UNIVERSITY OF NAIROBI

PAST AND FUTURE CLIMATE TRENDS, IMPACTS OF CHARCOAL PRODUCTION AND ADAPTATION OPTIONS FOR LOWER JUBBA OF SOMALIA

Thematic Area

Climate Risk Management and Food Security

By

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DECLARATION

I declare that this thesis is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other people's work or my own work has been used, this has properly been acknowledged and reference in accordance with the University of Nairobi's requirements.

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This proposal has been submitted to the Institute for Climate Change and Adaptation (ICCA) in partial fulfilment of the requirements for the degree of the Doctor of Philosophy in Climate Change and Adaptation, of the University of Nairobi with our approval as supervisors.

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DEDICATION

To quote Maya Angelou, *one isn't necessarily born with courage, but one is born with potential. Without courage, we cannot practice any other virtue with consistency.* This thesis is dedicated to my friends and family for their endless love and support, giving me the courage to be consistent in my pursuit of higher education.

To my late grandmothers, for not letting society define you and showing me how to be strong. To my father for your never ending support, for not letting me make excuses and slack off, I would not have gotten this far without you. To my mother for your constant “glass half full” encouragement, for always being positive in my moments of discouragements, thank you. To my sister for being my sounding board, for listening to me, encouraging me, reasoning with me, and giving me feedback whenever I needed it, thank you.

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ABSTRACT

Climate is changing at an alarming rate threatening the critical pillars for environmental, social and economic development. Somalia is one of the countries of the GHA that has faced unique climate variability and climate change challenges, within severe conflict environment. Charcoal production is causing serious land cover changes that could have far reaching socio-economic implications. The objective of this study was to examine the past and future climate trends and understand the impacts of charcoal production and the adaptation options for communities in Lower Jubba. Rainfall and temperature data extended from 1981-2012. The data were subjected to various statistical analyses including trend analysis. Analysis of land cover changes in Lower Jubba was done using remotely sensed data from Landsat imagery. Different images from 1993/95, 2000 and 2014 were analysed and compared. Information on the role of charcoal for the communities in Lower Jubba was collected through a survey. Descriptive, multiple univariate and multivariate analyses was done on the primary data. The future climate change scenarios for Lower Jubba region was studied using the downscaled CORDEX RCMs data available at ICPAC for both the historical and future period of 1950 – 2005 and 2006 – 2100 respectively, targeting the projected periods of 2030, 2050 and 2070. Possible societal impacts of the future climate for Lower Jubba of Somalia were assessed based on the results from analysis of projected climate data. The results showed high degree of inter-annual variability of rainfall with recurrences in high/low value extremes that are often associated with floods/droughts. Some of them occurred during El Niño/La Niña years when the observed rainfall and temperature anomalies seemed to have extended over most of Somalia. Results showed a 50% reduction in forest cover and a 17% reduction in woodlands between 1993/95 and 2014. If business continues as usual with deforestation, the area could face complete deforestation in the future. A survey on the community's perspectives showed that the rapid deforestation in Lower Jubba was primarily due to charcoal production. The survey linked most of the local socioeconomic challenges to climate change. Limited adaptation practices were found in the study area. The projected rainfall anomalies over Lower Jubba indicated dominance of meteorological drought in 2030. Significant increase in rainfall was exhibited in 2050 and 2070. Evidence of trend increase in minimum and maximum temperature was observed in the analysis. Projections from all the models showed increase in minimum and maximum temperatures in all seasons and sub periods. Global temperature increase worldwide has been associated with global warming. Due to limitation in the length of data used, no distinct climate change signal could however be delineated from the observed past rainfall and temperature characteristics over Lower Jubba.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS/ACRONYMS AND SYMBOLS

ACLED	The Armed Conflict Location & Event Data Project
AMISOM	African Union Mission in Somalia
ASAL	Arid and Semi-Arid Lands
AMJ	April, May, June
CC	Climate Change
CCD	Cold Cloud Duration
CDM	Clean Development Mechanisms
CFSR	Climate Forecast System Reanalysis
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station
CIA	The Central Intelligence Agency
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMP	Parties to the Kyoto Protocol
CNRM	Centre National de Recherches Météorologiques
CO_2	Carbon Dioxide
COP	Conference of Parties
CORDEX	Coordinated Regional Downscaling Experiment
CRU	Climate Research Unit
DJF	December, January, February
DN	Digital Number
DOS	The Dark Object Subtraction
EM-DAT	Emergency Events Database
ESM	Earth System Models
ETM+	Enhanced Thematic Mapper Plus
EWS	Early Warning System
EC	European Commission
ENSO	El Niño/Niña Southern Oscillation
EROS	Earth Resources Observation and Science
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FEWS NET	Famine Early Warning Network

FGS	Federal Government of Somalia
GCM	Global Climate Models
GPCC	Global Precipitation Climatology Centre
GDP	Gross Domestic Product
GFS	Government of Federal Somalia
GHA	Greater Horn of Africa
GHG	Greenhouse Gas
GIS	Geospatial Information Technology
GLOSS	Global Sea Level Observing System
GWP	Global Warming Potential
HDI	Human Development Index
HFA	Hyogo Framework for Action
ICHEC	The Irish Centre for High-End Computing
ICPAC	IGAD Climate Prediction and Applications Centre
IDP	Internally Displaced Person
ICHEC	Irish Centre for High End Computing
IGAD	Intergovernmental Panel on Authority
IGA	Interim Galmudug Administration
IHA	Interim HirShabelle Administration
IJA	Interim Jubba Administration
ISWA	Interim South State Administration
ILO	International Labour Organization
INDC	Intended Nationally Determined Contributions
IOD	Indian Ocean Dipole
IPCC	Inter-Governmental Panel on Climate Change
LTAP	Long-Term Acquisition Plan
INDCs	Intended Nationally Determined Contributions
INTERPOL	International Criminal Police Organization
ITCZ	Inter Tropical Convergence Zone
IUCN	International Union for the Conservation of Nature
JJA	June, July, August
LDC	Least Developed Country
LEG	LDC Expert Group

LULC	Land Use Land Cover
LULUCF	Land use, Land-use Change and Forestry
MAM	March, April, May
MDG	Millennium Development Goals
MIROC	Model for Interdisciplinary Research on Climate
MMD	Multi Model Data
MOCH	The Met Office Hadley Centre
MODIS	Moderate Resolution Imaging Spectroradiometer
MPI	Multidimensional Poverty Index
MTO	Money Transfer Organization
NASA	National Aeronautics and Space Administration
NAPA	National Adaptation Programme of Action
NBSAP	National Biodiversity Strategy and Action Plan
NDP	National Development Plan
NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental Organization
NIR	Near Infrared
NMG	Nation Media Group
NMHSs	National Meteorological and Hydrological Services
NO_X	Nitrogen Oxides
NOAA	National Oceanic and Atmospheric Administration
OLI	Operational Land Imager
OND	October, November, December
PIC	Products of Incomplete Combustion
QBO	Quasi-Biennial Oscillation
REDD	Reducing Emissions from Deforestation and forest Degradation in Developing Countries
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
RH	Relative Humidity
SBI	Subsidiary Body for Implementation
SBSTA	Subsidiary Body for Scientific and Technological Advice
SDGs	Sustainable Development Goals

SPSS	Statistical Package for Social Sciences
SFO	Office of the Facilitator for Somalia Peace and National Reconciliation
SST	Sea Surface Temperatures
SHARE	Support to Horn of Africa Resilience
SON	September, October, November
SWALIM	Somalia Water and Land Information Management
SWIR	The Short Wave Infrared
TFG	Transitional Federal Government
TM	Thematic Mapper
TNMHC	Total Non-Methane Hydrocarbons
TNMOC	Total Non-Methane Organic Compounds
ToA	Top-Atmosphere Reflectance
TRMM	Tropical Rainfall Measuring Mission
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNFPA	The United Nations Population Fund
UNHCR	United Nations High Commission for Refugees
UNISDR	United Nations International Strategy for Disaster Reduction
UNSC	United Nations Security Council
UCSB	University of California, Santa Barbara
USGS	U.S. Geological Survey
WCDRR	World Conference on Disaster Risk Reduction
WB	World Bank
WCRP	World Climate Research Programme
WFP	World Food Program
WHO	World Health Organization

CHAPTER 1 : INTRODUCTION

1.1 General Background

The majority of the hazards in Africa are climate-related such as droughts, floods, cyclones, extreme temperatures, strong winds, and sea level rise, among others (IPCC, 2007, 2013, 2014b; EM-DAT,2016). Increasing evidence shows that the characteristics of these hazards are rapidly changing since the world climate is changing, threatening environmental, social and economic development (IPCC, 2007, 2014b). Furthermore, climate change has been identified as a stressor to many communities in sub-Saharan Africa especially those who largely or totally rely on rain-fed agriculture or pastoralism for their livelihoods (Amissah-Arthur, 2003; Haile, 2005; Cooper, et al., 2006; Ogallo, et al., 2008; Connolly-Boutin & Smit, 2016).

Impacts of climate extremes are devastating as was witnessed by the floods over parts of Greater Horn of Africa (GHA) in 2008/9 which were immediately followed by severe drought in 2010/2011 that ravaged the GHA countries (IFRC, 2011). This sequence of events has resulted in challenges for communities within the region, many of who are struggling to cope effectively with the impacts of climate change and variability (Connolly-Boutin & Smit, 2016). The 2011 drought left four million people in Somalia unable to access basic food and non-food items needed for survival, and refugee flows to camps in Kenya and Ethiopia reached nearly two thousand people daily in spite the early warning given (Hillbruner & Moloney, 2012). The IPCC reports have highlighted that the risk of climate-related impacts, are associated with interaction of climate-related hazards with the vulnerability and exposure of human and natural systems, including their inability to adapt (IPCC, 2000, 2007, 2014a).

Vulnerability is a factor of one's sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2014a). Increased vulnerability of the society cannot be attributed to a single cause but to a number of intersecting social processes resulting in inequalities in income and exposure. Some of the factors that have been noted to influence vulnerability to climate change include distribution of wealth, demographics, migration, access to technology and information, employment patterns, the quality of adaptive responses, societal values, governance structures and institutions to resolve conflict (IPCC, 2000, 2007, 2014b).

According to Little (2004), Somalia is largely a pastoralist community; with over half the population keeping livestock as their main source of livelihood. They rely on trees and shrubs for animal feed, and rivers to water animals particularly during the dry season. In sub-Saharan

Africa, energy consumption in rural areas is almost limited exclusively to wood as source of fuel, this applies to approximately 90% of the population (Sedano, et al., 2016). Authors such as Robinson (1988) identified charcoal as the main source of energy for cooking in Somalia, used by millions of households and has been described as “black gold” because of the revenue it produces. However, charcoal burning leads to deforestation and degradation with a serious negative impact on an important natural resource that pastoralist communities depend on (USAID, 2014).

The United Nations Environment Programme (UNEP) and the International Criminal Police Organization (INTERPOL) conducted a joint study in 2014 on the global environmental crisis that listed charcoal trade value in Africa at about USD 1.9 billion annually (UNEP & INTERPOL, 2014). Further studies by SWALIM (2014) on Somalia have reported that illegal charcoal export makes an estimated USD 340-360 million per year. This is despite the UN issuing a ban on the export of charcoal from Somalia in 2012. The UN Security Council also added that the export of charcoal was a significant revenue source for the militant group Al Shabaab, and that the resulting deforestation exacerbated the food security crisis in Somalia (UNSC, 2012a).

Prolonged and frequent drought associated with climate change is already causing massive loss of livestock for pastoralists in Somalia (World Bank, 2017). Preliminary reports by the World Bank (2017) stated that the 2016/2017 drought alone led to livestock-related losses ranging between US$1.3 billion and US$1.7 billion, and losses of up to US$60 million from crop production. Deforestation and degradation further impacts on livelihoods for pastoralists, decreasing their adaptive capacity to climate extremes. Given that climate change is already an existing stressor, complete deforestation would amplify the effects of climate hazards for communities in Somalia.

The effects of the change in land cover due to charcoal production is not only a key threat to the natural vegetation but has been proposed to have a long-term impact on climate (Brink et.al, 2012). Forests also play an important role in emissions, sequestration, albedo and the hydrological cycle (IPCC, 2014a). Through evapotranspiration and moisture circulation forests affects local rainfall and temperature during dry seasons. Reduction of tropical forests has been shown to reduce rainfall (Garcia-Carreras & Parker, 2011).

Although Somalia published its first National Adaptation Programme of Action (NAPA) in April 2013 through the coordination of UNDP, the issue of climate change and adaptation are yet to be integrated into any level of governance (FGS, 2013). In addition, no policies have been formulated or any adaptation measures implemented at the national or local level. During the period of this study, there were no interventions by the Government due to the high insecurity experienced in the region. Aside from the various interventions by international NGOs at the national level, there is limited national planning in place for adaptation and mitigation to climate change after the publication of the NAPA and the Intended Nationally Determined Contributions (INDCs) (FGS, 2015). Very little information is available on climate change in Somalia largely due to lack of ground based stations and or available instrumental records.

Limited institutional capacity continues to be a challenge in Somalia due to prolonged and protracted crisis(UNDP, 2011). Four of the envisaged federal units have been agreed and interim administrations are in place in each, i.e. the Interim Jubba Administration (IJA), Interim South State Administration (ISWA), Interim Galmudug Administration (IGA), and the Interim HirShabelle Administration (IHA) (IGAD, 2016). These are in addition to Puntland and Somaliland, which existed before the formation of the FGS. Somaliland however continues to claim autonomy. Jubbaland was the first state formed in August 2013 after the Federal Government of Somalia (FGS) came into power in August 2012.

This study concentrated on the Lower Jubba region located in the South of Somalia. Lower Jubba was selected for the study because in all the States of Somalia, reports from various monitoring agencies indicate that it has the highest amount of tree cutting, trade and export of charcoal in the South of Somalia, particularly during occupation of the Kismayo port by Al Shabaab (Oduori, *et al.*, 2011; Rembold, *et al.*, 2013; FAO, 2014). Lower Jubba, despite being highly degraded shows a lot of potential for agriculture. In addition, as the first fully formed state by the Federal Government, implementation of climate change adaptation in this region would be a precedent for other emerging States to build upon. The relatively better security and stability in Lower Jubba was also a major factor in its selection for the the study in comparison to other emerging states in the South of Somalia.

1.2 Statement of the Problem

Rapid deforestation due to the destructive charcoal production, over-grazing and poor state of land are causing irreparable damage to the environment in Somalia (SWALIM, 2009b). Charcoal production continues to be a key threat to natural vegetation growth. Complete deforestation would increase the communities' vulnerability to climate variability and extremes by affecting an important food source for pastoralists as well as impacting local hydrological cycle.

Climate change can lead to the development of new weather/climate related hazards, some more intense and frequent extremes, thereby introducing new challenges to human and economic activities. For realistic risk reduction strategies to be developed and effectively implemented at global, regional, national and community levels, the hazards and risks posed needs to be understood. Deforestation in Jubbaland and other parts of Somalia creates a new challenge for local communities, particularly in the context of a changing climate. Understanding the extent of deforestation and degradation due to charcoal production enables the determination of future risks and vulnerability of the communities living in these areas. This study examines the consequences of environmental destruction and its future impacts on the people of Jubbaland in the context of a changing climate.

1.3 Research Questions

The research attempts to answer several questions including: has there been significant deforestation resulting from the highly reported charcoal production in Lower Jubba; what is the observed change in the past and present rainfall and temperature of the Lower Jubba; what is the projected climate for this region; and what is the future impact of charcoal production on the local community given the projected climate. This research conducts a study to observe the extent of deforestation in Lower Jubba arguably due charcoal production and its resulting impact.

1.4 Hypothesis

H_0: The community in Lower Jubba does not turn to charcoal production as a response to vulnerability to climate change impacts;

H_1: Charcoal production is a response to the community's vulnerability to climate change impacts;

Information on land use and climate change in Somalia and Southern Somalia in particular is very limited. The port of Kismayo in Lower Jubba has been in the headlines for vast export of charcoal (Robinson, 1988; Rembold, et al., 2013; SWALIM, 2014; UNEP & INTERPOL, 2014). This is despite the UN ban on export of charcoal from Somalia in 2012 (UNSC, 2012a). This study hypothesises that the high volume of charcoal exported from Lower Jubba has had a significant impact on deforestation and land degradation. The study further hypothesises that deforestation increases the communities' vulnerability further particularly in a changing climate. Given that pastoralist communities in this region rely on trees and shrubs for their livestock's survival, particularly during drought, complete deforestation in the long run will impact their livelihoods, reducing the communities' ability to adapt to climate extremes. In addition, climate change is projected to amplify existing risks and create new ones, adding to the already existing and future socio-economic challenges, while deforestation would exponentially increase the vulnerability of the local communities.

1.5 Research Objectives

The main objective of this study is to examine the past and future trends in climate, impacts of charcoal production and propose adaptation options for Lower Jubba, Somalia. The specific objectives are to:

i. Characterize the past and current climate patterns over Lower Jubba;
ii. Evaluate the changes in land cover in Lower Jubba from possible impacts of charcoal production;
iii. Determine the impacts of climate change and variability on the livelihoods of the communities and the significance of charcoal production to it;
iv. Assess the potential impacts of future climate change over Lower Jubba.

1.6 Justification of the study

Climate change can exacerbate hazards, leading to more intense and frequent extreme weather, thus introducing new challenges to human and economic activities. It is critical to understand the past, present and future climate change and variability in the study area. Knowing the characteristics of climate variability in Lower Jubba is important in the assessment of the community's vulnerability. This is integral for informed adaptation and mitigation strategies. It is also important to further examine if cutting down of trees for firewood and charcoal production has had significant impact on land cover. Understanding the land cover change and the extent of deforestation and degradation is important in determining the sustainability of charcoal production in Lower Jubba.

It is further important to examine whether communities in the affected areas are aware of the activities acting as contributing factors to land degradation, and the resulting impacts of deforestation and degradation. Development of realistic climate change adaptation strategies is necessary both to the regional and federal levels of government if the impacts of climate hazards are to be effectively managed. United Nations International Strategy for Disaster Reduction (UNISDR) indicated that the rate of weather - related disasters and hazards has grown, with the annual average of weather-related disasters increasing by 14% between 1995 and 2014, and was almost twice the average recorded from 1985 to 1995 (UNISDR, 2015; EM-DAT, 2016).

Climate data infrastructure in most parts of Africa is generally underdeveloped resulting in lack of reliable, long-term and well distributed data. Generally, there is lack of credible scientific climate findings in most parts of Africa due to poorly distributed, unreliable and short duration data for research (King'uyu, Ogallo, & Anyamba, 2000; WMO, 2003; Washington, Harrison, & Conway, 2004; Omondi et al., 2014). There is limited national data source for climate change or land cover generally in Somalia but even less data can be found on the South of Somalia as a result of insecurity. High-resolution data which would have provided some land cover data, is very costly. The need for enhanced climate knowledge globally has been recognised by the United Nations Framework Convention on Climate Change (UNFCCC) and new arrangements for UNFCCC implementation was adopted at the 21st UNFCCC conference of parties (COP21), that included issues linked to INDCs.

Between 1994 and 2013, the Emergency Events Database (EM-DAT) recorded 6,873 natural disasters worldwide, which claimed 1.35 million lives. Almost 68,000 lives on average are lost due to natural disasters each year with 20,000 fatalities due to drought in Somalia in 2010 alone (EM-DAT, 2016). Records show that low to middle-income countries experienced more disasters, but 81% of people who died in these disasters in the last two decade lived in developing countries (UNISDR, 2015; EM-DAT, 2016). The El Niño Southern Oscillation (ENSO) phenomenon affects more than 60 million people around the world, particularly those whose livelihoods depend on agriculture, fisheries and livestock (UNEP, 2005). In Somalia, the UN reported 3 million people affected by the 2010/11 drought that was attributed to La Niña (Maxwell & Fitzpatrick, 2012; EM-DAT, 2016).

According to Fasona and Omojola (2005), forests play a significant role in the achievement of human security through the provision of livelihood resources like food, medicine, cooking fuel, construction materials, among other uses. Barnett and Adger (2007), further explained that forests reduce the vulnerability of communities to disasters, by reducing their exposure to natural hazards and providing them with the livelihood resources to withstand and recover from crises. Forests are undeniably linked to the wellbeing and prosperity of people (Fasona & Omojola 2005; Barnett & Adger, 2007; Ogallo et al., 2008; Feeley & Rehim, 2012). Deforestation therefore leads to increased exposure to hazards resulting from reduction in an important resource base from which communities can draw on during times of crisis.

Despite the lack of empirical data to support wood-fuel collection as a key driver of deforestation on a global scale, evidence exists at the local level showing that deforestation can have significant impacts on forest degradation (SWALIM, 2014). The UN based project, Somali Water and Land Information Management (SWALIM) reported that Africa accounts for 55% of the global charcoal production (SWALIM, 2014) and demand for wood-fuels is projected to continue to grow for several decades (FAO, 2010).

In Somalia, wood-fuel production is not only triggered by domestic consumption, but also by high foreign demand (UNEP & INTERPOL, 2014). High demand for charcoal in the Gulf States due to strict laws preventing local deforestation has created opportunities for traders to accumulate large profits (Rembold et al., 2013;). A report by UNEP (2005) found that most of the charcoal that is exported to the Gulf is produced in Southern Somalia, of which more than 80 per cent of trees used are acacia species with very little reforestation taking place. Excessive harvesting of acacia trees for charcoal production is rapidly leading to reduced biodiversity, deforestation and desertification in Somalia (UNEP, 2005).

Millions of households in Somalia rely on charcoal as the main source of fuel for cooking; it has also been reported as an important source of revenue particularly supporting extremist groups (Rembold et al., 2013). In the absence of alternatives, the vast majority of Somalis continue to rely heavily on traditional solid fuels, particularly charcoal. Lack of alternative livelihood source will probably continue to be a major source of conflict in Somalia, where two-thirds of youth are unemployed, one of the highest rates of joblessness in the world (UNDP, 2012b). UNEP estimated 4.4 million of trees being logged annually to produce the 250 thousand tonnes of charcoal exported every year from Somalia to Saudi Arabia, Yemen and the United Arab Emirates (UNEP, 2005). The magnitude of the charcoal trade for both domestic consumption and export is not sustainable, particularly if there is no system for replenishment.

There is need to substantiate the speculation that has been made on extent of deforestation due to charcoal production in Somalia. State institutions in Somalia are either weak or collapsed, with limited or no institutional memory and service delivery. Deforestation not only has an impact on CO_2 and CH_4 emissions but also plays an important role in the hydrological cycle (Nakicenovic & Swart, 2000; Bala et al., 2006; Brovkin et al., 2006; IPCC, 2007). Development of adaptation and mitigation strategies in this region will require more data on both climate change and deforestation. This study therefore bridges some of the knowledge gaps on climate change and deforestation, with a focus on Lower Jubba Somalia.

This research has provided much of the needed information on deforestation resulting from the highly reported charcoal production; past and present changes of climate; the projected rainfall and temperature patterns for the region; implications of the future impacts of charcoal production on the local community given the changing climate. Results provide a knowledge base for building blocks towards the formulation of realistic adaptation and mitigation policies for Somalia.

1.7 Scope and Limitations

There are areas in Lower Jubba that are still under the militant group Al Shabaab restricting movement to some parts of the region. This was a challenge preventing ground truthing in some parts of Lower Jubba. This challenge was overcome through the use of high-resolution image spectroscopy. However because of the high cost of high-resolution images, a study area that covered samples of all the districts in Lower Jubba was selected instead of the entire Lower Jubba. Time constraints was a limiting factor in preventing the study of the three regions in the Jubbaland area namely Gedo, Lower and Middle Jubba region. The study area selected covers the port of Kismayo where the export of charcoal was highly reported as well as the largest forest in Somalia, Boni forest that extends all the way into Kenya.

Cultural limitations were also a challenge in conducting the surveys. Interactions between people of opposite gender are frowned upon. Language barrier was also an additional challenge. Training students from the local community to conduct the survey and translating the questionnaires to the local dialect overcame these challenges. Interpreters were also used to conduct some key informant interviews. The focus group discussions were attended by men only, this was largely because the only secure venue was a hotel which is largely frequented by men. Given that participation was voluntary, the discussions took place with the respondents who made themselves available at the selected venue. Security limitations prevented the use of a more culturally suitable venue for women to participate in a focus group discussion.

Limitations on the observed climate data were a challenge with lack of any national meteorological services. This was overcome using stations with data in Afmadow and Bardheere by Food and Agriculture Organization (FAO) Somalia Water and Land Information Management (SWALIM) which was blended with satellite data.

CHAPTER 2 : LITERATURE REVIEW

In this chapter, the literature relevant to this study is reviewed. The literature includes past studies on charcoal production and associated impacts on the environment, and climate variability and change globally, regionally, nationally over Somalia, and over Jubbaland.

Charcoal production leads to land degradation, which decreases the soils capacity to absorb water which increases flooding during heavy rains (Fox, 2014). Land degradation leads to soil erosion, which further reduces productivity of the land; degraded soil is less likely to support regeneration of vegetation which pastoralists depend on. Land degradation has direct impact on livelihoods and food (Pimentel, et al., 1995; Gisladottir & Stocking 2005; Blaikie & Brookfield, 2015). This increased vulnerability makes it harder for rural communities to withstand related extreme events such as flash floods and drought.

2.1 Climate Change

The IPCC (2007) defines Climate change as a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural processes within the earth/atmosphere system, or due to human related factors that lead to persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2007). It should be noted that in Article 1 of the United Nations Framework Convention on Climate Change (UNFCCC), climate change is defined as a change of climate that is attributed directly or indirectly to human activity. The UNFCCC thus makes a distinction between climate change attributable to natural causes and those that may be associated with human activities altering the atmospheric composition (Naomi , 2004; Rosenzweig, et al., 2008; Gordon , 2008; Anderegg, et al., 2010; Moss, et al., 2010; IPCC, 2014a).

Knutti and Hegerl (2008) state that climate sensitivity is largely determined by internal feedback processes that amplify or dampen the influence of radiative forcing on climate. The three fundamental ways to change the radiation balance of the Earth is by changing the incoming solar radiation by changes in Earth's orbit or in the Sun itself; changing the fraction of solar radiation that is reflected (albedo); and by altering the longwave radiation from Earth back towards space through change greenhouse gas concentrations. Gordon (2008) in his study further explains that the natural greenhouse effect leads to trapping of heat in the earth's atmosphere. An increase in greenhouse gases results in an increase in the heat trapped in the atmosphere resulting in global warming. The greenhouse gases that have the most effect on global warming are water vapour and carbon dioxide (CO_2).

Anderegg, et al., (2010) associated global warming with anthropogenic greenhouse gas (GHG) emissions driven largely by economic activities and population growth factors. Global surface temperature is projected to rise over the 21st century under all assessed GHG emission scenarios, with severe impacts on weather and climate extremes including: extreme precipitation events becoming more intense and frequent in many regions; ocean continuing to warm and acidify; sea level rising; more frequent and longer lasting heat waves occurring, that would have severe impacts on natural and human systems in all continents and across the oceans. In Africa impacts are likely to be more severe due to increased vulnerability caused by limited ability to adapt.

2.2 Climate Change Risks and Impacts

Climate change is projected to increase the frequency and severity of extreme weather and climate change impacts as well as trigger new ones. According to Lobell, et al., (2008) these would undermine the safety of ecosystems, sustainability of basic livelihoods, food security and health, among many other socio-economic impacts if no adaptation measures are taken. Evidence shows that changes in the climate system may already be affecting human health, including temperature related mortality and morbidity, with some of these effects being due to the change in the ecology of infectious diseases (Patz, *et al.*, 1996; IPCC, 2000; WHO, 2003; Patz, *et al.*, 2005; IPCC, 2007, 2014b).

Climate change impacts are also projected to slow down economic growth, making poverty reduction more difficult, prolonging existing and creating new poverty traps; these projections led to the convention of the Rio+20 United Nations Conference on Sustainable Development Goals (SDG). IPCC assessment indicate that the developing countries, especially the African countries and low lying coastal areas and islands are the most vulnerable. The high vulnerability of the African continent has been linked to low adaptive capacity, as well as recurrences of the climate related hazards. IPCC reports that climate change impacts are unevenly distributed, with developing countries projected to face the greatest challenges due to the low coping capacity and high vulnerability (IPCC, 2007; 2014b).

Climate change, water and poverty are deeply intertwined in developing countries (Paavola 2008). Authors such as Smit and Wandel, (2006) identify vulnerability as a factor of exposure, sensitivity and adaptive capacity. Smit and Wandel (2006) in their study found that in Africa, vulnerability is linked to population pressure, over utilization of natural resources, environment degradation, and unplanned settlements among other issues. Poverty reduction target for the Sustainable Development Goals (SDG) in Sub-Saharan Africa is unlikely to be met due to the slow pace of economic growth (UNDP, 2010). The link between climate change and poverty poses a further threat to sustaining the growth and goals that have been made. The differences in vulnerability and exposure in developing countries arises more from uneven development factors than from climatic factors (Smit & Wandel, 2006; IPCC, 2014b).

Ngigi (2016) describes vulnerability as absence of the adaptive capacity, the inability to cope to climate change stressors. Livelihoods in most cases in the region informs vulnerability and in sub-Saharan Africa, most livelihoods are linked to rain-fed agriculture, which is threatened by climate change (Cooper et al., 2006). Thurow, Herlocker, and Elmi (1989) stated that intersecting social processes that result in inequalities in socioeconomic status and income usually causes vulnerability. In Somalia, livelihoods are characterised by low levels of income and dependence on risky pastoralist practices (Thurow, Herlocker, & Elmi 1989).

A report by Cagnolati, Tempia, and Abdi (2006) found that Somalia experienced an estimated loss of US$ 109 million in the first ban on export of livestock due to Rift Valley Fever (RVF) between Feb 1998- May 1999, and a loss of US$ 326 million between Sept 2000 and Dec 2002 in the second ban. The losses from the RVF outbreak in 2006/2007 and temporary suspension in the export of livestock issued in October 2015, is yet to be quantified. Pastoralists in Somalia are reported to have turned to the trade of charcoal to supplement their income after the export ban. (Bachorz, 2012; NMG, 2012; Smith, Hudson, & Schreckenberg 2017). Farmers have been known to resort to charcoal production to cope with drought (Paavola 2008; Smith et al., 2017). Charcoal production therefore plays an important role in community livelihoods, therefore maintaining or increasing income levels to reduce vulnerability to climate change.

Somali people are generally marginalized and vulnerable to climate change (Raleigh, 2010). Limited adaptation and mitigation responses are in place in Somalia with a heavy reliance on existing traditional practices (NAPA Somalia, 2013). Impacts of climate-related extremes include alteration of ecosystems, disruption of food production and water supply, damage to infrastructure and settlements, morbidity and mortality, and consequences for mental health and human well-being (IPCC, 2001; 2007; Patt, et al., 2010; Coumou & Rahmstorf, 2012; IPCC, 2014a). Somalia has been vulnerable to frequent external and internal shocks, with frequent and recurring droughts being one internal shock that often disrupts economic activities. The UNEP reported droughts as being far more consequential to the society and development aspirations in Somalia than external shocks (UNEP, 2005). Table 2-1 and 2-2 shows a summary of the impact of the hydro meteorological disasters in Somalia.

Table 2-1: Summary of hydro meteorological disasters in Somalia 1973-2016 (EM-DAT, 2016)

Disaster type	Disaster subtype	Events count	Total deaths	Total affected
Drought	Drought	14	39673	18419124
Flood	Riverine flood	25	2580	2181100
Flood	--	7	234	1216296
Storm	Tropical cyclone	4	192	146380
Flood	Flash flood	9	57	95282

Table 2-2: Top twelve hydro meteorological disasters in Somalia 1973-2016 (EM-DAT, 2016)

Disaster Year	Type	Total affected	Totals deaths
1964	Drought	700000	50
1974	Drought	230000	19000
1977	Flood	40000	
1981	Flood	30000	5
1983	Drought		
1987	Drought	500000	600
1987	Flood	30000	
1988	Drought	53500	
1989	Flood	50000	34
1994	Flood		100
1995	Flood	8500	20
1996	Flood	100	3
1997	Flood	1230000	2311
1999	Drought	1200000	
2000	Drought	1200000	21
2000	Flood	373500	
2001	Flood	6500	
2003	Flood	300	1
2004	Drought	200000	
2005	Drought		2
2005	Flood	7520	12
2006	Flood	486500	102
2007	Flood	10012	25
2008	Drought	3300000	
2008	Flood	52000	
2009	Flood	1750	
2010	Drought	4000000	20000

2010	Flood	16200	11
2011	Drought	3000000	
2011	Flood	2800	
2012	Drought	3000000	
2012	Flood	32200	31
2013	Flood	105000	7
2014	Drought	535624	
2014	Flood	90000	
2015	Drought	4700000	
2015	Flood	916296	
2016	Flood		9

Climate change and variability can lead to scarcity of natural resources thus exacerbating the risks of civil conflicts (Scheffran & Battaglini, 2011; Raleigh & Kniveton, 2012; IPCC, 2014b). Conflict hampers adaptation, including infrastructure, institutions, natural resources, social capital and livelihood opportunities (IPCC, 2014c). Protracted conflict in Somalia since the collapse of the Somali Democratic Republic in 1991 has meant lack of education in the rural areas, destruction of infrastructure and lack of governance to pass and implement any form of legislation (Menkhaus, 2011; ACLED, 2013; Maystadt & Ecker, 2014; Jamal, 2015). This prolonged conflict has led to one of the fastest and largest population displacements ever recorded on the African continent (UNEP, 2005). Land degradation reduces productivity in agriculture. For pastoralists, climate change presents new conflict triggers for an already fragile state.

2.3 Environmental Management

Vegetation and the change of vegetation cover plays an important role in the carbon cycle; actions that affect the forest sector can have an impact on greenhouse gas emissions and so climate change (UN-REDD, 2015). Decreasing emissions from deforestation and forest degradation can reduce the amount of CO_2 in the atmosphere. The significance of the contribution of emissions from deforestation and forest degradation to climate change led Parties to the UNFCCC to take mitigation measures by creating a mechanism for Reducing Emissions from Deforestation and forest Degradation (REDD+).

IPCC defines deforestation as the conversion of forests to pasture, cropland, or other managed uses (IPCC, 2000). Forest degradation is defined as human activities that negatively impact on the forest, causing the part removal and loss of ecosystem function (UN-REDD, 2015). Conservation of forests can preserve their role as a carbon sink and restored forests can increase the sequestration of carbon, thus reducing the overall levels of CO_2 emissions in the atmosphere (IPCC, 2000). The forest sector acts as a carbon sink by storing and enhancing carbon from above ground biomass, below ground biomass, soil organic carbon, litter and dead wood (UN-REDD, 2015).

Trees contain substantial stores of carbon, removal of trees causes the release of some of the carbon stored within them (UN-REDD, 2015). Charcoal production is a key driver of land cover change in sub-Saharan Africa with over 80% of the urban population relying on charcoal for fuel (Zulu & Richardson, 2013). IPCC estimates that 10% of the total anthropogenic net CO_2 emissions is from land use change (IPCC, 2014c). The level of carbon dioxide emissions depends on the amount of carbon stored in the forest, the extent of damage to the vegetation cover and soil structure, as well as what happens to the land afterwards (UN-REDD, 2015). The effect of the loss of forest-sequestered carbon in Somalia is not yet quantified. Impacts of climate change are however has been felt through increase in frequent and prolonged droughts in the country, which has negatively impacted livelihoods (Maxwell & Fitzpatrick, 2012).

Pennis et al., (2001) found that charcoal making in Jubbaland varies greatly in structures and size, from simple earthen mounds to semi-permanent brick ovens. Carbonization creates a fuel of higher quality than the original fuel-wood. Because of inherent inefficiency in the process, however, there is a substantial loss of carbon and energy from the starting fuel-wood (primarily as carbon dioxide) and, because of the chemical process as well, a significant production of products of incomplete combustion (PIC) (Pennis et al., 2001). The PIC emitted during the charcoal making process include carbon monoxide (CO), methane (CH_4), total non-methane organic compounds (TNMOC), and particulate matter.

Oxides of nitrogen (e.g. Nitrogen monoxide [NO], Nitrogen dioxide [NO_2], and Nitrous monoxide [N_2O]) are emitted as well. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are important greenhouse gases (GHG) in that they directly absorb some of the Earth's outgoing radiation in the atmosphere. Carbon monoxide (CO) and Total Non-Methane Organic compounds (TNMOC) indirectly affect global warming through atmospheric photochemical reactions that in turn affect GHG levels. The emission of incomplete combustion products (such as CH_4, TNMHC, and CO) is quite important. This is due to the fact that CH_4, TNMHC, and CO have higher Global Warming Potential (GWP), or ability to cause warming of the Earth's atmosphere per mole or kilogram of carbon, than does CO_2 (Lashof & Ahuja, 1990; IPCC, 2000, 2007; Boucher, et al., 2009; IPCC, 2014b).

Aside from the potential role of forests in contributing to climate change mitigation through the reduction of emissions by afforestation, reforestation and conservation of forest carbon stocks, forest conservation also secures the livelihoods of communities that depend on them. More than 1.6 billion people depend on forests for food, water, fuel, medicines, traditional cultures and livelihoods (UN-REDD, 2015). Resilience for pastoralists is dependent on the herds' ability to access fodder provided by the trees being cut down for charcoal. Rural households also depend on fuel from forests. Land degradation has been shown to negatively impact livelihoods and food security (UNSC, 2012a; USAID, 2014). Degradation leads to declining land productivity which increases poverty, particularly in rural areas (USAID, 2014). Climate extremes and variability could further threaten the livelihoods and food security for the already vulnerable community.

The reduction in land productivity caused by deforestation and forest degradation increases the vulnerability of pastoral communities in Somalia by directly impacting their livelihoods. Furthermore deforestation can directly influence climatic conditions at local, regional and global scales by changing regional moisture convection currents (Feeley & Rehim, 2012). Although the albedo effect due to deforestation in the tropics is said to cause little change, cloud feedbacks initiated by evapotranspiration changes play a major role in determining the overall climatic impact of deforestation in the tropics (Bala et al., 2006). Deforestation and associated land degradation is projected to increase the water scarcity effects in Somalia, resulting in an increase in the population's vulnerability to drought (SWALIM, 2014).

Understanding land cover change for pastoral communities like those Somalia must therefore be considered to achieve realistic estimates of the future economic development. Land cover change is also essential in understanding the local change in climate particularly because of its role in the hydrological cycle (IPCC, 2014a). Conversion of large areas of tropical forest to grassland could therefore reduce water cycle and precipitation in the region as shown in **Figure 2-1** (IPCC, 2000, 2007; Miller & Janet, 2013; IPCC, 2014b). Major models have projected indirect impacts from deforestation relating to rainfall patterns and surface temperatures at local, regional and global levels (Shukala, *et al.*, 1990; IPCC, 2007; Miller & Janet, 2013; IPCC, 2014b).

Evapotranspiration and moisture circulation that occurs through forests is much larger than that of grassland (Miller & Janet, 2013). Studies on tropical forests show that deforestation results in reduced rainfall during the dry seasons (Lettau, *et al.*, 1979; D'Almeida, *et al.*, 2007; Garcia-

Carreras & Parker, 2011; IPCC, 2014b). Charcoal production can lead to change in land use from forest and woodlands to grassland which would impact soil moisture thus increasing surface runoff (Garcia-Carreras & Parker, 2011; IPCC, 2007, 2014b). The soil becomes highly compacted and rainwater cannot penetrate as easily becoming unavailable for transpiration later (IPCC, 2007). This in turn reduces the rainfall much needed by pastoralists during dry seasons, negatively impacting their livelihoods.

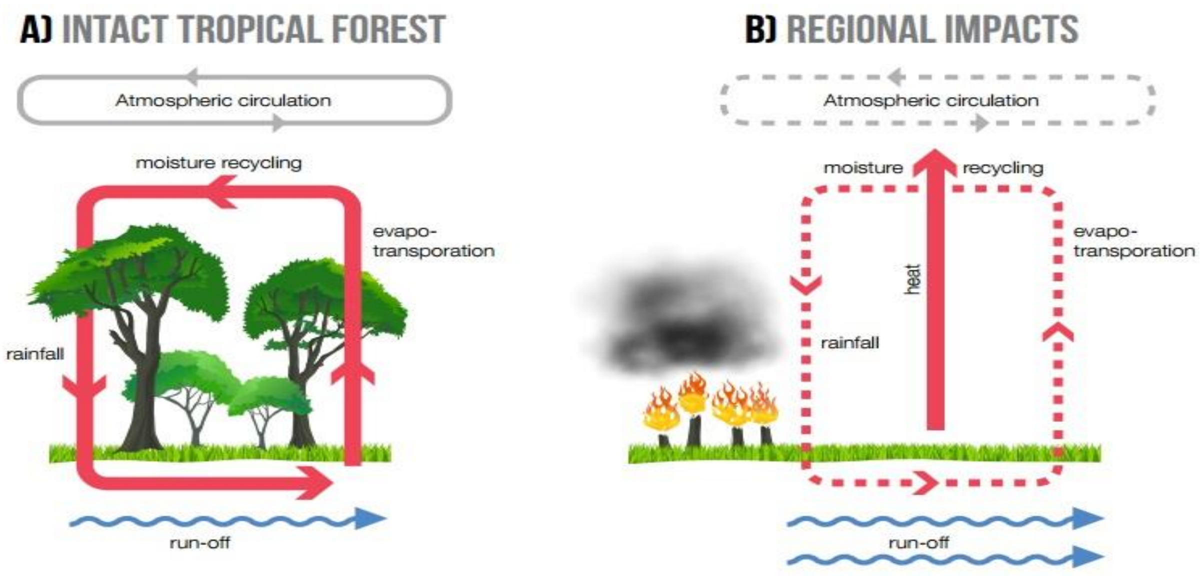


Figure 2-1: Impact of Deforestation on the Earth's Water Cycle (Miller & Janet, 2013)

Forests influence climate through physical, chemical, and biological processes that affect planetary energetics, the hydrologic cycle, and atmospheric composition which can dampen or amplify anthropogenic climate change. According to IPCC reports, emissions from land use, primarily deforestation, account for 23% of global CO_2 and 74% of CH_4 emissions (Nakicenovic & Swart, 2000). Land cover changes impacts atmospheric composition and climate primarily through biogeophysical and biogeochemical mechanisms. In biogeophysical mechanisms, surface albedo and evapotranspiration play a major role, and is thought to have had a global cooling effect, while biogeochemical mechanisms effects result from direct emissions of CO_2 into the atmosphere as a result of deforestation (Bala et al., 2006; Brovkin et al., 2006; IPCC, 2007; Kueppers, Snyder, & Sloan, 2007; Laguë & Swann, 2016).

Most Somalis continue to rely heavily on traditional solid fuels, particularly charcoal and firewood, but these energy resources are shrinking rapidly due to overexploitation for both energy and grazing needs thus contributing to deforestation and forest degradation (Robinson, 1988; SWALIM, 2014). Human security is tied to access to natural resources and vulnerabilities to environmental change (Sanjeev, Clark, & Firas, 2003). Social scientists have theorised that environmental change can create insecurity and possibly trigger violent conflict among people because it leads to scarcity and inequality driven conflict (Walters, 2008). Lack of resources is reported to have led a large number of youth in Somalia into charcoal production, piracy and recruitment into extremist groups (Bueger, 2012; Whitman, 2013).

Quantitative national-level information on drivers and activities causing deforestation and forest degradation are widely unknown (Hosonuma et al., 2012). However, population growth and economic factors have been speculated as some of the most significant drivers of land-use change (Lambin, *et al.*, 2001; Geist & Lambin, 2002; IPCC, 2007; Lambin & Meyfroidt, 2010) Energy consumption has been listed as deforestation driver in rural Africa, as energy in here is limited almost exclusively to fuel wood (Girard, 2002; Bailis et al., 2005; Brink et al., 2012; Sedano et al., 2016; SWALIM, 2014). Charcoal production is a significant driver of forest degradation in sub-Saharan Africa (Sedano et al., 2016). In Somalia, charcoal for export has been reported to generate very high revenue (Robinson, 1988; SWALIM, 2014).

Charcoal harvesting is currently the single largest contributor to environmental degradation in southern of Somalia (FGS, 2012b; UNSC, 2012a; USAID, 2014). High insecurity in the south has resulted in very little information available on tree cover loss in the southern part of Somalia. However, there is evidence that the war economy fuelled by the conflict is rapidly depleting the country's natural resources (Rembold et al., 2013). Though charcoal for fuel is widespread across Somalia in both rural and urban communities, it is the foreign demand that is of the highest concern with an estimated 4.4 million trees logged annually for export (SWALIM, 2014).

Charcoal developed into one of the major export products in Somalia (UNEP, 2005), and is commonly used in the Gulf for smoking *shisha* (USAID, 2014). Its production is said to have become a major source of income for 70% of poor and middle-income pastoralists in Somalia as minimal capital is required for production (Beier & Stephansson, 2012; WB, 2016a). Charcoal production in some parts of Somalia is reported to have become mechanized and controlled by cartels (USAID, 2014). Evidence of tree cover changes in the south of Somalia so far has largely been obtained through satellite imagery with no verification of data due to high insecurity (Oduori, *et al.*, 2011; Rembold, *et al.*, 2013; FAO, 2014).

