ASSESSMENT OF CLIMATE VARIABILITY AND CHANGE IMPACTS ON LIVELIHOODS AND COPING STRATEGIES IN UPPER NILE STATE, SOUTH SUDAN: A CASE STUDY OF MALAKAL COUNTY

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Declaration

I declare that this dissertation is my original work and it has not been presented for a degree in any other University

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Dedication

I am very delighted to dedicate this research dissertation to God who kept me healthy during the entire period of this study, to my mother and lastly but not the least to Dr. Elijah Mukhala who encouraged and inspired me, making me come this far.

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Abstract

Climate variability and change have serious environmental, economic, and social impacts on South Sudan in particular, where livelihoods of large populations depend on rain fed agriculture. Drought and flood are the major climatic factors affecting crop productivity in Malakal County. In addition, information related to weather such as seasonal forecast is hardly exists. Farmers in this area are expected to be more vulnerable since they used only their traditional knowledge and skills to forecast onset of seasonal rainfall and when to plant and decide which crop is suitable to be cultivated. This study was therefore conducted to address issues related to climate variability and change impact faced by farming community. The overall objective of this study was to assess the impacts of climate variability and change on livelihood based on agriculture in Malakal County South Sudan.

Long term daily (1973-2002) and monthly rainfall (1963-2010) data as well as space-borne remote sensing data were used to study variations in climate over Malakal County. The daily data were used to assess wet and dry spells during critical crop growing period. The monthly time series of NDVI and rainfall from 1982-2008 for Malakal were plotted. The study also investigated the impacts of climate change and variability on crop productivity taking farmers' perception and experience into account. This was done through randomized selection of 200 sample size of farmers whose farm was between one and two hectares and had been cultivating for at least 10 years. Vulnerability assessment of climate-related impacts on crop yields, coping mechanisms and resilience levels of farmer communities was also examined.

The study indicated that the probability of occurrence of 5 days dry spells was as high as 73%. Crop failure during growing season, incidences of pest and diseases and food shortage were some of the major impacts reported by the farmers. On average most of the rainfall occurred between June and October, with a maximum in August. The most vulnerable population to climate change and variability are farmers with few resources to assist cope with extreme weather conditions like drought, floods, erosion and diseases. Farmers reported different methods of coping with the negative impacts of climate variability and change that include, selling cattle, charcoal burning, fishing and sending some members of their household to urban area to look for jobs to earn extra incomes.

List of Acronyms and abbreviations

ASA	Arid and Semi-Arid Area
CPA	Comprehensive Peace Agreement
CFSAM	Crop and Food Supply Assessment Mission
DFID	Department for International Development
DRC	Democratic Republic of Congo
ET_o	Evapotranspiration or reference evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
FEW-NET	Famine Early Warning Systems Network
FSTS	Food Security Technical Secretariat
GCM	Global climate models
GDP	Gross Domestic Product
GoSS	Government of Southern Sudan
ICPAC	IGAD Climate Prediction and Applications Centre
IFIAS	International Federation of Institutes of Advanced Study
IGAD	Intergovernmental Authority on Development
IISD	International Institute for Sustainable Development
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
IDP	Internally Displaced persons
LVI	Livelihood Vulnerability Index
MAF	Ministry of Agriculture and Forestry
MDG	Millennium Development Goal
NGO	Non-governmental organization
RPA	Rural Participatory Approach
SDP	Sudanese Pounds
SMA	Sudan Meteorological Authority
SSLP	Southern Sudan Livelihood Profiles
UN	United Nations

UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United National Framework Convention on Climate Change
WFP	World Food Programme
WMO	World Meteorological Organization

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CHAPTER ONE

INTRODUCTION

1.0 Background

The world's climate is changing rapidly at rates that are anticipated to be exceptional in human history. Variations in weather and climate with extreme events affect most socio-economic sectors such as agriculture, water, health, transport, and energy among others. For example, frequent and severe droughts, floods and heat waves are some of the extreme weather events that have been experienced in Africa including Southern Sudan. Some of these changes have been attributed to climate variability and change that are as a consequence of global warming. The impacts of climate variability are inevitable and rural communities who depend on agriculture as a source of livelihood are more vulnerable to these impacts (IPCC, 2007b).

In the tropics and subtropical regions where rain fed is a major farming system, rainfall is one of the climatic parameters which limit agriculture production and sustainable development. Globally, over 80% of total agriculture is rain fed. Projections of future precipitation changes especially in tropical and subtropical regions is expected to influence the magnitude and direction of climate change impacts on crop production (Jemma et al, 2010). Increases in arid land coverage by 5-6% (60 to 90 million ha) and infestation of pests and diseases as a result of temperature increase are among projected impacts of climate variability and change in Africa by 2080 (IPCC, 2007a). Studies also suggest that overdependence of African economies on agriculture, primarily on rain fed agriculture, lack of improved technology and good governance are partly the reasons why the region is more vulnerable to the adverse effects of climate variability and change (Ariel et al 2008; Thornton et al 2006). Generally, agricultural sector constitutes approximately 34% of Africa's gross domestic products (GDP) and contributes about 50% of the total export value. Over 70% of the continent's population depends on agriculture for livelihood and employment (IPCC, 2007b; Ariel et al 2008).

In Southern Sudan, for example, agriculture plays a vital role in providing food, income and employment. However, the dominant farming practice is subsistence and about 90% of cultivated land is rain fed (FAO, 2006) and hence the rural livelihood is intrinsically linked to the high year-to-year variations of rainfall. Thus, any changes in the climatic conditions will affect livelihoods, wellbeing as well as the national economy (FAO, 2008). There is significant concern about addressing climate variability and change impacts on agricultural production in Africa. This study considers the example of Southern Sudan, particularly the Upper Nile state.

Climatic conditions of Upper Nile state are variable on seasonal time scales, with recurrent floods and droughts. These extreme events lead to crop losses, widespread pest and crop disease outbreaks and eventually the disruption of the well-being of the rural community in the region. On the other hand, overdependence on rain fed agriculture coupled with inadequate farm inputs such as improved seed varieties, fertilizer, cheap or poor agricultural technology, lack of weather information systems and good governance, are partly the reasons why the rural populations are vulnerable to climate variability and change impacts.

1.1 Problem statement

In Southern Sudan, especially in Malakal County there is lack of documented information regarding climate variability and change related issues and their impacts thereof. Farmers use their traditional knowledge in making decision regarding rainfall onset, selection of suitable crops and further ways to cushion themselves against extreme weather events. Much of arable land is cultivated by farmers using their traditional knowledge and skills under unreliable rainfall for their survival. In Malakal County, production of major cereal crops have been reduced and hunger becomes seasonal (happening seasonally) due food shortage inflicted by poor rainfall performance. Conditions and productivity of livestock have also been worsened because of insufficient pasture and water. Off-farm activities such as collecting wild fruit and burning charcoal are becoming than crop farming. In addition, no studies have been done on climate variability and change impacts within this region.

This study therefore is aiming at addressing the above short coming in order to help farmers adapt through recommendation of better and sustainable adaptation strategies under the prevailing and predicted climate variability and change conditions.

1.2 The objectives of study

The overall objective of this study was to assess climate variability and change impacts on agriculture based livelihood in Malakal County of South Sudan with a view to recommending possible adaptation measures. The specific objectives of this study were:

1. To assess the trend of rainfall and temperature in Malakal county
2. To assess rainfall and temperature variability impacts on livelihood and
3. To identify current coping strategies used to address the impacts of climate variability and change and recommend possible improvement.

1.3 Justification

In Malakal County, recurrent of flood and drought during crop growing period are the major weather extreme events that adversely affect crop yields and conservation of local food security. Since Malakal exhibits a semi-arid type of climate, weather fluctuations are likely to reduce crop yields and livestock numbers and productivity. Shifts in seasonal onset, poor distribution and frequent extreme events (flood and drought) are among the climate variability manifestations in the County. Consequently, low soil fertility, water logging and high temperature and moisture stresses have been the top challenges affecting crop and animal productivity (FAO, 2008).

Livestock is also an important source of livelihood, with production mainly based on traditional pastoral systems. Approximately 90 percent of the livestock in the region belong to the traditional pastoral production systems. Lack of pasture as the result of inadequate moisture and high temperatures to feed an estimated 8 million heads of cattle have affected the health and productivity of livestock, which significantly contribute to household income.

Besides, the long civil conflict in South Sudan dismantled the institutions which could provide vital information related to weather and climate. Apart from the lack of information, the levels of illiteracy and inadequate technologies have significantly affected rain fed agriculture production and endangered socio-economic status of the rural community of Malakal County. To better address the climate variability and change impacts on livelihood based on agriculture in Malakal, it is desirable to develop a broader research framework, which integrates bio-physical (crop) and socio-economic aspects of food systems and coping strategies used which can thereby address key questions of climate change impacts.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter presents a review of previous studies related to the activities and methodologies used in this study. Reviews of climate variability and change, agriculture vulnerability to climate variability and change in Upper Nile state, climate variability and change impact on socio-economic development and assessment of climate variability and change impacts framework are presented in the following sections.

2.1 Climate variability and change

There is a fundamental difference between climate change and climate variability. Climate change constitutes a shift in meteorological conditions that last for a long period of time (IPCC, 2007a) while climate variability is short-term fluctuations happening from year to year or seasonally. In this study both definitions were adopted. Global climate change is real and is widely happening with far reaching effects. Hulme et al., (2000) investigated climate change and variability over Africa cover the period of 1900 to 2100. These studies suggest that climate is not a phenomenon of the future, but one of the recent past. Therefore, the continent is warmer than it was 100 years ago and this warming occurred in the twentieth century at the rate of 0.5 °C.

Climate change, resulting from the effects of increased greenhouse gas emissions, poses greater threats than in previous decades by combining higher temperatures, less available water in regions where it is most needed and more frequent and intense extreme weather events (IPCC, 2007a). Because of human activities such as burning charcoal and oil, land cultivation for agriculture, there is a significant increase in the concentration of greenhouse gases, particularly of carbon dioxide. This enhanced' greenhouse effect traps more heat and further raises the earth's surface temperature (Thornton et al, 2006; IPCC, 2007a). In the context of an increasing population, these effects can become more dramatic. In particular, climate change has raised much concern regarding its impacts on future global agricultural production, varying by region, time, and socio-economic development path (Fischer et al 2002b).

Changes in climate variability and extremes of weather and climate events have received increased attention in the last few years. Understanding changes in climate variability and climate extremes is made difficult by interactions between the changes in the mean and variability. The issue of climate. change has become more threatening, not only to the sustainable development of socio-economic and agricultural activities of any nation, but to the totality of human existence. Human beings have been adapting to the variable climate around them for centuries worldwide. Local climate variability can influence peoples' decision with consequences for their social, economic, political, and personal conditions and can affect their lives and livelihood (UNFCCC, 2007). As further explained by United Nation Framework Convention on Climate Change (UNFCCC) the effect of climate change implies that the local climate variability that people have previously experienced and adapted to is changing and this change is observed in a relatively great speed.

2.2 Vulnerability of agriculture to climate variability and change impacts in Upper Nile State

While climate change is global in nature, potential changes are not expected to be globally uniform; rather, there may be dramatic regional differences. In Upper Nile state, the consequences of climate variability and climate change are potentially more significant for the poor farmers who rely on rain fed agriculture in an environment with unreliable rainfall. In addition, vulnerability to the impacts of climate change is generally a function of exposure to climate variables, sensitivity to those variables, and the adaptive capacity of the affected community. Often, the poor are dependent on economic activities that are sensitive to the climate. For example, agriculture and forestry activities depend on local weather and climate conditions; change in those conditions could therefore directly impact productivity levels and diminish livelihoods.

The contribution of agriculture to GDP varies across countries but some studies suggest that an average contribution of 21% (ranging from 10 to 70%) of GDP (Mendelssohn et al., 2000). The contribution of agriculture to South Sudan's GDP has been not quantified; however, reports suggest that the sector contributed significantly not only to national economy but also to the rural livelihoods (FAO, 2008). Furthermore, South Sudan depend entirely on natural resources and about 98% of national budget is from oil revenue and only 2% of this budget comes from non-oil revenue and other sources including agriculture. Thus, indicated that agriculture sector is under developed and the region therefore depends on exported food from neighboring countries mainly Uganda and Kenya and food aid from humanitarian agencies. FAO (2008) report suggests that security is the government of South Sudan's top a priority followed by road (infrastructure). This priority compromised the allocated budget to natural resources sector which included agriculture. Only 6.7% was allocated to natural resources while security and road sectors received more than 50%. That means agriculture, forestry, animal resources and fishery represents a share of only 1.6 % of government expenditure which is too little for developing agricultural institutions, training extension personnel and enhancing farmers' capacity and adopting new technology (Table 1).

Table 1: South Sudan expenditure by funding sources and sectors (2010)

Sector	GoSS budget	Donors' funds (SDP)	Total (SDP)	%
Accountability	157.5	52.2	209.6	3.4
Economic functions	164.5	60.4	224.9	3.6
Education	323.5	126.3	449.9	7.2
Health	189.4	406.3	595.7	9.5
Infrastructure	601.9	374.1	976.0	15.6
Natural resources	217.0	200.9	417.9	6.7
Public administration	571.6	112.3	683.8	10.9
Rule of law	487.9	76.5	564.4	9.0
Security	1145.8	304.9	1450.8	23.2
Social & humanitarian	99.0	58.6	157.5	2.5
Transfers to States	524.7		524.7	8.4
Total	4482.8	1772.4	6255.3	100.0

Source: FAO report (2011); SDP: Sudanese Pounds

In Upper Nile, farmers and pastoralists have to contend with other extreme natural resource challenges and constraints such as poor soil fertility, pests, crop diseases, and a lack of access to inputs and improved seeds. These challenges are usually aggravated by periods of prolonged droughts and/or floods and are often particularly severe during El Nino events (Mendelssohn et al., 2000; Biggs et al., 2004). Despite of oil deposit in Southern Sudan, agriculture remains the basic way of earning a living in Malakal County, and dependency of farmers on rain fed agriculture make the people's main livelihood, vulnerable to climate variability and change. Rainfall in Malakal is highly erratic and leads to late planting. Consecutive dry spell throughout the growing period affects crop productivity and hence food security situation. Based on FAO (2006) report, climate variability and change impacts have resulted in a decrease in area cultivated and agricultural productivity across South Sudan States. Table 2 indicates that both cultivated land and agricultural production in Greater Upper Nile have drastically decreased as compared to Greater Bahr el Ghazal and Equatoria. This variation could be explained by prevailing climatic conditions especially rainfall regime in particular State. For example, Greater Equatoria especially western and parts of the Central, observed reliable rainfall throughout the year. However, rainfall in Greater Upper Nile and Bahr el Ghazal is erratic and unpredictable in terms of onset, duration and cessation.

Table 2: Area planted and production in traditional sector in South Sudan (2001-2005)

	2001		2002		2003		2004		2005	
Agro-ecological zone	Area 000 ha	Prod. 000 t	Area 000 ha	Prod. 000t	Area 000 ha	Prod. 000 t	Area 000 ha	Produc. 000 t	Area 000 ha	Prod. 000 t
Greater Upper Nile, Nile/Sobat Corridor	**111**	**92**	**132**	**73**	**106**	**82**	**134**	**82**	**206**	**167**
Upper Nile	47	41	88	41	53	42	89	48	56	48
Unity	40	32	13	8	16	12	31	22	42	37
Jonglei	24	19	31	24	38	27	18	12	108	81
Greater Bahr el Ghazal Flood Plains, Ironstone plateau.	**286**	**195**	**312**	**162**	**402**	**306**	**451**	**306**	**415**	**355**
NBeGS	180	109	208	83	243	185	295	195	96	57
WBeGS	26	21	31	23	46	34	37	26	42	39
Lakes	80	65	73	56	113	87	119	85	105	97
Warrap	----	----	----	-----	-----	-----	-----	-----	172	162
Greater Equatoria, Greenbelt, hills and Mountains	**261**	**242**	**185**	**187**	**250**	**247**	**217**	**200**	**228**	**256**
Central	102	87	72	60	102	84	79	66	74	76
Eastern	45	22	13	7	13	7	13	7	34	25
Western	100	120	100	120	100	132	107	113	120	155
Total	**658**	**528**	**629**	**422**	**758**	**635**	**802**	**588**	**849**	**778**

Source: FAO report (2005/06)

Although there is no general consensus on the direction changes in terms of precipitation in the future, climate variability and change may have negative consequences on agricultural production and food security mainly in the arid and semi-arid areas (ASA) (Karanja, 2007).

Arid and semi-arid conditions are likely to be exacerbated even in places where an increase in precipitation is predicted because of higher evapotranspiration regimes due to higher temperatures. Extremes in the form of droughts and floods are expected to be frequent, putting an additional pressure on already stressed systems. South Sudan especially upper parts of the regions (9°.22´´ N) exhibit Sahel weather and changes in climatic conditions such as movement of air mass in North and West Africa affect local weather in the area. Mendelsohn et al., (2000) conducted climate sensitivity analysis on agriculture and concluded that three African countries will virtually lose their entire rain-fed agriculture by 2100 and two of them are Sahelian countries: Chad and Niger. However, simulation exercise carried out in Mali (assuming a temperature rise of between 1 and 2.75 °C and no adaptation measures applied) suggests that, by the year 2030, reduced precipitation will induce a decline in cereal harvest by 15–19 percent causing a doubling of food prices. The combined effects of lower production on farming household and higher prices on the consumer's access to food raises the risk of hunger from its present baseline of 34 percent to 64–70 percent of the Malian population by 2030 (Butt et al., 2003).

2.3 Climate change and variability impacts on socio-economic development

Impacts of climate variability and change on socio economic or agricultural sector are projected to steadily manifest directly from changes in land and water regimes, the likely primary conduits of change. Changes in the frequency and intensity of droughts, flooding, and storm damage are expected. Climate change is expected to result in long-term water and other resource shortages, worsening soil conditions, drought and desertification, disease and pest outbreaks on crops and livestock, sea-level rise, among others (IPCC, 2007). Among the climatic parameters rainfall and temperature are key features of climate that threaten agricultural productivity in the tropical and subtropical countries. Agricultural production depends on rainfall and atmospheric temperature. Rainfall is affected by the change of atmospheric temperature or global warming. In the recent years scientific research based on reliable world climate data reveals that the climate is being affected by the green house effect and temperature and precipitation are changing globally (IPPC, 2001).

The Intergovernmental Panel on Climate Change (IPCC) has warned that the latest scientific evidence points strongly towards a climate changing world (IPCC, 2007a), which has been supported by many researchers (Thornton et al., 2006; Ariel et al., 2008). Even though, the extend or level of the impact of the climate change and its distribution is still disputed, the current evidence of high temperatures, rising sea levels, arctic thinning, and low rainfall suggests that countries in temperate locations may benefit from small economic advantages because additional warming will increase their agricultural sector (Mendelsohn, et al., 2000). Many countries in tropical and sub-tropical regions, including South Sudan, are expected to be more vulnerable to warming because the additional temperature increases will affect their marginal water balance and harm their agricultural sector (Mendelsohn et. al., 2000). The problem is expected to be most severe in Africa, where current information indicates that it is the poorest continent where technological change has been the slowest, and the domestic economies depends heavily on the vulnerable agriculture (FAO, 2008).

Temperatures in Africa are expected to increase at least more than global average. This will have varying impacts depending upon ecological zones (IPCC, 2007a). Water availability is a critical factor in determining the impacts of climate change and variability in many places, especially in Africa. A number of studies suggest that rainfall and the length of the growing season are critical in determining whether climate change is positively or negatively affects agriculture (Karanja, 2007; Ariel et al., 2008). The expected variability of temperature, precipitation, atmospheric carbon oxide and extreme events are forecast to have profound effects on plant growth and yields, crops, soils, weed, diseases, livestock and water availability in sub Saharan Africa (IPCC, 2007b; Ariel et al., 2008).

Hulme et al., (2000) evaluated the rainfall pattern and assessed regional differences over Africa and concluded that Sahel displayed considerable multi-decadal variability with recent drying while east Africa appears to have a relatively stable rainfall regime (Hulme et al, 2001). However, global surface temperature on average has warmed by 0.8°C in the past century; and 0.6°C in the last three decades (Hansen et al., 2006), due to human activities (IPCC, 2001). If greenhouse gas emissions which are the major contributor to climate change, continue to rise, the mean global temperatures will increase by between 1.4 to 5.8°C by the end of the 21st century (IPCC, 2001) with a doubling of the CO_2 concentration in the atmosphere. Future impacts are projected to worsen as the temperature continues to rise and as precipitation becomes more unpredictable in amount and distribution (Houghton et al., 1996).

The historical climate records for Africa show warming of approximately 0.7°C over most of the continent during the 20th century with a decrease in rainfall over large portions of the

Sahel, and an increase in rain in east and central Africa (Ariel et al., 2008) Climate change scenarios for Africa, based on the IPCC analysis which result from several general circulation models using data collated by the IPCC data distribution centre, projects future warming across Africa ranging from 0.2 °C per decade for low scenario to more than 0.5°C per decade under high scenario. This warming is greatest over the interior of semi-arid margins of the Sahara and central southern Africa (IPCC, 2001; Thornton, et al., 2006). Projected future changes in the mean seasonal rainfall in Africa are less well defined. For example, under low warming scenario, few areas show trends that significantly exceed the natural 30-year variability. Under intermediate warming scenarios, most models project that by 2050 North Africa and the interior of southern Africa will experience decreases during the growing season that exceed one standard deviation of natural variability. Hulme et al., (2001) suggested that under intermediate warming scenarios, parts of equatorial East Africa will likely experience 5- 20% increased rainfall from December - February and 5-10 percent decreased rainfall from June- August by 2050. Climatic changes of this magnitude will have far reaching, negative impacts on the key sensitive sectors such as water resources, food and agricultural production, human health and biodiversity.

It has long been recognized that climate variability and change have an impact on food production, (Ariel et al., 2008), and the extent and nature of this impacts become certain especially in developing countries. Broadly speaking, food security is less seen in terms of sufficient global and national agricultural food production, and more in terms of livelihoods that are sufficient to provide enough food for individuals and households (Jane et al., 2006). In addition, scientific community perceives climate variability and change as the most significant environmental threat of the 21st century endangering the sustainability of the world's environment, its agriculture and consequently the health and well being of its people. IPCC (2007b) report confirms that while crops would respond positively to elevated CO_2 in the absence of climate change, the associated impacts of high temperatures, altered patterns of precipitation and possibly increased frequency of extreme events such as drought and floods in arid and semi areas, will probably combine to depress yields and increase production risks in many world regions, widening the gap between rich and poor countries (UNFCCC, 2007). A consensus has emerged that developing countries are more vulnerable to climate change than developed countries, because of the predominance of agriculture in their economies, the scarcity of capital for adaptation measures, their warmer baseline climates and their heightened exposure to extreme events (IPCC, 2007b).

Thus, climate change is also expected to have serious consequences in the developing world, where some 800 million people are undernourished. Of great concern is a group of more than 40 'least-developed' countries, mostly in sub-Saharan Africa, where domestic per capita food production declined by 10% in the last 20 years. Many interactive processes determine the dynamics of world food demand and supply: agro-climatic conditions, land resources and their management are clearly a key component, but they are critically affected by distinct socio-economic pressures, including current and projected trends in population growth, availability and access to technology and development. Projected climate change including variability of precipitation, temperature, atmospheric carbon content and extreme events are expected to have profound effects on crops growth and yields, soils, insect, diseases, weed, livestock and water availability in arid and semi arid areas (Mutau, et al., 2007). Karanja (2007) conducted climate change impact in arid areas aimed at assessing adaptation measures in Kenya, the study concluded that impact of climate variability and change in arid and semi arid areas (ASAs) including reduction in rainfall; rise in temperature affected livelihoods (agriculture and livestock) of many communities in dry areas in Kenya.

