>
</tr>
</tbody>
</table>
Derivation of climate and soil parameters

Climate data

i) Potential evapotranspiration (PE) input in millimeters

Evapotranspiration is the total water flux into the atmosphere, i.e. the sum of evaporation and transpiration (water flux through plant stomata) and Potential Evapotranspiration (PE) is the water flux under non-limiting soil water conditions (Allen et al., 1998). Direct measurement of evapotranspiration is impractical but a parallel approach to estimating evapotranspiration has been proposed by Penman (1950). The approach is based on the observation that evapotranspiration from a completely vegetated, moist (i.e. continually supplied with water) surface ($E_v$) is related to evaporation from a surface of open water ($E_o$) (Penman, 1948). Under ideal conditions, evapotranspiration is referred to as potential evapotranspiration ($PE$) and is related to open-water evaporation by an empirical factor, $f$, which varies in response to the duration of daylight throughout the year (equation 3). In equatorial regions, the consistency in daylight hours yields a conversion factor that deviates less than 5% throughout the year (Riou,
Thus a single factor can be applied throughout the year without encountering significant error.

\[ \text{PE}_w = f_1 \text{E}_o \]  

\[ \text{Equation 6} \]

ii) Pan evaporation (E\(_o\)) input in millimeters

Evaporation is the rate of water loss from a free water surface such as a reservoir, lake, pool, or saturated soil. E\(_o\) is estimated from either meteorological data or open-water evaporation pans. Penman (1948; 1949) developed a ‘semi-empirical’ equation that requires records of wind velocity mean vapor pressure and mean surface temperature. Less empirical equations have subsequently been derived (Rijtema, 1965; Van Bavel, 1966) but limited data sets for many regions including Uganda; do not make their application viable. Therefore evaporation from standardized pan (E\(_{\text{pan}}\)) is monitored and converted to E\(_o\) by use of a pan factor (Equation 4). A precise pan factor is not known however, the average of 0.70 is used. In the tropics, pan evaporation is often observed to exceed open-water evaporation due to exposure of the pan (Rijtema, 1965) so pan factors are less than unity.

\[ E_o = (\text{Pan factor}) \ E_{\text{pan}} \]  

\[ \text{Equation 7} \]

Gulu station did not have data on pan evaporation which could have been used to also estimate potential evapotranspiration and this became a limitation of the model however, pan evaporation data for lira station was used since Lira district is located in the same agro-climatic zone with Gulu district.

iii) Run off (RO) input in millimeters
In the absence of data regarding the intensity and duration of rainfall events, runoff is estimated on the basis of daily rainfall records, relief and an estimated soil infiltration capacity of 10mm h\(^{-1}\). For daily rainfall exceeding 10mm h\(^{-1}\), runoff was estimated to be 1% whereas rainfall events less than 10mm h\(^{-1}\) runoff was estimated to be zero (Howard and Kurundu, 1992).

**Soil data**

The soil samples were taken to the soil science laboratory in Makerere University for measurements and derivation of soil parameters required by the Penman Grindley soil moisture balance model for millet yield simulations.

i) Root constant (C)

Rooting depth multiplied by soil porosity (0.3) provides a root constant of 127 for farmland (Taylor, 1999)

Soil Moisture Deficit, Wilting point and Drying point Calculations according to; (Penman, 1949; Allen, 1998; Howard, 1999; FAO, 2013)

The Soil Moisture Deficit (SMD) is a measure of soil moisture between field capacity and existing moisture content, \(\theta_c\), multiplied by the root depth and it is calculated as follows:

\[
SMD = (\theta_c - \theta_i) \times RD \quad \text{Equation 8}
\]

\(\theta_c\) is the volumetric moisture contents at field capacity, \(\theta_i\) is the existing moisture content, and RD is the rooting depth of the crop for this case it was millet.

Before calculating SMD, other important soil parameters have to be derived which include porosity, \(\phi\); its volumetric moisture content, \(\theta\); its saturation, \(S\); its dry weight moisture fraction.
W; its bulk density, $\gamma_b$; and its specific weight, $\gamma_s$. The relationships among these parameters are as follows.

The porosity, $\phi$, of the soil is the ratio of the total volume of voids or pore space, $V_p$, to the total soil volume $V$:

$$\phi = \frac{V_p}{V} \quad \text{Equation 9}$$

The volumetric water content, $\theta$, is the ratio of water volume in the soil, $V_w$, to the total volume, $V$:

$$\theta = \frac{V_w}{V} \quad \text{Equation 10}$$

The saturation, $S$, is the portion of the pore space filled with water:

$$S = \frac{V_w}{V_p} \quad \text{Equation 11}$$

These terms are further related as follows:

$$\theta = S \times \phi \quad \text{Equation 12}$$

When a sample of field soil is collected and oven-dried, the soil moisture is reported as a dry Weight fraction, $W$:

$$W = \frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Dry Weight}} \quad \text{Equation 13}$$
To convert a dry weight soil moisture fraction into volumetric moisture content, the dry weight fraction is multiplied by the bulk density, $\gamma_b$; and divided by specific weight of water, $\gamma_w$ which can be assumed to have a value of unity. Thus:

$$\theta = \gamma_b W / \gamma_w \quad \text{Equation 14}$$

The $\gamma_b$ is defined as the specific weight of the soil particles, $\gamma_s$, multiplied by the particle volume or one-minus the porosity:

$$\gamma_b = \gamma_s * (1 - \phi) \quad \text{Equation 15}$$

The volumetric moisture contents at field capacity, $\theta_{fc}$, and permanent wilting point, $\theta_{wp}$, then are defined as follows:

$$\theta_{fc} = \gamma_b W_{fc} / \gamma_w \quad \text{Equation 16}$$

$$\theta_{wp} = \gamma_b W_{wp} / \gamma_w \quad \text{Equation 17}$$

Where $W_{fc}$ and $W_{wp}$ are the dry weight moisture fractions at each point.

