HARAMAYA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

CLIMATE AND LAND USE /LAND COVER CHANGE AND THEIR INTERCONNECTIONS WITH LIVESTOCK FEED RESOURCE MANAGEMENT IN ETHIOPIA

PhD Dissertation

Aklilu Mekasha

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Haramaya, Ethiopia

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In Partial Fulfillment of the Requirements for the award of the Degree of

Doctor of Philosophy in Agronomy/physiology

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As member of the dissertation research advisory committee, we hereby certify that we have read and evaluated this dissertation prepared under our guidance, by Aklilu Mekasha entitled "**Climate and Land Use /Land Cover Change and Their Interconnections with Livestock Feed Resource Management in Ethiopia**" We recommend that it can be submitted as fulfilling the PhD dissertation requirement.

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DEDICATION

I dedicate this dissertation to my late mother Yeshi Gebreselassie and father priest Mekasha Gebremariam.

STATEMENT OF THE AUTHOR

I declare that this dissertation is the result of my own work and that all sources of materials used for writing it have been duly acknowledged. This dissertation has been submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy at Haramaya University and is deposited at the library of the university to be made available to borrowers under the rules and regulations of the library. I solemnly declare that this dissertation has not been submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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Place: Haramaya University Date of submission: February, 2014

ABBREVIATION AND ACRONYMS

AMCEN	African Ministerial Council on the Environment.
AU	African Union.
CCI	Climate Change Indices.
CLIVAR	Climate Variability and Predictability.
DEM	Digital Elevation Model.
ET	Expert Team.
ETCCDI	Expert Team on Climate Change Detection Indices.
ETM	Enhanced Thematic Mapper.
FEWS NET	Famine Early Warning Systems Network.
GDP	Gross Domestic Product.
GIS	Geographic Information System.
GLM	General Linear Model.
IIA	Independence of Irrelevant Alternatives.
ILRI	International Livestock Research Institute.
IPCC	Intergovernmental Panel on Climate Change.
JOCMM	Commission for Oceanography and Marine Meteorology.
LULC	Land Use Land Cover.
LULCC	Land Use Land Cover Change.
MNL	Multinomial Logit Model.
MSS	Multispectral Scanner.
NMA	National Meteorological Agency of Ethiopia.
OLS	Ordinary Least Square.
SESRTCIC	Social, Economic and Social Research and Training for Islamic Countries.
SNNPR	Southern Nation Nationalities and Peoples Region.
SPSS	Statistical Package for Social Sciences.
SSA	Sub-Saharan Africa.
TLU	Tropical Livestock Unit.
TM	Thematic Mapper.

BIOGRAPHICAL SCETCH

The author was born on 26 May 1973 in Ethiopian highlands (around Bekoji town, Arsi Zone in Oromia National Regional State). He passed high school from Bekoji Senior Secondary School. He obtained a diploma as an intermediate Agricultural Extension Agent in Animal Production and Rangeland Management from Addis Ababa University Awassa College of Agriculture in 1993 and served in his capacity as development agent, supervisor and expert in Ministry of Agriculture at Konso Special District for over two years.

He then obtained BSc degree in Animal Production and Rangeland Management from the then Awasa College of Agriculture now Hawasa University in 1999 and joined the Ethiopian Institute of Agricultural Research (EIAR) at Melkassa Agricultural Research Center (MARC).

Thereafter, he left to pursue his MSc degree in Agronomy/physiology at the Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, India. After completion of MSc in 2005, he returned to EIAR at MARC and continued to serve as research staff until he left to pursue his PhD study at Haramaya University, Ethiopia.

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ABSTRACT

Climate extreme trends and land use/land cover changes were evaluated for their interconnections with feed resources availability and management in a case study in Ethiopia. A 42 years (1967-2008) annual trend was computed for 20 rainfall and temperature extreme indices/indicators at 11 stations located across three major eco-environments. Households' perceptions were also surveyed across eco-environments and seasons and compared with the recorded trends at nearby stations for selected rainfall and temperature extreme indices/indicators, and determinants of the perceptions were identified. Land use/land cover changes were analyzed from remotely sensed satellite images at districts located over the three eco-environments and compared with households' perception on relative contribution of different feed resources and feed deficit management strategies available to households over the last 30-40 years. Current altitudinal range and habitat area was surveyed for 67 herbaceous grassland species along altitudinal gradients (1342 m asl- 3410 m asl) and future distributions were predicted under no-migration and with migration scenarios to 4.2^{o}C increase of temperature by 2090. Most of the temperature and rainfall extreme indices did not show significant trends at many stations and the significant trends were not uniquely differentiated by eco-environment. However, more than 8 of the 11 stations showed positive trends for maximum value of the maximum temperature (TXx), warm days (TX90p), warm nights (TN90p) and warm spell duration indicators (WSDI) and negative trends for cool days (TX10p), cool nights (TN10p) and cold spell duration (CSDI) indicators. Precipitation extreme trends showed high variability among nearby stations within eco-environments and were not significant at many of the stations studied. The majority of households (52.5-98.8%) across the three eco-environments perceived increasing number of extreme warm days and warm nights and decreasing number of extreme cool days and cool nights for all seasons. In most cases, households' perceptions agreed with the recorded extreme temperature trends. The perceptions on seasonal total rainfall and daily rainfall intensity, however, varied across seasons and eco-environments, but agreed with recoded trends in the pastoral eco-environment in all seasons. Households' perceptions of the studied extreme events were significantly affected by literacy, eco-environment, agricultural extension service, and relief aid. Land use/land cover change is occurring across all eco-environments. Areas of grasslands are decreasing while that of cropland is increasing across all study sites. The contributions of feeds of grazing resources are decreasing while feeds of non-grazing resources such as crop residues, agro-industrial by-products and other feeds from crop lands are increasing across all study sites. Similarly the feed deficit management strategies of households are also changing significantly from mobility to herd management and feed conservation in the pastoral areas; from mobility to feed conservation and purchasing of feed in the agro-pastoral areas and from transhumance to feed conservation and purchase of feed in the mixed crop-livestock highland areas. All the studied grassland herbaceous species faced range contraction and habitat loss with range shift gaps among forty two species under the no-migration scenario. With the migration scenario, however, the forty two species with range shift gaps are predicted to benefit from at least some habitat area retention. Between growth forms, legumes are predicted to lose significantly more habitat area than grasses under the no-migration scenario while no significant difference in habitat area loss is predicted under the migration scenario. Thus the results indicated that availability and use of different feed resource and the management strategies followed are changing being at a cross roads of warming planet and changing land use/land cover across all eco-environments. There is a need for integrated research and policy interventions for eco-environment/ site specific feed resources development and management strategies that on one hand ensures sustainable availability of feeds both in quality and quantity, and conserve biodiversity of grasslands under warming climate and changing land use/ land cover.