IPCC (2007), indicates that the decreasing trend of rainfall for the last three decades has affected the whole of Eastern Africa but the people, who were worst hit, were those who lived in arid and semi-arid areas with erratic rainfall, like Southern Sudan (FAO, 2007). The prolonged dry spell during rainy season and heavy rains that lead to localized flash flood afflicted huge impacts on people and the tragic consequences it had on its people and economies was a wakeup call to the researchers and international community (FAO, 2006). The rural communities, who depended on farming and herding, have been badly affected by the climatic risk. The frequent wet and dry spell also triggered an unprecedented tide of mass migration from one State to another (within the region), from rural areas to nearby cities, and from county to the neighboring county/district and other State or province. However, the desiccation has had far reaching consequences on the Southern Sudan communities, which are home to some of the poorest in the world and whose economies are heavily based on agriculture. Many people migrated in search of pasture to feed their animals into neighboring areas, thus escalate conflict among society. Squatter settlements of returnees, internal displaced person (IDP) and urban overcrowding increased, accompanied by rising unemployment. Additional burdens were placed on limited social services, and political instability which intensified in the region.

2.4 Climate variability and change impacts assessment framework

Besides, literature on impacts, vulnerability and adaptation to climate change has developed over time. Based on these developments, various concepts and frameworks have been introduced and discussed in context, and the focus was initially on impacts assessment and later on shifted to vulnerability assessment and assessment of adaptive capacities, placing adaptation in context (Thornton et al., 2006). IPCC (2001) suggests that effective adaptation depends on the capacity or coping strategies of the affected community (system). The IPCC (2007b) third assessment report (TAR) defined vulnerability to climate change considering the inherent adaptive capacities that exist in those affected areas (regions) in being able to respond effectively to expected changes. The report; however, concluded that vulnerability of a given system (community) greatly depends on adaptive capacities of the system and its potential in coping effectively with associated risk (IPCC, 2007b). The relationship between vulnerability, impacts and adaptive capacity may be summarized in the equation 1 below:

$$V = f(I - AC) \quad (1)$$

Where:

V – Vulnerability, I – Impacts and AC – Adaptive capacities

Given the above equation, vulnerability is described as a function of biophysical and socio-economic factors, and these factors are basically aggregated into three components that include an estimate of adaptive capacity, sensitivity, and exposure to climate variability and change. Sensitivity and exposure to climate variability and change provide an estimate of the expected impacts among the community. On the other hand, socio-economic factors play vital role in determining the extent of vulnerability among the community or individual given the underlying adaptive capacity that prevail among the affected community.

Adaptive capacity is defined as the potential or ability of a system, community to adapt to the effect or impacts of climate change (Smit and Pilifosova, 2001). In case of communities, adaptive capacity is determined by the socio-economic characteristics of the communities and their abilities in responding effectively. This suggests that the most vulnerable communities are those that are most highly exposed to the changes expected in the climate and have limited adaptive capacity. Regions like Southern Sudan with limited economic resources, low level of technology, poor information and skills, poor infrastructure, weak institutions and inequitable employment and access to resources have little capacity to adapt and are highly vulnerable (IPCC, 2001).

There have been predominantly two different methods used to measure the economic impact of climate change on African agriculture: the crop simulation approach and the Ricardian approach. The crop simulation approach uses the direct effect of climate change on individual crops (Rosenzweig and Parry 1994; Parry et al., 2004). These studies reveal that the yields of the major grains grown in Africa would fall precipitously with warming. The Ricardian approach measures the relationship between net revenues from crops and climate using cross sectoral evidence (Kurukulasuriya et al., 2006; Kurukulasuriya and Mendelsohn, 2008). These studies also found that hot and dry climate scenarios would reduce crop net revenues in Africa. The Ricardian studies, however, generally estimate smaller damages than the crop simulation models. One explanation for this difference is the handling of adaptation. The Ricardian model captures endogenous adaptation, measures that farmers actually take to adjust to climate change. This adaptation is efficient since it makes the farmer better off. In contrast, the crop simulation studies examine only exogenous measures arbitrarily added by the researcher that are not necessarily efficient responses to climate change. However, the models do not consider rural community diversity as far as coping mechanisms are concerned.

In addition, a methodology of impact assessment in the field of climatic variability and change is quite new. It began in the mid-1970s when concern first arose over atmospheric ozone depletion, and was first applied to the issue of green house gas induced climate change in the early 1980 (Kate et al., 1985). Since then there have been some substantial advances in methodologies, from an initial focus on the one way impact of climatic risk related events on human activities to, more recently, a greater emphasis on the two way interactions between climate variability and change and human activity. More recent assessments which combine global and regional scale analysis, impacts of climate change on growing periods and agricultural systems, and possible livelihood implications, using computer based techniques (models) have also been explored. Based on the model scenario, General Circulation Models (GCMs) agree on areas of change in the coastal systems of southern and eastern Africa ((Thornton et al., 2006).

Furthermore, a variety of methods have been employed and among the techniques used, careful attention is given to the definition of vulnerability. Based on this, different non-climatic factors including socio-economic setting, trade, institutional structure and geographical weather are drawn to examine current vulnerability of affected community, risk of present and future climatic variations and responses to reduce present vulnerability and improve resilience to climate variability and change. Kurukulasuriya and Robert (2006) examine the impact of climate change on farmers in Africa using Ricardian approach analysis; the study however incorporated socio-economic factors including farm net farm revenue with observed climatic parameters to quantify the significance of climate change impact at household level. The study used Ricardian approach to integrate the dry land and irrigated land separately but treated the choice of the irrigation as indigenous.

Thus, it is important to link climate vulnerability to socio-economic studies and long-term periodic and socio-economic assessments. While preserving indigenous knowledge that is relevant to community level responses, studies on coping strategies and specific vulnerability assessments need to be highlighted as important elements to determining adaptation options (Thornton et al., 2006). Useful methodologies for assessing adaptation options include both top down and bottom-up approaches. Both methodologies need to be linked to promote integrated adaptation assessments. Top-down methodologies include the use of modeling and scenario analysis. This can respond to current climate variability. Top down approach is the vulnerability base, which incorporate human and economic dimensions of the local communities, particularly livelihood aspects and inter sectoral relationships. It is used in developing specific strategies and policy implementation (IPCC, 2001). However, it exhibits a weaker attribution to future climate change, provides useful background to decision making and is strong in terms of the biophysical aspects of impacts. The models also do not perform well in representing human interactions and local abilities to adapt. However, bottom-up, approach recognizes and builds upon local coping strategies and indigenous knowledge and technologies, and the capacity and coping range of communities, local institutions and sectors.

The study of the impact of climate change on the livelihoods of local populations is increasingly being forwarded as urgent research needs (Morton, 2007). However, exploring the local-level dynamics of people's vulnerability to climate change, of which adaptive capacity is a key component, it is important to find ways to embed such findings into wider scales. The key issues, therefore, in relation to the potential impacts of climate variability and change on food security in Sub-Sahara Africa encompass not only a narrow understanding of such impacts on food production but also a wider understanding of how such changes and impacts might interact with other environmental, social, economic and political factors that determine the vulnerability of households, communities and countries, as well as their capacity to adapt (Ariel et al., 2008).

However, vulnerability assessment has emerged to address the need to quantify how communities adapt to changing environmental conditions. Various researchers have tried to bridge the gap between the social, natural, and physical sciences and contributed new methodologies that confront this challenge (Polsky et al., 2007). Many of these rely heavily on the IPCC working definition of vulnerability as a function of exposure, sensitivity, and adaptive capacity (IPCC, 2001). Exposure in this case is the magnitude and duration of the climate-related exposure such as a drought or change in precipitation, sensitivity is the degree to which the system is affected by the exposure, and adaptive capacity is the system's ability to withstand or recover from the exposure. Fussel and Klein (2006) divided available studies into first generation vulnerability assessments based on climate impact assessments related to the baseline conditions and second-generation assessments that utilized adaptive capacity. In the second-generation assessments, a multitude of interpretations about how best to apply exposure, sensitivity, and adaptive capacity concepts to quantify vulnerability exist (Thornton et al., 2006; Polsky et al., 2007). Key differences among approaches include scale, methods used to select, group, and aggregate indicators, and methods used to display the results.

Many concepts are continuously recurring in the methodological literature which has been used in the analytical framework for the purpose of this study. Early impacts assessment approach were based on the assumption of a direct cause and effect relationship between a climatic extreme events (such as short term decrease in rainfall) and response within the ecosystem under study (e.g. decrease in crop yields, or migration of wildlife). Depending on the discipline, literatures use different terms and definitions for the term impact exist. Some of the terms include hazard, risk, biophysical vulnerability or generally vulnerability (Brooks, 2003).

There are still notations on what vulnerability is, and how it is related to risk and adaptive capacity. Various definitions of vulnerability have been reviewed by Adger et al., (2003) and Vicent (2004). In O'Brien et al., (2004), the end point and approach views vulnerability as a residual climate change impacts minus adaptation. Vulnerability is therefore viewed as an end point considers that adaptations and adaptive capacity determine the vulnerability while consider vulnerability as a starting point (approach that sees vulnerability as a general characteristic generated by multiple factors and processes) indicates that vulnerability determines adaptive capacity (Thornton et al., 2006; Anand et al., 1994)

Conceptually, livelihoods describe the means, activities, entitlements and assets by which people make a living. Assets, in this particular context, are defined as not only natural/biological (i.e., land, water, common-property resources, flora, fauna), but also social (i.e., community, family, social networks, participation, empowerment), human (i.e., knowledge, creation by skills) and physical (i.e., roads, markets, clinics, schools, bridges). The Brundtland Commission in 1987 introduced sustainability livelihood in terms of resource ownership and access to basic needs and livelihood security, especially in rural areas. The International Institute for Sustainable Development (IISD) however, defines sustainable livelihoods as being concerned with people's capacities to generate and maintain their means of living, enhance their well-being, and that of future generations.

The study of the impact of climate variability on livelihoods of local populations is increasingly advanced as urgent researches need (IPCC, 2007). However, appropriate definition and technique which could integrate climatic variables and socio-economic activity becomes a challenge although a multitude approaches and methodologies were used for this purpose. However, the study incorporated the UK's Department of Foreign and International Development (DFID) definitions. According to DFID, livelihood comprises the capabilities, assets (including both material and social resources), and activities required for a means of living. Therefore livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base (Chambers and Conway, 1992; David et al, 2006 and Deresa et al, 2008). Livelihood assessment is therefore a way of looking at how an individual, a household, or a community behaves under specific frame conditions. One of the ways to understand livelihood systems is to evaluate the coping and adaptive strategies pursued by individuals and communities as a response to external shocks and stresses such as drought, flood, and civil strife and policy failures. This study used rural participatory approach (RPA) technique to generate primary data both climatic and non-climatic data. Chambers and Conway (1992) state that RPA techniques have been accepted as important data collection tools throughout the development community.

The rural participatory approach (RPA) technique is, however, used to solve many kinds of problems directly related to the socio-economic factors, such as descriptions of livelihood systems (i.e., food economy characteristics), variations in livelihood and household types, reasons underlying household vulnerability, coping strategies under varying conditions, market and trader analysis, willingness to accept specific development interventions, local community priorities, and other development-related questions (Boko et al., 2007). In South Sudan context, secondary data on climatic parameters, crop yields, agricultural land price are seldom available and the study intended to use RPA to generate primary data. Gina Ziervogel et al., (2003) analyzed impact of seasonal forecast on livelihoods using livelihood approach as a basis for exploring the theoretical interaction of livelihoods and climate variability and change. Livelihoods approach draws both theoretical and spheres and the theoretical framework enable the components of rural livelihoods to be identified and links between components to be explore.

This study used livelihood and vulnerability approach to assess vulnerability of the affected society at the community level in target area. United Nations General Assembly (1997) recommended livelihoods approach, which looks at five types of household asset; natural, social, financial, physical, and human capital (livelihood components) (Chambers and Conway, 1992), as an approach used to view development program at the community level. However, vulnerability assessments have been used by many studies in many countries and in a variety of contexts including the USAID Famine Early Warning System (FEWS-NET) (USAID, 2007), the World Food Program's vulnerability analysis and mapping tool for targeting food aid (World Food Programme, 2007), and a variety of geographic analyses combining data on poverty, health status, biodiversity, and globalization (O'Brien et al., 2004; UNEP, 2004). Vulnerability assessment usually describes a diverse set of methods used to systematically integrate and examine interactions between humans and their physical and social surroundings. To capture all dimensions of vulnerability, the study consider IPCC's and livelihood, vulnerability Index (LVI) approach. IPCC exposure, sensitivity and adaptive capacity as the contributing factors to vulnerability (IPCC, 2007b) while LVI is the composite index comprised of seven (e.g. Socio-demographic profile, Livelihood strategies, Social networks, Health, Food, Water, and Natural Disasters and Climate Variability) major components of vulnerability and as indicators to climate variability and change (Boko et al., 2007).

There are two kinds of responses to crisis that overlaps across the temporal scale, these are coping strategies and adaptive capacity. Coping strategies are the actual responses to crisis on systems (community) in the face of unwelcome situations; however, these are considered as short-term responses (Berkes & Jolly 2001) while adaptive strategies are the strategies in which a region or a sector responds to changes in their livelihood through either autonomous or planned adaptation (Campbell 2008). Coping mechanisms may develop into adaptive strategies through times (Berkes & Jolly 2001). However, it is difficult to make a clear distinction between coping mechanisms and adaptations; however, this study considered both schemes as coping strategies. The resilience or the robustness of coping mechanisms depend on the availability and access to resources and technology (Adger et al., 2003).

Sudan has been at war for more than 20 years which left parts of the country, especially the south, under developed. Most institutions which could deliver basic service such as weather forecast to provide users with timely information regarding expected seasonal rainfall do not exist in the entire region. In most cases, farmers used their indigenous knowledge to forecast the onset of rainfall. Focus group discussions suggest that farmers have developed intricate systems of gathering, predicting, interpreting and making decisions in relation to weather. Indigenous methods of weather forecasting were known to complement farmers' planning activities in Malakal. Farmers reported that elderly men formulate hypotheses about seasonal rainfall by observing natural phenomena, while cultural and ritual specialists draw predictions from divination, visions or dreams. Timing of fruiting of certain local trees, water level of the streams and ponds and the nesting behavior of birds are some of the indicators observed during seasonal forecast by local community in Malakal. Observation of these natural features is carried in MAM which indicates the early onset of rainy season in the region and this gives farmers a hope for a good year (consistence rains) and made them to plan in advance to prepare their land and planting.

South Sudan is characterized as semi-arid region and thus susceptible to degradation or even desertification; semi-arid regions are subject to regular seasonal dryness and large inter-annual variability in precipitation. The crop yield variable or vegetation cover on annual and inter-annual timescales, as both natural ecosystems and non-irrigated such as pastures and crops rely on soil moisture derived from seasonal rains or springtime snow melt (Evans and Geerken, 2004). Climate-induced variability in semi-arid rain fed agriculture is a matter of both ecological interest and economic concern, as strong sensitivity to climate can result in rapid land use change (Vanacker et al., 2005) and vulnerability to human-induced degradation (Evans and Geerken, 2004). Climate is one of the most important factors affecting crop yield. Therefore, evaluation of the quantitative relationship between crop yield or vegetation response patterns and climate is an important object of applications of remote sensing at regional and global scales.

Studies indicated that Normalised Difference Vegetation Index (NDVI) images were used to monitor drought and land cover (Tucker and Seller, 1986). In this study, Normalized Difference Vegetation Index (NDVI) images were used as proxy of crop yield over the study area due to lack of observed crop yield. It is believed that NDVI images are highly correlated to green leaf density and can be viewed as a proxy for above-ground biomass (Tucker and Sellers, 1986). Variation between NDVI and its explanatory variables such crop yield or pastures could only be attributed by vegetation type, soil type, soil moisture (Peters, 2004; Foody, 2005). Vegetation cover processes play a crucial role in the water balance over a wide range of spatio-temporal scales (Betts et al., 1996). Unfortunately, vegetation dynamics and their interaction with climate are still largely unexplored. Under this framework, satellite data have proved to be very useful for monitoring realistic crop yield, land use and vegetation trends from local to global scale (Baulies et al., 1999).

The Normalised Difference Vegetation Index (NDVI is a nonlinear function that varies between -1 and +1 (undefined when NIR and VIS are zero). Values of NDVI for vegetated land generally range from about 0.1 to 0.7, with values greater than 0.5 indicating dense vegetation. Since NDVI measure the greenness, state and amount of vegetation at the land surface on dekadal basis, it can be used to estimate growth of vegetation and crop yields. The NDVI has been used for a long time to establish empirical relationships between spectral reflectance and biophysical parameters (e.g. biomass, leaf area or vegetation cover) and estimate the amount of absorbed photo-synthetically active radiation (PAR).

There are three concepts that are continuously recurring in the literature used in the analytical framework developed for the purpose of this study (Fig.2). Climate variability impacts, vulnerability and coping strategy assessment was carried out to generate outputs that are policy relevant. To do this, climate and household data were integrated and analyses across a range of sectors, and the results were tailored for policymakers and stakeholders.

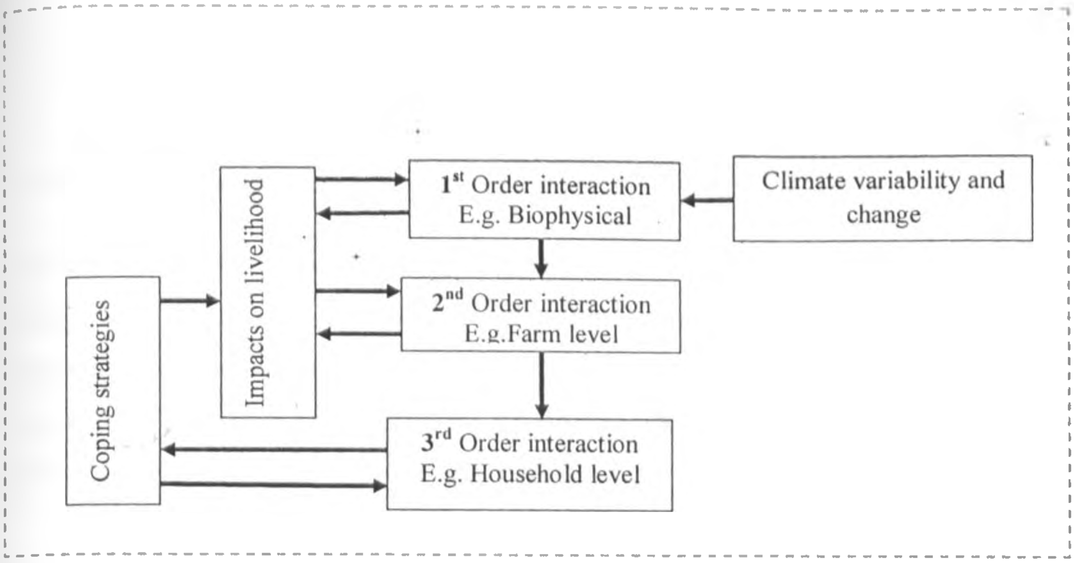

Figure 1: Schematic analytical approach to climate variability and change impact assessment

2.5 Scope and limitations

Climate variability and climate change influence the activity of ecosystems and agriculture production. Therefore, systematic and accurate ways to assess and predict climate events and changes that occur so that appropriate mitigation approach to reduce the impacts is put in place. Scientists have developed different models to predict expected climate and project scenarios. For instance, IGAD climate prediction and application center (ICPAC), uses such models to give seasonal outlooks (e.g. MAM, OND). However, these models generate data using historical data (climate) as the baseline. On the other hand, these models used to project physical parameters and cannot give biophysical information and livelihoods condition of the affected community and coping mechanisms used locally. Influences of climate variability and change on livelihoods and vulnerability (crops and livestock production) have been extensively documented in many places. A part from this, South Sudan is prone to adverse climatic-impacts (drought and flood) and documentations on climate impacts hardly exist. Therefore, lack of historical data of climate parameters, crop yields, and soil and lack of funds, infrastructure (communication and transport facilities) is anticipated to negatively contribute in quantifying the overall impact of climate variability and change on livelihoods and vulnerability of the affected community.

CHAPTER THREE
MATERIALS AND METHODS

3.0 Introduction

This chapter discusses the data and methods which were used to fulfill the objectives of this study. The data used in this study comprised climatic data, crop yields and household characteristic. The methods used also include the graphical, rainfall anomaly index (RAI) and Normalised Difference Vegetation Index (NDVI) images extraction. Farmers' perception on climate variability and change were also captured.

3.1 Area of the study

The study was conducted in Malakal county, upper Nile state. Administratively, South Sudan has adopted a federal system of government with 10 states; Upper Nile is one the states situated in drought and flood prone area in eastern part of the country bordering Ethiopia at southwest. The state (Upper Nile) is made up of twelve Counties. Malakal is one of these Counties where agriculture is believed to be negatively affected by climate parameters especially rainfall. Malakal has a population of 126,483 and 16, 892 households (SSCSE, 2008). Generally Upper Nile is an agricultural region which provides food to the rest of the States in Southern Sudan. This current study was conducted in Malakal County.

According to Southern Sudan livelihood profiles (2006), Upper Nile State falls under eastern flood plains zone. The eastern flood plains zone is characterized by flat-lying terrain with black cotton soil. Savannah grasslands and acacia trees are the typical vegetation cover. Rural households in this zone generally depend on crops, livestock, wild foods and fishing as the source of food.

3.1.1 Location

Malakal County lies between latitude 10° 45′ N and 9° 55′ N and longitude 31° 25′ E and 31° 65′ E and 1272 feet (388 meters) above sea level. A livelihood in this case was broadly defined as the way in which households obtain the things necessary for life, how they make ends meet year to year (SSCSE, 2006). For example, source of livelihoods in Malakal include crop farming, livestock and fishing activity. The livelihood profiles of South Sudan offer an analysis of rural livelihood and food security on a geographical basis. The physiographic and agro-climatic characteristic of Malakal County presented in this study was adopted from Southern Sudan livelihood profiles (SSCSE, 2006).

However, delineation of livelihood in terms of geographical basis is not the only thing that determines the pattern of livelihood. Local factors such as climate, soil, infrastructure and extend to which people exploit these options depends up on a number of factors, of which wealth is generally the most important factor. For example better-off households could own a large farm and produce more crops and be more food secure than their poor neighbors. Land is just a one aspect which determines income especially in agricultural community. However, livelihood is typically defined in term of land holdings, livestock holdings, education, skills, labor availability and social capital.

Hence, assessing local livelihoods and vulnerability is essential for a proper understanding the impacts of climate variability and change at household level. In general, Southern Sudan is divided into seven livelihood zones and these divisions offer a general description of local livelihood patterns (crop production, livestock rearing, off-farm income generation, etc.) within the framework of five types of capitals as well as the factors of vulnerability indicators (natural, physical, social, human and economic/financial). These include Greenbelt, Ironstone plateau, Hill and maintains, Arid/postural, Nile-Sobat River, Western floodplains and Eastern floodplains.

