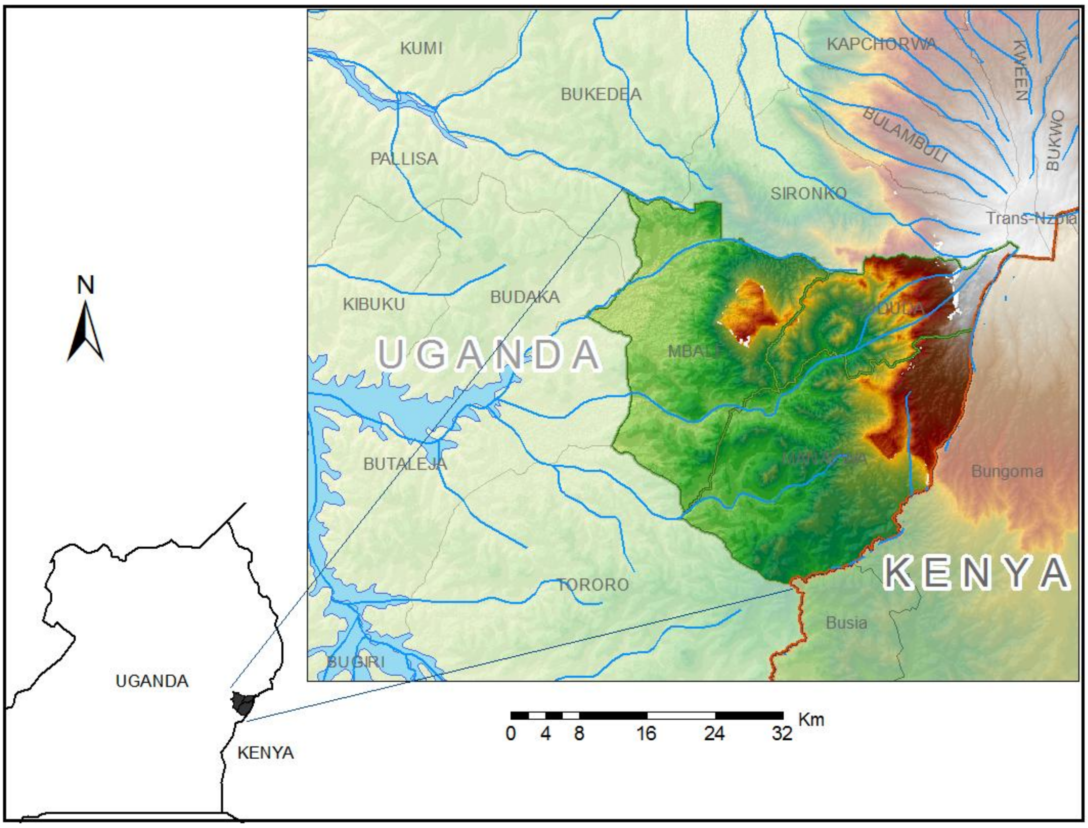
Climate Profiles and Climate Change Vulnerability Assessment for the Mbale Region of Uganda[1]



May 2013

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[1] Shortened version of full report prepared by Dr Michael Mbogga in 2012

Summary

This report presents an assessment of meteorological data, descriptions of the current climate and an assessment of climate projections and vulnerability to climate change for the Mbale region of Uganda.

Weather station data were obtained for the Mbale region covering the period 1960 to present. The quality and quantity of available climate data limited the description of climate for the Mbale region, as well as the development of strategies to deal with the impacts of climate change. The Mbale region historically had a good coverage of weather stations, most of which are currently non-functional. Efforts are therefore needed to collect weather data from as many representative locations as possible to be able to support climate risk management activities, as well as provide information that can be used for long-term climate change mitigation and adaptation planning.

There is evidence that climate in the Mbale region is changing, with expected continuing changes in future projections of temperature and rainfall. There has been an increase of between 0.4 and 1.2 ^{o}C in monthly temperatures in the Mbale region during the 2001-2011 period when compared to the 1961-1990 period, which is consistent with GCM projections for the future of an increase in temperature for the next 30 years. Recent changes (2001-2011) in rainfall are more difficult to detect and appear to be influenced by multi-decadal variability, sometimes trending in the same direction as future projections from Global Circulation Models (GCMs). For example, the observed reduction in February rainfall and increases in May rainfall during the 2000-2011 period is similar to projections from the majority of GCMs. More annual average rainfall is projected during the 2010 - 2039 period compared to the 1961-1990 average.

Reduced rainfall during the December to February period, as projected by the GCMs in the future, will likely increase water stress for crops and may lead to scarcity of water for domestic use during that period. Whilst beneficial for crops and domestic water use, higher rainfall in the wet seasons (March, April, May and September, October and November) can be expected to increase erosion, especially on steep slopes, as well as flooding in valleys and siltation of streams and rivers, especially if it is associated with increases in rainfall intensity. Higher rainfall, especially during the September to October period, however, provides an opportunity for growing a wide range of crops during the second rain season. Overall increases in temperature are expected to increase the spread of pests and diseases such as the coffee berry borer. Higher temperatures will also facilitate the spread of malaria to high elevation areas. Over the last one and half decades at Mbale, there has been a clear shift from April to May as the wettest month, with the onset of the rainfall season delayed. The other major trend has been towards more rainfall during the previously “shorter” rains period of September to November. Overall, a clear trend of more rainfall throughout the year is becoming apparent.

A multi-faceted approach is required to enhance the resilience and adaptive capacity of the environment and the people of the Mbale region to climate change impacts. One crucial area is population growth that was mentioned by all stakeholders, because resources in the region are already overstretched. Whereas reducing population pressure is a long-term objective, immediate interventions that promote improved farming techniques, increase awareness among the people about climate change, its impacts and the role each member of society needs to play for the enhancement of livelihoods are urgently required. Building on existing resources, the banana-coffee system will need to be strengthened through encouraging shade trees for the coffee, and adding minimum tillage crops to the system. Fruit trees would also help provide valuable income, necessary nourishment and protect soils. In terms of soil and water conservation, terraces will need to be encouraged and regulations implemented to limit cultivation on steep slopes, as well as encouraging tree planting.

Encouraging farmers groups and cooperatives will help improve incomes derived from agricultural produce, as well as the exchange of information and technologies between farmers. The current

willingness of the local government and political leaders needs to be harnessed for any climate change related intervention. This will also ensure the streamlining of climate change adaptation into relevant government interventions in the Mbale region.

Abbreviations and Acronyms

ACCRA	Africa Climate Change Resilience Alliance
ACTED	Agency for Technical Cooperation and Development
BCU	Bugisu Cooperative Union
CCAFS	Climate Change Agriculture and Food Security
CGIAR	Consultative Group on International Agricultural Research
CRU	Climate Research Unit, at the University of East Anglia, UK
CSA	Climate Smart Agriculture
DEM	Digital Elevation Model
DfID	Department for International development - UK
DJF	December January February season
DRR	Disaster Risk Reduction
FACE	Forests Absorbing Carbon dioxide Emissions
FIEFOC	Farm Income Enhancement and Forest Conservation
GCM	General Circulation Model
IPCC	Intergovernmental Panel on Climate Change
ITCP	Integrated Territorial Climate Plan
JJA	June July August season
MAM	March April May season
MERECP	Mt. Elgon Regional Ecosystem Conservation Programme
MWE	Ministry of Water and Environment - Uganda
NAADS	National Agricultural Advisory Services
NAPA	National Adaptation Plan for Action
NUSAF	Northern Uganda Social Action Fund Project
PRECIS	Providing Regional Climates for Impacts Studies
SON	September October November season
SRES	Special Report on Emissions Scenarios by the IPCC
TACC	Territorial Approach to Climate Change
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UWA	Uganda Wildlife Authority
WorldClim	set of global climate layers (climate grids) with a spatial resolution of about 1 square kilometer developed by Hijmans *et al* (2005)

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1 Introduction

1.1 Background

The Territorial Approach to Climate Change (TACC) project for the Mbale region of Uganda is implemented by the United Nations Development Programme (UNDP), with financial support from the Danish Embassy, the UK Government's Department of International Development (DFID) and UNDP, also from technical and development support provided by the Welsh Assembly Government. The TACC-Mbale is one of the pilot projects for the Global Initiative, "Down to Earth: Territorial Approach to Climate Change". The Global initiative is a collaborative effort involving the UNDP, the United Nations Environment Programme (UNEP) and eight associations of regions around the world. This global initiative aims at supporting sub-national governments to identify and develop projects which can meet local needs while building both climate resilience and the infrastructure needed for low-carbon growth. The initiative helps to achieve this through promoting robust collaborative actions amongst regions within industrial and developing countries, with international organizations, UN agencies and the private sector to foster knowledge transfer and direct investment to deal with the impacts of climate change.

The TACC-Mbale project is providing a coordinated mitigation and adaptation plan to address the negative impacts of climate change in three districts (Mbale, Manafwa and Bududa) of the Mbale Region of Uganda. The project will enable the region realize low carbon and climate change resilient development. Towards this objective, the TACC-Mbale project is assisting the Mbale Region to develop its own Integrated Territorial Climate Plan (ITCP), which integrates climate change adaptation and mitigation strategies into regional development planning. The process of developing the Mbale Region ITCP includes developing a policy and investment plan that identify appropriate regulatory and financial instruments for the implementation of the actions that have been selected by the ITCP and assist the region to access, combine and sequence a variety of financial resources needed to implement the plan. Outputs of the TACC-Mbale project include; a platform for climate change planning and programming, capacity building to integrate climate change issues into regional development plans and actions; an Integrated Territorial Climate Plan (ITCP) for the Mbale region; a climate change policy and investment package; and synthesis and dissemination (within and beyond Uganda) of lessons learned and best practices. This consultancy report presents climate profiles and an assessment of climate change risk and vulnerability for the Mbale region.

The Mbale Region of Uganda as defined for the TACC Mbale project comprises the present Bududa, Manawa and Mbale Districts (total area 137,128ha or 1371.3 sq km). The population of the districts is estimated at close to a million people, making the Mbale region one of the most densely populated regions of Uganda. The large number of people, together with the physiographic make-up of this region (mountainous, with steep terrain combined with high rainfall and unstable soils) make it very vulnerable to the impacts of climate change. Landslides of various magnitudes already occur nearly every year, some of which cause extensive damage to property and loss of life (NEMA, 2010). These landslides are mainly triggered by high rainfall, loss of tree cover and cultivation on steep slopes.

The Uganda National Adaptation Programmes of Action (NAPA) (RoU, 2007) notes that climate change may lead to an increase in the frequency and intensity of extreme weather events, including droughts, floods, landslides and heat waves. The report further notes that; rainfall is the most sensitive climate variable that affects social and economic activities; observed rainfall has been falling with greater intensity in some regions; western, northern and north-eastern districts are experiencing long droughts, which are becoming more frequent, recent years have witnessed erratic onset and cessation of rainfall seasons. These impacts are coupled with increasing frequency of droughts and sustained warming, particularly over southern parts of Uganda. The Mbale region has always has an erratic rainfall regime, which is intensifying; more intense rainfall due to increasing weather variability is already having devastating consequences to agricultural production and livelihoods.

A temperature increase of about 1.0 to 3.1°C has been projected, accompanied by low to moderate increase in precipitation over the next 40 years for most areas of Uganda (McSweeney et al., 2010). Changes in climate in sub-Saharan Africa will likely result in increased food insecurity, higher incidence of pests and diseases, soil erosion and land degradation, and reduced agricultural productivity and disrupting the functioning of natural systems (Parry et al., 2005; Schmidhuber and Tubiello, 2007). All these will ultimately affect livelihoods of smallholder farmers as well as the urban poor, whose numbers are projected to rise to more about 50% of the country's population by 2020. Smallholder farmers, who comprise the bulk of the country's population, have dealt with climate variability and extremes of weather in the past, for example the people of Mbale have braved hundreds of landslides in the last century. However, concerted effort is required to help these people to cope with current and projected changes in climate. Uganda's farming households are highly vulnerable to climate change because of a number of reasons. Production systems have rarely changed over the last 5 or so decades, almost all agricultural production is rain-fed, with little to no use of irrigation, fertilizers or other inputs. Without appropriate adaptation, these production methods will be threatened by changes in climate.

Because of recent and projected changes in climate, the only option for smallholder farmers is to adapt farming systems and other sources of livelihood to climate change. Development of adaptation strategies requires that climate trends are well understood, as well as information on the vulnerabilities of natural and human systems. Therefore understanding historical, current and projected climate of the area forms one of the most fundamental steps in the process of developing climate change adaptation strategies. The next stage is to have a good understanding of how vulnerable current systems are to the projected changes in climate.

The major goal of this report is to present current and projected climate profiles for the Mbale region and to assess vulnerabilities of the environment, society and the economy of the region to the projected changes in climate. Details of the prospective range of climate projections for the Mbale region are needed to inform investment strategies that will facilitate the transition to climate-resilient development. Assessment of vulnerability is important for efforts to develop climate change adaptation strategies.

Weather station data from station in the Mbale region and neighbouring districts has been used to describe the current climate for the Mbale region. Baseline climate for the region is described using spatial climate grids, WorldClim developed by a consortia or organizations working on climate change and agricultural and natural resources (Hijmans et al., 2005; Ramirez-Villegas et al.). Projections of future climate simulated by global circulation models (GCMs) and three emissions scenarios – A1B, A2 and B1. The magnitude of projected changes in climate were used together with socio-economic and topographic data to provide likely exposure of the Mbale region to climate hazards during the 2010-2039 and 2040-2069 future time slices. The final tasks involved assessing the how the environment, society and economy can be harnessed to enhance adaptive capacity of the region to climate change over the 21st century.

1.2 General information about the Mbale region of Uganda

1.2.1 Location and general description

The Mbale region of Uganda covers the present day districts of Bududa, Manafwa and Mbale (see Figure 1). The three districts were recently created out of three counties of the old Mbale District, (Bungokho, Manjiya and Bubulo), together with Mbale municipality. The Mbale region extends from the lower to the upper slopes of the southwestern slopes of Mt. Elgon in eastern Uganda and share a border with western Kenya.

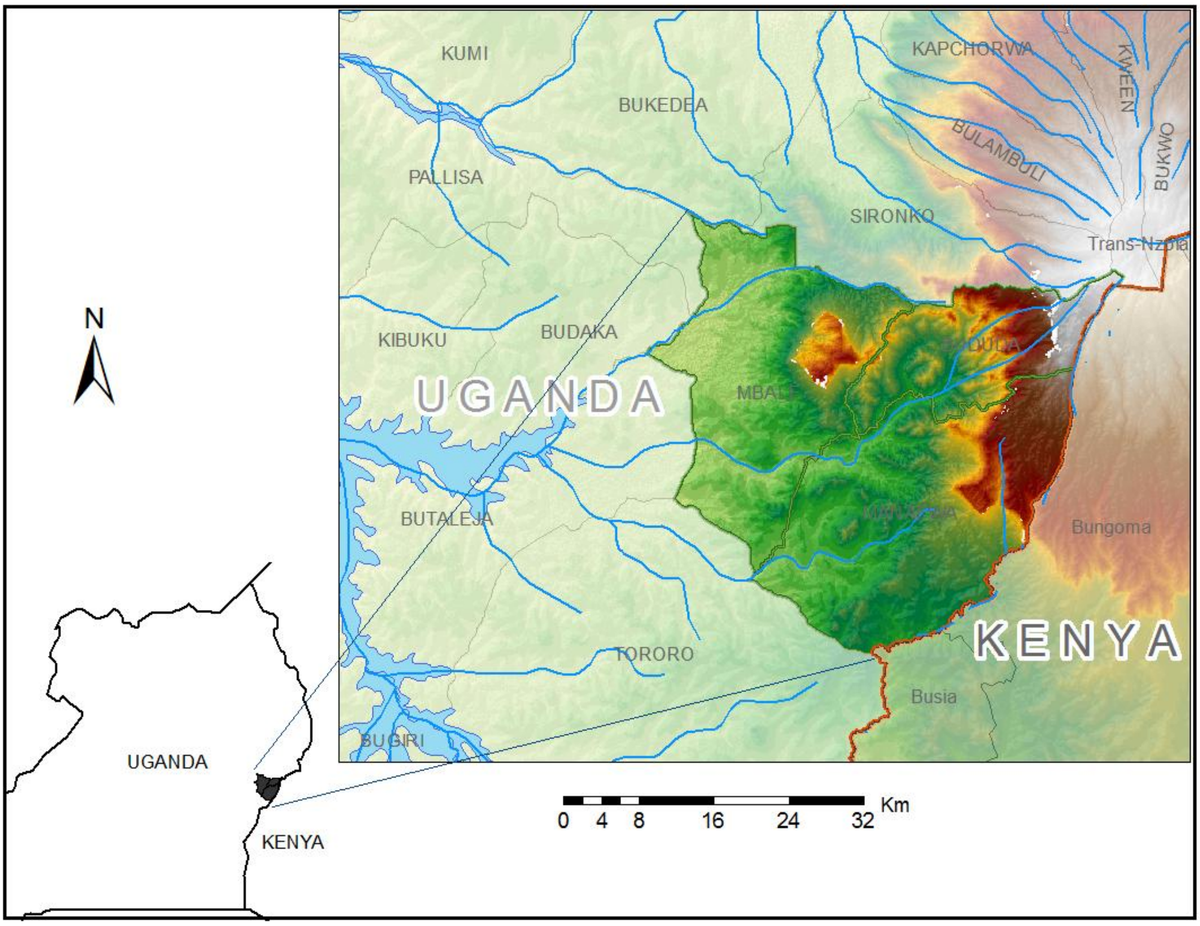

Figure 1: Map of the Mbale region districts (Bududa, Manafwa and Mbale)

Mbale District, the western-most district of the trio, is low to medium in elevation, with Wanale Hill the highest point in the district. Manafwa District is mainly medium to high elevation ranging from 1200m to 1800m asl. Bududa is also medium to high elevation, with most of its highest areas lying within Mt. Elgon Forest National Park. The Mbale region receives relatively higher rainfall compared to other locations at similar altitudes in other parts of the mountain. Rainfall received in the forest zone of the mountain makes Mt. Elgon an important catchment area for several million people in the region (van Heist, 1994). The administrative sub-divisions of Bududa, Manafwa and Mbale districts are shown in Figures 2, 3 and 4. Administratively, Bududa district has 7 sub-counties namely Bududa, Bubiita, Bukibokolo, Bukigai, Bulucheke, Bumayoka and Bushika (Figure 2). Manafwa district has 10 sub-counties including Bubutu, Bugobero, Bumbo, Bumwoni, Bupoto, Butiru, Buwabwala, Buwagogo, Kaato, and Sibanga (Figure 3). Mbale has the following 11 sub-counties Bufumbo, Bukonde, Bukyiende, Bungokho, Bungokho-mutoto, Busano, Busiu, Busoba, Nakaloke, Namanyonyi Wanale and 2 divisions, namely Industrial Northern Division and Wanale Division (Figure 4).

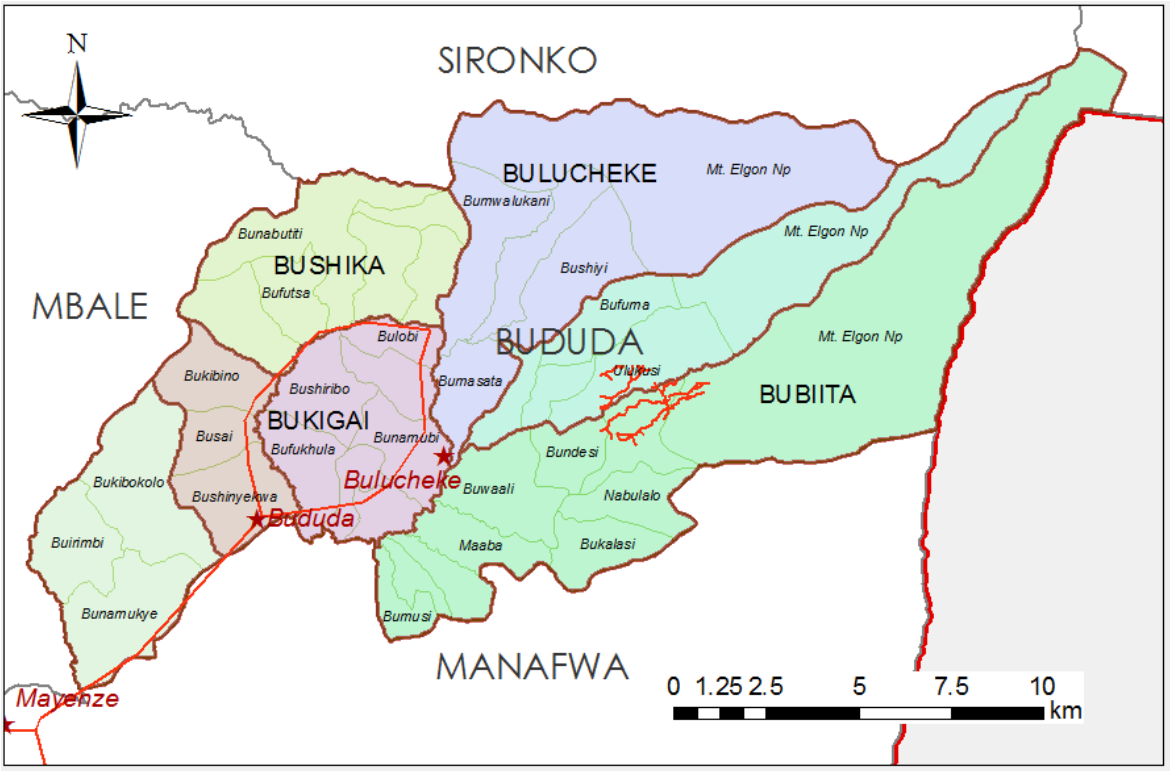

Figure 2: Sub-counties of Bududa District

1.2.2 Geology and Soils

The Pre-Cambrian rock system and the Cainozoic rock formations are the major formations underlying the Mbale region. The pre-Cambrian rock system is mainly granitic or high to medium metamorphosed formations, consisting of undifferentiated gneisses and elements of partly granitic and metamorphosed formations (NEMA (National Environment Management Authority), 2004). Cainozoic formations consist of Pleistocene to recent sediment, alluvium, black soils and moraines. The impermeable nature of these rocks make most of the areas adjacent the Mount Elgon Park susceptible to landslides in the rainy seasons of the year (NEMA 2004). Soils are majorly clayey in the highlands, clay loams in mid-altitude areas and sandy in the lowlands and valleys.

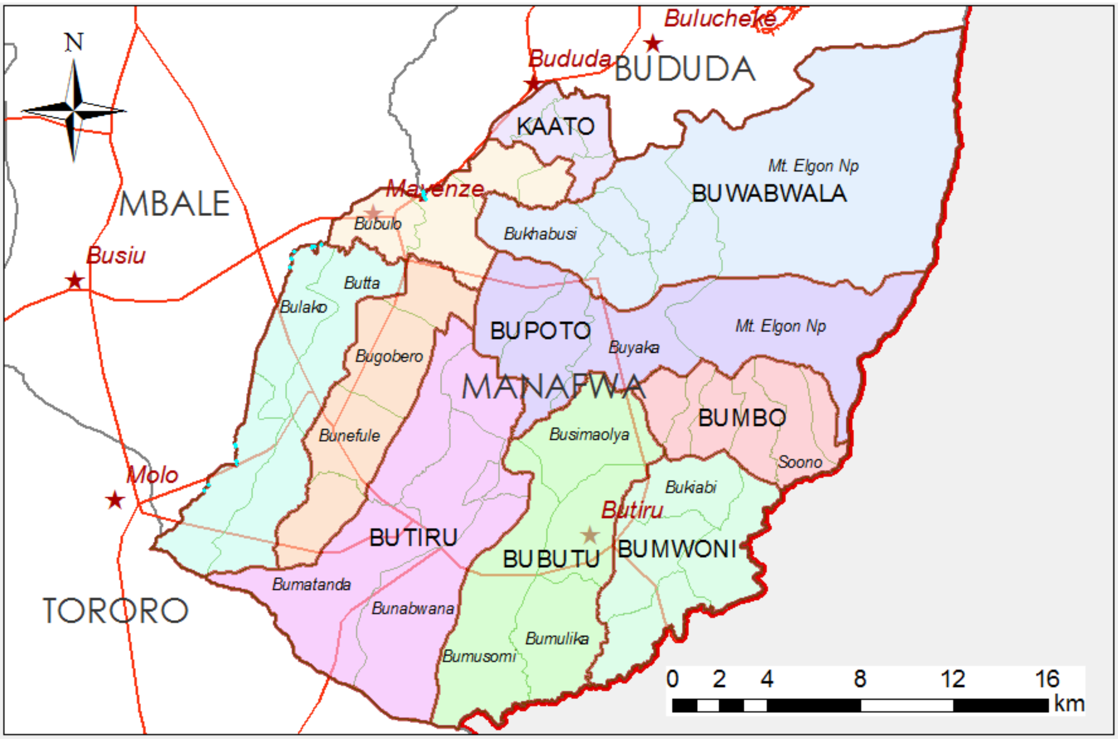

Figure 3: Sub-counties of Manafwa District

The geomorphology of Bududa is greatly controlled by the volcanism and doming of the rocks. The main geology is fenitized basement rocks and in the central part known as Bukigai, a pre-Elgon alkaline volcanic structure, the Butiriku carbonatite Complex stands out. This carbonatite intrusion of Oligocene-Miocene age (King *et al*, 1972) is one of the sub-volcanic complexes that occur along a 65km stretch in south-eastern Uganda. The Mt Elgon area is covered with the agglomerates. Soil surveys done by Isabirye *et al*, (2004), show that soils in this area have a sequence where the central carbonatite dome is covered by Rhodiandic Nitisols and the surrounding areas by Rhodiandic Luvisols, Hapliclixic Ferralsol and Humicandic Nitisols.

1.2.3 Vegetation

The Mbale region is heavily cultivated, with little to no remnants of natural vegetation in the lower and mid elevation areas. Natural vegetation remains in the higher elevation areas, most of which fall within the Mt. Elgon Forest National park. In the higher altitudes, the natural vegetation changes from montane, to grassland, bamboo then heath and moorland in that order. The supra-tropical forests up the mountain are dominated by with Camphor, *Aningeria adolfi-friederici*, *Podocarpus latifolius*, *Olea hochestetteri* and *Prunus africana* (Hamilton and Perrott, 1981). Mixed bamboo occurs at about 2,500-3,000m, which turns into open woodland dominated by *Hagenia abyssinica* and African rosewood, the heath zone 3,000-3,500m characterized by giant heath with grassy swards of tussock grass. The Afro-alpine region stretches from 3,500m to 4,321m asl, dominated by *Senecio elgonensis*.

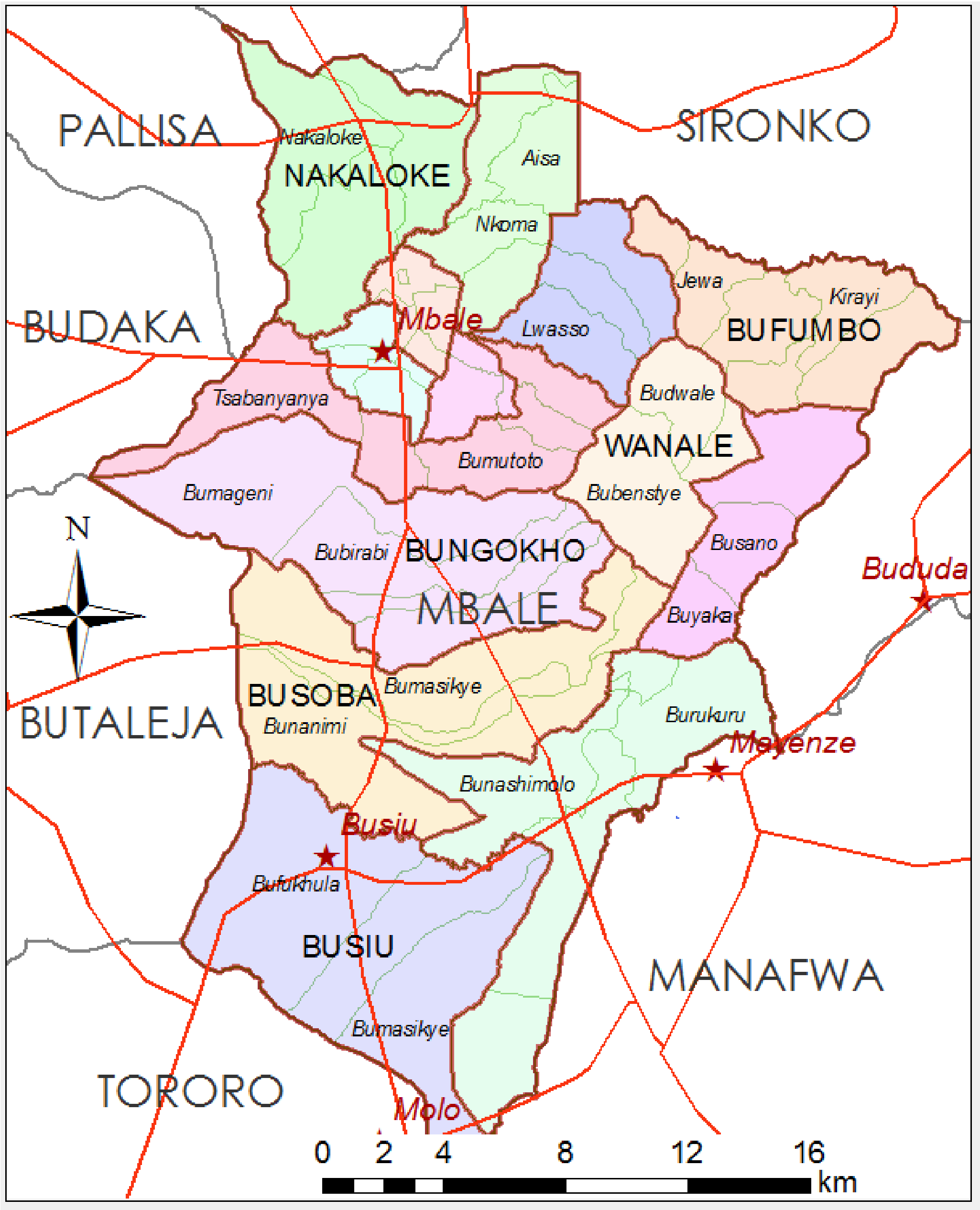

Figure 4: Sub-counties of Mbale District

Mt. Elgon National Park, which lies to the northeast of the region, was formerly a forest reserve with some members of the public still holding cultivation permits within the reserve. These permits were partly responsible for the degradation or encroachment on the forest, especially during periods when governance broke down in Uganda. Today the national park is relatively well protected and over recent years there have been several efforts to try to restore parts of the degraded forest.