Key words: Climate extremes trend; Feed deficit, Feed resource; herbaceous grassland species; Household perception.

1. GENERAL INTRODUCTION

1.1. Background

The Sub-Saharan Africa (SSA) region where Ethiopia is located covers over 2 billion hectares of land and is home to about 920 million people (FAO, 2013). Seventy one percent of the population is living in rural areas―higher than the world average 51% (FAO, 2013). Agriculture is the mainstay of the economy accounting for 20% of GDP and 60-90% of the total labor force (UN and AU, 2008).

The region has very diverse climatic and land use /land cover conditions ranging from arid deserts in the Sahel, to semiarid lowlands of eastern Africa, and the rainy humid and sub humid tropical conditions in the central and western Africa (Dixon *et al.*, 2001). The arid and semi-arid eco-environmental zones[1] make up 43% of the land area while the dry sub-humid zone account for 13% and the moist sub-humid and humid zones jointly together accounts for 38 % of the total land cover (Hazell and Diao, 2005). The annual precipitation in SSA is estimated at an average of 815 mm with a wide range of variation. The variation ranges from less than 100 mm in Sahel to above 1200 mm in Ethiopia and more than 2000 mm in coastal areas and some islands. The Central African sub-region usually receives the highest amount (40%) of the total precipitation while the Sudano-Sahelian sub-region the least amount (14%) (FAO, 2012).

In recent decades the human population of the region has increased considerably from 236 million in 1961 to 920 million in 2013 (FAO, 2013) triggering diversification of agricultural activities in order to meet the demands for food and welfare (Rosenzweig *et al.*, 2007). As a result considerable land use/ land cover change has occurred over the past decades. Agricultural lands have expanded from 958 million ha in 1961 to 1.1 billion ha in 2011, and considerable areas of grazing and forest lands have been converted to arable land, urban and rural settlements,

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[1] Eco-environment is defined as a spatially and functionally coherent unit of environment, and includes the living and nonliving components involved in a given environment as well as their interactions. Note the word "eco-environment" is used in this dissertation to describe inter connection or interactions among different components of the study environments over the classical "agro-ecology" which is limited in use to agriculture.

industrial and infrastructural development (FAO, 2013). Greenhouse gas such as CO_2, CH_4 and NO_2 emissions from agriculture have also increased considerably from 350, 201 and 148 million CO_2 equivalent gigagrams in 1990 to 533, 308 and 255 million CO_2 equivalent gigagrams, respectively in 2010 in the region (FAO, 2013), The land use/land cover transitions however, varied with region and localities. For example over the last three to four decades, large areas of water, forest and woodlands have been converted to intensive cultivation, mixed cultivation, degraded land and marshy areas in Ethiopian Rift Valley (Garedew *et al*., 2009, Meshesh *et al.*, 2012; Biazin and Sterk, 2013) while more areas of woodland and grasslands have gone to bush land and cultivated lands over the same period in Northern and Southern Ethiopia (Mesele *et al*., 2006; Tsegaye *et al*., 2010).

Over the last 50 years the SSA region experienced rapid increase in livestock population from 108 million TLU to 274 million TLU in 2011 (FAO, 2013). The production system has largely been based on traditional herding where animals range over extensive grazing lands with little or no supplementation. The bulk of feed for this barging animal population is obtained from grasslands, bush/scrublands and croplands (Ibrahim, 1999; Mengistu, 2005). However, the performance of the livestock sector and agriculture in general is low. More than 40% of the region's population is living below the poverty line with per capita incomes of less than US$1.25 per day (UN, 2010). Most SSA countries have struggled to eradicate extreme poverty and hunger (SESRTCIC, 2007). Of even more concern is that Sub-Saharan Africa is the only region in the world where the number of people facing poverty is still increasing and per capita food production is declining (Adesina, 2007). In the last three decades, undernourishment has increased significantly from over 200 million people in the mid-1990s to about 325 million people in 2000 (Hazell and Diao, 2005; Smith, 2007).

Without making a substantial contribution to global greenhouse gas emissions (only about 3.8 %), the SSA region and Africa as a whole has become a victim of global climate change (UN and AU, 2008). Although regional reports are variable (AMCEN, 2011), the temperature has increased by $0.7^{o}C$ over the last century and is projected to continue to increase in future by 1.5 to 3°C by 2050 and beyond (IPCC, 2001). These adverse climatic trends and the rain-dependent economic structures that underpin the economy make the region vulnerable to cycles of drought and flood (UN and AU, 2008). Since 1951, Sub-Saharan Africa has been the global region worst affected by increasing frequency, severity and duration of drought (Spinoni *et al*., 2013). For instance, the droughts of 1968-1971 in the Sahel, Ethiopia, Sudan, and Somalia, and the droughts of 1982-1985 and 1990 in both the Sahel and southern Africa, caused severe shocks (Jayne *et al.*, 2005). In Ethiopia alone, between 1999 and 2004, 46.8% of the households experienced drought shocks (Ruben, 2005) and at least two-thirds of the small farm population was under difficult circumstances (Jayne *et al.,* 2005).