FAO estimated a 3.3% loss of tree cover between 2011 and 2013 in the south of Somalia along the Juba River though results were not verified. The estimation was made by identifying possible kilns in the area and estimating the amount of charcoal being produced in each kiln. In North Eastern Somalia, another study on charcoal driven deforestation looked at two areas that had experienced a reduction in tree cover of 17% between 2001 and 2006. Conservation initiatives were taken in one area while business remained as usual in the second area. The area with no conservation measures had a further loss in tree cover of 24% while that with conservation measures had almost no loss at 0.64% between 2007 and 2010 (Oduori et al., 2011). Forests conservation is one of the largest and most cost-effective climate solutions available today. Studies done in Honduras, Nicaragua and Guatemala reported that there are great benefits of agroforestry as a solution to deforestation (Current, *et al.*, 1995).

The Conference of the Parties (COP) through the Subsidiary Body for Scientific and Technological Advice (SBSTA) and Subsidiary Body for Implementation (SBI) and other bodies, undertake work matters relating to:

- Land use;
- Land use, land-use change and forestry (LULUCF); and
- Reducing emissions from deforestation and forest degradation in developing countries (REDD).

These put into place mechanisms and methodologies for developing countries to reduce emissions from deforestation degradation. Conservation, sustainable management and restoration of forests can contribute to economic growth, poverty alleviation, rule of law, food security, climate resilience and biodiversity conservation (UN-REDD, 2015).

2.4 Adaptation and Mitigation

The 21st Conference of the Parties (COP21) of the UNFCCC that was held in Paris, adopted an agreement in December 2015 termed ‘Paris Agreement’, dealing with greenhouse gases emissions mitigation, adaptation and finance starting in the year 2020. Member countries to the UNFCCC agreed to publicly outline their post-2020 climate actions under the framework of the ‘Intended Nationally Determined Contributions (INDCs)’. The INDCs will become the first greenhouse gas targets under the UNFCCC that applies equally to both developed and developing countries.

Climate change is a threat to sustainable development particularly if no sound climate smart systems are developed, effectively applied, and integrated with multi-hazards disaster risk reduction and sustainable development frameworks within local, national, regional and international 'resilience agenda'. This has been recognized by post 2015 UN development agenda addressing Sustainable Development Goals (SDGs); and the Sendai Framework for Disaster Risk Reduction (2015-2030) that was adopted at the Third United Nations World Conference on Disaster Risk Reduction (WCDRR) in March 2015 in Sendai, Japan. The Sendai framework builds on the UN Hyogo Framework for Action 2005-2015 (HFA) - Building the Resilience of Nations and Communities to Disasters.

The need to strengthen Somalia's capacity to deal with major disasters such as the tsunami, floods and protracted droughts that it continues to face is critical (IUCN, 2006). With the global security and refugee crisis, donor support is becoming limited while the humanitarian crisis increases with each major climate related disaster (Lautze, *et al.*, 2012). Somalia in its national report for the 2004 WCDRR stated a lack of environment for planning for development, finances, infrastructure and limited knowledge as its main institutional challenges in ensuring preparedness for disasters (FGS, 2004). There is further need to integrate climate change and disaster risk reduction strategies with development agendas.

Adaptation is becoming embedded in some planning processes, with more limited implementation of responses (IPCC, 2014c). The lack of a completed political process in Somalia is a major hindrance to any national adaptation planning process (FGS, 2013). Five of the envisaged federal states have been formed but the constitution is not yet finalised, and as a result the operationalization of the federal system is not clear, making decentralization of any adaptation initiatives difficult. Protracted conflict and existence of extremist factions have led to high insecurity and lack of access to populations. This has also contributed to lack of climate data making an accurate assessment of climate change in Somalia difficult. Somalia has stated a lack of financial and human capacity as a hindrance in its ability to cope with natural disasters and long term environmental change (FGS, 2004, 2013).

Adaptation and mitigation choices in the near term will affect the risks of climate change throughout the 21st century. IPCC reports large uncertainties about future vulnerability, exposure, and responses of interlinked human and natural systems (Patt, et al., 2010; Coumou & Rahmstorf, 2012; IPCC, 2014c). Unless adaptation measures to climate change are taken, it is highly unlikely that Somalia will be able to achieve any of the Sustainable Development Goals (SDGs), which could have drastic effects on the development efforts.

Projects have been developed in Puntland and Somaliland that encourage use of solar cookers in the place of charcoal (Dini, 2011). Research on the potential for wind energy generation in Somalia shows that 85% of the country is suitable for wind power production, an area that is yet to be exploited (Pallabazzer & Gabow, 1991; Pallabazzer & Gabow, 1992). Somalia could contribute to mitigation actions by reducing emissions from deforestation; reducing emissions from forest degradation; conservation of forest carbon stocks; sustainable management of forests; enhancement of forest carbon stocks (UN-REDD, 2015).

An in-depth study of charcoal production in Malawi showed that for rural livelihoods, illegal charcoal production though not seen as a desirable livelihood strategy, is undertaken as it reduces households' vulnerability by providing a source of savings, asset building, reducing poverty levels and improving wellbeing. Unlike Somalia, anticipation in the trade of charcoal for rural communities in Malawi was reported as seasonal and largely based on need. 90% of charcoal production in Mozambique is illegal but unlike in Malawi production of charcoal is not practiced as a last resort (Luz, *et al.*, 2015; Jones, *et al.*, 2016). Even though a large number of the rural community is engaged in charcoal production the largest beneficiaries of the trade in Mozambique are the large-scale producers, most of whom are licensed (Luz *et al.*, 2015).

Kyoto Protocol makes provisions for climate mitigation through Clean Development Mechanisms (CDM) through afforestation/reforestation in developing countries to help achieve emission reduction targets and promote sustainable development (UNFCCC, 1998). Studies have shown that CDM contributes very little to sustainable development (Olsen, 2007; Sutter & Parreño, 2007), though it is reported that very few CDM projects are being undertaken on afforestation and reforestation. Finance, administration and governance issues have been stated as the reason for the few afforestation and reforestation projects (Thomas, *et al.*, 2010). Despite developing countries being unhappy with the structure of the mechanism, CDM offers financial incentives for governments and local communities to profit from afforestation and reforestation, providing a financial alternative to charcoal production.

Generally in Somalia, there exists a gap in knowledge and understanding of charcoal based livelihoods and particularly in the South of Somalia. Lack of empirical data on the extent of deforestation and degradation is a challenge to any empirical climate change impacts study.

Gaps further exist in the availability of information on climate change in Somalia generally. Effective adaptation and mitigation strategies require the availability of a long record of climate data. This study adds to the baseline information on rainfall and temperature on Lower Jubba. It intends to give informed science-based information on the impacts of deforestation and degradation, and further identifies some of the drivers of charcoal production in Lower Jubba. The information provided in this study will enable effective, efficient and equitable policies, actions and measures specific to Lower Jubba.

CHAPTER 3 : STUDY AREA, DATA AND METHODS

In this chapter, a detailed description of the study area, data and methods used to achieve the objectives of this study is given.

3.1 Study area

This study was conducted in Lower Jubba located in the Jubbaland, Somalia (**Figure 3-1**) which occupies an area of approximately 637,540 km^2, and is situated within latitudes 1.5ºS – 12.0ºN and longitudes 41.0ºE – 51.0ºE. Somalia is part of the Greater Horn of Africa which also includes Kenya, Sudan, South Sudan, Uganda, Ethiopia, Eritrea and Djibouti. It is bordered by Djibouti to the North-West, the Gulf of Aden to the North, the Indian Ocean to the East, Kenya to the Southwest and Ethiopia to the West (ICPAC, IGAD & WFP, 2017). Its coastline is the longest in Africa at over 3,025 km. This ranges from the Gulf of Aden in the North to the Indian Ocean in the East and South, with coastlines of around 1,000 km and 2,000 km respectively, making it one of the longest coastlines globally (CIA, 2016).

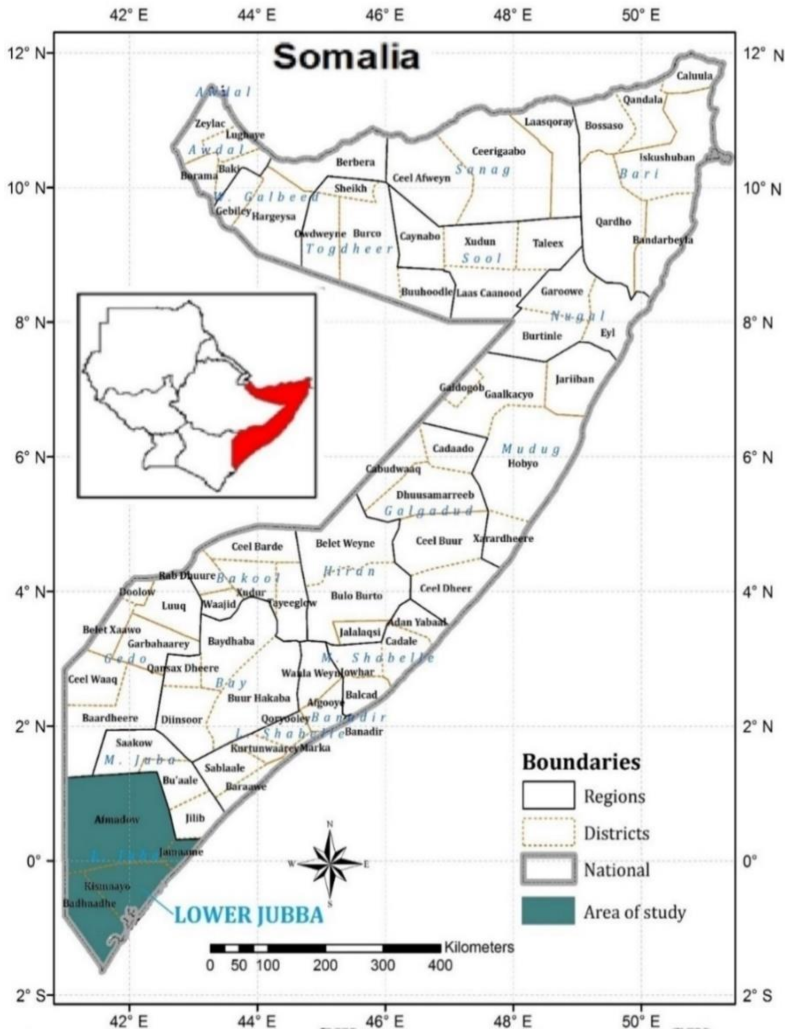


Figure 3-1: Map of Study Site in Somalia

The study specifically focused on Lower Jubba, located in the Jubbaland state of Somalia, whose administration was formed in 2013 (Maystadt & Ecker, 2014 Jamal, 2015). Jubbaland lies 40–60 km east of the Jubba River, stretching from Gedo to the Indian Ocean, and it borders the Garrisa, Wajir and Mandera County of Kenya on the western side (**Figure 3-2**). The state of Jubbaland consists of the Gedo, Lower Jubba and Middle Jubba regions. Kismayo, located in Lower Jubba, is the largest city in Jubbaland, and the third largest city in Somalia after Mogadishu and Hargesa (AMISOM, 2016).

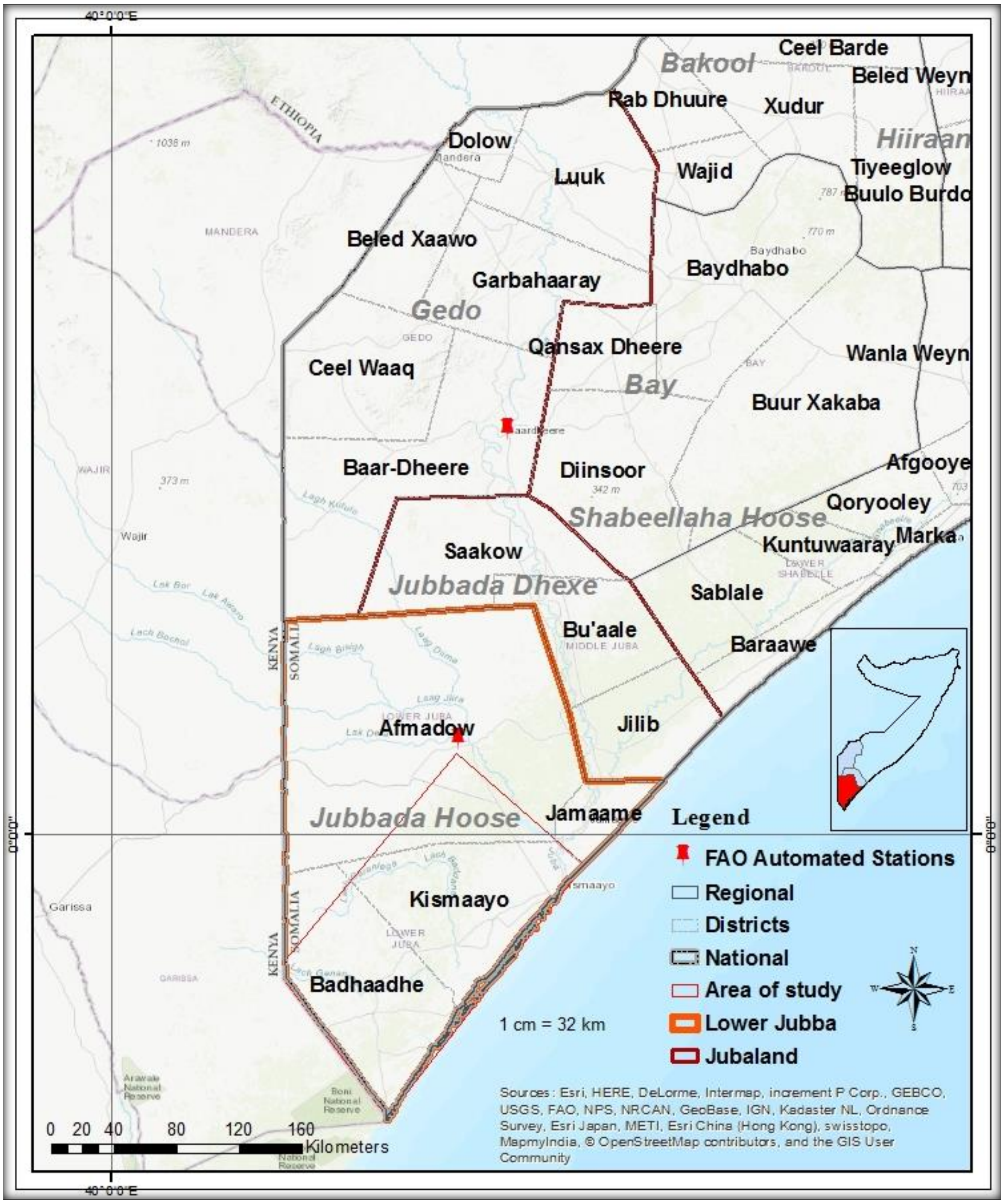


Figure 3-2: Specific Study Area

Lower Jubba covers about 35,114 square kilometres of relatively flat land, of which, more than 90 percent is classified as rangeland (Little, 2004). Lower Jubba is rich with fertile soils, with both the Jubba and Shabelle rivers flowing through it (AMISOM, 2016). The wetlands of the Jubba River Valley is known in Somalia for its rich grazing grounds, as it has good stands of perennial grass during dry season. UNDP (1998) reported that the concentration of cattle in the floodplains in the Jubba Valley is the highest of any region in the country and among the highest anywhere in eastern Africa.

3.1.1 Climatology of the Study Area

3.1.1.1 Climatology of rainfall

The Federal Government of Somalia (2013) stated the rainfall in the country is affected mainly by the Inter-Tropical Convergence Zone (ITCZ), monsoonal winds and ocean currents, jet-streams including the 'Somali Jetstream', easterly waves, tropical cyclones, the Indian Ocean and Red Sea conditions. It is also affected by teleconnections such as El-Niño/Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) (FGS, 2013). Pallabazzer & Gabow (1992) further stated that Somalia experiences permanent strong and dry winds from the Arabian Peninsula during June to September named *Kharif*, which are extremely favourable for solar and wind energy harnessing.

Somalia is characterised by four seasons, two dry seasons from December to March (*Jiilaal*) and from July to September (*Xagga*), and two rainy seasons from April to June (*Gu*) and October to November (and sometimes September) (*Deyr*) (FGS, 2013). ICPAC (2017) reported that Somalia generally experiences low and erratic rainfall with the annual average being about 250 mm, with the exception of the south-west that receives up to 700mm annually. The Federal Government (2013) stated that the average rainfall decreases inland in the South of Somalia, with the upper Shabelle River valley receiving up to 400mm/year while the area between the Shabelle and the Jubba River basins receive relatively higher rainfall of about 500 – 700mm/year.

Jubbaland state receives some of the highest amount of rainfall in Somalia with Badhaadhe, Kismayo, Afmadow, Buaale and Jilib getting about 630 - 830 mm/year. Jamame, Saakow and parts of Baardheere get 520- 630 mm of rainfall annually. Some parts of Baardheere, Ceel Waaq, Garbahaare, Luuq and Belet Xaawo get 400 – 520 mm of rainfall annually. Dolow and parts of Luuq get the lowest amount of rainfall of about 200-400 mm annually as shown in

Figure 3-3 (ICPAC, IGAD & WFP, 2017). Studies show that dry and wet precipitation extremes linked to droughts and floods are associated with increased risk of social conflict in competition for available resources (Barnett & Adger, 2007; Hendrix & Glaser, 2007; Maystadt & Ecker, 2014).

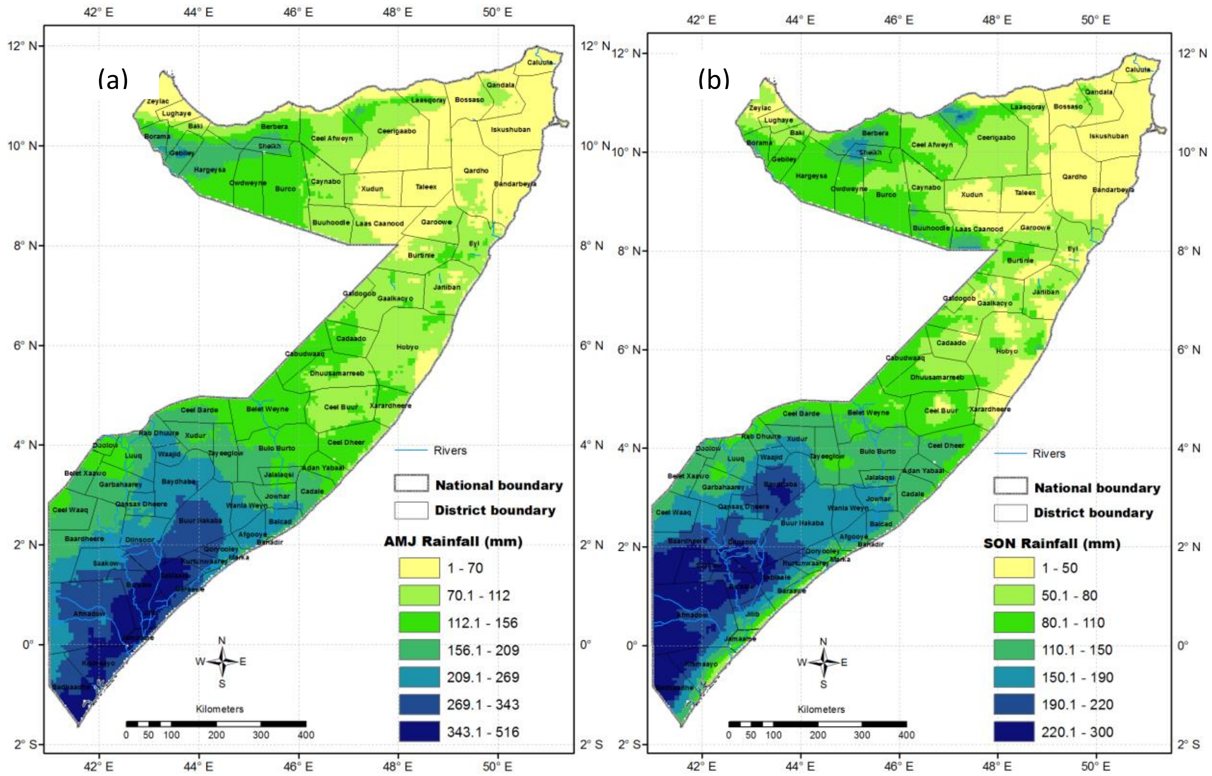


Figure 3-3: Map of Somalia Climatology of Somalia rainfall for (a) AMJ (*Gu*) and (b) SON (*Deyr*) (source: ICPAC, IGAD & WFP, 2017)

3.1.1.2 Climatology of surface temperature

The Federal Government of Somalia (2013) reports the mean surface temperature in most months and throughout the country at about 30ºC to 40ºC. Cooler temperatures are concentrated in the southern coastal regions and at higher elevations, while the coolest months are between July and August. The highest seasonal temperature variability occurs in the North when winter months bring below freezing temperatures to the highlands, and summer heats the Gulf of Aden coast up to more than 45ºC (ICPAC, IGAD & WFP, 2017). Generally, the hottest period in the South of Somalia is experienced in the months of March to April. Diurnal temperature fluctuations are high throughout the year and can range from 20°C to 35°C.

In the state of Jubbaland, the temperature is highest and ranges between 31-33°C in March and April around Bardheere, Luuq and in the south of Afmadow (FGS, 2013). The annual temperature in the Jubbaland state ranges between 27-30 °C with Gedo region recording the highest temperatures of 29-30 °C, and Middle and Lower Jubba recording temperatures of 27-29 °C. Temperatures are higher in the months December – March with the month of March being hottest (ICPAC, IGAD & WFP, 2017). ICPAC (2017) reports relative thermal uniformity in the South of Somalia due to the surface being largely homogeneous compared to the north where the surface varies as shown in **Figure 3-4**.

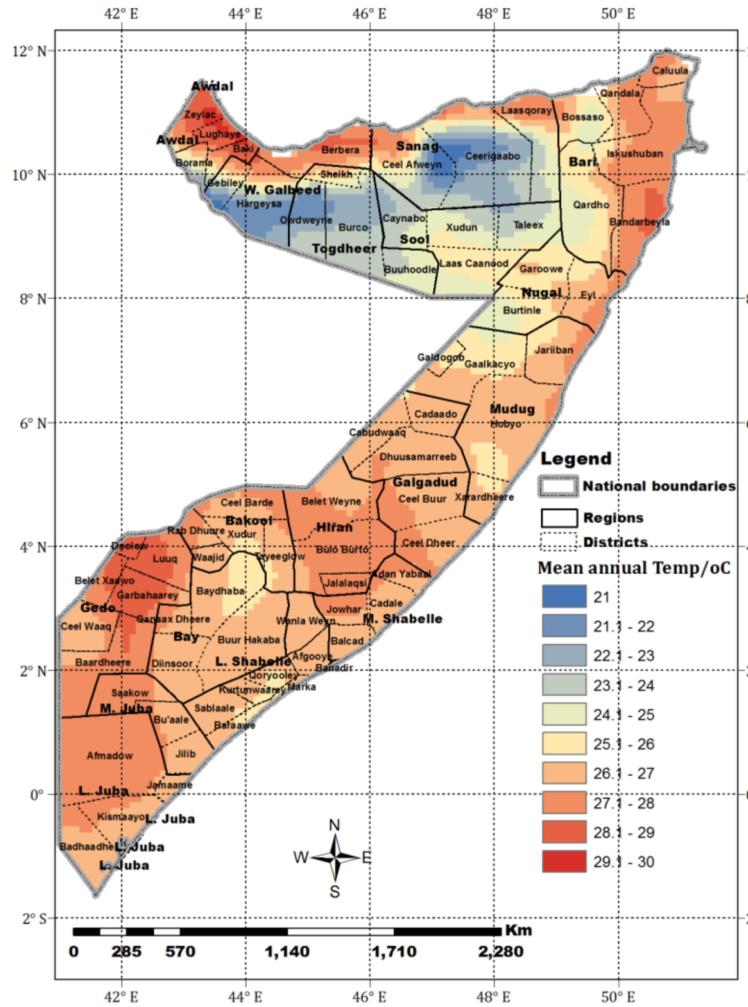


Figure 3-4: Annual mean surface temperature climatology of Somalia (source: ICPAC, IGAD & WFP, 2017)

3.1.2 Physiography and Drainage of Study Area

Jubbaland is characterised by an extensive system of costal sand dunes as well as sedimentary rocks such as limestone, sandstones. The Lower Jubba plain consists of clay, sandy clay, silt and gravel (SWALIM, 2007b). The South of Somalia is dominated by the country's only two permanent rivers, the Jubba and the Shabelle rivers (LOC, 1992). The rivers originate from the Ethiopian and Kenyan highlands, respectively. The Federal Government of Somalia (2013) reports that the Jubba River flows into the Indian Ocean through Kismayo, while the Shabelle River ends in the east of Jilib, near the Jubba River. It further reports that when flooded, the Shabelle River may break through to the Jubba River. The state of Jubbaland is part of the country's most arable zone and therefore holds the country's largest sedentary population. The lowland between the Jubba and Shabelle rivers supports rich pasture which draws pastoralists (Hadden, 2007).

Jubbaland features arid to sub-arid savannah, open woodland and thickets with an abundance of underlying grass. South of Jubbaland towards the border with Kenya is some areas of grassland and some dry evergreen forests. East African mangrove swamps are found along the coast of Kismayo (Hadden, 2007). Some tropical forests existed along the Jubba and Shabelle rivers but most of it is reported to have been cleared for agricultural use (FGS, 2015).

3.1.3 Socio- Economic Factors

UNDP (2014b) estimated the Somali population at 10 million in 2013, with an expanding annual growth of almost 3% and a fertility rate of 6.26 children per woman, the 4th highest in the world. USAID (2014) issued a report stating the poverty in Somalia as are very high, with over 94% of rural population and 98% of nomadic populations living in poverty. The Federal Government of Somalia (2015) reports pastoralism and crop production as the main livelihood base for 80% of the community, followed by fisheries and forestry. Charcoal has been reported by many as the most sought after commodity to fuel the war economy particularly in Lower Jubba, with militia groups generating revenue of millions per annum from illegal exports (UNSC, 2012a; UNSC, 2012b; UNEP & INTERPOL, 2014).

The World Bank (2016a) list Somalia as the fifth poorest nation in the world. UNDP's (2012a) Somalia Human Development Report further states that 82% of Somalis in both rural and urban areas are poor across multiple dimensions. In a separate report, UNDP (2014) further listed the unemployment rate in Somalia at 45.5% overall, 57.7% in urban areas and 42.8% in non-urban areas. Unemployment rate for youth aged 14 to 29 is 67%, 61% of which are males and 74% females. The literacy rate in Somalia is listed at 19%, with the percentage of primary school participation for girls between 2007 and 2010 being 23% and 42% for boys, with the net attendance ratio 15% and 18% respectively. The result of such high poverty and low literacy rates is the creation of climate refugees and Internally Displaced Persons (IDPs) into already existing camps to withstand climate shocks as seen during the 2010/2011 and 2016/2017 drought.

3.1.4 Land Uses in the Study Area

Somalia in the last two or so decades has been a failed state thus lacking in policies on issues of land use (Maystadt & Ecker, 2014; Jamal, 2015). IUCN (2006) reported pastoralism as the predominant source of livelihood in Somalia with the livestock industry employing over 60% of the population. According to SWALIM (2007b), land use in the study area mainly consists of grazing and wood collection for fuel and building material. In Jubbaland, SWALIM reports that livelihood here consist of raring livestock such as camels, cattle, sheep and goats with irrigation being done along the Jubba and Shebelle rivers as seen in **Figure 3-5**. Livestock in this region are watered from the Jubba and Shabelle Rivers, hand-dug wells, swamps, creeks and boreholes. Water reservoirs formed during the wet seasons also provide alternative water sources for pastoralist (SWALIM, 2007b).

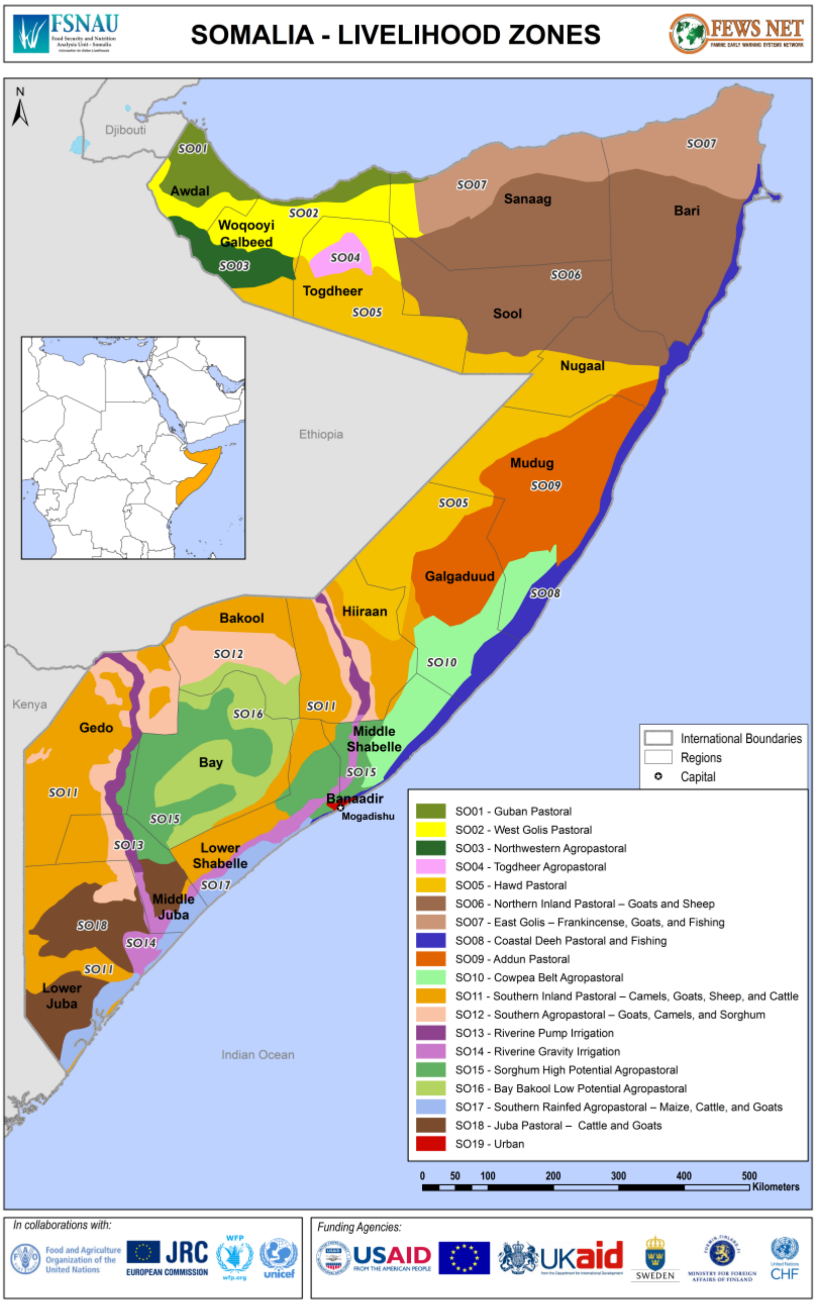


Figure 3-5: Somalia Livelihood Zones mapped by the Food Security and Nutrition Analysis Unit - Somalia (FSNAU -FEWS NET , 2017)

Somalia has a long history of irrigated agriculture along the Jubba and Shabelle rivers predating the civil war (SWALIM, 2009a; FGS, 2012b; AMISOM, 2016). According to SWALIM (2009b), about 50,000 hectares (ha) of land were under controlled irrigation and 110,000 ha under flood irrigation in 1980. Large commercial schemes of irrigated sugarcane, rice, and banana, citrus and other fruits used to operate in the Shabelle below Jowhar near Jilib. Since the early 1990s much of the irrigation infrastructure has deteriorated (SWALIM, 2009b). A study by Hadden (2007) showed that maize and vegetables are grown at a small scale, with bananas, sugarcane, mango, papaya and lemon being grown at a large scale, and is sometimes accompanied by pastoralism along the Jubba and Shabelle rivers. Rain-fed agriculture involving the production of sorghum, millet, maize, groundnuts, cowpeas, mung beans, cassava and other minor crops is also practiced (Hadden, 2007).

Beier & Stephansson (2012) stated that forests and woodlands cover about 23% of the country and are dominated by Acacia species. Forests alone was reported to cover about 11.4% of the total land area of Somalia with 1,078 known species of animals and 3,028 plant species. IUCN (2006) reports that in addition to the Acacia tree, other tree species found in the region include *Boswelia* species growing in the north-east, *Commiphora* (where *C.myrrha* is the preferred species), in the south-west, *Gum Arabic* from Acacia senegal, and *Cordeauxia edulis* (now endangered) which produces *yicib* nuts in the central regions, henna (*Lawsonia inermis*), various fruits (e.g. Tamarind), as well as many other trees which produce important medicinal products. Forests and woodlands are critical for pastoralist range management, particularly during dry seasons.

Many reports state that Somali men move their herds from season to season in search of pasture and water as a result of being a pastoralist community (Little, 2004; BICC, 2009; UNDP, 2011). Gomes (2006) reports that the livestock kept in Somalia feed primarily on natural vegetation and crop residue. SWALIM (2007a) further reports that pastoralists trade for crop residue with farmers who are mainly from the Somali Bantu clan. The crop residues from the trade provides forage for non-browsers such as cattle and sheep. During the dry season, animals are watered from the rivers. Thurow et al. (1989) reported a stong traditional system of governance that regulated the use of range land as well as traditional water wells. Gomes (2006) supported this claim stating the existence of a well-established traditional systems that creates a place for grievances among warring communities and a system of communal responsibility, critical in how the community withstands climate shocks.

Thurow et al. (1989) in his study claimed that migration has reduced for pastoralistsin some parts of Somalia due to the existence of fuel driven boreholes. Gomes (2006) supported this claim further by stating the existance of boreholes, dug in various places throughout Somalia through various relief projects. USAID (2014) reported the sedentary lifestyle for some pastoralist because of the boreholes has led to unplanned settlements and land degradation as a result of overgrazing. Whereas migration allowed for range land to recover, staying on the same land for long periods of time contributes to de-vegetation as well as pulverization and compaction of soil, leading to increased land degradation.

3.1.5 Environmental Policy and Governance in Somalia

Pressure on the environment in Somalia as reported by IUCN (2006) is caused by the effects of climate change, increased population pressures, natural resource based conflicts, increased urbanization, and the effects of decreasing remittances. Policy and legislation with respect to the environment is weak and outdated. Peace remains elusive and militates against re-building of institutions. Even with the formation of the Federal Government of Somalia, the nation has to prioritise state formation and security before any development agenda. Somalia has however developed a National Adaptation Programme of Action (NAPA). The last legislation on conservation of Flora and Fauna was issued before the former government before its collapse. This law saw to the conservation of the rangelands and forests by a specialised agency called the National Range Agency (NRA). A UNEP (1998) report stated that the Siad Barre government engaged the local community in conservation and management of forests. The country is yet to finalize and adopt a constitution that will determine how its newly formed states interact with the central government.

Somalia is a signatory to the following international and regional conventions affecting its forests:

- Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES);
- Protocol concerning Protected Areas and Wild Fauna and Flora in the Eastern Africa region;
- The IGAD Environment and Natural Resources Strategy;
- The IGAD Sub-regional Action Programme to implement regional needs of the IGAD member states priorities;
- United Nations Convention to Combat Desertification (UNCCD);

According to a report by UNEP (2005) Somalia has also signed but has so far failed to ratify the African Convention on the Conservation of Nature and Natural Resources.

3.2 Research Data

3.2.1 Rainfall Data

Observed climate data is a challenge in sub-Saharan region. Jubbaland State is no exception as it had no meteorological services during the period of study. However the Food and Agriculture Organization (FAO) Somalia Water and Land Information Management (SWALIM) manage automatic weather stations in Afmadow and Bardheere. The data at the SWALIM stations in Somalia is recorded as aggregated monthly totals. The precipitation data from these two stations for the period 1997 to 2015 were used in the study[1]. The data was sourced from SWALIM and shared through ICPAC.

Additional satellite rainfall data was used in the study from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) dataset (CHG, 2016). CHIRPS is a global dataset (50° S-50° N, 180° E-180° W), with a resolution of 0.05°, ranging from 1981 to near-present gridded precipitation time series. CHIRPS data are produced by scientists at the University of California, Santa Barbara (UCSB) Climate Hazard Group (CHG) and the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center. The data was developed to support the United States Agency for International Development Famine Early Warning Systems Network (FEWS NET) (Funk, et al., 2015). Rainfall Measuring Mission Multi-satellite Precipitation Analysis version 7 (TMPA 3B42 v7) is used to calibrate global Cold Cloud Duration (CCD) rainfall estimates.

The creation of a 1981 to present time-series of daily, pentadal, and monthly precipitation estimates uses geostationary infrared satellite observations for that period from NOAA, trained on NASA Tropical Rainfall Measuring Mission (TRMM) available from 1998 to present, as well as modelled precipitation fields from the NOAA Climate Forecast System Reanalysis (CFSR). The data is a blend of high-resolution CCD data and available station data and the resulting product is similar to that produced by the Global Precipitation Climatology Centre (GPCC) or University of East Anglia's Climate Research Unit (CRU) (Funk, et al., 2015). The final CHIRPS product is however produced monthly in NetCDF, GeoTiff, and Esri BIL formats.

[1] SWALIM datasets are not officially endorsed by the World Meteorological Organization (WMO) (WMO/TD - NO. 589, 1993; WMO/TD - NO. 1462, 2008).

The CHIRPS data used in this study is an improved version blending satellite data with additional rain gauge observations, for the period 1981 to 2015. Monthly totals were aggregated into annual totals on a calendar year basis. A real average rainfall data for Lower Juba was extracted and used in the study. This data was sourced from ICPAC. Details on CHIRPS data and their usability in the region are well documented by ICPAC among many others (GeoCLIM, 2016; ICPAC, 2016b).

3.2.2 Temperature Data

Due to limitations in getting station observed data for Somalia, the study exclusively used the gridded 10-day (dekadal) temperature data datasets from the Climate Hazard Group (CHG, 2016). The temperature data is derived from the GISS Surface Temperature Analysis (GISTEMP) by NASA. The data is collected at a spatial resolution of 2.0 degree latitude x 2.0 degree longitude (GISTEMP Team, 2017). Observed minimum, maximum and average temperature were investigated for all the standard global climatological seasons namely northern hemisphere summer, winter, autumn and spring seasons that correspond to June to August, December to February, September to November, March to May months. Data used was observed data for the period between 1981 and 2012. This data was also sourced from ICPAC. The average temperature data for Lower Juba was extracted and used in the study.

3.2.3 Quality control

Data quality control was undertaken to correct inconsistencies and anomalies introduced along the chain of collecting, digitizing, processing, transferring, storing and transmitting the climate data. An inspection of the data to isolate anomalous deviations and suspicions zeros in the space of missing data was done. The goal of quality control is check for errors and inconsistencies that could compromise the data. The quality control procedures in ClimSoft software were used to conduct rigorous checks and identify manual keying errors and unreasonable values (ICPAC, 2016a).

Homogeneity tests are conducted on long term data sets to ensure that variation in the climate data is not caused by non-climatic factors, thus creating a bias in the results (Aguilar , *et al.*, 2003). Common methods used for the assessment of the homogeneity of observed data are the double-mass curve (Kohler 1949), Buishand range test (Buishand, 1982) and the Multiple Linear Regression (Vincent, 1990; Peterson, *et al.*, 1998). The climate data in this study was subjected to the single mass curve test for homogeneity. The ClimSoft procedures check the data for accuracy, completeness, consistency, uniqueness and validity (McQuown, 2000;

ICPAC, 2016a). Where anomalous values could not be corrected, values were set to a missing values (-999). Outliers were checked and errors investigated and where values could not be verified, the values were also set to a missing value.

3.2.4 Climate Projections data

The climate modelling groups around the world have contributed to a coordinated set of the 20th and 21st century climate simulations for the Atmosphere Ocean coupled Global Climate Models (AOGCMs) in the Coupled Model Inter-comparison Project phase 5 (CMIP5) (Taylor et al., 2012). The climate scenarios data from the Regional Climate Models (RCMs) employed in the Coordinated Regional Climate Downscaling Experiment (CORDEX) Africa framework were used to investigate the qualitative aspects of future change in seasonal mean near surface air temperature and precipitation over this study region. These RCMs downscaled a subset of AOGCMs in the CMIP5 at 0.44 degrees (~50 km) spatial resolution over Africa domain. The CORDEX program is an initiative by World Climate Research Program (WCRP) of the World Meteorological Organization (WMO) that provides an opportunity for improved framework in generating high-resolution regional climate projections for impact assessment and adaptation studies within the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) timeline and beyond (Samuelsson et al., 2011; Nikulin, et al., 2012; Teichmann, et al., 2013; Endris, et al., 2013)

These RCMs describe the atmosphere and its coupling with the land surface with differing dynamics and physics formulations (Samuelsson et al., 2011; Giorgi et al., 2012; Teichmann et al., 2013). For each experiment the historical runs, forced by observed natural and anthropogenic atmospheric composition, cover the period from 1950 - 2005. The future projections (2006–2100) are forced with two Representative Concentration Pathways (RCP), namely; RCP4.5 (mid-range emissions) and RCP8.5 (high-end emissions) scenarios, which prescribe future atmospheric greenhouse gas concentrations and aerosols. Detail on the CORDEX RCMs can be found in Nikulin et al., 2012 and Endris et al., 2013.

Endris et al., 2013 evaluated the ability of the CORDEX RCMs in simulating the general characteristics of the climate over Eastern Africa region by analysing the annual cycle, spatial variability, pattern correlation and root mean square error using a Taylor diagram. The study found that these RCMs reasonably simulate the main features of the rainfall climatology over eastern Africa and also reproduce the majority of the documented regional responses to ENSO and IOD forcings. At the same time the analysis showed significant biases in individual models depending on sub-region and season; however, the ensemble mean had better agreement with observation than individual models. The analysis concluded that the multimodel ensemble mean simulates eastern Africa rainfall adequately and could therefore be used for the assessment of future climate projections for the region. The CORDEX RCMs data was obtained from ICPAC that coordinates the Eastern Africa group of scientists.

In this study the projected seasonal ensemble mean climate change was therefore analysed as simulated by the CORDEX Africa RCMs and their driving CMIP5 AOGCMs over the region (1.5ºS – 12.0ºN and longitudes 41.0ºE – 51.0ºE) covering Lower Jubba for the IPCC periods namely 2030 (sub-period 1), 2050 (sub-period 2), and 2070 (sub-period 3) with reference to a baseline period (1961–1990) for the Gu (April - June, AMJ) season.

Like rainfall, projected future mean, minimum and maximum temperature scenarios that extend up to 2079 are studied under similar IPCC timelines.

3.2.5 Land Cover Change Data

Joint application of remotely sensed data acquired from various sensors is very effective in monitoring global environment changes. The inter-satellite cross-comparison among multiple sensors has become indispensable (Jiang, & Feng, 2014), especially in areas where there are no "ground truth" data. The strategy used in the study was to compare different images 1993/1995, 2000 and 2014. The images were extracted from Landsat 5, Landsat 7 and Landsat 8 and used for land cover classification.

Landsat 5 (1-5) carries the Thematic Mapper (TM) sensor and consists of seven spectral bands with a spatial resolution of 30 meters for Bands 1 to 5 and 7. Landsat 7 (1-7) carries the Enhanced Thematic Mapper Plus (ETM+) sensor and has a spatial resolution of 30 m for the six reflective bands, 60 m for the thermal band, and includes a panchromatic (pan) band with a 15 m resolution. Landsat 8 carries the Operational Land Imager (OLI) sensor and keeps the same settings as Landsat 7 but also adds new bands, such as coastal and aerosol studies, cirrus cloud detection and a quality assessment band, and adjusts the wavelength of each band (Li et al., 2014).

GPS ground-truthing data was collected in the field in June 2016. Random points from field were collected and used for accuracy assessment of the classification. This was further supported with high-resolution photography from SPOT 6. SPOT 6 has a resolution of 1.5 meter panchromatic and 6 meter multispectral (blue, green, red, near-IR). Google earth imagery contains high-resolution imagery that was also useful in corroborating the resulting classification.

3.2.6 Primary Data

Primary data was collected through surveys, focus group discussions, interviews and direct observation of the study area. The survey was conducted in Lower Jubba. Data for the survey was collected through one on one interviews. Due to security concerns the survey was conducted by research assistants from the local university because of their access to the local community and their knowledge of the local language. The research assistants were trained on the survey tools. Cultural constraints also led to a larger number of men than women being interviewed. Two group discussions were held, one consisted of various community members and the other with local leaders. Key informant interviews were also conducted on one on one basis between Jan 2015 – October 2016. Some of the informants were interviewed once while others were interviewed multiple times depending on their knowledge of the subject matter to verify information.

3.3 Methods

3.3.1 Conceptual Framework

The forest is an important resource base for vulnerable communities source of livelihoods, reducing exposure particularly during times of crisis (Brink et al., 2012). The turn to the sale of charcoal as a means of survival particularly during prolonged droughts by vulnerable communities in Somalia has been reported widely (Thurow et al., 1989; Gomes 2006; Dini, 2011; Rembold, *et al.*, 2013; USAID, 2014). Numerous news reports have also been made on the export of charcoal out of Somalia and the South of Somalia in particular for decades. However, the impact on environmental degradation is yet to be extensively studied because of lack of access to the ground due to insecurity.

Figure 3-6 shows the conceptual framework of this study. Climate change and variability can be addressed through adaptation and mitigation measures. Mitigation through reforestation and afforestation could also reduce environmental degradation. Knowledge integration is useful in understanding the addressing the climate risks, community vulnerabilities and adaptive capacity. This will enable effective strategies to tackle the issues of environmental degradation in the study area as well as in the development of effective adaptation and mitigation strategies.