1.2.4 Socio-economic characteristics

The Mbale region has about 590 persons per square km, making it one of the most densely populated parts of Uganda. Mbale town is the major urban area with a population of more than 150,000. There are numerous other smaller towns, including Bududa, Manafwa that are now growing since each now hosts the headquarters of their respective districts. The majority of the people of Mbale region are ethnic Bagisu, who have inhabited the western slopes of Mt. Elgon for centuries. Most people are engaged in agriculture, which is the main economic activity employing more than 80% of the population. The major crops grown at high altitudes include banana, arabica coffee and Irish potatoes, while at lower elevations the dominant crops are maize, millet, cassava, beans and sweet potatoes, cabbage and tomatoes. The Mbale region as well as other parts of the slopes of Mt. Elgon is the major Arabica coffee producing areas in Uganda. The coffee is normally intercropped with bananas, maize and beans. Occasionally the coffee is grown under trees *(Albizia* or *Cordia*) for shade.

There has been increasing concern about climate change and its impacts to the Mbale region. The region is highly vulnerable given its high population, high poverty levels, and mountainous landscape. The region has had numerous outbreaks of cholera particularly in the rain season. Rural areas in mid to high elevation areas have had landslides, siltation of rivers as well as washing away of top soil, which depletes soil nutrients hence affecting agricultural yields.

1.3 Objectives of the study

This study was to develop climate profiles for the Mbale region and evaluate the vulnerability of the region to projected climate changes over the 21st century.

Specific objectives include:

i) Evaluate meteorological data available in the Mbale region;
ii) Describe and map current and projected climate for the Mbale region;
iii) Assess and map risks and vulnerability of the environment, society and the economy of the Mbale region to climate change.

Specific tasks for each of the objectives include the following:

Objective 1. Analyze available meteorological data for the Mbale region
Under the first objective, quality of available data was evaluated and an attempt was made to detect homogeneities in the data due to factors other than climate change. In addition, historical climate trends were described. Under this task a review of simulated change for the wider eastern Africa region was also performed.

Objective 2. Develop past and projected climate change profiles for the Mbale region.
Building on outputs of objective one, objective two used other available climate data sources, a climate database for the Mbale region has been developed covering baseline (1961-1990) and 21st century projections. Future climate to cover two time “slices” the 2020s (2010-2039) and 2050s (2040-2069) are projected.

Objective 3. Assess risk and vulnerability to climate change
The third objective evaluated how the environment, society and economy of Mbale, Manafwa and Bududa Districts will be affected (i.e. how sensitive it is to the changes), including how existing sectors of society will be affected by the projected climate changes. In addition, interaction of socio-economic trends and their impact on sensitivity to climate change, and the potential to cope with, recover and adjust to the impacts of climate change (i.e. its adaptive capacity) were assessed.

Objective 4. Develop climate change vulnerability maps
The objective developed digital vulnerability maps through analysis using a computer-based geographical information system (with maps of topography, hydrology, soils, vegetation / land use and aspects of human population). The analysis was verified with local and national experts.

1.4 Structure of this report

Following this general introduction, section two of the report covers analysis of meteorological data, section three provides Mbale region climate profiles with both current or baseline and projected climate for the 21st century. Section 4 discusses the risk and vulnerability of the region to climate change. Section 5 summaries key findings and messages of the report. A glossary of key terms related to climate change and climate change vulnerability assessment used in this report is provided in Annex 1.

2 Analysis of Meteorological Data for the Mbale Region

2.1 Role of meteorological data in climate studies

The first and most fundamental step in climate change studies is to gain a good understanding of climate trends (both historical and projected), which will help determine whether a change in climate is occurring against the natural variability and the magnitude of any changes. This information forms the basis for the development of climate change mitigation and adaptation strategies, as well as for incorporating climate change issues into development planning. Typically, climate data are generated from daily weather records taken at weather stations. In a few instances, climate data will be sourced from satellites. Thus having a good network of weather stations and taking regular and accurate records from a good number of weather variables are very crucial. Typically in Uganda, weather stations are located close to settlements, with very little coverage in remote areas. These weather stations will record rainfall, minimum and maximum temperature, relative humidity and wind velocity, among other weather variables. Weather station records are then used to describe the climate of an area. Climate is normally computed as long-term averages (usually 30 years) for each of these variables (see Annex 1 for definitions).

Assessment of climate trends as well as climate impact studies normally rely on weather data collected from weather stations and then used to describe climate for those locations as well for the development of climate grids that are often used in spatial analysis and climate impacts modeling. These regular climate grids are normally generated using a number of interpolation techniques including kriging, weighted distance, thin splines (Daly, 2006). The starting point in creating these grids is current climate data, which is compiled from weather station locations, whereas future climate projections are based on model experiments that attempt to recreate the global climate system and project likely changes in the future based on greenhouse gas forcings.

Future climate projections are generated as deviations or anomalies from climate for a chosen baseline period, following assumptions of future human activities and theories corresponding impacts on the global climate system. Keeping track of past and present changes in climate is important because these trends and associated impacts can inform resource managers about likely impacts of projected changes in climate. As projections of the future climate are usually made as deviations from the present or a chosen baseline, if the baseline is wrong, then future projections will also be unreliable. Thus climate change detection and climate change impact modelling require high quality observed weather / climate data to be able to accurately describe trends in climate as well as correctly relate observed impacts to changes in climate (Hofstra et al., 2008).

The following section uses observed weather station as well as other available climate grids for the Mbale region to evaluate the meteorological data available for climate description and climate change assessment for the Mbale region. Climate trends since 1960 for the region are described.

2.2 Climate profiles for Mbale region - data sources

Describing the climate profile for the Mbale region was performed using climate data from two major sources. The first was weather station records from the Mbale region and surrounding areas and the second was climate grids that have been developed by international climate research centers. The WorldClim data used for baseline climate grids was compared with another set of spatial climate data developed from regional climate modeling PRECIS (Providing REgional Climates for Impacts Studies).

Future climate projections are typically generated by general circulation models (GCMs) at very coarse resolution, usually at grid cells of several hundred kilometers, requiring downscaling before they can be used regionally or locally. GCMs simulate the global climate by calculating three dimensional evolution of the atmosphere typically over a 20-minute timestep, based on the physical laws for atmospheric mass, momentum, total energy, and the effects of various atmospheric components such as water vapour (Randall et al., 2007). Outputs of GCMs have been shown to closely reflect historical (Jansen *et al,* 2007) and current changes in climate in several regions around the world (Randall et al., 2007).

GCMs are realized based on greenhouse gas emission scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). These emission scenarios are alternative representations of the future, also referred to as “story lines” of potential population growth and economic development and corresponding levels of greenhouse gases in the atmosphere (Nakicenovic et al., 2000). There are generally four major story lines or emissions scenario families (A1, A2, B1, B2), recommended by the Intergovernmental Panel for Climate Change (Nakicenovic et al., 2000).

- A1 represents a trend of globalization, resource-intensive economic growth and rapid population increase;
- A2 assumes slower population growth and regionally fragmented economic growth;
- B1 assumes the same global population growth as A1, but a shift towards a service and information economy;
- B2 represents the lowest population increases and local, environmentally sustainable economies. The B2 scenario was not used because it has been deemed very unlikely given that recent emission correspond to projections for the B1 and A1 scenario families.

Climate change projections are highly uncertain. Climate model simulations differ for a range of reasons including technical issues such as spatial and vertical resolution, parameterization issues like representation of processes such as clouds, water vapour, ocean mixing, terrestrial processes, and feedbacks relating to water vapour, clouds, snow and terrestrial (Beaumont et al., 2008). Beaumont *et al*, (2008) suggest that more fuel intensive emissions scenarios such as A1 and A2 over the more conservative B1 and B2 scenarios be used because recent studies have demonstrated that fossil fuel CO_2 emissions since 2000 have increased at a greater rate than previous decades (Canadell *et al,* 2007; Raupach *et al,* 2007).

2.3 Quality control of available meteorological data

Weather stations used to provide meteorological data around the Mbale region include Mbale weather station (which is currently closed, Manafwa (recording only precipitation), Bugusege Coffee Research Station, and one in Buginyanya (recording minimum and maximum temperature, precipitation, relative humidity and wind velocity) (Table 1). A weather station was started in Bududa in late 2010 recording only rainfall. Data from this station could not be used in the description of climate profiles for this region because the station has not been in operation long enough. It is important to note that none of these weather stations has a complete record of all-weather variables from time when each of these stations started operating. Gaps in data have mainly been due to failure of the people responsible for taking weather records to take readings for all days.

Table 1: Weather stations, data collected and period covered in the Mbale region

Station Name	Data available	Time period	Operational
Mbale	- Maximum temperature - Minimum temperature - Rainfall	1960-1987 1960-1987 1970-1987	No
Manafwa	- Rainfall - maximum temperature - minimum temperature		Yes

Bududa	- Rainfall	2010 to present	Yes
Nabumali	- Temperature	1960-1976	No
Buginyanya	- Maximum temperature - Minimum temperature - Rainfall - Relative humidity - Wind velocity	1960 to present 1960 to present	Yes
Bugusege	- Rainfall	1940 to 1993	No

Given the recent changes in climate in the Mbale region, such as increasing frequency and magnitude of landslides, there have been efforts to improve weather data collection. A few weather stations have been set-up, however, issues remain with the weather data for the Mbale region include the following:

- Missing data results in no records for temperature, (on some datasheets it is mentioned that the officer is away on official duties);
- Use of different data entry forms or lack of proper data entry forms;
- Errors in calculation of monthly precipitation values;
- Areas not well covered by weather stations.

It is the role of the Meteorology Department in the Ministry of Water and Environment to compile weather data from all locations in the country. However not much of the data collected in the region had been entered. Thus, the author had to obtain some of the weather data for this study directly from field data sheets. It is recommended that the Meteorology Department should streamline the responsibility of regulating weather data recording, as well as coordinating the compilation and description of weather data recorded not only in the Mbale region but the entire country.

The rain gauge network in Uganda was relatively extensive and well maintained up until about 1990; however, reliable time-series data are difficult to obtain and, once obtained, there tend to be significant gaps in the time series (Asadullah *et al,* 2010). Whereas rainfall data can be derived from remotely sensed data, such products have been found to underestimate rainfall over mountain areas, attributed to satellites failing to pick up the orographic enhancement of rainfall (Asadullah *et al*, 2008 and Ebert *et al*, 2007). In other cases, satellite data overestimates dry season rainfall in mountainous areas (Dinku *et a,l* 2010).

2.4 Detecting homogeneities

The only weather station in the Mbale region with a near complete record of rainfall and temperature data since 1960 is the Buginyanya weather station. This weather station is actually not located within the Mbale region, but in Bulambuli District, Buginyanya lies a few kilometers to the north at 1835m above sea level. This elevation is representative of high elevation locations in Manafwa and Bududa Districts. Data collected at this weather station is however not representative of the weather conditions at lower elevation locations in the region such as in western parts of Mbale district of southern Manafwa. Another weather station that was valuable for rainfall data was located the Bugusege coffee station located in Sironko district to the north of the region at about 1400m asl. This elevation is representative for locations in Manafwa and Bududa districts. Spatial distribution of weather station used to describe historical and current climate for the Mbale region are shown in Figure 5.

From Figure 5, which also indicates the duration for which weather data is available for each of the stations, it is evident that at one time the region had a reasonably good coverage of weather stations, particularly for the low elevation areas, however the majority of these stations recorded weather for fewer than 20 years. In addition, these mainly recorded only rainfall. High elevation areas in western parts of Bududa and Manafwa were not well represented.

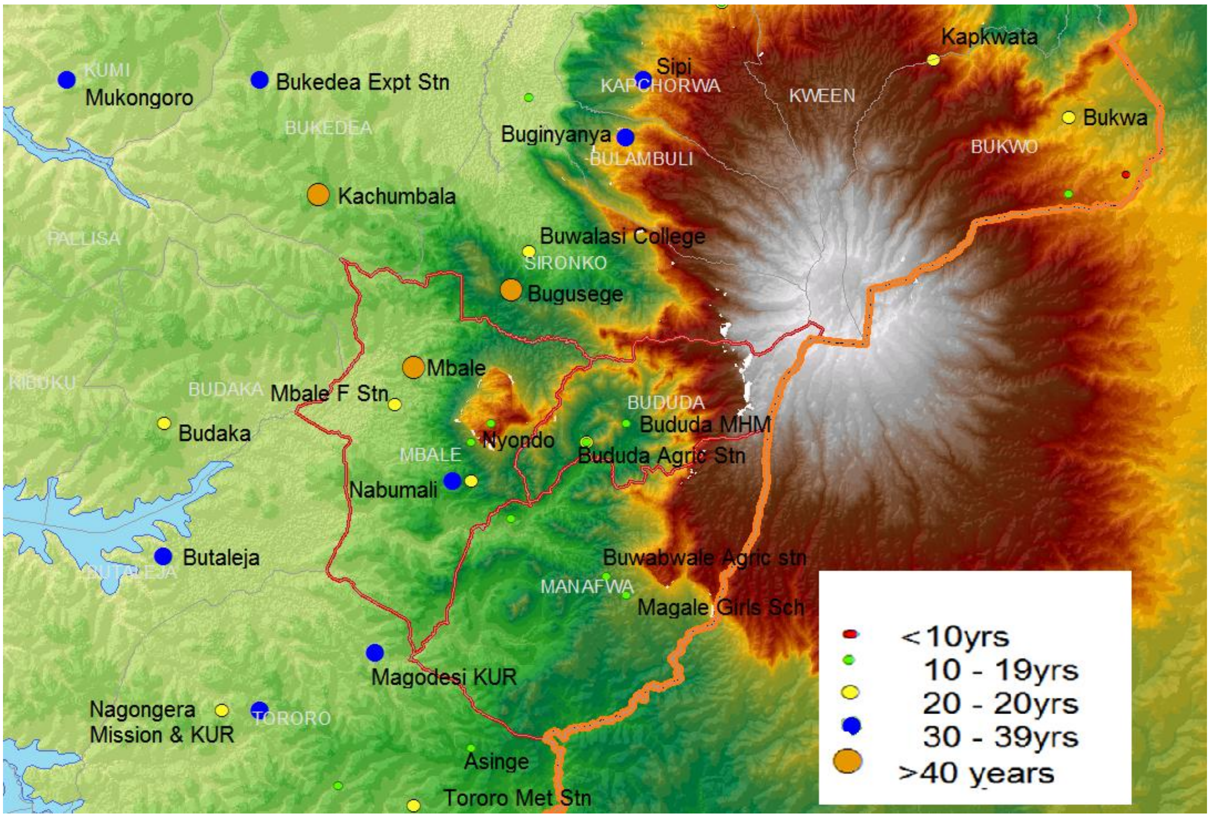

Figure 5: Spatial distribution of weather stations in and around the Mbale region, with the period covered by the weather records

This relatively good coverage of weather stations was not unique to the Mbale region, but was the case for the entire country. Coverage of weather stations in the country was reasonably ok in the 20the century up to about 1980s, however most of these stations are no longer operational. It is recommended that a fully functioning weather station should be maintained within each of the districts. In addition, given the wide range of elevations, Bududa and Manafwa could each operate at least two weather stations, one located in the mid elevation and another in the high elevation areas. These stations should preferably record rainfall, temperature, wind velocity and relative humidity.

2.5 Analysis of historical and current climate for the Mbale region

2.5.1 Historical and baseline climate data

In this study, all climate data collected prior to 2000 is described as historical and the 30-year period from 1961 to 1990 as the baseline climate. Temperature in the region varies both in time and space. Spatial variations in temperatures are larger than variations in time throughout the year (i.e. changes in temperature as one moves up the mountain are larger that seasonal changes in temperature in any one area). The large spatial temperature variation is driven by the large change in elevation from about 1100m asl to more than 4000m in the northeast. Mean annual temperature in the region ranges from 21-23 ^{o}C in the low elevation areas in the east to 15 to 16^{o}C in the high elevation areas in the west. Mean annual temperatures drop to as low as 2 ^{o}C high up the mountain in Eastern Bududa district. On an annual timescale, February has historically been the warmest month in the region with average maximum temperature of about 31.1°C (Figure 6, is an example of temperature from Buginyanya station representative of high elevation areas in the region, such details temperature records were not available for low elevation areas). Thus, the warmest three months are December, January and February. From March as the rain season sets in temperatures, start dropping up to June and July, which are the coolest months with average maximum temperature of 28°C. Then temperatures gradually rise again in August (Figure 6). Generally, there has been an increase in temperature in the Mbale region over the last 40 years. Again, February, which is the warmest month, registered higher changes in temperature than other months over time (Figure7).

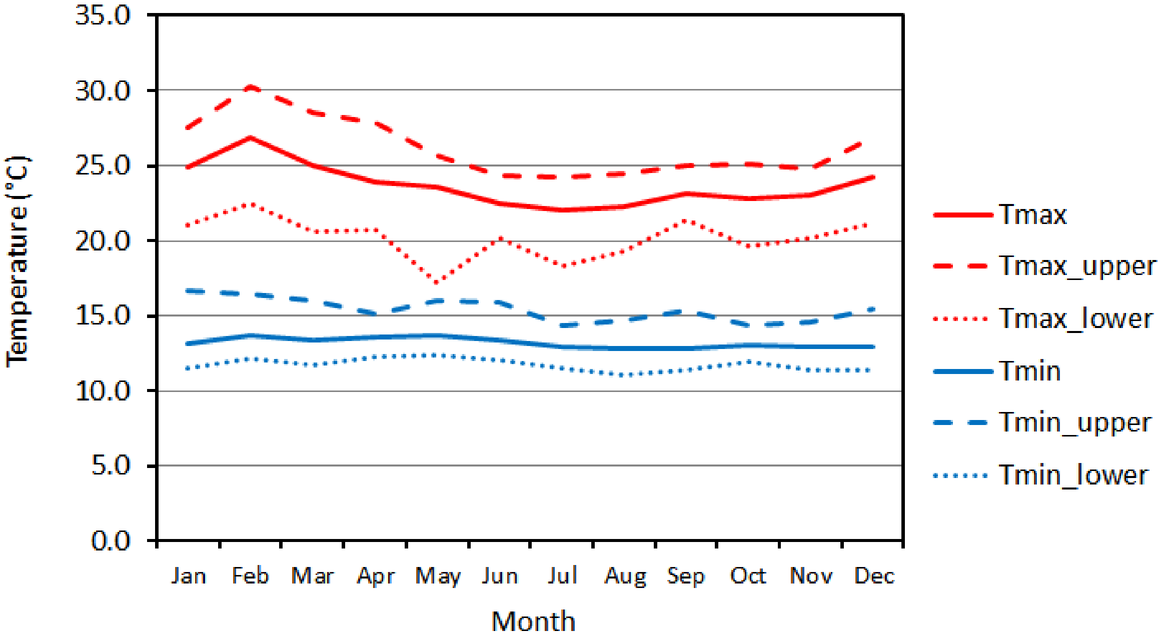

Figure 6: Mean monthly temperature range (maximum and minimum temperature, upper and lower limit of maximum and minimum temperature) for Buginyanya weather station for the 2002-2011 period.

As expected, temperatures in lower elevation areas in Mbale Region are warmer than high elevation areas up the Mount Elgon. There is wide temperature range from the low elevation such as west of Mbale town to the high elevation areas within the Mt. Elgon National Park in the eastern part of Bududa District (Table 2). Rainfall also varies with altitude, with high elevation areas wetter than low elevation areas.

There has generally been a 1°C increase in temperature in the last decade compared to the 1971-2000 normals. Larger changes in both minimum and maximum temperature have occurred in the dry season months, particular December, January and February (Figure 7 and 8). Figures 7 and 8 indicate differences between annual values from a long term 1971-2000 average and also indicate that overall, the change in minimum temperature is higher than the change in maximum temperature for most months of the year (September to April). February registered the highest change in temperature (Figure 8). The figures also show the large year-to-year variation in mean temperature values. However, despite the large year-to-year variation in mean temperatures the long-term trends for both minimum and maximum temperature are clear.

In terms of precipitation, Mbale District on average receives a lower rainfall than surrounding areas in Bududa and Manafwa Districts. The exception to this generalization is Wanale Hill, which receives high rainfall due to its altitude (Table 2).

Table 2: Comparing the annual temperature range and spatial temperature variation for five towns in the Mbale region

Variable		Town /Elevation (m asl)				
		Mbale / 1141	**Bulucheke/ 1347**	**Butiru/ 1384**	**Wanale / 2109**	**Mayenze / 1328**
Mean annual temperature (°C)		23	21.4	19	14	22.3
Min temperature (°C)	Feb	16.9	15.2	14.9	12.6	16.1
	June	16.8	14.9	14.5	12.2	15.8
	Oct	16.3	14.8	14.6	11.2	15.5
Max temperature (°C)	Feb	31.4	29.9	29.8	29.8	30.6
	Jun	28.2	27.0	26.9	23.6	27.5
	Oct	28.9	27.5	27.8	23.9	28.2
Mean annual precipitation (mm)		1183	1452	1458	2064	1373

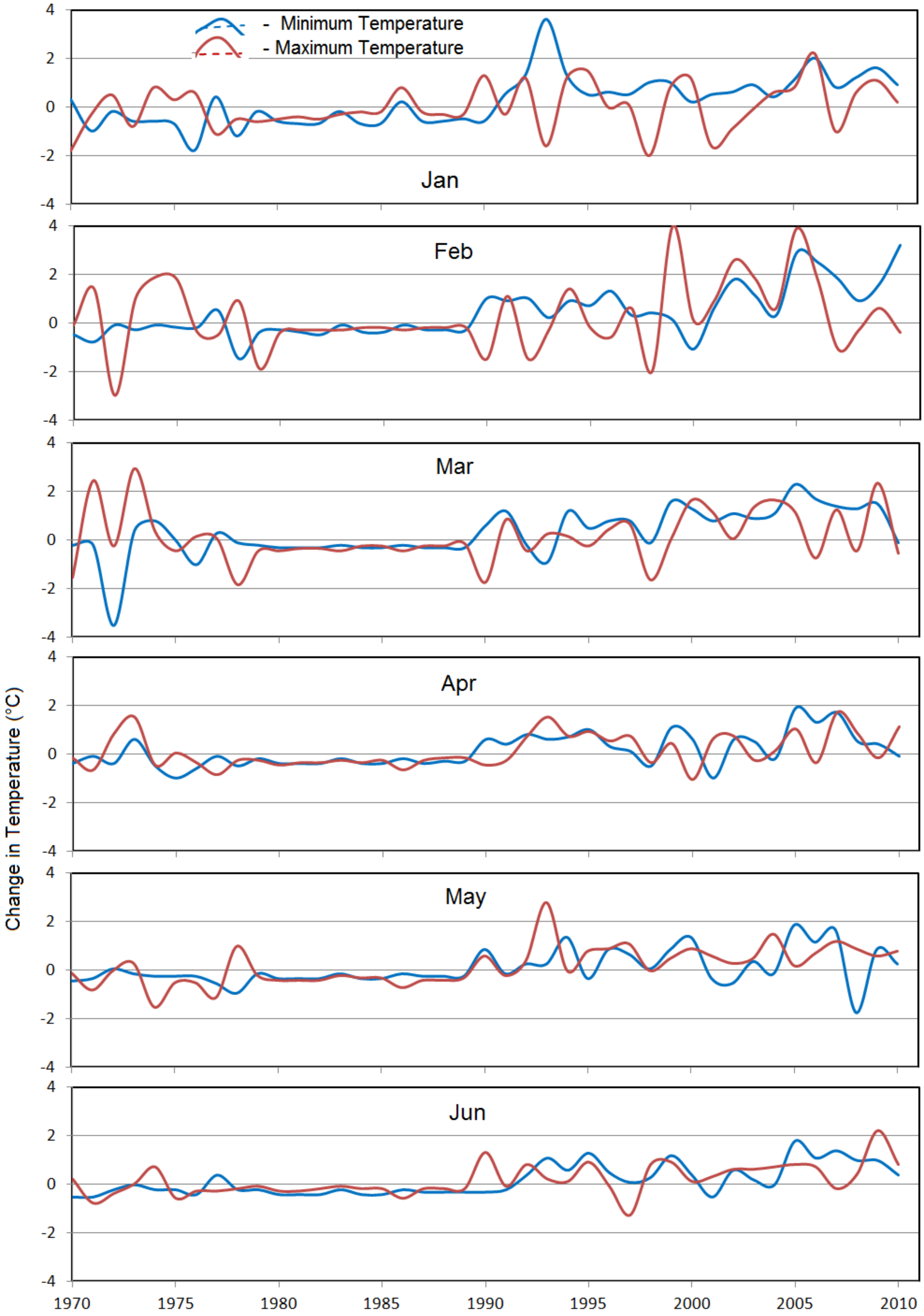

Figure 7: Temperature trends over a 40-year period for Buginyanya for January to June. Change in temperature is indicated as the difference between month values for each year from the 1971-2000 30-year average.

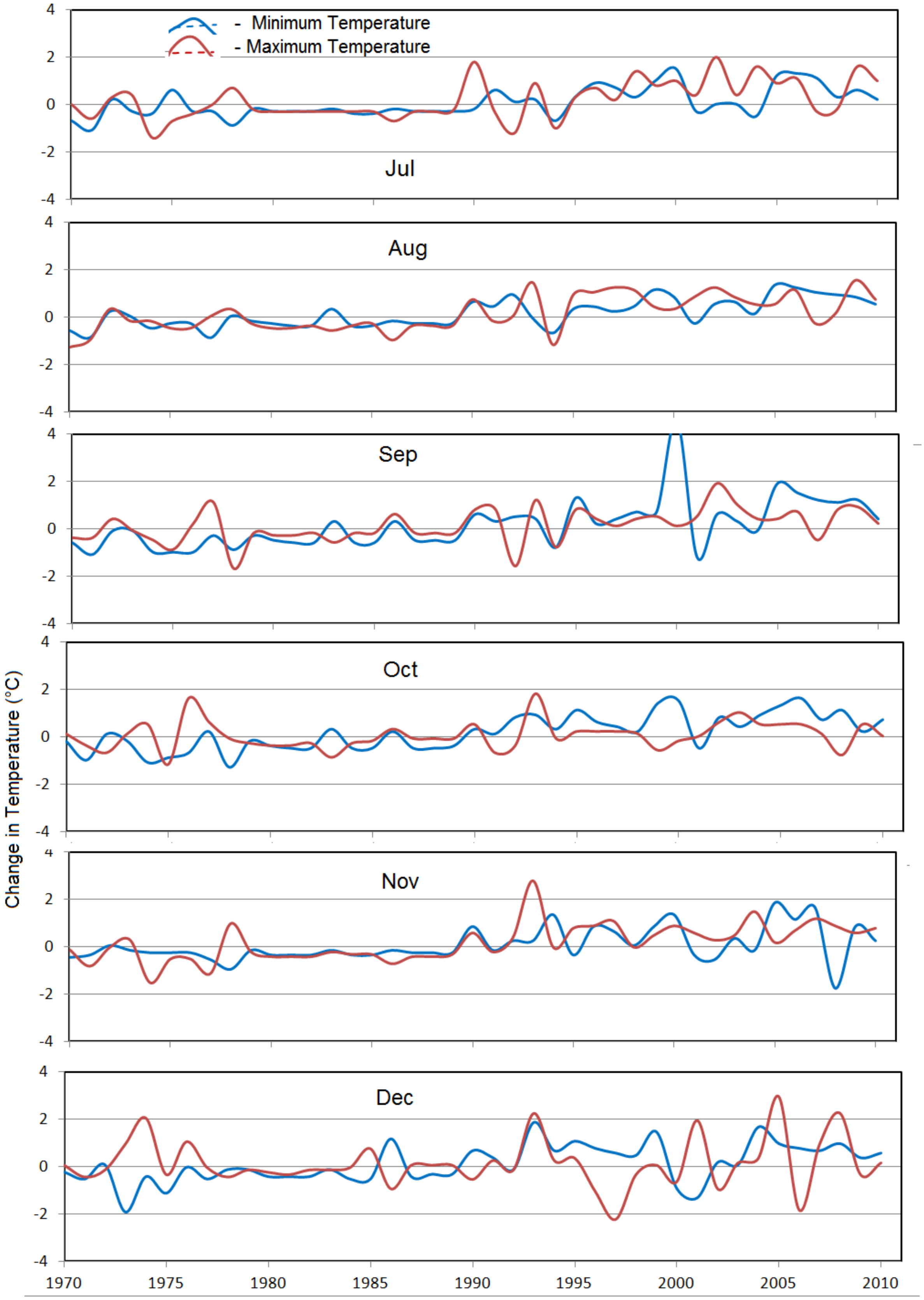

Figure 8: Temperature trends over a 40-year period for Buginyanya for July to December. Change in temperature is indicated as the difference between month values for each year from the 1971-2000 30-year average.