In an attempt to overcome the issue of food security amidst rapid population growth, agricultural activities has expanded including into fragile arid and semiarid areas once exclusively used for extensive livestock production (Garedew *et al*., 2009; Tsegaye *et al.*, 2010). This in turn has resulted in scarcity of grazing resources and shortages of feed (Benin et al., 2002; Sarwar *et al*., 2002; TECHNIPLAN, 2004; Berhe *et al.*, 2013) prompting the herding and farming households to look for alternative non-conventional feeds and feed deficit management strategies (Benin *et al*., 2002).

Such major impacts are partly the outcome of changes in climate extremes in conjunction with land use/land cover change. Climate change and climate variability are global issues (IPCC, 2001). The degree of impact, however, varies from region to region and sector to sector depending on the extent of exposure, sensitivity and coping capacity of the system. An understanding of how climate extremes and land use/land cover are changing globally, regionally, and locally is thus imperative for planning appropriate adaptation measures (Aguilar *et al.,* 2009). Aggregations of information at global and regional levels, however, usually under estimate the impact on the most vulnerable communities and sectors. Hence, it is important for the region in general and the country in particular to derive information on effects of change drivers disaggregating to specific site and at household level which is the subject of this study.

1.2. Motivation/ Rationale

In spite of the complex interplay of climate and land use/land cover, our understanding of the effect of climate change and land use/land cover change on feed resources is very limited in Ethiopia and the SSA region in general. To date considerable endeavors have been made at quantifying some of the agricultural impacts of climate change including mapping of “hot spot” areas (Thornton *et al.*, 2006; 2007), but most were carried out at low spatial resolutions (Parrya *et al.*, 2004; Thornton *et al.*, 2007) with a focus on the length of growing period. Such information is of limited importance for drawing generalizations for a region like sub-Saharan Africa in general and Ethiopia in particular where topographic and resource endowment heterogeneities are high (FEWS NET, 2003; Bewket and Conway, 2007). There is a need for high resolution information at local level.

Several studies (Osman and Sauerbon, 2002; Tadesse and Dagnachew, 2006; Cheung *et al*., 2008; Doherty *et al*., 2009; Bewket, 2009; Aguilar *et al.*, 2009; GebreMichael and Kifle, 2009; Makokha and Shisanya, 2010; Williams and Funk, 2011; Ayalew *et al.*, 2012) attempted to assess changes in rainfall and temperatures but analyses were often limited to showing trends of total annual rainfall and mean annual temperatures were generally crude. Important parameters such as frequency of occurrence of extreme temperature and precipitation events that have significant direct and indirect effects on the biophysical environment including feed resources have not been addressed adequately (New et al., 2006; Kruger and Shongwe, 2004; Kruger and Sekele, 2013). As a result there is a large spatio-temporal information gap on these and other important climate parameters which hampers design of climate-resilient polices and implementation of development strategies.

Dozens of studies have also attempted to investigate trajectories of land use/land cover transitions in the country and the SSA region as a whole. Many of these studies, however, focused on analysis of drivers of the changes (Reid *et al*., 2000; Amsalu *et al.*, 2007; Tsegaye *et al*., 2010; Meshesha *et al*., 2012; Biazin and Sterk, 2013), and only a few studies have dealt with consequences (Reid *et al*., 2000; Meshesha *et al*., 2012) and none have dealt with land use/land cover change and its effect on availability and management of livestock feed resources.

Through time, farmers and pastoralists of the region have accumulated a wealth of traditional knowledge on local climate and land cover to which they responded with innovative practices of managing feed resources that sustained livelihoods under variable conditions (GebreMichael and Kifle, 2009). The capacity of these practices to deal with change is now being surpassed and livelihoods are being threatened. The shift from communal grazing and fallow land-grazing to on-farm production and increasing use of by-products of low quality (in crop–livestock systems) has proceeded in parallel with changes in land use/land cover and climate. However, information is lacking on households perception of climate extremes trend, determinants of the perception and the changes in relative contribution of the different management options

It has also been well understood that the conversion of grasslands and forest areas into crop lands and lands of other use is causing habitat fragmentation and loss of niche for many of the important grassland species (Klein *et al*., 2007). Many studies have also shown that global warming is a threat to plant species distribution. Under warming climate species are expected to shift habitat area polward along latitude or upward along altitudinal gradients to allow survival in optimum thermal zones (Colwell *et al*., 2008; Kreyling *et al.*, 2010; Laurance *et al*., 2011; McCain and Colwell, 2011; Sheldon *et al*., 2011). Nevertheless, information is lacking on potential response of the important grassland species of the tropical environment in the country and the SSA region in general where land use/land cover change and the attendant habitat fragmentation is a barrier to species redistribution. Hence there is a wide knowledge gap to be filled particularly in the areas of feed resource dynamics and household reactions to cope with the changes under the changing climate and land use/land cover.

1.3. Research question

This dissertation using empirical evidences assesses the extent to which climate change and land use/land cover change intersect with livestock feed production and management over the different eco-environments by addressing the following research questions.

- Is there any historical trend in temperature and precipitation extremes? Can the trends be uniquely differentiated by eco-environment?
- What do households perceive about climate extreme trends? What are the factors that explain these perceptions?
- What was/is the land use/land cover classes 30-40 years ago and at present? What feed resources and feed deficit management strategies were/are available to households 30-40

years ago and at present? Which land use/land cover classes, feed resource and feed deficit management strategies have been changing?

- How herbaceous grassland species of feed importance are distributed along altitudinal gradients in terms of altitudinal range and habitat area? What will be the consequence of global warming on species distribution where land fragmentation is an impediment?