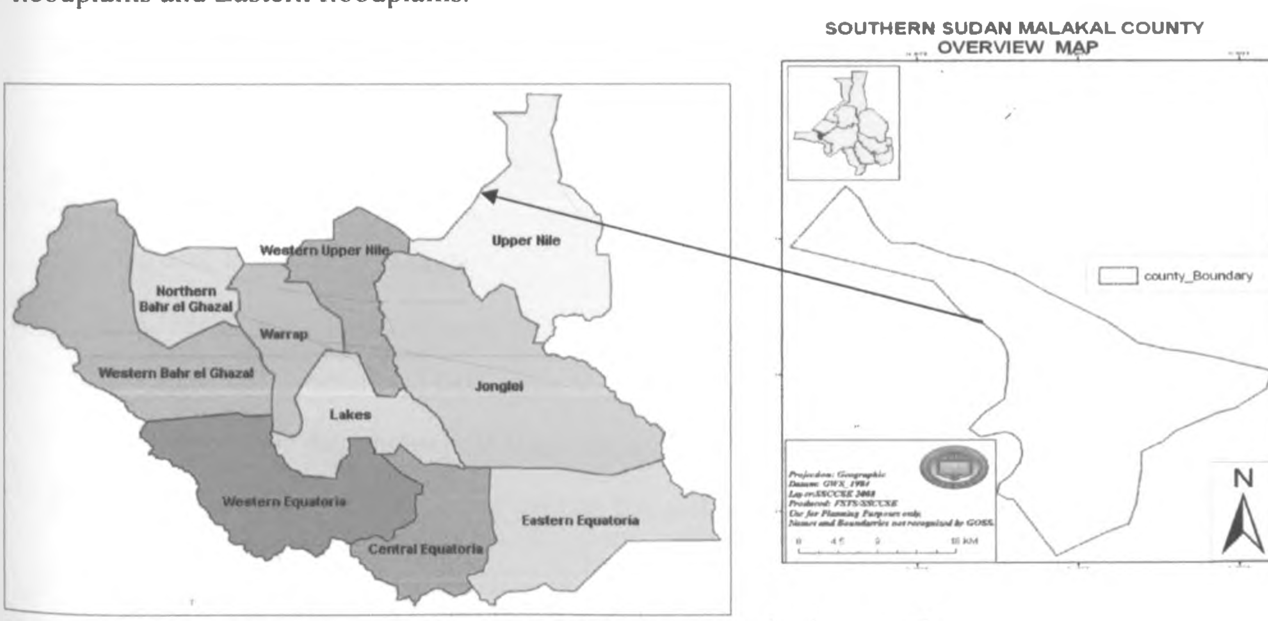

Figure 2: Map of Southern Sudan and Malakal County.

Source: Southern Sudan Centre for Census and Statistics and Evaluation

3.1.2 Climate and agro ecological zones

Generally, South Sudan is characterized by extreme climatic zones; from sub-tropical in the south, south western and part of southeast to semi-arid from the center, north western, north eastern and to the extreme north. The distribution of rainfall exhibits extreme unevenness both spatially and temporally. Mean annual rainfall diminishes northwards. From south to the northern parts of the country annual rainfall received range between 1300 mm to about 600 mm, with coefficient of variation from 30% to 100% respectively (Sendil et al., 1986). While the rainy season commences from March through early October in Greater Equatoria, the period spans from June to October in Greater Upper Nile and Bahr el Ghazal with some scarce rainfall in November throughout the country.

These climate parameters determine vegetation cover in particular area. Therefore South Sudan climate is categorized as savannah and steppe. In savannah climate, the mean maximum temperatures are as high as 35.9 °C throughout the year and the region could have experiences more rain during summer while steppe region have a high temperatures (40 °C) all year and with limited rainfall during the summer season. Upper Nile is however dominated by savannah grassland with acacia trees being the main vegetative cover of the state (SSCSE, 2006). In term of agro ecological zone, Upper Nile State is categorized under both Nile-Sobat and eastern floodplains. This zone is characterized by flat, low-lying terrain with black cotton (clay) soils. The region also experienced mono-modal rainfall with 3-4 months growing period. Variation of rainfall and temperatures is more significant throughout the year, and is characterized by unpredictable dry spell (drought) and excessive rainfall (flood).

3.2 Data types and sources

The data used in this study include:

1) Climatic data (daily and monthly rainfall, and temperature)
2) Crop yield (Normalized Difference Vegetation Index)
3) Non-climatic data (household characteristic)

These datasets are describes in the sub-section that follow.

3.2.1 Climatic and crop yield data

The climatic data used in this study consist of daily (1973-2006) and monthly (1961-2010) rainfall records. Monthly maximum and minimum temperature records (1963-2001) were used. This data were obtained from Sudan Meteorological Authority (SMA). Daily rainfall data were considered in order to assess seasonal onset, cessation, duration and episodes of dry and wet spells during crop growing period, while monthly data were used to assess the general rainfall variations and patterns over Malakal County.

Crop yield data were not available for Southern Sudan in general. As the result, Normalized Difference Vegetation Index (NDVI) images were downloaded from Africa Data portal, formerly African data dissemination service (ADDS) from 1985-2009 and used as proxy for crop yield. WinDisp version 5.1 was used to process the downloaded NDVI imageries. The WinDisp is a computer based program and has its origins with the Global Information and Early Warning System (GIEWS) of the Food and Agriculture Organization of the United Nations. This program offers varying degrees of automation and ease of use. The software allows users to compare multiple images; extract and graph, trends from a number of satellite images including NDVI image.

3.2.2 Non climatic data

The current vulnerability of livelihoods (agriculture) can be expressed as the combination of the climatic hazards, socio-economic conditions and adaptive capacity of affected community. The household data used in the present study include; size of the household, level of education; primary/secondary income or occupation; access to credit, health care, land and markets.

3.3 Methodology

Agricultural production is affected by many uncontrollable climatic factors. The major challenge in Malakal is the unreliable rainfall and high temperature to some extent. The role of rainfall as a direct input in crop production has been an area of interest to many researchers studying the climate variability and change impacts in tropical environment.

This study focused on issues pertaining to how climate affects agriculture, socio-economic activities and rural community well-being. The study tried to investigate vulnerability by assessing farmer's perception and current coping strategies they used to adapt to severe climatic events. The study adopted order of interaction of climate variability and change interaction and integrating framework approach. Since 1980, attempts to understand the interactions of potential impacts climate variability and change by assuming its event have been carried out. This approach was pioneered by the project on the Drought and Man of the International of Institutes Federation of Advanced Study (IFIAS) which investigated the role of drought in the deteriorating social and economic conditions in the Sahel in the 1970s (Martin, 1990).

In order to assess the impact of climate variability and change on agricultural production, it is necessary to understand season rainfall variability. Based on this, time series, regression and correlation analyses of secondary data were used to address stated research objectives.

3.3.1 Data quality control

Data quality control and assurance was carried out in order to detect inconsistencies to rectify erroneous data and in order to attain valid inference from the results of analysis. The errors could be attributed to instruments, observation procedures, transmission, recording, coding and decoding as well as data processing. Data quality control was done using homogeneity tests and estimation for missing data as detailed in the following sub-sections.

3.3.2 Test of Homogeneity

A test for data homogeneity was done using single mass curve technique to check for consistency or reliability of data set. This technique involved plotting cumulative rainfall or temperature against time. If the results of plotted value gave straight line, the dataset are regarded as homogenous while broken or discontinuity of this straight line means that there exists heterogeneity in data set.

3.3.3 Estimation of missing data

In situation where data was found to have missing values below recommended 10% threshold for data rejection (Stanley, 2009), correlation technique was used to estimate missing values. The technique involved computation of correlation coefficients of the year with the missing records and year with the highest correlation coefficient using the following equation;

$$yj = \frac{\bar{y}i}{\bar{y}i} \text{ X } \bar{y}j \text{------} (2)$$

i and j are notations. Where yj is the missing record of jth year, and yi is year with reliable record in ith year, $\bar{y}j$ and $\bar{y}i$ are long term mean.

3.3.4 Trend analysis of meteorological data

Trend analysis refers a technique for evaluating an underlying pattern of behavior over time. It can also be describes as the general movement of a series over an extended period of time or it is the long term change in the dependent variable over time.

Rainfall, temperature and crop yield data are collected over time and therefore are referred to as time series data, which is defined as a sequence of observations that varies over time (trend). Comparison of the trends and seasonality within the data sets provided an indication of crop yields dependent on climatic parameters (rainfall and temperature).

The most convenient and popular way of describing data is using graphical method. This method is easier to understand and interpret data when they are presented graphically than using other statistical method such as frequency table. This method is easy and it allows a pair of value (number) such as rainfall and crop yield data to be depicted by a single point placed suitably on a piece of graphic paper. The usefulness of graphical presentation arises partly from the quantity, information that can be displayed.

In this study, scatter, line graphs and bar chart were used to present variations of rainfall and temperature trend over time. The upward and downward movement of monthly and seasonal rainfall and temperatures was used to assess the trend of climate variability and change.

3.3.5 Rainfall Anomaly Index (RAI)

Rainfall anomaly index (RAI) was used in order to assess wet and dry periods. The RAI has been commonly used to monitor precipitation in drought-prone areas. In this study RAI was used to characterize wet and dry period for March-May (MAM), June-August (JJA) and September-November (SON). The December-February season was not considered because DJF is a dry period over Malakal. However, this (Decenber-Febraury) season is significance to pastoralist in the Greater Upper Nile, Bahr el Ghazal and Eastern Equatoria States where livestock is the main source of livelihood. In adequate pastures availability during this period affect livestock productivity.

The RAI were determined, for standardizing the rainfall data for a given station by subtracting the station's mean long term observed data and dividing the standard deviation of the station's historical data. The standardized rainfall value was determined using equation 3 below.

$$y'ij = \frac{yij - \bar{y}ij}{Si} \quad \text{-----} (3)$$

Where: $Y'ij$ is the normalized (seasonal or monthly) rainfall total for year *j* while yij and S_i the standard deviation of the rainfall total during a specified reference periods. The RAI was computed using equation 4 below:

$$\mathbf{RAI} = \frac{1}{n} \sum y'ij \quad \text{-----} (4)$$

Where: RAI is rainfall anomaly index for the j^{th} year and i^{th} station.

The wet and dry periods were associated with high/low values of RAI index. The years with positive (+1) one standard deviation above the mean were regard as wet while those with negative (-1) below the mean were considered as dry.

3.3.6 Onset, Cessation and duration of wet and dry spells

Three key parameters, which characterize the seasonal rainfall for crop production, have been identified as time of the onset, withdrawal of rains and the length or duration of the rainy season. In order to decide the criterion for the onset of the season, which is favorable for the commencement of cultivation operations, the rain that falls should percolated into the soil up to a considerable depth and also build a soil moisture profile therein after loss through evaporation.

The method proposed by Punyawardena (2001) for determining onset and cessation of rainfall season was used. Onset of the rainfall in Malakal was considered to be the earliest possible day after the 1st of April with more than 20 mm, or a day with cumulative rainfall of 20mm without considering previous rainy day. In addition at least 10 days should be rainy days and there should not be a dry spell of a length 10 days or more in the next 20 days. The first step was to derive the mean annual rainfall that occurred within 30 day interval. This is followed by accumulating the total rainfall of the 30 day periods. This was how these aspects were determined.

The average and extreme lengths of the wet and dry spells are decisive in agricultural activity. A wet spell is defined as a period of consecutive days with at least 20mm or more of rain. Dry spell is also defined as a day during which the daily rainfall is less than 20mm. In this study, five, seven, ten and fifteen dry spells were considered.

Normalised Difference Vegetation Index (NDVI)

Rainfall is one of the most important climatic parameter affecting vegetation condition. Therefore, evaluation of quantitative relationship between vegetation patterns and rainfall is an important application of remote sensing at regional and global scales. The Normalised Difference Vegetation Index (NDVI) is established to be highly correlated to green-leaf density and can be viewed as a proxy for above-ground biomass (crop).

Normalised Difference Vegetation Index (NDVI) images are satellite products generated by Advanced Very High Resolution Radiometer (AVHRR). This is a space-borne sensor flown on the National Oceanic and Atmospheric Administration (NOAA) family of polar orbiting platforms. The AVHRR is a scanning radiometer (comprised of five channels) primarily for weather forecasting; however, there are an increasing number of other applications, including drought monitoring and monitoring of land surface. The AVHRR instrument produces Normalized Difference Vegetation Index (NDVI) images on 10 days basis.

The NDVI data is calculated from two channels of the AVHRR sensor, near-infrared (NIR) and visible (VIS) wavelengths, using the algorithm formula;

$$NDVI = (NIR - VIS) / (NIR + VIS) \quad (5)$$

Where: NIR symbolizes Near infrared radiation, while VIS is Visible radiation.

The dekadal data were averaged into monthly values then aggregated into seasonal values for the growing seasons.

3.3.7 Field survey

Field survey was conducted to obtain data related to climate change impacts on livelihoods based on farmer's perception and how it affects agricultural practice and household food security. The main data for this study was based on a sample size of 200 households and the sampling design was objective and the technique for selecting the household depended on size of the farm and number of years the farmer has lived in that village. The farmer selected during household survey should have a farm size of one and two hectares (ha) and the farmer should had worked on that farm for at least 10 years. This was intended to identify farmer who could help in generating climate change and variability related information through base term experiences.

Study on perceptions and local knowledge of climate variability, impacts on farming and coping strategies at the household and community levels were collected using household questionnaires. This involved personal interviews, observations, consultation with local institutions and community based organizations. The questionnaire attempted to capture information on pertinent variables that were utilized to quantify climate impacts and vulnerability such as farmers' knowledge, attitudes and perception of climate variability and change and what they did in the previous season (Appendix 3).

Coping strategies related information such as evacuating to high land areas during flooding, growing drought escaping/tolerant crop during dry spells, selling cattle to buy food stuff and moving animals to another area for grazing, collecting firewood and burning charcoal were also collected using questionnaire.

3.3.8 Correlation analysis

Correlation is a statistical parameter, r used to define the strength and nature of the linear relationship between two variables (rainfall and crop yield). This study used correlation coefficient (r) to assess the relationship between variable x (rainfall) and variable y (yield). The simple correlation coefficient r between variable x and y is given below in equation 6 as:

$$r = \frac{\sum XY - \frac{\sum X \sum Y}{N}}{\sqrt{\left(\sum X^2 - \frac{(\sum X)^2}{N}\right)\left(\sum Y^2 - \frac{(\sum Y)^2}{N}\right)}} \quad \text{------(6)}$$

Where: **r** is the correlation coefficient; X and Y are the independent variable (rainfall) and dependent variable (crop yield). The value r^2 is a fraction between 0.0 and 1.0, and has no units. An r^2 value of 0.0 means that knowing X does not help you predicts Y and/or there is no linear relationship between X and Y. When r^2 equals 1.0, all points lie exactly on a straight line with no scatter. As the result, knowing X could allow you to an idea or predict Y perfectly.

3.3.9 Regression analysis

Regression analysis was carried out and the interest is directional, one variable is predicted (crop yield) and the other in the predictor (rainfall). Temperature and rainfall were regressed on crop yield. A form of regression equation developed is as of this form given equation 7 below:

$$Y_i = a + b_2 X_{2i} + \ldots + b_n X_{ni} \text{ --- (7)}$$

Where: Y_i - estimated crop yield in the i^{th} year

a – intercept;

b_2 to b_n – coefficient representing the Kg/ha unit of grain.

X_2 to X_{ni} - Weather variables such as precipitation and temperature in the i^{th} year.

Introductory statistic (INSTAT) is a computer program based with a special facility for process climatic data. This statistical package and Microsoft excel program were used to compute the rainfall and temperature and crop yield variables. Statistical package for social science (SPSS) version 16.0 were also used to analyze farm survey data related to household's characteristic and farmer's perceptions of the impacts of climate variability and climate change on his/her livelihood. Descriptive analysis such as frequencies and cross tabulations was used to determine the number of occurrence of a variable or relationship among variables. The significance of the regression parameters were tested using the standard error method.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.0 Introduction

This chapter presents the results of this study based on various methods which were adopted. These include data quality control, rainfall trend, rainfall anomalies and analysis of onset and cessation of seasonal rainfall as well as occurrence of dry/wet spell. Mean monthly maximum and minimum temperature trends are discussed in this chapter.

4.1 Data quality control

Quality control for rainfall and temperature data was carried out. Figure 3a to 3c show the single mass curves in which cumulative value of rainfall, maximum and minimum temperature were plotted against time. All the plots indicated straight lines whose regression equations showed $R^2 = 0.999$ value. This meant that the data sets for climatic parameters used in this study were homogeneous. Data collected directly from the farmers (primary data) were not tested for homogeneity. However, quality control for this data was conducted during field survey by observing the requisite data sampling procedure.

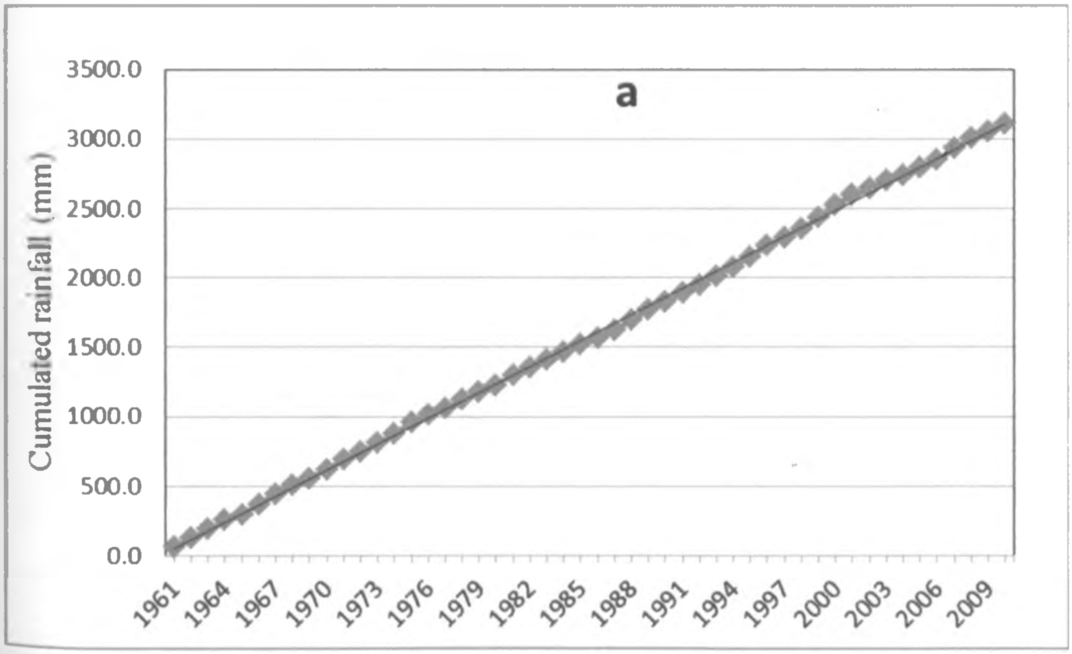

Figure 3a: Single mass curve of rainfall data for Malakal

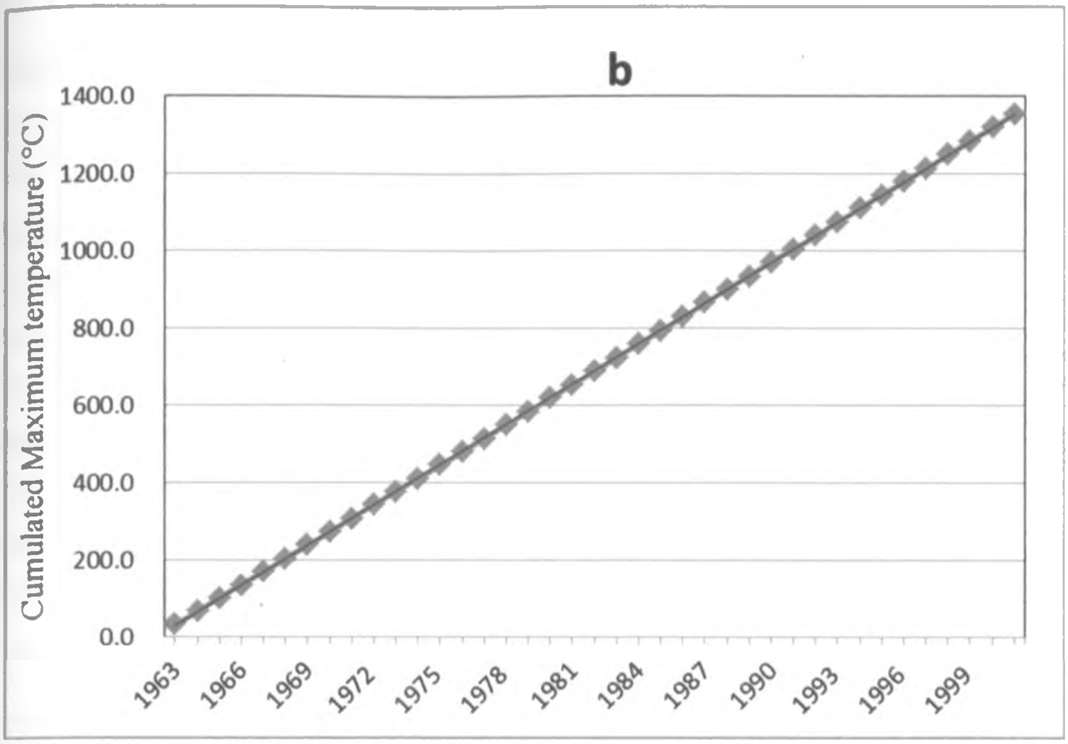

Figure 3b: Single mass curve of Maximum Temperature for Malakal

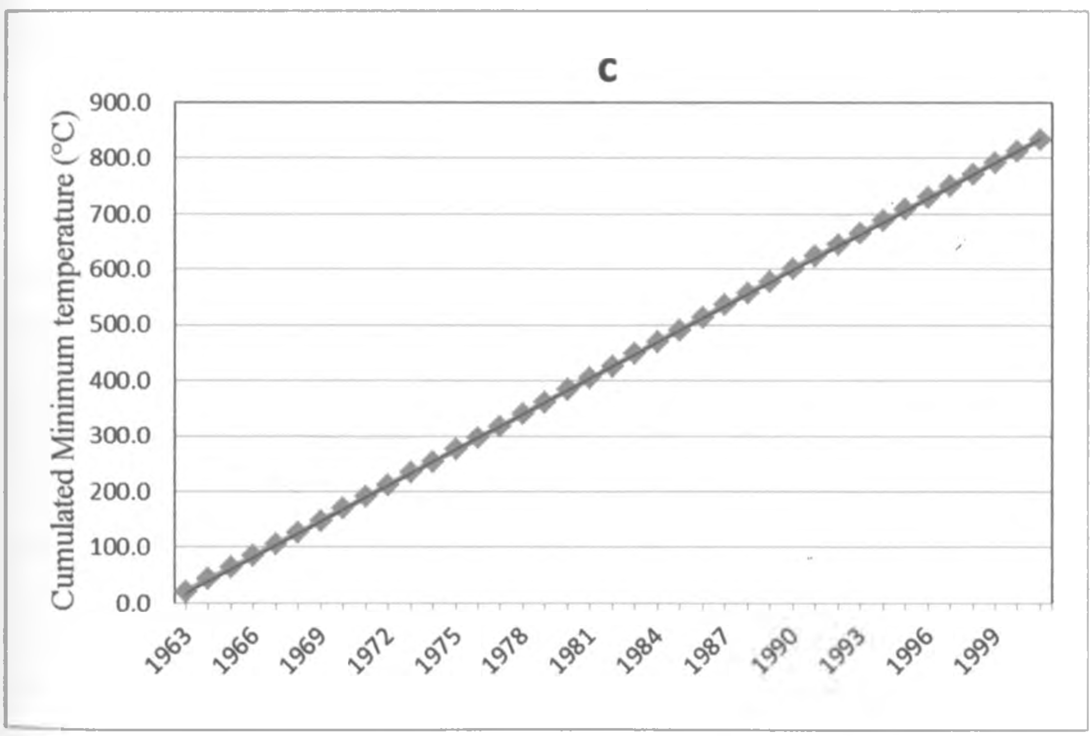

Figure 3c: Single mass curve of Minimum temperature for Malakal

4.2 Rainfall reliability

Table 3a shows monthly rainfall distribution in Malakal County. The results indicated that rainfall in Malakal is unimodal and peaks in August. Analysis of 50 years monthly rainfall data indicated that the mean annual rainfall received during 1961 to 2010 was 746.1 mm with standard deviation and coefficient of variation of 145.3 mm and 19.5% respectively (Table 3b). However, in this study three rainfall seasons, MAM, JJA and SON, were considered. These seasons are the main rainy seasons where agricultural activities are predominant in Malakal. The mean rainfall observed during MAM season was 118mm with high value of statistical coefficient of variation (57.1%). Plot of MAM rainfall showed that more than 20 years rainfalls fall below observed mean rainfall while about 5 years (1971, 1972, 1977, 1981 and 1985) were almost on average. According to the statistical summary (Table 3b), MAM season contributed about 15.9% to the annual rainfall; this period marks the season onset which is crucial period for the start of farm activity.