Table 3: Thirty-year average (1961 to 1990) monthly minimum, maximum temperature and monthly rainfall at Mbale (1141 m asl) and Buginyanya (1870 m asl) weather stations

Month	Minimum Temp (^{o}C)		Maximum Temp (^{o}C)		Rainfall (mm)	
	Mbale	Buginyanya	Mbale	Buginyanya	Mbale	Buginyanya
January	16.4	16.5	31.7	30.6	31	45
February	16.9	17.0	31.4	30.7	52	73
March	17.3	17.3	30.5	30.2	89	123
April	17.5	17.4	29.0	28.8	147	217
May	17.2	16.9	28.2	28.0	170	233
June	16.8	16.4	28.2	27.8	102	180
July	16.5	16.1	27.5	27.4	106	190
August	16.3	15.9	27.9	27.8	111	243
September	16.2	16.0	28.6	28.7	86	199
October	16.3	16.4	28.9	29.2	92	217
November	16.4	16.3	29.4	29.0	76	134
December	16.3	16.0	30.0	29.9	37	41

The rainfall pattern in the region is bimodal, with two rain seasons (Figure 9, 10 and 11). The first (main) rainy season starts at the end of March and stretches to end of May. The march to May rain comprise the main rain season. The second ("short") rainy season starts around June and continues to August or even October in some locations (Figures 9-11). In the past, the August to October period brings relatively less rainfall compared to the March to May period for most locations. The dry season in the Mbale region extends from the end of October until the end of February (Figures 9-11). The number on rainy days per month ranges from about 2-3 days in the dry season to about 12 days per month in the rainy season.

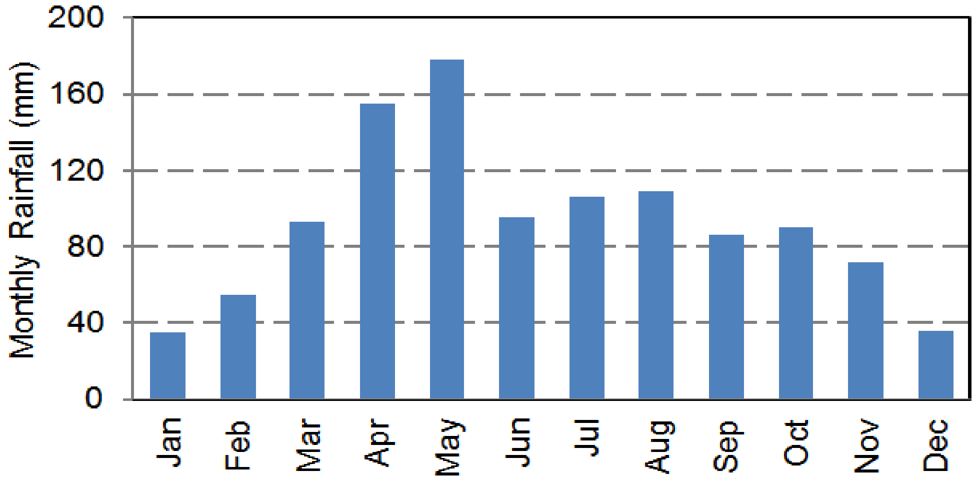

Figure 9: Average monthly rainfall totals recorded at Mbale weather station over the 1960 to 1987 period

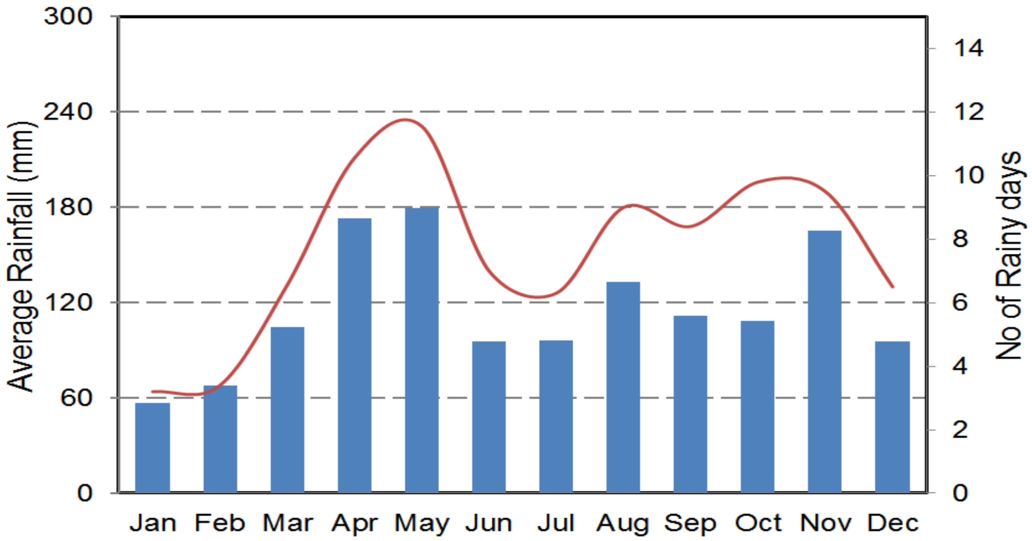

Figure 10: Average monthly rainfall totals and average number of rainy days per month recorded at Manafwa weather station over the 2002 to 2011 period

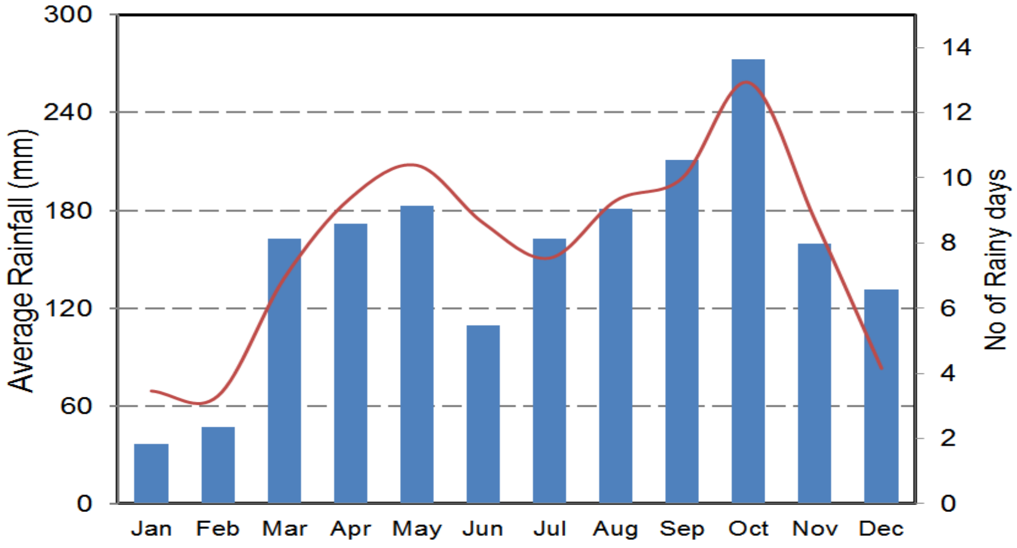

Figure 11: Average monthly rainfall totals and average number of rainy days per month recorded at Buginyanya weather station over the 2002 to 2011 period

The general trend for rainfall is not as straight forward as that for temperature; there is high variation in monthly rainfall amounts over time. For example, over the last 5 decades, the December to February period, which is a relatively dry season received on average less than 50mm of rainfall per month for both low elevation (Figure 12 and 13) and high elevation areas (Figure 14 and 15). There has been a recent trend towards higher rainfall amounts being received towards the end of the main rainy season, with more rainfall in May than in April or March. At the end of June, there is a short-duration dry spell but the region continues to receive some rainfall until November. This second rainy season peaks around September to October.

Low elevation parts of the Mbale Region in Mbale and Manafwa District, receive relatively lower rainfall amounts than high elevation areas in Bududa and Manafwa Districts (Table 3). Despite this elevation gradient, the distribution of rainfall in these areas is similar throughout the year.

Changes in rainfall have not been uniform throughout the region. Whereas higher elevation areas have recently received more rainfall (above 1961-1990 mean values), lower elevation areas to the west particularly around Mbale town are receiving moderately lower rainfall than the 1961-1990 mean values for all months except October (Figures 12 and 13). In other locations, the recent decades have seen higher rainfall totals recorded compared to the 1961-1990 normals. More rainfall was recorded at Buginyanya weather station for all months in the last 10 years except the dry season months of December, January and February and March (Figures 14 and 15). These values are in agreement with information gathered in discussions with local farmers and what is reported elsewhere on the dry season getting worse than before and the rains coming late. Typically, rains were expected at the beginning of March but more often, the rainy season now starts towards the end of March or even in April.

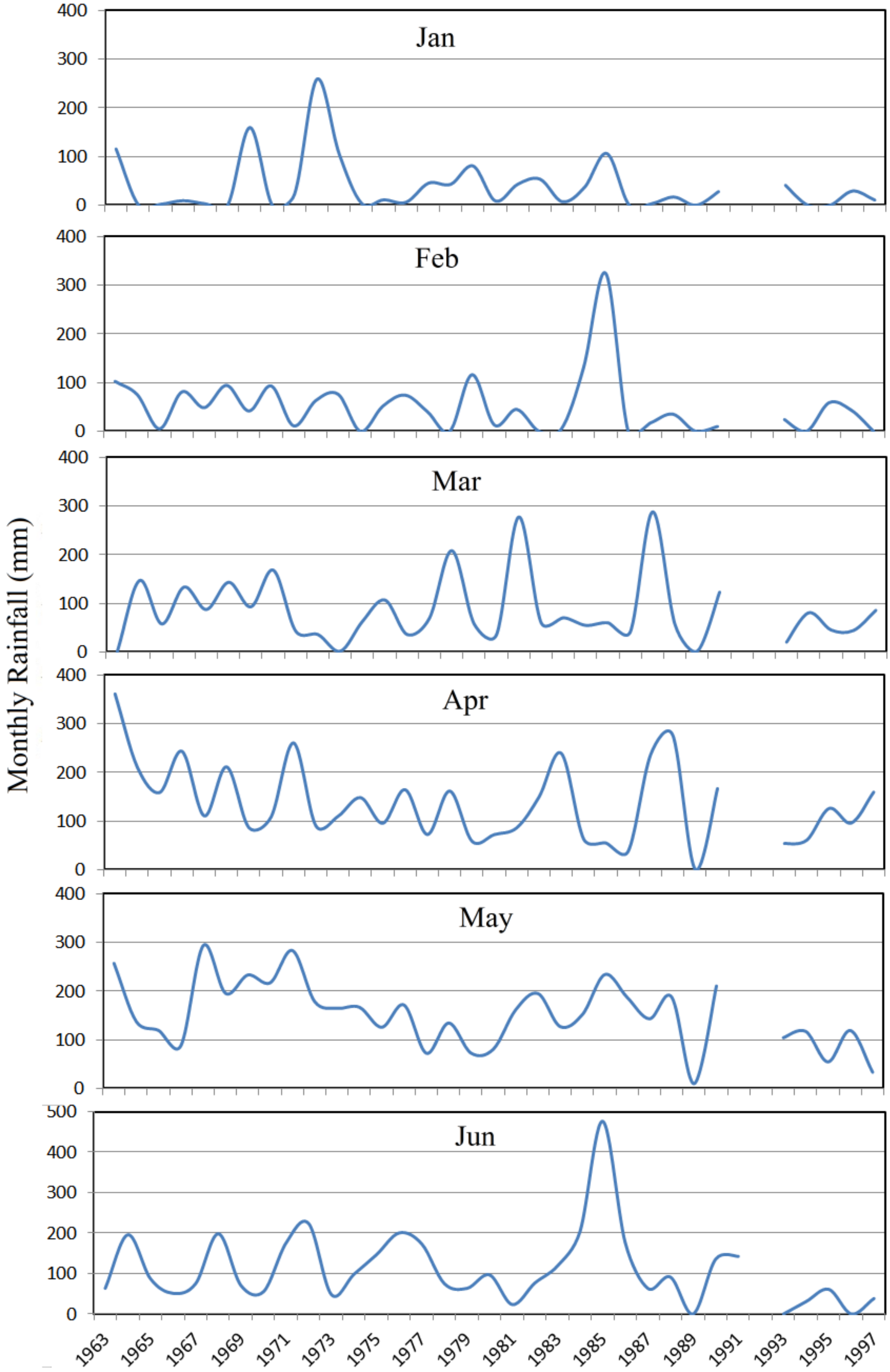

Figure 12: Trends in January to June rainfall recorded at Mbale weather station from 1963 to 1997

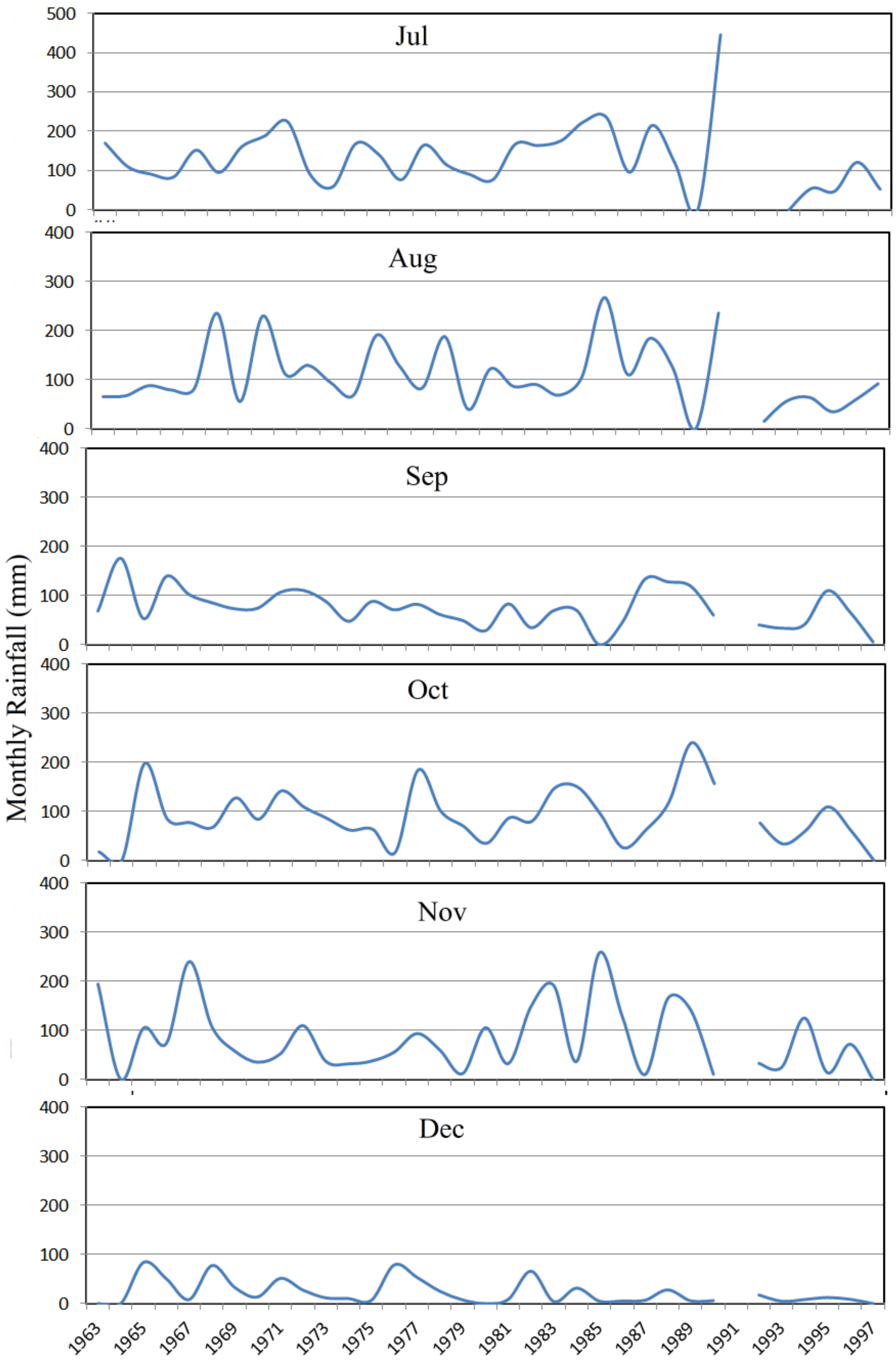

Figure 13: Trends in July to December rainfall recorded at Mbale weather station from 1963 to 1997

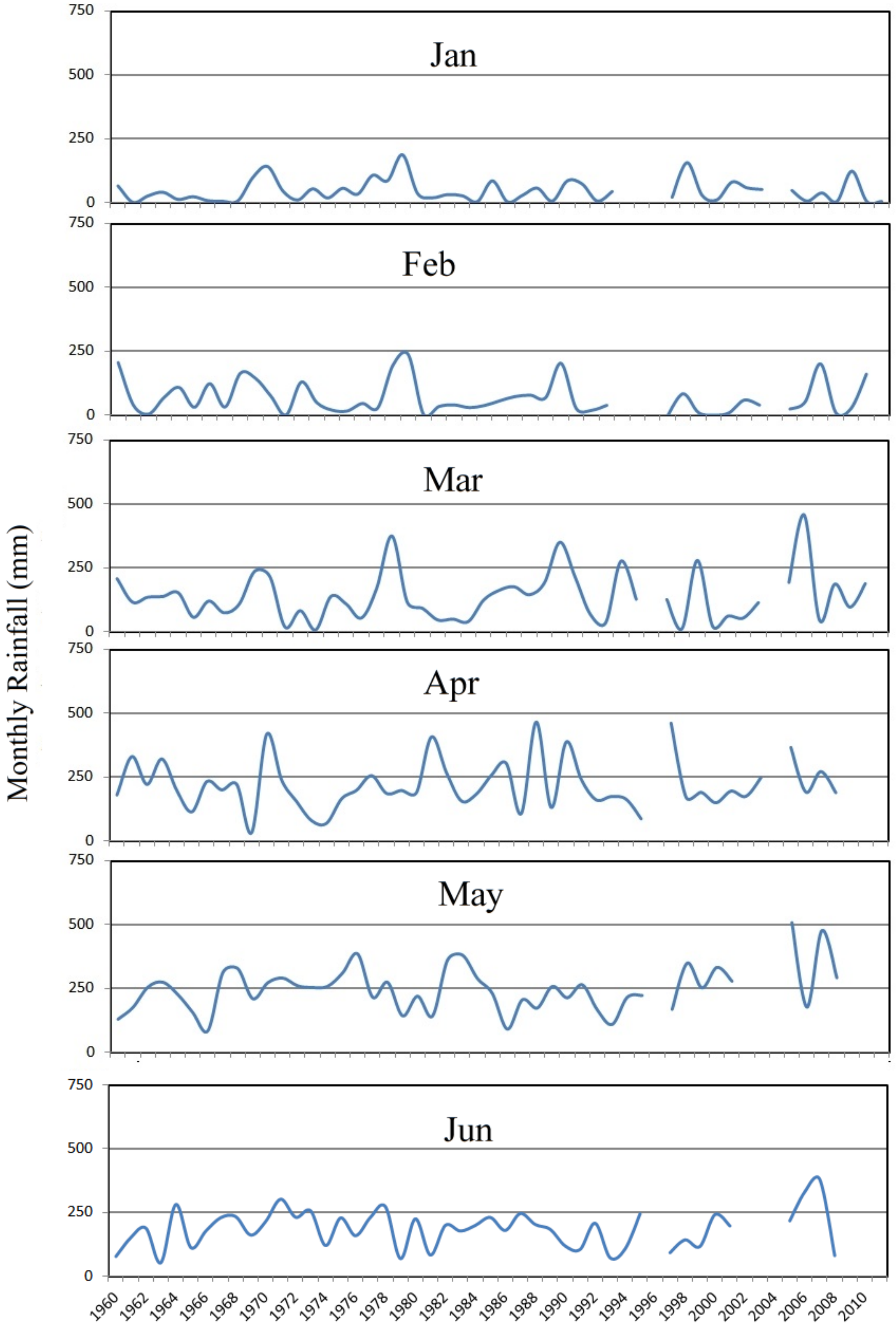

Figure 14: Trends in January to June rainfall recorded at Buginyanya weather station from 1960 to 2010

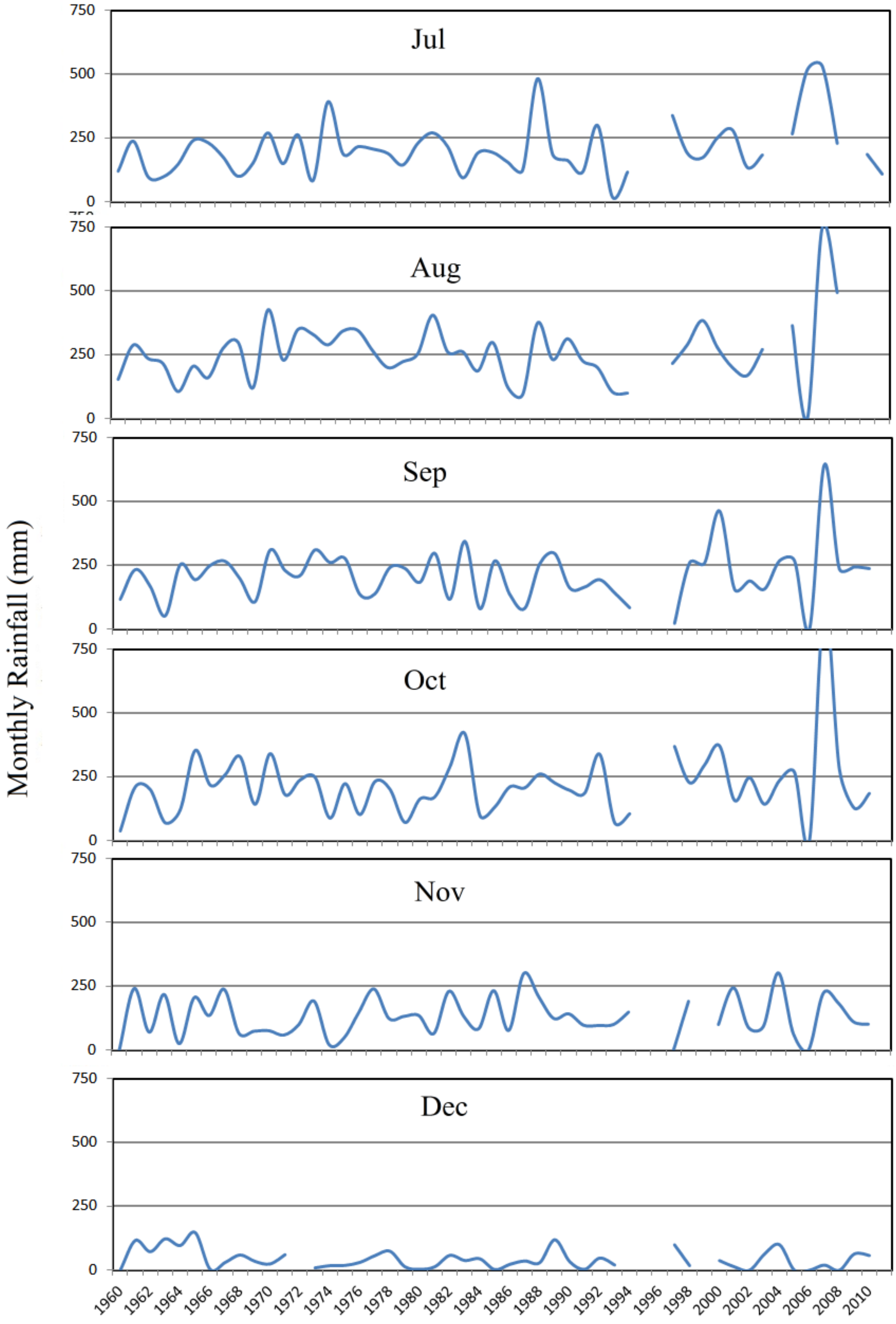

Figure 15: Trends in July to December rainfall recorded at Buginyanya weather station from 1960 to 2010

2.5.2 Baseline climate grids

Evaluation of climate change impacts typically makes use of both baseline and projected climate data to make spatial predictions of species habitat and anticipated changes in the future (Hijmans and Graham, 2006; Pearson and Dawson, 2003). Baseline climate data serve as the reference point for describing climate change. The other use of baseline climate grids data is that it is this data, which is combined with changes or anomalies which provide projections of future climate. Baseline climate data is used to establish the current vulnerability of environmental and socio-economic systems, identifying critical climate thresholds in characterizing risk and in defining features of high impact (extreme weather events) under present day climate (Lu 2007). The IPCC recommends the use of 1961 – 1990 period as the baseline for the assessment of climate change over the 21st century. This report will also use the 1961 – 1990 30-year period as the baseline for assessing change in climate over the Mbale region.

Numerous climate modeling efforts have generated climate grids, mainly from weather station data using a number of interpolation techniques. The quality of the climate grids is a function of the original weather station records as well as the interpolation techniques used to generate spatial grids from point climate data. Current climate data for the Mbale region of Uganda, as for many locations around the world, are available from global interpolation efforts such as Worldclim (Hijmans et al., 2005) that generated climate grids for maximum and minimum temperature and monthly precipitation at 30arc min or the equivalent (approximately 1km). The other common global scale climate dataset commonly used is from the Climate Research Unit (CRU) at the University of East Anglia in UK, which is at a 0.5 degree resolution (Mitchell and Jones, 2005). It is however recognized that the seemingly higher resolution in the Worldclim dataset is largely a result of the interpolation process and not related to the availability of ‘extra’ climate data.

An evaluation of a third climate dataset was performed to decide which set to use for describing climate for the Mbale region. Climate data from PRECIS (Providing REgional Climates for Impacts Studies) experiments for Uganda and surrounding region were part of Regional Climate Model (RCM) experiments conducted in by Lucinda Mileham at the Geography Department of the University College of London using PRECIS developed at the Hadley Centre of the UK Met Office. This data was also found to be at a coarser resolution than the WorldClim data and is dependent on model biases which render it unsuitable for describing the baseline climate of the region. The Worldclim dataset was therefore finally selected for the analysis of baseline and projected climate (Figure 16). The downscaled WorldClim data provides data which can be used for detailed analysis at local and regional scale (bearing in mind that its accuracy is ultimately dependent on the number of stations and interpolation technique used to produce the grids), such as for the Mbale region, compared to PRECIS or original GCM data, which provides one or two readings for the entire region..

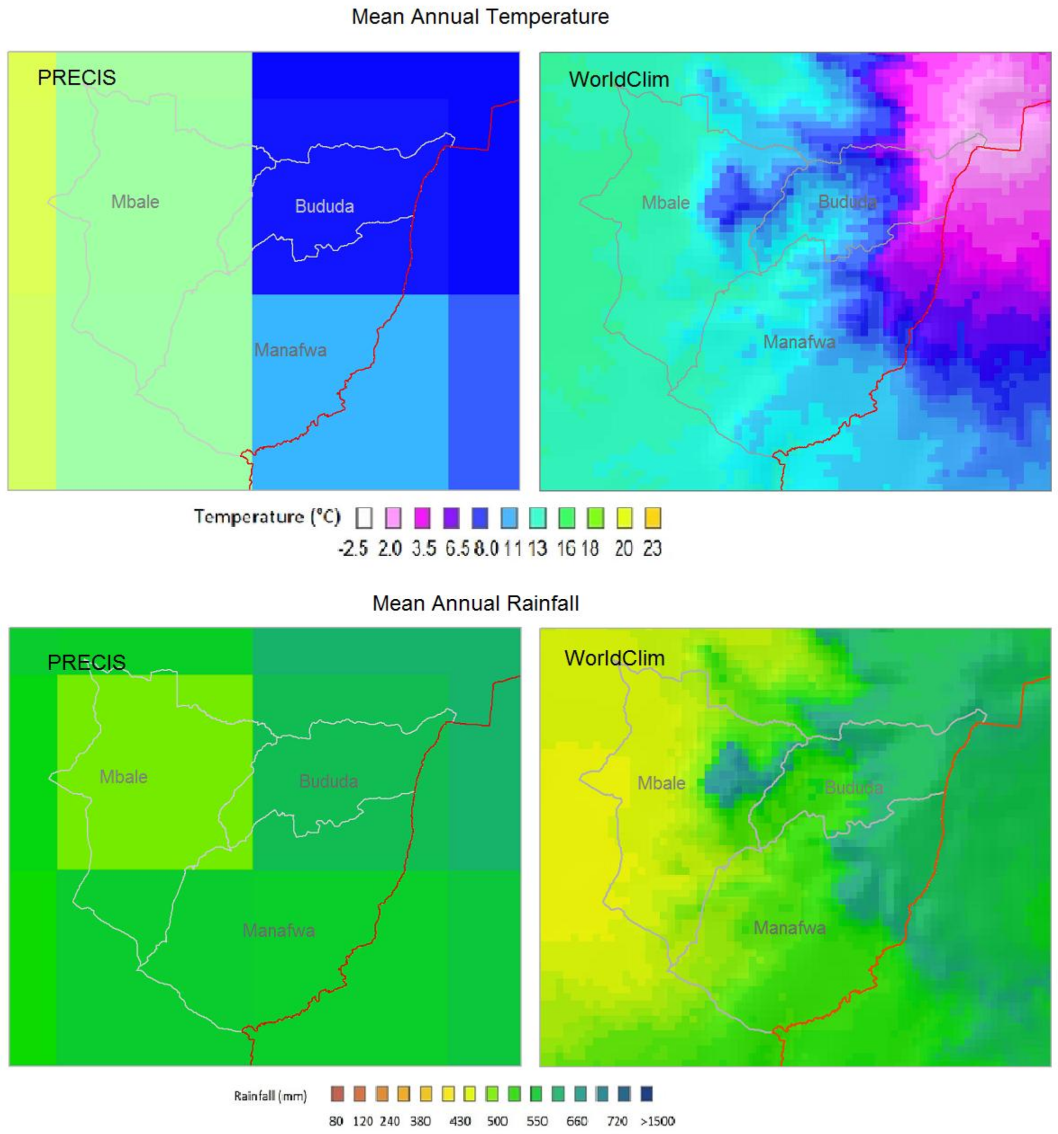

Figure 16: Comparison of available Mean Annual Temperature and Mean annual Precipitation grids for the Mbale region data for the 1961-1990 period from PRECIS and CCAFS downscaled Worldclim datasets

Based on mean annual temperature for the 1961 – 1990 period (Figure 17), within the Mbale region, western and southern parts of the region, particularly the sub-counties of Nakaloke, Bungokho, Busoba, Busiu and Bukiende in Mbale District and Sibanga and Bugobero in Manafwa District are relatively warm. Mid and high altitude locations that lie to the northeast of the region are relatively cooler. High temperatures through the year coincide with the dry season, conversely; the coldest quarter coincides with the main rainy season (Figure 18). Information on seasonal variation in temperature is valuable because this can be used to determine the expected levels of water stress for crops and plants, despite the general increase in rainfall amounts in the region.