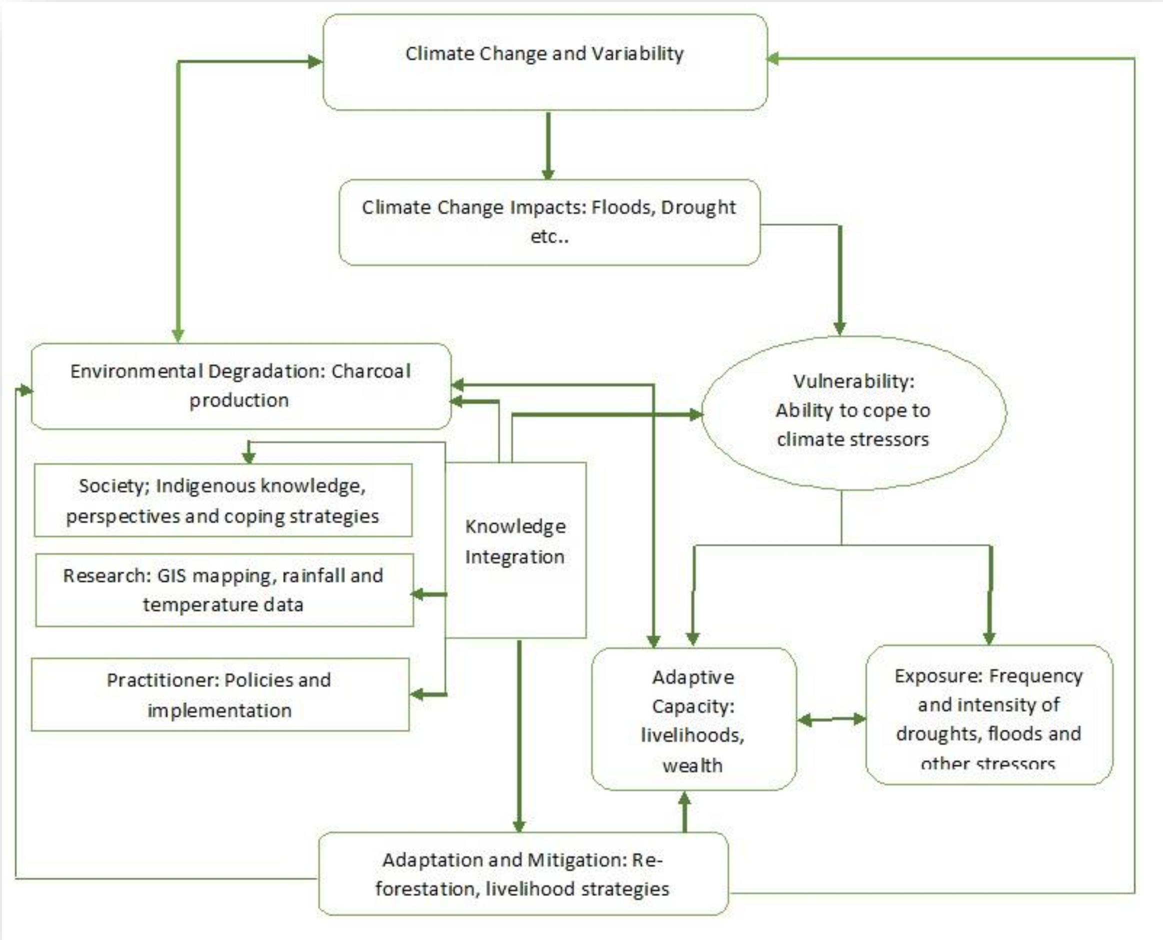


Figure 3-6: Conceptual Framework

3.3.2 Research Design

The research design used in this study was transdisciplinary, the local community was used to generate knowledge on both climate variability and charcoal production. The research design also employed scientific methodologies including geospatial information technology (GIS). This design as shown in **Figure 3-7** informed the research agenda and the resulting information produced.

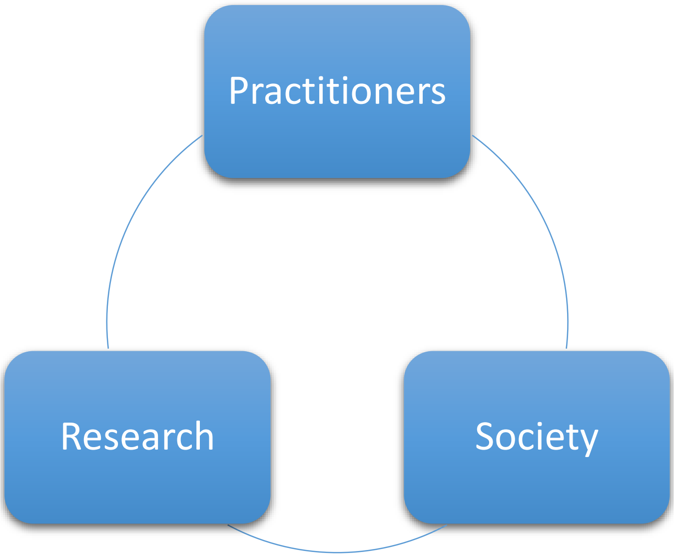


Figure 3-7: Research Design

The following sections outline the data collection tools and methods used in this study to meet all the specific objectives.

3.3.3 Analysis of Primary Data

Primary data was used to determine the impacts of climate and variability on the livelihoods of the community, as well as the significance of charcoal production. The primary data was also aimed at collecting information to meet all the specific objectives.

3.3.3.1 Sample size

Sampling is a way of selecting a number of individuals for a study to represent the larger group from which they were selected. The size of the sample population was determined using a sample size calculator in the Creative Research Systems survey software ("Creative Research Systems," 2016). The software uses the confidence interval, confidence level and population size to determine the sample size.

The confidence interval is the margin of error, while the confidence level shows the probability that the value of a parameter falls within the confidence interval. The confidence level selected for this study was 95%. This gave a sample size of one hundred and fifty for the estimated 183 000 people in the sample area. Probability sampling, also known as random sampling was used to select the one hundred and fifty participants for the survey, whereby every sample has an equal chance of being selected.

3.3.3.2 Survey

Permission was sought from the regional government to conduct the survey. Questionnaires were designed from the set of objectives and used to collect data from the population in Kismayo. The survey was conducted in the port town of Kismayo, in Lower Jubba. The advantage of carrying out the survey in Kismayo was that it is a melting pot of clans from all over Jubbaland and would therefore allow for collection of information that would create a complete picture of the region. There have been no population surveys carried out in Somalia since the collapse of the government in 1991 and the population is not known. The target population in Kismayo as estimated by African Union Mission in Somalia (AMISOM) is 183 000. The United Nations Population Fund (UNFPA) estimates the population in Kismayo to be 172,861 (UNFPA, 2014).

The questionnaire was divided into four segments, the first was designed to collect bio-data. The second section aimed at assessing climate change as understood and observed by the general population. The third section was aimed at understanding the state of the environment as well as understanding the behaviour and attitudes of the population towards charcoal production. The final section focused on community knowledge and practices on adaptation to climate change. The survey was translated to the local dialect, and five local students trained on how to conduct the survey. No incentives were offered to the participants in the survey. Participants from the survey were selected at random to participate in a focus group discussion, due to cultural restrictions, all participants who attended the discussions were male.

For ethical considerations, the participation in the survey was voluntary, the participants were asked for consent, information on the study given and anonymity assured. The respondents were given the freedom to answer the questions they wanted and ignore the questions that made them feel uncomfortable. To ensure validity, research questions were explored with key informants and discussed with supervisors before the actual study until a questionnaire that could meet the needs and the gaps was designed. To ensure reliability and consistency, questions were repeated in different formats to see if the respondents would yield the same answers.

The data once collected was scored, analysed and edited. Descriptive analysis was used to analyse the primary data, which was then presented in tables, charts and graphs. Multiple univariate and multivariate analyses were also done.

3.3.3.3 Key Informant Interviews

Key informant interviews are in depth interviews of people selected for their first-hand knowledge about a topic of interest (Tremblay, 2009). Interviews were conducted with key informants from the community in order to design the research, as well as to understand and identify history of land use in the area of interest. The key informants were also important in understanding the existing climate change related policies and any past and future planning on climate change adaptation and mitigation. The interviews also helped expand on the motives, views and attitudes of the respondents from the survey.

Key informants were essential in making recommendations for policy interventions on adaptation based on the final specific objective. The informants were representatives from international and regional organisations working in the South of Somalia, local NGOs, representatives from the Federal Government of Somalia, and the Jubbaland administration, as well as persons from Lower Jubba region with knowledge on the area. The methodology used for the interviews were both structured and unstructured. An interview guide was created to ensure all aspects of information required were included but the interviews ware unstructured. Some key informants were interviewed multiple times over a long period of time while others were interviewed once based on the scope of their knowledge and their willingness to engage in the research.

3.3.4 Analysis of past and present climate patterns

The analysis of the past and present climate patterns was done to meet the first objective that characterizes the past and current climate patterns over Lower Jubba. There are two rainy seasons and two dry seasons in Somalia. The rainfall analysis focused on the two wet rainfall seasons namely *Gu* (April to June) and *Deyr* (September to November). Seasonal temperature time series were however generated for all global standard temperature seasons namely June to August, December to February, September to November, March to May months and the results mapped.

3.3.4.1 Trend Analysis

Trend can be derived from graphical and statistical analyses allowing for temporal and spatial approaches. Trends present a measure of the time series long term. Both graphical and statistical techniques used in this study are similar to those that have been adopted in many studies in the region and the world at large (Ogallo, 1979, 1980; 1981; King'uyu, *et al.*, 2000; Omondi, *et al.*, 2009; Omay, *et al.*, 2016). Statistical techniques are generally preferred over graphical techniques because the graphical method is subjective. The graphical approach, through regression analysis and Mann-Kendall Rank Statistic test were used in this study.

The graphical method involves the plotting of the data in a scatter graph against time to generate a time series plot. In this study both seasonal rainfall and temperature data were plotted against time. Such time series can be smoothed out to remove the irregullar roughness in order to see important patterns in the data. The disadvantage of the graphical method is its dependency on visual judgment (Ogallo,1981).

Statistical methods take parametric or nonparametric approaches to test statistical significance of the trend. While using the parametric tests, an assumption is made that the data is normally distributed. A linear regression trend was investigated by examining the relationship between time (T) and the variable of interest (X), in this case rainfall and temperature (see equation (1)).

$$X = B_0 + B_1 (T) \qquad (1)$$

X is the dependent variable like rainfall or temperature while T is the time in years and B_0 and B_1 are estimates of the intercept and slope respectively. The slope indicates the average rate of change in the dependent variable in each year of the given time period. A positive slope shows an increasing trend while a negative slope shows a decreasing trend. This method however fails to detect trends that are nonlinear.

Nonparametric tests do not assume a normal distribution of data. The study used the most common non-parametric method based on rank statistics called Mann-Kendall rank statistics (Ogallo, 1980; 1981; Muthama , et al., 2012). In the Mann-Kendall analysis data is presented in time sequential order and then ranked. The time series values (X_1, X_2, X_3, X_4 ….., X_n) where X in this case represents temperature or rainfall are replaced by their relative ranks (R_1, R_2, R_3,R_4.., R_n) (starting from the lowest value up to n). The relative magnitudes of sample data is compared rather than the data values themselves (Kendall, 1938; 1945; 1948). The equation used is as follows, where S is the Kendall score given a dataset R with a sample size of n values:

$$S = \sum_{i=1}^{n-1}\left[\sum_{j=i+1}^{n}\operatorname{sgn}\left(\boldsymbol{R}_i - \boldsymbol{R}_l\right)\right] \qquad (2)$$

In Mann Kendall analysis, positive values indicate an increase in constituent with time, whereas negative values indicate a decrease in constituent with time. Mann-Kendall Rank statistics is used for trend analysis as it makes very few underlying assumptions about the structure of the data. The significant level of the Mann Kendall values were tested and where $p \leq 0.05$, then the time series was statistically significant, this was verified at a confidence level of 95%. Significant trends form one of the key foundations of climate change detection. Further details on this methods can be obtained from Kendall (Kendall, 1938; 1945; 1948).

GeoCLIM software was used to calculate a linear trend line for each pixel in the study area using regression analysis of the seasonal totals. The results map the slopes for each pixel in raster format. For the rainfall data, the result is given in mm of rainfall gained or lost per decade. The software also provides a raster showing the coefficient of determination (r^2) of the regression as an indication of the consistency of the trend. The resulting rasters were mapped to delinate the spatial patterns of the temperature and rainfall trends.

3.3.5 Land Cover Change Detection

Image classification was used to meet the second specific objective, which is to evaluate the changes in land cover in Lower Jubba from possible impacts of charcoal production. Rawat & Manish (2015) define land cover as the physical characteristics of earth's surface, captured in the distribution of vegetation, water, soil and other physical features of the land; while land-use is defined as the way in which land has been used by humans and their habitat. Southern Somalia has diverse land cover ranging from grassland, shrubland, woodland, bare soil and forest.

Land use land cover (LULC) change analyses based on Landsat imagery data is commonly used in change detection studies. According to Liang, Fang, & Chen (2001), Landsat imagery has been extensively used for agricultural evaluation, forest management inventories among other applications. Li et al. (2014) further states that many of the Landsat sensors are highly linearly related or vary slightly, which makes them useful for complementary data analysis. Landsat provides the longest continuous record of satellite-based observations and is therefore invaluable in monitoring global land use change. According to Chander, Markham, & Helde (2009) Landsat provides the only time series seasonal inventory of the global land surface. The strategy for this study was to compare 1993, 1995, 2000 and 2014 images. The images were from Landsat 5, Landsat 7 and Landsat 8 and used for land cover classification.

The specific objective of the study was to monitor the change in land cover over time. The sample size shown in **Figure 3-2** was selected for the land cover study as it covers all the three districts of lower Jubba and gives a realistic study site that can be completed during the time period. The analysis looks at Kismayo which is the most accessible area for ground verification and parts of Badhaadhe, Afmadow and Jamame, covering all districts in Lower Jubba as shown in **Figure 3-2**. The area was selected to provide a picture of the change in land cover as a result of charcoal production. The most standard technique for land cover change studies is to use a sampling strategy across the target area (Brink et al., 2012). **Figure 3-8** gives a summary of the land cover change detection methodology used in the study.

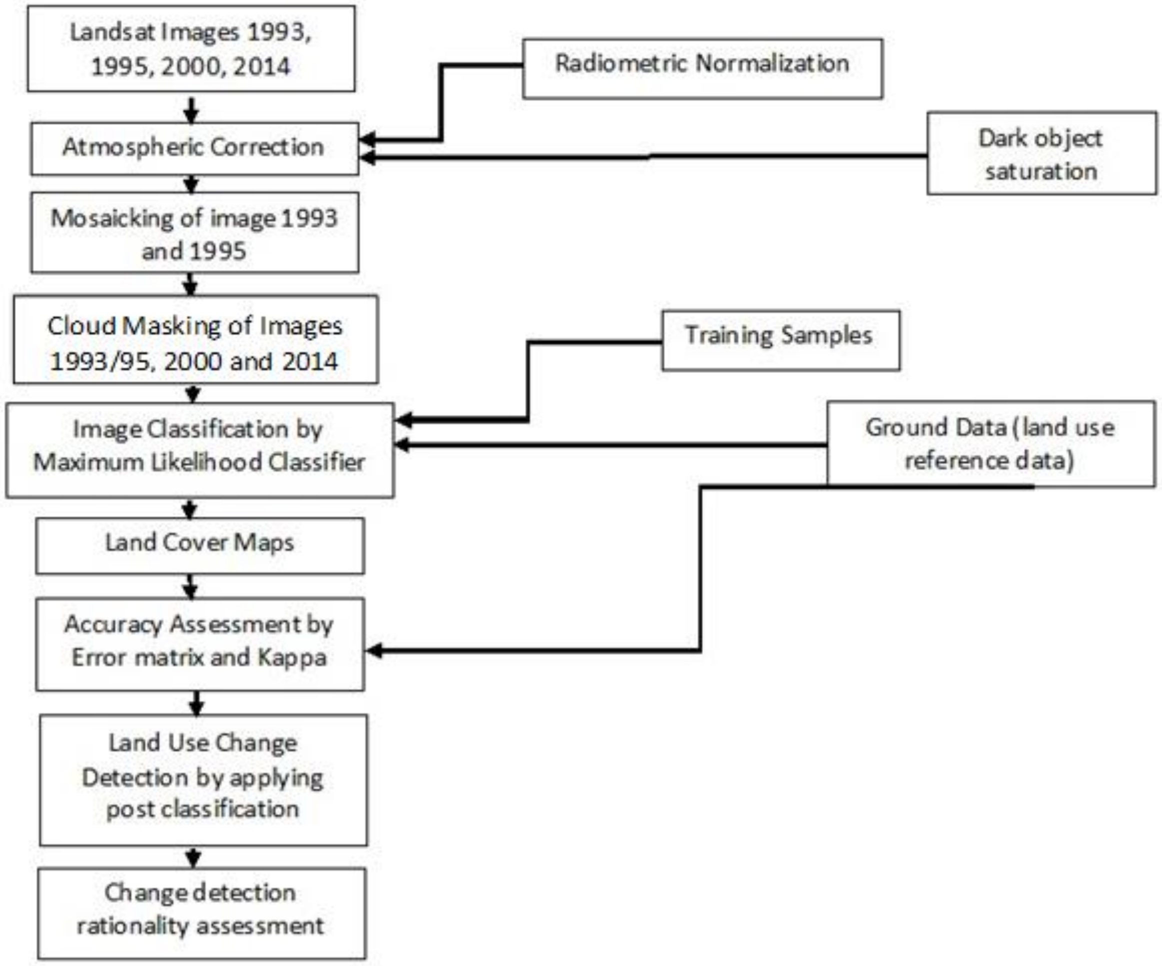


Figure 3-8: Land cover change assessment steps

The Landsat Thematic Mapper (TM) (Landsat 5) and Enhanced Thematic Mapper Plus (ETM+) (Landsat 7) sensors acquire temperature data and store this information as an 8-bit digital number (DN) with a range between 0 and 255 (Du, *et al.*, 2002). Atmospheric correction is done through radiometric normalization and dark object saturation methods (El Hajj, *et al.*, 2008). Radiometric normalization is required to remove radiometric distortions and make the images comparable so as to correct surface directionality and atmosphere effects due to images acquired on different dates under different conditions (Mateos, *et al.*, 2010).

A two-step process was used for the Landsat 5 and 7 images to convert the DNs to top-atmosphere reflectance (ToA) by first going through a spectral radiance conversion followed by a ToA reflectance conversion. Landsat 8 Operational Land Imagers stores information in reflectance rather than radiance as a 16-bit digital number (DN) data with a range from 0 and 65536, thus requiring only a ToA reflectance conversion. The purpose of the conversions was to minimise any spectral differences in the images caused by acquisition time, sun elevation and sun earth distance by calibrating to a common radiometric scale. The Dark Object Subtraction (DOS) method was applied to all the images to cancel out the haze component caused by additive scattering from remote sensing data. The study area was then clipped from the images.

The Red band (R) in the Landsat images discriminates vegetation, the Green band (G) emphasizes peak vegetation, which is useful for assessing plant vigour; the Blue band (B) which shows bathymetric mapping, distinguishing soil from vegetation and deciduous from coniferous vegetation; the near infrared band (NIR) which emphasizes biomass content and shorelines; the short wave infrared 1 (SWIR-1) which discriminates moisture content of soil and vegetation; penetrates thin clouds; and the short wave infrared 2 (SWIR-2) band which improves moisture content of soil and vegetation and thin cloud penetration. A layer stack was created from these bands.

Given that the region of interest is by the ocean most of the images had high cloud cover, thus images with low cloud cover were difficult to obtain. This led to the Mosaicking of the 1993 and 1995 Landsat Images. This challenge was then further overcome by the development of a cloud and shadow mask that comprises of the cloud area and shadow area obtained from a supervised classification. The mask was created for each year 1993/5, 2000 and 2014 as shown in **Figure 3-9**.

Through a raster operation, the masks created were added up to develop a common cloud and shadow mask, with cloud and shadow areas with a given a value of 0 resulting in **Figure 3-10**. This was to enable one to one change comparison in the cloud free images and avoid inaccurate land cover changes e.g. clouds to woodland.

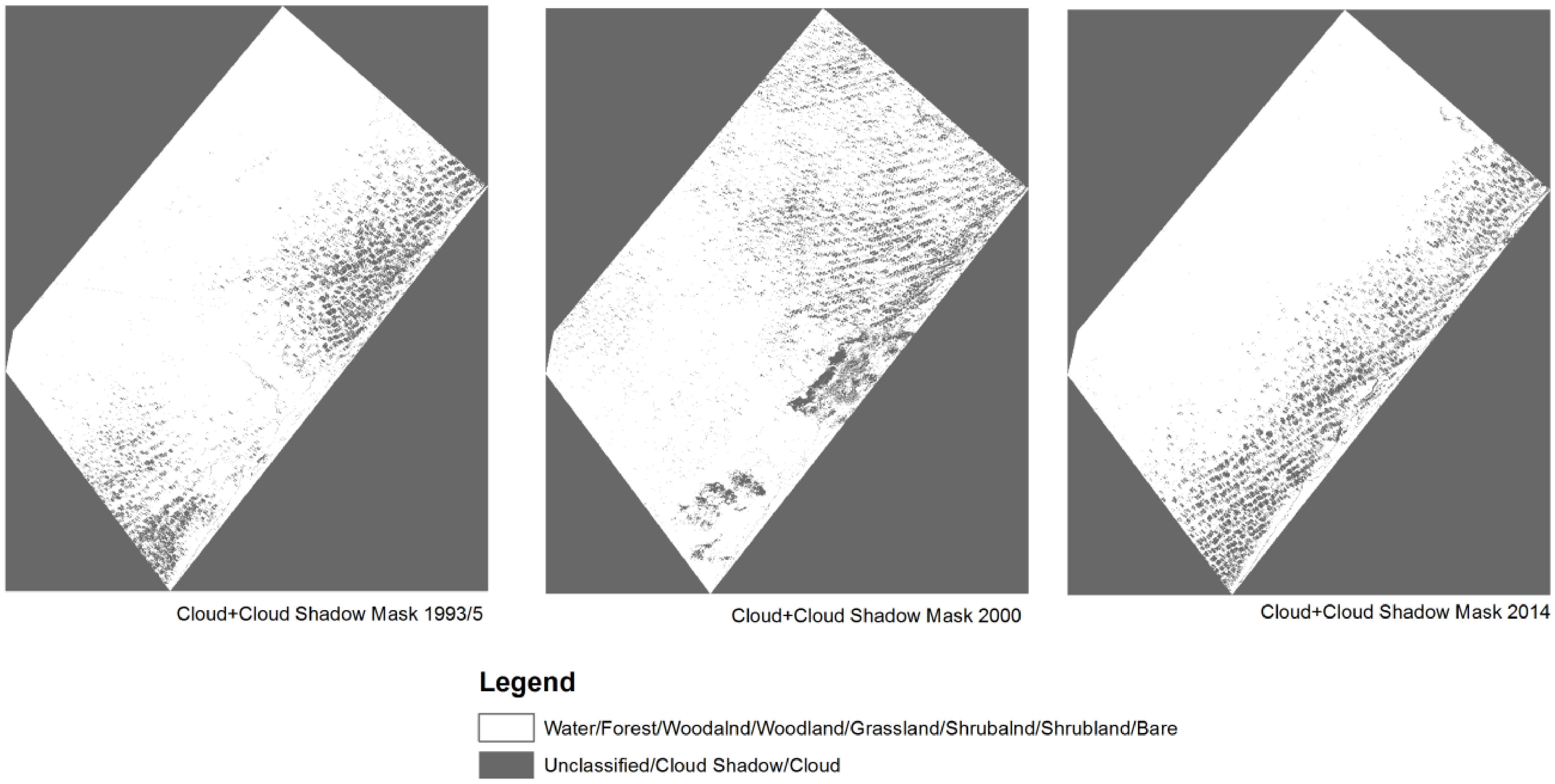


Figure 3-9: Cloud and Shadow mask

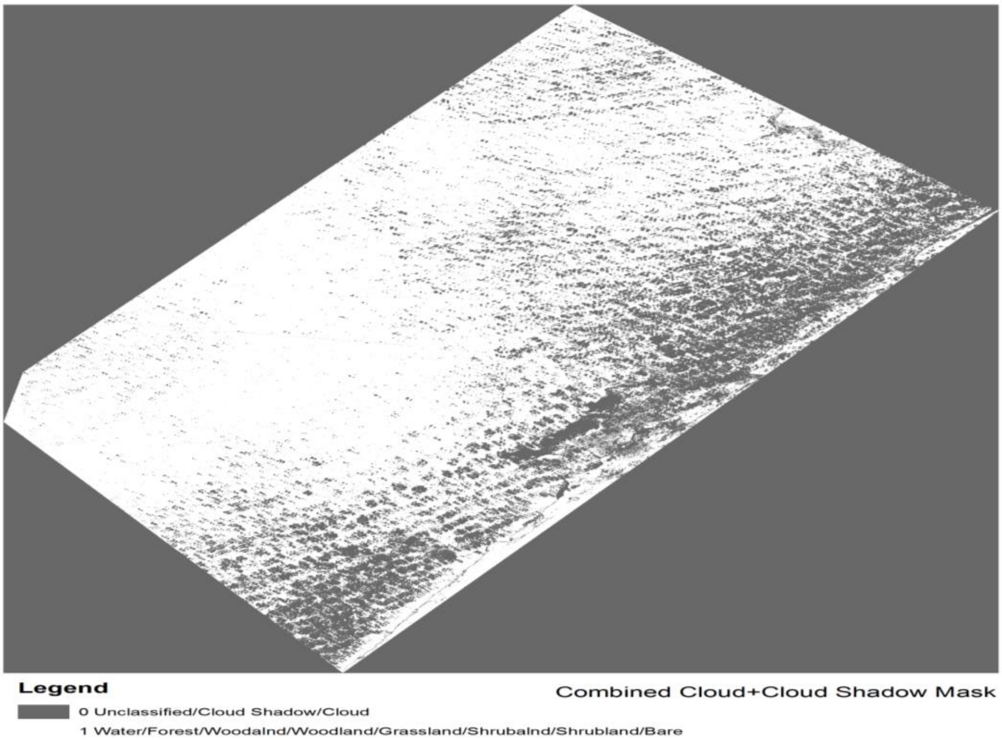


Figure 3-10: Combined Cloud and Shadow Mask

Image classification was done using supervised classification which applies maximum likelihood algorithm through ERDAS. This method assumes the probability that a pixel belongs to a particular class, and that the probabilities are equal for all classes and finally, that the input bands have normal distributions. A quantitative analysis of the different classes was then done using a change matrix so as to observe a visual output of the change in the classes over the years. Unfortunately the method tends to over-classify signatures with relatively large values in the covariance matrix, pixels that should be unclassified become classified, and class variability is not considered. The cloud mask demonstrated improvement in the accuracy of the analysis of the images used in the study and avoided inaccuracies like those that would for example present a transition of clouds to woodland.

Land cover change analysis was done for the images of 1993/95, 2000 and 2014 in the Erdas Imagine change matrix tool. The change matrix results were analysed in ArcGIS for identification of change areas. The resulting classification was therefore verified manually using high-resolution imagery and ground verification. Google earth also proved useful in the verification of data. In between classes, there were confusions that required manual manipulations that may have resulted in errors. Examples include: close similarities between grassland and shrubland, scarce woodland and dense shrubland, small-scale farms and shrubs.

Accuracy assessment of land cover classification is important to figure degree of ‘correctness’ of a classification (Congalton, 2001; Foody, 2002). The accuracy in this study was conducted by applying both ground data collected from the field and high-resolution imagery to the 2014 classified image. Accuracy assessment is done on the 2014 image because the reference images used are closer in the date of acquisition to the 2014 image than images from 2000 or 1993 and therefore more comparable. High-resolution imagery was largely used due to inaccessibility in some areas of Lower Jubba due to insecurity.

Mapping accuracy was done using the confusion matrix and Kappa Khat methods for the 2014 image according to the methodology described by Congalton (2001) and Butt et al. (2015). Butt et al. (2015) describes the Kappa Khat method as a measure of agreement between predefined producer ratings and user assigned ratings, calculated by the formula:

$$K=P(A) - P(E)/1-P(E) \quad \text{(3)}$$

Where P (A) is the number of times the *K* agrees, and P (E) is the number of times the *K* are expected to agree only by chance. The number of points used in the confusion matrix were 76 points using field points and high-resolution imagery. The overall accuracy of the classification was determined. The overall accuracy is the proportion of the total number of predictions that were correct. It is calculated by dividing the total number of correctly classified pixels by the total number of reference pixels.

According to Congalton (2001), the producer accuracy shows how well a certain area can be classified (omission error) this is the fraction of correctly classified pixels with regard to all pixels of that ground truth class. It is calculated by dividing the number of correctly classified pixels in each category by the total number of reference pixels “known” to be of that category. The user accuracy shows the probability that a pixel class on the map correlates with the category on the ground (commission error). The user accuracy is the fraction of correctly classified pixels with regard to all pixels classified as this class in the classified image. It is computed by dividing the number of correctly classified pixels in each category by the total number of pixels that were classified in that category.

Post processing of the classified image was compared using cross-tabulation in order to determine qualitative and quantitative aspects of the changes for the periods from 1993/95 to 2014 in ArcGIS 10.2. Interviews from focus group discussions and key informants were useful in verification of the resulting data.

3.3.6 Assessment of Model Skill in Simulating Observed Climate

The skill of the climate models to simulate observed data was tested through spatial plots, model bias and correlation analysis of monthly data. Individual CORDEX model data and the ensemble data was compared with the observed data and used to evaluate the deviation of the models and the ensemble from the observed. The observed data is used for calibration. The CORDEX data from the same time period as the observed data is then compared and plotted.

Correlation coefficient was used to measure the level of association between the model outputs and the observed data. A correlation coefficient of 0.0 represents no association between the observed and predicted values. On the other hand a correlation coefficient of 1.0 denotes a positive (direct) while -1.0 denotes a negative (inverse) linear relationship in the observed and predicted values. Biases could still be seen even in cases that have a perfect correlation (Bosire, 2012).

3.3.7 Analysis of Future Climate

The analysis of the future climate was done to meet the fourth specific objective which was to assess the potential impacts of future climate change over Lower Jubba. All the CORDEX models were averaged to create an ensemble. Using the arithmetic mean, the ensemble rainfall data was grouped according to the sub-periods 2030 (sub-period 1), 2050 (sub-period 2), and 2070 (sub-period 3), then grouped further according to the *Gu* (AMJ) season. The temperature data was also grouped together according to the sub-periods 2030 (sub-period 1), 2050 (sub-period 2), and 2070 (sub-period 3), then further according to the four climatic seasons (DJF, MAM, JJA, and SON). The results were mapped for comparison. A statistical analysis of the trend was conducted for the ensemble rainfall and temperature data for each sub-period according to the methodology described in **Section 3.3.4**.

CHAPTER 4 : RESULTS FROM THE ANALYSIS OF PAST AND PRESENT CLIMATE

This chapter presents the results that were obtained when past and present rainfall and temperature data were subjected to various analyses that are discussed in **Section 3.3.4**. The results presented in this chapter goes towards achieving the first specific objective which was to *characterize the past and current climate patterns over Lower Jubba*.

4.1 Past and Present Rainfall Patterns

4.1.1 Characteristics of Baseline Rainfall

The rainfall characteristics presented in this section include mean climatology, and annual cycles and trends for the period 1981 – 2015. **Figure 4-1** shows the spatial patterns of the average seasonal climatology of *Gu* during April to June (AMJ) and *Deyr* during September to December (SON) rainfall for the period 1981-2015 in Lower Jubba.

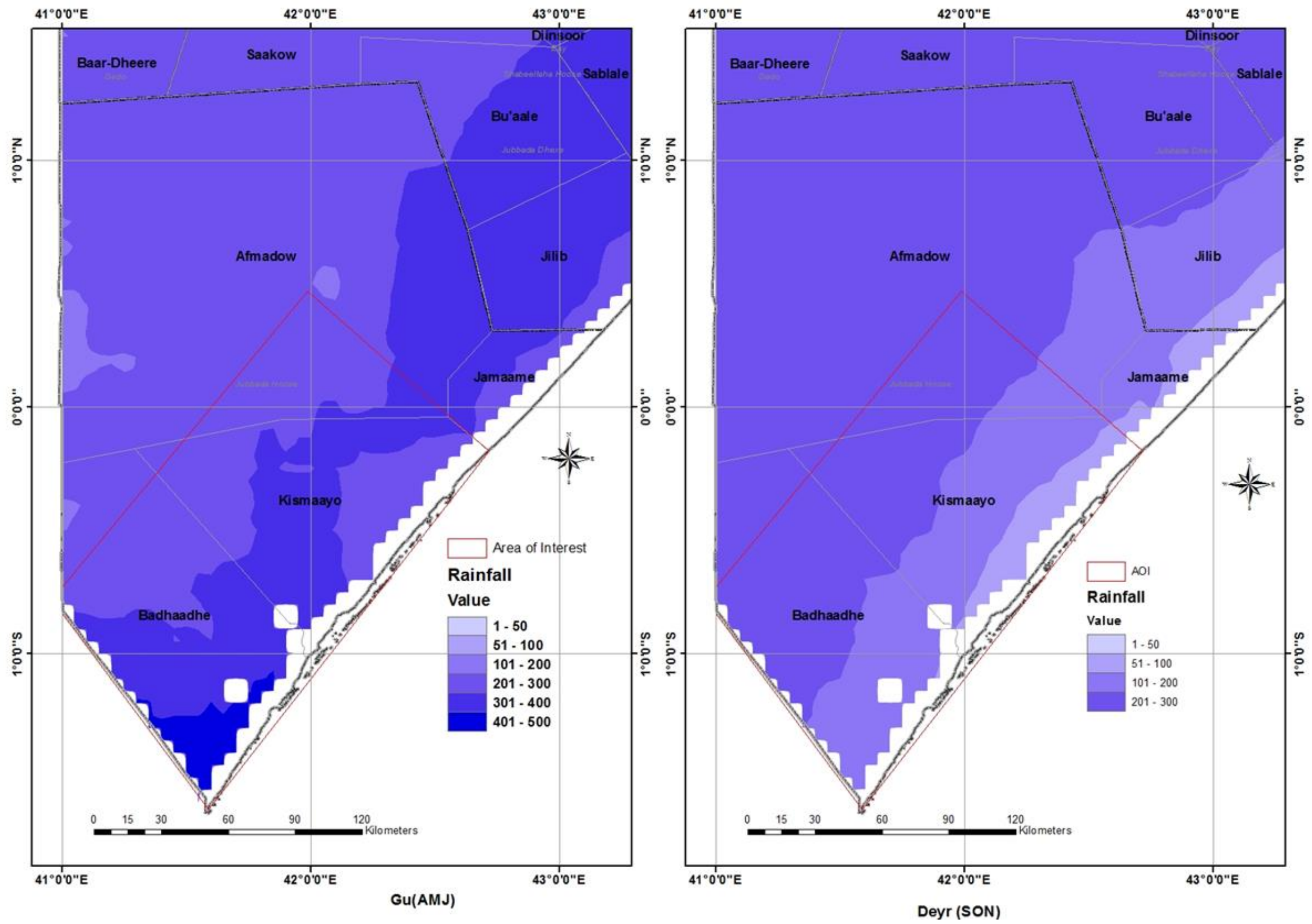


Figure 4-1: Map showing spatial distribution of average rainfall for (a) *Gu* (Apr-Jun) and (b) *Deyr* (Sept-Dec) seasons 1981-2015 in Lower Jubba

Results from this study showed that Lower Jubba receives relatively more rainfall during *Gu* (about 350mm) compared to *Deyr* (average 250mm) season. However, the latter season is more spatially homogeneous than the former. Average rainfall received in both seasons per district is displayed in **Table 4-1**. The mean seasonal rainfall are in line with the reports from the Federal Government of Somalia (2013) that show that Lower Jubba is one of the places with high amounts of seasonal rainfall in Somalia. According to the Federal Governments report the average rainfall during the *Gu* season in Lower Jubba to be 300mm and 200 mm during the *Deyr* season.

The rainfall results shown in this study for Lower Jubba during the September to November season despite heavy reliance on satellite rainfall data is similar to results by Mutia (2013) on the bordering counties of Garrisa, Wajir and Mandera in Kenya which was derived from station data. Mutia (2013) reported that during the short rain October to December (OND) season, the three counties receive an average of 110 to 200mm of rainfall. **Figure 4-1** further shows that the southern coastal band receives the highest precipitation compared to other areas in *Gu* season. During the *Deyr* season however, the coastal region is drier compared to other parts of the study area.

Parts of the Western/North Western regions receive the highest amount of rainfall in Lower Jubba during the *Deyr* season but in contrast, receive the lowest amounts of rainfall during the *Gu* season. **Table 4-1** gives the Seasonal Rainfall lowest/highest values at four locations in Lower Jubba. The large seasonal variability in the range between maximum/minimum values is common at all locations. The table confirms *Gu* as Lower Jubba's long rain season and *Deyr* as the short rain season.

Table 4-1: Seasonal Rainfall Values in Lower Jubba

	Gu (Rainfall (mm))		***Deyr (Rainfall (mm))***	
District	**Min**	**Max**	**Min**	**Max**
Badhaadhe	197	486	94	273
Afmadow	188	363	134	277
Jamaame	271	352	69	141
Kismaayo	233	339	61	244

4.1.2 Results from Trend Analysis

Figure 4-2(a) gives a time series plot for *Gu* rainfall season in Lower Jubba. A general decreasing trend in rainfall of 2.27mm/year is quite evident, though the trend was not statistically significant (p = 0.08). The decreasing trend is consistent with studies by Tierney, *et al.* (2015) on the Greater Horn of Africa that have shown a persistent decline in rainfall during the March-April-May (MAM) “long rains” season. Similar studies over the counties bordering Lower Jubba in the North Eastern parts of Kenyan done by Lyon & DeWitt (2012) also shows similar results. Several reports have stated that recurring failures in seasonal rainfall in the recent past has aggravated severe drought over the region (Lyon & DeWitt, 2012; Tierney, *et al.*, 2015; Connolly-Boutin & Smit, 2016).

During the *Deyr* “short rain” season, the results as shown in **Figure 4-2(a),** showed a general increase in rainfall of 1.23 mm/year, though the trend was statistically significant (p = 0.29). The increase in the short rainfall season is consistent with studies on the region that have shown an increase in the OND rainfall in the North Eastern parts of Kenya bordering Lower Jubba (Lyon, 2014; Lyon & DeWitt, 2012). According to Indeje, Semazzi, & Ogallo (2000), the short rains are important in maintaining the grasslands and shrublands, and its deficit creates unfavourable conditions for grazing, crops growth and development. The short and long rains in the Horn of Africa region are as a result of the seasonal shifts in the Inter-Tropical Convergence Zone (ITCZ) (Indeje, *et al.*, 2000; FGS, 2013).

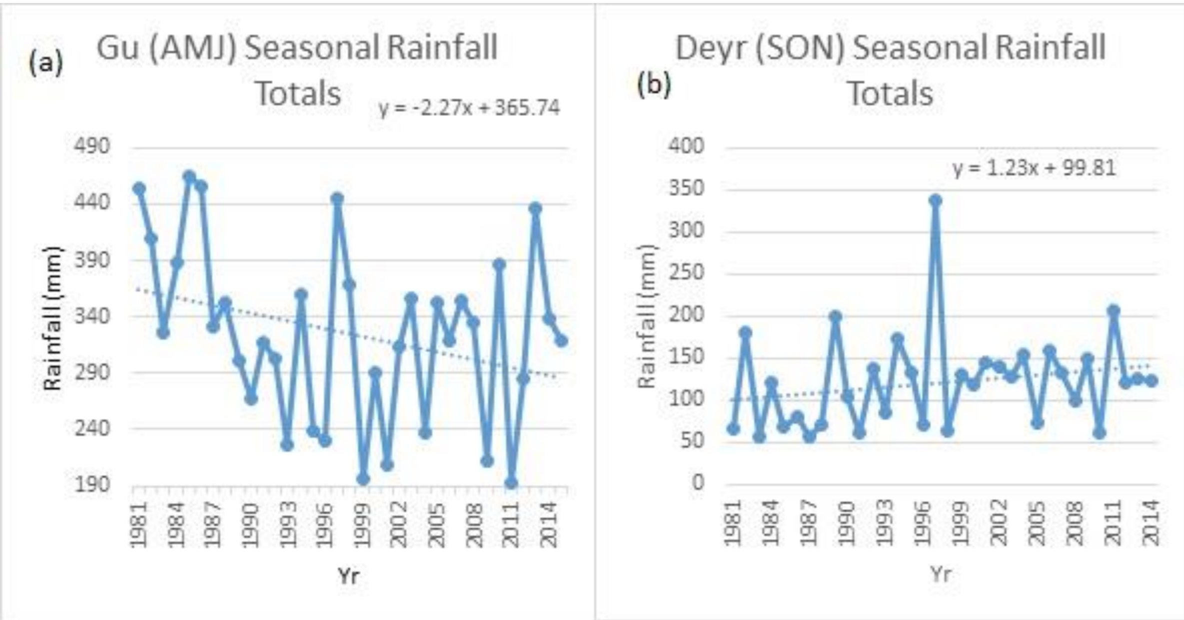


Figure 4-2: Graphs showing the inter-annual rainfall variability for (a) *Gu* and (b) *Deyr* seasons

Figure 4-3 (a & b) shows the spatial distribution of the seasonal rainfall over Lower Jubba for *Gu* and *Deyr* seasons between 1981-2014. The trends seen in **Figure 4-3** are not homogenous throughout the study area. As seen in **Figure 4-3 (a)**, some areas in Lower Jubba have experienced the general decreasing trend in rainfall during the long rain season similar to what is shown in the graph in **Figure 4-2 (a)** above. The results further shows that the decreasing trend that is observed in the graph in **Figure 4-2 (a)**, was however not consistent throughout Lower Jubba, as some areas are seen to have experienced and increase in rainfall.

Results as seen in **Figure 4-3 (b)** on the rainfall trend of the short rain season is more homogeneous. A general increasing trend in the short rain season is seen throughout Lower Jubba, the magnitude of the change differs spatially.

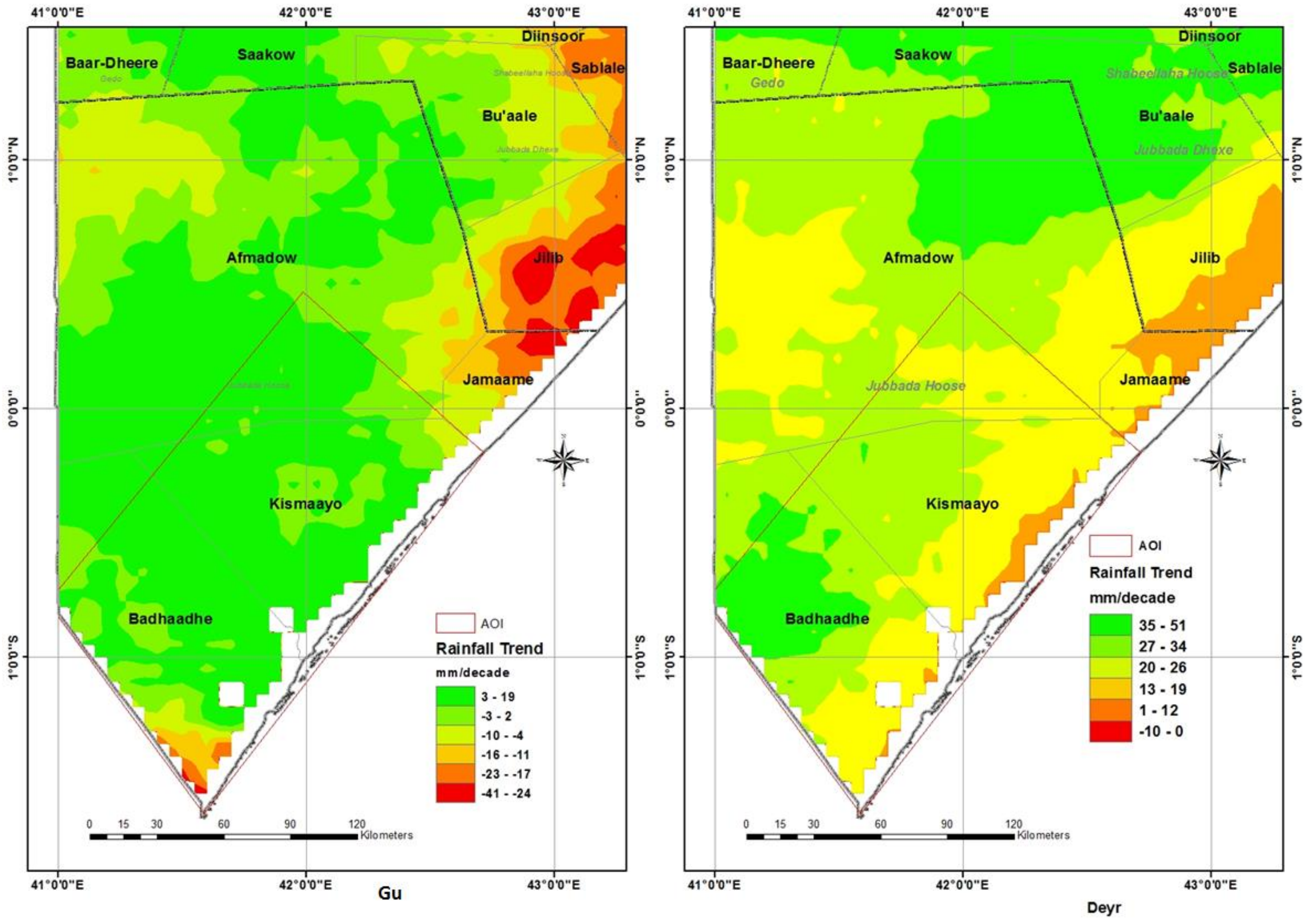


Figure 4-3: Map showing spatial distribution of the change in the seasonal rainfall for (a) *Gu* and (b) *Deyr* in Lower Jubba

Although the rainfall trends were not statistically significant, the complexity of the observed characteristics in the rainfall trends implies a need in the investment in a tailor made climate risk management as well as climate change mitigation and adaptation strategies for each district. Jamame district for example is experiencing a general decreasing trend in rainfall, while Kismayo is generally experiencing an increasing trend. Adaptation and mitigation strategies in Jamame should be drafted based on a decreasing trend in rainfall while those in Kismayo should be based on the observed increasing trend. Details of the pattern in the trend in each district can be seen in **Table 4-2**.