1.4. Objectives of the study

The general objective of the study was to generate information on temporal and spatial trends, and interconnections among climate, land use/land cover and livestock feed resource availability and management in a case study over three eco-environments of Ethiopia and thereby develop recommendations, which can lead to informed resource management, conservation and adaptation to climate change. The specific objectives were to:

a, characterize the nature of past temperature and precipitation extreme trends based on historical daily weather data from selected stations.
b, assess households' perceptions on temperature and precipitation extreme trends, compare with records and identify determinants of their perceptions.
c, assess land use / land cover change from remotely sensed satellite imagery and assess how this is related to feed resource dynamics from households' perceptions.
d, assess potential response of herbaceous grassland species to climate change under different land use scenarios.

1.5. Organization of the dissertation

The dissertation has been organized into six chapters. Chapter One addresses the general background, motivation/rationale, objectives and organization of the dissertation. Chapters Two to Five present individual papers with abstract, background, methodology, results, discussion and conclusions. Chapter Six gives a summary of the main findings of the work and draws conclusions and recommendations. Chapters 2, 4 and 5 are based on published article (bibliographic details in Appendix 8.3).

2. TRENDS IN DAILY OBSERVED TEMPERATURE AND PRECIPITATION EXTREMES OVER THREE ETHIOPIAN ECO-ENVIRONMENTS

(Published in International Journal of Climatology)

Abstract

Ethiopia has wide eco-environmental diversity ranging from extreme heat at one of the lowest places in the world to one of the coolest summits in Africa. Associated with this environmental diversity and climate change, climatic extremes are expected to change over time and also vary across eco-environments in the country. This study was conducted to examine the trends of past precipitation and temperature extremes over three eco-environments in Ethiopia. The study involved analysis of 20 extreme indices computed from daily temperature and precipitation data spanning over 42 years (1967 - 2008). The climate data were obtained from 11 stations selected from three major eco-environments (pastoral, agro-pastoral and highland). The results indicated positive trends for maximum value of the maximum temperature (TXx), warm days (TX90p), warm nights (TN90p) and warm spell duration indicators (WSDI) and negative trends for cool days (TX10p), cool nights (TN10p) and cold spell duration (CSDI) indicators in more than 8 of the 11 stations studied. However, most of the trends were not significant at many of the stations and the significant trends were not uniquely differentiated by eco-environments. Unlike temperature extremes, precipitation extreme trends showed high variability among nearby stations within eco-environments and were not significant at many of the stations studied. It is concluded that trends of temperature and precipitation extremes vary considerably among stations located within a given eco-environment indicating that the response of local climate to global warming could be different in physiographically diverse regions.

Key words: Climate change; Climate extremes; Eco-environment; Precipitation; Temperature; Trend

2.1.Introduction

Ethiopia is located in a tropical region where temperature differences are strongly modulated by elevation (Kreyling *et al.*, 2010). It has unusual eco-environmental settings ranging from extreme heat at one of the lowest places in the world (Dallol) to one of the coolest summits in Africa (Mt. Ras Dashan). The lowlands, below 1500 meters above sea level, constitute about 61% of the total land mass of the country and are generally warmer and drier than the highlands and mountains (McSweeney *et al.,*2010). The warm and drier lowlands, particularly extensive in the south east, eastern and north eastern parts of the country, are inherently areas of low and erratic precipitation not suitable for reliable crop production and are used for extensive pastoral livestock production (Coppock, 1994). The cool and moist highland plateau and mountains, on the other hand, are under extensive crop production. In between the two systems, there are transitional areas that share the properties of both. These are referred to as agro-pastoral systems and are characterized by a livestock-dominated crop production system. Agro-pastoralism is common particularly in the great East African Rift Valley region of the country. These varied eco-environmental settings in Ethiopia offer unique opportunities to study climate change in the tropics.

As in other parts of Africa and the rest of the world, studies on Ethiopia's climate have shown changes in temperature and precipitation trends during recent decades (Osman and Sauerbon, 2002; Seleshi and Zanke, 2004; Cheung *et al*., 2008; Doherty *et al*., 2009). Though the magnitude and trends of change reported vary with reports and locations, time series analysis of mean national maximum and minimum temperatures have shown positive trends (NMA, 2001; Belliethathan *et al.,* 2009; GebreMichael and Kifle, 2009). The observed warming is accompanied by a steady decline in precipitation in many parts of the country (Osman and Sauerbon, 2002; Genet and Alem, 2006; Abebe *et al.,* 2006; Tadesse and Dagnachew, 2006; Williams and Funk, 2011) although increases have been reported in some areas (NMA, 2001; Meze-Hausken, 2004) and no changes detected in others (Seleshi and Zanke, 2004; Rosell and Holmer, 2007). Associated with these long term changes in mean temperature and precipitation patterns (NMA, 2001; Osman and Sauerbon, 2002; Seleshi and Zanke, 2004; Lemi, 2005), changes in climatic extremes have been observed (Seleshi and Demaree, 1995; Funk *et al.*, 2005;

Seleshi and Camberlin, 2006; Bewket and Conway, 2007; McSweeney *et al*., 2010; Shang *et al.*, 2010). Climatic extreme events such as drought, flood and hail often have more significant negative effects on the biophysical environment than the long-term mean changes in temperature and precipitation alone (Weber *et al*., 1994; Meehl *et al*., 2000; Salinger and Griffiths, 2001; Vincent and Mekis, 2006, Zhou *et al*., 2009).