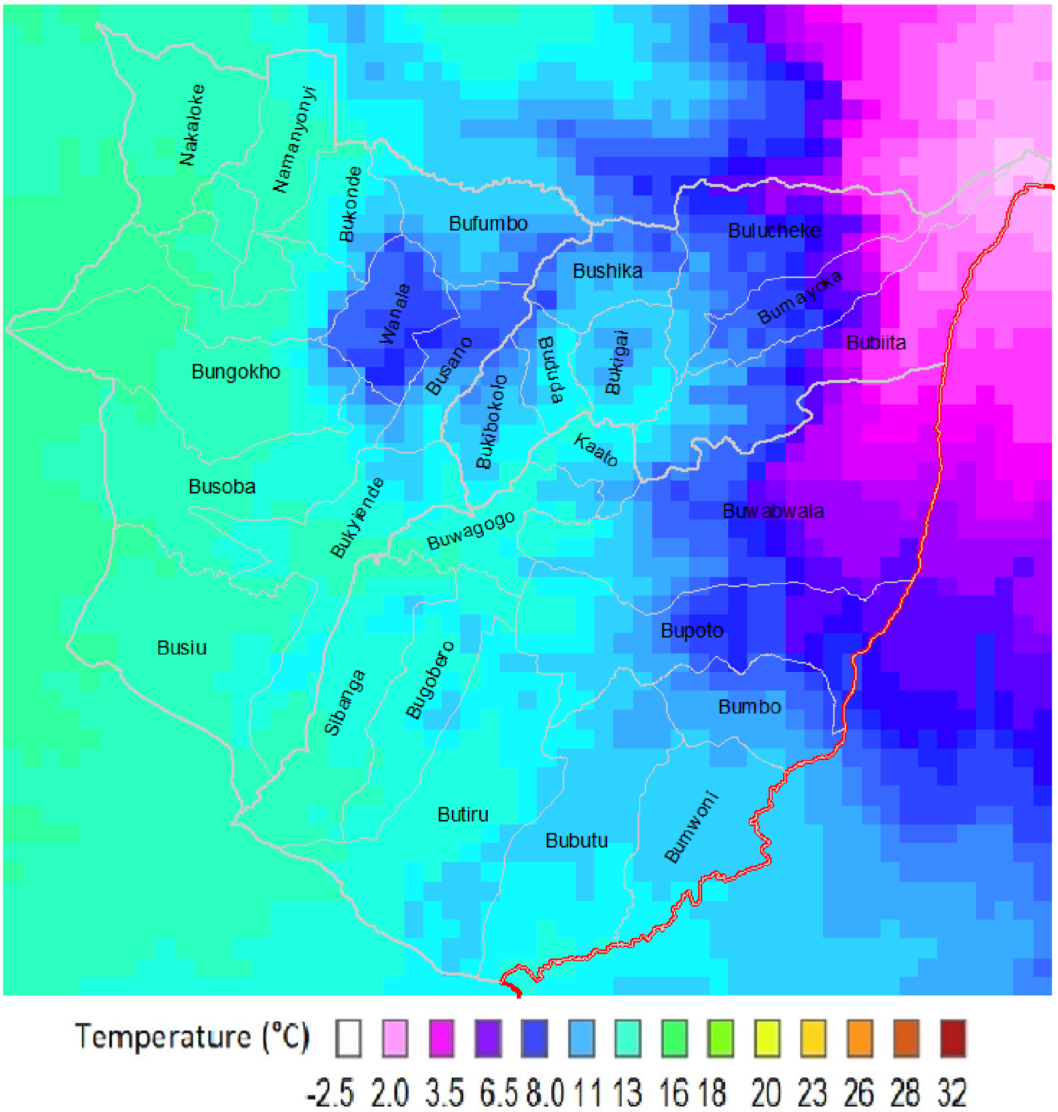

Figure 17: Mean annual temperature for the 1960-1990 baseline period for part of the eastern Africa region

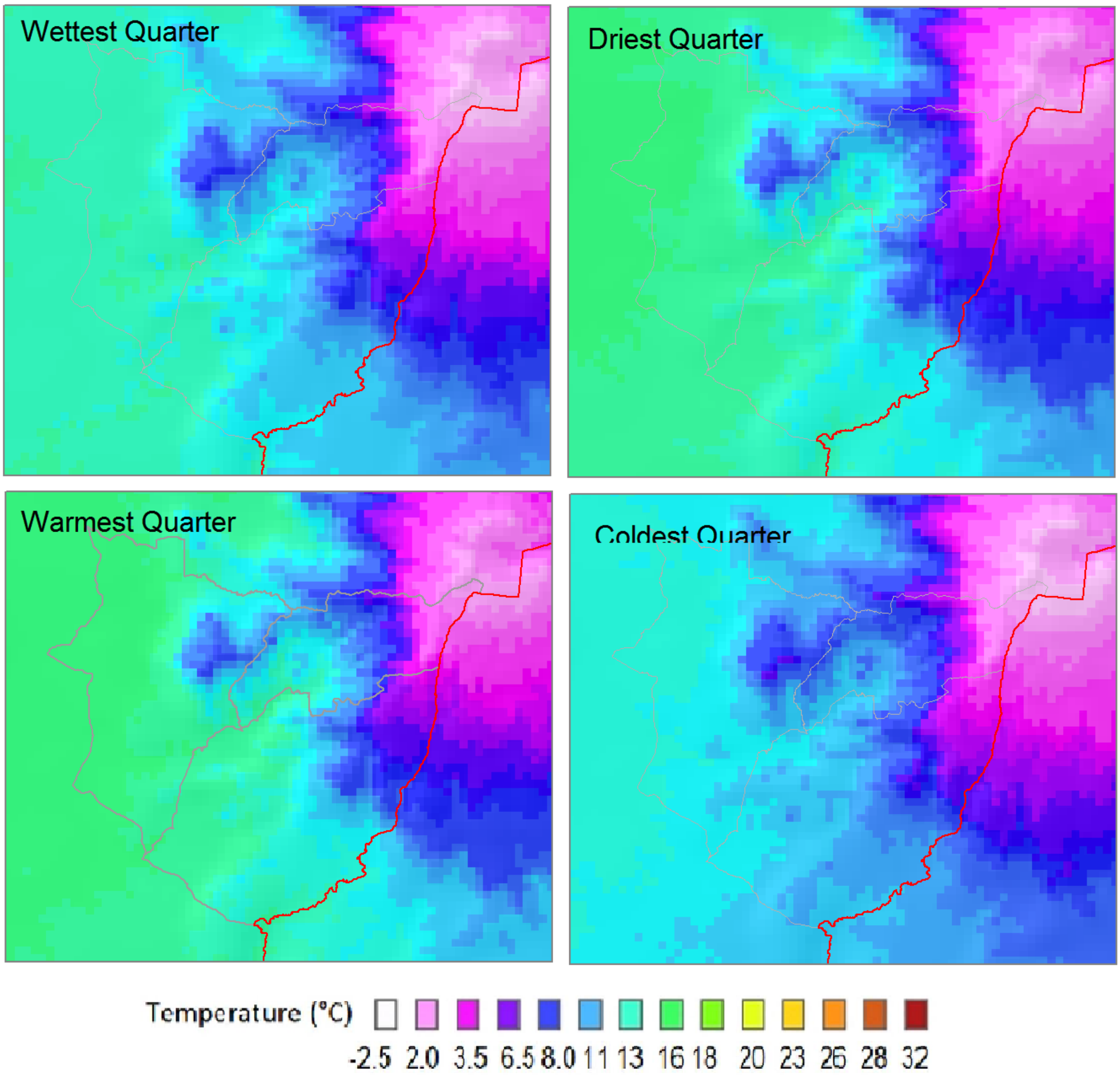

Figure 18: Mean temperature for the warmest, driest, wettest and driest quarter for the 1960-1990 periods

On a monthly time scale, minimum (Figure 19) and maximum temperatures (Figure 20), January February and March are much warmer than May, June and July. Maximum temperatures slowly rise from August and September; by December temperatures have risen to the dry season levels. The range of minimum temperatures in the region throughout the year is much narrower than the range of maximum temperatures.

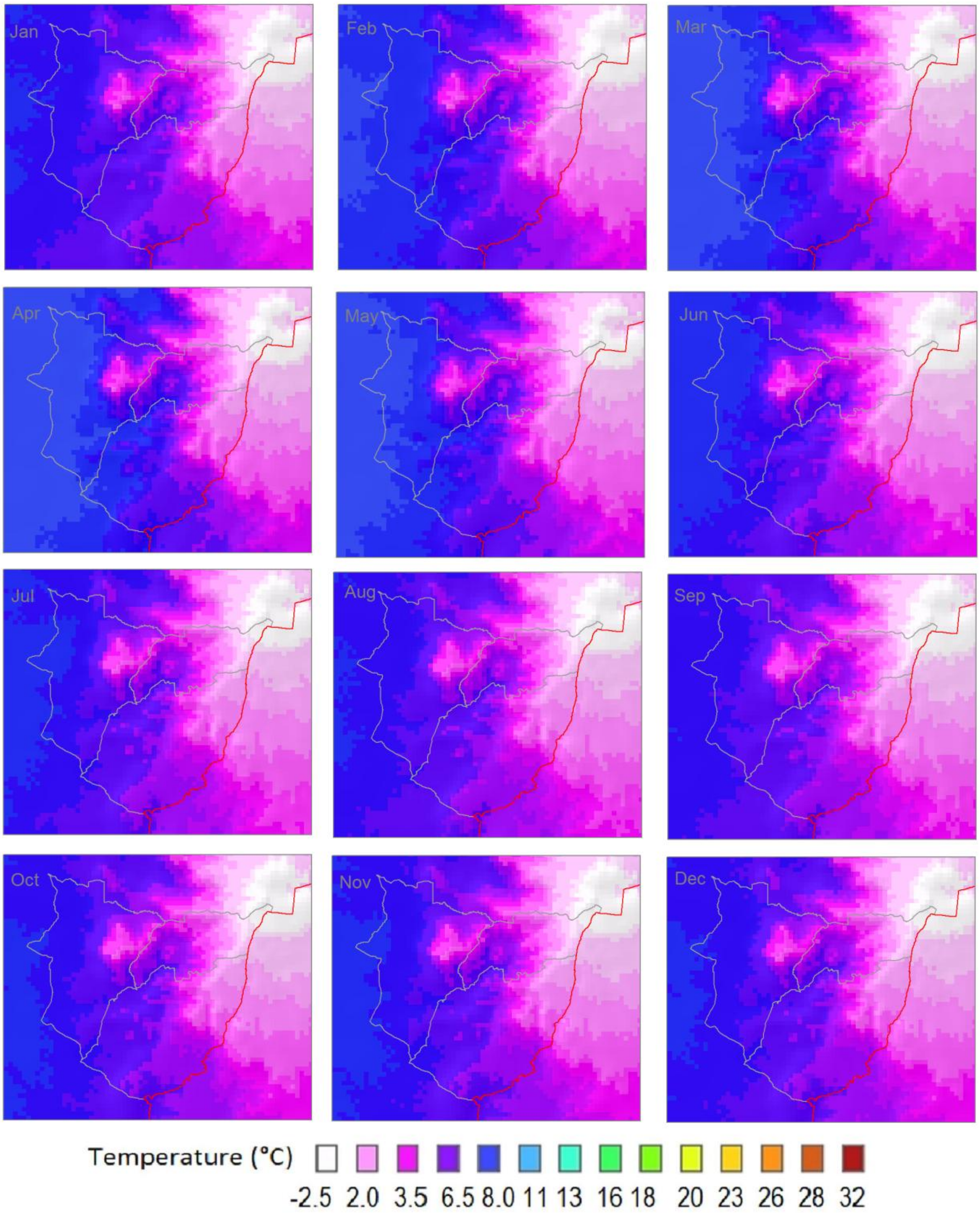

Figure 19: Average monthly minimum temperature for the 1961-1990

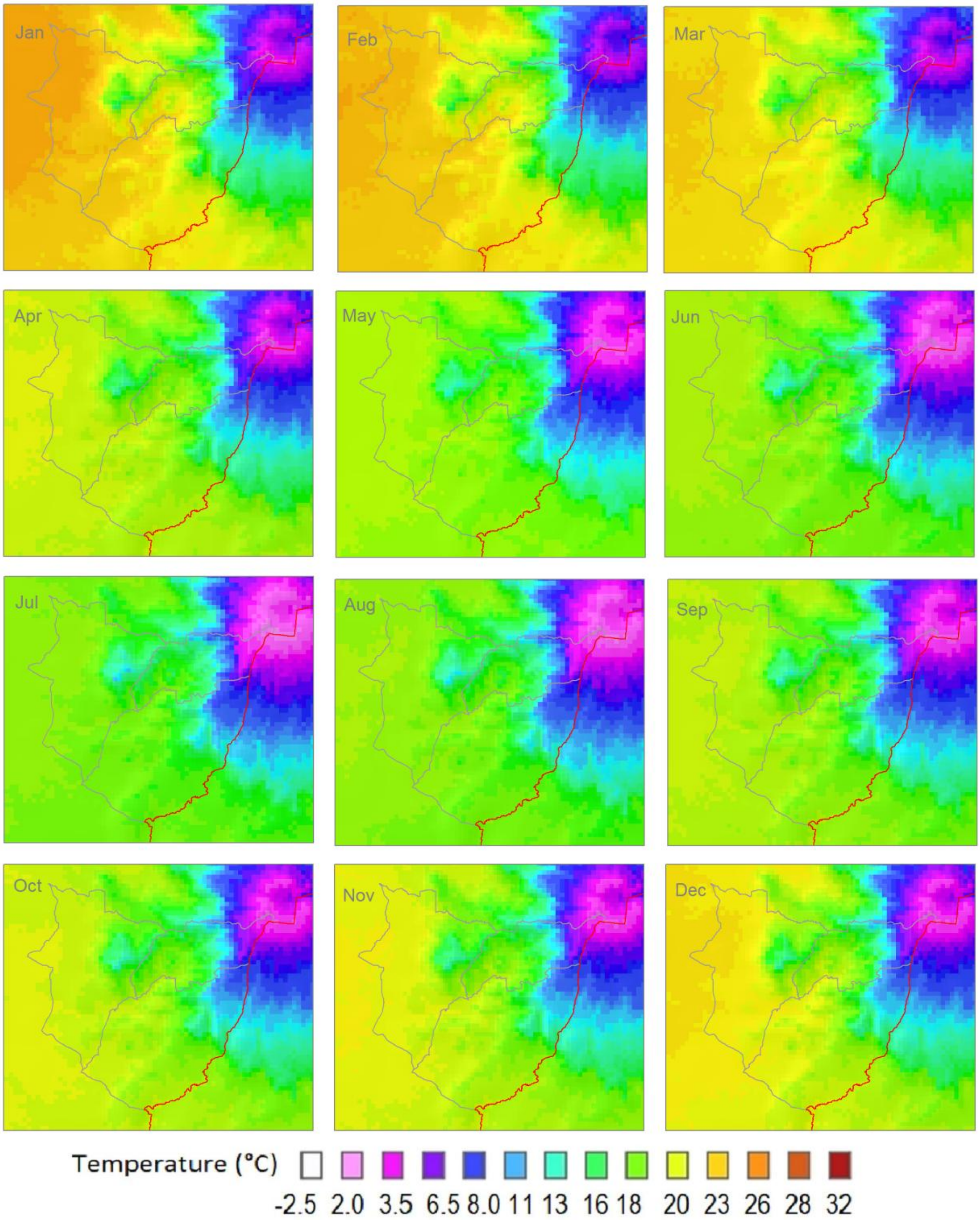

Figure 20: Average monthly maximum temperature for the 1961-1990 period for the Mbale region

Spatially, the amount of rainfall received is not uniform throughout the Mbale region. In general, there is higher rainfall in higher elevation areas. Sub-countries located in the eastern parts receive more rainfall than those to the western. Eastern sub-counties including the Mt. Elgon National Park (Bulucheke, Bumayoka and Bubiita in Bududa, Buwabwala, Bupoto and Bumbo) receive more rainfall probably because they lie at mid and high elevations (Figure 21). Wanale Hill, which is a high elevation area (>1800m asl) in Mbale District also receives relatively higher rainfall than the surrounding low elevation areas (~1200m asl).

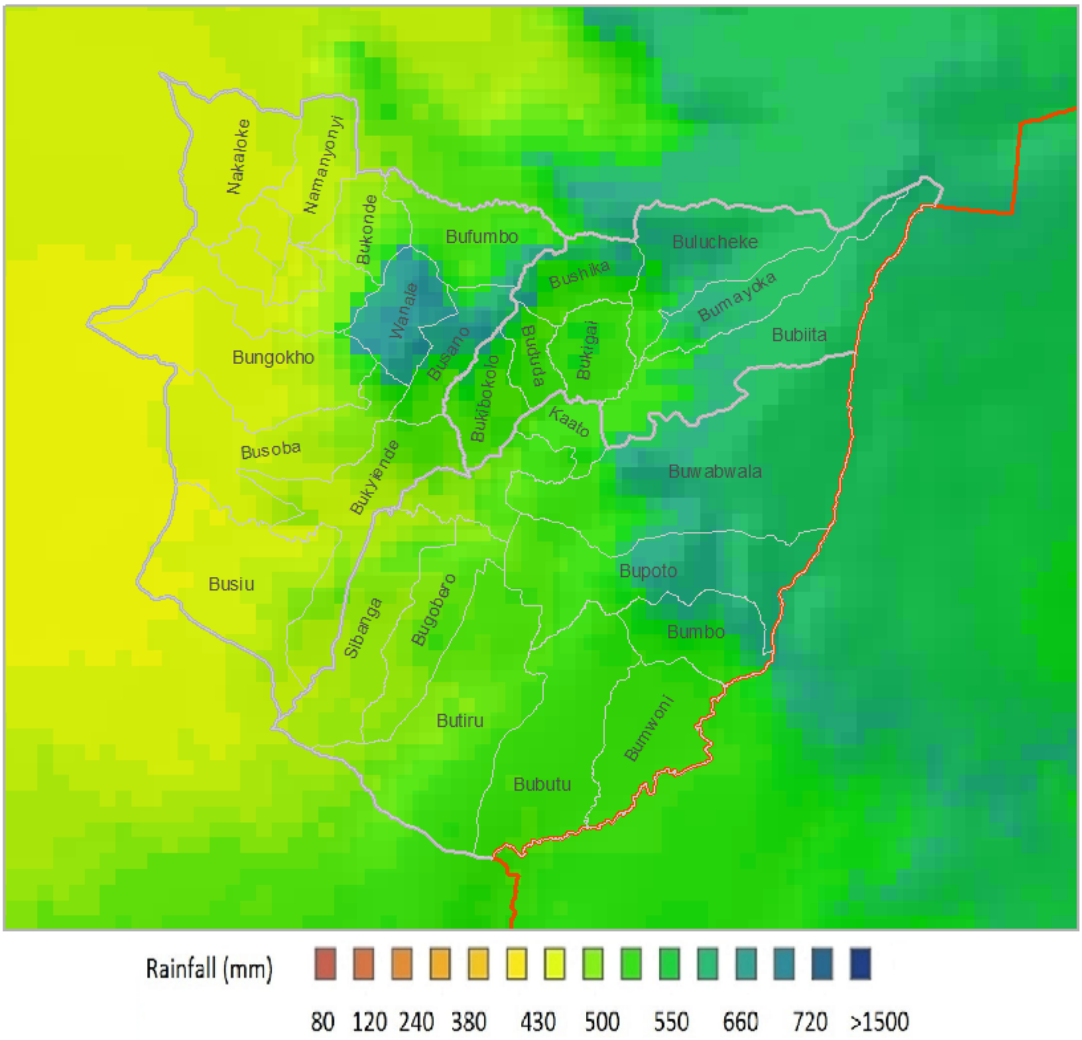

Figure 21: Mean Annual Precipitation for the 1960-1990 baseline period for the Mbale region

December and January were the driest months during the 1961-1990 period receiving less than 40mm rainfall. The first rain season starts in March and peaks in May with a monthly average of 180mm. Rainfall amounts drop in June to about 100mm for the next three months. For the next few months, August to December receive lower rainfall amounts, averaging to about 70mm per month. Patterns of rainfall in other parts of the region are similar to that in Mbale, only varying in magnitude (e.g. Buginyanya station averages about 200mm from April to October during the 1961-1990 period) (Figures 22 and 23).

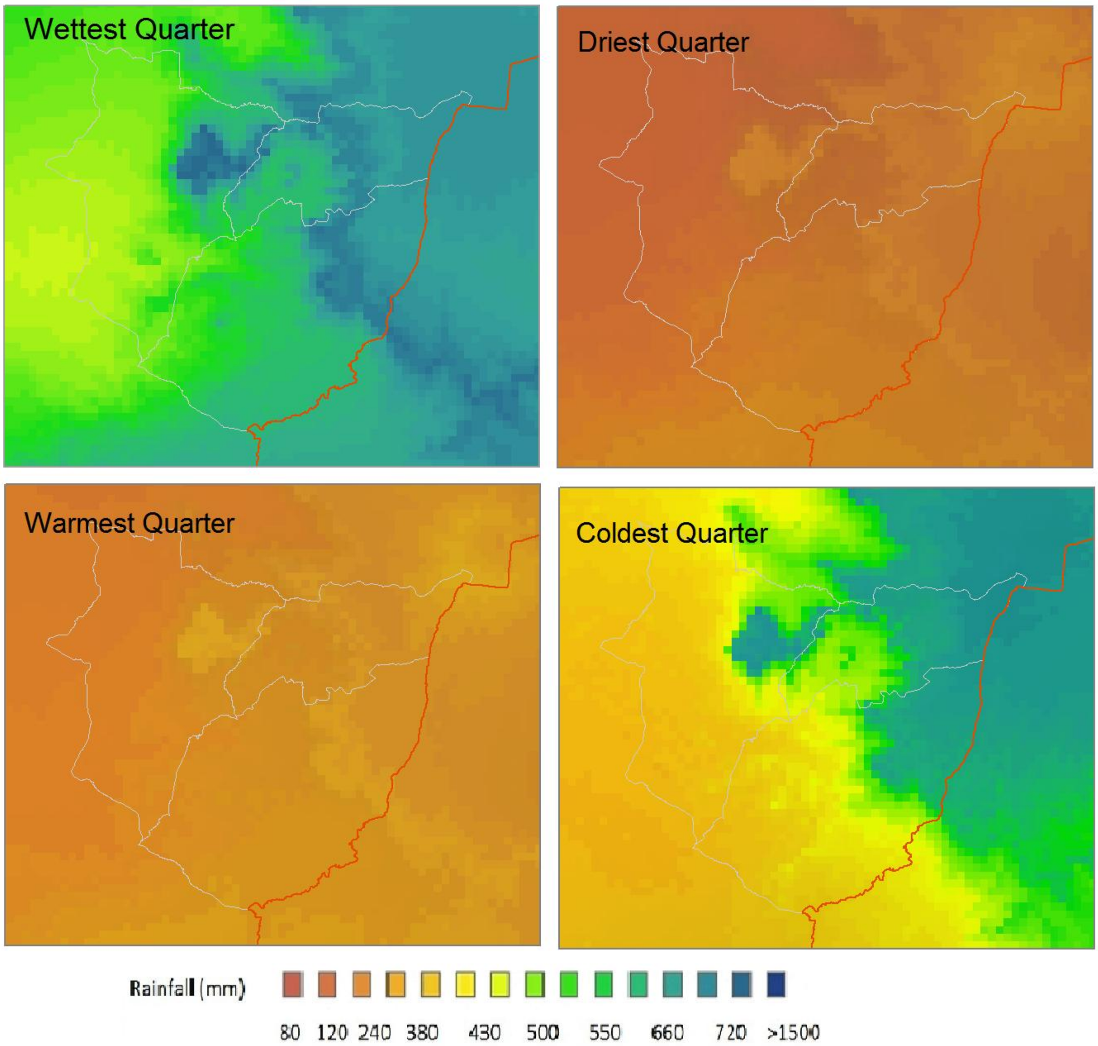

Figure 22: Mean Precipitation for the warmest quarter, coldest Quarter, wettest and driest quarters during the 1960-1990 baseline period for part of the eastern Africa region

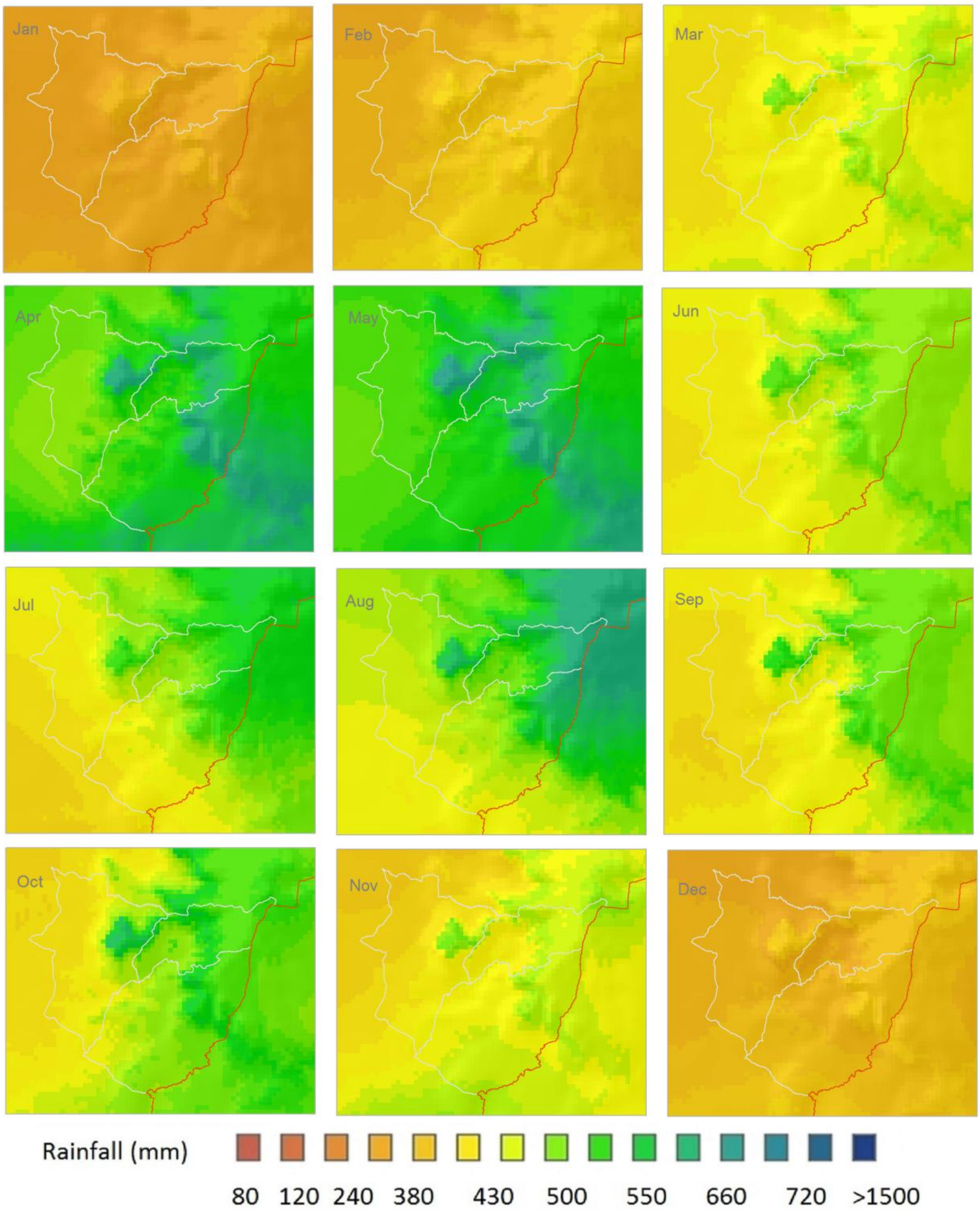

Figure 23: Average monthly rainfall for the 1961-1990 period for the Mbale region

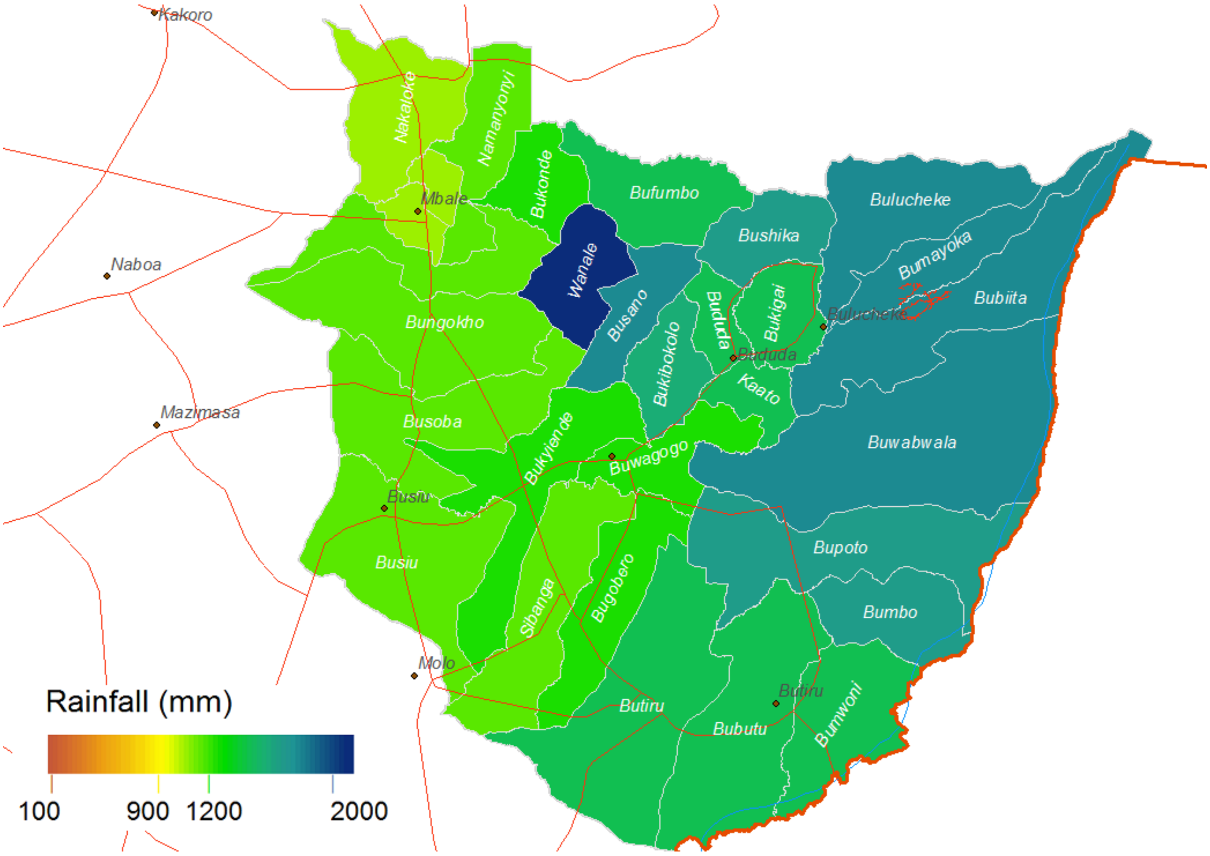

Figure 24: Mean annual precipitation by sub-county in the Mbale region for the 1961-1990 period

2.5.3 Current climate (2000-2011)

Mean maximum temperature over the last decade (2002 to 2011) for Buginyanya lie between 26.9 °C in February and 22.2°C in July. Maximum temperatures have ranged between 30.2 °C and 17.2°C. Mean minimum temperature ranged between 13.7°C and 12.9°C. There has been an increase of between 0.4 and 1.2°C in mean monthly temperatures in the Mbale region during the 2001-2011 period over the 1961-1990 normals (Table 4).