Distribution of monthly and seasonal rainfall in Malakal was presented in Table 3a and 3b. From the Table 3a, rainfall received in August appeared to be the highest with the mean of 161. 8 mm. This month (August) a lone contributed about 21.7% percent to annual rainfall. However, November seems to be the driest month during growing period with mean of 5.4 mm and contributed only 0.7% to the annual rainfall.

Table 3a: Malakal monthly rainfall distribution

Month	Mean (mm)	Standard deviation (mm)	CV (%)	Percent (%) of monthly rainfall	Z-test
Mar	7	14.7	209	0.9	0.5
Apr	25.5	28.8	112.9	3.4	0.48
May	85.9	54.1	62.9	11.5	0.49
Jun	113.2	55.1	48.7	15.2	0.5
Jul	146.5	55.4	37.8	19.6	0.5
Aug	161.8	61.5	38	21.7	0.47
Sep	120.4	47.5	39.4	16.1	0.49
Oct	80	43.7	54.7	10.7	1
Nov	5.4	9.3	171.5	0.7	0.49

Table 3b shows seasonal rainfall variations. The MAM season was highly variable with coefficient of variation of 57.1%. This shows that rainfall during this period is unreliable and it could not support crop growth and development. However, JJA season was found to be reliable as compared to MAM season.

Table 3b: Malakal seasonal rainfall variations

Season	Mean (mm)	Standard deviation (mm)	CV (%)	Percent (%) of seasonal rainfall	Z-test
Annual	746.1	145.3	19.5	100	0.49
MAM	118.5	67.6	57.1	15.9	0.49
JJA	421.6	106.7	25.3	56.5	0.64
SON	205.8	57.9	28.1	27.6	0.43

The mean season rainfall increased to about 421.6 mm in JJA season and declines gradually to a minimum of 205.8 mm during SON season. Figure 4a indicate that Malakal experienced annual rainfall amounts of less than annual mean in 2004 which clearly indicates the period with the least rainfall recorded for the last 50 years. High rainfall amounts were observed in 1975 and 2000. Most parts of South Sudan especially Greater Upper Nile and Bahr el Ghazal experience unimodal rainfall; in these places much of rainfall observed was concentrated in the months of May, June, July, August and September of the summer season (Table 3a). The plots of seasonal rainfall totals (Fig. 4a to 4d) combined with its mean showed high inter annual variability as shown by the mean and coefficients of variations (Table 3b). Generally, the MAM (March-May) and the SON (September-November) season rainfalls are much more variable compared to annual rainfall than the JJA (main rainy season, June-August).

The JJA mean appeared to be more than MAM and SON means. Figure 4c showed JJA rainfall total and mean during 1984, 1991 and 1993 were on average (421.8 mm) and rainfall amount received during JJA season contributed more than 50% to annual rainfall. This result suggests that deficit of annual rainfall and crop failure in Malakal is significantly contributed by the poor rainfall performance during JJA season. About 27.6% of annual rainfall is contributed by SON season; however, out of 50 years rainfall data about 15 years were below mean during SON period. The year 2004 appeared to be the driest period during SON season (Fig. 4d). Rainfall in SON period makes a considerable contribution not only to the annual rainfall but to the crop yield since it coincides with vegetative stages of late planted and/or replanted crops in case early planted crops are destroyed by dry/wet spells.

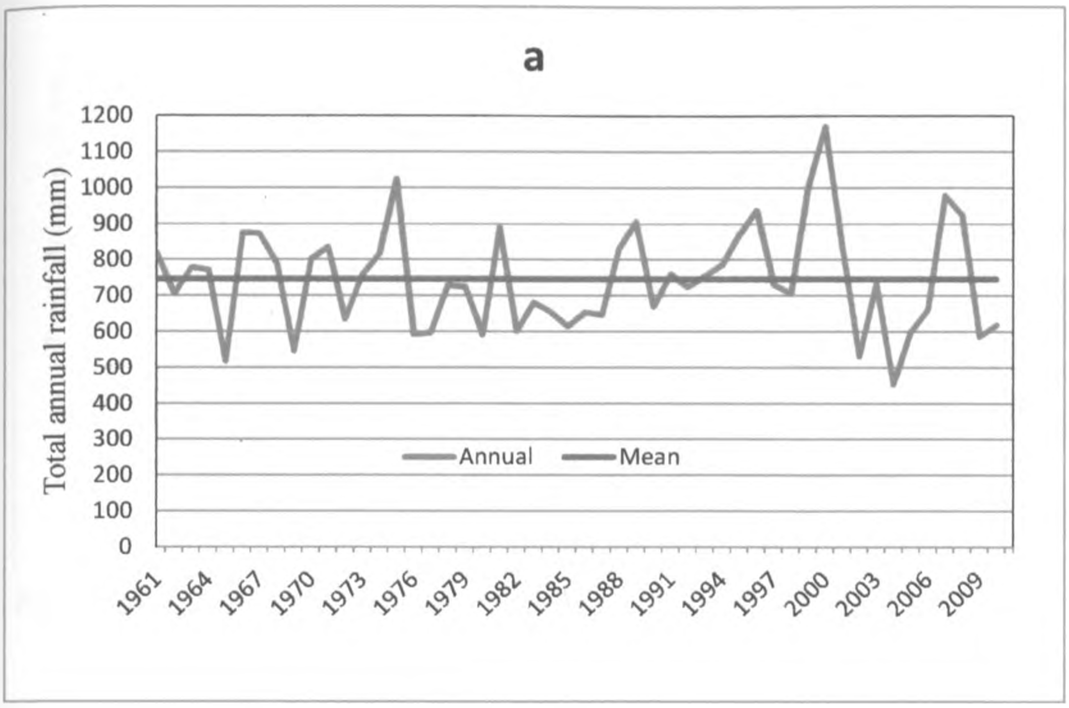

Figure 4a: Malakal annual total and mean rainfall for 1961-2010

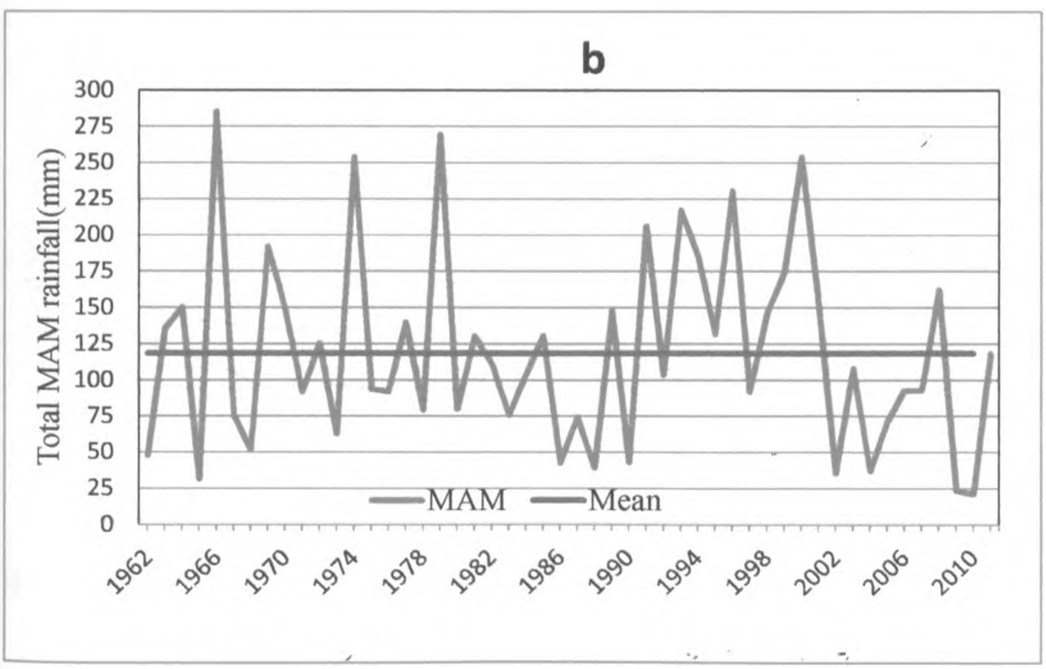

Figure 4b: Malakal MAM total and mean rainfall for 1961-2010

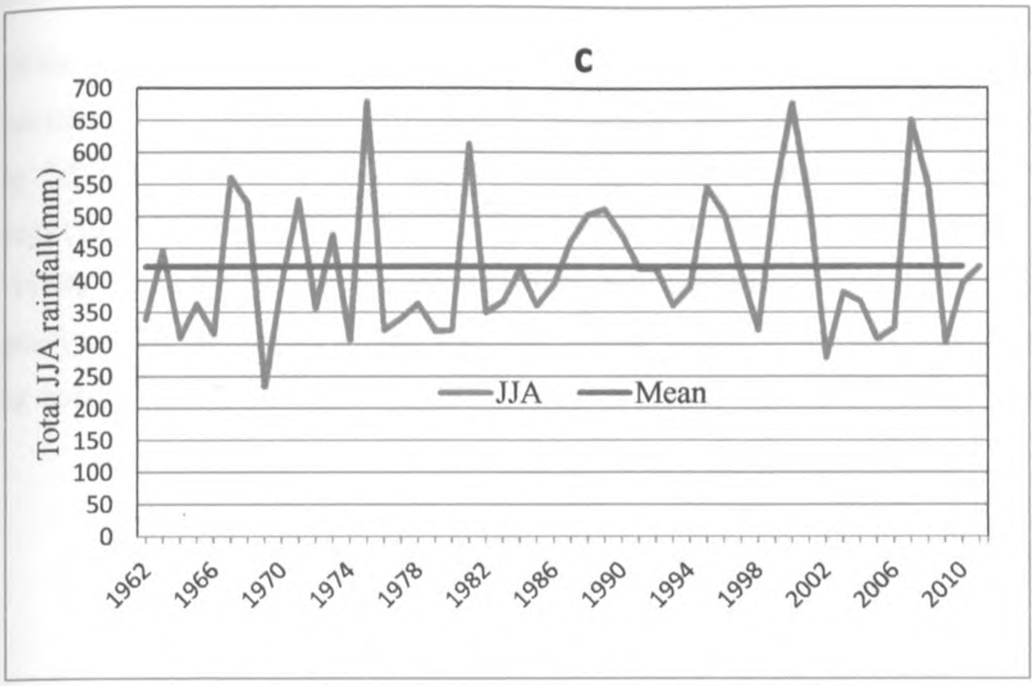

Figure 4c: Malakal JJA total and mean rainfall for 1961-2010

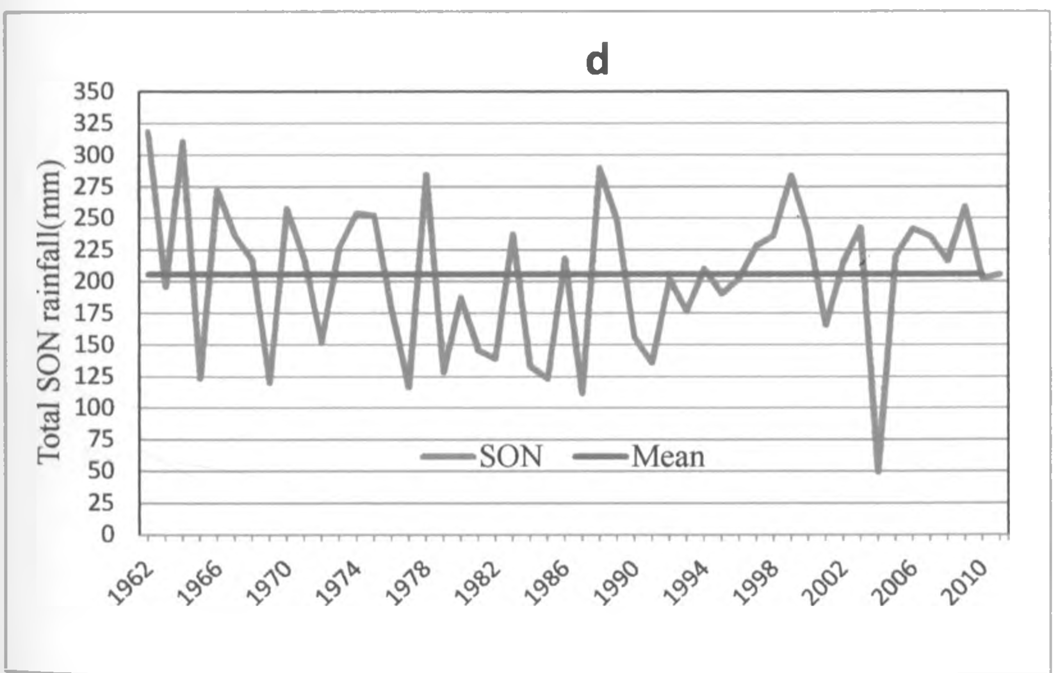

Figure 4d: SON total and mean rainfall in Malakal for 1961-2010

4.3 Rainfall trend analysis

Results of the trend analysis are also presented in Figures 5a-d. The annual rainfall generally showed no trend (Fig. 5a). A slightly decreasing trend was observed in MAM (Fig. 5b) and SON (Fig. 5d) seasons, while JJA season showed a significant increasing trend for the last two decades (1988-2010) (Fig. 5c). The reduction in rainfall amount in June, July and August in early 1960s and 1980s has been associated with late onset of seasonal rainfall (Fig. 7). Mean annual rainfall and MAM season was near normal (Fig.5b). The JJA season showed increasing trend in early 1988 while both MAM and SON rainfall have declined.

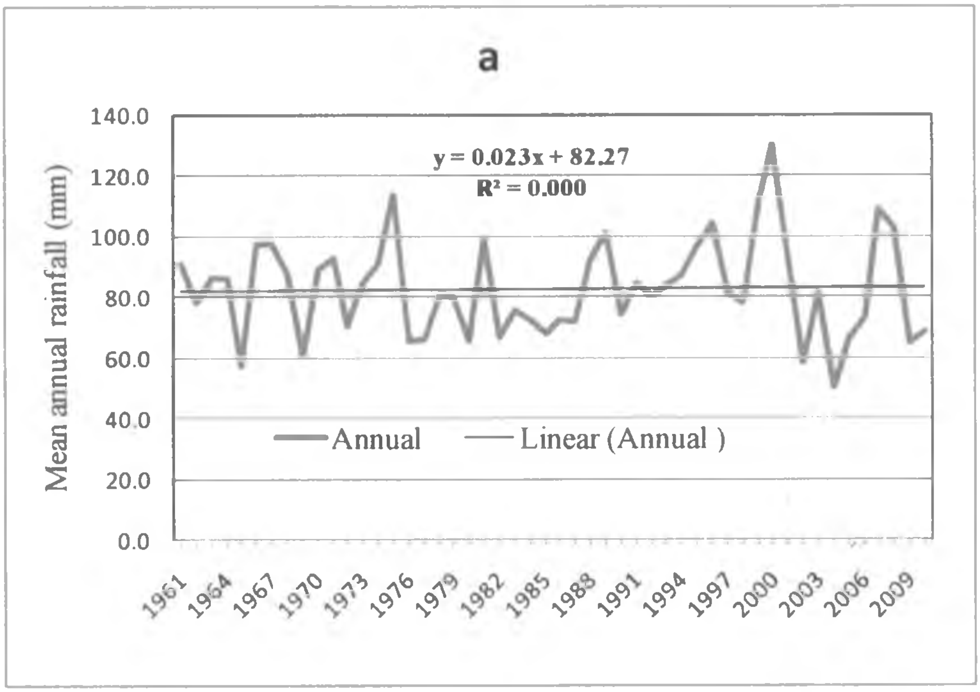

Figure 5a: Annual rainfall trend for Malakal for 1961-2010

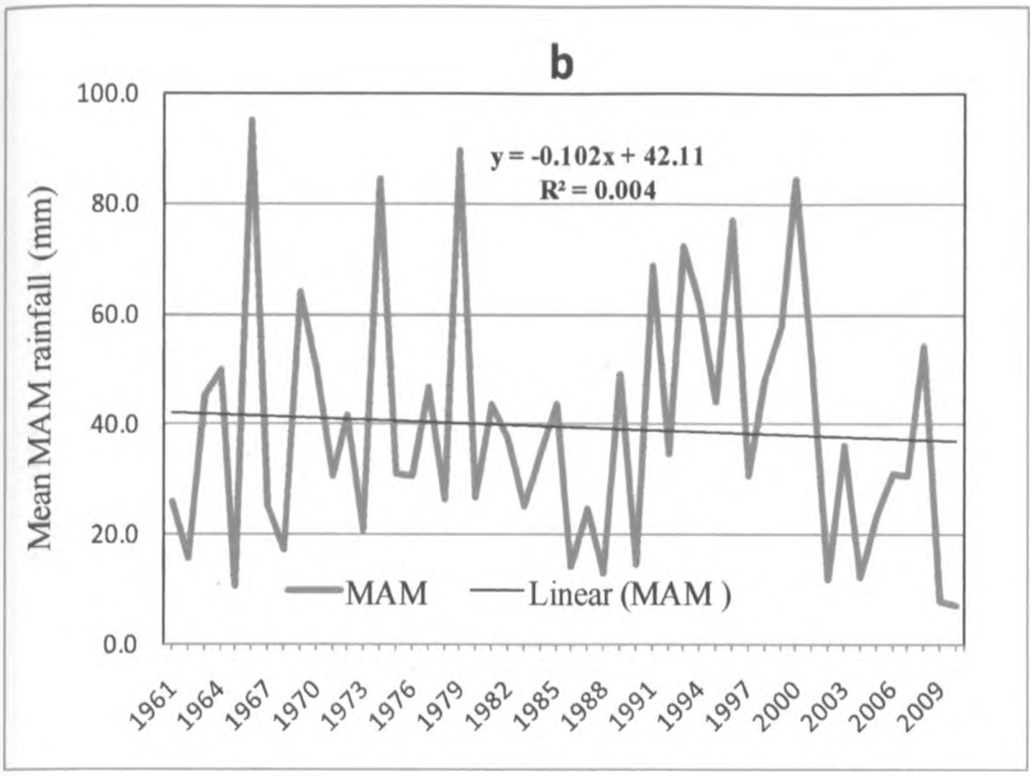

Figure 5b: MAM rainfall trend for Malakal for 1961-2010

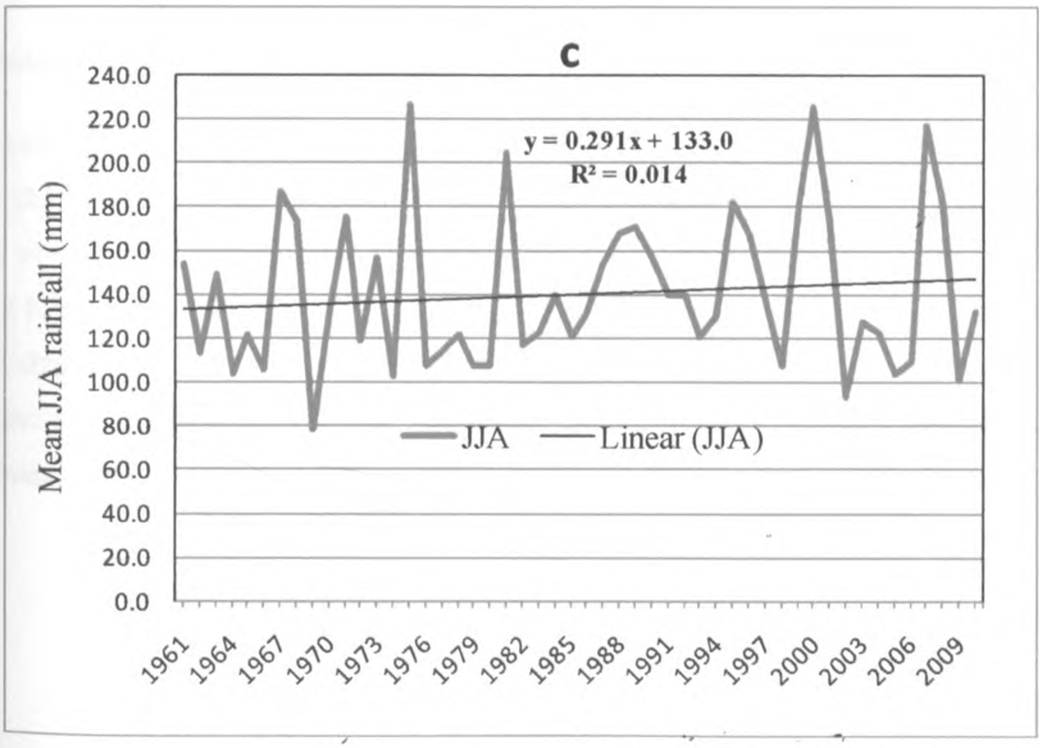

Figure 5c: JJA rainfall trend for Malakal for 1961-2010

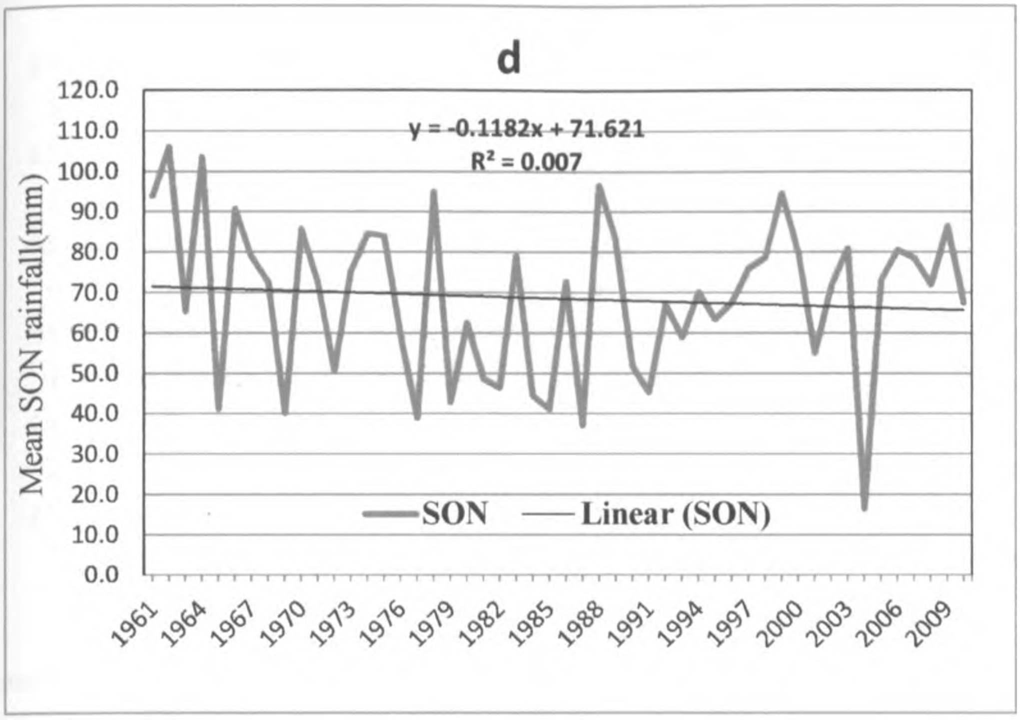

Figure 5d: SON rainfall trend for Malakal for 1961-2010

4.4 Rainfall anomaly index (RAI) analysis

In this section annual and seasonal rainfall anomalies were computed using rainfall anomaly indices (RAI) or standardized equation to identify wet and dry periods. To classify the extreme events over Malakal, the time series of standardized anomalies were plotted as shown in Figure 6a to 6d. The plotted time series indicated that rainfall received in the area is characterized by alternation of wet and dry years in a periodic pattern and the four wettest years observed over the area during 1961-2010 were 1967, 1971, 1975 and 2000. The corresponding driest years were 1969, 1976 and 2002 (Fig. 6a).