Table 4-2: Summary of the Range of Rainfall Trends in Lower Jubba

District	*Gu (Rainfall Trend (mm/ decade))*		*Deyr (Rainfall Trend (mm/decade))*	
	Min value	**Max value**	**Min value**	**Max value**
Badhaadhe	-35	15	11	42
Afmadow	-14	14	12	48
Jamaame	-26	-2	8	18
Kismaayo	-3	19	8	36

For a region that is heavily reliant on pastoralism, and whose movements are dependent on the search of pasture and water, migration from areas of Lower Jubba experiencing negative trend in rainfall to areas experiencing increase in rainfall is common. Such movements are common drivers of conflict amongst pastoralist in the struggle for limited pasture and water. The observed increasing trend in rainfall in some areas and a decreasing trend in other areas if continues could impact human security as climate induced migration increases. Many studies have associated long-term decreasing trends in climate and short term climatic variance with the likelihood of civil conflict as natural resources become limited (Barnett & Adger, 2007; Hendrix & Glaser, 2007; Maystadt & Ecker, 2014).

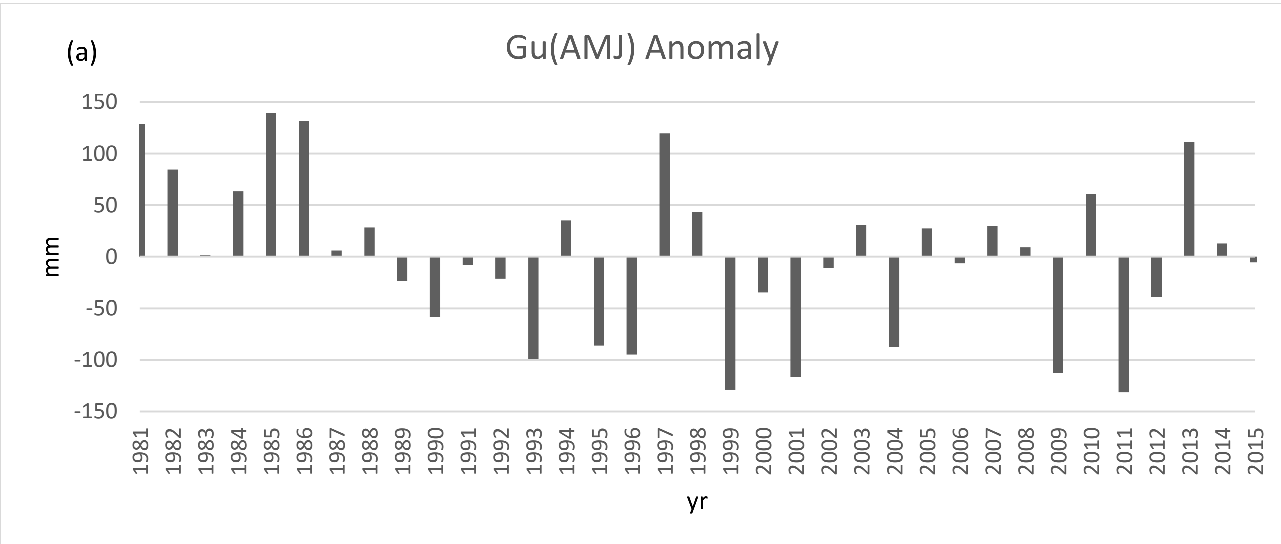
Results as seen in **Figures 4-4 (a & b)** show the real rainfall anomalies computed relative to 1981-2010 for the *Gu* and *Deyr* seasons respectively. Results show that Lower Jubba experienced an increase in occurrence of depressed rainfall usually associated with drought during the long rain season (*Gu*) as shown in **Figure 4-4 (a)**. The frequency of above normal rainfall associated with floods decreased during the study period. This is in agreement with the general negative rainfall trend observed during the long rain season shown in **Figure 4-2 (a)**, even though this trend is statistically insignificant Several studies on the March-May long rains in the GHA region have also shown a decrease in rainfall (Schreck & Semazzi, 2004; Omondi, *et al.*, 2009; Omondi, *et al.*, 2014).

The enhanced rainfall peaks in the *Deyr* season in 1997 (**Figure 4-4(b)**) coincides with the floods reported for Somalia by the international disaster database (2016) that affected 1,230,000 and killed 2,311 people and has been linked to the strong El Niño-Southern Oscillation (ENSO) event of 1997–98 shown in **Table 4-3.** The ENSO phenomenon has been linked by many to some rainfall anomalies in the Horn of Africa, with catastrophic disruption of socio-economic infrastructure and loss of life (Ogallo, 1988; Indeje, *et al.*, 2000; Schreck & Semazzi, 2004; Bowden & Semazzi 2007; P. A. Omondi, *et al.*, 2014).

Table 4-3: El Niño and La Niña Years in Intensity *(Golden Gate Weather Services, 2017)*

El Niño				La Niña		
Weak	**Moderate**	**Strong**	**Very Strong**	**Weak**	**Moderate**	**Strong - 7**
2004-05	1986-87	1987-88	1982-83	1983-84	1995-96*	1988-89
2006-07	1994-95	1991-92	1997-98	1984-85	2011-12*	1998-99*
2014-15	2002-03		2015-16	2000-01		1999-00*
	2009-10			2005-06*		2007-08*
				2008-09		2010-11*
				2016-17		

Some of the below normal rainfall in the **Figure 4-4(b)** also overlaps with reports of consecutive seasons of poor rainfall that resulted in droughts in Somalia. Droughts reported for Somalia in 1987, 1998, 2008-09, 2010, 2011/12 2016/17 all coincided with La Niña phenomenon in the same years (EM-DAT, 2016). The ENSO phenomenon and Indian Ocean Dipole (IOD) have been reported as the primary drivers of climate variability over the Horn of Africa (Ogallo, 1988; Schreck & Semazzi, 2004; Bowden & Semazzi 2007; IPCC, 2007; Lyon, 2014).



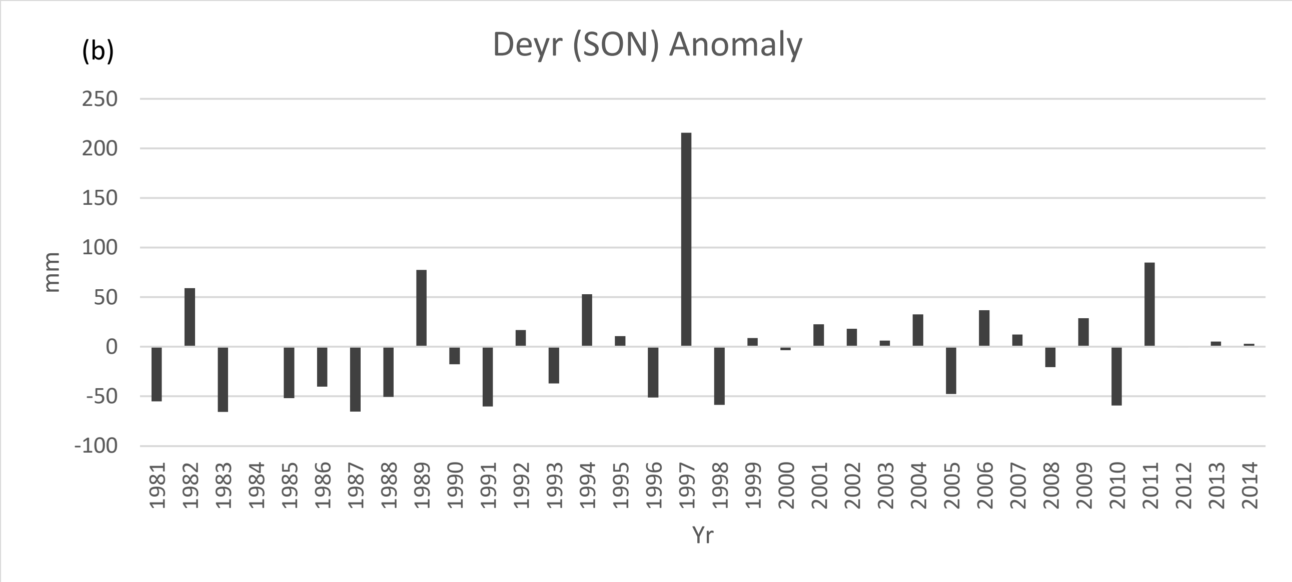


Figure 4-4: Graph showing the rainfall anomalies for (a) Gu and (b) *Deyr* rainfall season between 1981 and 2014

In conclusion, the results from analysis of interannual characteristics of rainfall over Lower Jubba revealed a high degree of interannual variability with recurrences in high/low value extremes that are often associated with floods/droughts. Some of these extremes occurred during the El Niño/ La Niña years. A general increase in occurrence of depressed rainfall usually associated with drought, along with a decrease in frequency of above normal seasons associated with floods, was seen during the study period. A general decreasing trend in rainfall during the *Gu* season and a general increasing trend during the *Deyr* season were also observed, though these delineated trends were not spatially consistent.

Results discussed in this chapter help meet the specific objective by characterising the past and present climate in Lower Jubba. Due to the limitation in the length of data, it is difficult to associate the observed rainfall trends to climate change. Studies on the Horn of Africa region have however shown that climate related extremes have been the dominant trigger of natural disasters which includes Somalia (Omondi et al., 2014). The HoA region has witnessed frequent episodes of both excessive and deficient rainfall (Ogallo, 1979, 1980, 1982; Omondi et al., 2009; Omondi et al., 2014).

These results for the first time provide more insight into climate variability for Somalia that could be of great use for planning and management of all socio-economic systems.

4.2 Past and Present Mean Surface Temperature Patterns

4.2.1 Results from Characteristics of Baseline Temperature

This section presents results from the past and present patterns of the minimum, maximum and average temperature over Lower Jubba. **Figure 4-5 (a, b, c)** presents the annual cycle the average minimum, maximum and average temperature between 1981 and 2012.

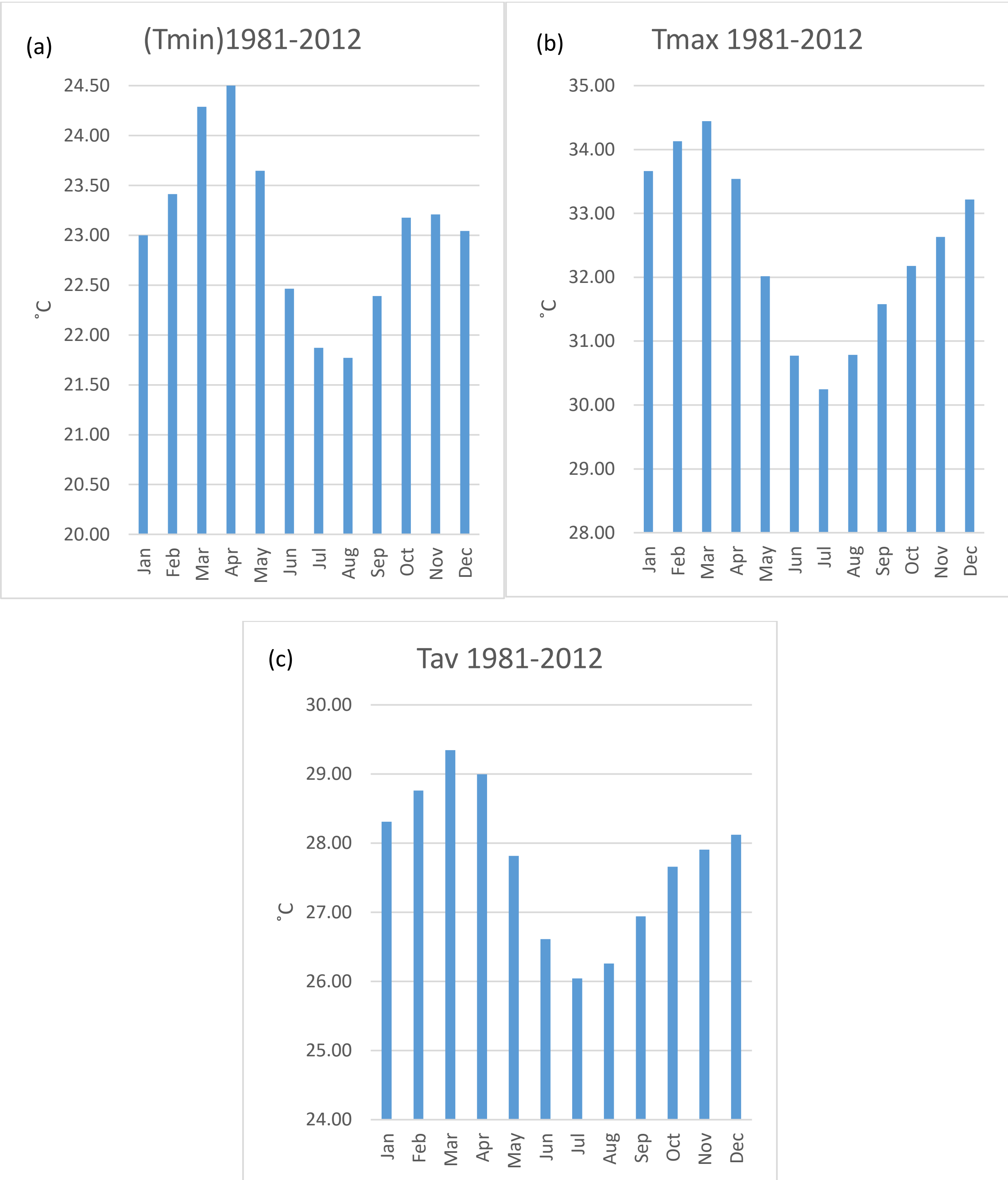


Figure 4-5: Annual temperature cycle in the (a) minimum (Tmin), (b) maximum (Tmax) and (c) average (Tav) temperature between 1981 and 2012

Figure 4-5 (a) shows the results for the minimum temperature where July and August are seen as the coldest months while March and April recorded the highest temperatures. February and May also recorded relatively high temperatures. From the maximum temperature seen in **Figure 4-5 (b),** June and July are the coldest months while February and March records the highest temperatures. Overall, for the average temperature as seen in **Figure 4-5 (c),** June, July and August record the lowest temperatures while March records the highest temperature. February, Jan and April also recorded high temperature values overall.

The *Gu* (AMJ) rainfall season had both the highest and the lowers average temperatures, as a result, the standard global climatic seasons were used to analyse the temperature data. **Figure 4-6** looks at the spatial distribution of the average temperature in the seasons DJF, MAM, JJA and SON in the years 1981-2012 from the satellite data by the Climate Hazard Group. Overall, the average temperature seems to be lower towards the southern costal band. This could be due to a due to the influence of cold ocean currents (Jaswal, Singh, & Bhambak, 2012). The map also shows JJA as the coldest of the four seasons.

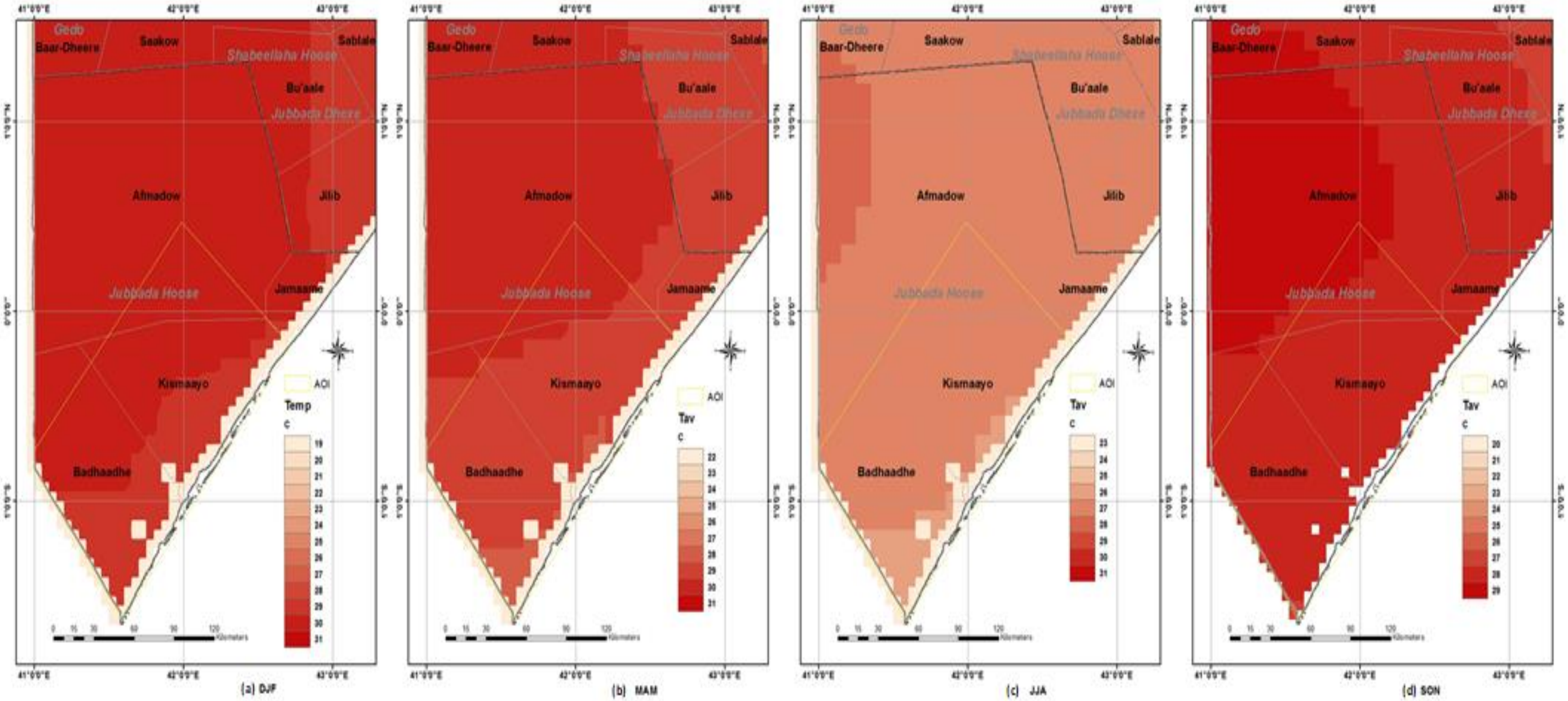


Figure 4-6: Map showing the spatial distribution of the average (Tav) temperature in the DJF(a), MAM(b), JJA(c), and SON(d) Season (1981 to 2012)

4.2.2 Results from Trend Analysis

Figure 4-7 shows a time series on the average temperature in Lower Jubba from 1981 to 2012 in the DJF, MAM, JJA and SON seasons. The results show a positive trend in in all seasons with an increase of 0.01 ˚C/year in all seasons but MAM which showed an increase of 0.02 ˚C/year. All the results are statistically significant at 0.05% significance level (p=0.04). King'uyu et al. (2000) reported an increase in temperature in the Horn of Africa region as well. Several other studies have also reported an increasing trend in temperature globally (King'uyu, Ogallo, & Anyamba, 2000; Easterling, *et al.*, 2009; IPCC, 2014a).

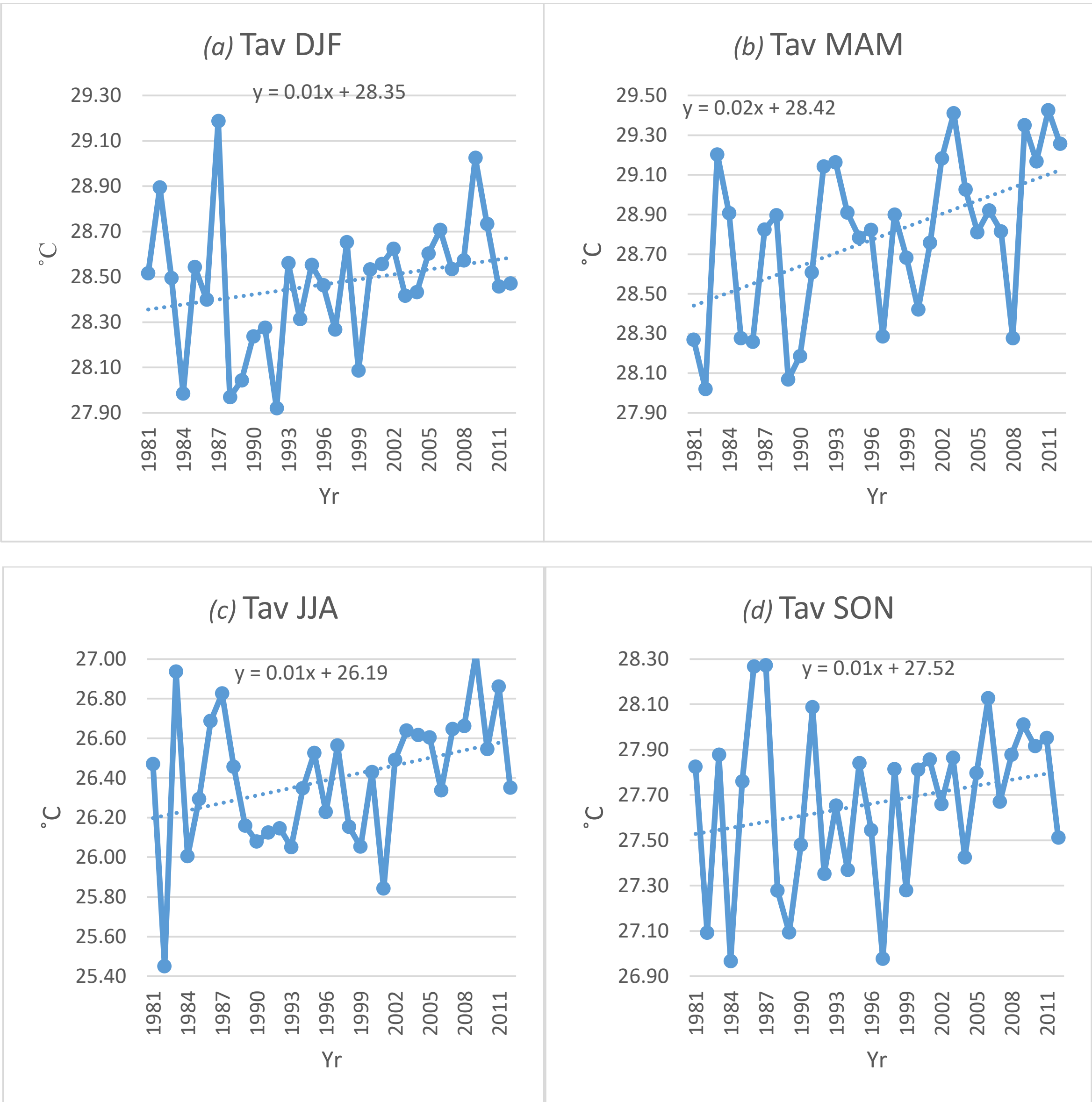


Figure 4-7: Time-series plot of the seasonal average temperature (Tav) in the DJF (a), MAM (b), JJA (c), and SON (d) Season (1981 to 2012)

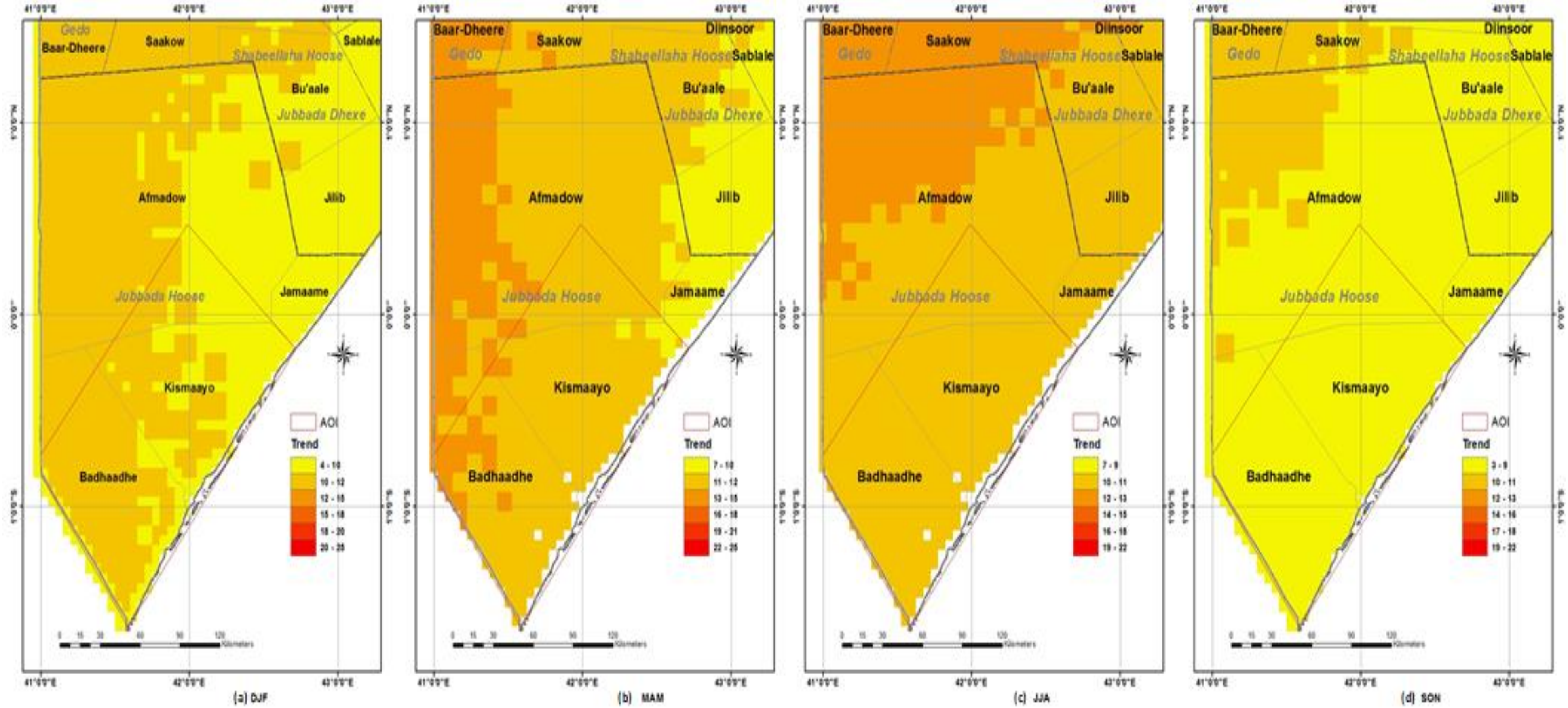


Figure 4-8: Spatial distribution of the change in average (Tav) temperature in the DJF (a), MAM (b), JJA (c), and SON (d) Season (1981 to 2012)

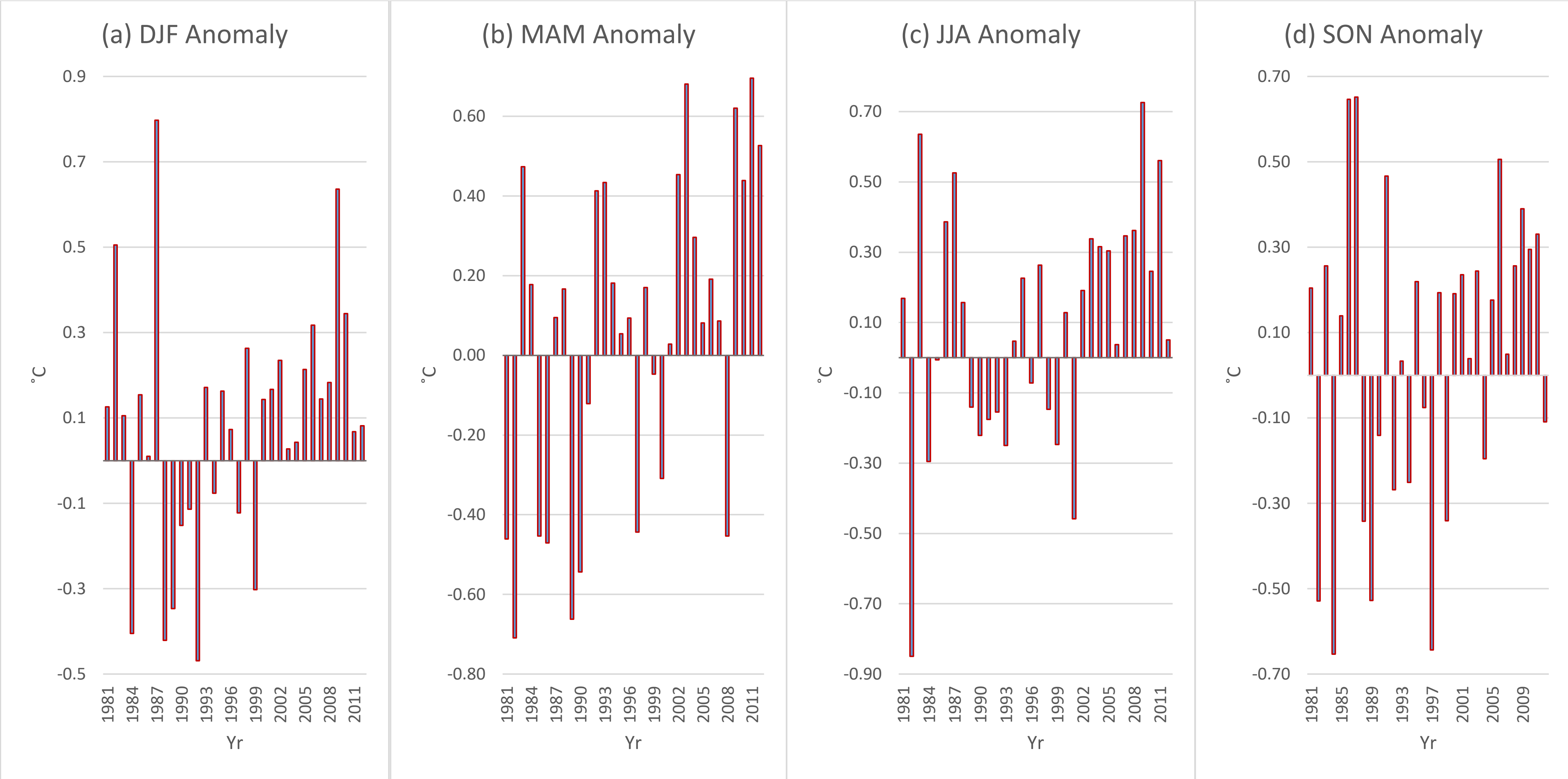


Figure 4-9: Anomalies in temperature during minimum (Tmin) (a), maximum (Tmax) (b) and average (Tav) (c) temperature in the DJF, MAM, JJA, and SON Season (1981 to 2012)

Figure 4-8 shows a spatial distribution in the changes in temperature. A genreally positive trend in the change in temperature is observed in the entire region, though the spatial distribution varies from season to season. **Figure 4-9** shows the anomalies observed in the average temperatures. The recurrence of below normal and above normal extremes persists as seen in **Figure 4-9** though some are very large. Increase in temperature could change the ecology of infectious diseases as well as increase temperature related mortality and morbidity of people and livestock (Patz, *et al.*, 1996; WMO, 2003; IPCC, 2014c).

It may be concluded from temperature analyses that like the global observation, both minimum and maximum temperatures are observed to increase in all seasons in Lower Jubba. These are consistent with the results from many recent studies worldwide (King'uyu, et al., 2000, Easterling, et al., 2009; IPCC, 2014). Like in the case of rainfall time series, there were also evidences of recurrences of extreme high/low values in the interannual patterns of both max/min temperatures. Some of the high/low temperature values observed during the period of low/high rainfall linked to El Niño/ La Niña and anomalies in other regional rainfall systems. Due to limited data however, it was also difficult to link the observed temperature changes in Lower Jubba entirely to climate change. Many worldwide changes in max/min temperatures have been linked to climate change induced global warning.

These results for the first time provide more insight knowledge regarding climate variability, which could inform the development of climate smart strategies for Lower Jubba region in support of sustainable livelihoods, and the general planning and management of all socio-economic systems.

CHAPTER 5 : RESULTS FROM LAND COVER ANALYSIS

The second specific objective of the study was to *evaluate the changes in land cover in Lower Jubba from possible impacts of charcoal production*. The results associated with this specific objective are presented in this section.

5.1 Land Cover Change (LCC) Results

The following section displays the results derived from the land cover change analyses based on the methods outlined in **section 3.3.5.**

5.1.1 Classification Results

The initial classification resulted into 36 signatures, these were checked for accuracy and assigned new classes for generation of 6 classes as summarized in **Table 5-1** below.

Table 5-1: Land Cover Classes

Class Name	Land Cover Types
1. Forest	Dense trees mainly in hilly areas and along the rivers
2. Woodland	Acacia and other woodlot in less dense formation
3. Shrub land	Areas with shrub vegetation interspersed with grass
4. Grassland	Savannah grassland
5. Bare/Rock/Urban	Rocky river bed, rocks, bare soils and Urban Areas
6. Water	Open water in rivers and the Indian Ocean

The spatial distribution of land cover is shown in **Figure 5-1 (a, b, c).** Some of the changes in the vegetation can be seen in the progression from the 1993_95 image, to 2000 image and 2014 image. A decrease in vegetation and increase in bare-land from 1993_95 to 2014 is evident in **Figure 5-1**. Many studies on the African land cover also show a change in the distribution of grasslands and shrublands, savannas and woodlands, and forests (Lambin, *et al.*, 2001; IPCC, 2007; 2014).

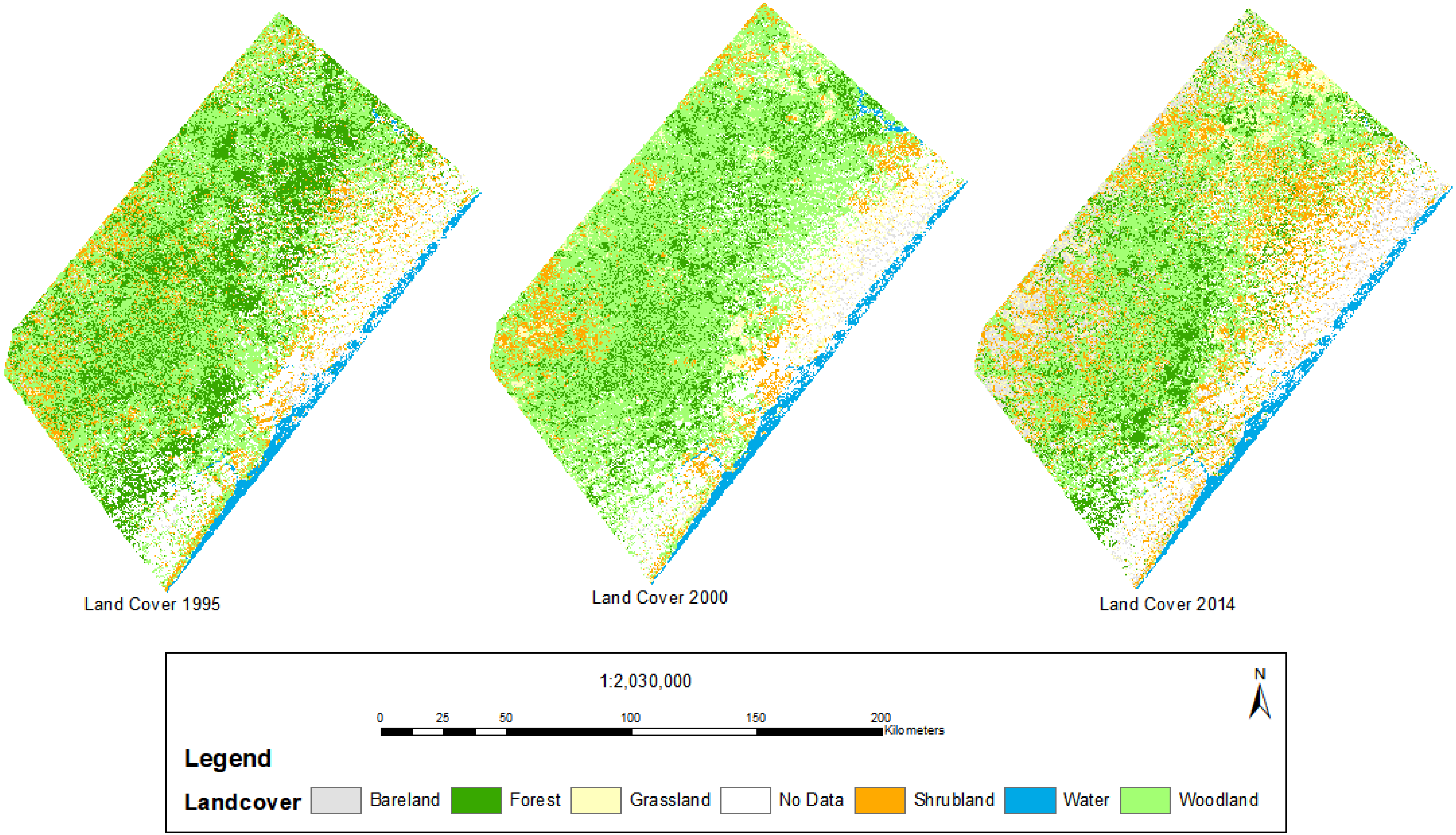


Figure 5-1: Classified images of the land cover in the study area shown in **Figure 3-2** in 1993/95(a), 2000(b), 2014(c)

5.1.2 Accuracy Assessment

The results of the accuracy assessment showed an overall accuracy of 88.16% with a Kappa coefficient of 0.84. This means that 88% of the image classification matched the reference data. According to Foody (2002), the general target for an accuracy assessment is 85%. The accuracy for this study exceeded this target and the results therefore represent a strong agreement. **Table 5-2** shows the producer and user accuracy for each class.

Table 5-2: Accuracy Assessment Tabulation

		Actual Classification							
Predicted	Class	Water	Forest	Woodland	Grassland	Shrubland	Bare Land/ Artificial	Totals	Users Accuracy %
	Water	**5**	0	0	0	0	0	5	100.0
	Forest	0	**9**	1	0	0	0	10	90.0
	Woodland	0	2	**8**	0	0	0	10	80.0
	Grassland	0	0	1	**5**	0	0	6	83.3
	Shrubland	0	0	3	0	**10**	1	14	71.4
	Bare Land/ Artificial	0	0	0	1	0	**30**	31	96.8
	Total Predictions	5	11	13	6	10	31	76	
	Total Correct								**67**
	Producers Accuracy %	100.0	81.8	61.5	83.3	100.0	96.8		

A user accuracy of 90% was reported for the forests, this is probably because the forested areas are well known and easily classified. The woodlands reported a user accuracy of 80% while 71% was reported for the shrublands. Bare land/artificial had the highest accuracy of 97% probably because the residential areas classified under this classification are close together and easy to spot. The use of remote sensing and GIS to determine the change in land-use and land cover has been used by many as a satisfactory method (Gautam, *et al.*, 2003; Dewan & Yamaguchi, 2009; El-Kawy, *et al.*, 2011; Butt, *et al.*, 2015; Rawat & Manish, 2015).

5.1.3 Land Cover Change

The land cover changes were analysed and categorized based on loss or gain in vegetation as summarized in **Table 5-3** below.

Table 5-3: Summary of land cover change categorization

Change Type	Cover category

Deforestation	Forest, Woodland to Shrubs, Grassland and Bare
Degradation	Forest to Woodland
No Change	Constant cover type
Reforestation	Woodland to Forest; Grassland, Shrub or Bare to Woodland/Forest
Other Change	Other changes

Figure 5-2(a, b & c) maps out the land cover changes in Lower Jubba. Results seen in **Figure 5-2(a)** shows that the most significant change between 1993_5 to 2000 was degradation from forests and woodland. This type of degradation shows a threat to the natural vegetation and has implications on carbon stocks. The degradation that is observed coincides with reports by Cagnolati et al. (2006) that stated that pastoralists turning to charcoal trade after the ban on export of livestock due to Rift Valley Fever (RVF) that hit Somalia in 1998/1999. The Rift Valley Fever outbreak is also linked to excessive flooding reported in Somalia around the same period, (EM-DAT, 2016) and coincides with the enhanced rainfall anomalies in 1997–98 shown in **section 4.1.2**.

The most significant change seen in **Figure 5-2 (b & c)** is deforestation. In this study deforestation was categorised as the change from forests or woodlands to grassland, bare land or shrubs. Results in **Figure 5-2 (b)** show significant deforestation from 2000 to 2014. The period also coincides with reports by Cagnolati et al. (2006) of a Rift Valley Fever outbreak in 2000-2002 and 2006-2007 that also lead to a ban in the export of livestock from Somalia. The deforestation seen in this study is similar to reports of pastoralists coping to loss of livelihood by cutting trees for charcoal production (Beier & Stephansson, 2012; WB, 2016a). **Figure 5-2 (c)** shows significant deforestation overall between 1993_5 to 2014.

The extended periods of below normal rainfall shown in **section 4.1.2** shows climate variability could be preventing the re-growth of natural vegetation, resulting in the overall magnitude deforestation and degradation seen in **Figure 5-2 (c).** Natural re-sprouting and re-growth of wood biomass is an important source of regeneration of deforested and degraded areas. Vieira & Scariot (2006) stated that a shortcut for forest recovery after injury, such as slash and burn inflicted by charcoal production is the re-sprouting of forests. Zhang, Kang, & Yang (2017) further reported that climatic change-induced water stress has been found to threaten the viability of trees by inhibiting their recruitment. In fact several studies have shown the risk posed by drought to forests (Vieira & Scariot, 2006; Huang & Anderegg , 2012; Zhang, Kang, & Yang , 2017).

Figure 5-2: Change in Land Use Map 1993 to 2014 for Lowe Jubba, Somalia

Figure 5-3 highlights specific areas of forest conversion to woodland and to bare land. From the images an area that has a dense population of trees taken in 1993/95 becomes sparsely populated with trees in 2000, and becomes shrubland and grass land, verifying the deforestation. SWALIM (2014) identified the dark spots shown in the images in **Figure 5-3** as charcoal production sites. The images shows several charcoal production sites in the area that is classified as having experienced deforestation, further verifying the results of the study.

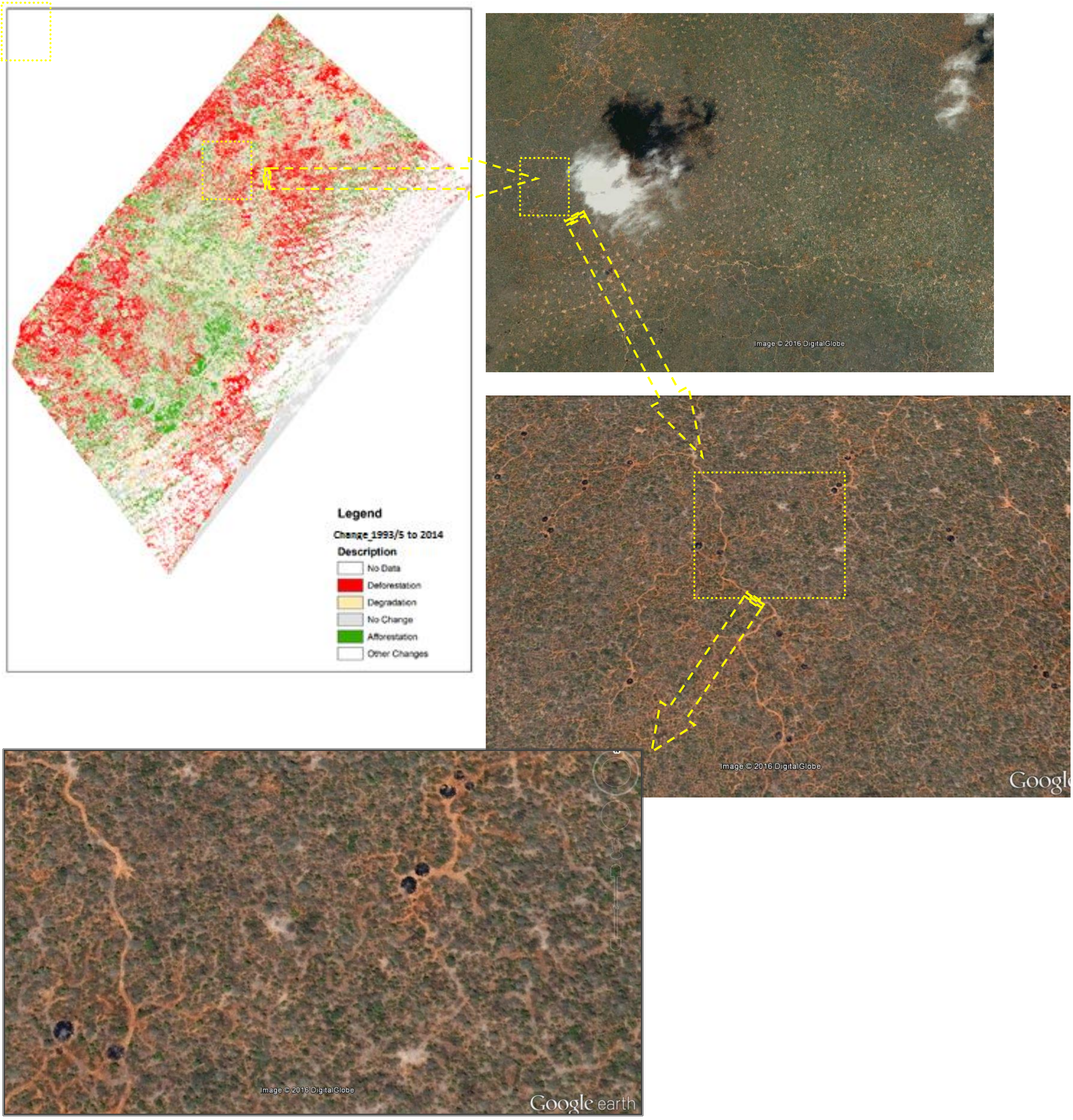


Figure 5-3: Forest conversion to woodland then to bare land

Figure 5-4 shows some images of the woodland and shrubs taken from the field in 2016, used in the ground truthing process.