The three districts (Mbale, Bududa and Manafwa) lie on the southwestern slopes of Mt. Elgon. The rainy season begins in March. There has been no significant change in the last two decades for March, April precipitation. However, whilst there are indications that May, June and July have received up to a 13-15% increase in rainfall in the last decade at Buginyanya station (Table 5), there were often decreases in the previous decade relative to the 1961-1990 baseline period. This suggests that multi-decadal changes (wet and dry periods over 10-20 year periods) are significant and care must be taken in attributing rainfall changes over 10 years to climate change.

Rainfall has remained biomodal, as described during the baseline period, the main rainy season being March to May and the other rainy season from September to November. One noticeable trend from data recorded at the Buginyanya station is that of relatively higher rainfall in the September to November period (Table 5, Figure 14-15) during the last decade with increases greater than any decreases experienced in the previous decade.

2.5.4 Observed climate changes in the Mbale region

Despite projections into the future, there is no better evidence of changes in climate than the current trends. The most recent decade (2001-2010) has on average been warmer than the three previous decades (1961-2000). According to data from Buginyanya weather station, changes in temperature have been more pronounced in February during which maximum temperature has increased by 1°C and minimum temperature, which is 1.4°C higher than then 1971-2000 average. Overall, maximum temperature in the last decade has increased mainly in January, February and the May to August period. On the other hand, maximum temperatures have increased mainly during the February to March as well as in May to September (Table 4).

Temperature and rainfall records from the Buginyanya station (Table 4 and 5) indicate that the changes in rainfall over the last decade are indicative of more rainfall for the region as a whole, though this is using data from only one station. Rainfall for February, the driest month has continued to reduce over the past 40 years (Table 5). The recent 20 years (1991-2010) period was more than 20% drier than normal. Timeseries for April at Mbale (figure 12) also suggest that rainfall has been decreasing, leading to a later start of the rains in May at that station. In contrast the April to December period (with the exception of June) has become wetter than the baseline at Buginyanya. The increase in rainfall during the July to November period presents an opportunity for growing a wider range of crops than before during the hitherto short second rain season, though it should be stressed that it is not clear if this situation will persist in the future.

Table 4: Changes in minimum (T-Min) and maximum (T-Max) temperature at Buginyanya weather station for the 2001-2010 (10 year average) compared to the 1961 to 1990 baseline

Month	**T-Min (°C)**		**T-Max(°C)**	
	1971-2000	10-yr change (2001- 2010)	1971-2000	10-yr change (2001- 2010)
Jan	**16.1**	+1.0	**30.7**	+0.4
Feb	**16.6**	+1.4	**31.0**	+1.0
Mar	**16.9**	+1.2	**30.4**	+0.9
Apr	**17.3**	+0.6	**29.2**	+0.4
May	**16.8**	+0.5	**28.4**	+0.8
Jun	**16.2**	+0.7	**28.0**	+0.7
Jul	**15.9**	+0.6	**27.6**	+0.9
Aug	**15.7**	+0.8	**28.2**	+0.8
Sep	**15.6**	+1.2	**28.8**	+0.6
Oct	**16.1**	+0.9	**29.4**	+0.3
Nov	**16.2**	+0.6	**29.1**	+0.1
Dec	**15.8**	+0.3	**30.0**	+0.4

Table 5: Changes in monthly rainfall at Buginyanya weather station for the 1991-2000 and 2001-2010 (10 year averages) compared to the 1961 to 1990 baseline period

Month	Baseline (1961-1990)	1991-2000 change (%)	2001-2010 change (%)
Jan	**45**	+18.8	+4.4
Feb	**73**	-25.7	-27.0
Mar	**123**	+4.2	-1.3
Apr	**217**	+1.6	+4.8
May	**233**	-11.8	+14.5
Jun	**180**	-27.9	-2.6

Jul	**190**	-9.1	+20.5
Aug	**243**	-9.4	+24.6
Sep	**199**	-13.0	+30.3
Oct	**217**	+1.8	+31.5
Nov	**134**	-4.5	+10.9
Dec	**41**	-14.6	+37.3

2.6 Projecting future climate data for the Mbale region.

Comparisons of projections of future climate were performed for 44 climate variables (monthly maximum and minimum temperature monthly precipitation for 12 months). In addition, data for biologically important variables such as mean annual temperature, mean temperature of the warmest quarter, mean temperature of the coldest quarter, mean temperature of the wettest quarter, mean temperature of the driest quarter, total precipitation of the wettest quarter, total precipitation of the driest quarter, precipitation of the hottest quarter and precipitation of the coldest quarter (see Annex 2 for a description of all the climate variables).

Data presented covers the 2011 to 2040 and the 2041 to 2060 30-year time slices or the 2020s and 2050s respectively and from the 4 general circulation models and 3 emissions scenarios as indicated in Annex 3. The general trend shows more warming in the future. Changes in minimum temperature are small compared to those in maximum temperature for all locations. Large increases in temperature during the wettest quarter means that the effect of higher rainfall may not be as significant as if temperatures remain unchanged, due to increasing evaporation. On the other hand, higher temperatures during the driest quarter points to worsening of the dry season in the Mbale region, due to increasing evapotranspiration.

Projected changes in rainfall are not uniform in space and time, some months are projected to get wetter while other drier (see above). Despite this, there is a reasonable level of consistency in the projected trends for higher annual rainfall. For example, all models agree with the projected reduction in the rainfall for April for both the 2010-2039 to 2040-2069 periods (Table 5). Additionally there is agreement in projected increase in rainfall for May for the 2010-2039. There is little agreement in projected changes in rainfall for the 2040-2069 period. This is not considered a serious a limitation in the context of this study, since the near future (2010-2039) is the most relevant period for most development planning in response to climate change.

Table 6: Range of projected changes in mean annual rainfall at six selected sites in the Mbale region

Location	Baseline (mm)	Projected changes (% min to max)	
		2020s	2050s
Buluchecke	1776	-5.1 to +8.3	-5.1 to +8.3
Bududa	1188.0	-7.6 to +11.4	-7.6 to +11.4
Mayenze	1783.0	-5.1 to +8.1	-5.1 to +8.1
Butiru	1226.0	-7.4 to +11.3	-7.4 to +11.3
Busiu	1781.0	-5.1 to +8.3	-5.1 to +8.3
Mbale	1178.0	-8.0 to +11.6	-8.0 to +11.6

Projected changes in precipitation or temperature remain uncertain. Uncertainties in projections come from various sources, including emissions scenarios. Firstly, the link between economic development, global population growth and their corresponding effects on the global climate system are not very direct. Most population growth in the 21st century is expected in sub-Saharan Africa, yet the per capita impact of Africa's population is very small compared to that of people in the developed world. Other factors of uncertainty in future climate projections are the numerous global circulation models that realize the emissions scenarios, each of the climate modeling groups is driven by a different set of assumptions and build their atmosphere–ocean coupled general circulation models differently. Despite high levels of uncertainty associated with future climate projections, there is high level of confidence in projections for the Mbale region simply because these changes are already being observed in the weather over the decade to 2010 (i.e. reduction in rainfall during the dry season has been observed coupled with increase in rainfall during May as well as for the October and November).

Future climate projections are valuable for a number of reasons; they provide levels of potential climate-related risks and can be used to gauge the likely future hazards. Future climate data can be an integral part of planning process, with the effects of climate change being incorporated in the plans, with provisions to cater for any shortfalls as a result of changes in climate or take advantage of any opportunities climate change may bring out. Indeed, it is also becoming common practice to use recent climate trends in addition to future climate projections for development planning. This helps reduce the level on uncertainty associated with projections enabling development planners prepare for realistic changes in climate. However, for planning adaptation interventions, it is recommended to use a range of projections this give resource managers the probability of success in dealing with changes in climate that will eventually manifest in the future.

3. Mbale Climate Change Profiles

3.1 Developing climate profiles

This section presents a description of climate for the Mbale region for the 1961-1990 baseline period as well as future climate projections for two time slices; the current 30-year period (2010-2039) and for the 2040 to 2069 period. For each time slice, data is available for 55 climate variables including monthly maximum and minimum temperature, monthly precipitation/rainfall (that is; minimum temperature for 12 months, Tmin01 –tmin12, maximum temperature for 12 months Tmax01 – Tmax12, monthly precipitation for 12 months, prec01-prec12) together with a list of 19 other biologically important variables (Annex 2 provides a list of all variables,).

The description of the Mbale region baseline and projected climate is based on downscaled version of the WorldClim data set. WorldClim is a set of global climate layers (climate grids) with a spatial resolution of about 1 square kilometer (Hijmans *et al*, 2005). Future climate projections were available from a downscaled GCMs projection by the CCAFS. This data is available for down load from this website http://www.ccafs-climate.org/

Projections of future climate for the Mbale region are based on two emissions scenarios (A1b and A2) and are from at least 5 General Circulation Models. This implies that for each of the 55 climate variables there are at least 10 likely options (2 emissions scenarios x 5 GCMs). Such a range of projections would require a huge effort on the part of resource managers in deciding which one of these versions is likely to manifest in the future. Obviously, such a task has no quick answer. First, the IPCC recommended in 2001 that each of the emissions scenarios should be treated as a potential scenario of what might happen in the future. Then, in terms of the GCMs, it is a question of which is the right or more realistic. Recent studies are now recommending that a whole range of future climate scenarios is used to provide a picture of what is likely to happen in the future, with an emphasis to be put where most of the scenarios and GCMs agree most. Since 2001 when the SRES was released, we know that the most conservative emissions scenarios B1 and B2 are very unlikely because observed emissions have exceeded these and are now in the A1 and A2 range.

Projected changes have been presented as average of GCMs values for each emission scenario.

3.2 Climate change projections for Mbale region

The Mbale region is projected to get warmer in the future. Projected changes in temperature are larger for maximum temperature as opposed to changes in minimum temperature. Whereas some GCMs project reductions in minimum temperature for some months during the earlier period (2020s), due largely to natural decadal variability (Table 8, 9 and 19), there is general agreement across all GCMs and Scenarios that monthly maximum temperature will go up over the 2020s and 2050s. Larger temperature changes have been projected for January and February and in June, July and August for most locations in the region (Table 8, 9 and 10 and Figures 28 and 29).

It is also clear from the projected trends that high elevation areas such as Bulucheke (1,776m asl), are cooler than lower elevation areas such as Mbale (1,170m asl). Despite the elevation driven spatial variation in temperature in the Mbale region, projected changes are of the same magnitude for different locations in the region (Tables 6, 7 and 8), largely because the data is interpolated from the coarse scale GCM data.

Table 7: The range of projected changes in minimum and maximum temperature from three emission scenarios for Bulucheke, in Bududa district a high elevation location within the Mbale region

Month	Minimum Temperature (^{o}C)			Maximum Temperature(^{o}C)		
	Baseline	Projected Change		Baseline	Projected Change	
	1961-1990	2020s	2050s	1961-1990	2020s	2050s
Jan	15.0	-1.0 – +1.5	+1.6 – +2.2	29.8	+0.9 – +12	+1.4 – +14
Feb	15.2	-0.7 – +1.5	+2.1 – +2.2	29.7	+0.5 – +12	+1.5 – +14
Mar	15.7	-0.6 – 0.0	+1.6 – +2.4	29.1	+0.8 – +11	+2.2 – +12
April	15.6	-0.7 – +0.3	+1.4 – +2.3	27.9	+0.2 – +8	+1.8 – +9
May	15.2	-0.3– 0.0	+1.8 – +3.0	27.3	+0.3 – +8	+2.6 – +8
Jun	14.9	-0.9 – -0.1	+1.3 – +3.1	27.0	+1.9 – +9	+3.7 – +9
Jul	14.9	-1.6 – +0.1	+1.4 – +3.3	26.4	+2.3 – +10	+3.2 – +11
Aug	14.8	-0.9 – +0.1	+1.6 – +2.8	26.8	+1.0 – +10	+2.1 – +11
Sep	14.7	-0.7 – 0.0	+1.2 – +2.3	27.2	+0.6 – +9	+1.9 – +11
Oct	14.6	-0.3 – 0.1	+1.6 – +2.2	27.5	+0.2 – +8	+1.6 – +9
Nov	14.8	0.1 – +0.2	+1.6 – +2.2	27.6	+0.1 – +7	+2.4 – +8
Dec	15.0	-0.5 – +0.9	+2.0 – +2.3	28.3	+0.8 – 9	+1.7 – +10

Table 8: The range of projected changes in minimum and maximum temperature from three emission scenarios for Butiru, a mid-elevation location in Manafwa district within the Mbale region

Month	Minimum Temperature (^{o}C)			Maximum Temperature(^{o}C)		
	Baseline	Projected Change		Baseline	Projected Change	
	1961-1990	2020s	2050s	1961-1990	2020s	2050s
Jan	14.7	-1.2 – +1.5	+1.7 – +2.3	29.7	+1.2 – +12	+1.2 – +14
Feb	14.9	-0.7 – +1.5	+2.1 – +2.2	29.8	+0.7 – +12	+1.7 – +14
Mar	15.4	-0.7 – +0.1	+1.7 – +2.4	29.3	+1.1 – +11	+2.2 – +12
April	15.4	-0.7 – +0.7	+1.4 –	28.0	+0.7 – +9	+1.8 – +9

			+2.3			
May	**13.1**	+1.5 – +1.6	+3.6 – +4.5	**27.1**	+0.8 – +8	+2.8 – +8
Jun	**14.5**	-1.1 – +0.1	+1.4 – +3.0	**26.9**	+2.2 – +9	+3.4 – +9
Jul	**14.2**	-1.7 – +0.8	+3.2 – +1.6	**26.4**	+2.6 – +10	+3.3 – +11
Aug	**14.2**	-1.0 – +0.3	+1.8 – +2.8	**26.6**	+1.6 – +10	+2.2 – +11
Sep	**14.3**	-0.7 – +0.2	+1.4 – +2.3	**27.3**	+0.9 – +9	+1.8 – +11
Oct	**14.6**	-0.5 – 0.0	+1.6 – +2.2	**27.8**	+0.2 – +8	+1.9 – +9
Nov	**14.7**	-0.1 – +0.2	-1.6 – +2.1	**27.9**	+0.1 – +7	+2.4 – +8
Dec	**14.6**	-0.6 – +0.9	+1.9 – +2.2	**28.4**	+1.0 – 9	+2.7 – +10

Table 9: The range of projected changes in minimum and maximum temperature for Mbale Town, a low elevation area within the region

Month	Minimum Temperature (°C)			Maximum Temperature(°C)		
	Baseline	Projected Change		Baseline	Projected Change	
	1961-1990	2020s	2050s	1961-1990	2020s	2050s
Jan	**16.4**	-0.9 – +1.7	+1.7 – +2.3	**31.7**	+0.9 – +12	+1.2 – +14
Feb	**16.9**	-0.7 – +1.6	+2.1 – +2.2	**31.4**	+0.4 – +12	+1.8 – +14
Mar	**17.3**	-0.3 – +0.2	+1.7 – +2.6	**30.5**	+0.8 – +10	+2.3 – +12
April	**17.5**	-0.3 – +0.7	+1.3 – +2.4	**29.0**	+0.4 – +9	+1.8 – +9
May	**17.2**	-0.2 – -0.5	+1.6 – +2.5	**28.3**	+0.1 – +8	+2.8 – +8
Jun	**16.8**	-1.2 – -0.3	+1.3 – +3.1	**28.2**	+1.8 – +9	+3.6 – +9
Jul	**16.5**	-1.3 – -0.5	+1.6 – +3.3	**27.5**	+2.3 – +10	+3.3 – +11
Aug	**16.3**	-0.6 – +0.3	+1.8 – +2.8	**27.9**	+1.2 – +10	+2.3 – +11
Sep	**16.2**	-0.5 – +0.2	+1.4 – +2.3	**28.6**	+0.5 – +9	+1.9 – +10
Oct	**16.3**	-0.2 – 0.0	+1.6 – +2.2	**28.9**	-0.3 –- +8	+1.8 – +9
Nov	**16.4**	+0.1 – +0.1	+1.6– +2.2	**29.4**	-0.1 – +7	+2.4 – +8
Dec	**16.3**	-0.5 – +0.9	+1.9 – +2.2	**30.0**	+0.7 – +9	+1.8 – +10

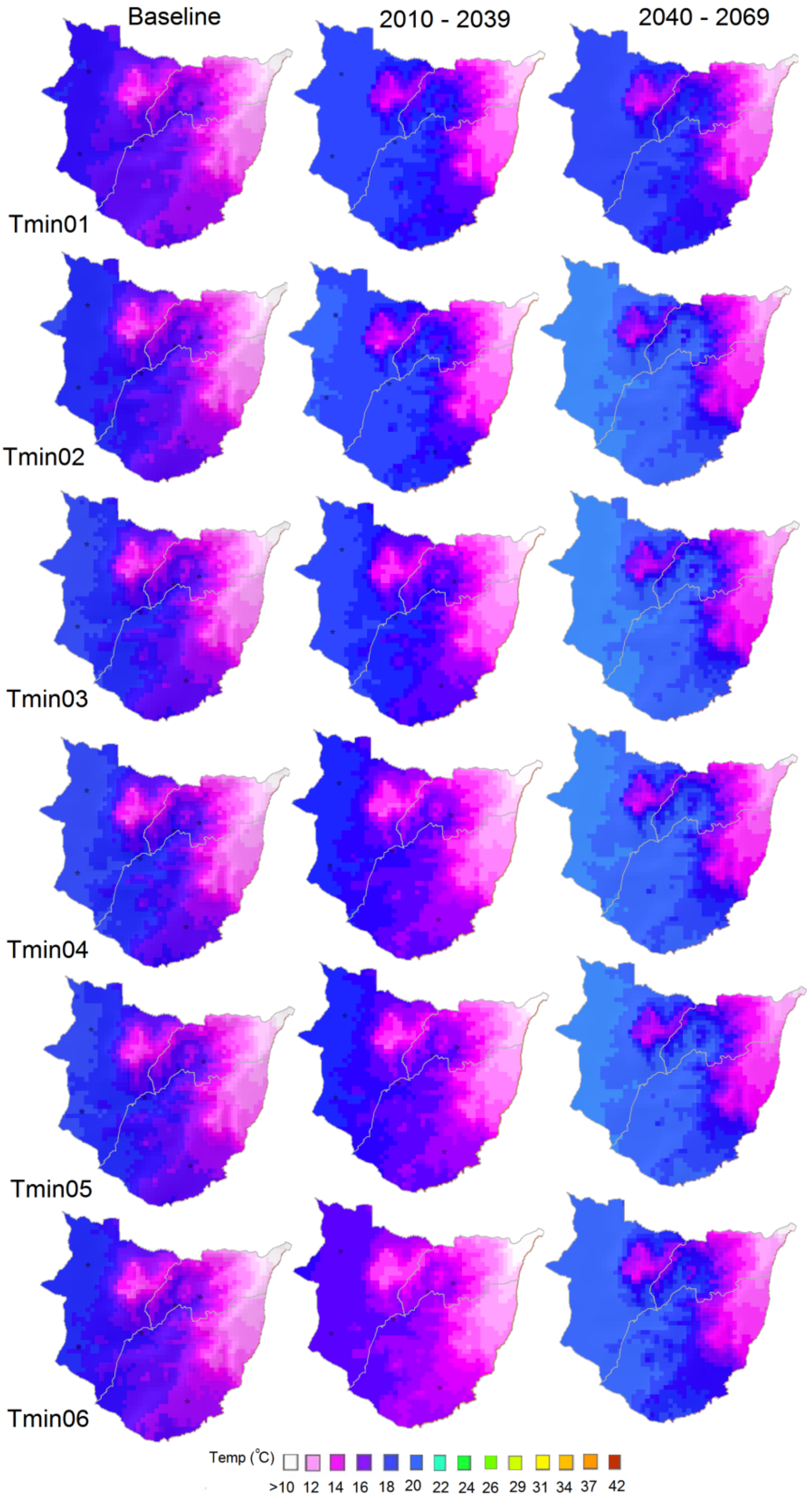

Figure 25: Baseline and projected monthly minimum temperature for January to June (Tmin01 – Tmin06) for two future time slices, the 2010 – 2039 (2020s) and 2040 – 2049 (2050s) for the Mbale region in Uganda

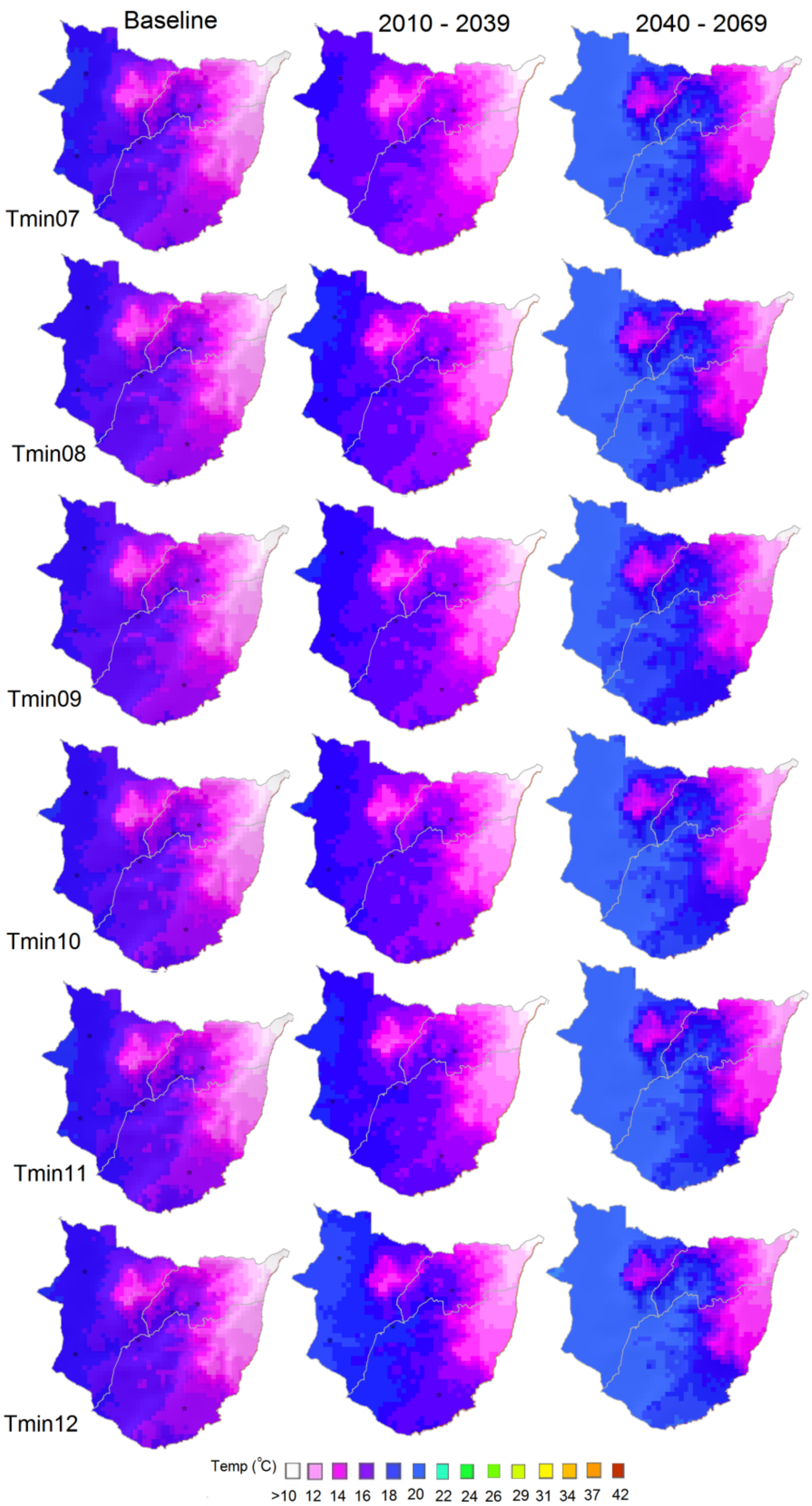

Figure 26: Baseline and projected monthly minimum temperature for July to December (Tmin07 – Tmin12) for two future time slices, the 2010 – 2039 (2020s) and 2040 – 2049 (2050s) for the Mbale region in Uganda

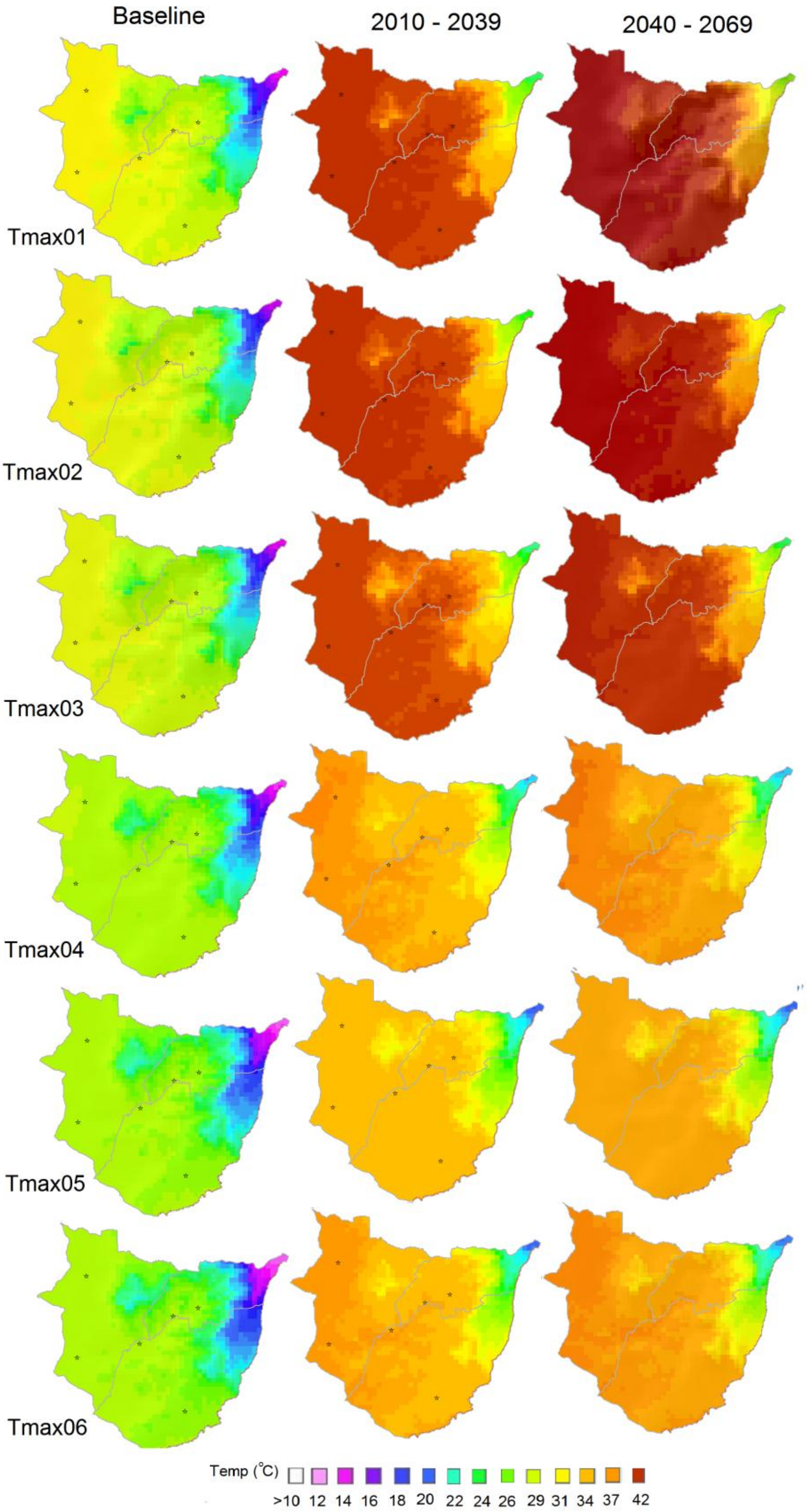

Figure 27: Baseline and projected monthly maximum temperature for January tor June (Tmin01 – Tmax06) for two future time slices, the 2010 – 2039 (2020s) and 2040 – 2069 (2050s) for the Mbale region in Uganda

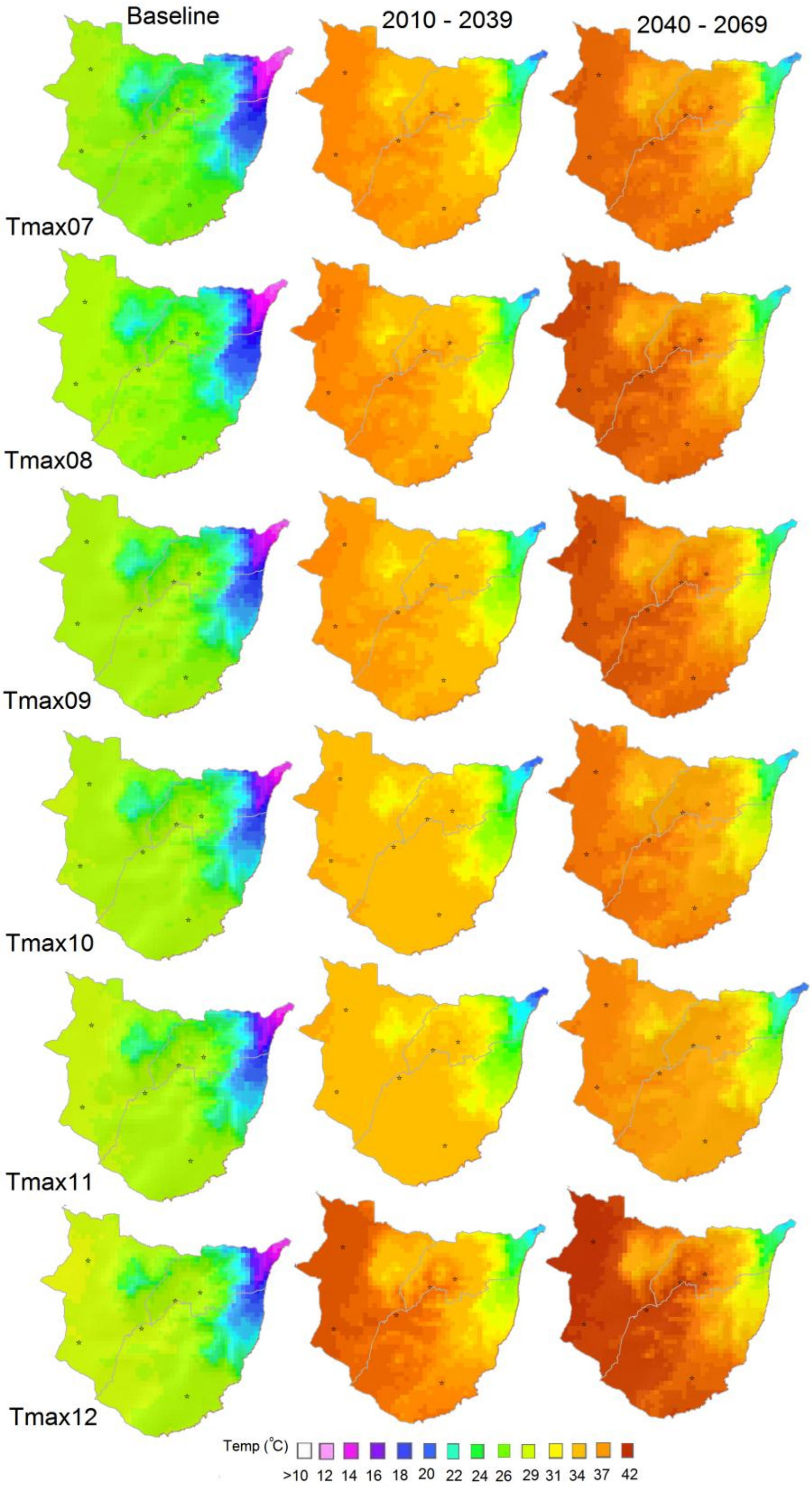

Figure 28: Baseline and projected monthly maximum temperature for July to December (Tmax07 – Tmax12) for two future time slices, the 2010 – 2039 (2020s) and 2040 – 2069 (2050s) for the Mbale region in Uganda

Most GCMs and emission scenarios project an increase in rainfall over the Mbale region for the 2010 - 2039 period. Projected rainfall, will in most locations, be higher than normals based on the 1961 - 1990 period. Rainfall will increase by up to 20% in all parts of the Mbale region (Figure 30). The projected increase in rainfall is not likely to be uniform both spatially and temporally. Some locations will see larger increase in rainfall compared to others. In addition, reduced precipitation has been projected for some locations in the region during the 2040-2069 period, particularly in the western sub-counties of Mbale municipality, Nakaloke, Bunghkho, Busiu. The western part of the Mbale region lie in some form of rain shadow and will generally receive less rainfall than the other region as is the trend with observed climate (Figure 31).