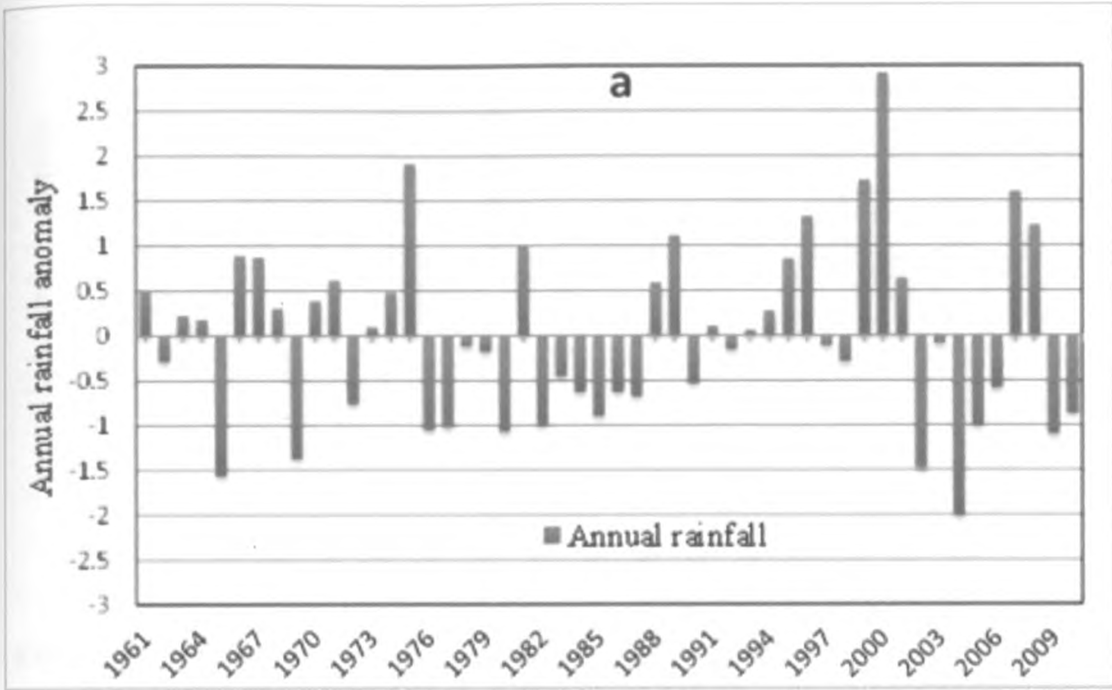

Figure 6a: Malakal annual rainfall anomaly for 1961-2010

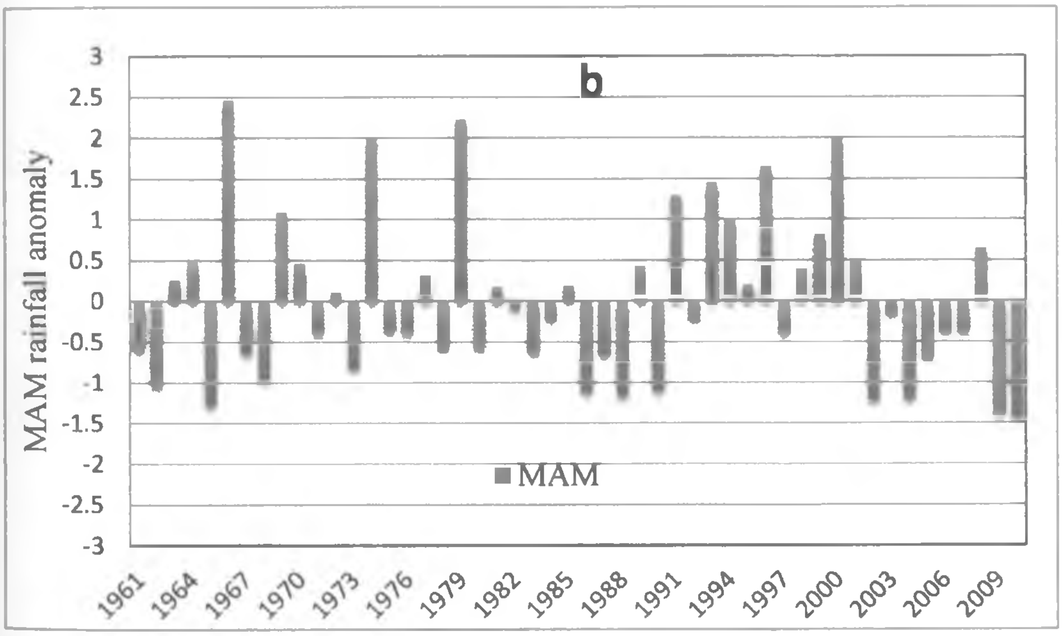

Figure 6b: Malakal MAM rainfall anomaly for 1961-2010

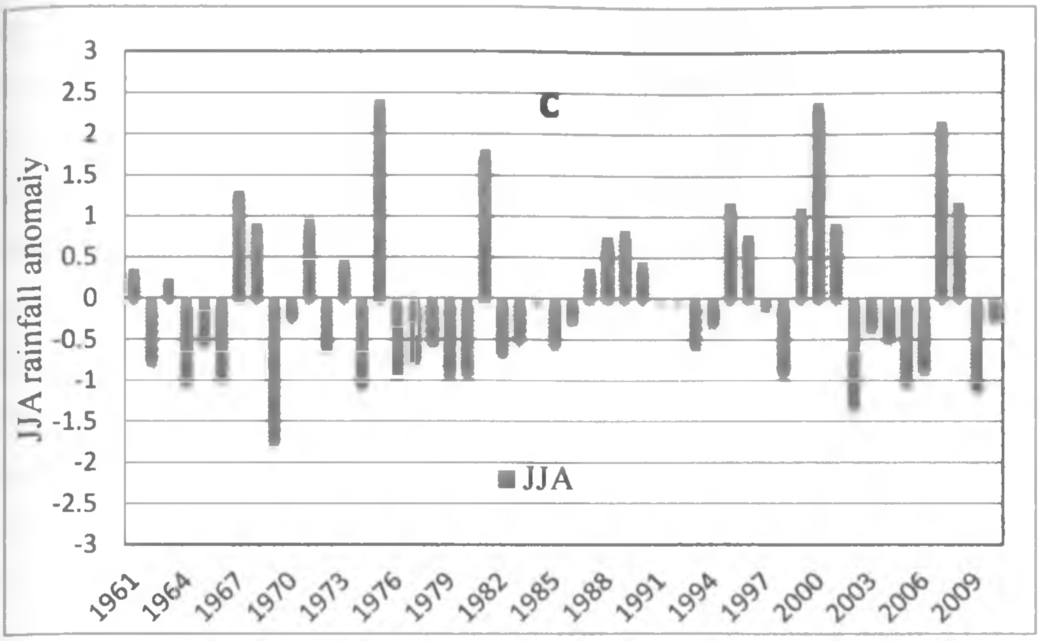

Figure 6c: Malakal JJA rainfall anomaly for 1961-2010

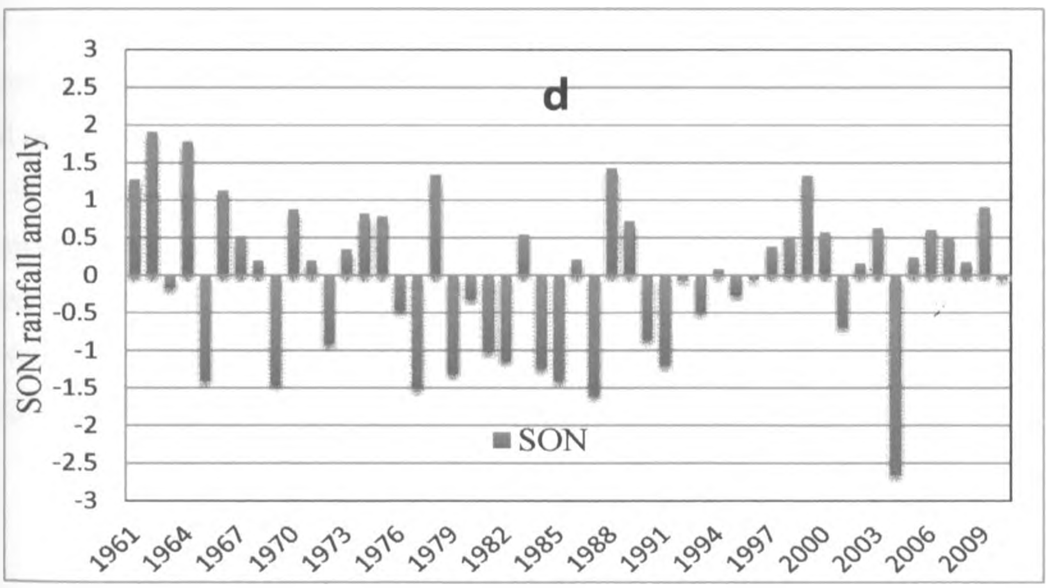

Figure 6d: Malakal SON rainfall anomaly for 1961-2010

Figure 6a above indicates that 1965, 1974, 1979 and 1994 were wet periods while 1965 and 2010 were classified as the extremely dry periods. However, MAM season wet/dry period cannot be used to identify wet and dry period because these events are contributed by early and late onset of rainy season. Thus, dry and wet period in this case are linked with late and early onset of rainfall throughout the years (Fig. 6b).

The years 1971, 1973 and 1984 were the wettest during JJA season while 1962, 1977 and 1981 were the driest years (Fig. 6c). It is clear from these results that the decline in the annual rainfall is predominantly contributed by the decline in JJA rainfall which contributed significantly higher amount to the annual rainfall compared to MAM and SON seasons. South Sudan is located within sub-tropical region where rainfall patterns are influenced by the movement of inter tropical convergence zone (ITCZ) hence, SON season is affected by retreating of ITCZ (Okoola, 1996) which in turn marked the rainfall cessation in the region. However, 1985 and 2004 were extremely dry during SON season and highest (wet) rainfall was observed in 1967, 1974, 1988 and 1996 (Fig. 6d). This result is in good agreement with the study of Eldredge et al., (1988) for Western Sudan in which the study found that relative dry conditions persisted in the region since 1960s mainly due to a decline in rainfall during July, August and September. These are the months in which rainfall received reach their maximum.

4.5 Onset and cessation of rainfall analysis

A part from annual and seasonal anomalies as well as trend analysis, seasonal onset and cessation analysis was carried out to assess the variability of rainfall over time scale. Daily rainfall data were used to assess onset and cessation dates since this period (onset) is a major factor in farmer's decision and farm activities. Fig. 7 shows mean onset, cessation and duration of rainfall over Malakal County. Seasonal onset mean was found to be 146 days with standard deviation of 21 days. This figure (146 days) corresponds to May 29th (green straight line) which was identified as the mean date of seasonal onset while the mean (267 days) cessation date corresponds to September 23rd (red straight line).

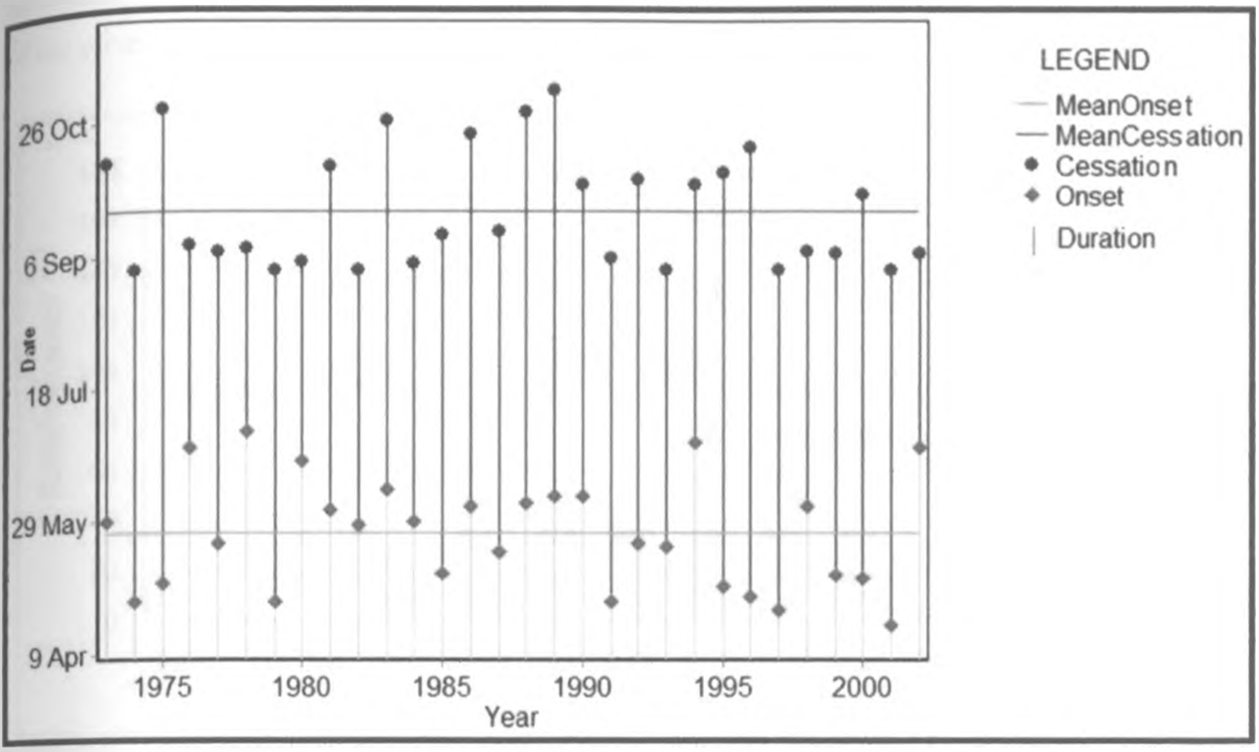

Fig. 7: Onset, cessation and duration of rainfall in Malakal for 1973-2002

Figure 7 above shows that about 19 years appeared to be below the mean. Seasonal duration was analyzed and the mean duration of rainfall over the area was 122 days (4 months) with standard deviation of 27 days. On the other hand, seasonal onset delay was observed for about 19 (63%) years although the rest of the years (11) had experienced early onset of rainfall. The green and red ball represented onset and cessation dates. The early rainfall (onset date) seems to have occurred in April and late cessation in November. Figure 7 indicates that 1975, 1995, 1996 and 2000 have experienced early onset. It was quite evident that for years with early onset, rainfall retreated late while for years of late onset (1976, 1978, 1980 and 1998), withdrew early. Thus, on average, the years with early onset had longer rainfall duration as compared to the years with late onset. However, the standard deviation, i.e. the inter-annual variability of the onset, is three weeks (21 days).

Plots of monthly rainfall received over Malakal (Fig. 8) showed that substantial amount of rainfall was observed during the month of June to September and August and this period marked the peak of rainfall in the area. Excessive rainfall usually exacerbated flash flood which destroyed crops in the field and reduced expected yield. This figure suggests that flood comes immediately when rains become consistent around August and September. This event could affect not only crops but could also kill animals and affect human health and damage agricultural land and therefore, influence effective management and sustainable development of the socio-economic activities which are heavily rain- dependent.

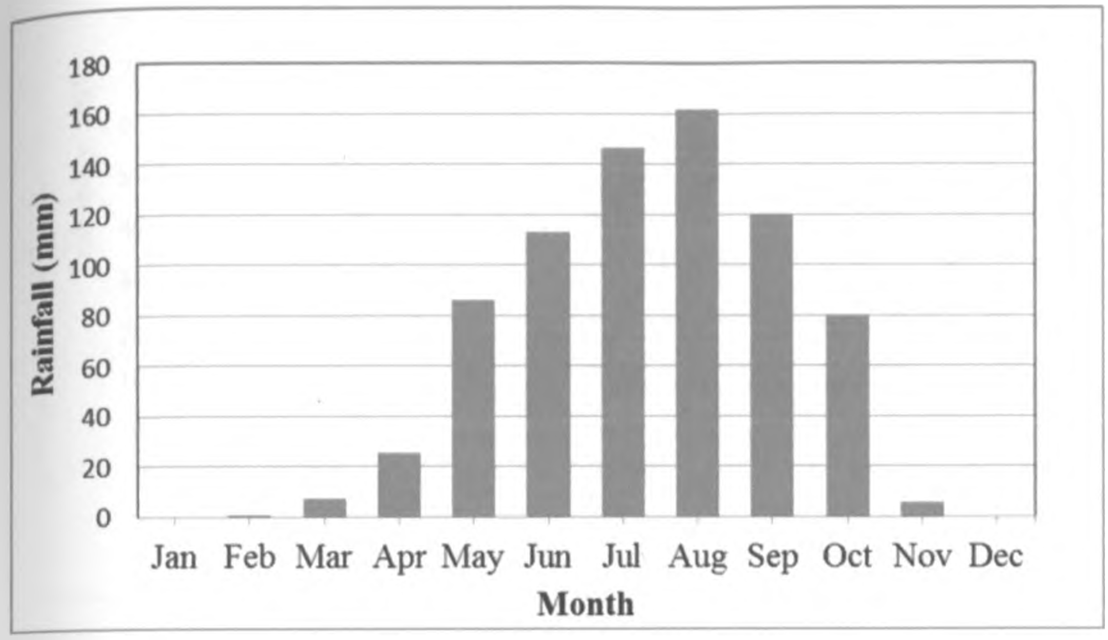

Figure 8: Mean monthly rainfall in Malakal

Dry spells were analyzed to determine probability of occurrence of rains during the critical water requirement periods of sorghum and maize growth in the main rainy season (JJA) which is believed to be more reliable for crop production in Malakal. Dry spells were described as periods with 0.85 mm of rainfall or less. Analysis of dry spells occurrence was carried out for periods of five, seven, ten and fifteen consecutive days after the last rains. Figure 9 shows probability of occurrence of dry spells during the rainy season and the result indicated that occurrence of 5 day dry spells was high at about 73%. However, the 15 days dry spells were not as frequent as 5 and 7 day. This finding suggest that crop development and growth within 5 and 7 day where incidence of dry spells were high may be explained by available soil moisture, temperature and rate prevailing evapotranspiration rate prevailing.

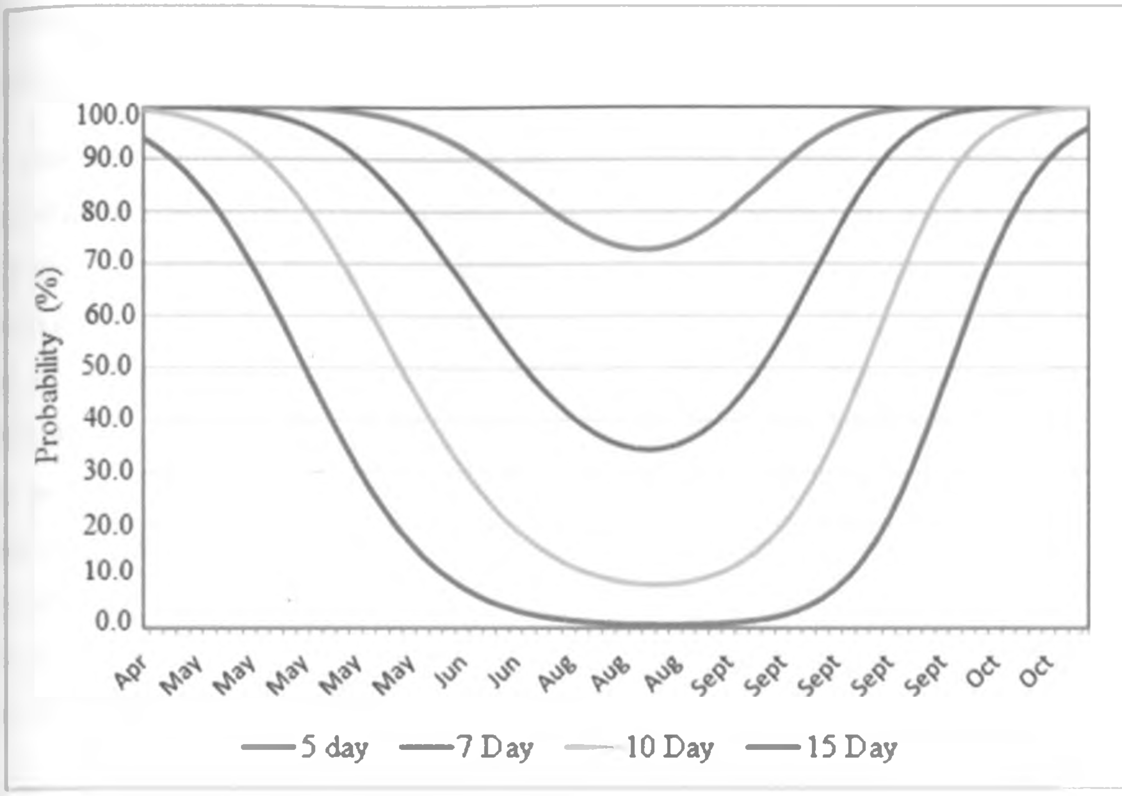

Figure 9: Probability of occurrence of dry spells in Malakal

4.6 Temperature trend analysis

The analysis of long-term variation of air temperature was performed and annual mean maximum temperature over Malakal showed an increasing trend (R^2=0.280) whereas annual mean minimum temperature did not show any significant trend. In order to find the increase/decrease in temperature, means of first 18 years (1963-1981) and later 19 years (1982- 2001) were compared. It was found that maximum temperature has increased by 0.6°C and April appeared to be the warmest month in Malakal. Figure 10a shows that April appeared to be warmest period in Malakal while August is the coldest month during growing period with minimum temperature of 21.6 °C. This heat could affects crop depending on crop type and development. Farmers during field survey suggested that air temperature during the growing season was warmer than during the dry period. Weather conditions in Malakal from late December up to mid-February are usually under the influence of southeast monsoon. Time series analysis of temperature indicates increasing trend in early 1980s, thus could be characterized as a warm period, taking into account the positive anomalies of both maximum and minimum air temperatures. In contrast, cold period was observed in 1960s while annual maximum air temperature has slightly increased.

The analysis of annual average maximum temperature over a period of 38 years 1963-2001 showed an increase in the maximum temperature by 0.6°C (Figure 10b). Such a change is not surprising and it shows that global warming can be revealed at local scales. Fischer et al. (2002) reported that changes in rainfall amount and patterns, in addition to shifts in thermal regimes influence local seasonal and annual water balances. These in turn affect the distribution of periods during which temperature and moisture conditions permit agricultural crop production. According to IPCC (2007), increase in average temperature will adversely affect crops, especially in semi-arid regions, where already water and heat are limiting factor of production. Increased temperature also increase evaporation rates of soil and water bodies as well as evapotranspiration rate of plants, and increase chances of severe drought. It means that with warmer temperatures plants require more water.