The total available water, TAW is the difference between field capacity and wilting point moisture contents multiplied by the depth of the root zone,

$$\text{TAW} = (\theta_{fc} - \theta_{wp}) \text{RD} \quad \text{Equation 18}$$
The Soil Moisture Deficit, SMD, is then calculated as a measure of soil moisture between field capacity, $\theta_{fc}$ and existing moisture content, $\theta_i$, multiplied by the root depth and it is calculated as follows:

$$SMD = (\theta_{fc} - \theta_i) \times RD$$ as indicated at the beginning.

Equation 16 indicate the resulting output of the soil moisture balance model

$$SM \ g/l = f(C, D, F, RO, SMD, P, PE_t, E_o)$$

Equation 19

Where, SM g/l is the net gain/loss of soil moisture,

C is the root constant,

D is the wilting point,

F is the drying point,

RO is runoff,

SMD is soil moisture deficit,

PE, is potential evapotranspiration,

Eo is pan evaporation.
APPENDIX B

Questionnaire

An assessment of climate variability and change and its effects on millet yields in Paicho Sub County, Gulu district.

Dear Sir/ Madam,

I am currently undertaking a master’s Degree of Geography in Makerere University and part of the requirement is a research thesis. I am investigating in the area highlighted in the topic above.

In light of your experience and expertise; you have been identified as a resourceful person to make this study possible. You are therefore, humbly requested to contribute by responding to questions contained in this questionnaire.

The information given will be treated with the highest degree of confidentiality and for academic purposes only.

Thank you very much in advance for your time given

ORIANGI GEORGE
Please kindly tick the appropriate answer or fill in the blank spaces.

Parish…………………………,
Village……………………………….
LCI…………………………………………
…………………………...
Date......................................
1 (a) Name of household head………………………………………………
..
(b) Name of respondent (if different from household head above)
…………………………………………
(C) Sex…………………………,
Age……………………………………
……...
2. Household type: (a) Male headed, (b) Female headed
3. What is your average weekly income? (a) < 10,000shs (b) 10,000-20,000shs (c) 20,000-50,000shs. (d) 50,000-100,000shs (e) > 100,000shs.
4. What is the size of your land in acres?
   a) 1-10. b) 11-20. c) 21-50 d) 50+
5. Do you receive farmer-to-farmer extension service?
   (a) Yes (b) No
6. Do you have access to credit? (a) Yes (b) No

Evidence of climate change and variability
7. Have you noticed changes in climate in your village in the last 30 years? (a) Yes (b) No (c) don’t know

8. If yes, indicate which parameters have changed most by ranking from the most changed to is the least changed.
   (a) Rain fall  (b) Temperature  (c) Wind speed and direction (d) humidity (f) cloud cover (g) sunshine hours (h) others
   (specify)……………………………………
   ……………

9. If yes which season has changed most?
   (a) Dry season (b) Wet season (c) Others
   (specify)……………………………………
   ……..

10. How predictable is the onset rains now compared to 15 or 30 years back?  (1) Less predictable/ Unpredictable; (2) Predictable; (3) don’t know.

Coping mechanisms to climate stressors

11. How have you managed to cope up with the effects of climate variability and change in your area? (a) asking neighbors for water during drought (b) migrating from water stressed areas (c) contacting veterinary personnel (d) buying food (e) stocking drugs (f) water harvesting (g) pasture preservation (h) getting food help from relatives, food agencies and community(i) exchange of labor for food (g) others
   (specify)……………………………………
   ……………

Adaptation strategies to climate stressors

12. Which of the following adaptation strategies do you undertake to reduce the effects caused by climate change and variability on your agricultural production?
   (a) Getting other jobs outside agriculture
   (b) Adjusting on planting dates and diversification of production
   (c) Mixed cropping
(d) Rearing improved animal breeds
(e) Growing improved crop varieties
(f) Migrating from water stressed and flood prone areas
(g) Growing first season crops in second season and growing second season crops in first season
(h) Carrying out irrigation agriculture
(i) Addition of fertilizers
(j) Others
specify..................................................
..................................................

14. If yes tick any one of the following institutions that exist in your area?

a) Local councils
b) Farmers groups
c) Clan/ elders networks
d) Family network
e) Religious institutions
f) NGO’s/CBO’s

15. For any institution selected above, identify its major role among the following roles?

a) Governing entitlements to key resources
b) Making decisions on when farmers should plant crops
c) Avoiding tree cutting
d) Avoiding bush burning
e) Providing access to credit
f) Providing access to information

The role of institutions in community adaptation

13. Are there any institutions in your area that enable your household to cope and adapt to climate variability and change? (a) Yes  (b) No
g) Capacity building

(h) Others

specify……………………………………

……………………………………