Whereas projected changes in temperature will steadily continue in the 21st century, changes in precipitation will not follow the same trend. A good number of GCMs and scenarios project an overall precipitation increase in mean annual precipitation over the 2010-2039 and 2040-2060 period or the 2020s and 2050s respectively. However, GCMs do not seem to agree on precipitation trends during the 2049 to 2069 period. Some GCMS project continued increase (ECHAM, MUIB-ECHO) while others project reduced precipitation amounts compared to 2010-2039 totals (MEDRES, GISS). Faced with such information, most climatologists would advise adopting the direction or trend from the majority of projections. Nevertheless, it is also risky to ignore projections of a lesser or even contradicting changes.

Whereas the range of projected changes mean annual rainfall are up to +5% in the 2020s and +5 to 9% for the 2050s above the 1961 – 1990 mean values, projected changes in monthly rainfall amounts are much larger. Larger changes have been projected for November, December, January and February (Table 9). It is worth mentioning that it is not easy to get general agreement between the ranges of projections at the monthly level. The only obvious one is a trend towards more rainfall for the July to December period. The worst-case scenario for projected changes in rainfall includes up to 50% reduction in January and February rainfall. The best-case scenario are in the second rain season where there is a net increase projected for the July to December. Given this range of uncertainty in projected changes in rainfall, it is important that the region prepares for both the best-case and worst-case scenario for each month.

Projections of annual rainfall are summarized as averages from the different projections. This helps to give the overall trends, however this would not be a good way of summarizing monthly rainfall projections because of the large month to month variation in rainfall totals and the wide range in projected changes. Overall, the A1b and A2 scenarios project 2-5% increase in mean annual rainfall over the 1961-1990 values for the Mbale region for the 2020s and 5-9% increase for the 2050s (Figures 27 and 28). The A2 scenarios project slightly higher rainfall increase than the A1b scenarios for all GCMs (Figure 28). Whereas reduced rainfall is projected for some months by some GCMs (Table 9), the general trend is for more rainfall over the year.

Table 10: Range of projected changes in rainfall over three selected locations, Bulucheke in Bududa District, Butiru in Manafwa District and Mbale in Mbale district in the Mbale region

Month	Bulucheke			Butiru			Mbale		
	Baseline (mm)	Range of projected change (%)		Baseline (mm)	Range of projected change (%)		Baseline (mm)	Range of projected change (%)	
		2020s	2050s		2020s	2050s		2020s	2050s
Jan	**37**	-41 to +32	-41 to +46	**45**	-36 to +31	-36 to +44	**32**	-53 to +34	-47 to +50
Feb	**73**	-10 to +16	-8 to +26	**85**	-40 to +13	-6 to +24	**52**	-63 to +21	-13 to +35
Mar	**110**	-7 to +27	5 to +39	**115**	-8 to +25	6 to +38	**100**	-9 to +28	5 to +43
Apr	**177**	-36 to +8	-31 to +8	**201**	-32 to +6	-27 to +7	**150**	-76 to +9	-37 to +9
May	**203**	-3 to +14	-22 to +19	**189**	-3 to +14	-12 to +21	**167**	-4 to +17	-13 to +22
Jun	**129**	-14 to +19	-20 to +53	**122**	-15 to +20	-22 to +19	**107**	-17 to +24	-25 to +21
Jul	**144**	-15 to +24	-13 to +26	**119**	-17 to +28	-3 to +30	**112**	-19 to +29	-4 to +30
Aug	**156**	-19 to +10	-14 to +15	**131**	-23 to +13	-18 to +19	**132**	-21 to +11	-16 to +21
Sep	**120**	-22 to +25	-23 to +39	**115**	-22 to +26	-91 to +17	**98**	-28 to +28	-31 to +20
Oct	**146**	-16 to + 20	-21 to +43	**150**	-15 to +18	-18 to +42	**96**	-26 to +29	-25 to +66
Nov	**107**	-33 to +29	-26 to +48	**123**	-31 to +24	-24 to +31	**85**	-40 to +36	-32 to +44
Dec	**49**	-18 to +61	-10 to +133	**63**	-13 to +49	-10 to +103	**52**	-17 to +58	-10 to +125

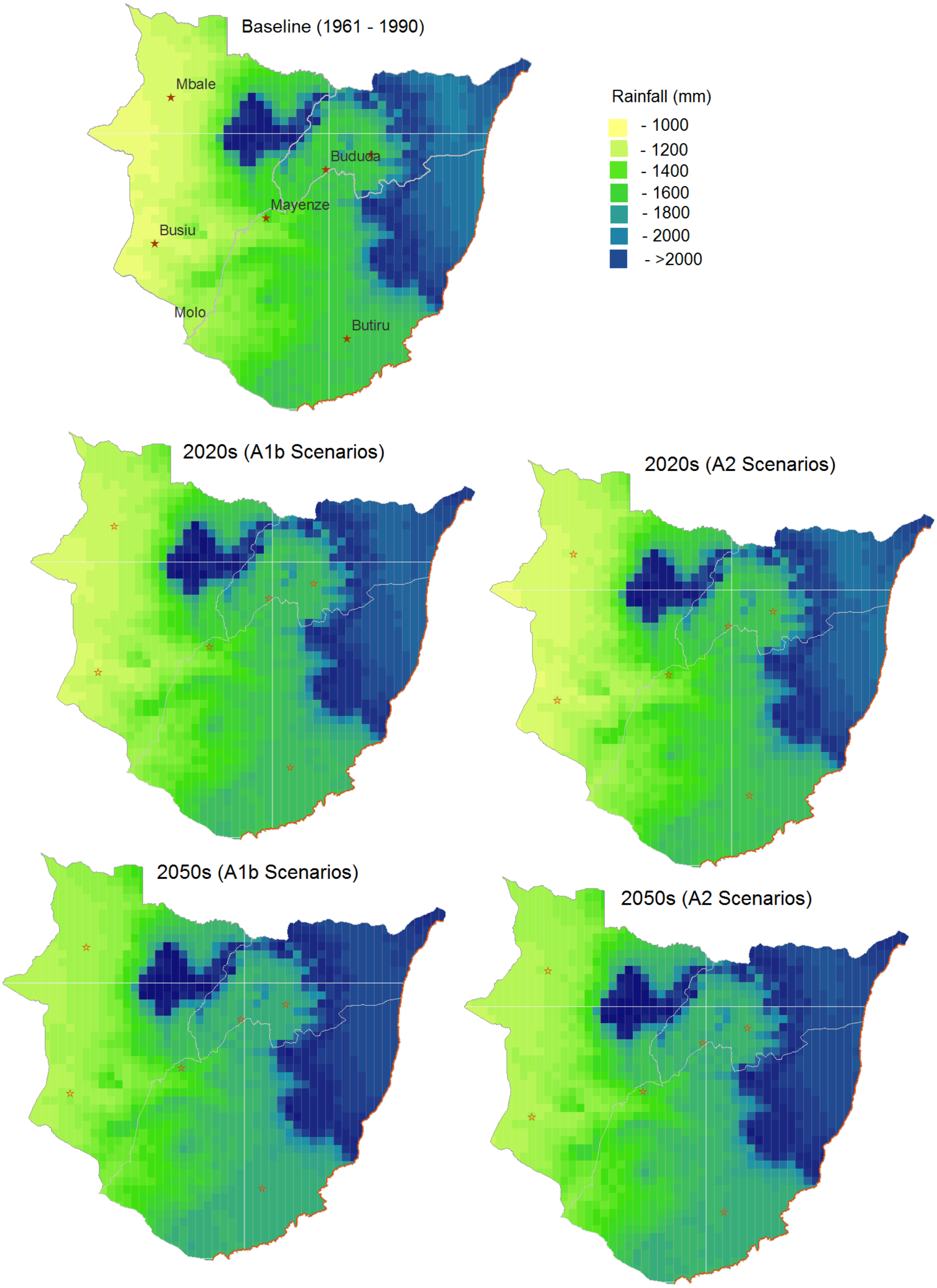

Figure 29: Mbale region baseline and A1b and A2 ensemble projected mean annual rainfall for the 2020s (2010-2039) and 2050s (2040-2069)

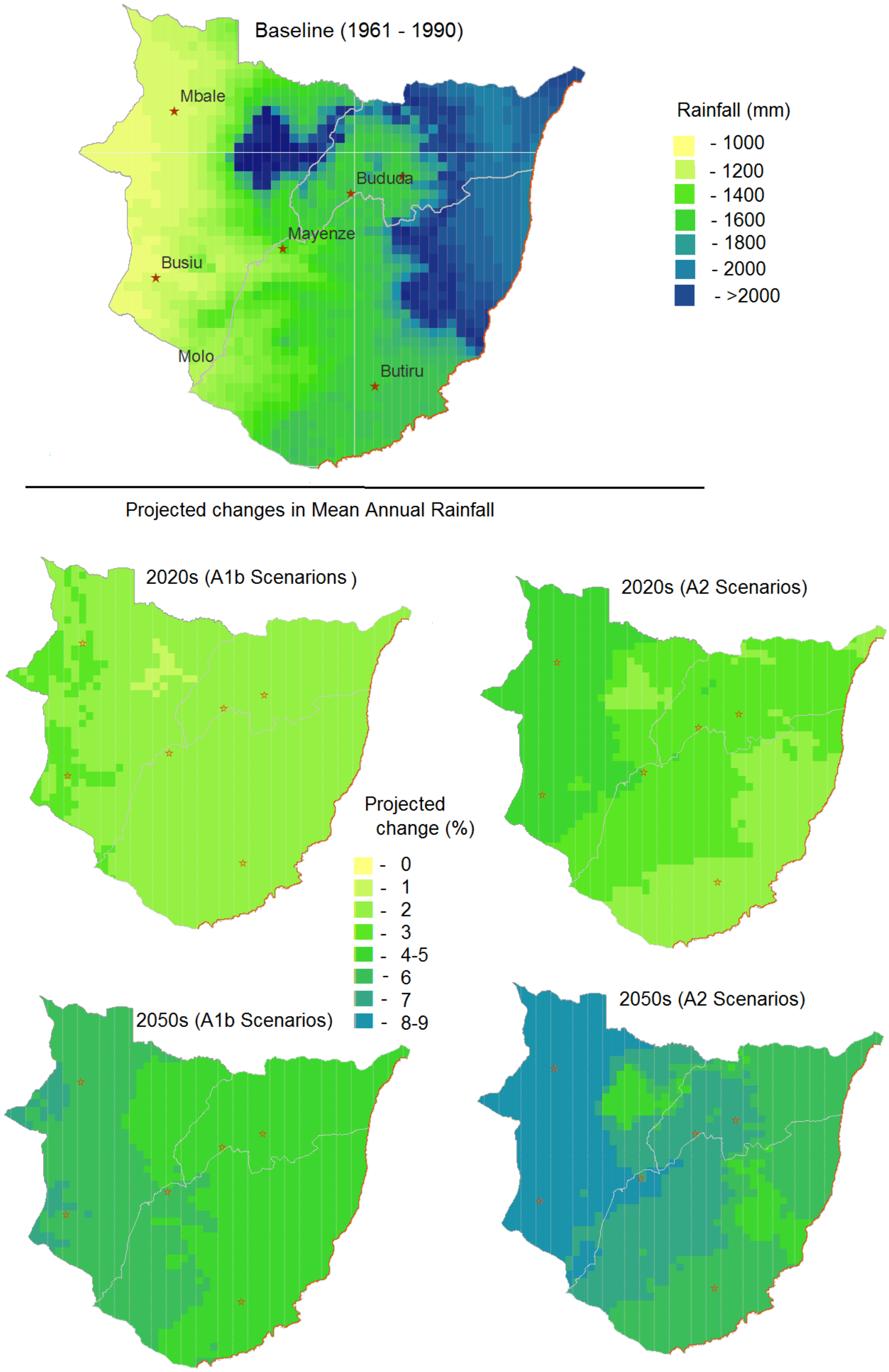

Figure 30: Percent change in Mbale region A1b and A2 ensemble projections of mean annual rainfall for the 2020s (2010-2039) and 2050s (2040-2069)

3.3 Climate change impacts to the Mbale region

3.3.1 Climate change impacts on the environment

Trees and forests: The Mbale region has lost most of its natural forests to cultivation and settlement, with the exception of the Mt. Elgon National Park to the northeast, which is still, has forests and other natural vegetation at high elevations. However, the Mt. Elgon National Park also faces threats from excessive cutting of trees of timber and other uses as well as clearing of all forest vegetation for farming. Undoubtedly, projected increase in temperature and rainfall will result into expansion of the tree cover in the high elevation areas that are currently covered with grassland. However, this has no direct effect on people that live below but may affect grazing areas for pastoralists that graze the animals in high elevation areas. Expansion of the tree-line to higher elevation areas will threaten species characteristic of the grassland that will eventually be replaced.

An increase in the severity of the dry season is expected, associated with increase in temperature over the hottest months of the year (December, January and February) associated with a reduction in rainfall expected during the same period. These changes might result into various effects such as increased incidence of wildfires at high elevations that might spread into the bamboo and montane forests on Mt. Elgon National Park.

Hydrology and Water resources: most scenarios project higher precipitation especially in the high elevation areas of the Mbale region and the rest of the Mt. Elgon particularly for the 2020s. Indeed, other analyses have described a potential reduction in water stress in the entire east African region (Conway 2009 and McSweeny *et al*, 2008). Higher rainfall is obviously good for agriculture and other sectors; however, most of the landscape where natural vegetation has been lost will be liable to increased runoff. This will result into high rates of erosion that will wash away the topsoil, where nutrients and organic matter are concentrated. Washing away of top soil has various implications including a reduction in soil fertility, reduction in stream and river water quality and siltation of streams and rivers. Cases of water scarcity are likely to increase during the dry season. Water scarcity will be an outcome of increased temperature during the dry season coupled with reduced rainfall.

Despite a projected increase in total rainfall over the year, the same models project reduced rainfall during the December, January and February months. This is likely to translate into increased water stress for crops over these months.

Soils: Soils in the region will be faced with increased water stress in the dry season. There is increased risk of washing away of nutrients in the rain season as well as siltation of streams and rivers

Infrastructure: The sides of cut-out roads will be destabilized especially as a result of heavy rainfall; culverts and bridges will be silted as a net result of bare ground and high rainfall. Bridges may get submerged under heavy downpours interrupting traffic. Houses and other building will be threatened by erosion and in extreme cases of landslides.

Wildlife: the impact of climate change on wildlife is a result of direct effect such as floods and drought, as well as long term effect that will be a result of responses by humans. Fires are an important threat to wildlife. Increase of the incidence of wild fires as a result on higher temperatures in the dry season months of December, January and February will lead to loss of wildlife habitats and threaten wildlife.

3.3.2 Impacts of climate change on agriculture and livestock

Major crops grown in the region include banana, coffee, maize, beans, tomatoes, cabbage. Other crops grown on a smaller scale include Irish potatoes, sweet potatoes, cassava and rice. Crop production is normally affected by numerous factors such as the climate, soils, pests and diseases, as well as several other management aspects. The most important climate variables with respect to agricultural production are rainfall and temperature, mainly because nearly all-agricultural production in the Mbale region is rain-fed. Farmers mainly rely on rains and on water in streams to irrigate dry season crops such as cabbage.

Stakeholders pointed to remarkable seasonal change within the Mbale region in the recent past. Shifts or changes in seasons has already affected crop production as well as reduced pasture for livestock. Changes in climate affecting the seasons will increase with greater impacts on agriculture. For example, the dry season is projected by most scenarios to get worse in February. Increased rainfall in May will result into increased erosion with negative impacts on agricultural productivity in the region.

Banana which is one of the main staples in the Mbale region is increasingly being affected by the banana wilt disease. Arabica coffee prefers cold shady environment with an optimum temperature range of 15 - 24^{o}C and about 1500 to 2000 mm or rainfall (ITC, 2010). As a result of projected changes in precipitation and temperature, traditional coffee growing regions may shrink or disappear at lower elevation and new ones many emerge at high elevations (Laderach *et al*, 2009). Areas that are currently too cold for coffee particularly in high elevation areas will become suitable for coffee growing under warmer temperatures. Impact of climate change on coffee berry borer was investigated by (Jaramillo et al., 2011) who reported increased incidence of the pest as temperatures increase. The suitability of the Mbale region for coffee growing is likely to shift from low to high elevation areas under future climate. In addition to affecting quantities, climate change will affect the quality of arabica produced. Higher temperatures have been reported to cause early ripening of coffee beans reducing the quality of the product.

Other crops particularly those grown in the dry season such as cabbage will require additional watering. Dry seasons will particularly affect livestock. Pasture will be scare and farmers will have to spend more to get adequate pasture for their livestock. Higher temperatures in the future have also been associated with the spread of tsetse flies to high elevations where they have not been observed before.

Table 11: Climate risk factor in the Mbale region

Phenomenon and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios	Major projected impacts by sector			
		Agriculture, forestry and ecosystems	Water resources	Human health	Socio-economic
Mostly in the dry season warmer and fewer cold days and nights, warmer and more frequent hot days and nights.	Virtually certain	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snowmelt; effects on some water supplies	Reduced human mortality from decreased cold hazards	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand; water quality problems, e.g. algal blooms	Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially isolated	Reduction in quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young and poor
Heavy precipitation events. Frequency increases over the high elevation areas	Very likely	Damage to crops; soil erosion, inability to cultivate land due to water logging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures; loss of property
Incidence of drought increase in low elevation areas in Mbale and Manafwa districts	Likely	Land degradation; lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water-and food borne diseases	Water shortage for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration

4 Risk and Vulnerability ofMbale Region to Climate Change

4.1 Vulnerability to climate change

The IPCC's Third Assessment Report (TAR) defines vulnerability to climate change as "the degree to which a system is susceptible to or unable to cope with, adverse effects of climate change, including climate variability and extremes of weather (IPCC, 2001). Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity. Exposure is defined as the nature and degree to which a system is exposed to significant climatic variations. Sensitivity is the degree to which a system is affected with adversely or beneficially by climate-related stimuli. Adaptive capacity is the ability of a system to adjust to climate change to moderate potential damages, to take advantage of opportunities or to cope with the consequences.

Turner *et al* (2003) suggest that assessing vulnerability will involve finding answers to such questions as: Who and what are vulnerable to the climate changes underway, and where? How are these changes and their consequences attenuated or amplified by different human and environmental conditions? What can be done to reduce vulnerability to change? How many more resilient and adaptive communities and societies be built? Society's ability to adapt to climate change could be limited by a whole range of factors such as levels of knowledge, culture (Adger et al., 2009). A whole range of socioeconomic characteristics of the three districts in the Mbale region such as levels of population, levels of literacy and other traditional ways of living and their present or potential link to climate change adaptation were collected. Another factor is the conflict in ownership or use of resources such as the Mt. Elgon National Park.

UNDP's guidelines outline four steps for assessing vulnerability to climate change. The first is to assess the past and present climate trends. The second is to assess the past and present sensitivity to known hazards (including both extreme events and incremental change). The third and fourth steps start to embrace uncertainty, as the exact types of future physical changes in climate and socio-economic changes that will affect sensitivity of sectors are unknown and could follow a number of different pathways. The third is assessing future exposure to climate risk, and the fourth is assessing future sensitivity of sectors to that risk.

Because not all areas will be affected in the same way or to the same magnitude (Schneider et al., 2007) an effort was made to spatially represent climate change vulnerabilities across the Mbale region. The clear emphasis on local context and the development of integrated perspectives on vulnerability points to vulnerability mapping as a useful tool for building understanding regarding complexity in coupled human/environmental systems at a scale that is practical for subsequent discussions around adaptation (Preston et al., 2011). Spatial tools and techniques were used to map vulnerability of different sections and sectors of Mbale region to climate change impact. Assessing vulnerability to climate change also benefited from interactions with relevant stakeholders and experts on various sectors as well as interest groups in Mbale region.

4.2 Vulnerability of the environment of Mbale to projected climate

4.2.1 The environment

Natural vegetation

Natural vegetation of Mbale region is mainly comprised of the Mt. Elgon forest national park, there are few remnants of natural vegetation outside the park since the rest of the region is highly cultivated (Figure 32). Mt. Elgon National Park is not a production forest, yet it is still faced with problems of illegal timber exploitation and some level of encroachment. Thus, all activities that reduce tree cover will increase the vulnerability of the mountain ecosystems to landslides, and washing away of arable soil, particularly on steep slopes where the trees serve to protect the soil.

The Mbale region has loose soils. Because of the mountainous landscape the soils are usually kept in place by plant roots, thus removal of trees and other vegetation from the landscape increases the vulnerability of the soils to erosion and in cases of extreme rainfall events, landslides. Natural vegetation provides a range of resources to rural communities, including wild fruits, medicines and materials for craft making. These products are valuable sources of livelihood especially during periods when crops do not perform well. Reduction or a complete loss of natural vegetation in the region implies that rural communities now have limited alternative sources of livelihood beyond the farm/garden.

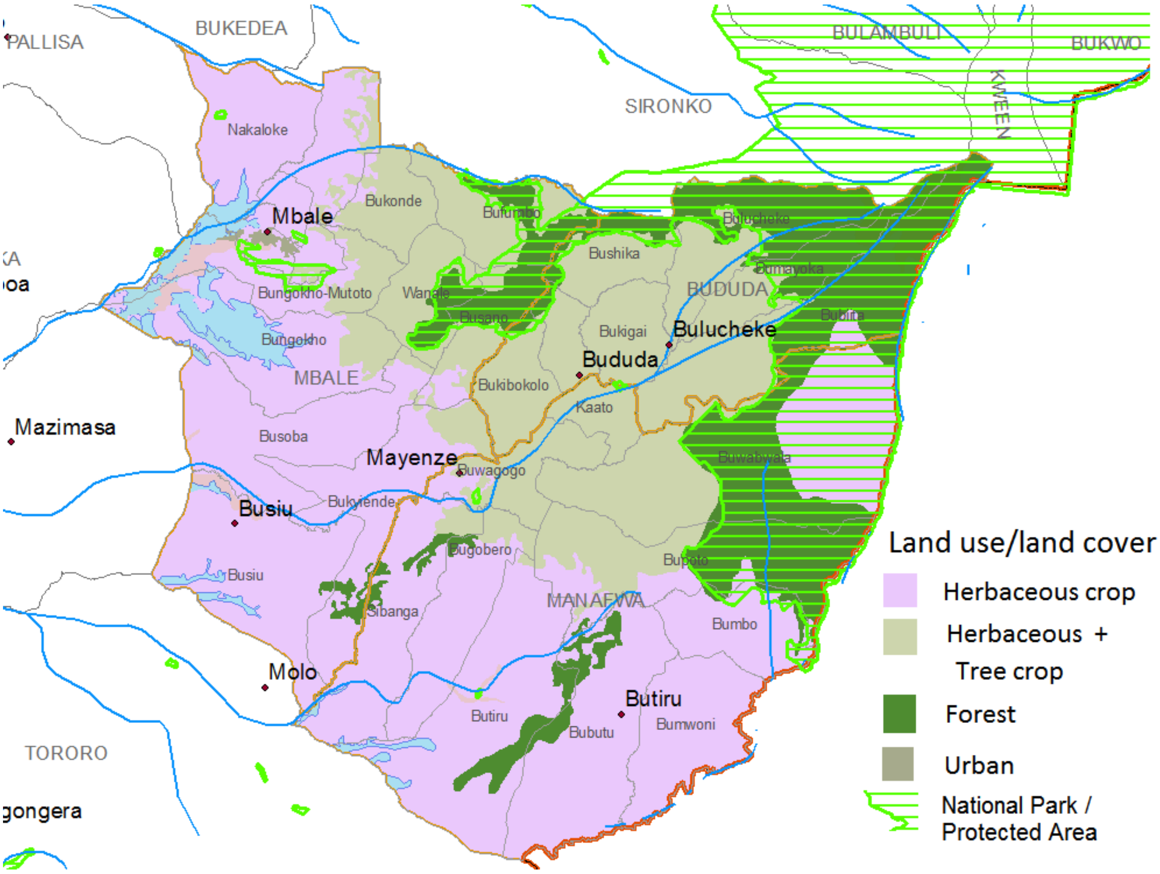

Figure 31: Land use/ land cover for the Mbale region in Uganda (map based on AFRICOVER classifications)

There have been various attempts to restore forest vegetation in Mt. Elgon. The best example is the Face is Forest Absorbing Carbon dioxide Emission - FACE project, working with Uganda Wildlife Authority - UWA embarked on a tree planting exercise covering a 2km strip around the entire boundary of Mt. Elgon National Park. By 2006, 8000 out of the planned 25000ha had been planted. However, in some locations particularly where the boundary interfaces with peoples fields, a lot of these trees have been cut by the communities. The Mt. Elgon Regional Ecosystem Conservation Programme (MERECP) is being run in both the Kenyan and Uganda side of the mountain which has registered success in restoration planning.

Table 12: Climate change risk and opportunities for the environment in the Mbale region

Risks	Opportunities
Wildfires increased in the dry seasons	Increased vegetation cover in high altitudes
Water stress for vegetation increased in the dry season	Rain water could be harvested for irrigation or domestic use
Soil erosion increased on all cultivated and bare slopes	

Landslides increases risk in high slopes	
Floods increase in valleys and wetlands	
Siltation of streams and rivers increase in the rain season	

The soils: soils have been described as clay in the uphill areas and sandy loam in the valleys. The soils are generally fertile but need to be well maintained to sustain the productivity. Valleys are an important source of sand for construction. The clay in the uphill areas provides a good source raw material for the brick-making industry. Excavation of sand in the valleys and use of clay in the uphill areas for brick-making presents a destabilizing element of the soils. Poor cultivation in the upper hill areas is one of the major factors destabilizing the soils. Cultivation that leaves the soil bare for much of the year expose the land to erosion. This is particularly a problem where the slopes are high.