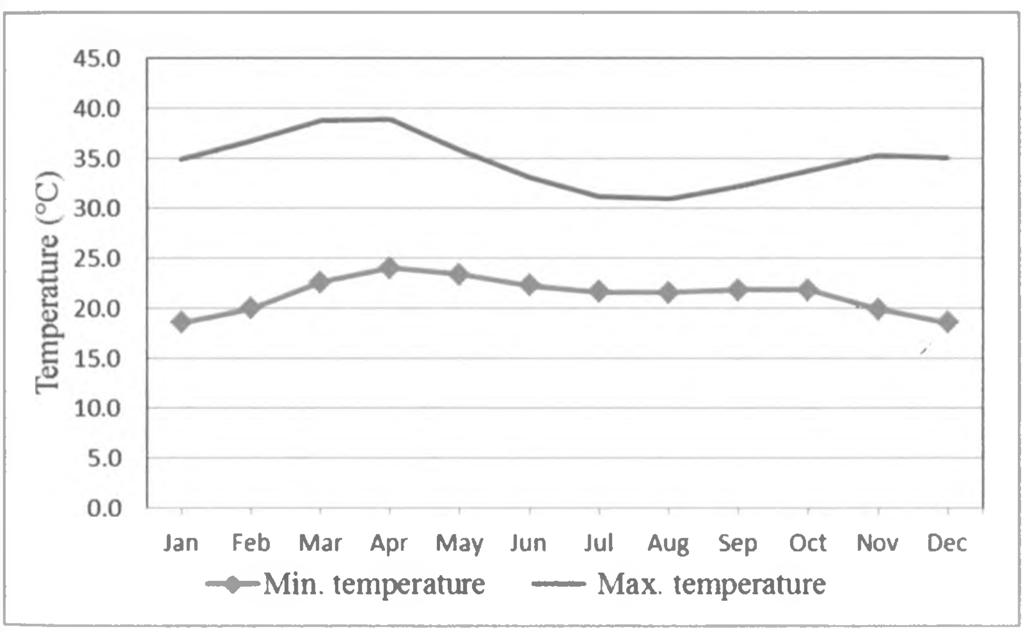

Figure 10a: Malakal mean monthly maximum and minimum temperature

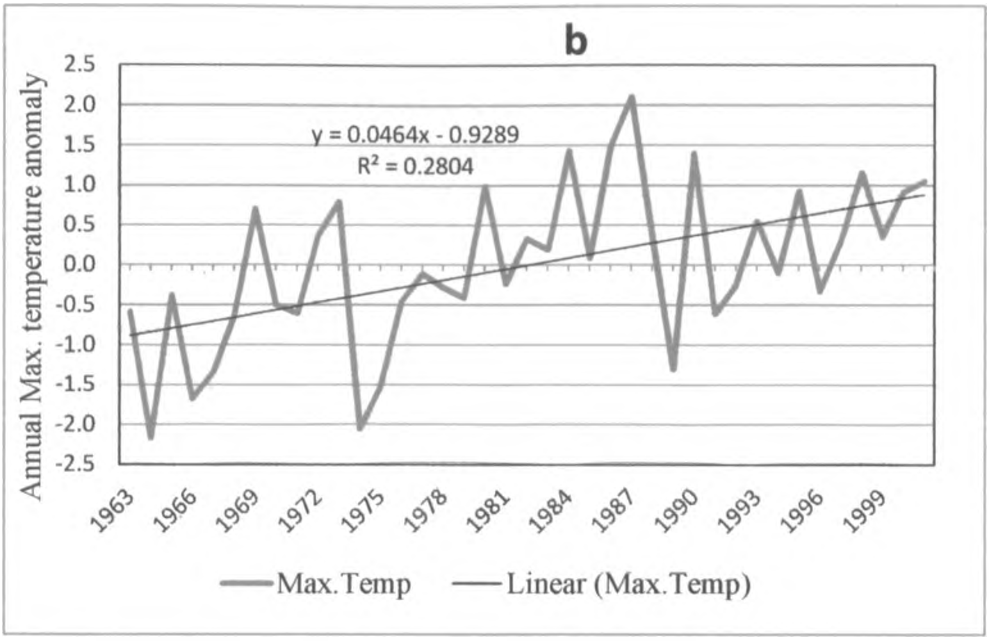

Figure 10b: Maximum temperature anomaly of Malakal

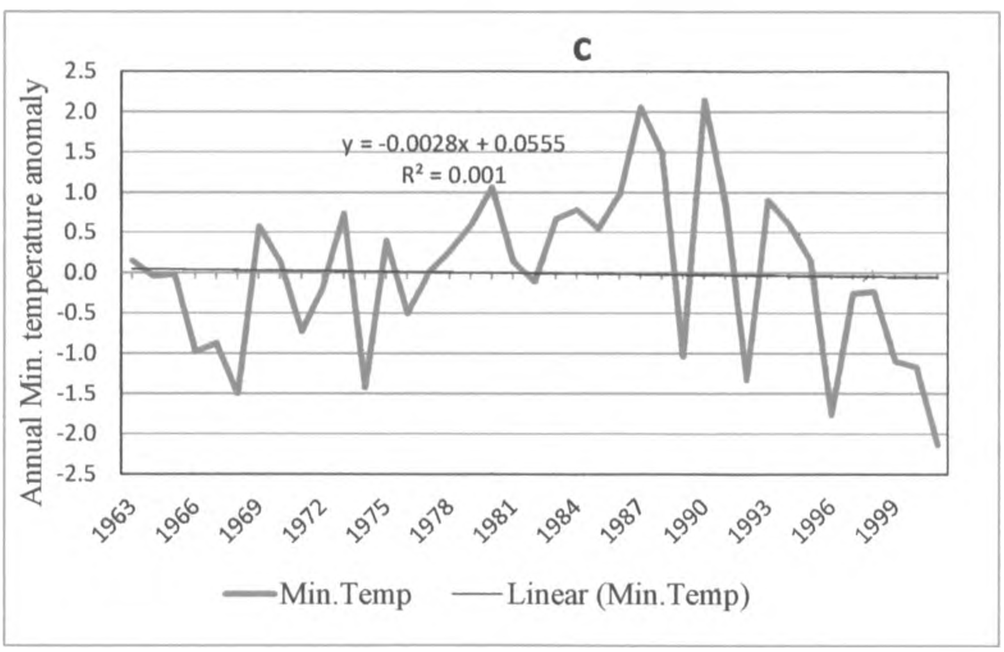

Figure 10c: Minimum temperature anomaly of Malakal

There are concerns among the scientific community regarding the outbreak of diseases due to increased temperature, as well as its negative impact on biodiversity (Cynthia et al., 2000). Changes in temperature and rainfall are creating favorable environments for pests, diseases and invasive species to emerge, spread and encroach on agriculture and forestlands. Although there are no studies carried out on the spread of crop diseases and pests in South Sudan, local communities have already experienced the emergence of stiga and other diseases which they claimed are new to them. Farmers observed that disease and pests outbreak especially during dry spells had a significant impact on crop growth and yield. Focus group discussions suggest that production of major crops such as sorghum had declined to some extent due to spread of stiga. Farmers link the emergence of these other new invasive species with increased temperature and floods.

4.7 Relationship between crop yields and seasonal rainfall

Figure 11a below shows average monthly rainfall and vegetation respond over Malakal. This analysis suggests that NDVI images have a correlation value of 0.57 with a maximum response in August to September. The mean monthly NDVI was about 0.46 and the values greater than this figure were found to be strongly related with July to October rainfall. Figures 11c to 11d show the anomalies of NDVI and seasonal rainfall for selected periods. The year with negative anomaly value below -1 has regarded as a bad year of which harvested crop yield was below expected potential yield while year with value above +1 was regarded as a good year where harvested yield was above expected yields. The years with value between +1 and -1 were considered to be normal or harvested yield was on average.

For instance, during MAM season, 1986, 1988, 1998, 1990, 2002 and 2004 were bad years as compared to 1991, 1993, 1996 and 2002 where above normal where positive vegetation responses were observed (Fig. 11b). In addition, crop performance was poor and crop yield was below average during JJA season. Significant increases of vegetation responses to more than 50% were observed in 1997, 2001, 2006, 2007 and 2008. Most of the pronounced crop growth and development (greenness) was significant in 2008. Below average vegetation response was observed in 1983, 1986, 1990, 1998 and 2002 during JJA period and this pattern deteriorated in 1990 and 1998. This condition is chiefly attributed by extreme events such as protracted wet and dry spells (Fig. 9).

These high NDVI values persisted towards the end of year in November and December indicating the lagged response of vegetation to rainfall in Malakal (Nicholson et al., 1996). The extent of these values across Upper Nile state especially in Malakal is an indicator of rainfall variations. The low NDVI values lower than 0.46 were distributed from January to June, indicating the prevalence of dry conditions. The extent and duration of these NDVI response can be used as an indicator of the strength and duration of the rainfall to produce mechanisms associated with the ITCZ (Inter tropical Convergence Zone) since vegetation growth in the Southern Sudan is primarily controlled by rainfall, although other factors including potential evaporation influence the fluctuating boundary (Okoola, 1996).

MAM season marked the seasonal onset and Fig.11b indicated below average vegetation (NDVI) conditions and most extreme negative departures reached more than 100%. In this period plant water stresses deteriorated in 1994, 1995 and 1998. However, moisture availability that is marked by positive departures of NDVI responses ranged between 50-150% or more in 1988, 1996, 1999, 2000, 2005, 2006, 2007 and 2008. The whole region showed a high NDVI level of above normal vegetation conditions and had positive anomalies ranging from 20 and 100%. However, a substantial increase of NDVI was experienced during JJA up to early SON season. The above average greening in 1988 was associated with positive rainfall anomalies during the months of August, September and October (Fig.6c).

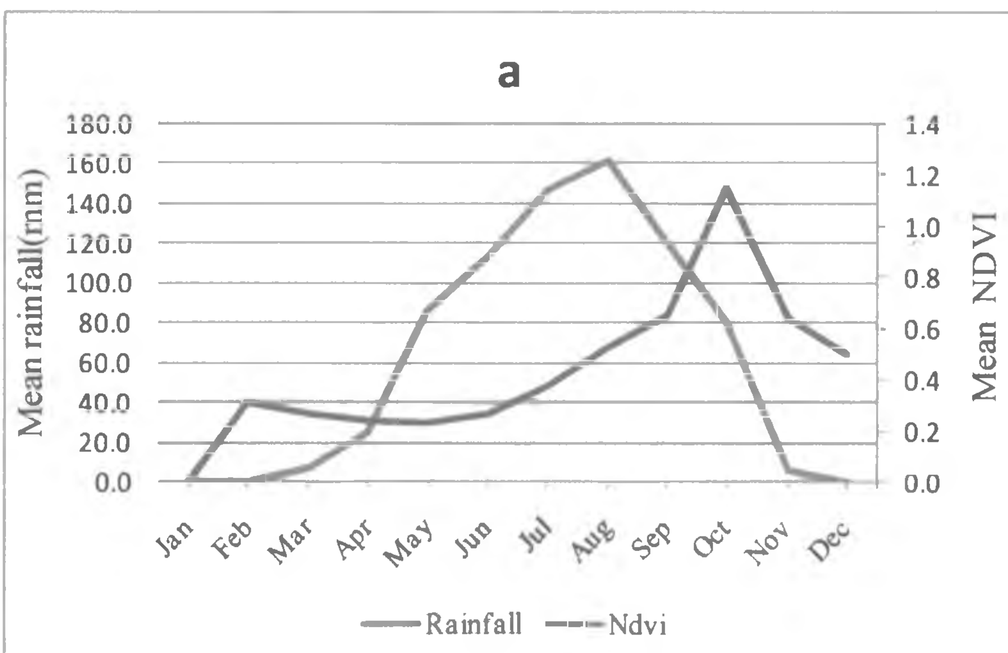

Figure 11a: Malakal mean monthly rainfall and vegetation (NDVI)

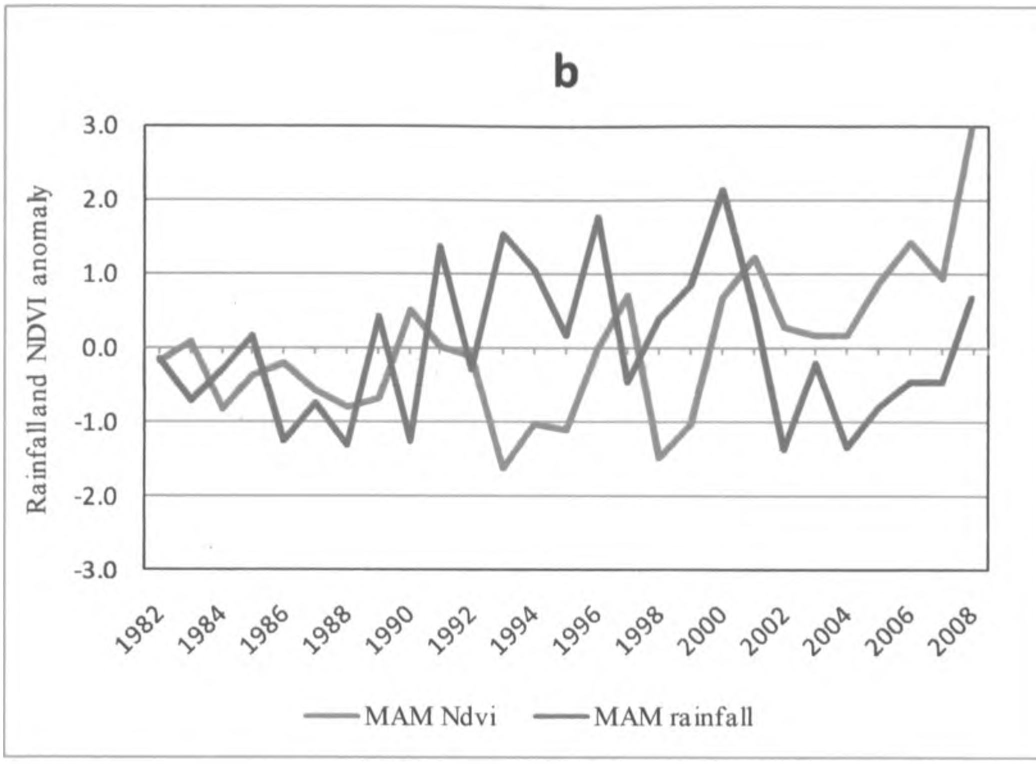

Figure 11b: MAM rainfall and NDVI anomaly

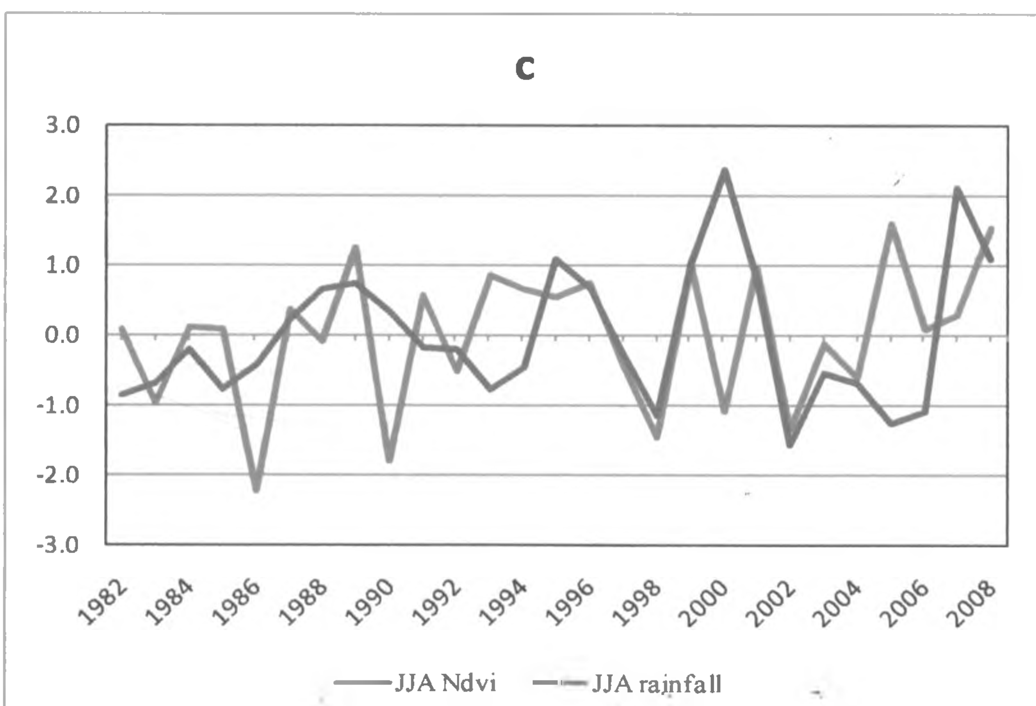

Figure 11c: JJA rainfall and NDVI anomaly

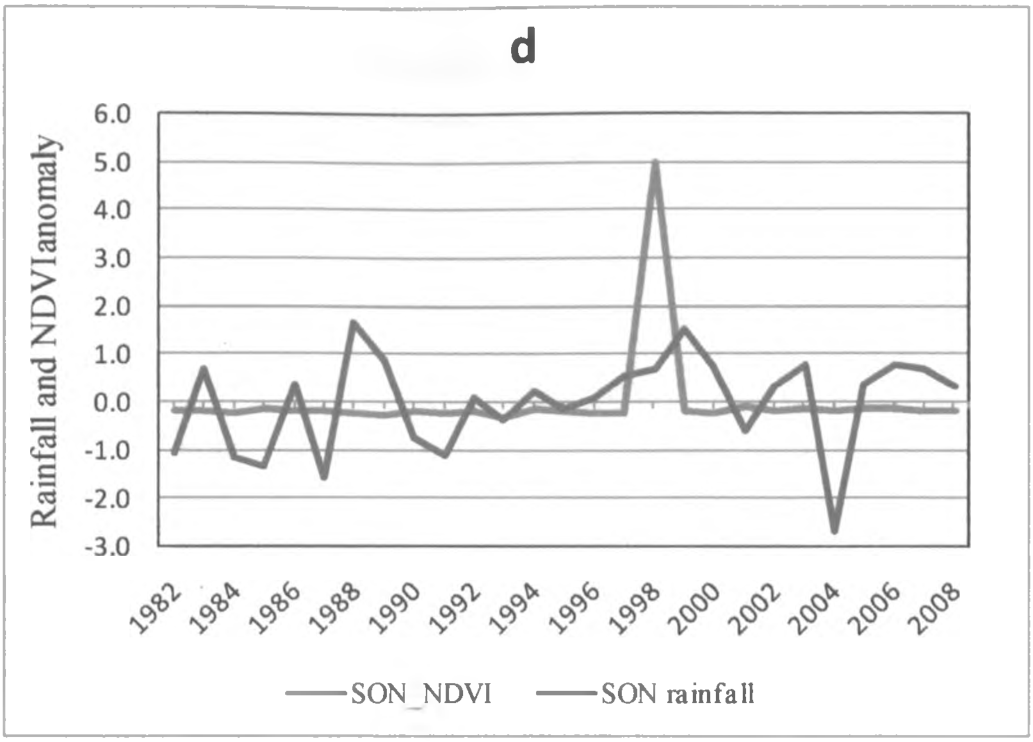

Figure 11d: SON rainfall and NDVI anomaly

4.8 Correlation and regression analysis of seasons with crop yield

Annual rainfall was correlated with MAM, JJA and SON seasonal rainfall. This was to assess the relationship between seasonal and annual rainfall and contribution of seasonal rainfall to annual rainfall (Table 3b).

Table 4 shows the results of correlation analysis of seasonal and annual rainfall and crop yield. The analysis indicated negative correlation coefficient for annual and JJA rainfall, while correlation between crop yield MAM and SON seasons were positive. The correlation for JJA (r= -0.237, P= 0.296) showed the highest degree of relationship between crop yield. The relationship between annual rainfall and crop yield was weak with correlation coefficient value -0.043. This indicates that crop productivity in Malakal is not determined by annual rainfall but a function of rainfall received during JJA season.

The regression (R^2) for all seasons were found to be low with only 0.209 (r) being the highest for JJA. This implies that 4.4% of the variability in crop yields could be explained by JJA rainfall while other factor such as pest and crop diseases and farm management etc. could contribute to the rest of percentage.

Table 4: Correlations of seasonal rainfall and crop yield for Malakal

Seasonal rainfall	Correlation coefficient	R^2 (%)
Annual	-0.043	0.18
MAM	0.091*	0.82
JJA	-0.209**	4.40
SON	0.152*	2.31

* Significant at the 0.1 level and ** significant at the 0.05 level

4.9 Demographic

Household characteristic

Gender dimension analysis in climate change impact is essential for developing countries like Southern Sudan, where socio-economic activities are vulnerable. Out of households surveyed 64% were male respondents and only 36% respondents were female. Female representation during focus group discussion (FGD) on climate change based on farmer's perspective participated actively throughout field survey. In Malakal, the age group which was actively involved in farming ranged between 35-40 years old representing 31% of the farmers interviewed. However, about 6% of these population (farmers) were bellows the age of 30 and about 1% were above the age of 60 (Table 5). However, 33 and 57% of female and male respondents were found to be the head of the household.

About 23% of interviewed farmers had attended various levels of school. The education embeds in it a potential gender-bias with only about 4% of female attending primary school. Table 5 showed that about 75% of respondents had not attended school, and this indicates that illiteracy rate is high in Malakal County. Apart from disruption of education and the displacement during political instability which affected everybody within the region irrespective of gender and age limit, both male (43%) and female (32%) did not have chance to attend primary school (Table 5). Thus, only 18% respondents had attended primary school and this figure is higher than the total number of farmers/respondents who attended high schools (6%) and colleges (1%).

FGD suggested that political instability in the region had forced many young people to join the armed forces. This has possibly contributed not only to the loss of human life and destruction of infrastructure but also significantly contributed to destruction of human and socio-economic development. In addition, value and norms had been lessened and this encouraged early marriage which led to huge number of girl child drop out of school. Majority of male (43%) had not attended primary school. Focus group discussions stated that priority is given to male child than female child when it comes to education opportunities. It was further reported that drop out of school is high in female as compared to male child due to early marriage. However, the farmers explained that most of these schools do not function properly due to insecurity, lack of materials and teachers. Besides, 50% of famers were male and about 32% were female.

Table 5: Age and educational distribution by gender

	Age (year)						Educational leveln(%)			
Gender	20-25	25-30	35-40	45-50	55-60	65-70	Not attended school	Educated up to primary school	Educated up to secondary school	Graduate
Male	5	17	21	13	6	1	43	14	6	1
Female	1	12	10	10	4	0	32	4	0	0
Total	6	29	31	23	10	1	75	18	6	1

Household income level is relatively low at study site. Most people depend on subsistence rainfed agriculture that does not meet household demands. About 5% households were reported to have monthly income of less than 300 Sudanese Pounds (SPs). Majority of respondents were found to have engaged in various on-farm and off-farm activities, including sale of agricultural and livestock products. Well off households invested in trading food crop commodity using boats as system of transport to nearby counties. Community members also engaged in wage labor and migrated to north (Khartoum) and Juba (Capital of South Sudan) for employment. Earnings were reported to have been used on food, medicine, clothes and children's education (Table 6).

The primary income activity of households in Malakal is agriculture and this combines both crop farming and grazing. Up to 82% of the respondents were engaged in crop farming; however, they have other petty business such as growing okra crop on river shore during dry season to earn cash. The second, third and fourth ranked occupations are wild food collection, fishing and those employed in government sectors. Livestock was another important economic activity (29%) in the County, all livestock keepers were farmers; although majority of the respondents were not keeping livestock. Some farmers were also involved in business activities; however, the activity appeared to be of less importance (3%) as compared to crop production. This implies that rural farmers in Malakal were more vulnerable to climate variability since most farmers were only content with crop cultivation which depends on unreliable the rainfall.

Table 6: Head of household and occupation distribution by gender

	Are you the head of household?		Occupation (%)						
Gender	Yes	No	Farmer	Famer and civic servant	Farmer and trader	Farmer and teacher	Farmer and student	Farmer and fisherman	Famer and wildfood collector
Male	57	6	50	5	1	0	0	3	3
Female	33	4	32	0	2	0	0	0	4
Total	90	10	82	5	3	0	0	3	7

The empirical adoption literatures showed that household size has mixed impacts on farmers' adoption of agricultural activities. Larger family size is expected to enable farmers to take up labor intensive adaptation measures (Ariel et al., 2008). Alternatively, a large family might be forced to divert part of its labor force into non-farm activities to generate more income and balance consumption demands. However, the opportunity cost of labor might be low in most smallholder farming systems as off-farm opportunities are rare. It is expected that farm households with more labor are better able to take up adaptations in response to changes in climate.

Table 7: Access to water and health care distributin by household income

Occupation	Access of household to safe drinking water.				Do you have access to health care?		What is the average houshold access to health care?			
	Low	Mild	Moderate	High	Yes	No	Low	Mild	Moderate	High
Farmer	153	17	7	13	165	25	150	13	15	12
Famer and civic servant	4	0	0	1	4	1	2	1	1	1
Farmer and trader	2	0	0	0	1	1	2	0	0	0
Farmer and teacher	0	0	0	0	0	0	0	0	0	0
Farmer and student	0	0	0	0	0	0	0	0	0	0
Farmer and fisherman	1	0	0	0	1	0	1	0	0	0
Famer and wildfood collector	2	0	0	0	2	0	2	0	0	0
Total	162	17	7	14	173	27	157	14	16	13

Table 8 showed access to farm inputs by farmers as far as gender dimension is concerned. In general, 61% of farmers have access to land and majority of these population are male (45%) farmers. Female farmers (36%) who have access to land as well as credit were represented by 16% and 2% respectively.