Figure 5-4: Images of Acacia trees and Commiphora shrubs in Lower Jubba used in accuracy assessment studies

The region of study experienced about 50% reduction in forest cover between 1993_95 and 2014, and 16% reduction of woodland in the same time period as shown in **Table 5-4**. The reduction of tree and forest cover is further evidenced by the increase in bare-land and grassland by over 300% each. There was an increase in woodland between 1993/5 and 2000, showing that some of the areas that had forest cover had been converted into woodlands, and can be seen in **Figure 5-5**.

Results from the analysis on the change in land cover is seen in **Table 5-4** below.

Table 5-4: Land cover in area of interest in 1993/95, 2000 and 2014

	Area in Ha			**% change**		
CLASS	**93_5**	**2000**	**2014**	**2000-93/5**	**2014-2000**	**2014-93/5**
Water	57172.5	61212.15	58458.06	7%	-5%	2%
Forest	520163.7	288206.5	259764	-45%	-5%	-50%
Woodland	786299	1015097	655032.1	29%	-46%	-17%
Grassland	49258.71	137856.1	198129.3	180%	122%	302%
Shrubland	200753.6	131611.1	293250.7	-34%	81%	46%
Bare-land/ Artificial land	47270.43	26935.56	196283.9	-43%	358%	315%

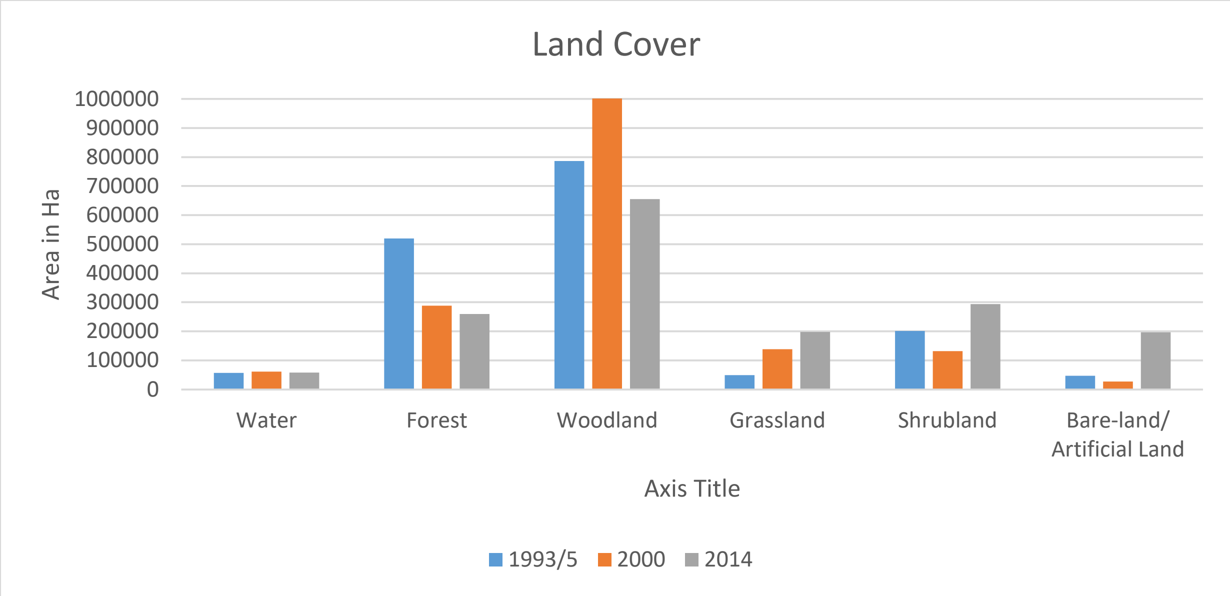


Figure 5-5: Land Cover between 1993/5 and 2014

Results from this study show that the rate of deforestations in Lower Jubba is much higher than reports by IPCC (2014b) on Sub-Saharan Africa, which give a 16% decrease in total forest cover and 5% decrease in total non-forest cover. Natural regeneration of deforested areas would have been influenced by the recurrence of below normal anomalies between the year 1993 and 2014 shown in **Section 4.1.2**. Aside from impacting the natural regeneration of vegetation, the droughts reported for Somalia in 1999, 2008-09 and 2010/11 (EM-DAT, 2016) also has an impact on livelihoods as a result of availability on water and pasture. The impact of climate variability is driving pastoralists to charcoal production resulting in increasing land degradation.

If deforestation and degradation continue at the same rates shown in **Table 5-4**, Lower Jubba could experience complete deforestation in the future, particularly if no mitigation measures are taken. Complete deforestation would create significant livelihood challenges for pastoralists in this region. Deforestation could increase the risk and spread of disease by increasing artificial water pools that can become breeding sites for malaria-carrying mosquitoes. It could also possibly extend tsetse zones which would negatively impact livestock in the region. Enwezor & Sackey (2005) report camel trypanosomosis caused by tsetse flies as the most prominent single cause of economic losses in camel rearing areas, causing morbidity of up to 30.0% and mortality of around 3.0%.

Complete deforestation means that charcoal production, which is a coping mechanism for loss of livelihoods for communities in Lower Jubba, is maladaptive. A major crisis in supply of trees looms ahead for communities if the status quo remains. Reforestation and tree farming could address the need for charcoal while simultaneously engage in soil and water protection. Investment in weather forecasting will help communities in Lower Jubba employ alternative adaptation practice like the vaccination of livestock against Rift Valley Fever to reduce their vulnerability.

Deforestation increases the community's vulnerability even further through its impact on the local climate. Several studies have shown that deforestation reduces evapotranspiration which in turn reduces localised rainfall during dry seasons (Shukala, *et al.*, 1990; IPCC, 2007; Miller & Janet, 2013; IPCC, 2014b). Climate change modelling by Miller & Janet (2013) project a 2-3 mm/day decrease in rainfall in the dry season after complete tropical deforestation in Africa projects a 2-3mm/day. Several studies further report that deforestation also impacts local thermodynamics, resulting in a decrease in heat released to the atmosphere (IPCC, 2007; Miller & Janet, 2013; IPCC, 2014b). In South Sudan, Miller & Janet (2013) showed that when complete deforestation was reported to have reached two thirds by 2001, local temperatures were also reported to have increased locally between 1.2-2.4°C following the deforestation.

CHAPTER 6 : RESULTS FROM THE SURVEY ON OBSERVATIONS OF CLIMATE CHANGE AND SIGNIFICANCE OF CHARCOAL PRODUCTION

The third specific objective was to *determine the impacts of climate variability on the livelihoods of the community and the significance of charcoal production in it*. This section gives results from the survey undertaken in the study area according to the methodology described in **Section 3.3.3**. One hundred and fifty questionnaires were distributed and the analysis of the results is presented.

6.1 Impacts of Climate on Livelihood

6.1.1 Observed Rainfall Characteristics

Figure 6-1 shows the communities view on rainfall variability, with 83% of the respondents interviewed in the survey reporting an increase in drought in Lower Jubba. The survey also found that 61% of the population in Lower Jubba rely on groundwater as their main source of water, which is impacted by recurring drought. 97% of the respondents surveyed stated an observed change in rainfall patterns stating that the rainfall had become less reliable. The reliability of rainfall in this survey was defined by the delay in the onset of rainfall as well as the quantity of rainfall received. This supports the results of the rainfall anomalies seen in **Figure 4-4** that show the recurrence of depressed rainfall. 51% of the households stated that they had been directly affected by flooding also corresponding with the above normal rainfall peaks also seen in **Figure 4-4**.

Figure 6-1 supports results discussed in **section 4.1.2** that showed that the few significant trends that were delineated at some locations were not spatially consistent over large areas. Some respondents observed an increase in rainfall while others observed a decrease in rainfall over the years. This result further support the need for a tailor made climate change adaptation strategies.

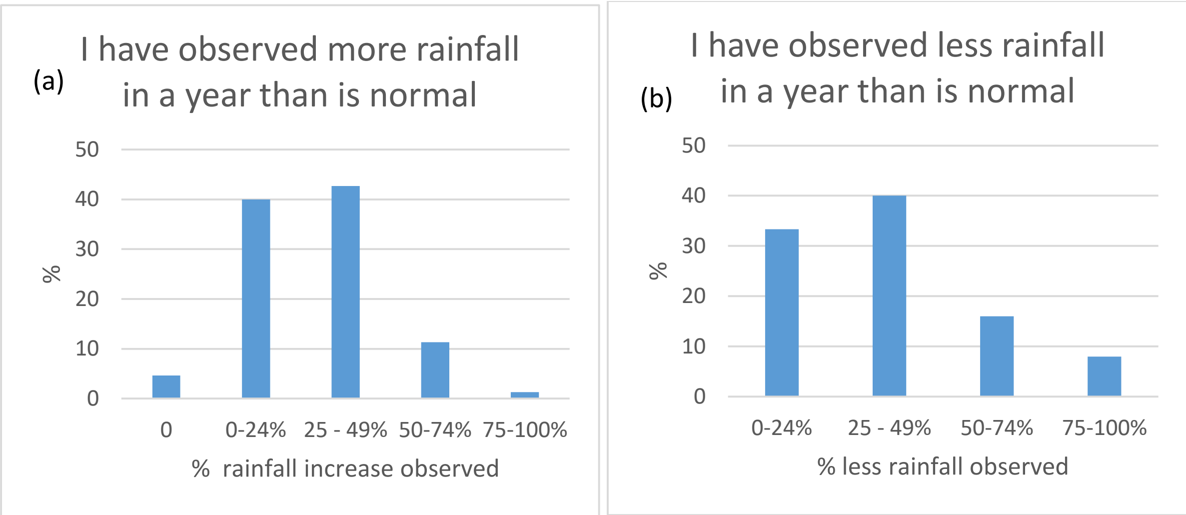


Figure 6-1: Graphs show the observed range in the change in rainfall in Lower Jubba

6.1.2 Observed Temperature Characteristics

66% of the respondents in the survey stated that they had observed an increase in temperature over the years as shown in **Figure 6-2**. This supports the increasing positive trend in temperature shown in **Section 4.1.2**. It also supports the reports on unequivocal increase in temperature reported by IPCC (2014b) in the continent and in most parts of the world.

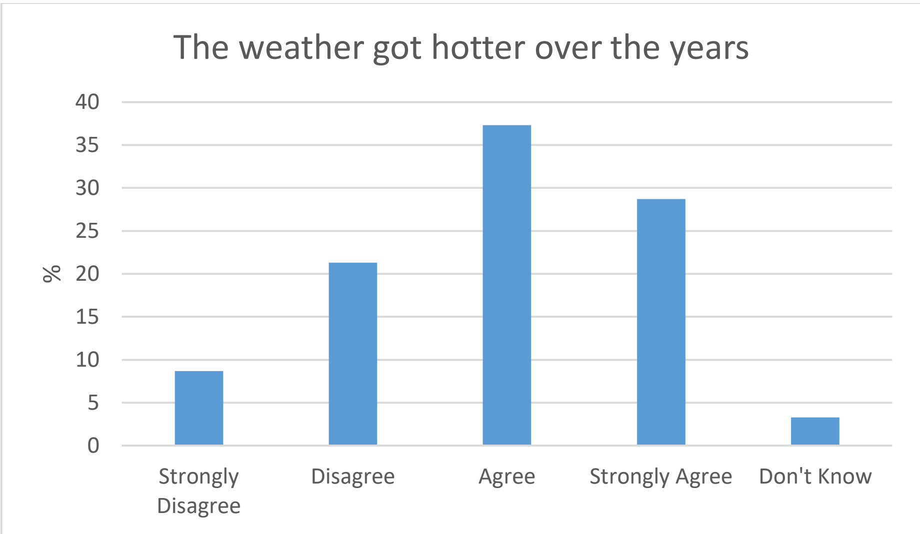


Figure 6-2: Observed increase in temperature

54% of the respondents observed an increase in strong winds as shown in **Figure 6-3.** Strong winds contribute to dust and sand storms, increasing soil erosion particularly in areas experiencing land degradation.

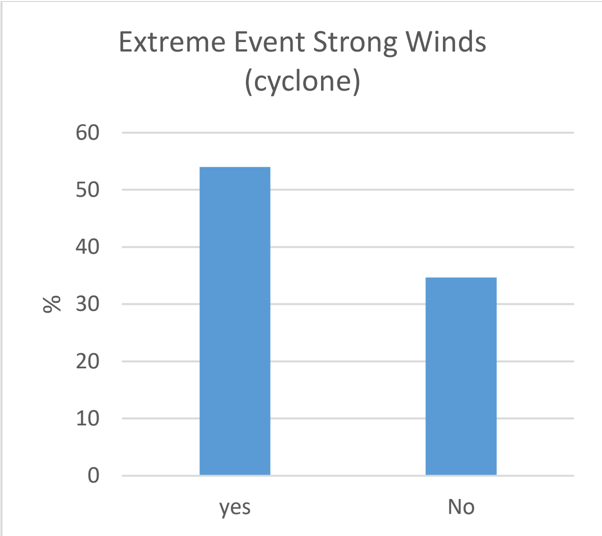


Figure 6-3: Observed increase in temperature

6.1.3 Impacts of Climate Variability

The impact of inter-annual variability seen in the archived data discussed in **section 4.1.2** has been observed by the community. From **Figure 6-4**, it can be seen that a large number of pastoralists stated an unreliability in rainfall as they years have progressed. The report on Somaliland by the MoPD&E (2004), stated that charcoal production is largely conducted by young pastoralists who have lost livestock or pastoralists who want to grow their stock. A large number of people in the charcoal trade and other occupations outside of agriculture also stated that the rainfall had become unreliable. Studies by Paavola (2008) on Morogoro, Tanzania (2008) and by Smith et al. (2017) on southern Malawi, have shown that pastoralists are turning to charcoal and other trades due to loss of livestock as a result of climate variability.

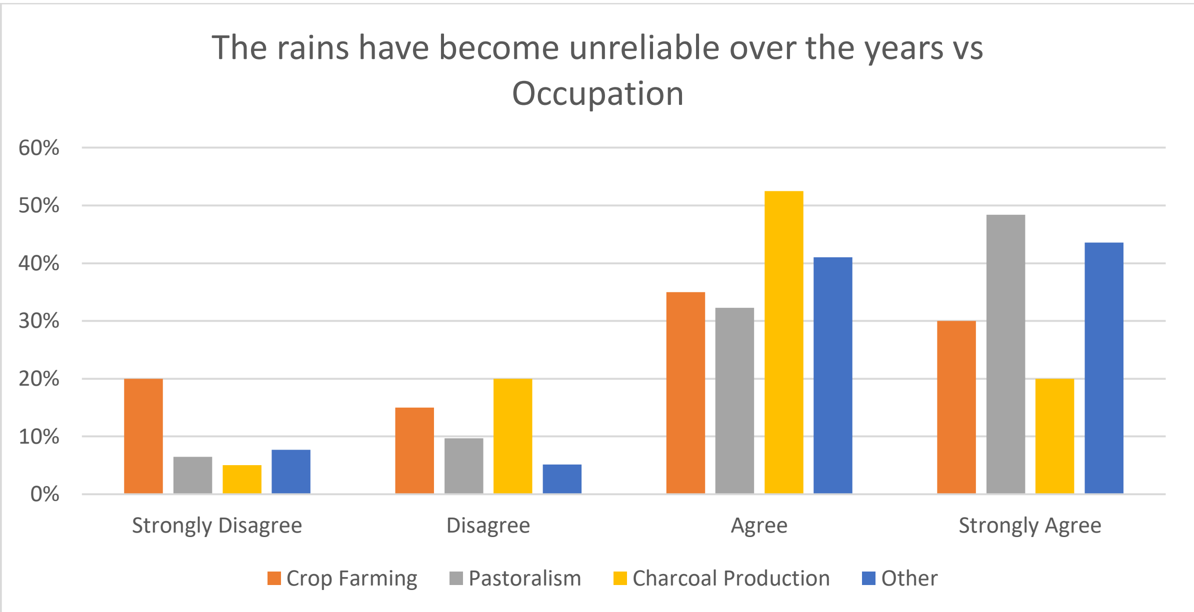


Figure 6-4: Cross-tabulation of observed rainfall variability by occupation of respondents

The rainfall anomalies seen in the climate data in **section 4.1.2** was supported by results from the survey. 51% of respondents stated that they had witnessed an increase in the occurrence of extreme flooding while 83% stated an increase in the occurrence of extreme drought as seen in **Figure 6-5**. 73% of respondents reported losses in livelihoods due to the impacts of climate variability while 82% looked for alternative sources of livelihood, most of who resorted to charcoal production. Movement of pastoralists is determined by distribution of pasture and water, with patterns of movement designed to avoid hostilities, forcing warring clans apart. Several studies have shown that climate variability, and drought in particular causes a change in the movement patterns, that could result in an increase in the risk of conflict (Mkutu, 2001; Barnett & Adger, 2007; Maystadt & Ecker, 2014).

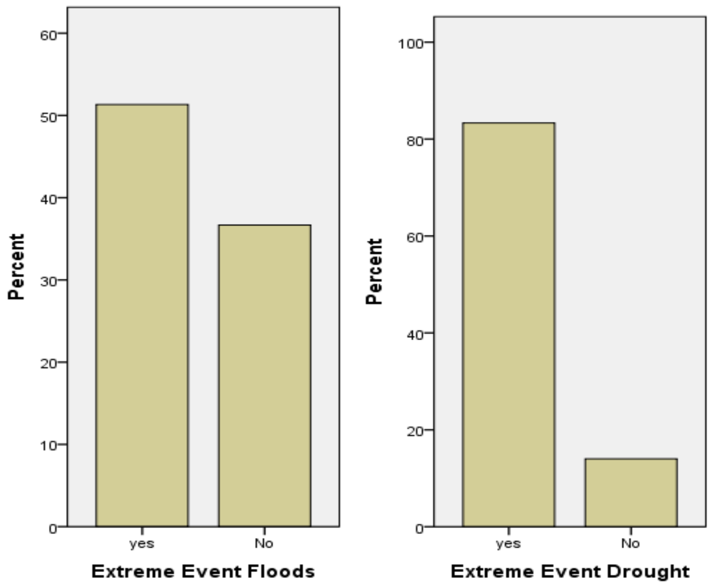


Figure 6-5: Observed increase in extreme events

Figure 6-6 (a, b & c) looks at the impact of climate variability on livestock and crop production by occupation. A large number of respondents whose occupations are not in agriculture and charcoal production reported losses in crops or livestock due to climate variability. The respondents further stated that they had to supplement their income as a result of the losses. It can therefore be inferred that pastoralists in Lower Jubba are also turning to charcoal and other trades as a result of the impacts of climate variability. This is also observed in **Figure 6-6 (c)** where a large number of pastoralists stated the need to supplement their income due to climate variability. A majority of the pastoralists agreed that the variability in climate in the region had negatively impacted their livelihoods, the response from crop farmers however varied. This could be due to the fact that most of the farming in this region is done through irrigation along the rivers (Hadden, 2007).

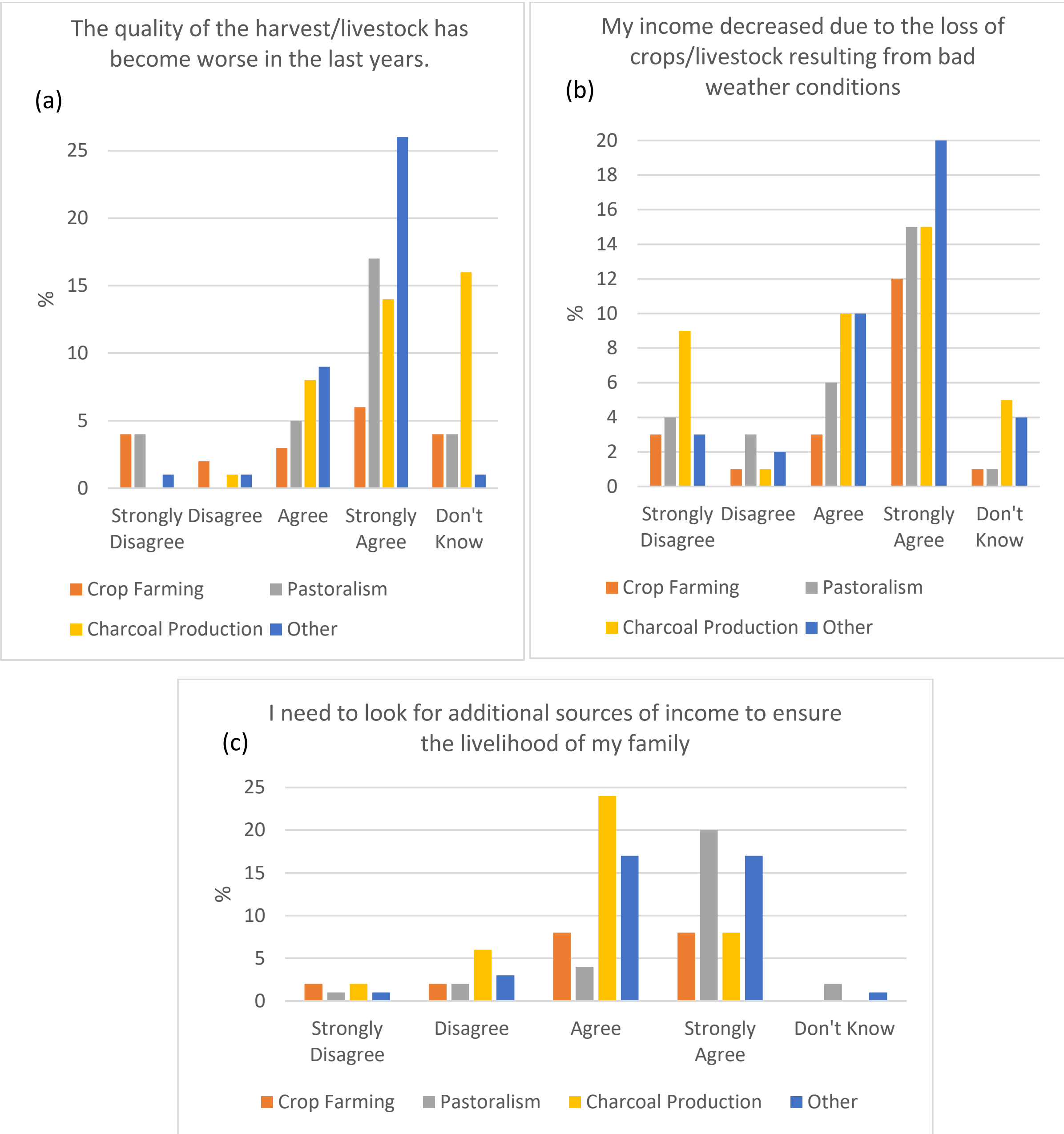


Figure 6-6: Observed impact of climate variability on livelihood vs occupation of respondents

6.1.4 Adaptation

Results from the study showed droughts and floods as the major hydro-meteorological hazards in Lower Jubba. Flooding in this region primarily occurs around the rivers shown in **Figure 6-7.**

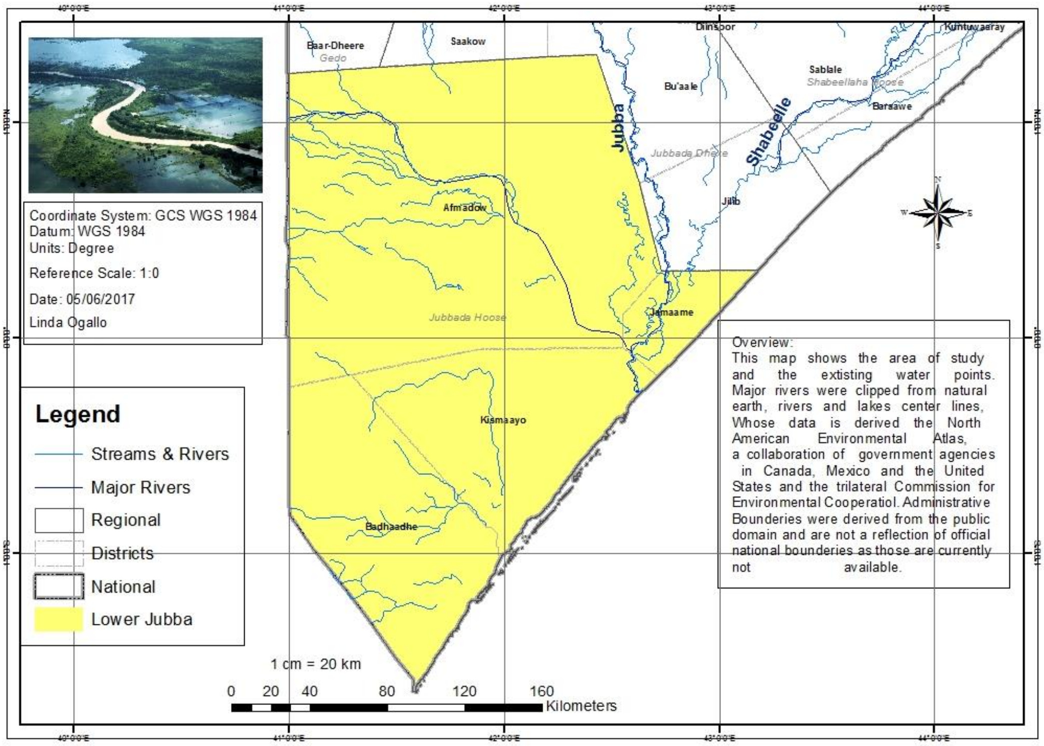


Figure 6-7: Map showing the streams and rivers in Lower Jubba

Results from the survey has shown that low financial capacity coupled with lack of education on climate adaptation mechanisms is a barrier to climate change adaptation in Lower Jubba. IPCC (2014a) has stated that the overall adaptive capacity in Africa is low due to economic, demographic, health, education, infrastructure, governance, and natural factors. Stringer et al.(2009) further stated that adaptation is often in response to multiple pressures and changes that affect people's lives. This results shown in this study is similar to many reports that show massive loss of livestock due to climate induced stress in Somalia (Little, 2004; BICC, 2009; UNDP, 2011; Maystadt & Ecker, 2014).

Results from the survey showed that in Lower Jubba migration is the most common adaptation method for flooding as seen in **Figure 6-8**. Lack of any meteorological systems in Lower Jubba has meant no weather forecasting or early warning systems in place to prepare the community for any weather related shocks despite the many climate related disasters experienced by the community. Key informant interviews showed limited involvement by the government in adaptation measures during the study period. The interviews further stated that limited institutional capacity resulted in lack of agricultural extension services in the region. IPCC (2014a) reports that the adaptation in Africa is mostly reactive, and from the survey it was clear that Lower Jubba is not an exception.

Lower Jubba is one of the regions that is planned for the repatriation of refugees from Kenya (UNHCR, 2015) which would significantly increase population. An increase in population would have an impact on the diminishing forests and woodlands in this region as the need for housing and charcoal for energy increases further. Lower Jubba needs adaptation strategies that anticipate future risks and is able to address ongoing and projected challenges. Interviews with iNGOs working in Lower Jubba stated that prolonged drought has been the biggest risks to most families. Some of the iNGOs in other parts of Somalia provide the local communities with money when the rains fail to enable them to buy water until the rains return and plan to do the same in this region as well. Many studies have proven that when done successfully, adaptation can reduce vulnerability and build resilience (IPCC 2001; 2007; 2014a; UN, 2003; Pandey, *et al.*, 2003; Cooper, *et al.*, 2006; O'Brien *et al.*, 2008; Sheffield, *et al.*, 2014; Connolly-Boutin & Smit, 2016).

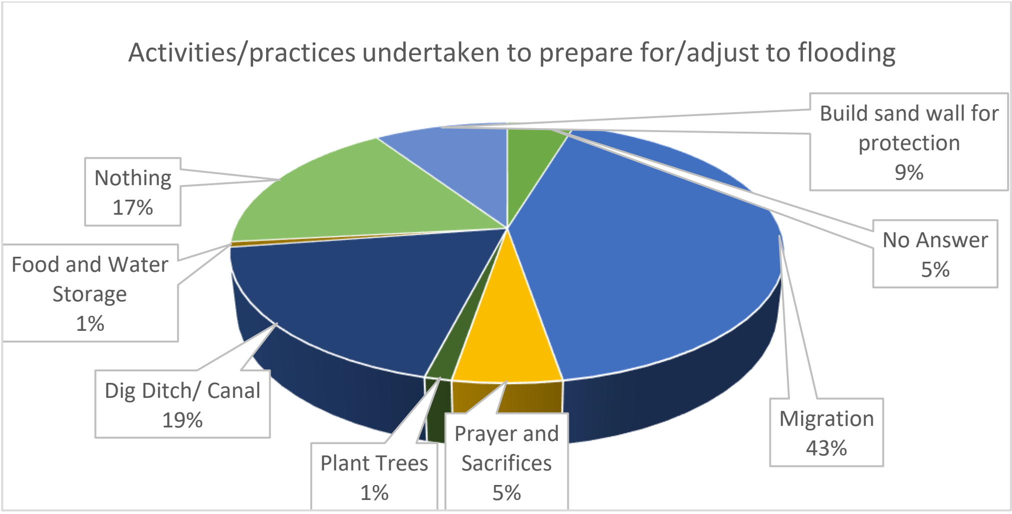


Figure 6-8: Community response to adaptation to floods

58% of pastoralists stated prayer and offering sacrifices as their way of preparing for drought. The response for prayer and sacrifices as a way to prepare for drought/floods was similar across all educational backgrounds as shown in **Figure 6-9**. Traditional mechanisms in Lower Jubba call for communal responsibility which in the past resulted in significant support being drawn mainly from family members living abroad. Maimbo (2006) reported that remittances contributed to 40% of the income of urban households. World Bank (2016b) further reported that contribution from remittances amounted to 23% of Somalia's GDP. IUCN (2006) reported remittance as a huge source of income for many Somalis, meaning that the role of Somalis living in the diaspora in adaptation and mitigation strategies should be taken into consideration.

Religious leaders could also play an important role in adaptation as the role of religion for communities in Lower Jubba is strong.

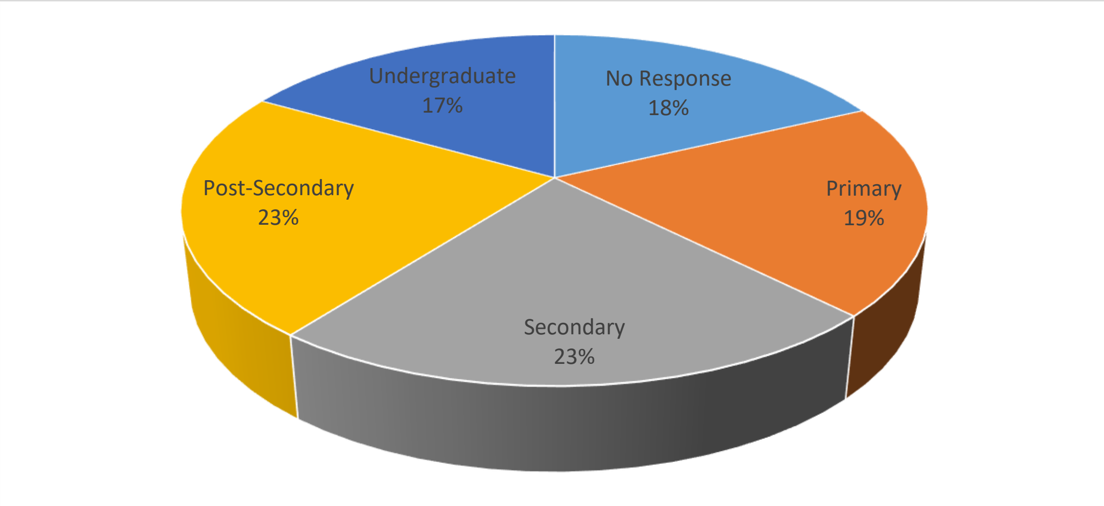


Figure 6-9: Educational level vs prayer and sacrifice as a response to flood preparation

As a newly formed state, peace and security rightfully takes centre stage in the government agenda. Adaptation measures or lack thereof is due to limited capacity and financing of climate change issues. Respondents showed lack of a clear understanding of climate change adaptation measures. This calls for clear disaster risk reduction strategy as recommended by the Sendai Framework for Disaster Risk Reduction. This study provides information useful for disaster risk reduction in support of Somalia's development agenda. Lessons from projects undertaken on climate change resilience in Puntland and Somaliland (Muller, 2014; Candle Light, 2015; UNDP, 2015; German Red Cross, 2016), could inform climate change strategies for the Jubbaland administration.

6.1.5 Mitigation

Results from the key informant interviews showed no mitigation measures currently in place in Lower Jubba to combat climate change. National and sub-national adaptation policies and strategies are not implemented because they are incomplete and under-resourced. Re-forestation in Lower Jubba would not only reduce the amount of Carbon Dioxide in the atmosphere but also helps the community adapt to climate change. All IPCC reports state that mitigation is expected to reduce the root cause of climate change. IPCC (2014a) on climate change mitigation in Africa states that most development strategies in the continent are unable to counter climate risks. The competency to manage complex socio-ecological change is stated as low and often translates into a largely ad-hoc and project-level approach, which is often donor driven.

Given the co-dependent relationship between charcoal burning and livelihoods in Lower Jubba, re-forestation is a logical first step in preventing complete deforestation. Jubbaland administration should engage in conservation, sustainable management of forests and enhancement of forest carbon stocks. Mitigation can be achieved through activities in the land use, land use change and forestry (LULUCF) sector. LULUCF activities are important because of their potential reversibility, as they remove greenhouse gases from the atmosphere, and would renew an important resource for communities in Lower Jubba.

6.2 Community Behaviours and Attitudes

6.2.1 Land Cover Change

Charcoal production was reported by key informants as a widely accepted practice among the local community, though many understand it is a topic of taboo not to be discussed with the international community. 90% of the respondents in the survey admitted that they cut trees for household fuel consumption while 69% stated that they cut trees for charcoal export as seen in **Figure 6-10**. Some of the community members view the ban on the export of charcoal as an imposition by the international community. Some of the local community does not understand the risks posed by the practice. Key informants further stated that charcoal from Somalia in the past has been shipped under falsified documents to by-pass the international ban. Due to high international scrutiny, the newly formed local administration also placed a ban on the export of charcoal in June 2013.

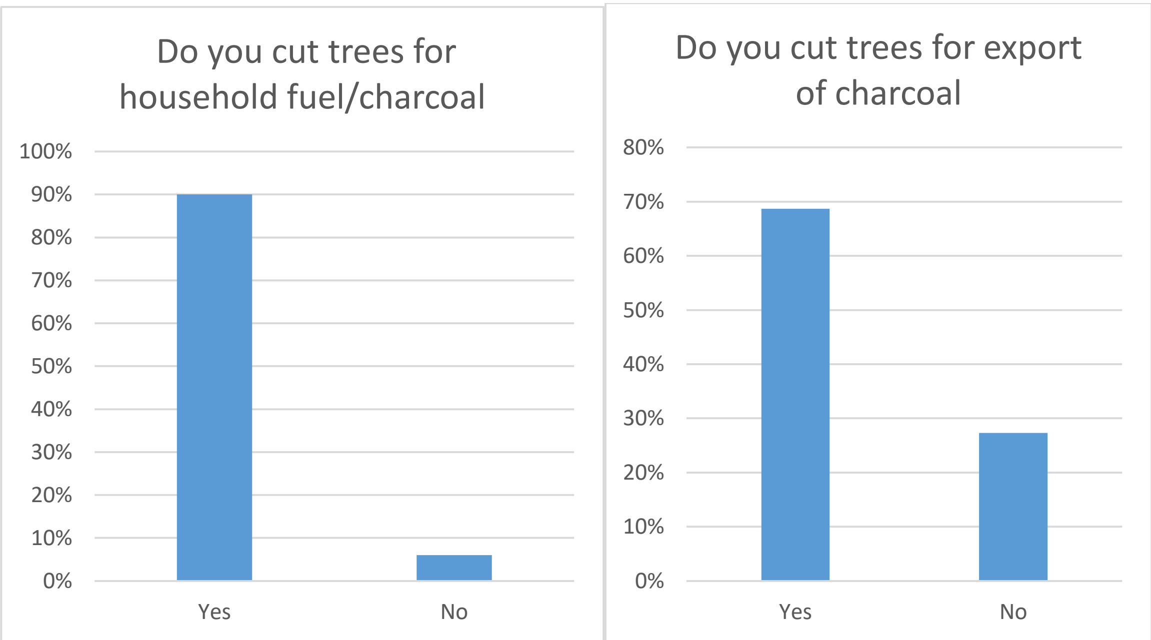


Figure 6-10: Respondents participation in tree cutting activities

40% of the respondents agreed that development and environmental protection should go hand in hand, though 18% believe that the government should prioritise development above all else. 44% believe that cutting trees is alright if it brings economic benefit while 66% believe that selling charcoal is an important means of supporting the economy as seen in **Figure 6-11**. Despite a large number of the respondents stating charcoal production as an important means of livelihood, when asked if they would play an active role in stopping the production of charcoal, 66% of the respondents stated that they would. The charcoal production problem is complex and is one that was done with no regulation for over two decades. A recurrence of depressed rainfall as shown in **section 4.1.2** means the natural regeneration to assist in the recovery of disturbed vegetation is not occurring as fast as the deforestation and degradation. Charcoal production in this community is tied to economic development, the struggle for many seems to be out of necessity and not apathy.

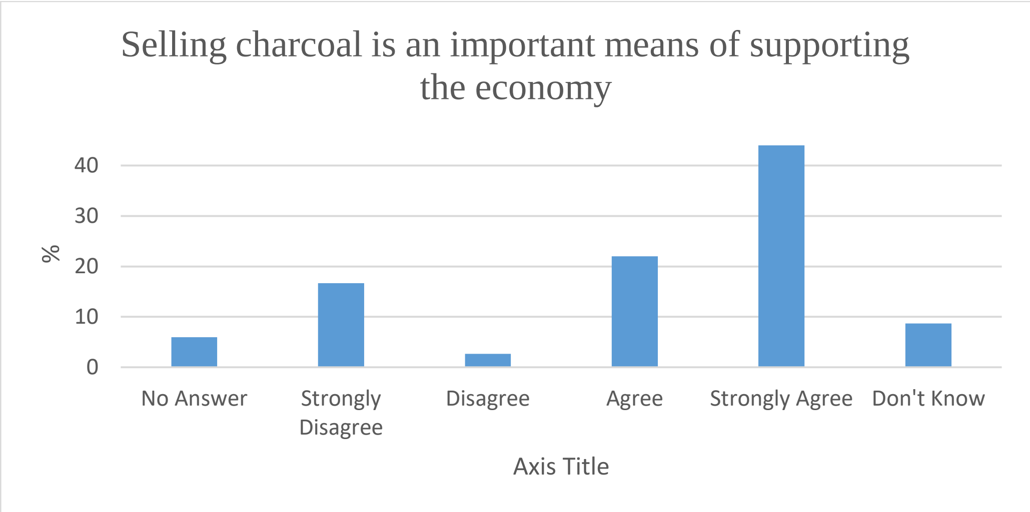


Figure 6-11: Respondents attitudes towards contribution of charcoal burning to the economy

People from all occupations participate in charcoal production as a means to supplement their income as seen in **Figure 6-12**. It is important to note that a large number of respondents that identified their occupation as in charcoal production stated that the charcoal they produce was not for export but for local consumption. 85% of pastoralists admitted to cutting trees for charcoal export while 88% stated that they do it for local sale as shown in **Figure 6-12 (a & b)**. Liberation of Lower Jubba has driven militia into hiding in the forests which has restricted access to the forest. This is supported by respondents who stated minimal access to the forest as seen in **Figure 6-13**. The forests are as a result being protected by the militia who now need it to provide security cover.

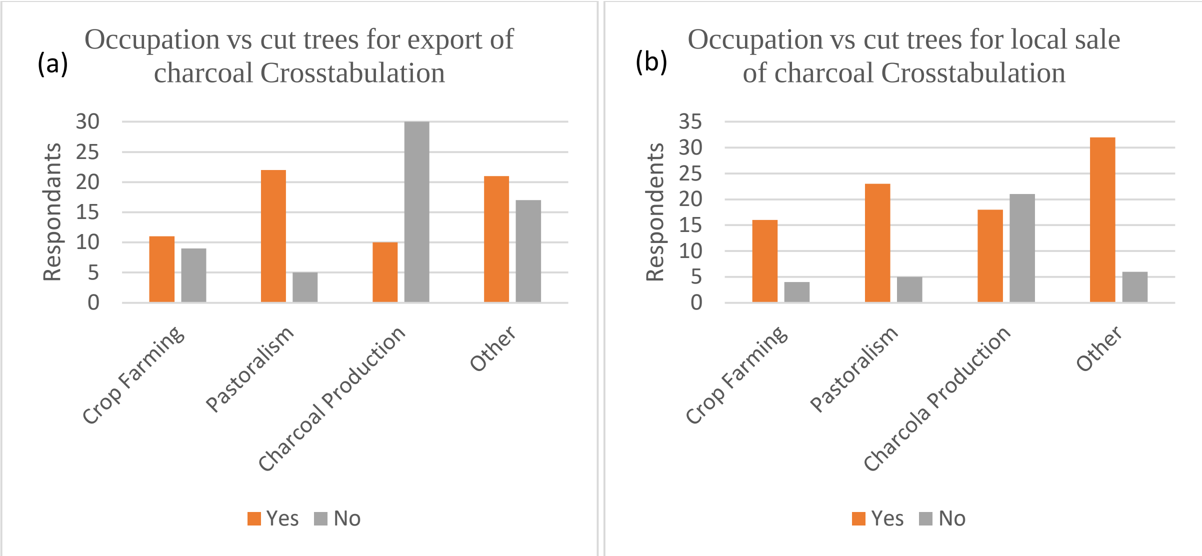


Figure 6-12: Participants occupation compared with their participation of tree cutting for charcoal production

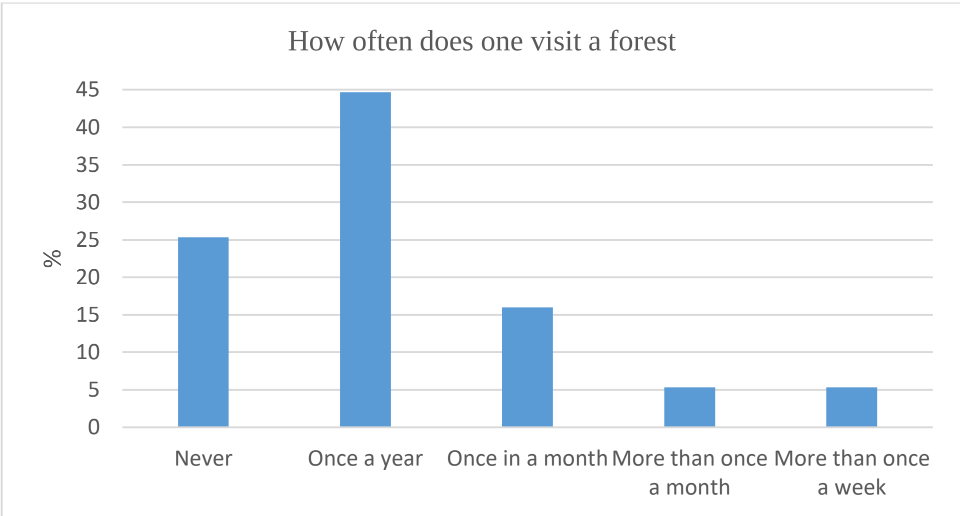


Figure 6-13: Graph showing how often respondents visit a forest

The survey shows that in Lower Jubba charcoal is the primary source of energy. 90% of the respondents agreed that charcoal burning is one of the primary reasons for tree cutting in Lower Jubba. The Federal Government (2015) reports that 98% of the urban households in Somalia use traditional inefficient charcoal stoves, and most of the rural and nomadic population use firewood and inefficient biomass stoves. The Federal Government of Somalia has further stated a need to ensure the sustainability of household fuels supply by reducing pressure on the biomass resources (vegetative cover) of Somalia and through substitution of modern fuels, kerosene and liquefied petroleum gas (LPG) for biomass fuels. This had not been implemented in Lower Jubba during the period of study.