On the other hand, the occurrence of most climatic extremes is rare and change detection can be problematic. The development of various indices - absolute and percentile-that can be described by computational statistics and software packages available since the late 1990s, has made the monthly, seasonal and annual temperature and precipitation extremes easily measurable from daily temperature and precipitation data records (Bonsal *et al.*, 2001). As a result, during the last ten to fifteen years several extreme temperature and precipitation indices have been computed around the world from daily temperature and precipitation data (Manson, 1999; Zhai *et.al*, 1999; Haylock and Nichlls, 2000; Bonsal *et al.*, 2001; Zhang *et al.*, 2001; Suppiah *et al.*, 2001; Osborn and Hulme, 2002; Tank and Konnen, 2003; Liu *et al.*, 2005; Vincent and Mekis, 2006; Nandintsetseg *et al*., 2007; Soltani and Soltani, 2008; Pal and Al-Tabbaa, 2009; Rahimzadeh *et al.*, 2009; Kruger and Sekele, 2013).

Existing reports on extremes for Ethiopia indicate declining trends in frequency of heavy rains (Easterling, *et al*., 2000, Endalew, 2007), increase in frequency of dry extremes (Endalew, 2007) and increases in the number of warm days and nights (McSweeney *et al*., 2010). Despite this, information available so far is limited in scope, fragmented in coverage and does not give a full picture of the diverse topography, relief features, and eco-environments of the country (Bewket and Conway, 2007; McSweeney *et al*., 2010). Hence to fill this information gap the current paper reports an assessment of trends in temperature and precipitation extremes using observed climate data from stations located in three major eco-environments of the country.

2.2. Materials and Methods

2.2.1. Description of the study areas

Eleven weather stations were selected for the study from three major eco-environments in Ethiopia. The study area comprises the Rift Valley, the southern rangelands and the eastern highlands falling in elevation ranges designated the lowland ‘Kola’ (less than 1500 m asl), midland ‘ Weina Dega’ (1501-2000 m asl) and highland ‘Dga’ (greater than 2001 m asl) (Fig 1). The three major eco-environments represented by these altitudinal ranges are the pastoral, agro-pastoral and highland eco-environments. The pastoral eco-environment constitutes a significant proportion of the low-lying areas of four states, namely Oromia, Afar, Somali Region and the Southern Nations Nationalities and Peoples Region (SNNPR) regional governments of the Federal Democratic Republic of Ethiopia (Figure 2.1).

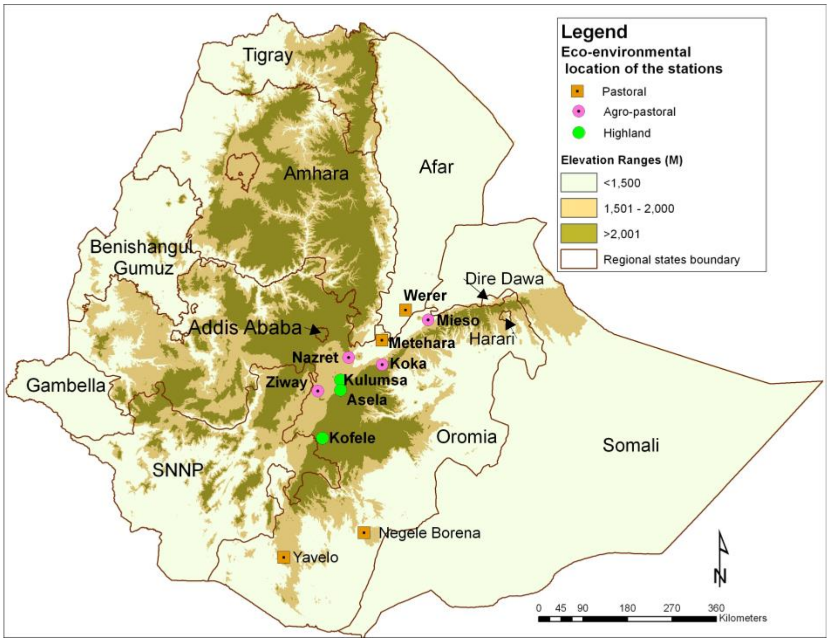

Figure 2.1. Map of Ethiopia showing geographic location of the study stations and eco-environments.

The pastoral eco-environment is not suitable for rainfed crop production unless supplemented with irrigation (Coppock, 1994; Abebe, 2000; Desta, 2000). The highlands - dissected by the great Rift Valley into western and eastern highlands - constitute the central part of the country where precipitation is sufficient both in amount and distribution for good crop production. Thus the major land use in the highlands is extensive smallholder crop production (Gebru, 2001). The agro-pastoral eco-environment is intermediate between the more livestock-based pastoral and the crop-dominated highland systems. It is fairly widely distributed in a number of Ethiopia's regional states without having the clear spatial coherence and boundaries characterizing the pastoral and highland eco-environments. The agro-pastoral eco-environment is particularly dominant in the central areas of the great east African Rift Valley part of the country.

2.2.2. Data source and station selection

Although there are over a thousand meteorological stations in the country, their spatial distribution over the different eco-environments varies greatly from less than a few kilometers between two stations in some parts of the highlands to hundreds of kilometers between stations in pastoral eco-environments. Initially, daily precipitation, maximum and minimum temperature records as long as the stations' history were sourced from the National Meteorological Agency of Ethiopia for 20 stations in the pastoral, 18 in the agro-pastoral and 27 in the highland environments. Unfortunately, most of the stations in all the three eco-environments have records only over a short period or have major discontinuities. Stations for final study were selected based on representativeness within a given eco-environment, length of record period, and the lowest proportion of missing data. In station selection, previous studies considered stations with less than four (Haylock *et al.,* 2006) to 30 percent (Peralta-Hernandez, 2009) missing days. For this study stations with more than 25% missing days for the entire duration of the study period were discarded. Accordingly we found 11 stations (listed in Table 2.1), four of which represent the pastoral eco-environment, four the agro-pastoral and the remaining three the highland eco-environments. Elevation wise three of the 11 stations are in the lowland 'Kola', five in the midland 'Weina Dega' and the other three in the highland 'Dega' ranges. Geographically six of the 11 stations are located in the Rift Valley, two in the southern rangelands and the remaining three in the eastern highlands of the country (Figure 2.1). The 11 selected stations have been functional for varying durations with start years ranging from 1941-1970 with large discontinuities in their early years of establishment mostly before 1967. To minimize the number of missing data points, records before 1967 were disregarded uniformly from the analysis.