Even though internal displaced person (IDP) and returnee resettlement and reintegration has been a challenge to the state government, farmers had not mentioned access to land as a limiting factor to crop yield reduction. Table 8 shows area under cultivation, access to land and credit. The table suggests that 61% of farmers have access to land while only 5% have access to credit. For the majority of farmers who have access to land, about 57% had cultivated one hectare and only 43% respondents had cultivated more than one hectare. This finding indicates that area under cultivation in the County is small as compared to area under vegetation. Focus group discussions stated that local farmers have no access to credit. Farmers indicated that they were not aware about the opportunity of acquiring loans from the bank regarding agricultural activities. The few who were aware about the existence of Agricultural Bank of Sudan (ABS) and applied had not been granted loans.

In addition, pests and diseases outbreaks during growing period have been a concern to many growers. Among these the spread of stiga in the region has substantially contributed to crop failure especially sorghum crop. Farmers have no access to pesticide, insecticide and herbicide as well. Farmers stated that they had not used fertilizer, agricultural policy in the government of Southern Sudan (GoSS) does not allow inorganic farming and therefore fertilizers application has not been encouraged by the government policy.

Table 8: Distribution of area planted, access to credit and land own by occupation in Malakal

Occupation	Area planted (ha)		% of respond to land own		% of respond to access to credit	
	1	2	Yes	No	Yes	No
Farmer	21	11	56	38	5	90
Famer and civic servant	1	7	2	0	0	2
Farmer and trader	9	13	1	1	0	1
Farmer and teacher	3	6	0	0	0	0
Farmer and student	2	0	0	0	0	0
Farmer and fisherman	17	5	1	0	0	1
Famer and wildfood collector	4	1	1	0	0	1
Total	57	43	61	39	5	95

During focus group discussions, farmers stated that lack of seed is also a major challenges for the last two five years; however, respondent expressed that Food and Agriculture Organization (FAO) of the United Nations and its partners have been distributing seed of staple food crop such as sorghum and maize but these seed were not enough to farmers. Crop cultivated also vary significantly among the farmers interviewed. Figure 12 indicated that 31.1% of farmers cultivated sorghum as compared to 23% and 11% farmers who cultivated only maize and millet. However, mixed crops were also cultivated with about 34.5% of farmers practicing mixed cropping mainly sorghum with other crops such as maize, millet, bean and okra. Most of the households depend on streams, pond and river as their sources of water. Focus group discussions stated that those farmers depending on streams and water drawn from the Nile had increased incidences of water borne diseases such cholera.

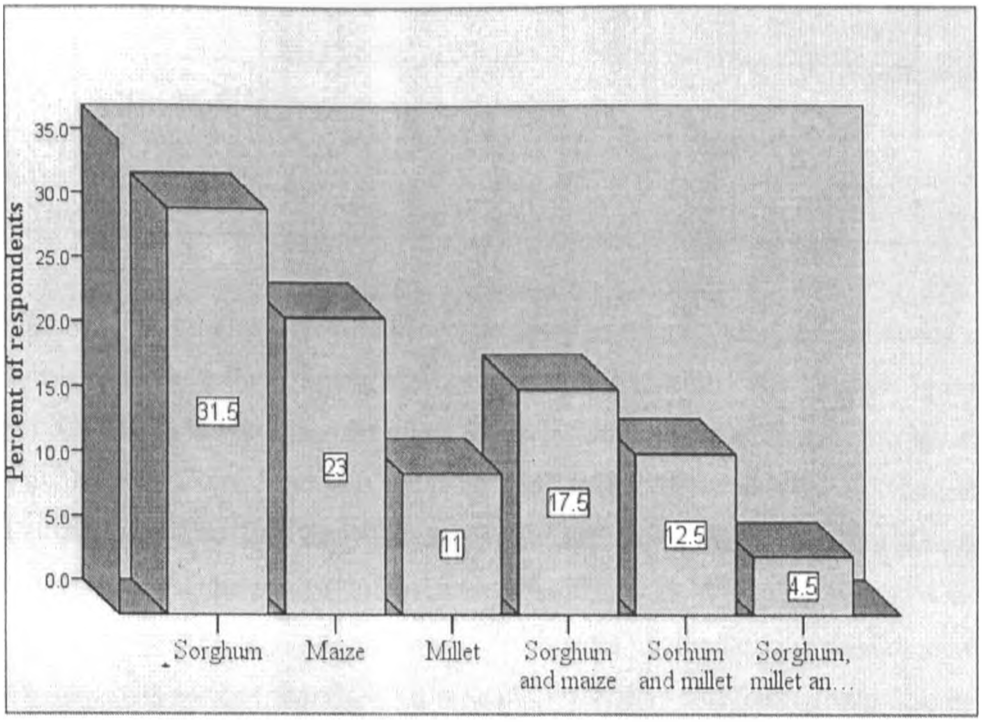

Figure 12: Type of crop pattern grown in Malakal

4.9.1 Climate variability and associated impact based on farmer's experience

Assessment of climate variability and change impact on livelihood and vulnerability requires the consideration of both the magnitude and stresses affecting rural livelihoods. Rural livelihoods were subject to multiple shocks and stresses that have increased household vulnerability. Rainfall variability was one of the stresses that individuals and communities in rural areas particularly Malakal were coping with. Seasonal changes in the past can form a basis of forecasting the vulnerability of the communities in future. This can help to prepare for and adapt to climate variability and change. Based on farmers' experience, about 66% respondents observed that rainfall amount has significantly reduced over the area which affects crop productivity and food availability (Table 9) and about 8% of respondents suggested that seasonal pattern has changed.

Table 9: Observed changes of seasonal rainfall in Makalak

	Respondents	Percent	Valid Percent	Cumulative Percent
Highly changed	8	4.0	4.0	4.0
Moderately changed	16	8.0	8.0	12.0
Reduced	44	22.0	22.0	34.0
Highly reduced	132	66.0	66.0	100.0
Total	200	100.0	100.0	

Table 10 below, showed a moderate to severe impacts on the three major livelihoods sector and the stressors include flood, droughts, heat and heavy rainfall. The changes in climate have been observed by the farmers for much longer as noted during the in-depth interviews and focus group discussions. Results of the study indicate that there were specific households exposed to climate change risks. Short intensive rains had led to flash floods but slow on-set floods had also been experienced in the area. Results of field survey indicated a high vulnerability of Malakal to variations climatic. The changes in climate have been observed by the farmers for a long time as noted during in-depth interviews and focus group discussions. With or without external support, farmers in the county have been adapting to climate change impacts though limited by their capacity to adapt to these effects.

Table 10: Impact of climate variability and change on livelihoods in Malakal

	Respondents	Percent	Valid Percent	Cumulative Percent
Low	5	2.5	2.5	2.5
Mild	4	2.0	2.0	4.5
Moderate	24	12.0	12.0	16.5
Severe	167	83.5	83.5	100.0
Total	200	100.0	100.0	

A part from responses as to when rains start in Malakal, it appeared that farmers have a reasonable accurate perception about seasonal patterns. Many farmers suggested the months of April to May as the main seasonal onset in Malakal. However, 27% of respondents suggested that mid May is when rainfall started in Malakal (Table 11). This finding is supported to information provided by climatic data where May was found to be the mean of seasonal onset. In Malakal rainfall is erratic and unreliable, this situation influenced farm activity especially land preparation and planting period and majority of the farmers (89%) acknowledge that May (i.e. early- late May) is the planting period while only 8% of respondents indicated June as the planting month (Table 12). Majority of farmers (43%) stated that planting commenced in Mid May although replanting after crops were destroyed by either consecutive dry spells or heavy rainfall was common over the area and this activity is carried out in mid June up to August (Table 12). In addition, seasonal cessation was also assessed and about 51% of respondents indicated end of October as the end of the rainy season.

Table 11: Variations of seasonal onset in Malakal County

Occupation/Respondents	Date of seasonal onset							
	Early April	Mid April	Late April	Early May	Mid May	Late May	Early June	Mid June
Farmer	4	9	11	20	25	19	5	0
Famer and civic servant	1	0	1	0	0	0	0	0
Farmer and trader	0	1	0	0	1	0	0	0
Farmer and teacher	0	0	0	0	0	0	0	0
Farmer and student	0	0	0	0	0	0	0	0
Farmer and fisherman	0	0	0	0	0	0	0	0
Famer and wildfood collector	0	0	0	1	1	0	0	0
Total	5	11	12	21	27	19	5	0

Table 12: Variations of planting date in Malakal County

Occupation/Respondents	Palnting date (farmers' experience)							
	April	Early May	Mid May	Late May	Early June	Mid June	Late June	July
Farmer	2	26	40	19	4	2	1	0
Famer and civic servant	0	0	2	0	0	0	0	0
Farmer and trader	0	0	0	1	1	0	0	0
Farmer and teacher	0	0	0	0	0	0	0	0
Farmer and student	0	0	0	0	0	0	0	0
Farmer and fisherman	1	0	0	0	0	0	0	0
Famer and wildfood collector	0	0	1	0	0	0	0	0
Total	3	26	43	20	5	2	1	0

Table 13: Seasonal cessation variations in Malakal County

Occupation	Cessation of rainy season (farmers' experience)				
	Early October	Mid October	Early November	Mid November	Early December
Farmer	25	50	17	3	0
Famer and civic servant	1	1	1	0	0
Farmer and trader	0	0	1	0	0
Farmer and teacher	0	0	0	0	0
Farmer and student	0	0	0	0	0
Farmer and fisherman	0	0	1	0	0
Famer and wildfood collector	0	0	0	0	0
Total	26	51	20	3	0

Table 14 revealed that farmers had experienced various manifestations of climate variability in the recent years. This information was obtained by asking respondents whether they had have experienced climate related risks/hazards so far, and all respondents (100%) had observed some climatic risks/hazard while about 99% had experienced temperature variations. More than 90% had experienced drought and flooding and their associated impacts (Table 14). During the focus group discussion, farmers confirmed that floods and droughts had become more frequent. In addition, 48% of respondents reported that drought had contributed significantly to crop failure and loss of livestock. Late onset and dry spells occurrence had been reported more frequently and these events affected households' livelihood in the entire region. Floods ranked second after drought while about 67% respondents had expressed the crop diseases incidence in the area (Table 15). Focus group discussions reported that excessive water leading to flash flood during the peak of rainfall season in Malakal, especially in August and September, is pronounced. This period coincides with pronounced overspill of River Nile flood is waters affecting not only livelihood but also human health and infrastructure.

Table 14: Climate variability and change based on farmers' experience in Malakal

Occupation	% respond to impact of flood/drought experienced		% respond to temperature variability		% respond to risk/hazard experienced	
	Yes	No	Yes	No	Yes	No
Farmer	51	2	31	1	33	0
Famer and civic servant	3	0	9	0	5	0
Farmer and trader	6	0	2	0	8	0
Farmer and teacher	0	0	20	0	11	0
Farmer and student	0	0	0	0	5	0
Farmer and fisherman	26	0	14	0	21	0
Famer and wildfood collector	12	0	23	0	17	0
Total	98	2	99	1	100	0

Information gathered during discussions suggests that farmers' perception about rainfall pattern was interesting. They have specific local names even to recognize the rainfall durations in specific months that were associated with different agricultural activities. For instance, land preparation is carried out in April while planting date is determined by amount of rainfall received in May. Farmers have confirmed that flooding was attributed not only by excessive rainfall received but also by overspill of river Nile. Thus, residents and farmers in Malakal were most vulnerable to seasonal flood as compared to other Counties in the state (Upper Nile) because this is the County where many homesteads were located along the River and therefor seasonally subjected to flooding. Drought and heavy rainfall were reported to severely affect shelters, crops and animals while dry period affected crops and reduced pasture availability. This was revealed during field surveys where farmers expressed their concern about the scarcity of pastures. Crops grown include; cassava, maize, sorghum and vegetables and all these were reported to be affected severely by floods, droughts, heavy rainfall (sometimes associated with strong wind) and erosion.

This study has also revealed that there was a growing perception among the farmers that climate change and variability is already occurring. Most of the respondents in the study area (90% to 97% in Malakal) acknowledged change in climatic conditions. The concept of climate change was associated with variability in weather conditions which was related to rainfall variability and which included inconsistency and unpredictability over years rather than actual change in amounts. The seasonal variability was also related to variations in agricultural production in a given period. Major concerns were related to indicators like late onset and reduced amounts of rainfall received and increased temperatures during the growing seasons, increased incidences of drought and decreased crop productivity (Table 15). This result suggests that decreased rainfall amount has significantly contributed to decrease of crop yield by about 65% and 53% of animal production. Reduction of crop productivity is caused not only by decline of rainfall amount but also incidence of crop diseases and pest as the result of temperature variation.

Table 15: Indicators of climate change and variability impact on livelihood in Malakal

Indicator	% estimated of losses due climate change
Decreased rainfall amount	97
Late onset rainfall	83
Increased dry spells occurrence	80
Increased temperature	78
Increased crop diseases incidence	67
Decreased crop productivity	65
Increased seasonal hunger/food shortage	56
Decreased number of livestock	53

According to Table 15, the indicators that were ranked from high to the lowest showed a significant impact on livelihood. Farmers stated that climate is continuously changing and it is getting worse over time. Bad years are becoming more frequent than ever before, resulting in crop failure and food shortages in the area. It was further reported that rainfall patterns have changed with time, and perceived to have decreased especially during the past 2 years. Majority of farmers in Malakal depends heavily on rain-fed agriculture, making rural livelihoods and food security highly vulnerable to climate variability, such as shifts in growing season conditions and unreliability of rainfall. High sensitivity crop production to climate parameters makes it vulnerable whenever extreme changes occur. Focus group discussion in the study area revealed that crop production, the main source of livelihood, had significantly been affected by protracted dry spells and flooding. Farmers (98%) claimed that drought and flood have considerably contributed to yields reduction especially for sorghum and maize crop (Table 14 and 15). For instance, 63% of respondents reported that they used to harvest about 2-4 bags/ha in the past but the harvest had reduced to 1 to 2 bags/ha. This situation was exacerbated by prolonged dry spells, inadequate and uneven distribution of rainfall as well as late onset of rains, which had often caused crop failures (Fig. 13).

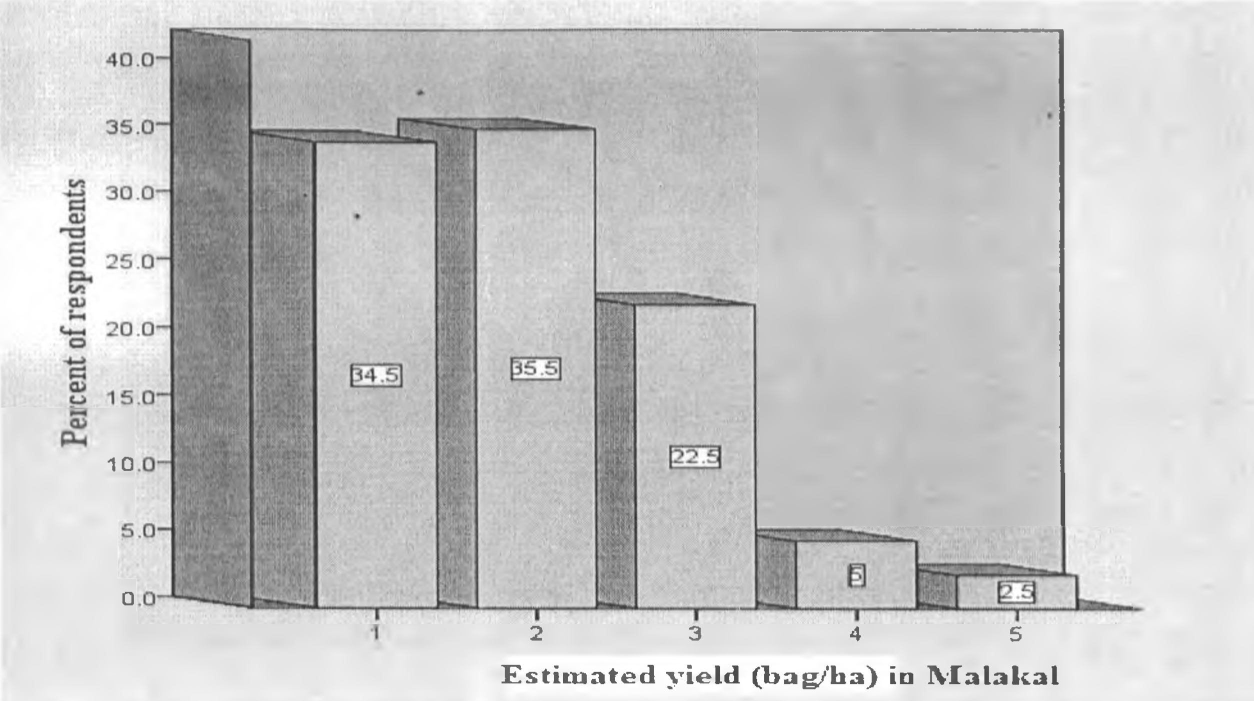

Figure 13: Crop yield estimate using bag as the unit measurement

Farmers suggested that decreased of crop yield were also associated with other non-climatic factors such as pest and diseases and inadequate extension services. Therefore, crop productivity reduction becomes significant when there is interaction with other non-climatic stressors. Majority of respondents in Malakal stated that crop productivity have been affected through decrease in rainfall and prolonged drought which had also contributed to lack of soil moisture. This eventually affect pastures availability and vegetation cover. Based on household surveyed, it appeared that late onset and dry spells are the most important constraints to crop production (Table 11). During the focus group discussion, respondents ranked the impacts of climate variability in the order of their influence. These include unpredictability of seasonal onset/cessation, decreased rainfall amount, increased pests and diseases incidences which were linked to warming and declining soil fertility associated with frequent drought and flooding. It has been reported that delay of seasonal rains coupled with unexpected earlier onset than usual, leading to poor germination of seeds, requiring farmers to replant as much as possible. Poor crop performance has partly been contributed by the dry spells and flooding. However, pest and crop diseases especially stiga has been reported as a major factor influencing crop yield (Fig. 16).

Figure 14: Drying maize plants at tussling stage for Malakal County

Droughts and flood appeared to be the major climatic stressors on livelihoods in the area. Table 16 shows type of hazards and intensity of each climatic hazard. Occurrence of drought seems to be high followed by flood; however, incidence of crop disease (11%) was also reported (Table 16). Figure 15 and 16 showed hazards experienced and their associated effect such as wider spread of flood during growing period and crop pest and diseases infestation. This condition is frequent in Malakal especially in August and September which finds crop at various vegetative stages. Study suggests that the effect of flood is negatively significant depending on area's topography (flat at between 0 to one per cent slopes) and soil type and stage of crop (Eldredge, 1988). This physiographic feature is important in determining vulnerability of area to flooding due to the susceptibility of households, crop fields and grazing land to floods. Focus group discussions reported that drought and flood have affected crop and animal productivity. Other climatic parameter such as hailstorm affects both shelter and crop. Leaf tearing and breaking of plants attributed by hailstorm during rainy seasons

Apart from climatic impacts on crop growth and development as the result of moisture deficiency, birds and crop diseases are the major challenge in farming and no proper policy in the Ministry of Agriculture (both at national and State Ministry) to control birds and Quelea quelea, sorghum bug (Agonoscelis pubescens) and grasshoppers. Quelea in the northern Sudan for example is classified as a national pest and, as such, its control was regarded as the responsibility of the national government especially ministry of agriculture and forestry (FAO, 2006). Striga is a perennial problem for sorghum producers. Famers stated that when infestation reaches a certain threshold the farmer will switch to millet which is less susceptible to the parasitic weed (Figure 16).

Table 16: Type of hazard/risk experienced and their intensities in Malakal

Type of hazard/risk experienced	% of respond to the intensity of the hazard/risk			Total
	Mild	Moderate	High	
Drought	0	10	38	48
Flood	1	4	26	31
Hailstorm	0	1	3	4
Soil erosion	1	1	4	6
Crop pests and diseases	0	4	7	11
Total	2	20	78	100

Figure 15: Extension workers measuring area occupied by the flood in Malakal

Figure 16: Stiga infestation in sorghum plants in Malakal County

4.9.2 Adaptation and coping strategies in Malakal County

In Malakal, there are some local coping and adaptation strategies adopted by farmers or communities in response to potential/observed risks and hazards related to climate. Based on hazards experienced (Table 15), these results of information analysis indicated that the poor is more vulnerable to impacts of climate variability. Among the contributing factors to such high vulnerability risk are possession of small pieces of land and lack of agricultural areas under cultivation, spending much of their time as laborers as a coping mechanism to manage food shortages. Among the major coping strategies of the most vulnerable group to droughts are engagement in casual off-farm activities such as water vending, brick making and trading of firewood and charcoal (Fig.17). It was further identified that farmers were not planning measures that could have reduced the impacts of recurrent floods and droughts. Their only strategy was spiritual on making prayers once they are hit by the event. It was observed that the low level of education and lack of access to basic information like early warning information and weather forecast has contributed to the situation.

Table 17 shows that about 48% of the respondents ranked burning charcoal and selling firewood as the major local coping strategy during food shortage while collecting wild foods was ranked as the second most significant coping strategies (15%). Wild foods are foods collected from wild and/or naturally growing plants and game animals. Thus wild plant foods are effective as a survival strategy in Malakal. It has been reported that farmers had specific plants that were traditionally collected in Southern Sudan. These include Balanites aegyptiaca and Tamarindus indica (locally known as Thow and koat respectively). Figure 18 showed different species of Balanites fruit collected and ready for consumption. These wild foods are collected and available over the whole year on the market, because of a high demand and their excellent storage capacity. However, these wild food plants are not documented in term of how foods are collected prepared and preserved as well as their nutritional content.