It may be concluded from the study that significant change in land cover has occurred in Lower Jubba. If business continues as usual, then Lower Jubba could have complete deforestation in the future. This would negatively impact the lives and livelihoods of the communities that rely largely on local environmental resources. As the region stabilizes, the growth of the population is expected, particularly with repatriation of refugees back to their homes. Population growth means an increase in demand for charcoal, which is currently the main source of energy. This would increase the rate of degradation even further if effective measures are not taken to counter it. The natural process of regeneration of vegetation that would have naturally reduced the overall degradation has been hindered by frequent and prolonged drought.

The issue of enforcement of existing policy on charcoal export in Somalia is one that has persisted. With a government in its infancy, peace and stability continues to be the priority. It is hard to ignore the potential contribution to economic development that the charcoal trade has had on this community. With the recurring ban on export of livestock due to the Rift Valley Fever epidemic, prolonged droughts, the protracted civil crisis, limited governance, and extreme poverty, the charcoal trade played a unique role in sustaining many families in this region. Tackling this issue therefore requires speedy and multifaceted approach that deals with the complex reasons behind the trade. Poverty alleviation and alternative livelihood sources are core issues that need to be addressed if any sustainable strategies for deforestation are to be implemented.

The next section looks at the perspective of the community on the underlying causes of charcoal production.

6.2.2 Livelihood Challenges

Figure 6-14 shows the distribution of employment in Lower Jubba, a number of those surveyed were traders, fishermen, civil servants, teachers, health workers among other careers. Some reports state that fisheries is one of the fastest growing economic activities in the port of Kismayo (AMISOM, 2016). Insecurity, frequent droughts and disease epidemics have resulted in widespread poverty in Somalia (UNDP, 1998, 2011). 82% of Somalis struggle with the issue of poverty (UNDP, 2012a).

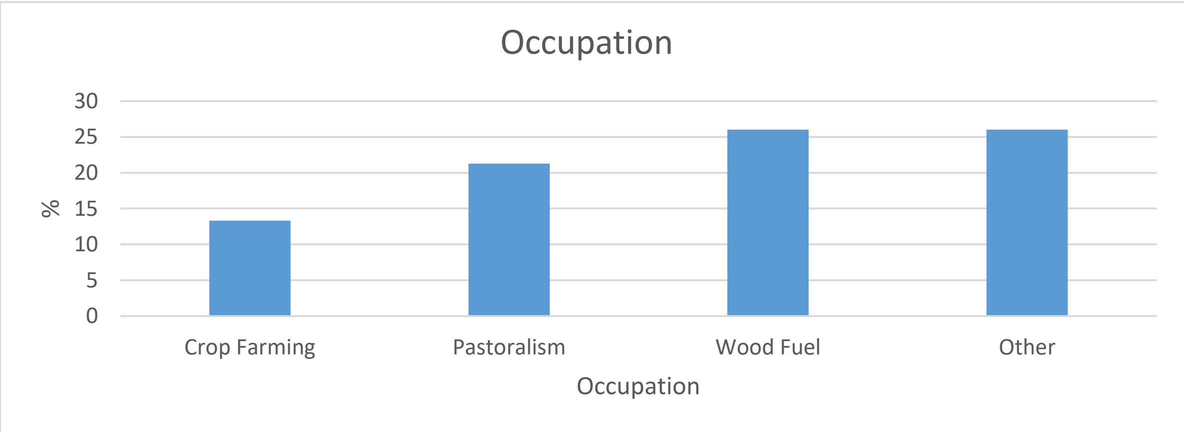


Figure 6-14: Occupation of Respondents

Results from the survey showed that the main drivers of changes in land cover in Lower Jubba are charcoal production, the expansion of agriculture and urbanization (**Figure 6-15)**. Several studies have attributed deforestation to charcoal production in Sub-Saharan Africa to similar drivers (Brink et al., 2012; Sedano et al., 2016; SWALIM, 2014). The results of the study further supports literature that lists population growth and economic factors as drivers of land cover change (Lambin, *et al.*, 2001; Geist & Lambin, 2002; Lambin & Meyfroidt, 2010).

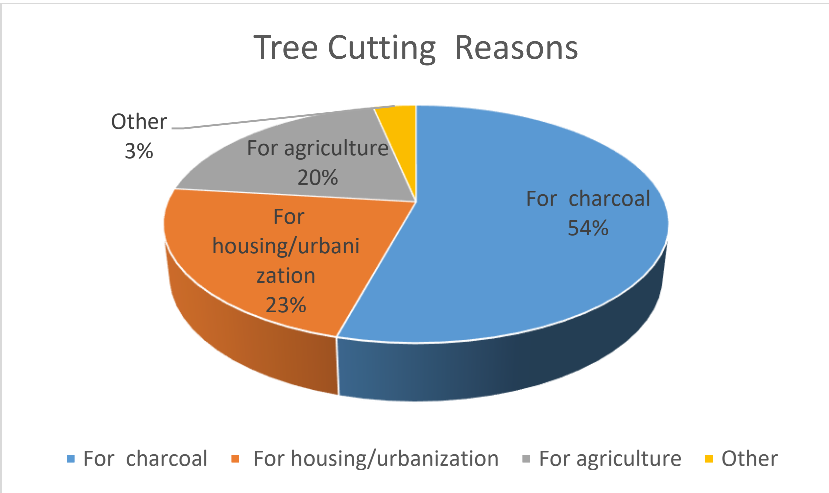


Figure 6-15: Reasons for tree cutting in Lower Jubba

Of the respondents that admitted to participating in charcoal production for export, 29% of these were pastoralists, 14% crop farmers and 28% listed their occupation as other than agriculture or charcoal production (**Figure 6-16**). Several other studies have shown that pastoralists in Somalia participated in the trade of charcoal as a result of the loss of livestock due to climate variability, and the ban in the export of livestock that occurred between 1998 and 2008 due to Rift Valley Fever (RVF) epidemics (Cagnolati, *et al.*, 2006; Bachorz, 2012; NMG, 2012).

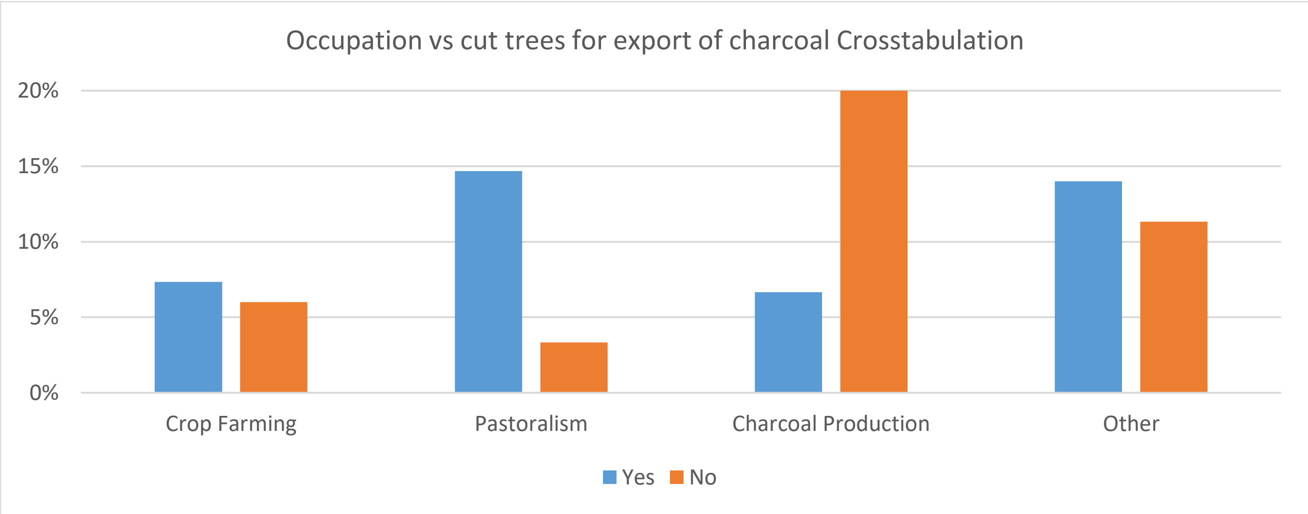


Figure 6-16: Occupation of respondents participating in the export of charcoal

Results further show that the export of charcoal is as a result of a livelihood challenge affecting not just the pastoralists but the entire community as well. Adverse impact of climate variability on livelihoods is high with 73% of the respondents having a significant decrease in household income as a result of bad weather conditions. Frequent and prolonged drought in this region is increasing the community's vulnerability reducing their ability to further adapt to climate shocks. Pastoralists in Lower Jubba are not unique in this instance as studies on pastoralists in Somaliland, Malawi, Tanzania, southern Ethiopia, also turn to charcoal production as an alternative means of livelihood particularly when faced with climate extremes (MoPD&E, 2004; Paavola 2008; Melaku & Zenebe, 2014; Smith, *et al.*, 2017).

Poverty has played a role in the engagement of the local community in charcoal production. Key informants stated that the income received by majority of the local community in Lower Jubba from the charcoal trade is not much. This reports are similar to several other studies on the trade of charcoal in other parts of Africa that state the small profits from charcoal trade for the local community (Paavola 2008; Melaku & Zenebe, 2014; Jones, *et al.*, 2016; Smith, *et al.*, 2017). Charcoal production is not a means to get rich for the local community but to put food on the table and to afford to send their children to school. The charcoal production business in Lower Jubba is however said to be growing in popularity and involving not only the impoverished people. Continued news reports of it being a multi-million dollar industry has led to diverse populations getting into the trade with some areas reported to have highly mechanized systems for harvesting and producing the charcoal.

73% of the respondents indicated that climate variability has had an impact on their livelihood as seen in **Figure 6-17**. Over 50% of those that reported losses in crops/livestock reported a loss of around 50%, and an additional 29% reported losses of over 75% due to climate hazards. Several studies link the impact of climate variability to food security and livelihoods (Challinor, *et al.*, 2007; Schmidhuber & Tubiello, 2007; Brown & Funk, 2008; Lobell, *et al.*, 2008). IPCC reports further link gender inequality to increased community vulnerability to climate change (IPCC, 2007, 2014a). In Lower Jubba only 10% of the crop farmers were female and 32% of the crop farmers identified themselves as pastoralists. Somalia holds the fourth highest position globally in gender inequality (UNFPA, 2014).

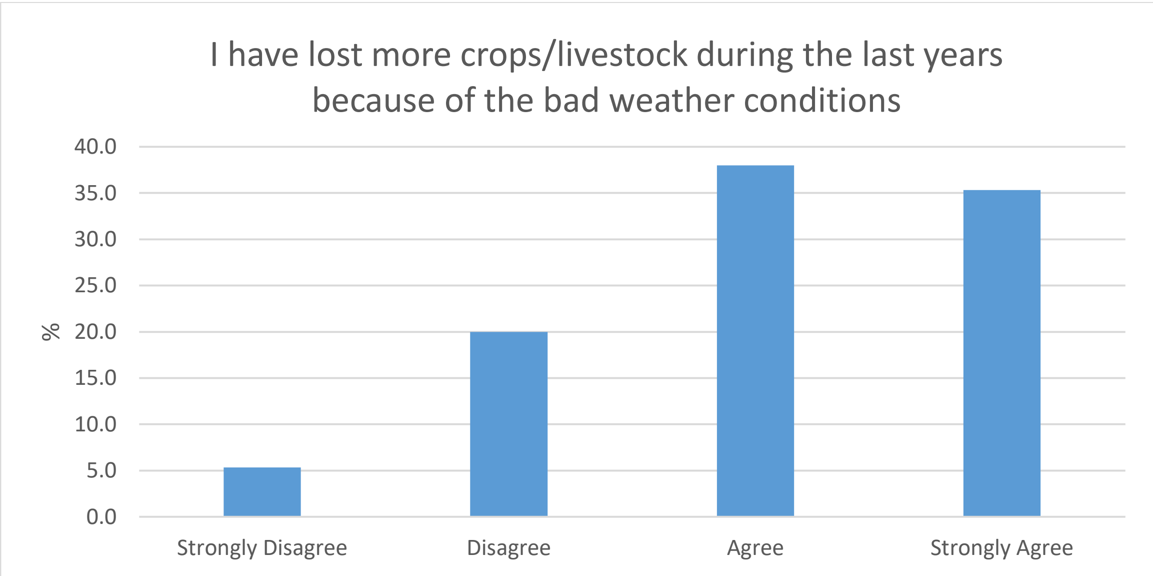


Figure 6-17: Impact of bad weather on livelihoods

It may be concluded that climate variability further increases the poverty and livelihood challenge for communities in Lower Jubba. These challenges have contributed to the change in land cover through the engagement in charcoal production. Complete deforestation for communities means that the alternative means of livelihood to withstand climate shocks is taken away and for pastoralists, it also means that the source of sustenance for their livestock is taken away.

6.2.3 Community Education and Knowledge

According to the survey, 19% of the population in Lower Jubba have had up to a primary school level education; 42% have had up to a secondary school education; 24% have had some training beyond secondary school; 9% having up to an undergraduate level university; and 1% having higher than an undergraduate level of education. The United Nations Educational, Scientific and Cultural Organization (UNESCO) reports that adult literacy in Somalia is currently at 37.8% with 49.7% in men and 25.8% in women (UNESCO, 2016).

64% of the respondents agreed that protection of the forest is important for the community's future. Opinions on the knowledge of the impact of deforestation and degradation varied across different levels of education as shown in **Figure 6-18.** No one with an undergraduate degree or higher however disagreed on the importance of forest protection in securing the communities future. The majority of the community in Lower Jubba agreed that environmental protection should go hand in hand with development and neither prioritised over the other as shown in **Figure 6-19**.

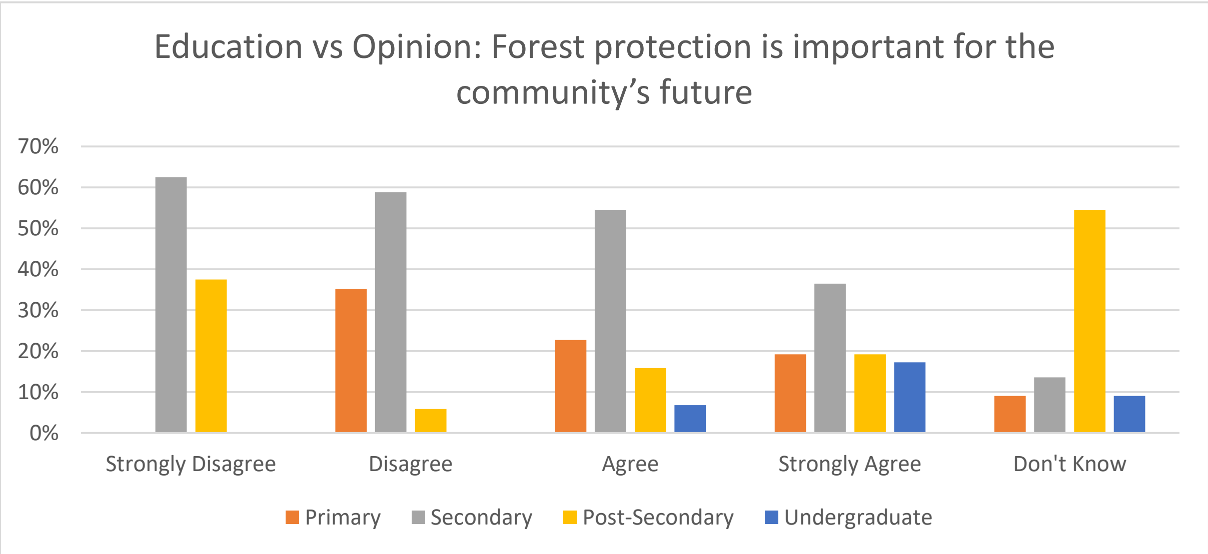


Figure 6-18: Comparison of attitude towards deforestation vs education level of respondents

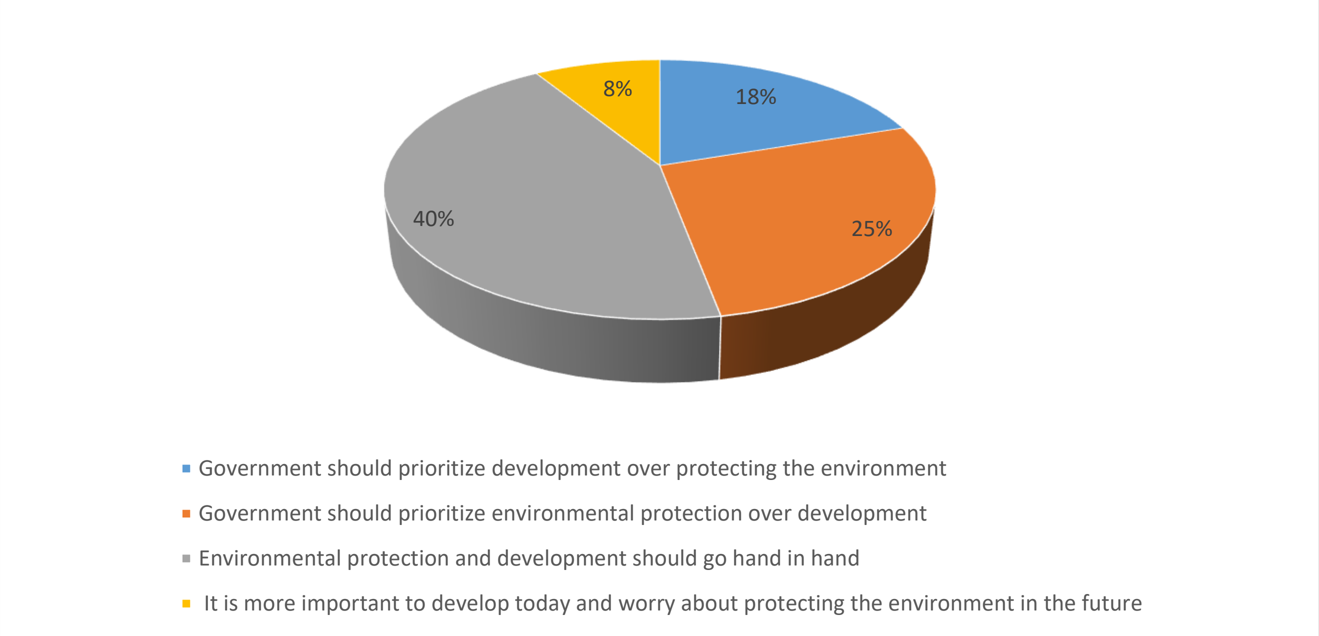


Figure 6-19: Community attitude towards environmental protection vs development

6.2.4 Environment Laws

30% of the respondents were not aware of any laws traditional or otherwise protecting the forest. Education played a factor in the community's knowledge of environmental law as shown in **Figure 6-20**. Of those who were aware of some environmental law, 45% had up to a primary level of education, 43% a secondary education, 56% a postsecondary education, and 67% with an undergraduate education. One of the limitations of a post conflict government like Somalia is the issue of capacity. Lack of institutional capacity has prevented the enforcement of the bans placed on charcoal exportation.

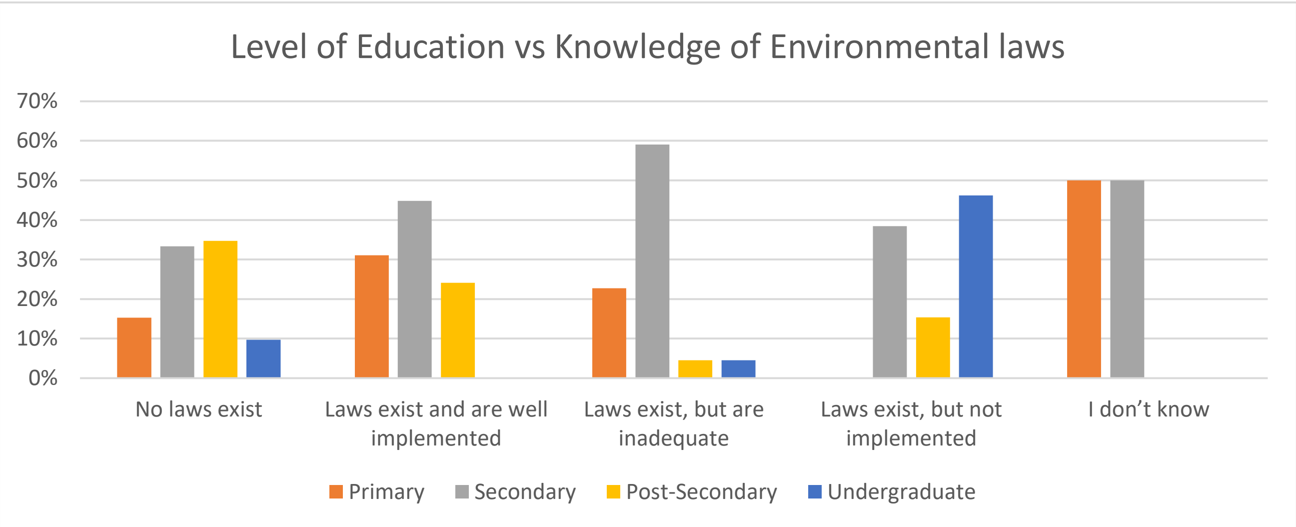


Figure 6-20: Graph showing the knowledge of environmental law compared with the level of education of the respondents

A majority of the population are aware of some law protecting the forests though the views on the implementation of these laws varied as well as seen in **Figure 6-21**. Environmental law was last in place during the Siad Barre era. Key informants reported that the Siad Barre regime saw to the regulation of charcoal trade, with the government issuing licenses and regulating the production of charcoal. Lower Jubba was a tourist attraction and used to be known for its flora and fauna before the civil war. In the absence of an effective governance system communities in Somalia have relied on its traditional law, Xeer. Xeer law is an unwritten system of laws administered through consultations among elders. Key informants stated that Xeer laws cover issues on land management and environmental protection, though over time many of these laws have been forgotten.

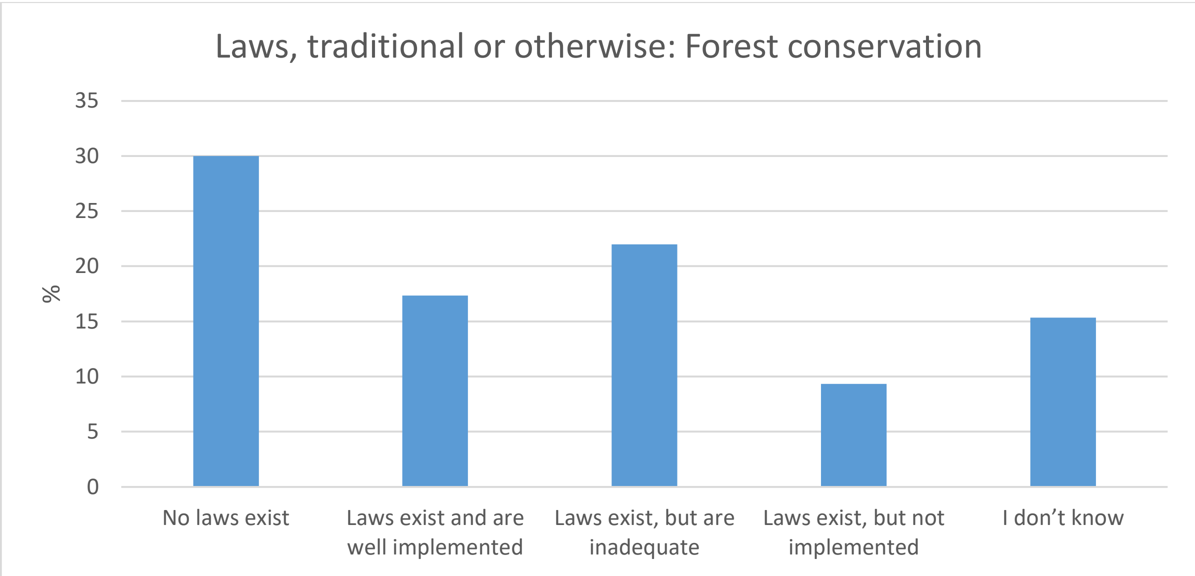


Figure 6-21: Graph showing knowledge of Environmental Laws

Charcoal production may profit a number of people but the resulting impacts of land degradation is felt by the entire community. Key informants state that despite the large scale charcoal export that has been reported in Lower Jubba, only a few key players really profit from it. Most of the communities engaged in the trade garner low income from it. Lambin et al. (2001) reported that the high rates of deforestation within Africa as largely driven by changing economic opportunities. Several other studies report that charcoal export has in the past brought in hundreds of millions of dollars in illicit charcoal trade for extremist groups in the South of Somalia (Hosonuma, *et al.*, 2012; Rembold, *et al.*, 2013; SWALIM, 2014; UNEP & INTERPOL, 2014).

It may be concluded from the results of the survey that climate variability has impacted the community’s livelihood. It may also be concluded that the local community copes with the resulting impacts of prolonged drought and floods on their livelihoods by turning to the charcoal trade. The local community in Lower Jubba engages in charcoal production for local use and for export and as a result charcoal production is a key driver to land cover changes in the region. Land degradation, especially from charcoal burning is causing serious land degradation and deforestation in Lower Jubba with devastating implications on the environment and local climate. Local climate further impacts land degradation and deforestation.

The impact of environment degradation and climate change in the region is exacerbated by the low coping capacity and high vulnerability of the society. Fragmented institutions are an additional challenge in addressing the issue of climate change and deforestation in Lower Jubba. Somalia is in a unique position to build its institutions to ensure sustainability by embedding climate risk management and adaptation strategies and policies in all its sectors. Lower Jubba should employ disaster risk reduction, social protection, technological and infrastructural adaptation, ecosystem-based approaches, and livelihood diversification to reduce vulnerability. This will ensure communities are able to withstand climate shocks and gains made are not reversed by climate hazards.

Lower Jubba needs sound and well-integrated environment, disaster risk reduction and climate change policies that also effectively address the current challenges of deforestation and land degradation in the region that can also contribute to Emissions from Deforestation and Forest Degradation (REDD+). The benefits in the design and implementation of REDD+ programmes has been part of the recent climate change debates, including how to promote sustainable forest management, forest conservation, enhance forest carbon sinks and to address the many direct and indirect drivers of deforestation and forest degradation (IPCC 2001; 2007; 2014; UN-REDD, 2015). Such policies must also address the implementation of UNFCCC 21 conference of party's recommendation in Paris in December2015, like those linked to the communication of Intended Nationally-Determined Contributions (INDCs) for the post-2020 period.

CHAPTER 7 : RESULTS FROM THE ANALYSIS OF FUTURE CLIMATE

This section presents the results from the fourth specific objective that is to *assess the potential impacts of future climate change over the study area*. As discussed in **section 3.3.7**, the RCP emission scenarios developed for the IPCC were used in the study. Results from simulations of future climate of the region using mean ensemble RCMs for future periods 2030, 2050 and 2070 for the various RCPs are presented.

7.1 Model Verification

7.1.1 Rainfall Annual Cycle over Study Area

The annual cycle of Gu (AMJ) and Deyr (SON) season near surface air temperature and rainfall for the baseline period, are analysed based on the gridded CHIRPS observations with RCMs over the study area. **Figure 7-1 & Figure 7-2** illustrate the performance of CORDEX RCMs in simulating annual rainfall and temperature cycles over the study area as compared to the CHIRPS data. **Figure 7-1** shows that the rainfall pattern follows the north-south migration of the ITCZ, with associated locations of maximum rainfall being depicted fairly well by the ensemble model. However, some models overestimate the *Gu* and *Deyr* rainfall peaks. For the study area, the ensemble mean has been found to have a fairly good agreement in the annual rainfall cycle compared to individual RCM models.

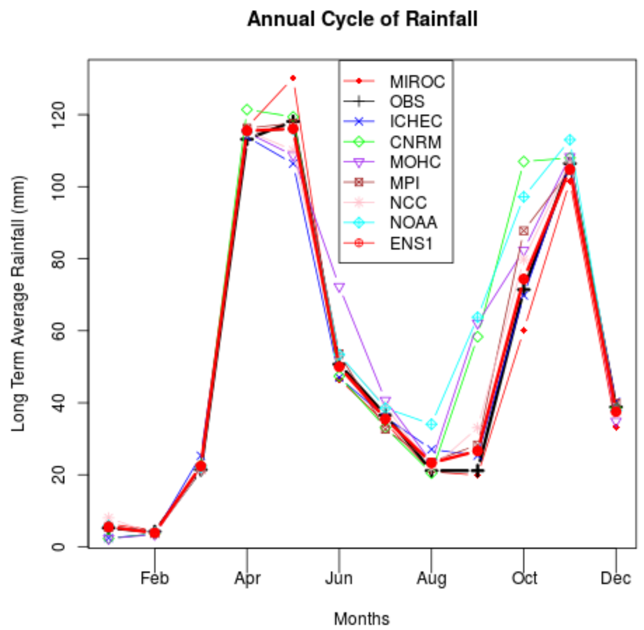


Figure 7-1: Graph shows the performance of the different models in comparison to the observed rainfall

In general, there is a fairly good agreement between annual rainfall cycle simulated by ensemble of CORDEX RCMs and the CHIRPS data as shown in the Pearson correlation in **Table 7-1**. The most notable shortcoming in most RCMs as seen in **Figure 7-1,** is the early peak and overestimation of the mean monthly rainfall during in both Gu and *Deyr* season. This result correlates with studies that have shown that GCMs tend to overestimate rainfall in the Horn of Africa region during October–November–December (Anyah & Qiu, 2012, IPCC, 2014a) season. IPCC (2014a) further reports a natural limitation in the extent of skilful rainfall projection that is due to the nonlinear and chaotic nature of the climate system. The CORDEX data used in this study has been reported to represent a good simulated precipitation over the region and thus can be used to inform on adaptation and mitigation strategies (Nikulin, *et al.*, 2012; Gbobaniyi, *et al.*, 2013; Kalognomou, *et al.*, 2013; Endris et al., 2013; Buontempo, *et al.*, 2014; Ngaina, *et al.*, 2015).

Table 7-1: Pearson Correlation Coefficient between Observed Precipitation and Temperature Projected Data

Model	**Correlation**	
	Precipitation	**Temperature**
CNRM	0.947886773	0.8554162
ICHEC	0.994987978	0.8643511
MIROC	0.991846886	0.9437751
MOHC	0.94632178	0.9363303
MPI	0.992334631	0.9390621
NCC	0.993160462	0.8757774
NOAA	0.948394457	0.8746084
ENS	0.987406	0.931277

Figure 7-2 shows the performance of CORDEX RCMs in simulating the mean surface temperature over Jubbaland compared to the observed temperature data. The ensemble model seems to overestimate temperature when compared to the observed data during the hot months of Jan-April while underestimate during July to December, **Figure 7-2**. The use of ensemble models has been shown to lead to better uncertainty estimates for model projections than the use of one single model (Gbobaniyi, *et al.*, 2013; Kalognomou, *et al.*, 2013; Buontempo, *et al.*, 2014).

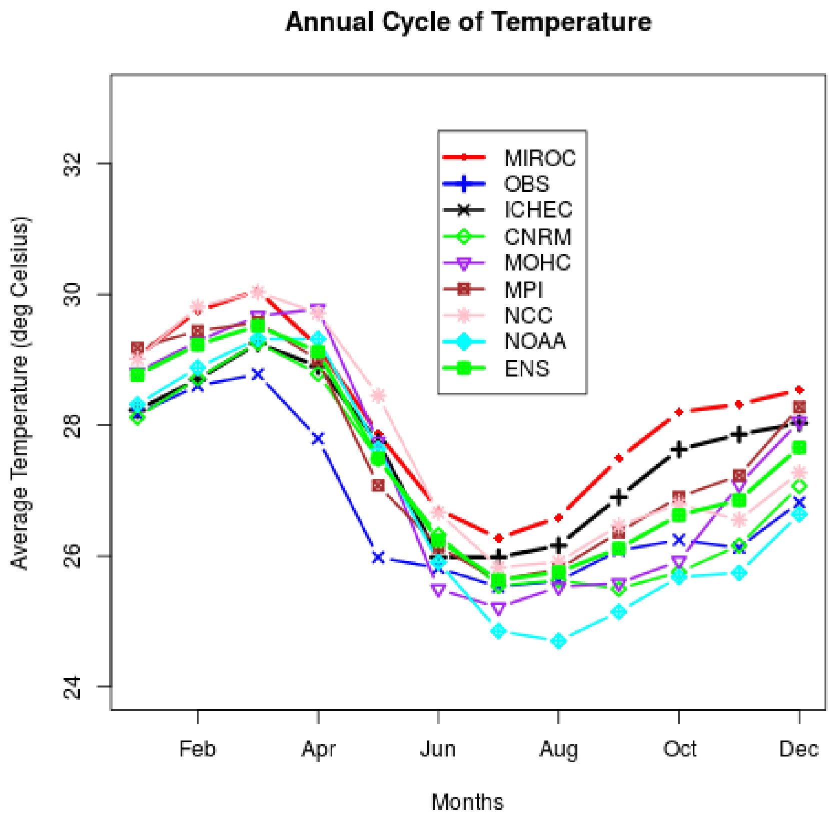


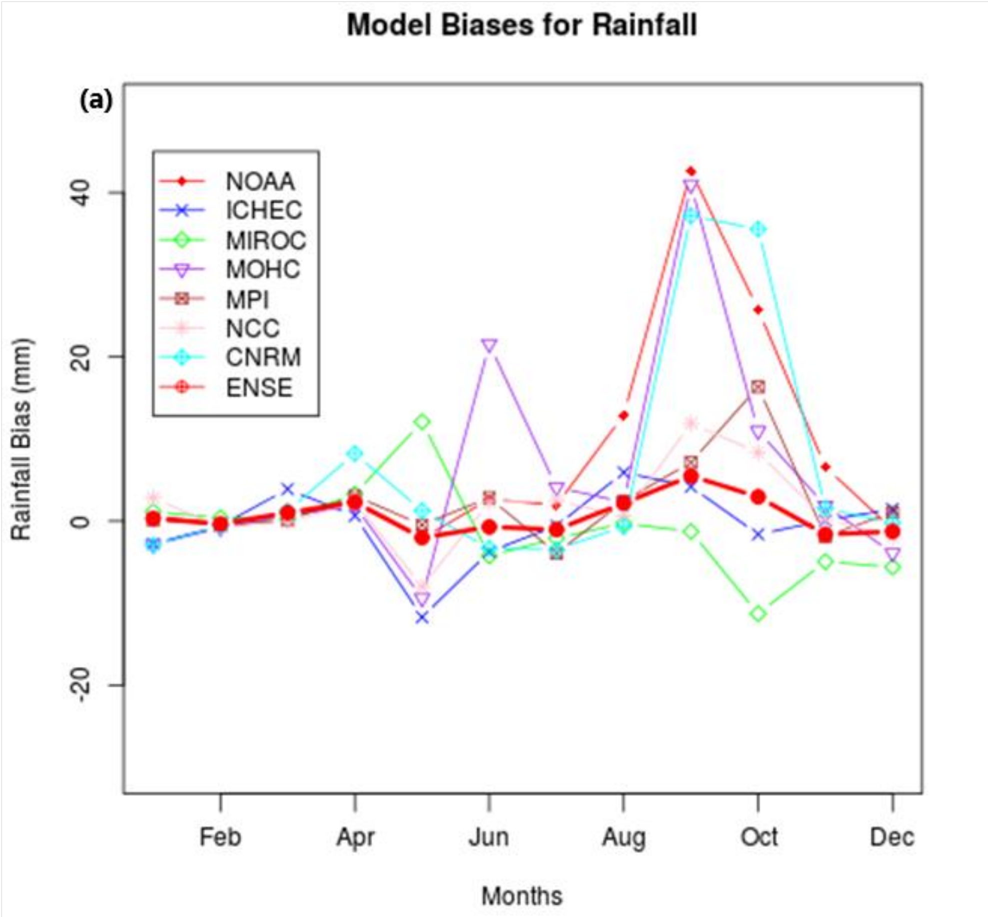
Figure 7-2: Graph shows the performance of the different models in comparison to the observed temperature data.

7.1.2 Model Biases over Study Area

The multi-model ensemble overlaps the observed data more than any individual RCM model as shown in **Figure 7-3 (a, b)**. All of the RCMs show a correlation value above 0.95 when compared with the annual temperature over Lower Jubba as seen in **Table 7-1**, though significant biases can be found in individual models depending on the seasons as seen in **Figure 7-3 (a, b)**. The model bias for precipitation in each individual model varies from month to month as shown in **Figure 7-3 (a)**. NOAA, CNRM and MPI overestimate the rainfall data between August and November while MIROC underestimates the rainfall data in the same period.

Figure 7-3 (b) also shows a variation in performance from month to month in the temperature data. ICHEC underestimates the between Jan and June, while NOAA underestimated the data between July and December. MOCH and NCC overestimate the data in April as shown in **Figure 7-3 (b)**. Several studies undertaken using CORDEX RCMs in other parts of Africa also support the use of a multi-model ensemble in projection of climate data (Gbobaniyi, *et al.*, 2013; Kalognomou, *et al.*, 2013; Buontempo, *et al.*, 2014). In fact, IPCC (2004) states that ensemble models closely reproduce observed climate features better because of the cancellation of biases from each individual model, thus providing higher quality and more quantitative climate change information.

Individually, as shown in **Figure 7-3 (a, b)** all the models perform differently in each month. Due to the complexity of the climate system the use of multi-model ensemble is one way many scientist choose to attempt to represent the uncertainties that are embodied by a spectrum of modelling choices providing more credibility for future predictions (Min & Hense, 2006; Tebaldi & Knutti, 2007; Buser, *et al.*, 2009; Zhou, *et al.*, 2010).



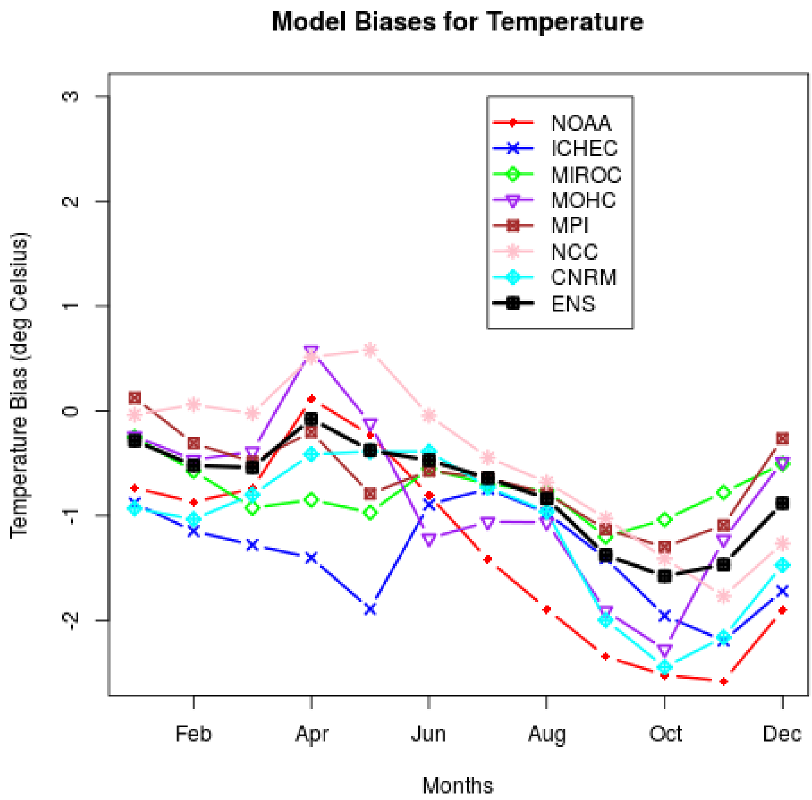


Figure 7-3: Graph showing model bias, calculated by subtracting observed (a) rainfall and (b) temperature data from each model

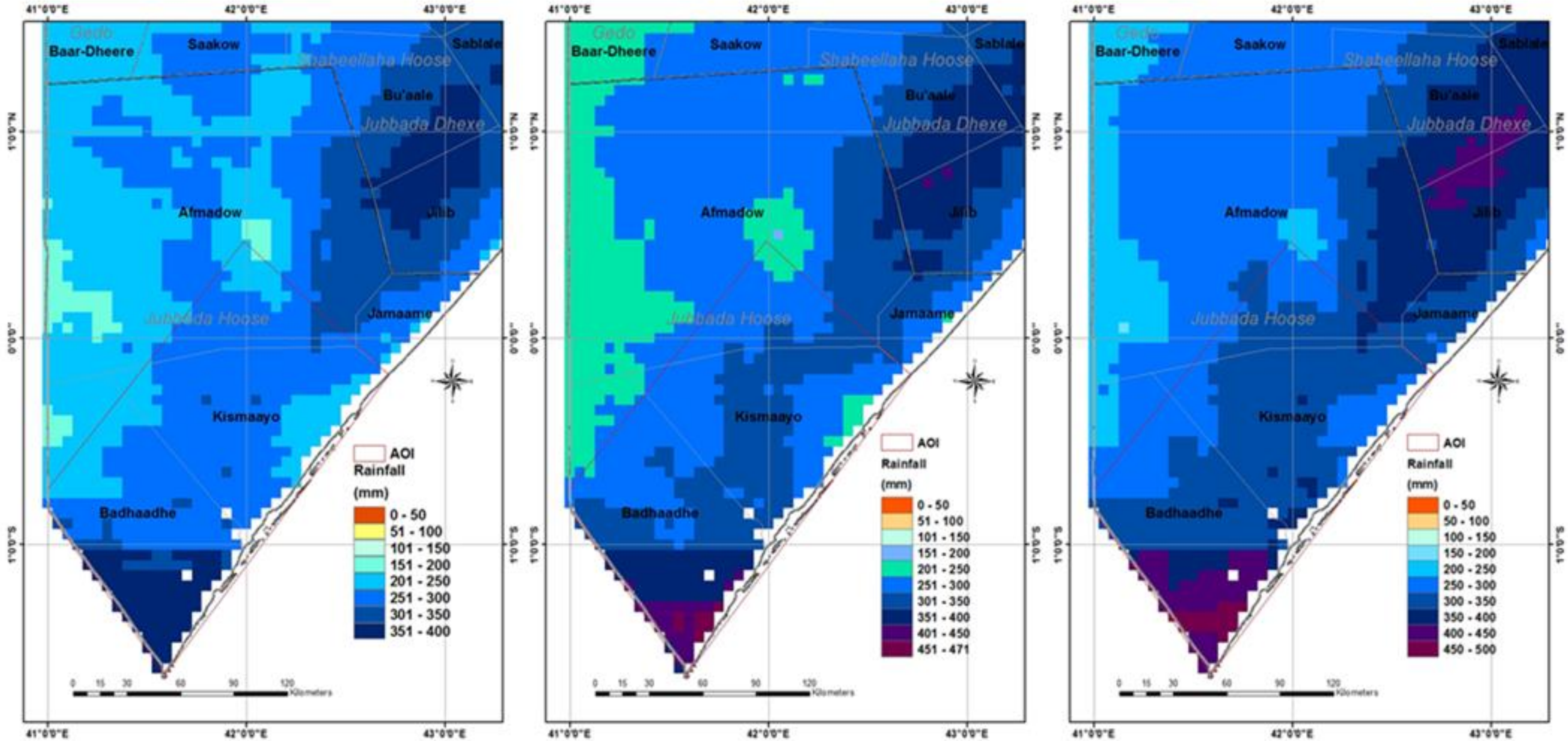
The future projections were conducted using the ensemble model for the period 2030 (sub-period 1), 2050 (sub-period 2) and 2070 (sub-period 3) covering the IPCC periods of study namely 2030, 2050 and 2070.

7.2 Future Rainfall Projections

7.2.1 Spatial Distribution of the Projected Rainfall

Figure 7-4 shows mean projected by the ensemble model for the *Gu* seasonal rainfall for 2030, 2050 and 2070. The geographical distribution exhibits notable spatial variability in rainfall over Lower Jubba. Badhaadhe district towards the southern coast exhibits the highest amount of rainfall. The southen costal region shows the highest projected amount of rainfall in Lower Jubba throughout all three sub-periods as was seen with the historical data (**section 4.1.1)**.

The spatial patterns of the projected seasonal ensemble mean Gu rainfall based on the RCMs are shown for the three sub-periods namely 2030, 2050 and 2070 relative to the baseline period 1981-2010 **(Figure 7-4**). The magnitude of the projected seasonal rainfall is found to vary from place to place, season, sub-periods and scenario used for the RCMs.



Projected Rainfall Sub-Period 1 (2030) | Projected Rainfall Sub-Period 2 (2050) | Projected Rainfall Sub-Period 3 (2070)

Figure 7-4: Projected mean *Gu* rainfall for (a) Sub-Period 1 (2030) (b) Sub-Period 2 (2050) and (c) Sub-Period 3 (2070) for the RCP 4.5

The results project a general increase in rainfall in Lower Jubba from 2030 to 2070. The projected rainfall is however not homogeneous throughout the region with the inland region receiving the least amount of rainfall. Similar results are reported in the Somali NAPA which shows an increase in rainfall in 2050 and 2080 (FGS, 2013). IPCC (2014b) report on Africa also projected an increase in MAM rainfall in 2050 – 2100 in most parts of Eastern Africa. AEA Group (2008) further reported that North eastern Kenya boardering Lower Jubba is projected to receave an increase in rainfall of 40% relative to the baseline period (1981-2010) by 2100 during its long rain season. **Table 7-2** shows the lowest and highest seasonal precipitation during the *Gu* long rain season projected over the districts in Jubbaland with RCP4.5 scenarios for the three sub-periods 2030, 2050 and 2070.