Table 2.1. Description of selected stations.

No	Station	Geographical coordinates		Elevation (m)	Period (years)
		Latitude (N)	Longitude (E)		
1	Werer	9°25’	40°20’	740	1967-2008
2	Metehara	8°52’	39°54’	930	1967-2008
3	Mieso	9°14’	40°45’	1400	1967-2008
4	Negele-Borana	5°20’	39°34’	1544	1967-2008
5	Koka	8°25’	39°54’	1595	1967-2008
6	Nazret	8°33’	39°17’	1622	1967-2008
7	Ziway	7°56’	38°43’	1640	1970-2008
8	Yavelo	4°53’	38°06’	1740	1967-2008
9	Kulumsa	8°08’	39°08’	2200	1967-2008
10	Asela	7°57’	39°08’	2350	1967-2008
11	Kofele	7°04’	38°48’	2620	1967-2008

2.2.3. Data quality control

For quality control, the data of the 11 stations were plotted against time in days of the year format and subjected to visual examination for the presence of discontinuities and special codes for missing values. Special codes were removed, typing errors such as Tmin greater than Tmax , duplicated years and outliers defined as values above or below the mean plus or minus 4 times the standard deviation (Albert *et al.,* 2009) were treated case by case using information from the day before and after the event and also by reference to nearby stations. Duplicates were removed and those identified as due to keying errors were corrected and missing values filled by *artefact* data generated using ClimGen (http:/www.sipeaa.it/ASP/ASP2/ClimGen.asp).

2.2.4. Defining the extreme parameters

A wet day in this study is a day with precipitation greater than 1mm. This was to avoid artificial trends due to sensitivity of lower thresholds to changes in units and underreporting of small precipitation events due to higher thresholds (Haylock *et al.,* 2006; Manton *et al., 2001* and Wijngaard *et al.,* 2003). The temperature and precipitation extreme indices were computed for the period 1967-2008 for ten stations while data from 1970-2008 were used for the remaining station (Table 2.1). The period from 1971-2000 was used as the base period. Definitions of indices were taken from ETCCDI (http://cccma.seos.uvic.ca/ETCCDI) (Tables 2.2 and 2.3).

Table 2.2. Extreme temperature indices selected for the study and their definition.

No	Index	Definition of the index	Unit
1	TXx	Max Tmax: Monthly maximum value of daily maximum temperature	°C
2	TXn	Min Tmax: Monthly minimum value of daily maximum temperature	°C
3	TNx	Max Tmin: Monthly maximum value of daily minimum temperature	°C
4	TNn	Min Tmin: Monthly minimum value of daily minimum temperature	°C
5	TN10p	Cool nights: Percentage of days when TN <10th percentile of base period	Days
6	TX10p	Cool days: Percentage of days when TX <10th percentile of base period	Days
7	TN90p	Warm nights: Percentage of days when TN >90th percentile of base period	Days
8	TX90p	Warm days: Percentage of days when TX >90th percentile of base period	Days
9	WSDI	Warm spell duration indicator: Annual count of days with at least 6 consecutive days when TX >90th percentile of base period	Days
10	CSDI	Cold spell duration indicator: Annual count of days with at least 6 consecutive days when TN<10th percentile of base period	Days
11	DTR	Diurnal temperature range: Monthly mean difference between TX and TN	°C

2.2.5. Trend analysis

The data of the selected 11 stations was subjected to trend analysis using the RClimDex package of the open source R software (R Development Core Team, 2012) widely used for trend analysis (Vincent *et al.,* 2005; Haylock *et al*., 2006; New *et al*., 2006; Pal and Al-Tabbaa, 2009; Rahimzadeh *et al*., 2009; Kruger and Sekele, 2013). A linear trend was fitted using Kendal's *tau* and the slope of the line, as an indicator of the rate of change, was computed using the Sen's slope estimator. Rates of changes were assumed to be significant at the 5% probability level.

Table 2.3. Extreme precipitation indices selected for the study and their definition.

No	Index	Definition of the index	Unit
1	Rx1DAY	Max 1-day precipitation: Monthly maximum 1 day precipitation	mm
2	Rx5DAY	Max 5-day precipitation: Monthly maximum consecutive 5 days precipitation	mm
3	SDII	Simple daily intensity index: Annual total precipitation on wet days divided by number of days with precipitation ≥1 mm	mm/day
4	R10mm	Heavy precipitation days: Number of days with precipitation ≥10 mm in a year	Days
5	R25mm	Very heavy precipitation days: number of days with precipitation ≥25 mm in a year	Days
6	CDD	Consecutive dry days: Maximum number of consecutive days with precipitation <1 mm in a year	Days
7	CWD	Consecutive wet days: Maximum number of consecutive days with precipitation > 1mm in a year	Days
8	R95p	Very wet days: Fraction of annual total precipitation exceeding the base period 95th percentile	%
9	R99p	Extremely wet days: Fraction of annual total precipitation exceeding the base period 99th percentile	%

2.3. Results

2.3.1. Trends in temperature extremes

2.3.1.1. Max Tmax (TXx) and min Tmax (TXn)

With respect to TXx, significant increasing trends were observed at Werer, Ziway, Nazret and Asela, whereas a significant decreasing trend was observed only at Mieso (Figure 2.2a). On the other hand, trends of TXx were not significant at Metehara, Negele-Borana, Koka, Yavelo, Kulumsa and Kofele stations. Except a decreasing trend at Werer, the TXn values were not significantly changing over time at almost all the stations (Figure 2.2b).