Table 17: Local coping strategies adopted in Malakal

	% respond to local coping strategies used						
Occupation	Collecting wildfood	Selling firewood or charcoal	Selling livestock	Migrating to town to look for a job	Fishing	Assistance from relatives	Total
rmer	23	9	4	3	0	3	42
rmer and civic servant	0	0	0	0	0	0	0
rmer and trader	0	1	6	0	1	0	8
rmer and teacher	0	0	0	1	0	0	1
rmer and student	0	0	4	0	0	0	4
rmer and fisherman	1	3	0	0	2	1	7
mer and wildfood llector	0	35	1	2	0	0	38
tal	24	48	15	6	3	4	100

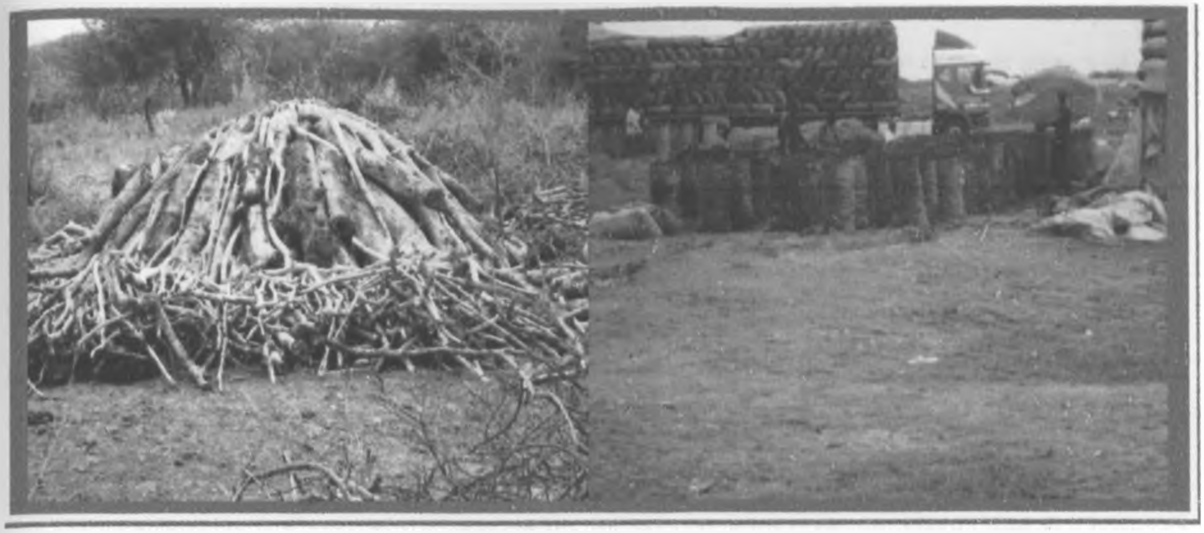

Figure 17: Charcoal burning industry as coping strategies in Malakal County

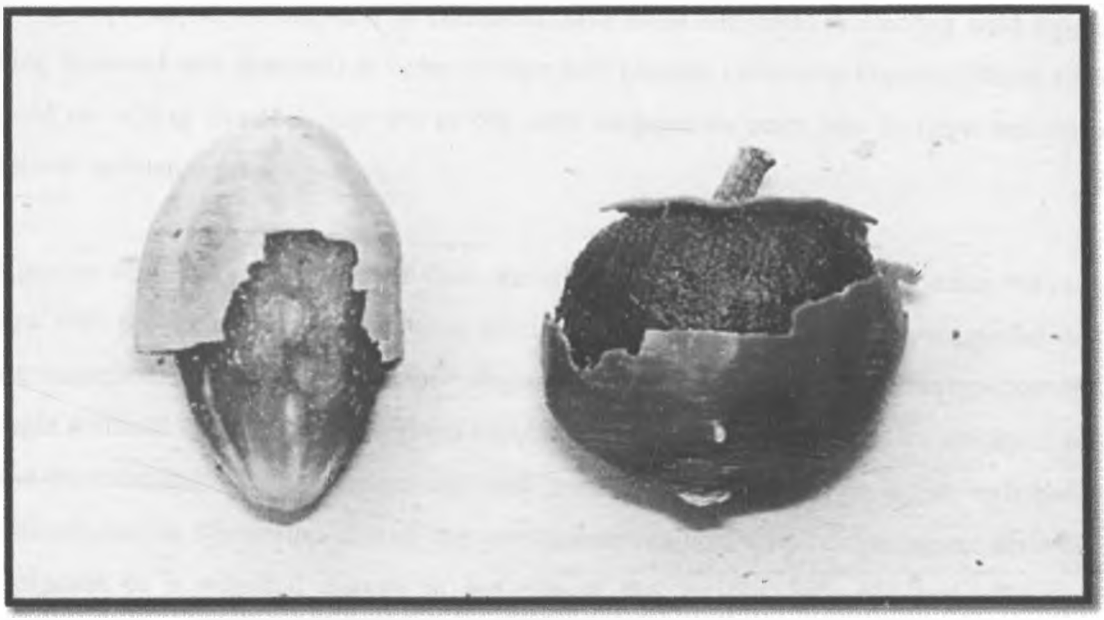

Figure 18: Different wild species of Balanites aegyptiaca fruit in Malakal

Fishing and selling livestock is also another important coping strategies used by farmers who keep livestock. However, farmers also expressed concern about massive migration of households to urban areas. About 6% of respond indicated that many people have moved to town. Focus group discussions indicated that available resource for individual or household influenced their perception of risk to dry spells, flood and/or seasonal shifts. In addition, some local coping and adaptation strategies adopted in response to observed risks and hazards related to climate and non-climatic factors. For instance, farmers grow Okra plant to earn cash during dry season on the shore of rivers. Okra is commonly used as stew and it is sold as either fresh or dry product.

In fact, most of the coping activities followed by local peoples were in response to change they have experienced (Ellis, 2000) in daily life according to their traditional beliefs. These measures were found to be event specific based on local knowledge and innovations, because most of the respondents were not aware about when these impacts of climate variability and change are expected or could occur. Much of the climate change adaptation literature provides similar patterns in temporal and spatial scales.

Flooding and drought were therefore the major stressors for which adaptations were necessary. During floods some families move to their relatives on drier land. Food and Agriculture Organization report (2006) suggests that dependency on remittances from urban areas and/or abroad in recent year has increased. From Table 17, it is observed that 24% to 48% of respondents are engaged in casual/off-farm labor and trade (collecting wild foods, selling firewood and charcoal) in order to cope with climate variability impacts. About 15% depend on selling livestock and 4% to 6% were engaged in petty jobs in town and from relatives' assistance respectively.

Adaptation from agronomic point of view, including changing crop variety to match the crop stages with prevailing weather is being practices. Focus group discussions suggested that some households keep replanting until August. Use of early maturing of maize crop and drought resistant crops such as sorghum had begun; however, other crops like chickpea and beans were also cultivated. Many management-level adaptation options are largely extensions or intensifications of existing climate risk management or production enhancement activities in response to a potential change in the climate risk profile. Seasonal and off-season vegetable cultivation was one recent practice among farmers to cope with extreme weather events and losses of major crops and vegetables. Farmers have started to produce off-season vegetables especially Okra, tomato and carrot during winter. Farmers were using some local strategies to cope and adapt to climate change impacts. These include changing the cropping patterns and crop varieties.

4.9.3 Social and institutional strategies in Malakal, Upper Nile state

Social and institutional preparation for coping with risks and hazards was relatively weak in Malakal County. Farmers depend on UN agencies and NGOs which focus on income generations and empowerment programs.

Table 18 shows that 89% respondents indicated that UN agencies and NGOs played major role especially in distribution of agricultural inputs basically seeds and fishing equipment. Focus group discussion acknowledged that Food and Agriculture Organization (FAO), World Food Program (WFP) and Medicine San Frontier (MSF) had been assisting farmers for very long time. The FAO and other local as well as international organizations have been distributing cereal seeds crop seasonally while MSF had been providing veterinary services to household who keep livestock but many farmers claimed that their animals have not been treated. In addition, WFP have been providing relief food during the period of turmoil. However, after comprehensive peace agreement (CPA) this food aids has been channeled to returnee and those who are affected by hunger (seasonal hunger) which is inflicted by late onset of rainfall or flood. Attempt have been made by the government (state) to intervene in the event of weather hazards although there was no documented policy and/or appropriate policy on climate change and extreme risk related adaptation. However, about 6% of respondents acknowledged the intervention of the government, especially the State Ministry of Agriculture in collaboration with UN agencies and other Non governmental organizations. Respondents indicated that community based organizations (CBOs) and churches have been very supportive and assist to a great extent. About 2 to 6% of respondents confirmed the churches and CBOs intervention during weather hazards (Table 18).

Table 18: Institutions intervened during climate hazard/risk

Occupation	% respond to institutions which help during hazard			
	Community base organizations (CBOs)	Church orgnizations	Government institutions	UN and NGOs agencies
Farmer	2	0	1	69
Famer and civic servant	0	0	2	2
Farmer and trader	1	0	3	1
Farmer and teacher	0	2	0	0
Farmer and student	0	0	0	0
Farmer and fisherman	0	0	0	6
Famer and wildfood collector	0	0	0	11
Total	3	2	6	89

Institutional governance and group dynamics play an important role in identifying options and opportunities for building resilience of affected communities. This study showed that the stronger the group, the stronger the initiatives and activities in terms of helping the poor and supporting their livelihoods. However, existing local knowledge, practices and available technology influence coping and adaptation strategies of farmers. Observation and group discussions in Malakal showed that available technologies and knowledge were limited.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary and conclusion

Annual rainfall indicated no significant trend while MAM and SON season showed slight decrease of rainfall trend. However, JJA seasonal rainfall indicates significant increase which appeared to favor crop productivity in Malakal. These inter seasonal variations of rainfall during growing period affect crop and animal production. Focus group discussions suggest that bad years were becoming more frequent than before, resulting in food shortages in the area. This would also be attributed by flood and droughts are the major climatic hazards experienced by farmers who practiced rain fed agriculture in the study area.

Analysis of probability and occurrence of dry and wet spell indicated that chances of 5 to 7 days dry spell occurrence are high (above 70%) during growing period. The nature of dry spells during this period is very important as it affects most crops at their crucial period of growth and development (tasseling and seed setting).

Drought and flood have contributed to production loss and food insecurity while increase in temperature was connected to increase in the incidences of crop pests and diseases. Farmers acknowledged the link between climate change and increased incidences of crop pests and diseases. It was revealed that, new pests and diseases were emerging while old pests were exhibiting new feeding behaviors. They perceived this frequent of drought and flood, and prolonged dry spells are strongly associated to climate variability and change. According to their perception, such changes have occurred in the recent ten years as compared to the previous decades. This implies that farmers in the study area who depend on rain fed agriculture as a sole livelihood activity are at risk of becoming food insecure. It was revealed that majority of farmers in Malakal have acknowledged decreasing food crop production.

The impacts of climate change will increase the challenge of ongoing poverty alleviation efforts in Southern Sudan. It will hit hardest those whose livelihoods are more intimately tied to natural resource which are more sensitive to climate. Survey findings point to high vulnerability within the agriculture and fishing based livelihood system. This demonstrates that there is immediate need for assessing vulnerability of affected population and recommend appropriate and sustainable adaptation measures can be implemented swiftly. In addition, within these subsistence farmers, those who are at higher risk women, elderly, and the ill/disabled. In Malakal, for example, farmers stated that occurrence of cholera as the result of unclean water has endangered many household's welfare. The specific impacts of climate change on rural populations around Upper Nile state are many; however it appears that the ultimate result will be a reduction in food security, water quality and supply, and income. Livelihood options are becoming scarce or more difficult, leading to conversion or migration. Population pressure is cited continuously as an external driving force that compounds the impacts of climate change.

From the discussion, climate change impacts in Malakal are far reaching and affecting the well-being of the rural farmers. Crop farming and fishing are the major livelihood strategies in the area. All these are affected differently by effects of climate change including flooding, droughts, heavy rainfall, heat and erosion of the banks. Impacts on livelihoods range from moderate to severe impacts depending of the livelihood and stressor. Whereas heavy rainfall and flooding affects crop farming more, droughts affects grazing and fishing highly. Different coping mechanisms have been implemented by the communities to the major livelihoods and though some indicate mal-adaptation, the community has responded to the stressors and is innovative.

This study indicated that there are high rainfall variations between seasons and from one year to the other year and variations between annual and seasons and/or inter seasonal rainfall variation is significant. The climate-induced variations of the years significantly affect socio-economic activities (mainly rainfed agriculture) and community livelihoods which are mainly dependent on wetlands resources. As a result, community livelihoods are vulnerable to climate variability and its extreme phases that correspond to drought and flood conditions in Malakal.

Crop yields were found to be negatively correlated with annual and JJA rainfall. However, correlation between JJA rainfall and crop yields appeared to be high as compared to MAM and SON seasonal rainfall. This indicated that 4.4% of crop yields variations can be explained by JJA rainfall.

5.2 Recommendations

Based on the findings from this study, the following recommendations are made to increase farmers' ability to cope with climate variability and change impacts with a particular reference to droughts and flooding (excessive rainfall) related stresses in the context of Upper Nile state:

- Meteorological department should be established and strengthened in terms of capacity building and logistics in order to provide effective and timely information such as seasonal forecast to the users.
- Regional meteorological stations network should be improved. Currently there are only two meteorological stations (Renk and Malakal) in whole state (Upper Nile) or province.
- Meteorological department should also work in collaboration with extension officers in order to translate this (early warning) information to the users (farmers) and advice farmers on when to plant and selection of suitable crops.
- Specialized research institutions should be established in order to recommend suitable crop in drought prone areas.
- Farmers should switch into growing drought escaping/tolerant crop to reduce crop failure during growing season.

5.3 Suggestions for future studies

- This study should be extended to other parts of the Country considering the dynamic coping strategies and farm practices in each of States of South Sudan.
- This study has only looked at climate variability and change impacts on livelihoods and coping strategies used at household level. Other factors induced by climate change such as environmental degradation, effect of climate variability on particular crop and technology (e.g. fertilizer application) were not considered in this study; hence, it is recommended that further studies should be conducted to address these issues
- Government should develop a policy to conserve forest in order to reduce deforestation in the region.

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Appendix 1: Regression analysis

Source	df	Sum of Squares	Mean Squares	F-ratio	P value
Regression	3	0.114	0.038	1.025	0.400
Residual	23	0.851	0.37		
Total	26	0.965			

R^2= 0.118

Appendix 2: Test of significance of seasonal rainfall and crop yield (NDVI)

Variables	df	Mean	Std. Deviation	Std. Error	95% confidence interval of the difference		t	p value
					Lower	Upper		
Ann-NDVI	26	-8.35	17.69	3.40	-76.56	-90.53	24.51	.000
MAM-NDVI	26	3.981	20.76	3.99	-31.60	-48.0	9.97	.000
JJA-NDVI	26	-1.45	33.60	6.47	-131.97	-158,57	22.46	.000
SON-NDVI	26	-6.55	18.58	3.58	-58.24	-72.94	18.34	.000

Appendix 3: A questionnaire for climate variability and change impacts based on farmers' perception.

Part 1. Climate variability and change impacts assessment questions related to household/farmer

Please state the status/rank of the respondent to household of the farm_________________

Q1. Are you a resident of this village for more than 10 year? **Yes** _______ **No**__________ If (yes please fill the table below)

(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
Gender	**Age**	**Marital status**	**Educated up to which level**	**Please state the size of your household**	**Occupation or any other source of livelihoods**	**Do you have access to land?**	**Please state how much land you owned (ha)**	**Do you have access to credit?**
Key (a) 1) Male 2) Female	Key(b) 1)>20 2)>30 3)>40 4)>50 5)>60 6)>70	Key (c) 1) Single 2) Married	Key (d) 1) Not attend school 2) Primary school 3) Secondary school 4) Graduate	Key (e) 1) 3 2) 4 3) 5 4) 6 5) 7 6) 8 7) 9 8) > 10	Key (f) 1) Farmer 2) Trader 3) Civil servant 4) Unemployed 5) Student 6) Wild food collector 7) Fishing	Key(g) 1) Yes 2) No	Key(h) 1) 1 2) 2	Key (i) 1)Yes 2) No

Q2. You and your household members; do you have access to health care? **Yes**_________
No__________ If (yes please fill the table below)

(a)	(b)	(c)	(d)	(e)
Type of diseases	**Have you ever experienced any incidence of water borne diseases?**	**To what extent does it affect people?**	**What is the average household access to primary health care facilities in this village?**	**What extent do you have access to safe drinking water in the dry season and/or what extent do you have access to safe drinking water in the wet season?**
Key (a) 1) Diarrhea 2) Malaria 3) Cholera 4) Typhoid fever	**Key (b)** 1) yes 2) No	**Key (c)** 1) Low 2) Mild 3) Moderate 4) High	**Key (d)** 1) Low 2) Mild 3) Moderate 4) High	**Key (e)** 1) Low 2) Mild 3) Moderate 4) High

Part 2. Climate variability and change impacts assessment questions related to livelihood (crop and livestock)

Q1. Crop(s) is/are primarily grown in Malakal. Please state the name of crop grown.

(a)	(b)	(c)	(d)	(e)	(f)
Type of crop	**Area planted (ha)**	**Area Harvested (ha)**	**Estimated yield (Kg/ha)**	**To what extent the crop yield is affected?**	**Which crop is more resilient to climate variability?**

Key (a) 1) Sorghum 2) Millet 3) Maize 4) Rice 5) Wheat 6) Sesame 7) Groundnut 8) Bean 9) Tomato 10) Okra 11) Other (specify)____	**Key (b)** 1) 1 2) 2	**Key (c)** 1) 0.5 2) 1.0 3) 1.5	**Key (d)** 1)________ 2)________ 3)________ 4)________	**Key (e)** 1) Low 2) Mild 3) Moderate 4) High	**Key (e)** 1) Sorghum 2) Millet 3) Maize 4) Rice 5) Wheat 6) Sesame 7) Groundnut 8) Bean 9) Tomato 10) Okra 11) Other (specify)____

Q2. Do you have livestock, poultry or other farm animals? **Yes**____________ **No**__________ If (yes please fill the table below)

(a)	(b)	(c)	(c)	(d)
Type	**Number currently owned**	**Risk or hazard indicator**	**What livestock populations are most vulnerable to climate-related health problems**	**To what extent are veterinary services required to maintain animal health?**

Key (a)	Key (b)	Key (c)	Key (c)	Key (d)
1) Cattle 2) Goat 3) Sheep 4) Chicken 5) Other (Specify)_____	1)__________ 2)__________ 3)__________ 4)__________	1) Drought 2) Floods 3) Land slides 4) Soil erosion 5) Hailstorms 6) Fire outbreak 7) Livestock disease epidemic 8) Heavy rainfall 9) High temperature 10)Other (specify)_____	1) Cattle 2) Goat 3) Sheep 4) Chicken 5) Other (Specify)_____	1) Low 2) Mild 3) Moderate 4) High

Q3. From your experience as farmer, have you observed any climate variability such as flood/drought affecting land suitability for agriculture? **Yes**_______ **No** _____ If (Yes, please fill the table below).

(a)	(b)	(c)	(d)	(e)
Vulnerability indicator	**To what extent does rainfall or storm events affect/delayed land preparation?**	**To what extent do temperature and rainfall patterns altered traditional planting time, fertilization, watering, weeding practices and harvesting?**	**To what extent are post-harvest losses within the farming system ever attributable to weather events?**	**When do climate variability factors inflict pest infestations and plant diseases?**

Key (a) 1) Land preparation 2) Planting practices 3) Crop nutrition and weeding 4) Crop protection 5) Harvesting practices 6) Post-harvest practices 7) Other (specify)__	**Key (b)** 1) Low 2) Mild 3) Moderate 4) High 5) Other (Specify)_____	**Key (c)** 1) Low 2) Mild 3) Moderate 4) High	**Key (d)** 1) Low 2) Mild 3) Moderate 4) High	**Key (e)** 1) Dry period 2) Wet period 3) Other (Specific)_____

Part 3. Identification of climate change and variability indicators

Q 1. From you experience, have you observed or experienced any decreased or increased of rainfall? **Yes**_________ **No** ________ (If Yes, please fill the table below).

(a)	(b)	(c)	(d)	(e)
Climatic indicator	**When does the rain start in Malakal?**	**When does the rain end/stop?**	**When was your first time you experienced the increased or decreased of rainfall**	**To what extent does it changed?**
Key (a) 8) Rainfall	**Key (b)** 1) April 2) Early May 3) Mid May 4) Early June 5) Mid June	**Key (c)** 1) Early October 2) Mid October 3) Early November 4) Mid	**Key (d)** 1) Last season 2) Last one year 3) Last two years	**Key (e)** 1) Low 2) Mild

		November 5) Early December	4) Last three years 5) Last four years 6) Last five years 7) Other (specify)______	3) Moderate 4) High

Q2. Have you also noticed or experienced any increased or decreased in temperature?
Yes__________ **No** _________ (If Yes, please fill the table below).

(a)	(b)	(c)	(d)
Climatic indicator	**When does the temperature change?**	**When was last you experienced the changed**	**To what extent does the temperature varied?**
Key (a) 1) Temperature	**Key (b)** 1) Growing season 2) Dry season 3) Other (Specify)__________	**Key (d)** 1) Last season 2) Last one year 3) Last two years 4) Last three years 5) Last four years 6) Last five years Other (specify)______	**Key (e)** 1) cold 2) warm

Q3. Have you experienced any climate related risk or hazards? **Yes**________ **No** ______ If (Yes, please fill the table below).

(a)	(b)	(c)	(d)
Type of risk/hazard	**How often does the**	**When was the first time you**	**What was the intensity of this**

	risk/hazard occur?	experienced the risk/hazard?	risk?
Key (a) 1) Drought 2) Floods 3) Land slides 4) Soil erosion 5) Hailstorms 6) Fire outbreak 7) Livestock disease epidemic 8) Crop pests and diseases 9) Human disease epidemic	**Key (b)** 1) Seasonally 2) Yearly 3) Every two years 4) Every three years 5) Every four years 6) Every five years 7) Other (Specify)_________	**Key (c)** 1) Last season 2) Last one year 3) Last two years 4) Last three years 5) Last four years 6) Last five years 7) Other (specify)________	**Key (d)** 1) Low 2) Mild 3) Moderate 4) Severe

Q4. Have you observed the climate change and variability impact or hazard(s) on your livelihoods? **Yes**_______**No**_______ If (Yes, please fills the table below and indicates how of each these hazards (floods, drought, hailstorm, landslides and soil erosion) affect your asset/livelihoods)

(a)	(b)	(c)	(d)	(e)
Floods	**Drought**	**Hailstorm**	**Landslides**	**Soil erosion**

Key (a)	Key (b)	Key (c)	Key (d)	Key (e)
1) Loss of crops 2) Loss of animals 3) Damage agric. land 4) Effect on drinking water 5) Effect on irrigation 6) Effect on houses and animal shed	1) Reduce crop productivity. 2) Water scarcity 3) Losses of animals	1) Roof damage 2) Crops damage 3) Injure people	1) Loss of crops 2) Loss of animals 3) Effect on houses and animal shed 4) Effect on forest land	1) Cutting and damage agricultural land 2) Reduce agricultural productivity 3) Create irrigation problem 4) Damage other infrastructure

Q5. In case you have experienced any of these hazards (flood, drought, hailstorm, landslides and soil erosion) indicate the extent of the impact of these hazard on agricultural practices

(a)	(b)	(c)	(d)	(e)	(f)
Risk or hazard	**To what extent does it affect (agric. Land) land preparation?**	**To what extent does it affect planting?**	**To what extent does it affect weeding and harvesting?**	**To what extent does it affect pasture?**	**To what extent does it affect crops/animals productivity**
Key (a) 1) Drought 2) Floods 3) Land slides 4) Soil erosion 5) Hailstorms 6) Fire outbreak	**Key (b)** 1) Low 2) Mild 3) Moderate 4) High 5) Other (Specify)____	**Key (c)** 1) Low 2) Mild 3) Moderate 4) High	**Key (d)** 1) Low 2) Mild 3) Moderate 4) High	**Key (e)** 1) Low 2) Mild 3) Moderate 4) High	**Key(f)** 1) Low 2) Mild 3) Moderate 4) High

7) Livestock disease epidemic 8) Crop pests and diseases 9) Human disease epidemic					

Part 4. Adaptations and coping strategies assessment related question

Q1. Among the climatic hazard you experienced, has your livelihood affected? **Yes** _________________**No** ______________If (yes please fill the table below)

(a)	(b)	(c)	(d)	(e)	(f)
Which climatic risk or hazard is common and affected you in this village?	**What do you do when there is flood?**	**What happens when there is drought?**	**What happens when there is soil erosion?**	**To what extent does this affect your income?**	**What was the intensity of this risk?**
<u>Key (a)</u> 1) Drought 2) Floods 3) Land slides 4) Soil erosion 5) Hailstorms 6) Fire outbreak 7) Livestock disease epidemic 8) Crop pests and diseases	<u>Key (b)</u> 1) Construction of embankment 2) Plantation 3) Abandon the place 4) Other (Specify)__	Key (c) 1) look for crop which needs less amount water 2) Irrigation is carried out using kitten from River 3) Construction of irrigation canal 4) Irrigation is carried using pump water	<u>Key (d)</u> 1)Planting 2) Control grazing 3) Control ploughing 4) Construction of check dams	<u>Key(e)</u> 1) Low, 2) Mild 3) Moderate 4) Severe	<u>Key (f)</u> 1) Low 2) Mild 3) Moderate 4) Severe

9) Human disease epidemic 10)Other (specify)______					

Q2. What do you do when there is flood/drought? What are the local coping mechanisms used to reduce the impacts?

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Q5. What is the institutions effort to reduce future impacts?

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