Table 7-2: Projected ensemble mean seasonal precipitation Projected for Gu Rainfall values in over districts in Lower Jubba for the RCP 4.5

District	Rainfall (mm)					
	2030		2050		2070	
	Min	Max	Min	Max	Min	Max
Badhaadhe	191	445	209	471	225	498
Afmadow	180	353	199	368	189	395
Jamaame	234	337	250	351	284	383
Kismaayo	203	310	225	330	260	358

7.2.2 Projected Rainfall Trends

The temporal evolution of the projected precipitation over this region is shown in **Figure 7-5 (a, b & c).** The results show a decreasing trend of 0.09mm/year for the first sub-period **Figure 7-5 (a),** followed by an increasigtrend of 1.97mm/year for the second and 2.39mm/year third sub-periods **Figures 7-5 (b, c)**. The trends are however not statistically significant at a 95% confidence level (p = 0.92 (a), 0.09 (b), 0.10 (c)). Tierney et al. (2015) reported similar results over the region, and IPCC (2014b) projects that in Africa, almost all countries except South Africa will probably experience a significant reduction in precipitation until 2050, which then increases significantly between 2050 and 2100. These studies corroborates the results displayed in **Figures 7-5 (a, b, c)**. Infact, IPCC (2014b) projects the averaged mean water vapour, evaporation and precipitation to increase globally by 2100. The use of climate change knowledge, particularly when mainstreamed into planned policies and poverty reduction stratergies can provide a starting point for the identification of climate risks at a district, regional and national level.

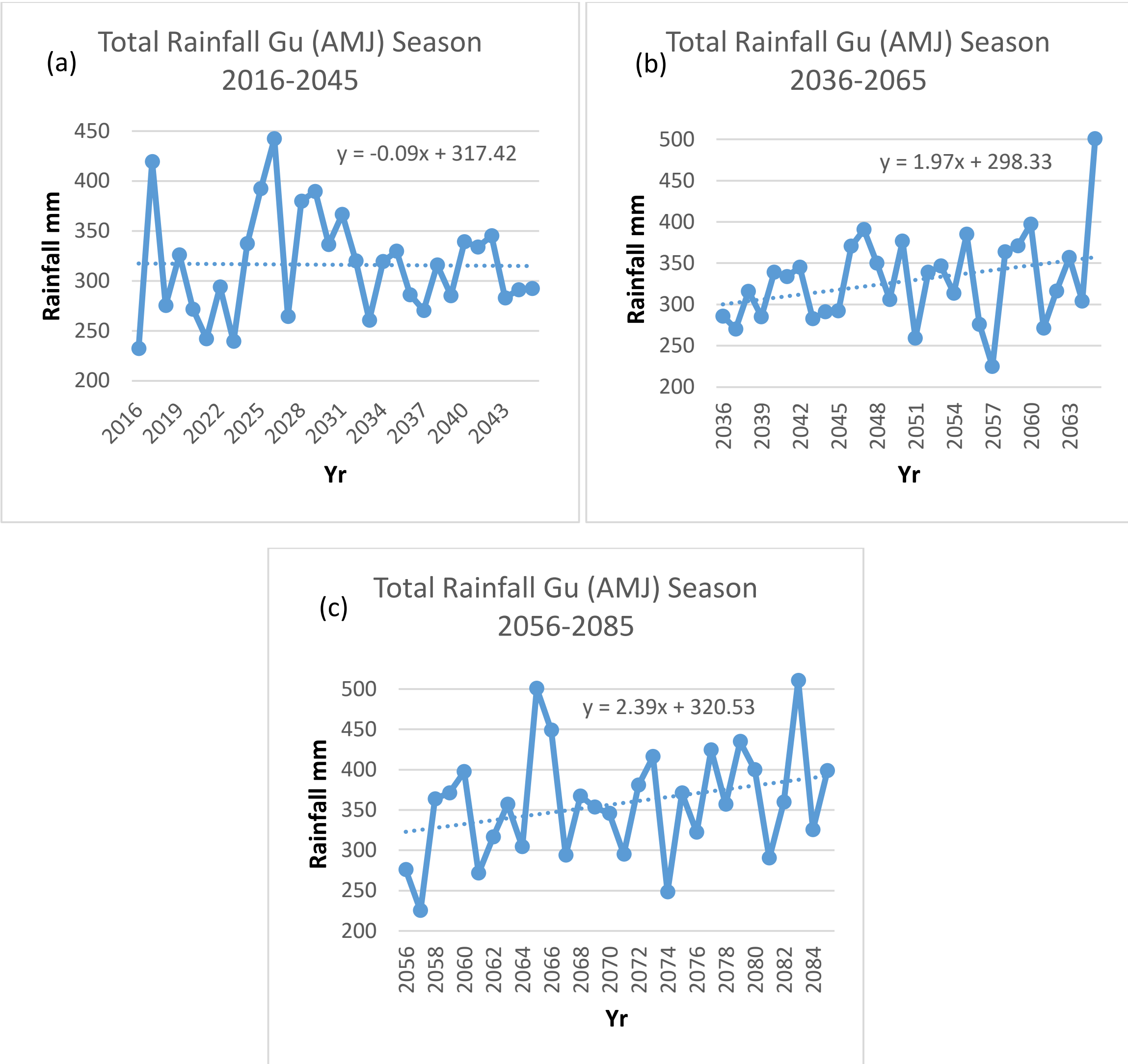


Figure 7-5: Total seasonal Rainfall during the *Gu* Rainfall season in Lower Jubba in (a) 2016-2045, (b) 2026-2065 and (c) 2056-2085

The projected rainfall show future variability, including dominant dry and wet phases of the *Gu* season, requiring sustained investment in early warning mechanisms. The spatial representation of the projected rainfall trend is seen in **Figure 7-6**. These projected trends, as seen with the observed data, are not homogenous throughout the study area. In sub-period 1 (**Figure 7-6a)**, some areas in Lower Jubba are projected to have general decrease in rainfall during the long rain season while other areas are projected to have a general increase in rainfall. In sub-period 2 and 3 (**Figure 7-6 b, c)**, the general increasing trend is seen throughout Lower Jubba; the magnitude of the change however differs.

Although the projected rainfall trends were still not statistically significant, the complexity of the observed characteristics of the changes continues to call for tailored mitigation and adaptation strategies for each district. Statistical results associated with these patterns can be obtained from **Table 7-3**.

Table 7-3: Summary of Projected Rainfall Trends in Lower Jubba

District	*Projected Rainfall Trend (mm/decade)*					
	2030		2050		2070	
	Min	Max	Min	Max	Min	Max
Badhaadhe	4	10	10	23	7	33
Afmadow	-1	8	5	18	6	24
Jamaame	-3	-1	18	23	25	29
Kismaayo	-2	9	11	20	8	28

Parts of Badhadhe and Afmadow districts are projected to experience the largest positive trend in rainfall in Lower Jubba by 2030, while Jamame district will see the largest negative trend (**Figure 7-6a**). In 2050 and 2070 Lower Jubba is projected to experience a positive trend in the entire area but unlike in sub-period 1, Jamame district is projected to receive some of the highest positive trends (**Figure 7-6 b & c**).

The projected 2030 regime shows dominant recurrence of depressed rainfall associated with droughts (**Figure 7-7**). Results continue to stress the need for investment in early warning mechanisms in Lower Jubba. Connolly-Boutin & Smit (2016) projected similar results for Africa, where the study reported that the impacts of climate change would be exacerbated by widespread poverty, diseases and high population growth rates, which would intensify the demand for food, water and livestock.

The projected recurrence of depressed rainfall for the near future is significant for a country that according to UNDP (2012b), is already highly vulnerable with high poverty levels across multiple dimensions. Somalia is already experiencing food insecurity, the implication of a futher risk to food and water security could pose a threat on security in a struggle for avalable resources. Further more, results from this study have shown that communities in Lower Jubba revert to charcoal production when their livelihoods are threatened, the impact of which is forest degradation. The projected precipitation presented in this study call for urgency in finding short and mid-term solutions.

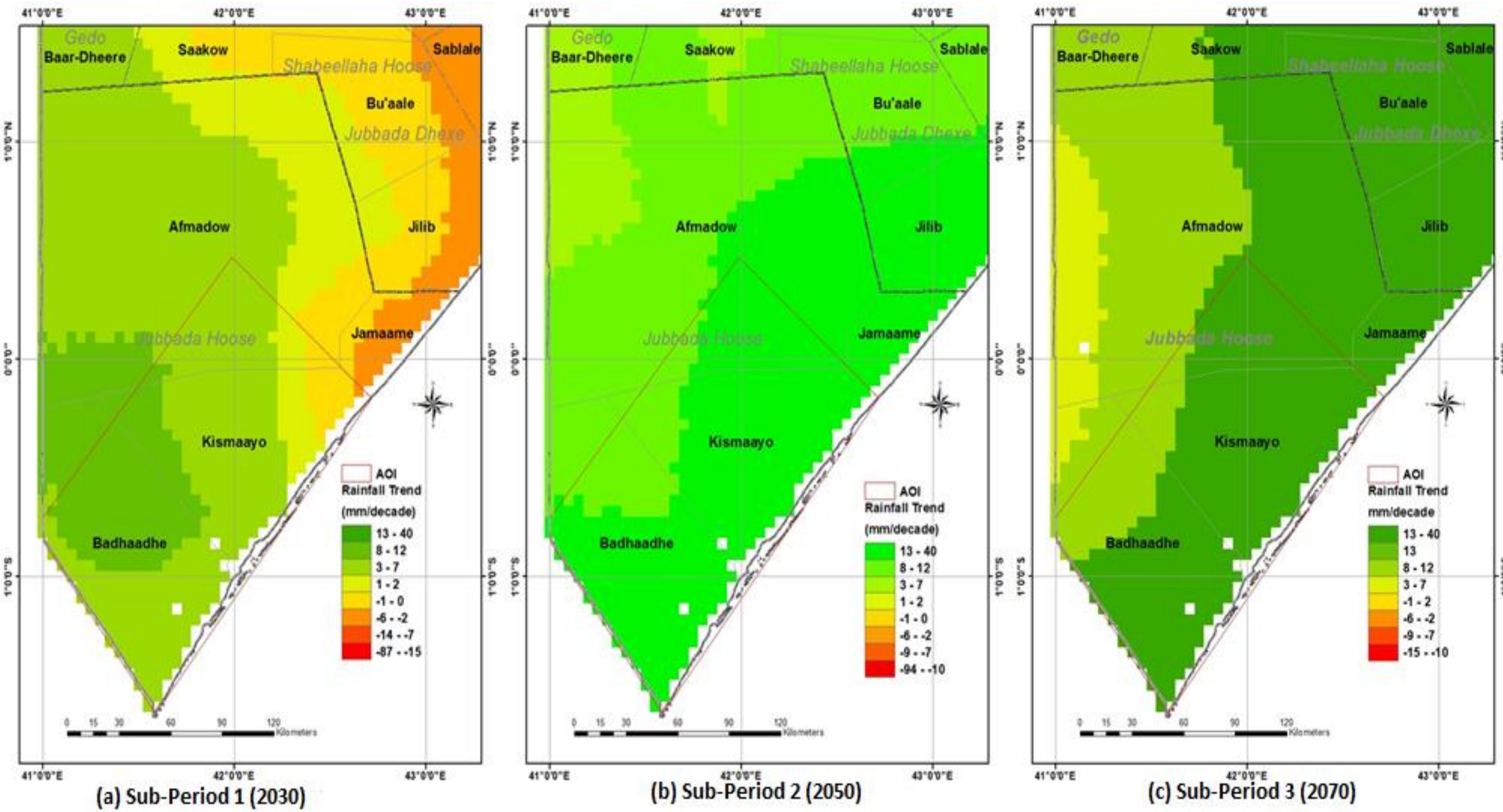


Figure 7-6: Map showing change in rainfall per decade in the (a) 2030, (b) 2050 and (c) 2070 during the *Gu* (AMJ) season

The increase in above average rainfall associated with floods as seen in **Figure 7-7** by in sub-period 2 (2050) is also consistent with Tierney, et al.(2015) and IPCC (2014b) that project increased precipitation in Africa generally during the same period. The magnitude of the above and below average rainfall for the projected future are not the same as seen in **Figure 7-7.** Similar results by AEA Group (2008) on the bordering regions in Kenya, project an increase in intensity of rainfall, and extreme rainfall events. Extreme cases of above normal rainfall usually associated with flooding are very frequent and dominant after 2050. The recurrence of extreme below normal rainfall often associated with drought is also evident, given the communities use of charcoal as an adaptation strategy**,** an increase in deforestation and degradation can be expected.

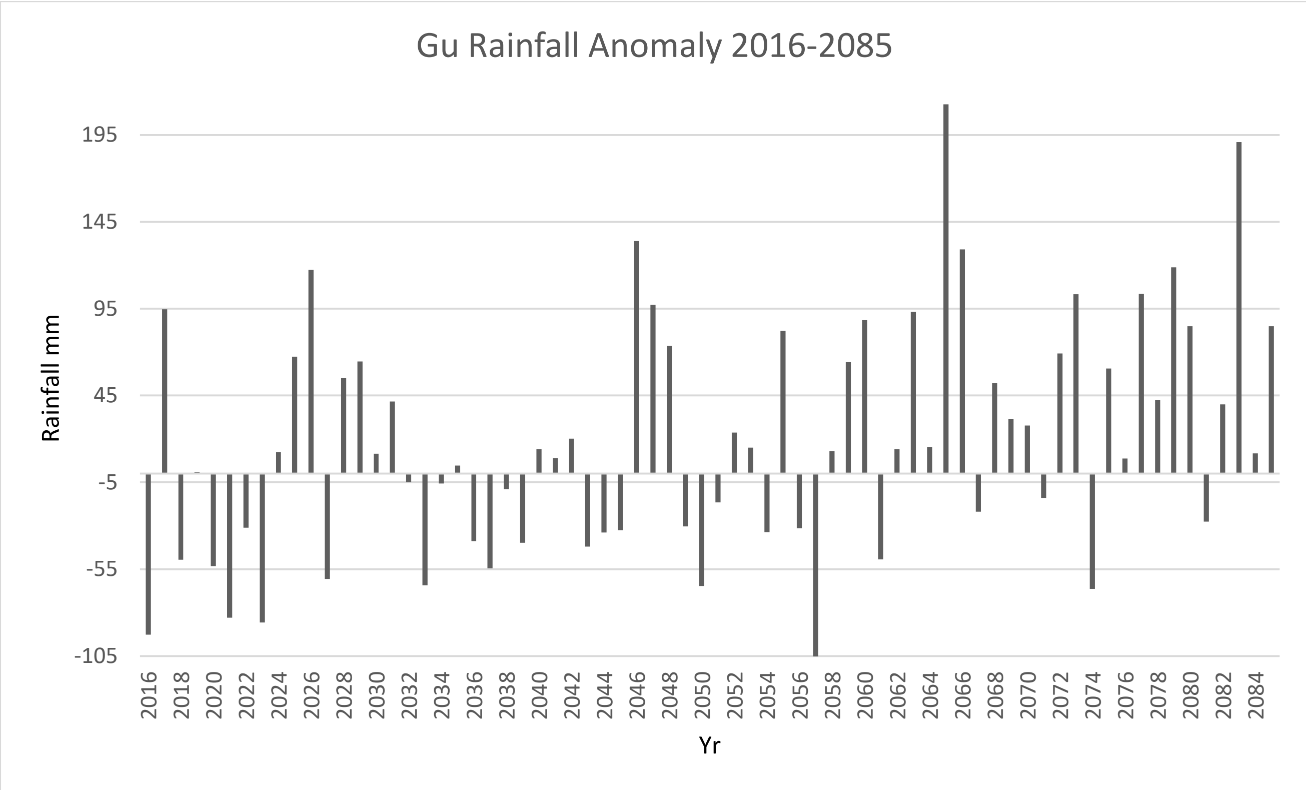


Figure 7-7: Rainfall anomalies (2016-2085) relative to the observed rainfall 1981- 2015

Recurring drought and floods could cause acute stress on a developing economy such as that of Lower Jubba particularly given the fact that most of the socio-economic activities in Lower Jubba are rain dependent. Complete deforestation would further increase the community’s vulnerability as charcoal production is an important coping mechanism in Lower Jubba. Rainfall variability, particularly the projected recurrence of below average extremes in the near future would also impact the rate of restoration of disturbed vegetation. A reduction in regeneration would affect the overall rate of deforestation and degradation in this region and speed up the complete deforestation projected for this region in the future. Efforts to achieve food security in most parts of African including Somalia have long been hampered by civil wars, political volatility, rapid population growth, floods and drought (Indeje, *et al.,* 2000; Haile, 2005; Omondi, *et al.*, 2014; Sheffield, *et al.*, 2014).

The study further provides some important knowledge on rainfall variability and change over the region that would be of great use in the next (6^{th}) IPCC assessment report on the state of global climate change. The results provide additional support for IPCC (2014b) studies that also predict substantial increases in the variability of rainfall patterns over time in Africa, which would lead to more frequent and intense floods and droughts. The knowledge on the past, present and future rainfall patterns derived from this study are important in the development of any effective disaster risk reduction and sustainable development strategies.

Long term adaptation planning by the Jubbaland Administration for Lower Jubba must take an integrated approach to both floods and drought for both the near, mid and far future. Investment in early warning systems for daily, monthly, seasonal and inter-annual prediction is critical for any effective adaptation strategy. Timely seasonal forecasts and drought monitoring is essential for drought risk reduction in Lower Jubba where livelihoods are closely intertwined with climate variability (Amissah-Arthur, 2003; Ogallo et al., 2008; Sheffield et al., 2014).

It may be concluded from the results of the future rainfall projections that all of the CORDEX RCMs have a fairly good simulation in comparison to the observed rainfall seasonality in Jubbaland. The most notable shortcoming in most RCMs is overestimation of the monthly mean in *Deyr* season. During *Gu* season and within each of the three projection sub-periods, a general increase in rainfall was exhibited over Lower Jubba, with the coastal area expected to exhibit a higher amount of rainfall than the inland areas. The projections of the individual rainfall anomalies indicate that in the near future Lower Jubba recurrence of depressed rainfall associated with droughts is dominant while occurrences of higher rainfall values will be dominant in the later projection period. The above average rainfall usually associated with flooding are frequent and dominant after 2050.

7.3 Temperature Projections

7.3.1 Spatial Distribution of the Projected Temperature

The spatial pattern of the projected seasonal ensemble mean surface temperature based on the RCMs are shown for the three sub-periods namely 2030, 2050 and 2070 relative to the baseline period 1981-2010 (**Figure 7-8**). The magnitude of the projected seasonal warming is found to vary with areas, season, averaging period and scenario used for the RCMs. The seasonal temperature change over the eastern region of study area appears to be relatively higher (lower) than in the western region in all the seasons for the sub-periods under both scenarios.

Figure 7-8 displays the spatial results for the three time periods. Results shows that projected change in temperature will vary from season to season and district to district. Like the observed GISTEMP data, the average temperature seems to increase towards the southern costal band in all seasons. Jaswal, et al (2012) attributes similar temperature patters to influence by the sea surface temperature (SST). The ensemble model seems to overestimate the temperature in JJA which according to the observed data as seen in **Figure 4-5** should register the lowest temperature but seems to register the highest temperatures compared to all other seasons as seen in **Figure 7-8**.

7.3.2 Projected Temperature Trend

Results from **Figure 7-9** show an increasing temperatures in the near to long term future of 0.02 ˚C/year. Results are statistically significant (p = 4.84E-24) at 95% confidence level. This is in line with global and regional reports that project an increase in the average temperature by 2030 and a further increase by 2050 (King'uyu , *et al.*, 2000; Easterling, *et al.*, 2009; Anyah & Qiu, 2012; IPCC, 2014b). Changes in temperature and humidity are reportedly linked to increased vectorborne diseases and helminthes infections (Few, et al., 2015). However the impact of projected climate change and variability on animals and plant diseases in the region is yet to be detirmened.

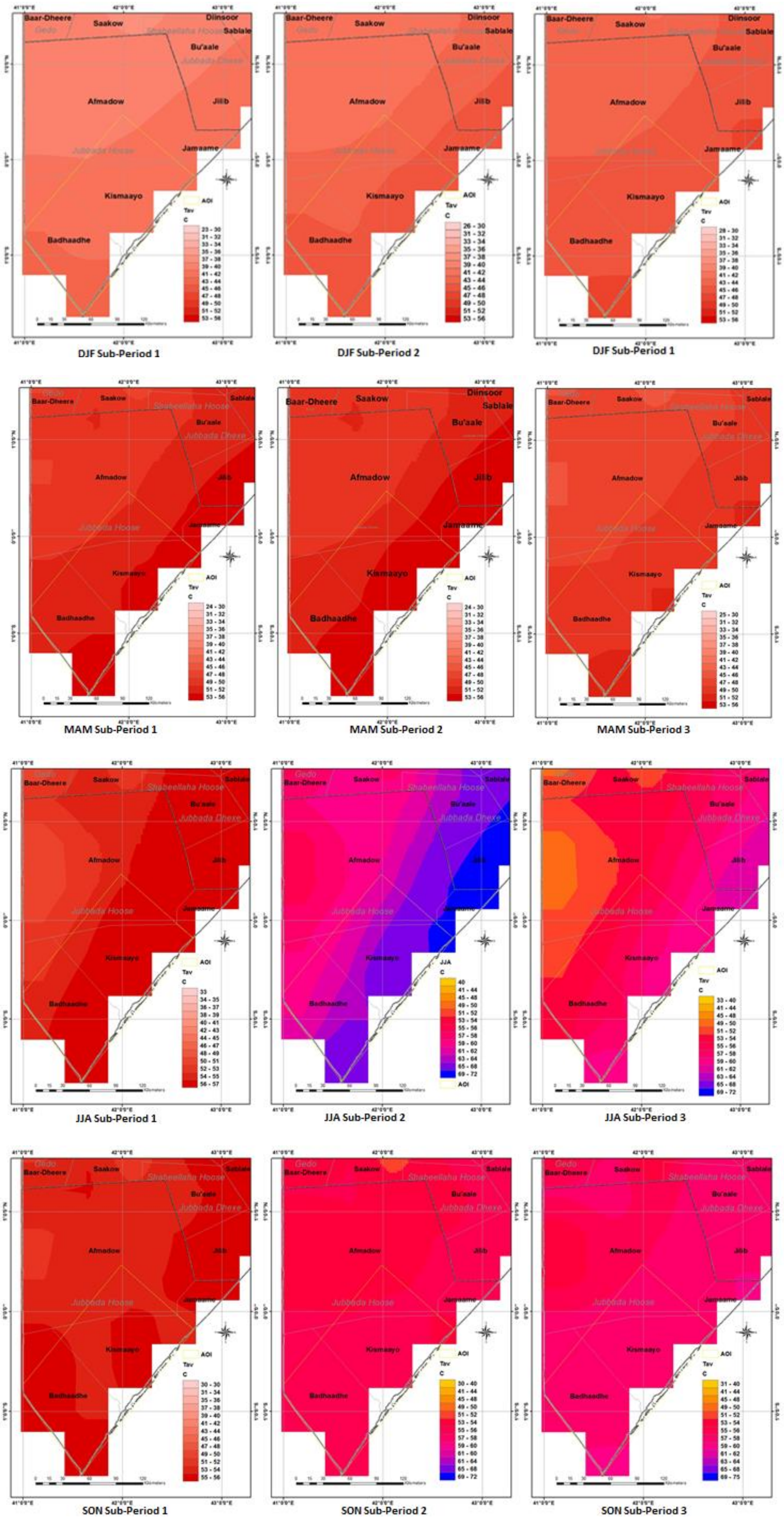


Figure 7-8: Average Temperature DJF, MAM, JJA, SON Season sin the sub-period 1 (2030), sub-period 2 (2050), and sub-period 3(2070) (Higher resolutions can be found in annex 1)

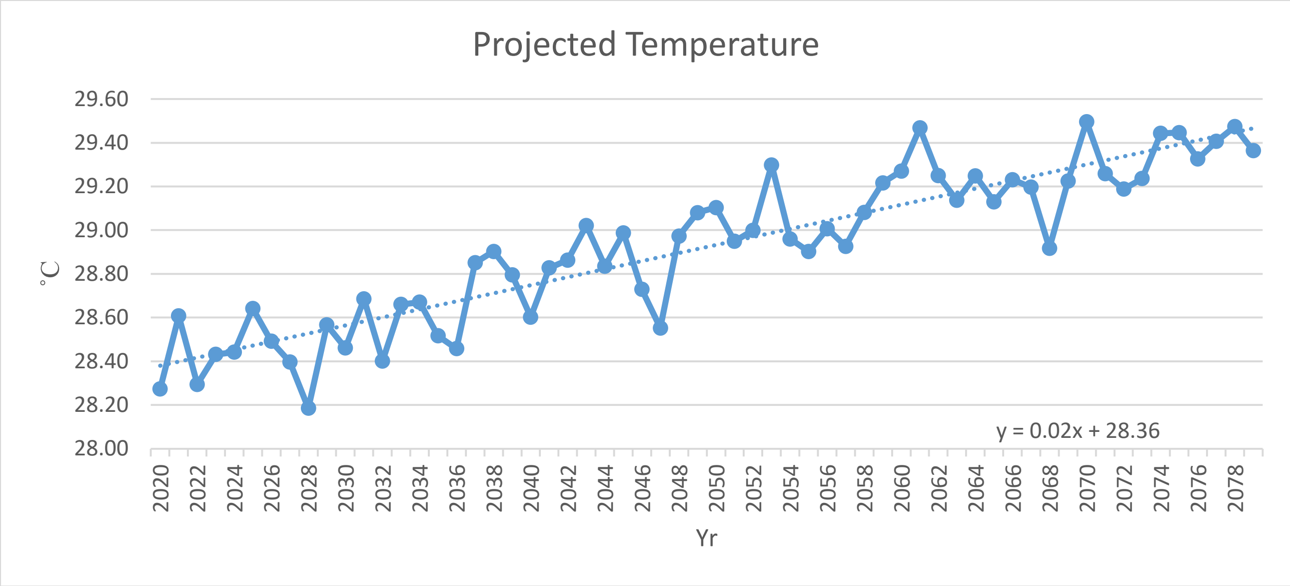


Figure 7-9: Projected Annual Average Temperature 2020-2079

Figure 7-10 shows the anomalies in the projected temperature. IPCC (2014a) reports also project more hot and fewer cold temperature extremes in most places as global mean temperatures increase in a seasonal time scale. They further projects an increase in temperature by 0.3 to 0.7 degrees by 2035 and not more than 3 degrees by 2100. The impact of an increasing temperature would be far reaching for most socio-economic sectors including community safety, water, food, energy, infrestructure, among others (Patz, *et al.*, 1996; Patz, *et al.*, 2005; McMichael, *et al.*, 2006; IPCC, 2007, 2014b). The projected temperature would also exacerbate health issues with heat related mobidity and mortality in Africa being projected to increase (Patz, *et al.*, 1996; WHO, 2003; Patz, *et al.*, 2005; McMichael, *et al.*, 2006; Paaijmansa, *et al.*, 2010). Studies have also projected that the geographical distribution of disease prone areas like Malaria will increase as climatic conditions change, creating more condusive conditions for new diseases to breed in areas that were previously disease free (Martens, *et al.*, 1995; Patz, *et al.*, 2005; Patz & Olson, 2006; Paaijmansa, *et al.*, 2010).

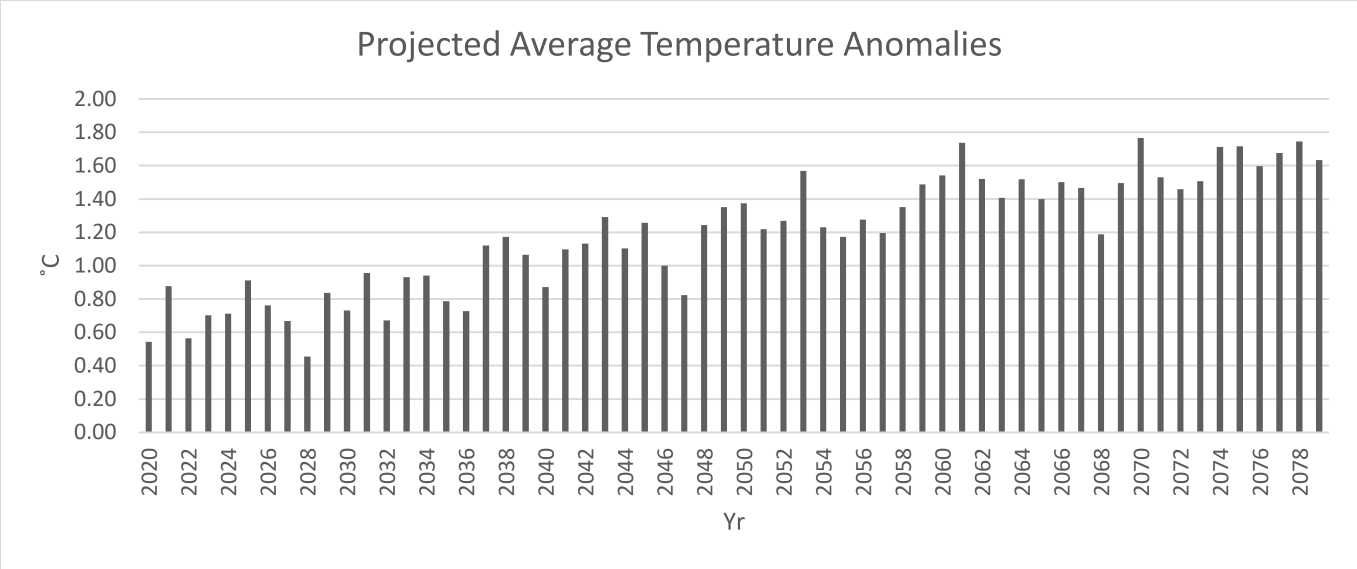


Figure 7-10: Projected Annual Average Temperature Anomalies

The projections for Lower Jubba indicated an increase in minimum and maximum temperatures in all seasons in the projection periods 2030, 2050 and 2070. Temperature anomalies indicate recurrences of positive anomalies within all the three projected periods. Temperature projections are critical in the development of effective and realistic climate change adaptation and disaster risk reduction strategies.

CHAPTER 8 : SYNTHESIS, CONCLUSION AND RECOMMENDATIONS

8.1 Synthesis

This chapter provides an integrated presentation of the major results from the study. The data used included remotely sensed data, observed climate data and primary data collected from questionnaires and interviews. Comparisons of the characteristics of rainfall and temperature were made, with data used in the study extending from 1981-2015 and 1981-2012 respectively. Observed rainfall data used in the study was a hybrid of satellite data from the Climate Hazard Group and station data from FAO SWALIM. Decadal satellite temperature data from the Climate Hazard Group was used to analyse the observed temperature. Two statistical approaches namely linear regression and Man-Kendal non-parametric statistics were employed in testing the significance of the slope of the rainfall and temperature time series for specific seasons.

Analysis of land cover changes in Lower Jubba was done using Landsat imagery data, commonly used in change detection studies. Different images from 1993, 1995, 2000 and 2014 were compared. Radiometric normalization was conducted to correct for surface directionality and atmosphere effects due to images acquired on different dates under different conditions. Dark Subtraction was conducted to remove noise and haze. Mosaicking of the 1993 and 1995 images was done to reduce the high cloud cover that appeared in all the images during that time period. A common cloud and shadow mask was then developed for the three resulting images for uniform change detection analysis. A confusion matrix and Kappa statistics was used to determine the accuracy of the resulting classification.

Community perspectives on the impact of climate change and the underlying causes of land cover change were assessed based on results from questionnaires and key informant interviews. A survey was conducted in the port town of Kismayo, to delineate the community perspectives regarding the deforestation and the local climate. The survey was also targeted at understanding the existing and planned adaptation and mitigation strategies for Jubbaland state. The results obtained were used to examine possible underlying causes in the land use and land cover changes and understand community behaviours and attitudes towards charcoal production.

The future climate scenarios were down scaled for Lower Jubba region using eight Global Climate Models (GCMs) from the CORDEX-Africa project. The projections targeted IPCCs projected 2030, 2050 and 2070 bench marks. Full details of the models can be found in Endris, et al., 2013.

8.1.1 Results from Past and Present Climate Patterns

The first specific objectives of the study was to characterize the past and current climate patterns over Lower Jubba. This objective was based on several studies that have shown that most livelihoods and development systems in the region of study are rainfall dependent (Little, 2004; BICC, 2009; UNDP, 2011). In addition to that, natural regeneration of vegetation is also rainfall dependent. The characterisation of the past and present rainfall was concentrated on the two rainfall seasons namely *Gu* and *Deyr*. The most dominant characteristics of rainfall time series found in the study were, a high degree of interannual variability and recurrences in high/low value extremes that are often associated with floods/droughts, some of which were observed during El Niño / Niña years.

A decreasing trend in rainfall was observed during the *Gu* long rains season while the *Deyr* short rain season observed a general increasing trend. The results showed that most of the trends observed were not statistically significant. Few significant trends that were delineated at some locations were not spatially consistent over large areas. The results are however similar to studies done on the region by several authors (Ogallo, 1988; Schreck & Semazzi, 2004; Bowden and Semazzi , 2007; Omondi, *et al.*, 2014; IPCC 2007; Lyon, 2014). Studies further show that the region GHA region has witnessed frequent episodes of both excessive and deficient rainfall (Omondi, *et al.*, 2014; Mwangi *et al.*, 2014; Omay, *et al.*, 2016).

The significance of the observed rainfall data is that is shows continued exposure for communities in Lower Jubba to recurring events of drought and flooding. The high/low rainfall extremes create unfavourable conditions for pastoralists in Lower Jubba. Recurring floods are linked to outbreaks of Rift Valley Fever that led to recurring bans in the export of livestock from Somalia. Recurring drought on the other hand has led to loss of livestock due to lack of water and pasture. These results provide new knowledge regarding climate variability for Somalia that could be used in the planning and management of all socio-economic systems.

The analysis of the observed temperature data showed an increase in temperature in both minimum, maximum and mean temperatures at all locations and all seasons. Some specific area differences were however common from the spatial maps of the observed temperature trends. Recurrences of extreme high/low values were also common in the interannual temperatures patterns at all locations.

Due to limitation in the length of temperature data used in this study, it is not possible to link the observed temperature changes in Lower Jubba entirely to climate change. The results are however very consistent with regional and global data that have reported an increase in temperature, that has been linked with high confidence to global warming and climate change (IPCC, 2007; 2014a). This study provides for the first time detailed knowledge of local temperatures Knowledge of temperature extremes are very important in climate smart planning.

8.1.2 Results from the Land Cover Change Analysis

Results from the first objective proved the existence of climate extremes in Lower Jubba, this impacts significantly on livelihoods as well as on natural regeneration of vegetation in degraded lands. The second specific objective then focused on evaluating the changes in land cover in Lower Jubba based on studies that showed charcoal production particularly for export as a concern in Somalia (Robinson, 1988; Beier & Stephansson, 2012; Rembold, *et al.*, 2013; SWALIM, 2014; UNEP & INTERPOL, 2014). The results from the study revealed that Lower Jubba has experienced significant deforestation of up to 50% reduction in forest cover between 1993 and 2014 with a user accuracy of 90%.

The region has further experienced significant degradation in the same period with up to 17% reduction in woodlands. The classification of woodlands reported a user accuracy of 80%. Bare land/artificial land increased to 315%, which could also be associated to an increase in settlement. An increase in grassland and shrubland was seen as well. The overall accuracy of the classified data was 88% which is above the 85% mark for a good classification with a Kappa coefficient of 0.84.The reasons for the rapid deforestation and degradation in Lower Jubba was primarily due to charcoal production, but expansion for agriculture and urbanization were listed as well. Additional land degradation due to population is expected, particularly with repatriation of refugees back to their homes.

Results from the first specific objective showed the reality of climate risks for communities in Lower Jubba, and the results of second specific objective showed that the rate of degradation in Lower Jubba could mean complete deforestation in the future. Complete deforestation would also affect the energy, local hydrologic cycle, biological productivity of the land and contribute to changes in the atmospheric composition of greenhouse gasses. This has the potential to dampen or amplify anthropogenic climate change (Bala, *et al.*, 2006; Brovkin , *et al.*, 2006; Kueppers, *et al.*, 2007; IPCC, 2014b; Laguë & Swann, 2016). The impact of deforestation on emissions, sequestration, and albedo plays an important role in the global carbon cycle (IPCC, 2014b). Depressed rainfall is predicted to have contributed further to the deforestation and degradation rate by reducing natural regeneration of vegetation (Vieira & Scariot, 2006). The urgent need for integrated land use, sustainable community development, disaster risk reduction and climate change policies is one of the key recommendations from the study.

8.1.3 Results from Community Observations, Behaviours and Attitudes

The study sought to look at the impacts of climate characteristics on the livelihoods of the community and the significance of charcoal production in the third specific objective. Results showed that climate variability in Lower Jubba had resulted in the loss of livestock and livelihood. Frequent and prolonged drought had led to loss of livestock due to lack of water and pasture. Flooding on the other hand had led to outbreaks of Rift Valley Fever leading to the banning of the export of livestock from Somalia to the Gulf States. Livelihoods in Jubbaland consist primarily of pastoralism with the rearing of livestock such as camels, cattle, sheep and goats as well as irrigation being done along the Jubba and Shebelle rivers (Little, 2004; IUCN, 2006; UNDP, 2011).

The study showed that climate extremes have been recurring in Lower Jubba. The study has also shown that deforestation and land degradation is rapidly occurring in this region. Results from this specific objective shows that the loss of livelihood due to recurring drought and floods is driving the communities' involvement in charcoal production. While communities in Lower Jubba understand that deforestation could negatively impact their future, the need for survival now supersedes any need to secure the future. Any effort to curb deforestation and degradation will prove difficult to implement successfully without first addressing the issue of livelihoods in the community.

8.1.4 Results from Projected Climate Patterns

The final specific objective was to assess the potential impacts of future climate change over Lower Jubba. The specific objective allows for a context on which adaptation and mitigation measures can be made. All of the CORDEX RCMs have a fairly good agreement between the annual rainfall and simulated rainfall seasonality over Lower Jubba. The most notable shortcoming in most RCMs is overestimation of the monthly mean in the *Deyr* season. The coastal areas seemed to exhibit a higher amount of rainfall than the inland areas during the *Gu* season. The models projected a recurrence of depressed rainfall associated with droughts in the near future, centred around 2030. Large and more frequent rainfall events associated with flooding were dominant in the later projected sub-periods 2050 and 2070.

Results from CORDEX RCMs under RCP4.5 scenarios in simulating annual average temperature cycle capture a fairly good agreement in comparison to the annual temperature seasonality in Lower Jubba. The study also showed conclusive evidence that like the rest of the globe (IPCC, 2000, 2007, 2014b), the temperature in Lower Jubba is increasing. The projections indicated increase in minimum and maximum temperatures in all seasons in the projection periods 2030, 2050 and 2070. Temperature anomalies indicate recurrences of positive anomalies within all the three projected periods. Seasonal differences in the observed temperature projections was quite evident requires more studies for effective and realistic development of climate change and disaster risk reduction strategies.

Global temperature increment has been associated with global warming and climate change. The projected climate patterns delineated in this study have been shown by IPCC (2014a) to have serious implications on safety of life and livelihoods, economic resources, desertification, human settlements, natural resources and biodiversity, water, health, energy, agriculture including livestock, food security, and infrastructure, among many other socio-economic activities.

The main objective of this study was to examine the past and future patterns of climate extremes and trends, as well as providing some understanding of the potential impacts of charcoal production for Lower Jubba Somalia. The study has shown that the floods and droughts seen in the past in lower Jubba are projected not only to continue but to increase in frequency and intensity. Results have also shown that turning to charcoal production is a as key livelihood and adaptation strategy for communities' to respond to the resulting impacts of the floods and drought. Results further show rapid deforestation and degradation driven primarily by charcoal production in Lower Jubba. The Jubbaland administration must seriously address the consequences of climate change and environmental challenges as integral component of sustainable development and economic stability strategies. The newly formed Jubbaland state has the difficult task of re-constructing a government where none has existed for over two decades; the above mentioned impacts would impede and reverse the government's developmental efforts.

The projected results for Lower Jubba indicate that unless adaptation and mitigation measures are undertaken, communities will continue to incur losses in their livelihoods as a result of flooding and drought. Flooding in Lower Jubba has been linked to RVF outbreaks which in the past has resulted in a ban in the export of livestock from Somalia and led to massive losses for communities and the Somali economy (Cagnolati et al., 2006; Bachorz, 2012; NMG, 2012).

With charcoal production as the communities copping mechanism, deforestation and land degradation should be expected to continue if no appropriate measures are taken. With complete deforestation projected for the future, a critical need for mid and long term adaptation strategies for communities in Lower Jubba should be addressed. Deforestation creates a new challenge due to an implied change in the hydrological system. Deforestation also leads to increase surface runoff which increases soil erosion, reducing the productivity of the land.

Complete deforestation in Lower Jubba could impact changes to rainfall patterns and surface temperatures leading to reduced rainfall during the dry seasons. It would also impact soil moisture thus increasing surface runoff which would possibly increase flooding around the rivers and in low-lying areas and also lead to soil erosion. Reuveny (2007) reported on scenarios for climate change-induced conflict, linking it to the scope of degradation and the extent to which it influences migration. Walters (2008) further reported that complete deforestation could create insecurity and possibly trigger violent conflict among people as it leads to scarcity and inequality. UN-REDD (2015) reports on the possibility of triggering conflict when resources like food, water, fuel, medicines, traditional cultures and livelihoods that forests provide are threatened.

The vulnerability of the community warrants urgent proactive measures to reduce the imminent threat of climate change amidst rapid deforestation. Strategies for economic development at a regional and national level must take a resilience pathway. Knowledge from the study including the projected changes in the patterns of rainfall extremes provide critical foundation for the development of the national and community disaster risk reduction and climate change adaptation strategies. The study also provides some important knowledge on rainfall variability and change over the regional that would of great use in the 6th IPCC assessment report on the state of global climate change.

8.2 Conclusions

The study characterised the past present and future climate patterns in Lower Jubba to assess the community's vulnerability to climate change. The study further sought to understand the significance and sustainability of charcoal production in adaptation in Lower Jubba. The study analysed changes in land use and cover in Lower Jubba and the possible underlying causes. Results for the first time showed conclusively rapid deforestation and degradation with a decrease of 50% in forest cover and 17% in woodlands in less than two decades. Depressed rainfall played a role in preventing the natural re-generation of vegetation in the region, contributing to the observed land degradation and deforestation. The study calls for an urgent need for intervention to prevent complete deforestation in this region in the future. The drivers of the change in land cover were largely due to charcoal production that is driven by high demand for sale and domestic use for fuel.

The study also characterised the past, present and projected climate of the Lower Jubba. Results from both rainfall and temperature analyses showed trends in both rainfall and temperature records recurrences in high/low value extremes that are often associated El Niño/La Niña events. Models projected an increase in the recurrence of depressed rainfall associated with droughts near future and occurrence of higher rainfall values in the later projection period. The projected depressed rainfall could speed up complete deforestation as natural regeneration of damaged vegetation requires rainfall. An increase in temperature was observed in all parts of Lower Jubba during all seasons, consistent with what has been observed in many regional study as well as other parts of the world (King'uyu, *et al.*, 2000; IPCC, 2007; 2014; Omay, *et al.*, 2016). Increase in minimum and maximum temperatures was projected by all climate models in all seasons and regions.

Lower Jubba's low coping capacity due to high levels of poverty and level of exposure increases its vulnerability to climate change. Communities in Lower Jubba face multiple stressors that interact with climate variability, amplifying their vulnerability. Stressors like land degradation, increased variability in access to water, and fragmentation of grazing areas is causing undue stress. Charcoal plays the role of strengthening the communities' ability to adapt to climate stressors. The projected complete deforestation not only directly and indirectly impacts the local climate but takes away an important resource for the community to withstand climate shocks. Loss of livestock under prolonged drought has been a critical risk for populations in Lower Jubba with tree cover playing a key role in the sustenance of the livestock.

The knowledge derived in this study is fundamental in any efforts to develop sustainable development, disaster risk reduction and climate change strategy for the newly formed Jubbaland state, and create a model for other states to build on. The study provides important knowledge on rainfall variability and change over the regional that would be of great use in the next (6th) IPCC assessment report on the state of global climate change. Investment in early warning systems for daily, monthly, seasonal and inter-annual prediction will be critical for any effective adaptation strategy. Given that livelihoods in Lower Jubba are intertwined with climate variability, investment should be made on giving the community timely seasonal forecasts and drought monitoring, which is essential for drought risk reduction.

Somalia presented its INDCs ahead of the 2015 Paris Agreement on climate change where it committed to climate change mitigation through afforestation and re-afforestation (FGS, 2015). The UNFCCC (2012) states a need in building long-term national adaptive capacity and resilience. An effective monitoring and evaluation system of adaptation needs and measures and ways to address the needs should be put in place. The World Bank (2016a) futher stresses that a successful adaptation strategies require a participatory, multidisciplinary and complementary approach that builds upon relevant existing plans and programmes. Adaptation plans should give particular consideration to marginalized groups such as women and be simple, flexible, cost effective and community driven.