2.3.1.2. Min Tmin (TNn) and Max Tmin (TNx)

A significant increasing trend in TNn was observed at one station in the pastoral eco-environment (Negele-Borana) and at another station in the highland eco-environment (Asela), whereas trends were not significant at the remaining nine stations (Figure 2.2c).

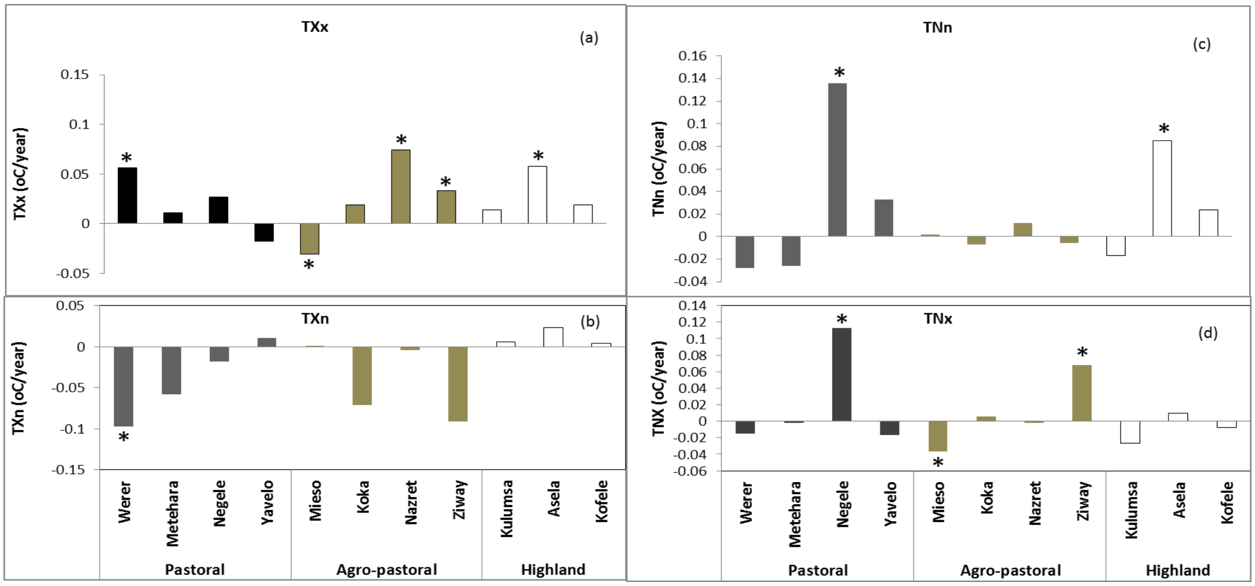

Figure 2.2. Annual trends in TXx (°C/year), TXn (°C/year), TNx (°C/year) and TNn (°C/year) for the 1967-2008 period at different stations over the pastoral, agro-pastoral and highland eco-environments of Ethiopia. The star (*) on bar graph represents significant trends at p <5% probability level.

This indicated that TNn is not significantly changing at many of the stations, particularly at all stations in the agro-pastoral eco-environment. Although 7 out of the 11 stations tend to show a negative TNx trend, only one station (Mieso) had a significant decreasing trend, whereas two stations (Negle-Borana and Ziway) had a significant increasing trend in TNx (Figure 2.2d).

2.3.1.3. Diurnal temperature range (DTR)

Trends in DTR are not significant at 9 of the 11 stations (Figure 2.3) indicating that daily maximum and minimum temperatures are not changing in opposite direction at many of the stations studied. Only Negele-Borena and Kulumsa stations showed significant decreasing and increasing trends in DTR, respectively.

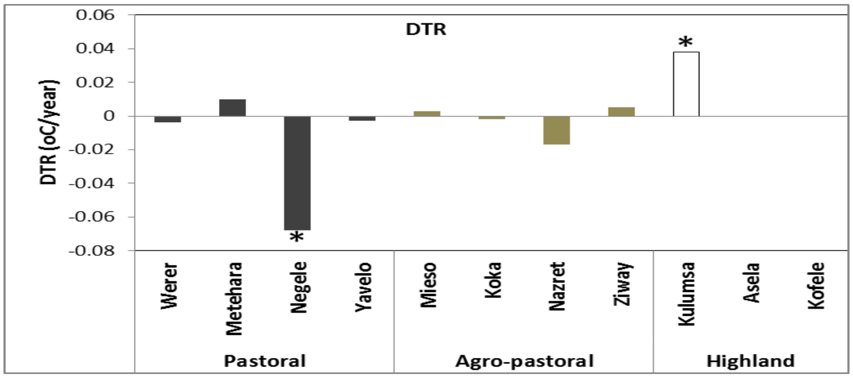

Figure 2.3. Annual trends in DTR (°C/year) for the 1967-2008 period at different stations over the pastoral, agro-pastoral and highland eco-environments of Ethiopia. The star (*) on bar graph represents significant trends at p <5% probability level.

2.3.1.4. Warm days (TX90p) and warm nights (TN90p)

Although a tendency of increasing trends in TX90p was observed at 8 of the 11 stations, the trends were significant at only four of the stations (Metehara, Negele-Borana, Ziway and Asela) which represent three different eco-environments (Figure 2.4a). Mieso, Kulumsa and Kofele stations showed decreasing but non-significant trends in TX90p. Similar to the case in TX90p, nine of the eleven stations showed increasing trends in TN90p, but trends were significant at only four (Metehara, Negele-Borana, Yavelo and Asela) of the nine stations (Figure 2.4b). On the other hand, Koka and Kofele stations had a negative but non-significant tends in TN90p.