The result of cultivation and brick-making has destabilized slopes and thus led to high levels of erosion. Cultivation leaves the ground on sleep slopes bare for the larger part of the year, in addition soil on cultivated landscape is loose and can easily be washed down the slope when it rains. Brick making on the other hand involves the removal of about 30 to 50 cm of top soil that is used for brick making. Removal of this top soil lager also destabilizes the slopes. This is particularly a problem in high elevation area. Addressing this challenge will include extensive restoration of the excavated sites combined with an increase in vegetation or tree cover and proper soil and water management.

Terracing could be recommended where slopes exceed 25%. Terracing, which is a practice that would have contributed to soil conservation the activity is deemed to increase vulnerability of the soils to erosion. This is perhaps from not doing the terraces well. Besides it takes a few years before terraces stabilized with grass are stable enough to stop erosion of the soil.

Infrastructure: Roads in the Mbale region are mainly murram (loesse surface) and these are very vulnerable to heavy rains. Sandy soils in the valleys made the roads high risk during the rain season.

4.2.2 Agriculture and livestock

Agriculture is the main economic activity in the Mbale region. Nearly 87% of all people in the region are employed in agriculture. Major crops grown include bananas, coffee, beans, maize. The crops are mainly grown in a banana coffee system. Coffee is mainly grown under *Cordia macrophylla* shade. Other coffee shade trees include *Albizia* species, *Grevellia, Eucalyptus grandis* woodlots are also found scattered over the landscape.

Cultivation on steep slopes increases the risk of erosion. This also results into siltation of rivers. Terraces that are one of the techniques that make cultivation on slopes sustainable are a very rare sight in the Mbale region. Stakeholders talked to mentioned that the soil on the slopes is “too loose” to support terracing and that attempts to make terraces have resulted into increased washing away of the soils once the rains start before the terraces have stabilized. Vetiver grass *Vetiveria zizanioides*, which is native to south east Asia has been extensively used for soil erosion, sediment control and for steep slope stabilization. The grass has been used to stabilize slopes in Ethiopia. This multiple use grass develops roots that are more than 3m deep. The grass is palatable to livestock especially before it flowers, thus can be a valuable pasture. Important attributes of the grass includes its deep root system, it does not seed reducing its changes of becoming a weed and is long lived.

The other effect of climate change is erratic rainfall. Projections of rainfall from some scenarios give more than 100% reduction of increase in monthly rainfall. The first rains which are normally expected at end of March, are now delayed up to the end of April. Future climate scenarios point to a larger reduction (up to 40%) in April rainfall over the 2020s. The observed and projected trends towards more rain in May point to a shift of the on-set of the first rains from March. This also implies that the dry season that starts in December is now longer. These trends will continue in the future mainly affecting short rotation crops.

Off-farm impacts include fluctuation in the prices of agricultural produce mainly of coffee. Farmers would normally respond to this by cultivating larger areas of land, however expansion of land under agriculture in not possible in the Mbale region with its high population. The only alternative is to improve techniques employed by the farmers to improve yields and maintain soil fertility and protect the general landscape.

A good proportion of households have at least one animal, normally a hybrid cow that is kept under zero-grazing. Animals are usually fed on pasture grown along rows and boundaries or bought. Another important source of animal feed the banana pseudo stems that are chopped into pieces to feed animals once the bananas have been harvested. Animals provide a kind of safely net, provide milk to the household for consumption and a little income and provide manure that help improve productivity of the soil and have the potential to be used for biogas production. Aspects of vulnerability of livestock are associated with higher temperatures favouring spread of animal diseases, especially tsetse fly that was historically limited to the low elevation areas by lower temperatures in high elevation areas. Extended dry periods reduce the pasture availability as well as milk yield. Households would have to purchase nearly all pastures from those farmers growing in the valleys.

Due to the relatively cooler temperatures, livestock in the mountains is less susceptible to tick borne disease such as east coast fever (Rubaire-akiiki *et al*, 2004) however increase in temperatures at high elevation areas will increase the prevalence of tick borne diseases in these areas hence threatening livestock.

4.2.3 Vulnerability of coffee to climate change in the Mbale region

Increased incidence of pests and diseases of coffee have been projected in coffee growing areas of Uganda. According to (Jaramillo et al., 2011) and increase in temperature of 2^{o}C and above will result into spread of the coffee berry borer. The coffee berry borer, *Hypothenemus hampei*, which is the most important biotic constraint for commercial coffee production, is expanding its range under warming temperatures in Eastern Africa. The pest was reported uncommon at elevations over 1520 m asl but has recently been observed at 1800m asl, and the spread that has been partly attributed to rising temperature (Kecol *et al*, 2008; Kyamanywa *et al*, 2009).

Shade coffee has been found to be relatively resistant to attack by the coffee berry borer, thus providing the potential for reducing susceptibility of arabica coffee to attack by the pest. The other option suggested could be growing alternative crops at lower elevations especially fruit trees, or growing the coffee at higher altitudes where the pest is projected to have low suitability. The only constraint to growing coffee at higher altitudes under warmer climate is that the high elevation areas that would favour Arabica coffee growing lie within the Mt. Elgon Forest National Park.

Coffee contributes 20-25% of Uganda foreign exchange earnings and is an important source of livelihood for the people of the Mbale region. For instance a 5% increase in coffee price results in 14% increase in disposable income in Mbale and by up to 47% increase in disposable income for the poorest households. Projected changes in climate will affect coffee production and livelihoods. Thus a 5% reduction in coffee production in the region could result in some households losing more than 40% of their income. In the meantime, farmers could be helped get better income through value addition. The coffee cooperative in the region, Bugisu Cooperative Union-BCU is an excellent opportunity to help farmers earn more from their coffee. Involvement of multinational companies that deal in coffee such as Nestle, Starbucks coffee could also help provide the farmers with valuable information and other resources for adaptation of coffee production systems to climate change.

4.2.4 Effect of climate change on human health

Malaria is one of the most significant health problems in Uganda. Mosquitoes are responsible for the spread of malaria thrive under warm temperatures. Mosquito species reported in Mbale include *Culex vansomereni* susp *elgonicus* (Buginyanya, Mbale), *Culex hancoki* Bulambuli (2745 m asl) is a high altitude species (Lutwama , 2000). According to (Lutwama, 2000), most of present Mbale district and parts of western Manafwa district have endemic Malaria. Parts of western Bududa had marginal malaria incidences. This roughly corresponds with the low elevation (<1300m asl) areas of the Mbale region.The rest of the Mbale region, especially high elevation areas in eastern Manafwa and most of Bududa, Malaria was not prevalent (Craig et al., 1999). Temperatures that are effective for transmission of *Plasmodium falciparum* range between 16 °C and 22 °C and above suitable and over 32°C cause high vector population turnover (Craig et al., 1999). Incidence of frost that kills the vectors helps to reduce prevalence of the disease in high elevations. Projected changes in temperature indicate that whereas malaria was marginally present in Mbale and parts Manafwa and Bududa, it will become a major threat to people's livelihoods in the region during the 2010-2039 (Figure 33). Extent of spread of malaria in the Mbale region was modeled using simple regression and minimum monthly temperature values which are critical for the survival of the mosquito vectors.

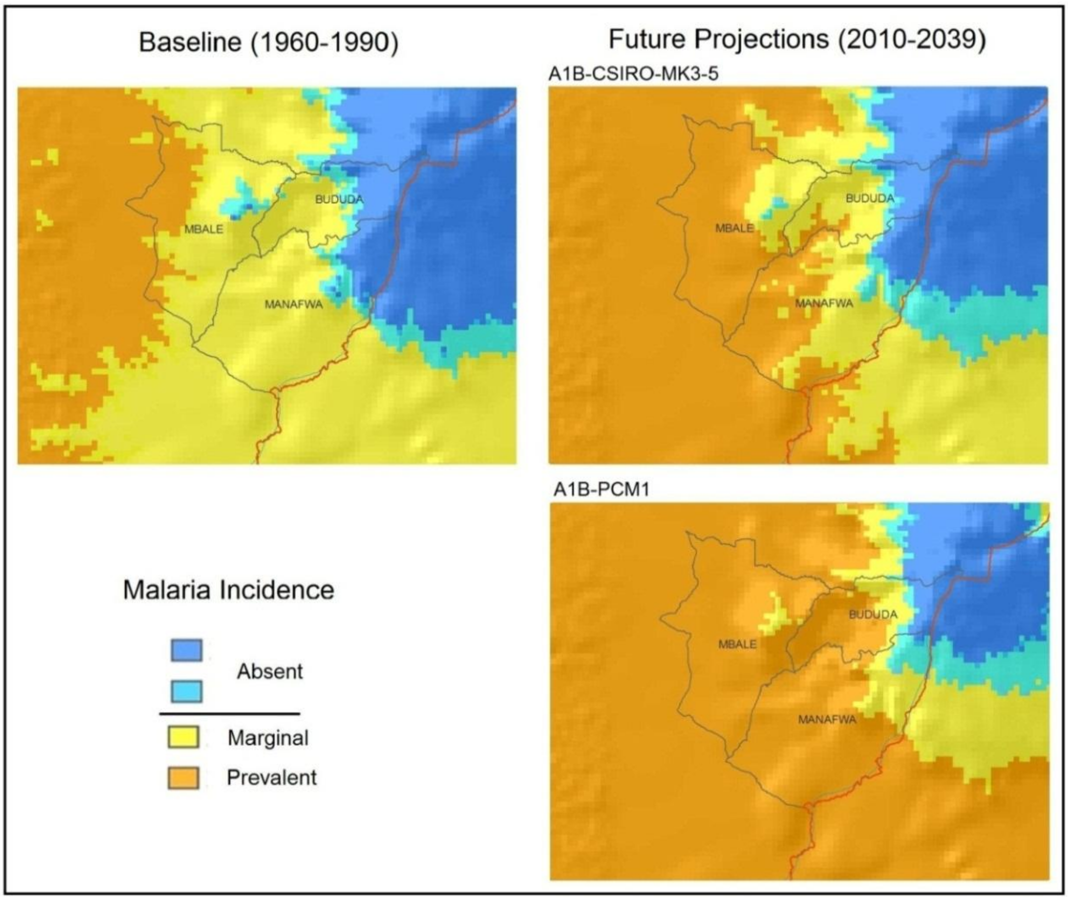

Figure 32: Prevalence of malaria based on baseline (1960-1990) temperature and projections for the 2020s (2010 – 2039) based on two general circulation model (CSIRO-mk3 and PCM) realizations of the A1B scenario

The risk of malaria is not new in the Mbale region but has mainly been low and limited to low elevation areas. However, under changing climate, malaria will change from marginal to prevalent in most of lower elevation locations in the region. This has implications to the productivity of the region. Adults in parts of Uganda where Malaria is prevalent spend at least 20 days in a year bedridden from malaria. The disease is also a major cause of mortality in infants. It is however not easy to put a direct economic or other impact of the increased incidence of malaria to the people of Mbale. Given the low temperature at high altitude, high elevation areas in western Bududa and Manafwa will not support the development of malaria under future climate, so these will continue to remain free of Malaria even under changing climate.

Another significant health problem in the Mbale region is cholera. There has been high incidence of cholera in the Mbale region in the recent past. The first half of 2012 alone has had more than four reported outbreaks of cholera in Bududa and Mbale. Cholera is a disease associated with improper disposal of human waste, resulting in faecal bacteria contaminating food. The spread of this disease can thus be eliminated by proper disposal of human waste. The nature of the landscape in the Mbale region means that contamination can start in high elevation areas and spread to mid elevation and low elevation areas especially during the rain season. According to the state of environment health for Uganda in 2005, Bufumbo, Bungokho in Mbale district and Butiru and Buwabwala in Manafwa district has the largest number of households without pit latrines (Figure 34). Unless the level of coverage of pit latrines increases in these regions, the risk of cholera is likely to increase with the projected increase in rainfall over the Mbale region. Thus the risk of cholera outbreak in March April May and September, October and November will increase.

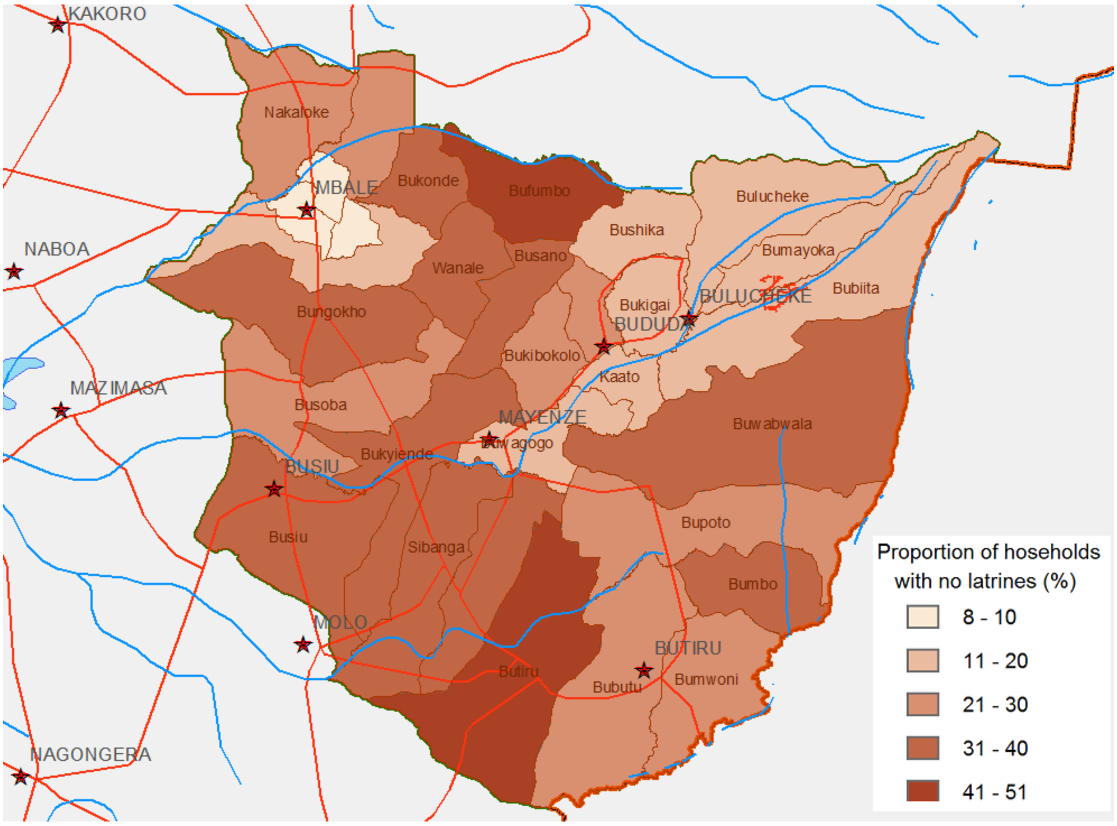

Figure 33: Proportion of total households per county in the Mbale region that do not have latrines map developed from data collected in 2005).

4.3 Climate hazards in the Mbale region

A climate hazard is a climate/weather event causing harm and damage to people, property, infrastructure and land use. According to Oxfam, the primary hazards around the Mt. Elgon region include; landslides and floods these are a direct result from increased rainfall. Others are increased deforestation as farmers forced to higher levels and species loss. From discussions with leaders and technical staff in the Mbale region, landslides were singled out as one of the most important climate hazards. There has been an increase in the incidence of landslides linked to an increase in occurrence of intense rain storms in the region, coupled with other climate related hazards mentioned include hailstones, drought, and soil erosion. On non-climate related disasters that will either affect people's livelihoods as well as their ability to deal with climate change disasters the major one was poverty. Whereas all groups agreed that poverty was a disaster, incidence of disease particularly HIV/AIDS, malaria and cholera featured prominently. There have been rampant outbreaks of cholera in the Mbale region in the recent past the most recent having been in March April 2012. Influx of refugees was also mentioned as a hazard. All these combine to affect people's ability to adapt to climate change and its effects.

Climate-related disasters are by far the most frequent natural disasters, exacting a heavy toll on people and economies (UNDSR 2012). For example the Bududa region has had 6 major landslides in the past 100 years (Kitutu 2010). These landslides have resulted into loss of lives and property. Concerted effort is needed to reduce vulnerability of the region to landslides through proper land management practices or even resettlement for people that are currently occupying very delicate landscapes in the Mbale region.

4.3.1 Drought and floods

An increase in the incidence of floods in the low elevation areas in the Mbale region has been reported (NEMA 2010). Drought has been mainly in the January to February period. February has gotten drier and hotter in the last few decades, in addition the major rain season that used to start in March now appears late in April. Drought affects agriculture many fold, first it affects agricultural yield, and thus directly affect food security and livelihoods. Drought also results into drying of wells, leading to scarcity of water for both domestic use and for livestock in the dry season, farmers need to spend more on irrigation tools or time collecting water in order to maintain the yield on dry season crops such as cabbage that are sometimes exclusively grown with the help of irrigation. Scarcity of water for domestic use has a direct impact on people's health, and ability to produce. Household with no easy access to water will spend a large part of time during the day to collect water, this leaves very little time for them to engage in productive activities, and particularly affects women and girls.

Drought and flooding were also pointed out by stakeholders as the main outcome of recent seasonal changes. Whereas drought is a disaster in some locations and during the dry season, the wet season comes with flooding. High rainfall, removal of vegetation cover interact to increase run-off, which increases the risk of flooding. Floods affect yield from crops such maize that are grown in valleys. Flooding also causes loss of property and makes it hard for farmers to sell their produce as some roads get cut-off by floods.

4.3.2 Development of landslides and associated risks

Given the high rainfall and nature of the hilly terrain, there is high risk for landslides in the Mbale region particularity in the high elevation areas in Bududa and western Manafwa. Landslides are normally driven by a number of factors including steepness of the slopes, the nature of the soil as well as human factors mainly removal of tree cover. There have been many landslides in the Mbale region, particularly in Bududa district since the beginning of the 20th century (Knapen *et al*, 2005). Most of these landslides have occurred in Bulucheke and Bubita and less in Bududa and Bukugai. Understanding the long list of natural factors that bring about the risk of landslides as well as the triggering factors is important in assessing the future risk of landslides in the future.

In addition to steep slopes, landslides will occur on loose unstable ground. Soils in the Mbale region are mainly dominated by highly weathered soils. The situation is exacerbated by complete loss of natural vegetation on most slopes, and the landscape dominated by agriculture. Slopes have also been excavated for house construction, making footpaths, removing lateral support making them highly vulnerable.

Slopes steeper than 60% are cultivated in the region yet these should ideally be kept under forest or other vegetation to protect the slopes (Knapen *et al*, 2005). Since 1991, the population of the region is growing at about 5.6%. Lack of terraces, very little to no tree cover and increasing population all combine to increase the risk of landslides in the future when rainfall is projected to increase particularly in the wet months (April to May and October to November). Absence of landslides in forested slopes in Bukasai and Nusu areas underline the importance of tree cover in protecting the land against mass movement (Knapen *et al*, 2005). Figure 35 shows landslide risk in the Bududa area.

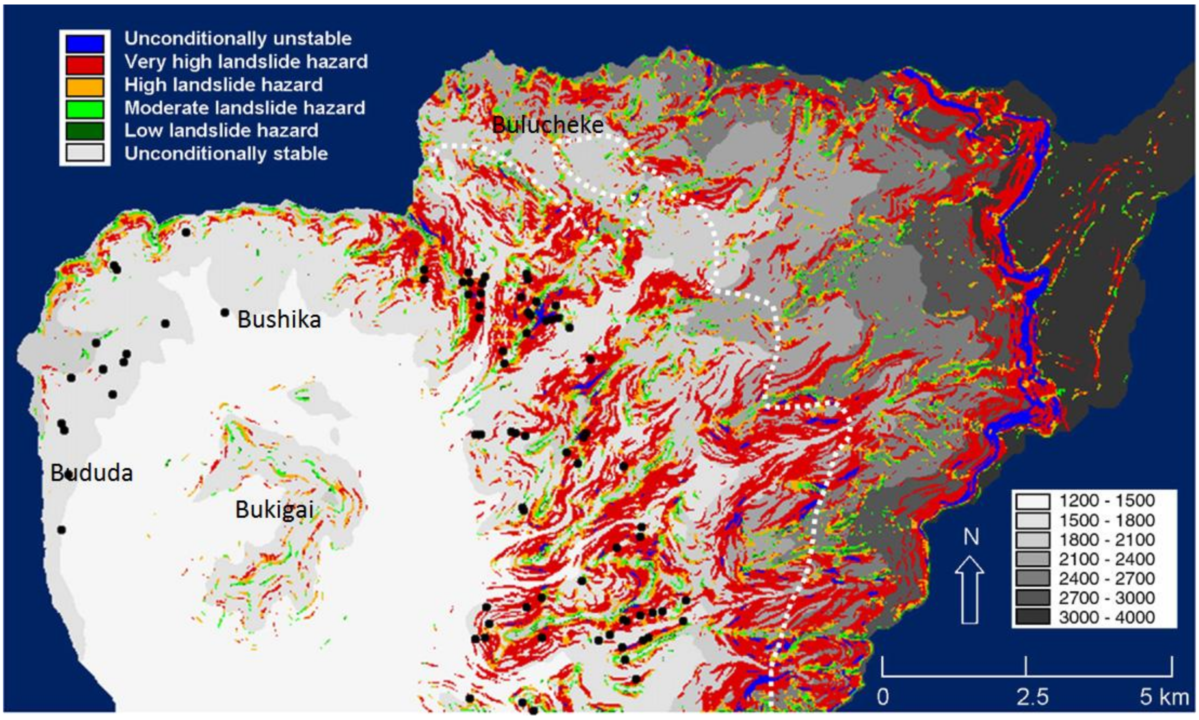

Figure 34: Classified landslide hazards (Qcr, legend top left) calculated with LAPSUS-LS and the classified DEM (legend down right) for the Bududa area [Adapted from Claessens *et al,* 2007]

There is increased risk to human life to increased occurrence of landslides in the cultivated high elevation areas of Mbale region. This risk could be reduced by encouraging people to settle only where the risk of landslides is minimal even when fields are maintained in the areas with high landslide risk. Bylaws could be enacted to limit house construction in areas with very high risk of landslides, and incentives given to those willing to settle elsewhere. The Department of Disaster Preparedness in the Uganda's Office of the Prime Minister has managed to resettle Landslide victims from Bududa in Kirandongo a district in the western part of the country. Plans are underway to expand the resettlement scheme to cover other parts of the Mt. Elgon region that are affected by landslides.

A study on landslides in Bududa by Kitutu (2010) revealed that whereas landslide formation is a function of various processes, the occurrence of landslides will be triggered by rainfall, yet there are little efforts to record rainfall in the region. Further, in their analysis of the soils in the Bududa, Kitutu *et al*, 2009 found that landslides are not influenced by soil type, which is mainly clayet with more or less a uniform hue down the profile. They found that landslides in western parts of Bukigai are mainly due to soil horizon stratification that favours water stagnation in the lower horizons and they are only confined to places where there is water stagnation in the lower soil horizons. The other factors that were of significance to the risk of landslides were soil texture, depth to the bedrock, land use and slope shape. Landslides in Bududa District predominantly occur on concave slopes (Claessens *et al*, 2007). And landslides on these slopes will be triggered by high rainfall, and human interference.

Most of the Mbale region, where slopes exceed 45%, are at risk of landslides. However parts of Bududa District that are in mid and high elevation areas have been pointed out as being at higher risk than the rest of the region. The increased risk of landslides is a function of the soils slope and increased rainfall projected for these reasons.

4.4 Socio-economic vulnerability of Mbale to projected climate

Kelly and Adger (2007) defined social vulnerability as the capacity of individuals and social groupings to respond to – or to cope with, recover from or adapt to –any external stress placed on their livelihoods and well-being, focusing on socio economic and institutional constraints that limit the ability to respond effectively. Members of the society that have little access to information, less income and illiterate are most at risk from the impact of climate change. Literacy levels are lower among the women and this makes them a little more vulnerable than the men. Enhancing adaptive capacity will require that women and men get equivalent access to information and other resources. For instance, radios are the major source of information yet in many households; the men control the use of radios, allowing limited access to the women and children and hence limited access to information. Efforts to promote resilience to climate change need to emphasize the importance of access to information across all layers of the society.

Socio-economic impacts of climate change are twofold. The first obvious ones come from the direct impacts of extreme weather events or climate related hazards such as drought, floods, landslides, hailstones. These will include loss or reduced harvest, destruction of property and loss of livestock. Impacts such as these are very easy to observe and to relate to the causes given that they happen during or immediately after the climate hazard. Changes in temperature and rainfall regimes have been associated with increased wind throws; lightning; leading to damage to crop fields, livestock and property.

The other category of climate change impacts to society are less obvious and are only related to the trends or sudden changes in climate. These impacts will come from effects such as the gradual reduction in agricultural yield, gradual reduction in incomes, gradual effect on people’s health. These may occur as a result gradual change in climate combined with the impacts that arise out of the methods or techniques people employ to deal with climate change. For instance in addition to affecting agricultural yield through crop failure, an extremely dry season will also result in drying of wells implying that a given household will spend more time and resources trying to get water for domestic use and for livestock.

To the question; are there current socio-economic trends that interact with these sensitivities (and in particular run the risk of amplifying them), the answer is a big yes. The biggest culprit is high population of the region, which has continued to expand. The Mbale region is highly populated. Number of persons per square km is higher in Bushuka, Bududa, Bukiga and Kaato sub-counties in Bududa District, Bumbo in Manafwa District and most of sub-counties in North of Mbale District (Figure 36). The risk from climate change to people in northern Mbale is likely coming from erratic rainfall, which is projected by future scenarios. Conversely, highly populated sub-counties in Bududa are more at risk from higher than normal rainfall during the rainy season. Whereas northern Mbale could benefit from abstraction of water either in valley dams, both regions can benefit from improved soil and water management technologies such as terraces, grass bunds, mulching, tree planting etc.

Most parts of the less populated sub-counties of western Bududa and Manafwa Districts lie within the Mt. Elgon Forest National Park. Less populated Busano sub-county in Mbale is also part of the National Park. These locations are well covered with trees and less at risk from impact of climate change even as future climate projections indicate higher than normal rainfall. However, levels of illegal activities such as logging and cultivation in the National park will increase vulnerability of that location to climate change. Loss of tree cover will result into slopes that are not well-protected, hence higher erosion rates and increased risk of landslides.

High population exerts too much pressure on natural resources; nearly all locations outside the national park are cultivated. Bududa is mainly high altitude with slopes more than 60%. The risk of landslides is high, and that of erosion is higher. Crop failure as a result of a shorter rain season and extended dry seasons will particularly affect production of annual crops in the region. When farmers are not sure when to plant, then there is increased risk of them losing their seed when the rains come in late.

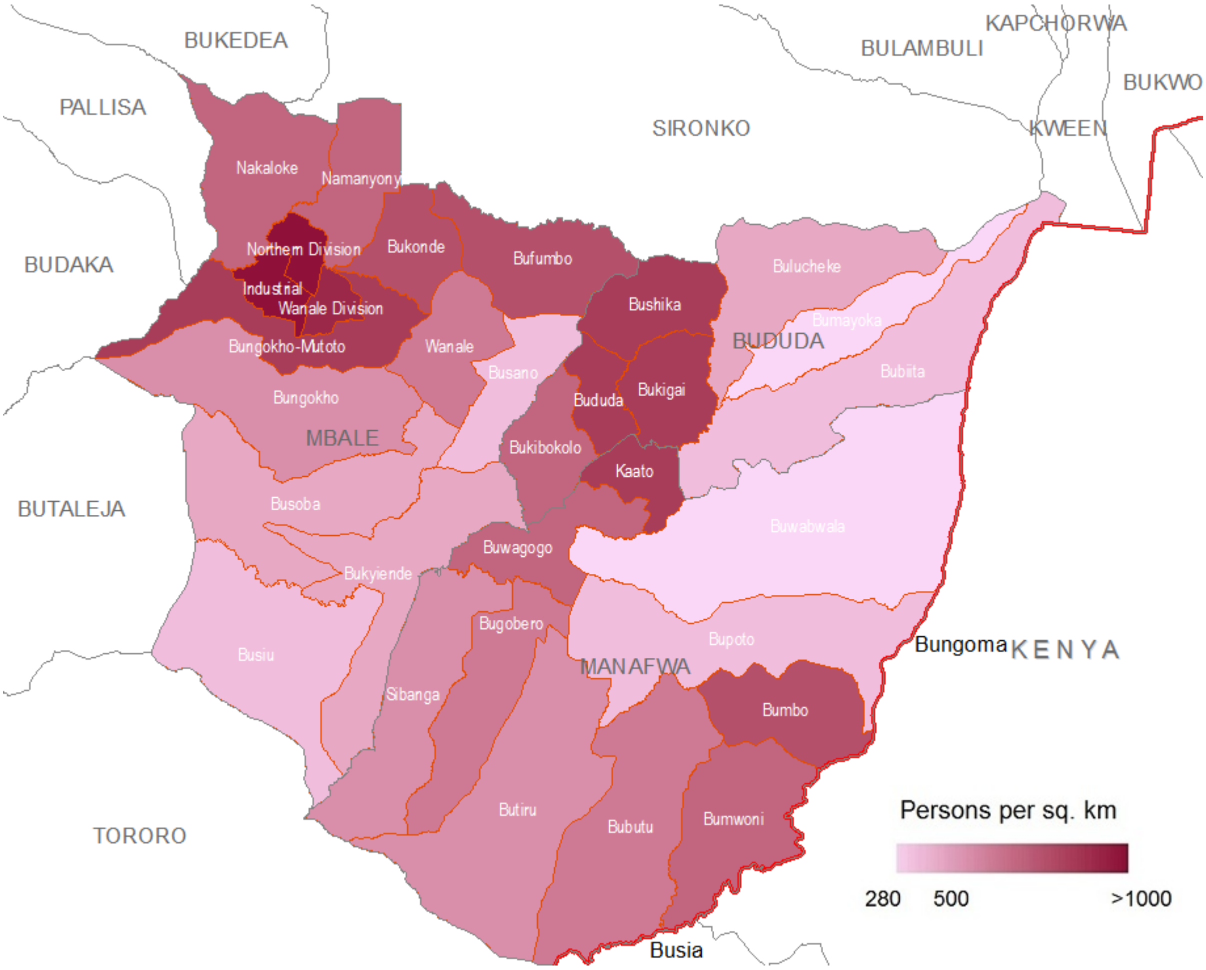

Figure 35: Population density of Mbale region sub-counties

The Mbale region provides access to the Mt. Elgon National Park, an important tourist destination. Changes in climate that affect the movement of people in the region will affect tourism activities. The region provides several routes to the top of the mountain…if the road are impassible due to flooding or landslides, tourists will then change to alternative routes in district to the north or even choose routes that access the top of the mountain from the East in Kenya. This will affect people whose livelihoods depend on income from tourists.