At the beginning of the study the hypothesised that the high volume of charcoal being exported from Somalia has had a significant impact on deforestation, and this in the long run will affect the community’s ability to adapt to climate change. The study proved this hypothesis.

8.3 Recommendations

Environmental degradation and climate change will have different impacts on various socio-economic sectors. This section on recommendation has therefore been targeted to different stakeholders and sectors.

8.3.1 Recommendations to the Federal Government of Somalia

There is a need for the Federal Government of Somalia to strengthen the Ministry responsible for Environment. There is need to have effective and integrated strategies for mainstreaming disaster risk reduction and climate change adaptation for resilience into all development plans that are country-driven, gender-sensitive, participatory and fully transparent, taking into consideration vulnerable groups, communities and ecosystems. UNFCCC (2012) recommended that adaptation plans should be based on and guided by the best available science and, as appropriate, traditional and indigenous knowledge, and by gender-sensitive approaches, with a view to integrating adaptation into relevant social, economic and environmental policies and actions.

The Federal Government of Somalia should work with the available global systems to aid in creating strategies for sustainable development. The Sendai Framework for Disaster Risk Reduction 2015-2030 adopted by the Third UN World Conference on Disaster Risk Reduction in March 2015 provides a global instrument to manage disaster risk in support of development. The United Nations convention to combat desertification (UNCCD) addresses the drylands, with the goal of reversing and preventing desertification/land degradation and to mitigating the effects of drought in affected areas in order to support poverty reduction and environmental sustainability.

Somalia can take advantage of UNFCCCs safeguards that enhance social and environmental benefits while protecting territories and cultures of the local communities. A participatory national strategy to combat forest deforestation and degradation should be developed. Furthermore, a national information system should be created to monitor land use patterns and collect data on overall greenhouse emissions related to the forest sector in Somalia. This not only stores data on forest carbon stocks but enables Somalia to be eligible for results-based financing projects for future activities that address the drivers of degradation and deforestation. International organisations that have frameworks which fund forest-based initiatives include, the World Bank Operational Policies, REDD+, and other various forest certification schemes.

Organs to implement and monitor policy needs to be established and/or strengthened in order to control abuses and illegal practices at the relevant levels of administration. The Government should promote alternative fuels and encourage the use of fuel-efficient stoves, with particular focus on urban centres. The Government should further reinforce communal, clan or other traditional means of information sharing and resource management.

8.3.2 Recommendations to the Jubbaland Administration

Investment in weather forecasting should be made and information downscaled in a way that is relevant to different stakeholders. The people in Lower Jubba need to be assisted to develop adequate policies that will guide the sustainable use of their natural resource base. The direct and indirect drivers for charcoal production need to be addressed through a holistic approach. Sustainable forest management like the introduction of bamboo farming for charcoal as an alternative should be promoted. Existing policies and laws should be reviewed using a consultative and participatory process, new policies and laws should be developed where they do not exist, and updated where laws exist. A participatory and consultative process in developing and implementing plans with the local communities is necessary for sustainable environmental management.

The Jubbaland Administration should strengthen inter-linkages between adaptation and development strategies that enable communities to build resilience. Policies should be linked across different sectors of government at both the local and federal level. Sectoral level policy makers, planners and managers should be given information in suitable forms as they are most likely to mainstream adaptation efforts into their planned work. The Jubbaland administrations should identify the capacity gaps and build capacity for planning and implementing adaptation.

Environmental governance needs to be strengthened in order to ensure the sustainable management of the country's natural resource. Key informants reported the increase in stabilization in the South of Somalia has led to wildlife returning to the Lag Badana-Bushbush national park and Kismayo National park, established in the South of Somalia in the 1980s. Management of these natural habitats that were homes to over twenty endemic plant species provides the administration an incentive for resources in the form of ecotourism, even as the region becomes more secure. Jubbaland Administration needs to develop and build the capacity of enforcement agencies to control illegal production and enforce regulations.

8.3.3 Recommendations to International Partners

Jubbaland requires significant financial resources, technological support, and investment in institutional and capacity development needed to address the deforestation and climate risk issues. The international community should support and encourage the regional and federal government to develop, rebuild and strengthen the necessary institutions that will help to ensure good environmental and climate change governance. Technical assistance, capacity building, provision of equipment and materials, and other required forms of support should be provided.

Results from this study show an urgent need in this region for investment in early warning systems, for daily, monthly, seasonal and inter-annual prediction to ensure effective drought and flood monitoring and is essential for drought risk reduction. Partners should assist the Federal Government of Somalia and the Jubbaland administration to prioritise investment in meteorological equipment for early warning for disaster risk reduction. This will enable the government to identify potential threats to the environment and people's livelihoods.

International partners should support Somalia fulfil its Intended Nationally Determined Contributions (INDCs). Somalia pledges to promote alternative sources of energy so as to reduce the reliance on charcoal for fuel as well as introduce alternative sources of livelihood to persons participating in charcoal production. International partners should further support Somalia's pledge for reforestation and afforestation programmes for the rehabilitation of degraded lands in its INDC.

8.3.4 Recommendations to Regional Partners

Regional organisations like IGAD and the African Union should prepare a framework to monitor and regulate charcoal export. Member states should provide Somalia with their experience in adaptation and mitigation policies. Information sharing and study tours should be done especially in Kenya and Ethiopia that share borders with Jubbaland. IGAD should facilitate capacity building for officials from Somalia from its member states.

Regional partners should provide institutional and financial structures though which donor funds can be directed as Somalia strengthens its own institutions.

8.3.5 Recommendations to the Local Community

Degradation of natural resources as a result of both over-exploitation and climate change in Jubbaland will contribute to increased conflicts over the distribution of these resources. Finding alternative sources of livelihood and encouraging agro-forestry could reduce the extremely high rate of deforestation in this region. If the roots causes of poverty and vulnerability are not addresses then climate change will overwhelm the community's ability to cope and force even larger numbers into charcoal production that has become the means of coping.

Climate change adaptation for resilience programmes should be at the centre of development efforts in Jubbaland. The local community needs to be sensitised on the impacts on charcoal production and develop a community based strategy to reduce deforestation. Soil and water management has been proven as an effective adaptive strategy in Africa (Scoones , *et al.*, 1996; Pandey, *et al.*, 2003; Nhemachena & Hassan, 2007; Rockstro, *et al.*, 2009). Drought can be adapted to by various water harvesting and saving systems devices. Setting up of water pans, village tanks with accompanying systems of delivery to harvest rain water can help local communities adapt. Farmers can adopt drought tolerant agriculture as well as move from rain fed agriculture to irrigation.

Steps have been taken at the international, federal and local level by declaring a ban on charcoal export. However large reliance on charcoal as the main source of energy locally and the long coastline leaves the reality that charcoal production in this region is a complex problem that needs high financial investment currently not available. Households and communities dependent on charcoal production and trade need to find alternative sources of livelihood that does not degrade the environment.

8.3.6 Recommendation for Research

The quantity and quality of data available in and to LDCs is currently limited. There is also very little information on climate change and deforestation on the South of Somalia. Lack of data continues to be a challenge in Lower Jubba. Investment in data management and climate monitoring systems is required to enhance the knowledge base that informs the basis for effective strategies and policies. Research on climate change mitigation and adaptation activities that can be effectively apply to communities in Lower Jubba should be done by the local universities. Research into low cost energy to replace the dependency on charcoal in this region should be looked into.

With the projected floods and droughts in Lower Jubba, research into the implication of the projections on livestock, vector- and water-borne diseases, under-nutrition, and migration will be important. IPCC (2014a) projects that the risks for food insecurity in Africa are is very high, with limited potential for risk reduction through adaptation, studies on how this will translate in Lower Jubba should be looked into. Reports on multiple threats faced in Africa in food security from entrenched poverty, environmental degradation, rapid urbanization, high population growth rates, and climate change and variability are high (Jones & Thornton, 2003; Schmidhuber & Tubiello, 2007; Challinor, *et al.*, 2007; Lobell, *et al.*, 2008; Brown & Funk, 2008).

The implication of climate change on pests and diseases on both humans and livestock in this area should be looked into. Effects of increased heat on livestock in this region should be studied extensively given that livestock is a significant source of livelihood in this region. Changing temperature and precipitation patterns have been reported to impact health including malnutrition, diarrheal diseases, and malaria and other vector-borne diseases (Patz, et al., 1996; WHO, 2003; Patz, et al., 2005; McMichael, et al., 2006; IPCC; 2007; 2012; 2014a).

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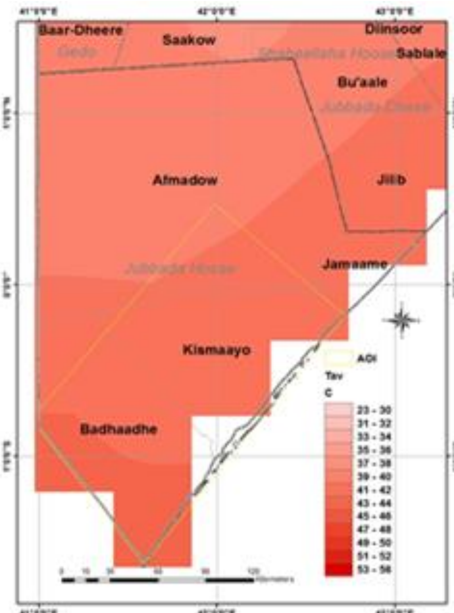
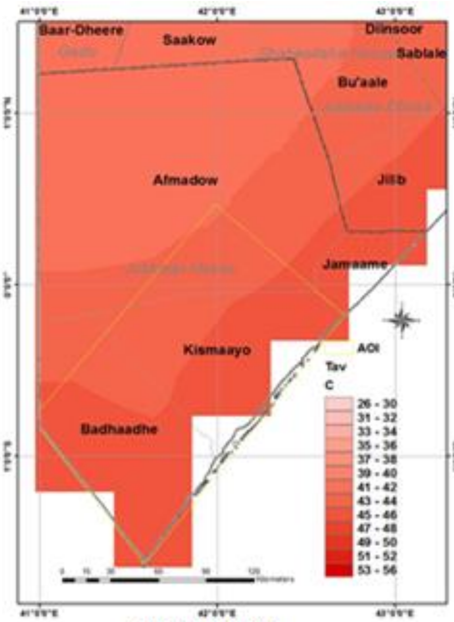
ANNEX 1: Graphs, charts and maps

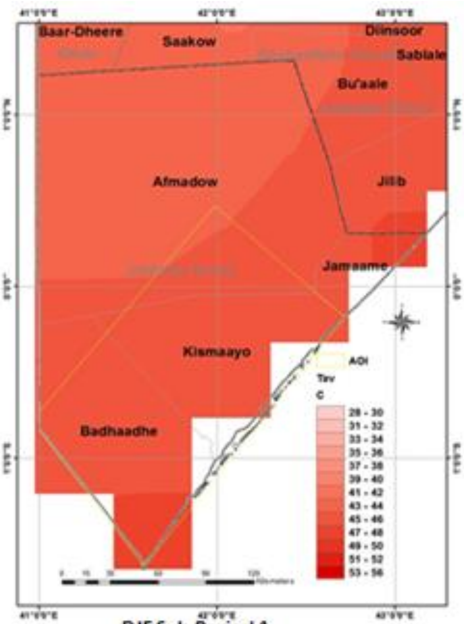
1. Map showing the average temperature in the DJF, MAM, JJA, and SON Season (1960 to 2012)



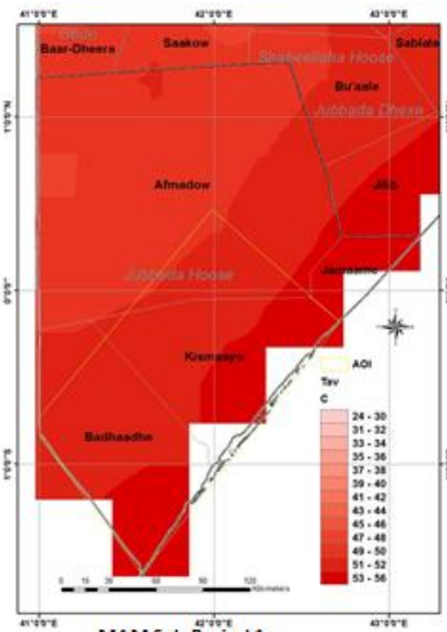
DJF Sub-Period 1



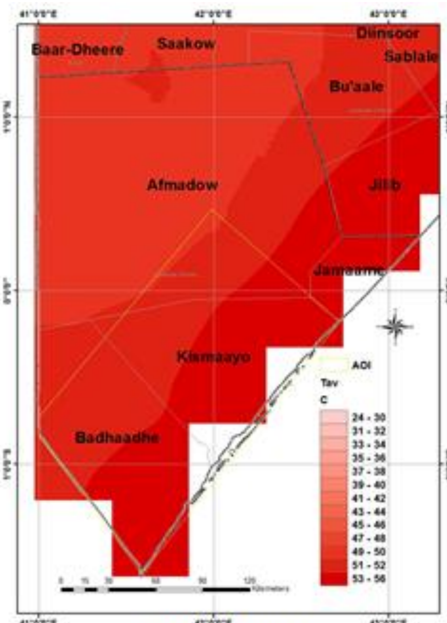
DJF Sub-Period 2



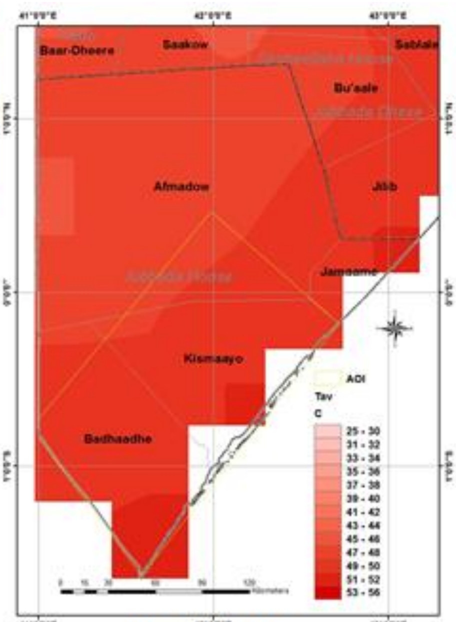
DJF Sub-Period 1



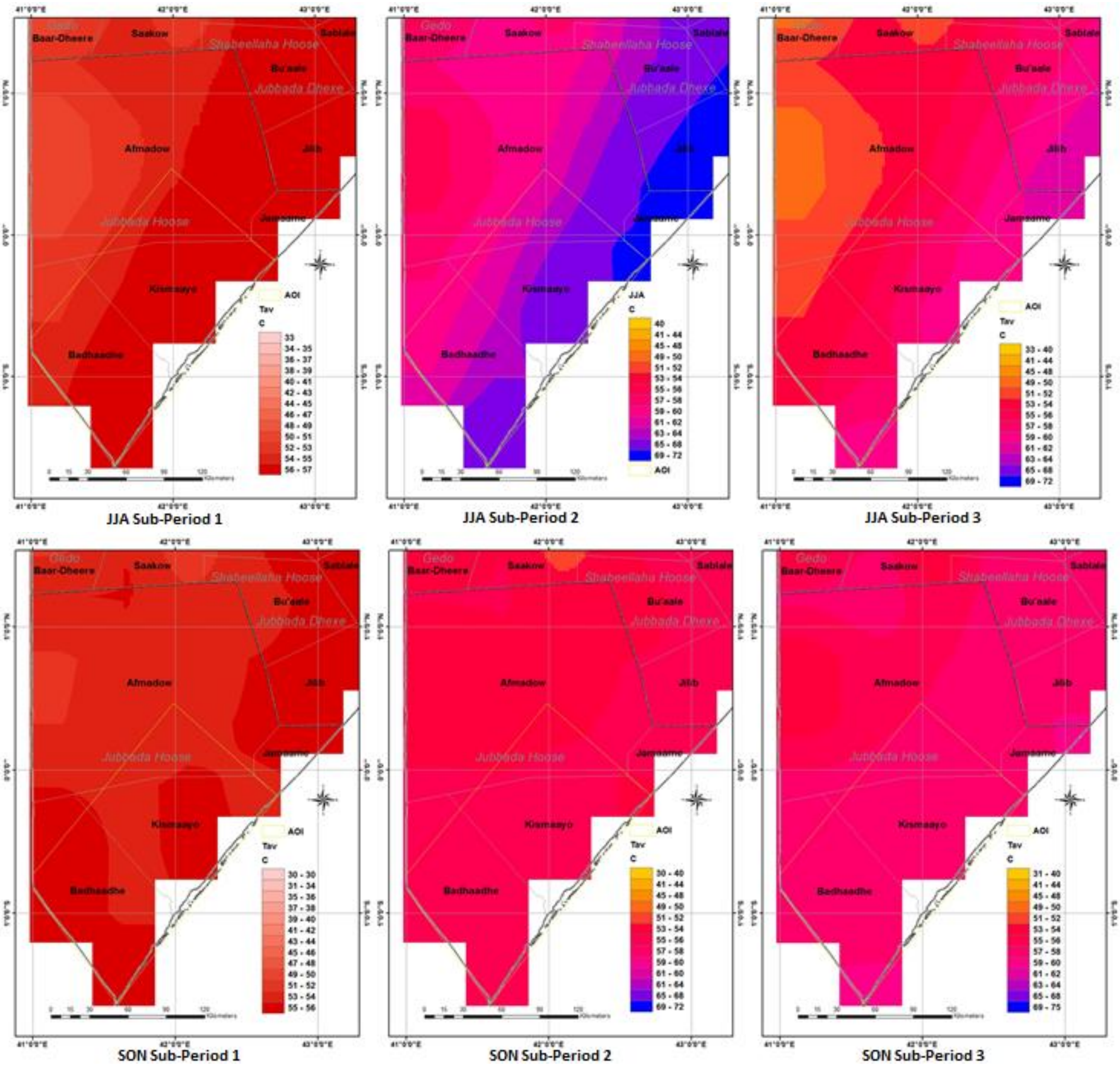
MAM Sub-Period 1



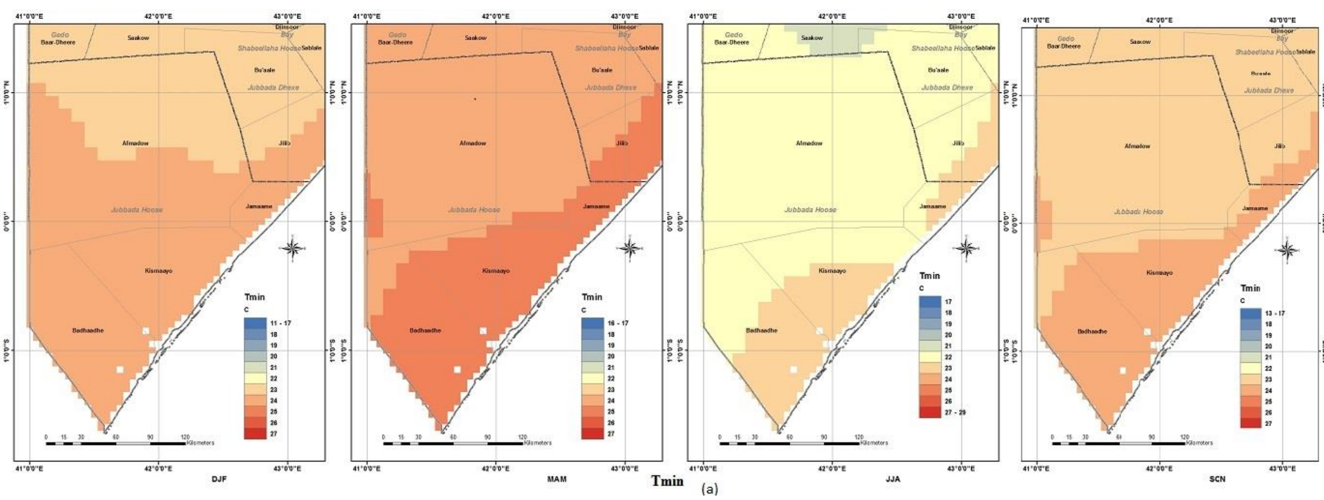
MAM Sub-Period 2



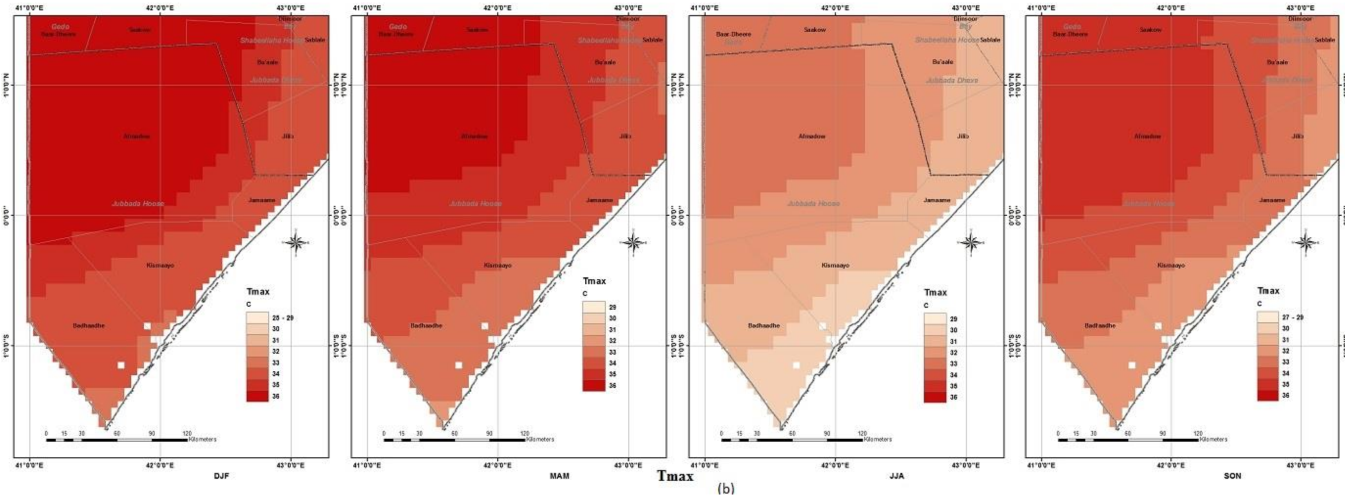
MAM Sub-Period 3



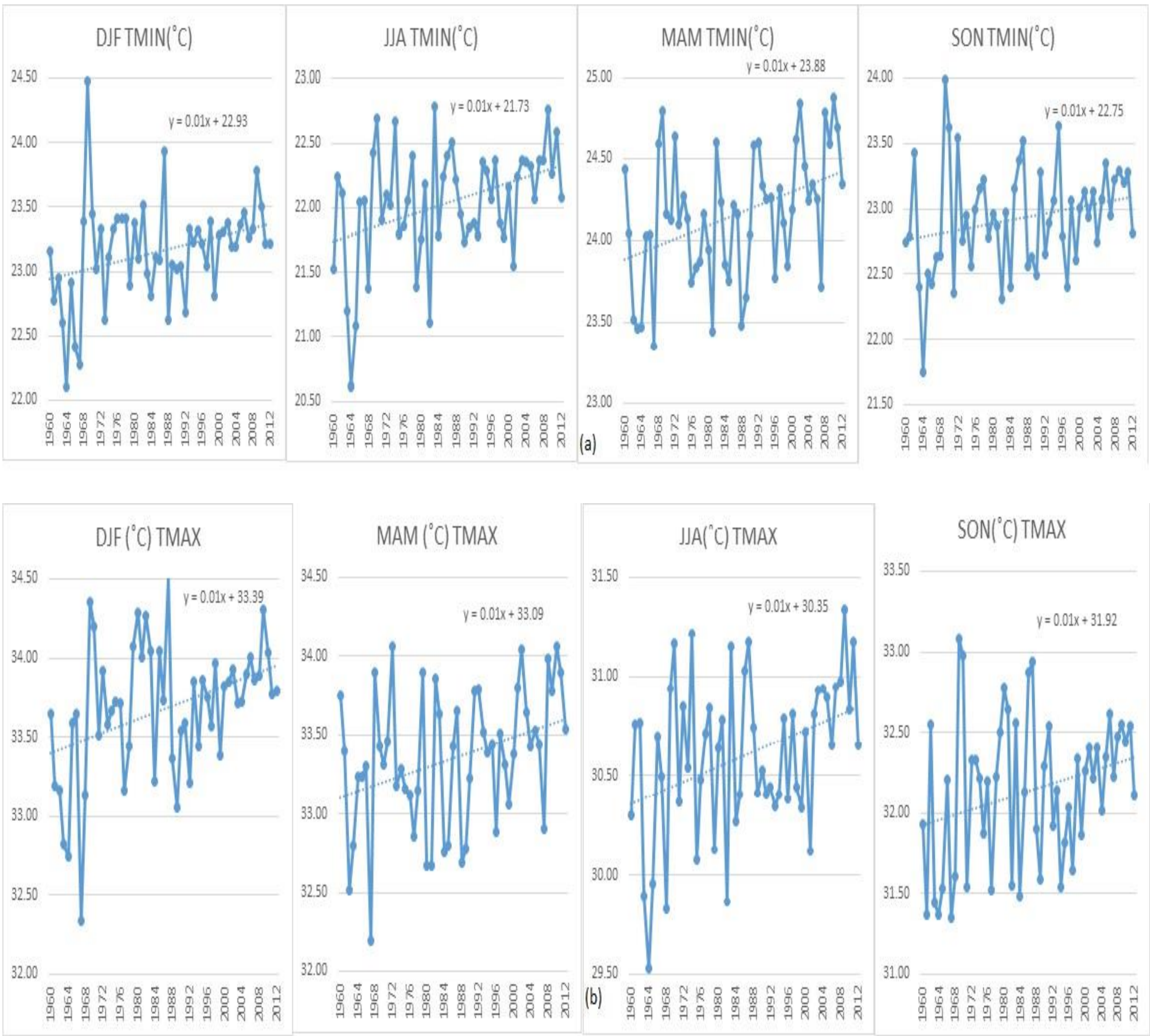
2. Map showing the spatial distribution of the minimum (Tmin) (a) and maximum (Tmax) temperature in the DJF, MAM, JJA, and SON Season (1960 to 2012)



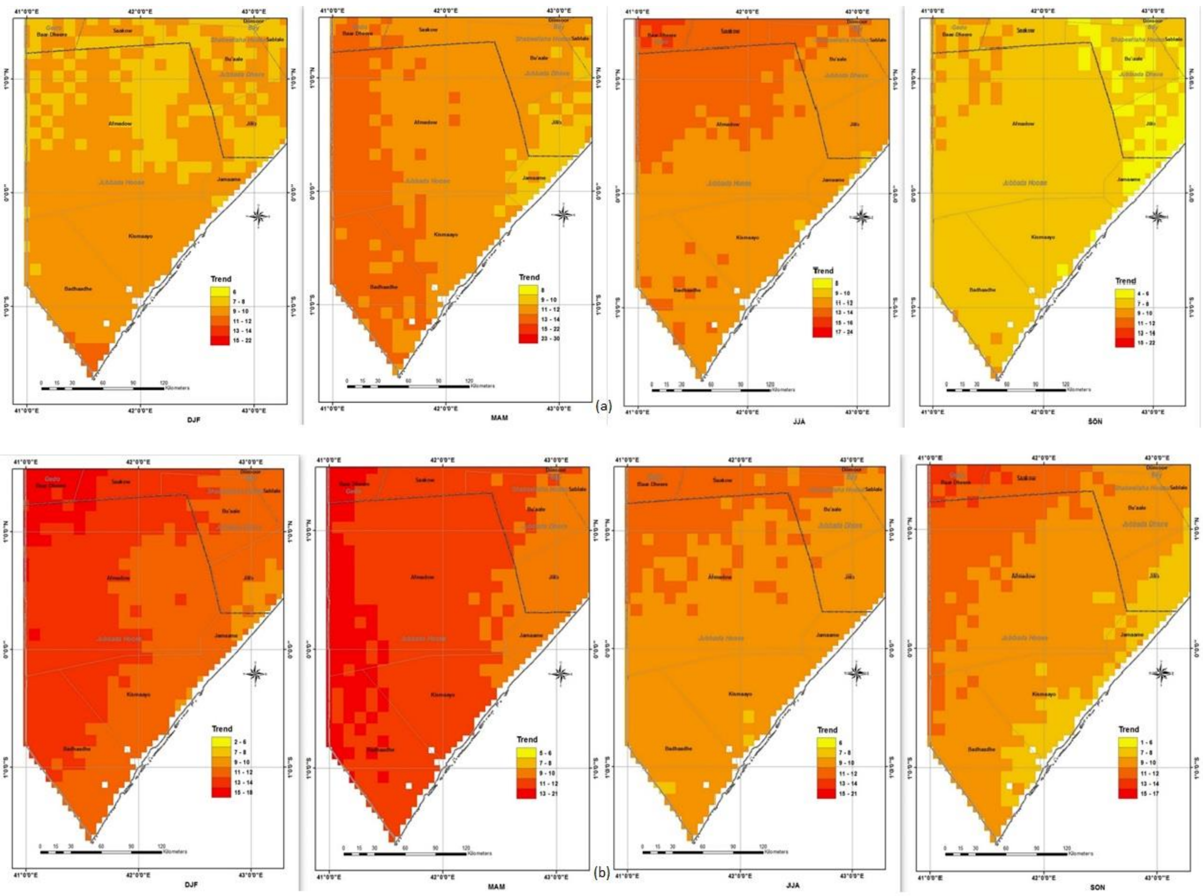
Tmin (a)



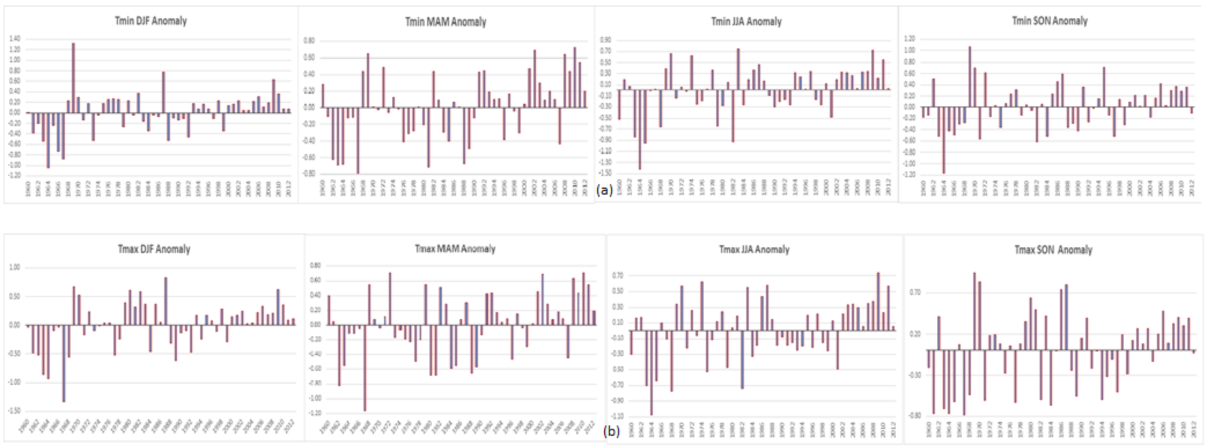
3. Time-series plot of the average seasonal minimum (Tmin) (a) and maximum (Tmax) (b)



4. Spatial distribution of the change in minimum (Tmin) (a), maximum (Tmax) (b) and average (Tav) (c) temperature in the DJF, MAM, JJA, and SON Season (1960 to 2012)



5. Anomalies in temperature during minimum (Tmin) (a) and maximum (Tmax) (b) temperature in the DJF, MAM, JJA, and SON Season (1960 to 2012)



ANNEX 2: Questionnaire

Suala waxaa loo loosamaynaya duruus waxbarasha owgayad ooh ah mahadka Isbadalka Cilmada iyo Laqabsigaa ee Jamacadda Nairobi . Muhimadaa suaalahan waa inlaa fahmaa isticmalka dulka iyo Isbadalka Sanadihi dambe ee Jubada Hoose.

SUALAHA

Daganka ad daganthay					
Jinsiyada	Rag ☐		Dumar ☐		
Dahda	18-24 ☐ 25-34 ☐ 35-44 ☐ 45-54 ☐ 55-64 ☐ Above 65 ☐				
Herka waxbarasha	Dugsi hoose ☐	Dugsi Sare ☐		Dugsi sare kakoree ☐	Jamcada shahada ☐
Xaalada Guurka:	Doob ☐		Xaasle ama xaas ☐		
Shaqada	Beera qodasho ☐ Xoolo dhaqasho ☐ Xaabada la shito ☐ Waxyaabo kale________________				
Intaqof oo kuguhosnol					
guuriga waxaad Kaahay	Abo ☐	Hoyoo ☐	Cunug ☐	Kuwakale(sheg) ☐	
meqaa sanaad ayad lanoshahay qoymiyadan	1-5 sano ☐ 6-10 sano ☐ 11-15 sano ☐ 15-20 sano ☐ 20 sano ☐ Kakore				

QAYBTA A: OGANSHAHA ISBEDALKA CIMILADA

1. Waliga miyaadd maqashahy Erayga Isbadalka cimilada ? Haa ☐ Maya ☐
2. Isbadal Nohee ayaad Kuuaragay Gabalka?

	Isbadalka %	**Dagmoyinka Qaska ah**
Rob oh kabadan intii lahali jiraay sanadki		
Rob kayar inti laheli jiraay sandki		
Miyay jiraan fatahdya oo mar mar ah sheg		
Yaransha oo imadka Fatahadyada		
Badnasha imashada Abaaraha		
Yaran oo imashada abaaraha		

3. Rerkayga waxaa samayay kuwaan ooh ah Dhacdo baan ee Cimilada (Sax mesha kuhaboon)

Dhacdo aad u daran	**Haa**	**Maya**
Daad		
Abaaraha		
Dabayl xoog badan (Duufaan)		

4. Cimilada helay kulul sanadihii la soo dhaafay. : a. Sii hog ah u Diiddan__ b. Diiddan ___ c. Raacsanayn____ d. Sii hog ah Raacsanayn ______ e. Magaranyo______
5. Roobabka ayaa waxay noqdeen kuwo aan la saadaalin karin (Waqtig Munsaba ah iyo Dah) sanadihii la soo dhaafay: a. Sii hog ah u Diiddan__ b. Diiddan ___ c. Raacsanayn____ d. Sii hog ah Raacsanayn ______ e. Magaranyo______
6. Cimilada sii saadaalin karin sannad ka sannad a. Sii hog ah u Diiddan__ b. Diiddan ___ c. Raacsanayn____ d. Sii hog ah Raacsanayn ______ e. Magaranyo______
7. Waa maxay isha ugu muhiimsan ee biyo qoyskaaga____
8. Waxaan ayaa igalumay xoolaha iyo dalagga inta lagu guda jiro sano ee la soo dhaafay sababtoo ah xaaladaha cimilada xun: a. Sii hog ah u Diiddan__ b. Diiddan ___ c. Raacsanayn____ d. Sii hog ah Raacsanayn ______ e. Magaranyo______
9. Meqaa boqolkiiba oh ah dalagyada / xoolaha ayad aminsantahay inay kudunta cimilada xun? (%) _________
10. Tayada goosashada / xoolaha ayaa sii xumaadaa kii sannadihii la soo dhaafay. a. Sii hog ah u Diiddan__ b. Diiddan ___ c. Raacsanayn____ d. Sii hog ah Raacsanayn ______ e. Magaranyo______
11. Waxaan ka iibin aan xoolaha / dalagyada 1. Gudaha____ 2. Caalami /Dhoofinta______ 3. Isticmaalka guriga oo kaliya ____

12. My income decreased due to the loss of crops/livestock resulting from bad weather conditions. Dakhliga hoos ayuu udahay sabab u ah luminta dalagga / xoolaha ka dhashay xaaladaha cimilada xun. a. Sii hog ah u Diiddan__ b. Diiddan ___ c. Raacsanayn____ d. Sii hog ah Raacsanayn ______ e. Magaranyo______
13. Waxaan u baahanahay in la raadiyo ilaha dakhli oo dheeraad ah si loo xaqiijiyo hab-nololeedka ee qoyskeyga Xoog. a. Sii hog ah u Diiddan__ b. Diiddan ___ c. Raacsanayn____ d. Sii hog ah Raacsanayn ______ e. Magaranyo______

QEYBTA B DEEGAANKA GUUD

Sida aad u aragta isbedel ee helidda deegaanka ku wareegsan meesha aad degan tahay ka badan tobankii sano ee la soo dhaafay (2005) iyo wixii ka dambeeyey	Isbadal malahan	Si wacaan	Ka xun	Magaranyo
tayada hawo (hawo nadiif ah , ciiryaamada , qayb , urta)				
Biyaha Cabitaanka tayada iyo helitaanka				
Tayada biyaha oogada iyo helitaanka (harooyinka , webiyada, balliyada				
Ground water availability(water hole)				
Dulka kufadiyo Dirtaa (Kaynta)				
Noocyada shimbiraha ee magaalada aad kunoshahay(Shimbirrood , Diiqu) iyo kuwa kale				
Noocyada xoolaha ee magaalada aad kunoshahay				
Qashinka iyo maareynta qashinka (ururinta qashinka , dhiigmiiradka ,iyo kuwa kale				

14. Ma taqaan sharciyada, dhaqanka ama haddii kale cinwaanka in walaac soo socda?

	Sharciyada Majiraan	Sharciyada way jiraann wana lamel mariyaa	Sharciyada way jiraann lakiin kumaa filnaa	Sharciyada way jiraann mana lamel mariyaa	Magaranayo
Wasakhda hawada					
Wasakhda Biyaha					
Helitaanka Biyaha					
Maareynta qashinka					
Ilalinta Dirtaa					

15. Fadlan sax hadalada raacsan tahay hoos
    a) Xukuumaddu waa in ay mudnaanta siiyaan horumarka ka badan ilaalinta deegaanka
    b) Xukuumaddu waa in ay mudnaanta siiyaan ilaalinta deegaanka ka badan horumark
    c) Ilaalinta deegaanka iyo horumarinta waa in ay tagaan gacanta ee gacanta
    d) Waxa muhiim ah in la horumariyo maanta iyo walaaca ku saabsan ilaalinta deegaanka ee mustaqbalka
16. Imisa jeer baad u qaataan soo socda ?

	Marna	Sanadki Halmar	Bishi Halmar	Bil kabadan halmar	Isbuh kabadan halmar
Visit a forest or adjoining area (not necessarily in your city) Booqo kaynta ama la jaarka ah meel (qasab maaha in magaalada aadahato)					
Talal geed					
Jaritanka Geed					

17. Adiga ra'yigada wamaxay qaar ka mid ah sababaha ay dadka gooyaa geedaha Jubbada Hoose?

	Haa	Maya
Waayo, shidaalka qoryo guriga (ama dhuxusha)		
Iibinta dhuxusha (degaanka)		
Waayo, dhoofinta dhuxusha		
Waayo, guryaha / magaalaynta		
Waayo, beeraha		
Sabab kale (fadlan qor) _______________________		

18. Goynta dhirta waa ok haddii ay keentaa faa'iido dhaqaalet: a. Sii hog ah u Diiddan__ b. Diiddan ___ c. Raacsanayn____ d. Sii hog ah Raacsanayn ______ e. Magaranyo______
19. Ma jiraan wax qalad ah waa haddii dhirtii oo dhammu ee aan bulshada waa la wada baabbi'iyey. a. Sii hog ah u Diiddan__ b. Diiddan ___ c. Raacsanayn____ d. Sii hog ah Raacsanayn ______ e. Magaranyo______
20. Waxaan samayn lahaa wax si ay u joojiyaan wax guba dhuxusha in aan bulshada: a. Sii hog ah u Diiddan__ b. Diiddan ___ c. Raacsanayn____ d. Sii hog ah Raacsanayn ______ e. Magaranyo______
21. Dhuxusha Iibinta waa hab muhiim ah oo ka taageeraya dhaqaalaha: a. Sii hog ah u Diiddan___ b. Diiddan ____ c. Raacsanayn____ d. Sii hog ah Raacsanayn ______ e. Magaranyo______
22. Goynta dhir Gubista dhuxushu khatar ah in mustaqbalka a. Sii hog ah u Diiddan__ b. Diiddan ___ c. Raacsanayn____ d. Sii hog ah Raacsanayn ______ e. Magaranyo______
23. Ilaalinta Kaydat ay muhiim u tahay mustaqbalka bulshada Sii hog ah u Diiddan____ Diiddan___ Raacsanayn ____ Sii hog ah raacsanayn ___ Magaranyo ____
24. Yaa door kuleh in la ilaaliyo kaynta? a.Dowladaa____ b. Oday Daqamayd_____ c. Bulshada____ d. Qof walbaa_____ e. Qofna_____ f. Magaranyo______

QAYBTA C TALLAABOOYIN LA QABSASHADA

25. Fadlan qor hawlaha / dhaqanka haddii kasta oo aad samayso si aad isugu diyaariso iyo qabsato daadadka____ ____
26. Fadlan qor hawlaha / dhaqanka haddii kasta oo aad sameyn si ay isugu diyaariyaan in ay u diyaar garoobaan oo la qabsato abaarta ____ ____
27. Dhaqan ahaan waxa aanu bulshada u sameeyaan marka abaaraha ka timid?____ ____
28. Dhaqan ahaan waxa aanu bulshada u sameeyaan marka daadad ka timid? ____ ____

ANNEX 3: Key Informant Interview

Area of Residence:

Occupation:

PART A: ASSESSMENT OF CLIMATE CHANGE

1. Has there been any observed change in climate in Jubbaland? _____________________________________ ____
2. Kindly describe the rainfall patterns in this area in the past 15-30yrs ___________________________ ____
3. Kindly describe the temperature patterns in this area in the past 15-30yrs ______________________ ____ ____
4. Is climate change a main objective of the government? ____ ____
5. What interventions has the government made in relation to climate change? ________________________

____
____

PART B: OVERALL ENVIRONMENT

6. How would you describe the state of the environment in Jubbaland last ten years (2005) onwards:

	No Change	Better	Worse	Don't Know
Air quality				
Drinking water quality and availability				
Surface water quality and availability				
Ground water availability				
Tree cover				
Number of birds and/or animal species				
Waste and waste management				

7. Are you aware of any government policies that address the following environmental concerns?

	No government policies exist	Policies exist and are well implemented	Policies exist, but are inadequate	Policies exist, but not implemented	I don't know
Air pollution					
Water pollution					
Water availability					
Waste management					
Forest conservation					

8. What part of Jubbaland has experienced the largest amount of environmental change over the last decade in Jubbaland (please list the king of observed change)? ______________________________
____

9. What would you attribute the change to? ____

____

10. What has the impact of the environmental change been to the local community? ______________

____

11. In your opinion what are some of the reasons people cut trees in Lower Jubba?

	Yes	No
For household wood fuel (or charcoal)		
For sale of charcoal (locally)		
For export of charcoal		
For housing/urbanization		
For agriculture		

Other reason (please list) ____

12. It has been reported in several news articles that ban on export of livestock triggered the increase in charcoal production, is this true, if not, what in your opinion triggered it? ___________________________
____
____
13. What in your opinion should take priority, development and economic needs or environmental protection?
____
____
14. In your opinion is there a need for government intervention in environmental protection in this area?
____
15. What are the priorities for environmental protection if any in this area? ____________________________
____

PART C: ADAPTATION MEASURES

16. What kind of adaptive capacity has been done for Jubbaland (e.g. research, mapping and modelling impacts and vulnerability, risk assessments, planning/strategy development, developing and participating in networks, awareness-raising, training) ____
____
17. What policies are in place in Jubbaland , including new/revised legislation, bills, acts of parliament etc.
____
____
18. What are the key information sources influencing the legislation for adaptation in Jubbaland ? _____
____
19. What are the traditional measures on adaption practiced by the local community? ______________
____
20. What challenges are faced by the community in Jubbaland in relation to climate adaptation? ______
____
21. The following table lists a number of potential adaptation measures. Please indicate (x) which of these are planned or have been implemented in your region as a response to climate change concerns.

PART D: Further information

22. The following table provides a decision framework on climate variability and climate change. Please indicate the type of climate information you use or would like to use for which type of decisions.

Type of decision	Climate		**Weather**
	Long term (10–50 years)	**Medium term (6–9 months)**	**Short term (0–10 days)**
	Decadal changes	**Seasonal Forecasts**	**Real time**
Strategy/policy			
Planning			
Operational			

23. Please indicate in the table below what your opinion is on the availability of information and tools for different climate related aspects as indicated above, if you would need guidance on these aspects, and if you are interested to assist in developing such tools?

Adaptation measure	**Implemented**	**Planned**	**Effective/-necessary (but not planned yet)**	**Not relevant/ necessary**
Flood protection				
Flood protection				
Natural retention of flood water (e.g. floodplain restoration, change of land use)				
Restriction of settlement/building development in risk areas				
Improving forecasting and information				
Improving insurance schemes against flood damage				
Others, please specify:				
Drought/low flow protection				
Increasing water supply				
Increasing efficiency of water use				
Restriction of water uses				
Improvement of water balance				
Improving forecasting, monitoring, information				
Improving insurance schemes against drought damage				
Others, please specify:				
General adaptation measures				
Policy – including new/revised legislation, bills, Acts of Parliament, etc.				
Economic incentives and financial mechanisms				
Awareness-raising or information campaigns				
Others, please				

Tools	**Availability of information or tools**	**Need for guidance (tools development)**	**Interested in helping to develop the tools**
Climate information			
Vulnerability assessments			
Adaptation process			
Development/climate-proofing			