Social and gender inequalities: A lot of resources at the household level are controlled by the men. Women have little say in decision-making that involves land, or allocation of land to different uses. This limits their contribution to overall wellbeing of the household. School enrolment for girls is lower than that for boys. Majority of the girls are married of early. Women groups exist…efforts to get the girl child in school are also underway but more needs to be done.

Inadequate off-farm employment opportunities and skills: the proportion of the population in Mbale, Bududa or Manafwa are engaged in off-farm employment. Off-farm employment provides an opportunity for households to survive under harsh conditions resulting from crop failure or from natural or climate related hazards.

4.5 Adaptive capacity of the environment, society and economy of Mbale to projected climate

4.5.1 Resilience and adaptation to climate change

Adaptation is one of the three components of vulnerability to climate change. Adaptation is used to describe all those activities that increase resilience and the adaptive capacity of individuals / households / communities. The level of capital owned and assets have been the main focus of traditional attempts to understand adaptive capacity, both at national and local levels (Brooks *et al*, 2005). Giving significant emphasis on the role of physical assets in helping communities adapt to climate change asset-oriented approaches will mask the role of processes and functions and institutions in supporting adaptive capacity (Jones 2010). Understanding adaptive capacity, therefore, entails recognizing the importance of various intangible processes: decision-making and governance; the fostering of innovation, experimentation and opportunity exploitation; and the structure of institutions and entitlements, for example. Doing this requires moving away from simply looking at what a system has that enables it to adapt, to recognizing what a system does to enable it to adapt (WRI, 2009).

Table 13: Characteristics of climate adaptive capacity (from the African Climate Change Resilience Alliance –ACCRA)

Characteristic	Description
Asset base	this includes the various financial, physical, natural, social, political and human capitals necessary to best prepare a system to respond to a changing climate. Farmers will require improved access to assets and resources to replace those damaged due to the impacts of climate change
Institutions and entitlements	appropriate institutional environment to allow fair access and entitlement to key assets and capitals by setting up seed banks and green house groups. In order to be successful, it is important that such newly established institutions are socially rooted and conform to existing norms about group membership and power relations. It was reported that it was difficult to get all households to invest in activities that delivered communal benefits such as maintaining the irrigation canals. Farmers in northern Uganda are working as part of farmer field schools. Community seed centers have been established where farmers ….as part of a holistic approach to building adaptive capacity
Innovations	farmers need access to new crops, technologies for water harvesting, production and processing
Knowledge and information	access to information about changes and trends in the local climate in the Mbale region and in Uganda is poor. The local communities need to be actively involved in the identification and documentation of changes in the local climate and existing indigenous coping mechanisms, which combined with scientific information on regional climate trends, can be used to identify a series of suitable interventions to develop resilience
Decision making and governance	Flexible forward-thinking Decision Making and Governance is required. The system is able to anticipate, incorporate and respond to changes with regards to its governance structures and future planning

Assessments of adaptive capacity to date have focused on assets and capital as indicators at the community level. In addition, it involves understanding processes like decision making and governance, the fostering of innovation, experimentation and opportunity exploitation, as well as the structure of institutions and entitlements. The African climate Change Resilience Alliance – ACCRA identified 5 characteristics of local adaptive capacity to climate change that comprise; the asset base, institutions and entitlements, innovations, decision making and governance and knowledge and information (Ibrahim and Ward, 2012).

Given the foregoing, adaptation to climate change will mostly comprise activities that are already being implemented (McGray *et al*, 2007). Improving disaster response especially through sharing of information is key in dealing with the impacts of climate change. The first and fundamental course of action in the region is to develop adequate capacity to manage present climate risks. It is also important to ensure that concerns and agreed courses of action in dealing with climate risk and vulnerabilities in the Mbale region fall within key priorities highlighted in Uganda's national adaptation programme of action-NAPA (GoU, 2007). For example ACTED is working with local communities in the Karamoja region to collect information about indicators of changes in seasons and impacts on crops and livestock. This information is combined with assessments from weather records and forecasts to prepare advisory information for the farmers.

4.5.2 The banana - coffee system

Banana is one of the major staples for the Mbale region. Banana poses unique challenges in terms of food storage not much of it can be stored. Most bananas are consumed straight from the garden. However, interactions with the people revealed that bananas have traditionally been dried and stored. That happened because there were no clear market channels for the bananas. Combine traditional methods of drying bananas with contemporary technologies such as the use of solar driers to dry bananas.

Shade trees in coffee such as *Albizia* species and *Cordia milleni* and *C. Africana*. These species have proved to help improve yield of coffee Arabica. Shade coffee has traditionally been grown in Mbale, however the practice is not wide spread, partly because farmers want to grow other crops under the coffee canopy given the small land holding. In addition to shade coffee, is mulching to help conserve moisture in the soil. Trenches can also help with soil and water management but reducing erosion and increasing infiltration on the land. Irrigation could help improve production of coffee in cooler environment where rainfall is low (ITC, 2010). Better management of the banana coffee system can improve resilience to the impact of climate change among households in the Mbale region.

Improve the productivity of the banana-coffee system through the addition of minimum tillage crops that can thrive under the banana-coffee shade. A good example is vanilla (*Vanilla* spp) and climbing beans. Introduce and promote temperate fruits such as apples in the cooler high elevation areas.

4.5.3 Livestock

Livestock provide a valuable safety net for farmers providing nourishment, income as well as manure and source of biogas. More households should be encouraged to keep livestock. One of the best ways of doing this is through a scheme that loans animals to the women for instance. Efforts to ensure that breeds of animals kept can withstand conditions in the region should be promoted. Farmers will need to be trained in better methods of efficiently managing livestock on small land parcels.

4.5.4 Soil and water conservation and management

Because most of the Mbale region is cultivation, one of the key interventions to ensure soil and water conservation is to emphasize crops that need minimum cultivation. Coffee and banana intercrop provide an appropriate system. Cultivation on steep slopes increases the risk of erosion. This also results into siltation of rivers. Terraces that are one of the techniques that make cultivation on slopes sustainable are very rare sight in the Mbale region. Stakeholders talked to mentioned that the soil on the slopes is "too loose" to support terracing and that attempts to make terraces have resulted into increased washing away of the soils once the rains start before the terraces have stabilized. Vetiver grass (*Vetiveria zizanioides)*, which is native to Southeast Asia, has been extensively used for soil erosion, sediment control and for steep slope stabilization. The grass has been used to stabilize slopes in Ethiopia. This multiple use grass develops roots that are more than 3m deep. The grass is palatable especially before it flowers. Important attributes of the grass includes its deep root system, it does not seed reducing its changes of becoming a weed and is long lived.

There have been numerous efforts on tree planting initiatives in the Mbale region, going far back as the colonial times. The Mvule (*Milicia excelsa*) trees that dot theMbale region landscape were planted by Semei Kakungulu in the 1900s. More recent tree planting efforts include that by the forest department in the late 1990s. Recent and current ones include the Straight Talk foundation that promotes tree growing on school premises and the Farm Income Enhancement and Forest Conservation – FIEFOC project spearheaded by the Ministry of Water and Environment – MWE's Forest Sector Support Department – FSSD. FIEFOC promoted tree growing by supplying tree seedlings to farmers in the region. The other major tree planting initiative was the Forest for Absorbing Carbon dioxide Emissions-FACE project which working with the Uganda Wildlife Authority - UWA embarked on a tree planting exercise covering a 2km strip around the entire boundary of Mt. Elgon National Park. By 2006, 8000 out of the planned 25000ha had been planted. However, in some locations particularly where the boundary interfaces with peoples fields, many of these trees have been cut by the communities.

Tree growing has been promoted as a soil conservation measure. Trees will stabilize slopes through their roots holding the soil firm, and reducing surface flow and consequently erosion. However wide scale tree planting particularly with fast tree growing can have an impact on in situ water use with consequences on the overall hydrological balance downstream (Trabucco *et al*, 2008). Fast growing trees will result into reduced surface runoff as well as flow in streams that are mainly dependent on surface flow.

Interventions that could promote soil and water conservation on farmers' fields include planting grass strips across the fields and on the cut-out on road sides. In many places in the region elephant grass has been planted across fields an on the roadsides, though the practice is not wide spread. Grass can also provide pasture for animals. Other activities that could help improve soil organic content will increase the water holding capacity of the soil thereby reducing runoff. Policy interventions are also required, for example to limit cultivation on slopes higher than a chosen threshold, to require all land owners to implement a minimum number of soil and water conservation technologies such as terraces, promote awareness and build capacity for soil and water conservation.

4.5.5 Resources available to the people of the Mbale region

Whereas stakeholder mentioned that income from boda bodas helps a few households when crops fail, there is need to plan for more reliable on and off-farm sources of income and livelihoods. Tree planting is one of the many options that enable farmers have some additional income. Eucalyptus woods are a common sight in the region and these provide valuable income from the sale of fuel wood, poles and timber. Farmers could also be encouraged to engage in bee keeping which can supplement food crops as well as support an entire industry based on honey and bee products processing.

The level of adoption of fruit tree growing in low in the Mbale region. Fruit trees provide additional sources of food and nourishment to households, and can be very important sources of key nutrients. Fruit and be sold for incomes both local and regionally. Avocado (*Persia americana*), papaya (*Carica papaya*) and jack fruit (*Autocapus macrocarpa*) are some the fruit trees grown and have potential for expansion.

Farmer groups and cooperatives are one of the ways to help farmers deal with the challenges facing in agriculture. Through these groups, quick flow of ideas and innovations is ensured because one of the limiting factors for adapting to better production systems is lack of information. Mbale region has the only functioning cooperative in Uganda, the Bugisu Cooperative Union-BCU. The BCU in mainly concerned with coffee. There several other cooperative that operates on village or county level. Such groups can help farmers access information easily, demand for improved services from government, purchase improved crop varieties or better equipment. An example of a small group of farmers is Peace Kawomera.

Thorpe and Fennell (2012) discuss supply chain responsibility to help small-scale producers deal with extreme weather events. Fluctuations in world coffee prices for instance can have significant effects on livelihoods of farmers in Mbale that depend on coffee. They suggest that companies can help the communities through activities such as providing reliable weather or climate information. Increasing awareness in the communities and supporting community development venture as well as providing much needed research information on financing, options for diversification or a responsible exit strategy. They point to an example of a coffee giant, Starbuck coffee that has worked with arabica coffee farmers in Colombia, to provide disease resistant varieties of arabica, access credit etc.

Table 14: Population distribution within the sub-counties in the Mbale region

Bududa		Manafwa		Mbale	
Sub-county	Population (no. of households)	Sub-county	Population (no. of households)	Sub-county	Population (no. of households)
Bubiita	32,000 (5255)	Bubutu	52,700 (8205)	Bufumbo	39,500 (7495)
Bududa	16,700 (2739)	Bugobero	30,700 (5099)	Bukonde	21,600 (3885)
Bukibokolo	21,600 (3265)	Bumbo	32,400 (5346)	Bukyiende	30,000 (5086)
Bukigai	32,900 (5567)	Bumwoni	41,000 (6820)	Bungokho	38,500 (6820)
Bulucheke	26,000 (4265)	Bupoto	34,500 (5564)	Bungokho-mutoto	47,000 (8591)
Bumayoka	11,400 (2099)	Butiru	53,000 (8603)	Busano	10,800 (1796)
Bushika	33,100 (4719	Buwabwala	38,500 (7095)	Busiu	33,200 (5529)
		Buwagogo	24,000 (3650)	Busoba	33,800 (5688)
		Kaato	17,300 (2730)	Nakaloke	39,500 (6368)
		Sibanga	31,300 (5139)	Namanyonyi	25,300 (4043)
				Wanale	17,800 (2678)
				Industrial	41,000 (7427)
				Northern Division	37,100 (7445)
				Wanale Division	13,700()
Total	**173,700**	**Total**	**355,400**	**Total**	**428,800**

Population data adapted from Rural Communications Development Fund www.ucc.co.ug/rcdf

Mbale region is one of the most densely populated parts of Uganda. According to the 2011 estimates, the three districts of the region nearly a million (957,900). Bududa is estimated to have 173,700, Manafwa 355,400 and Mbale is estimate to have 428,800 people. Table 11 shows population in the Mbale region by sub-county. Thus, one of the greatest resources for the region is its people. It is also important to point out that the high population also could the greatest liability for the region. Any intervention to improve livelihoods of the people of Mbale will go a long way in helping them deal with the impact of climate change. For example, education of all children of school going age needs to be taken seriously. It is here that children will learn the basic life skills. Numerous initiatives target children and youth in programmes such as tree planting. The best example is the Straight Talk Foundation that helps children in primary and secondary schools establish woodlots within the school premises.

On a more positive side, there has been a steady increase in the demand for agricultural produce. Demand comes from neighboring urban centers and other neighboring jurisdictions (Sironko, Kapchorwa in Uganda and Kitale in neighbouring Kenya). Whereas this drives the prices up ensuring that farmers have better returns, communities in the Mbale region could benefit from the expanded market by engaging in processing or produce.

Biogas is an important source of energy in the region. There is a relatively fair adoption of the use of biogas at the household level in the Mbale region. Increasing the level of adoption of biogas will reduce the demand for scarce fuel wood as the major source of energy in the household. This will free some labour at the household level for people to engage in other income generating activities other than finding fuel wood. The practice will also save a good proportion of the few planted or remnant trees in the agricultural landscape. In addition, biogas could be harnessed on a larger scale from human waste and garbage in urban centers that are already highly populated. The limitations to adoption of biogas include lack of animals, the initial high cost and a general lack of awareness. Intervention to address these challenges such as through more awareness, providing loans can help improve adoption of the technologies.

4.5.6 Climate-Smart Agriculture (CSA)

Farmers are one of the most vulnerable groups to climate change. However, farming can also be part of the solution to anthropogenic climate change during the 21st century. Agriculture contributes 13% of the global climate change emissions and agriculture together with deforestation, which is in most cases related or caused by expansion of agriculture contribute 30% of total emissions (Eliasch 2008). The phrase climate smart agriculture has been coined to reflect agriculture that increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation) and enhances achievement of national food security and development goals. CSA increases organic content of the soil, water holding capacity increases and reduces erosion.

The triple win: interventions that would increase yields, make farms more resilient to the impacts of climate change, and make the farm a solution to the climate change problem rather than part of the problem.

Making use of technologies as old as the green revolution can go a long way in helping farmers cope with climate change. For example, irrigation can help farmers deal with drought or erratic rainfall that is now coming late.

4.5.7 Institutional and legal framework for climate change vulnerability

Adaptive capacity is not limited to resources available but also to the institutional framework that helps the community adapt to climate change (Adger et al., 2009; Hulme et al., 2007). Discussions identified some of the key players in helping farmers deal with climate change as NUSAF, NAADS Eco-Trust, UN-Habitat and local Councils. It was clear from discussions with stakeholders in the Mbale region that there is high-level commitment to dealing with climate change at both the professional and political level. There are challenges however to do with officials in elected offices whose approach undermines the professionalism. In addition, an integrated approach is also required. For instance promoting agriculture or certain crops such as coffee needs to be in tandem with the objectives of environmental and natural resources management promoted by the team in the natural resources and environment sector. Otherwise, objectives of sustainable development cannot be achieved if expansion of one crop leads to encroachment of forests or wetlands.

It was also pointed out that political influence should be dealt with because politicians have on several occasions disregarded the advice given to the farmers by technocrats and have on several occasions fought good climate protection causes. One of the challenges to developing an integrated climate plan for the Mbale region would be the political timeframe for Uganda is normally 5 years. This in essence requires that political leaders deliver results within this timeframe yet planning for activities for dealing with climate change will normally require timeframes longer than 5 years. How then can political leaders be motivated to actively contribute to activities whose benefits are only likely to be realized long after the political term of the politicians?

While global negotiations on mitigation continue, decision makers in Africa and elsewhere, must strive to develop a broad range of adaptation strategies to address current and future impacts of climate change (ADF, 2010).

Climate risk management (CRM) is the use of climate information to cope with possible impacts of climate change on development and resource management. It covers a broad range of potential actions including early response systems, risk spreading through diversification, dynamic resource-allocation rules, financial instruments, infrastructure design and capacity-building (ADF, 2010). CRM seeks to minimize adverse outcomes and maximize opportunities in climate-sensitive economic sectors through improved resource management. It addresses adaptation to climate change and disaster risk reduction in any climate sensitive development sector by focusing on actions that can be taken today to improve outcomes and preparedness, and by better understanding and then anticipating interactions of economic, environmental and social systems with possible future climates.

Climate risk management approach is that it provides immediate assistance to the public and private sectors, while helping stakeholders to confront possible future climate change scenarios. Climate risk management identifies immediate actions needed to manage the climate variability that is currently affecting societies. The main issues to be addressed in climate risk management are: climate monitoring, vulnerability assessment and institutional strengthening; climate services and information provision to decision makers and partnerships; deploying regionally-integrated and community-based early warning systems; and instilling and sustaining a shared culture of sectoral climate risk management.

Farmers in the Mbale region are already responding and taking actions to adapt to changes in climate and development pressures. However, the bulk of these interventions are reactive and focus on the short term, with very few of these being focused on dealing with climate change impacts on the longer term (Jones, ACCRA report for Uganda). For example, a lot of resources are spend whenever there is a land slide in Bududa, to respond to the crisis, but very little is done to improve resilience of the communities to future landslides in the region.

Table 15: Relevant institutions in the region for climate change adaptation

Name	Current/ Potential Role
Local governments in Mbale, Manafwa and Bududa districts	• Overall coordinator of development programmes in the districts.
Local councils (1-3) including sub-county chief	• Coordinate data weather data collection • Coordinate information dissemination
Schools	• Sensitive students on value of sustainable resource use • Training in better farming methods • Tree planting
Uganda Wildlife Authority	• Mt. Elgon watershed protection
	• Forest conservation, training
Cooperatives (eg BCU, and others) and other	• Value addition, processing of agricultural produce. • outreach
Community-based Organizations	•

Universities (Islamic University in Uganda, Busitema University)	- Research and outreach - Training of technical staff
NGOs (Local and international)	- Resource mobilization - Research and outreach - training
National Agricultural Research Organisation	- Research in locally adapted, disease resistant and/or early maturing crop varieties and livestock lines
	- Value addition, processing of agricultural produce

5. Conclusions and Recommendations

5.1 Conclusions

This work set out to answer very specific questions relating to climate in the Mbale region of Uganda. These questions fall into two broad groups: the first set of question on climate sought to get an assessment of meteorological data collected at Mbale weather station, compare this to that collected in neighboring areas and use it to make a description of the climate profile for the Mbale region as well as making projections into the future. Whereas weather records from the Mbale and other weather stations in the region have been used to describe current climate for the region. The work as detailed description of the climate profile for the Mbale region within the context of the wider eastern Africa region mainly relied on data that already existed. It should however be pointed out that the existing spatial grids used also rely on weather station data from the region as well as other locations. Again, description of future climate projections was based on spatial grids that have been done by a large team of climate and meteorology experts.

To ensure that all data on climate change about our region is reliable, we need to do a number of things, one establish a good number of weather stations, representative of the unique environments, such as the low lands, mid altitude as well as high elevation areas. This network could also benefit from expert knowledge for the region, for instance, the Mbale region receives more rainfall than other parts of the Mt. Elgon. However, some locations such as Mbale municipality lie is a clear rain shadow, receiving relatively low rainfall compared to surrounding areas at the same altitude. Capturing such information requires that weather stations are carefully positioned to represent these features. Efforts of the local or district governments need to be augmented by the central government in boosting the network of weather station in the country. Because weather data analysis required specialized skills, this again should be strengthened at the meteorological department in the Ministry of Water and Environment.

Climate in the Mbale region can be described as…rainfall is mainly bimodal with the first rain season occurring late march to June and from September to November. Over the last one and half decades, there has been a clear shift from April to May as the wettest month meaning that the onset of the first rains delays until sometime in April. The other major trend has been towards more rainfall during the previously “shorter” rains period of September to November. Overall, all a clear trend of more rainfall throughout the year is apparent.

Temperature increases have been noticeable in the warmest February month of the year. The implication of increasing temperatures during the driest period of the year point to likely increase in water stress over the dry season.

Projections of temperature and rainfall over the Mbale region point to an overall increase in minimum temperature, and increase in the dry season temperature particularly in February. Additionally, more rainfall is projected about 5- 14% more in the rain season. More rainfall will be expected in the SON (Sept / Oct / Nov) season.

Whereas biophysical attributes of the Mbale region such as clay soils and hilly terrain make it vulnerable to effect of climate change particularly erosion. These attributes also make this region unique; the cool temperatures make the growing of arabica coffee possible. Arabica coffee, grown together with bananas, are the sources of livelihoods for majority of people. Changes in climate will threaten coffer growing in two major ways; increased temperatures affect yield and quality of coffee in addition make conditions favourable for coffee pests, most important of these is the coffee berry borer. Better methods of cultivation and soil and water management can enhance the adaptive capacity of the region to climate change. These techniques include terraces, mulching.

Vulnerability of the Mbale region is increased by the high population of the region. With more than 590 persons per square km the Mbale region is the most densely populated part of Uganda.

Stakeholders emphasized that methods of controlling population growth are required if the region is to cope with climate change.

The lack of adequate climate records for the Mbale region combined with uncertainty in climate change projections and climate change impacts can become limiting factors in helping communities deal with the impacts of climate change. What have been obvious for this region are the direct, often disastrous impacts of extreme weather events. Thus, responding to climate change impacts does not have to wait for more accurate projections of climate, because projected changes in temperature and rainfall for the Mbale region in recent decade (2000-2011) are comparable to what was projected for the 2010-2039 period. Information flow and management is key to dealing with climate change, information about climate trends, projected impact. Adaptive management of resources, involves changes in the techniques and methods of responding to climate change in response to changes in climate that are underway.

5.2 Recommendations

Recommendations will mainly focus on aspects and interventions that will help to enhance the development of climate change mitigation and adaptation interventions for the Mbale region of Uganda.

One of the constraints to climate change studies for the Mbale region is limits on weather data collected. There is need to **improve collection of weather data in the region**. Whereas weathers station are normally located in urban areas, weather stations need to be strategically distributed within the region to adequately represent low and high elevation areas. Improvement of weather data collection will also go hand in hand with **promoting awareness and building capacity among the Mbale region stakeholders** particularly local governments, technical officers and schools about the need to and the appropriate methods for collecting weather data.

Improve information flow, not only through opening up communication channels between technical people and the local communities but also facilitating the flow of information along those channels for example through ensuring that information is translated so it can be accessed and understood by all members of the community.

Vulnerability to climate change is a function of exposure, sensitivity and adaptive capacity of the environment and society to deal with the risks of climate change. Whereas exposure and sensitivity cannot be easily changed, reducing vulnerability to climate change in the Mbale region will mostly be through enhancing adaptive capacity. **Enhancing climate change adaptive capacity** of **the environment and the people of Mbale region** requires increase in tree cover coupled with reduction in excessive cutting of trees on farm and clearing of forests, strengthening the banana-coffee system and encouraging minimum tillage crops. The high population of the Mbale region implies that most locations are supporting people beyond the carrying capacity. Establish carrying capacity of the region and enforce regulations respecting that. Regulations are also needed to control settlements on steep slopes because cultivation and house construction on these slopes increases the risk of landslides.

Enhancing climate change adaptive capacity of the people of Mbale region will require that the literacy of the society improved, that the society is aware of how human activities increase vulnerability to climate change, and with viable alternative sources of livelihoods and with opportunities to participate in decision making affecting their region. Multinational companies dealing in coffee could be taken onboard to help local coffee cooperatives plan targeted interventions to dealing with the impacts of climate change.

Developing climate change mitigation and adaptation plans needs to **build upon development interventions that have been or are currently underway** in the Mbale region. This will help in consolidating achievement and build on lessons, making use of information from existing or recent climate change adaptation interventions. A good example is the Mt. Elgon Regional Ecosystem Conservation Programme (MERECP). The goal of MERECP was integrated ecosystem conservation and management of natural resources and biodiversity and enhanced well-being to people and the environment.

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Annexes

Annex 1: Glossary of Climate Change Terminology

Weather:

- Describes the state of the atmosphere. The major weather variables are temperature and precipitation.
- "Weather" refers to the short-term average (trend) and also to the size of the variations around the trend (weather variability).

Climate:

- Climate" refers to the long-term average (trend) and also to the size of the variations around the trend (climate variability).
- Climate can also be described as average of individual weather states, taken over sufficiently long periods of time. While weather impacts our daily lives, climate influences our decisions about where to live, and where and how to grow food. In this way, it directly influences how societies and economies develop and flourish. Changes in climate are associated with more fundamental changes to the global climate system, involving interactions and feedbacks between the atmosphere, the oceans, land and ice surfaces and all living things (the biosphere).

Climate Variability:

- Reflects shorter-term extreme weather events, such as tropical hurricanes and the El Niño Southern Oscillation (ENSO), and North Atlantic Oscillation (NAO). Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Extreme Events:

- Weather events departing markedly from the average values or trends, and that is exceptional. Mostly, the return period substantially exceeds 10 years.

Climate Change:

- the UNFCCC defines climate change as “a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods”
- the IPCC define climate change as a “statistically significant variation in either the state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings or to persistent anthropogenic change in the composition of the atmosphere or in land use.

Emission scenario:

- A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships.

Climate Change Adaptation:

- One or more processes by which strategies (policies, actions and other initiatives) to moderate, cope with or take advantage of the consequences of climatic events are enhanced, developed and implemented.

Climate Change Mitigation:

- Response measures that reduce the emission of greenhouse gases into the atmosphere or enhance their sinks, aimed at reducing their atmospheric concentrations and therefore the probability of reaching a given level of climate change.

Climate Risk:

- The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between climate-induced hazards and vulnerable conditions.

Climate Risk Management:

- An approach to systematically manage climate-related risks affecting activities, strategies or investments, by taking account of the risk of current variability and extremes in weather as well as long-term climate change.

Vulnerability to Climate Change:

- Climate change vulnerability refers to the state of susceptibility to harm from exposure to climate hazards, and the ability of the sub-national territory (or other unit of analysis) to cope with, and recover from, such exposure as well as manage incremental and long-term change in climate. In addition, climate change vulnerability encompasses how much the sub-national territory (the environment, society, and economy) will be affected – in other words, how sensitive it is to the change. It also includes the territory's potential to cope with, recover, and adjust to the impacts of climate change, that is, its adaptive capacity. Identifying vulnerability is therefore a necessary prerequisite to developing low-emission climate-resilient plans and strategies, and to ensuring that societies are resilient in the face of climate change.

Adaptive Capacity:

- The ability of a system to adjust its characteristics or behaviour in order to expand its coping capacity under existing climate variability or future climate conditions. Actions that lead to adaptation can enhance a system's coping capacity and increase its coping range thereby reducing its vulnerability to climate hazards. The adaptive capacity inherent in a system represents the set of resources available for adaptation, as well as the ability or capacity of that system to use these resources effectively in the pursuit of adaptation.

Climate Proofing:

- Actions to ensure that development efforts are protected from negative impacts of climate change, climate variability, and extreme weather events and to ensure that climate-friendly development strategies are pursued to delay and reduce damages caused byclimate change.

Climate Resilience:

- The capacity of a system, community or society potentially exposed to climate hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organizing itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures.

Mainstreaming:

- In the context of addressing climate change and related issues, the term "mainstreaming" is used to describe the integration of policies and measures to address climate change in ongoing and new development policies, plans, and actions. Mainstreaming adaptation aims to enhance the effectiveness, efficiency, and longevity of initiatives directed at reducing climate-related risks, while at the same time contributing to sustainable development and improved quality of life.

National Adaptation Programme of Action:

- National Adaptation Programmes of Action (NAPAs) are intended to communicate priority activities addressing the urgent and immediate needs and concerns of Least Developed Countries (LDCs), relating to adaptation to the adverse effects of climate change.

For more information see www.ipcc.ch/pdf/assessment- report/ar4/syr/ar4_syr_appendix.pdf

Annex 2: Climate variables generated for Worldclim and downscaled GCM projections

Baseline and future climate for Mbale region covers the following climate variables

- monthly values for maximum, minimum temperature and (tmax to 12 and tmin1 to 12)
- monthly precipitation (prec1 to prec12)
- plus 19 biologically relevant climate variables including:

bio1 - annual mean temperature
bio2 - mean diurnal range (mean of monthly max temp-min temp)
bio3 - isothermality
bio4 - temperature seasonality (SDx100)
bio5 - maximum temperature of warmest month
bio6 - minimum temperature of coldest month
bio7 - temperature annual range (bio5 - bio6)
bio8 - mean temperature of wettest quarter
bio9 - mean temperature of driest quarter
bio10 - mean temperature of warmest quarter
bio11 - mean temperature of coldest quarter
bio12 - annual precipitation
bio13 - precipitation of warmest month
bio14 - precipitation of driest month
bio15 - precipitation seasonality
bio16 - precipitation of wettest quarter
bio17 - precipitation of driest quarter
bio18 - precipitation of warmest quarter
bio19 - precipitation of coldest quarter

In all, 55 climate variables are available for each times slice (1961 - 1990, 2010 - 2039, 2040 - 2069).

Annex 3: List of Global Circulation Models and emission scenarios used

GCM	Emission Scenario
ECHAM	A1b, A2, B1
GFDL	A1b, A2, B1
HADGM	A1b, A2, B1
MEDRES	A1b, A2, B1
PCM	A1b, A2, B1