2.3.1.5. Cool days (TX10p) and cool nights (TN10p)

The TX10p showed significant decreasing trends at Negele-Borana, Mieso, Kulumsa and Asela stations and a non-significant negative trend at Werer, Metehara, Koka, Nazret, Ziway, Yavelo and Kofele (Figure 2.4(c). Two stations in the agro-pastoral eco-environment (Koka and Nazret) had positive but non-significant trends in TX10p. Although 10 of the 11 stations had negative trends in TN10p, the trends were significant only at Asela, Negele-Borana, Mieso and Yavelo stations (Figure 2.4d). Kulumsa is the only station where a significant increasing trend in TN10p was observed.

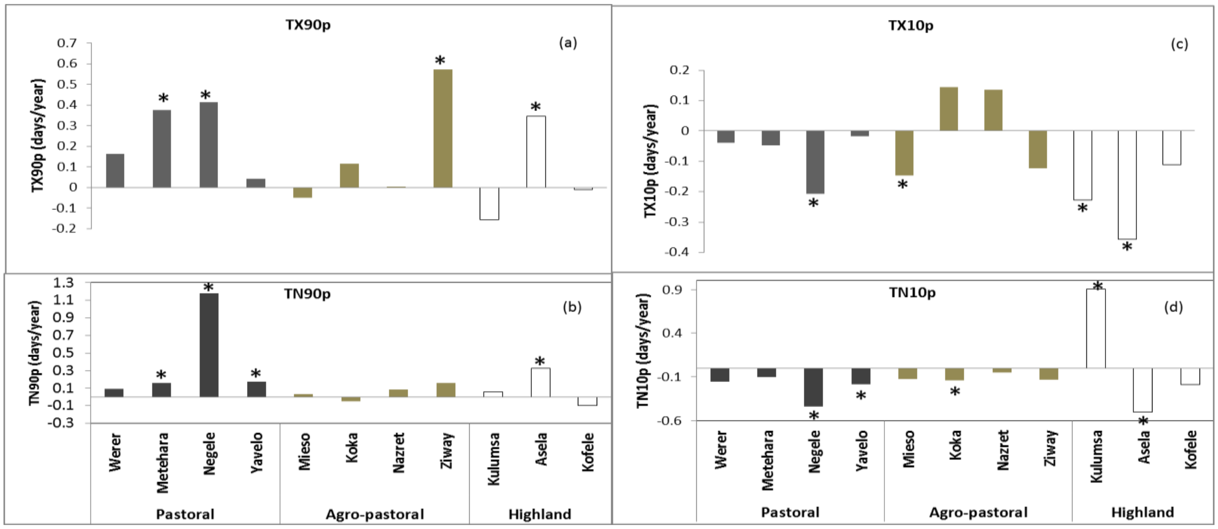

Figure 2.4. Annual trends in TX90p, TN90p (days/year), TX10p (days/year) and TN10p (days/year) for the 1967-2008 period at different stations over the pastoral, agro-pastoral and highland eco-environments of Ethiopia. The star (*) on bar graph represents significant trends at p <5% probability level.

2.3.1.6. Warm spell duration indicator (WSDI) and cold spell duration indicator (CSDI)

Among seven of the 11 stations that showed increasing trends in WSDI, only three (Metehara, Negele-Borana, and Ziway) stations had significant increasing trends (Figure 2.5a). On the other hand, four stations tend to show decreasing trends in WSDI but the trend was significant only at Kulumsa. With respect to CSDI, a significant increasing trend was observed at Kulumsa, whereas significant decreasing trends were observed at Werer, Metehara, Negele-Borana, Koka, Ziway, and Asela (Figure 2.5b) indicating a decline in number of consecutive cool days at the stations. However, like the other temperature indices, there was no spatial coherence among the stations within a given eco-environment with respect to WSDI and CSDI.

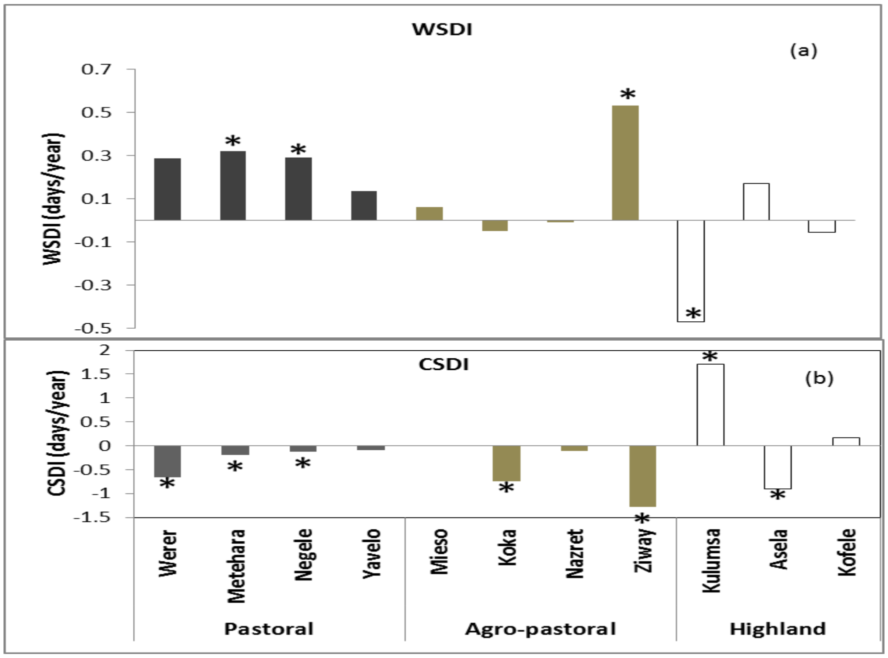

Figure 2.5. Annual trends inWSDI (days/year) and CSDI (days/year) for the 1967-2008 period at different stations over the pastoral, agro-pastoral and highland eco-environments of Ethiopia. The star (*) on bar graph represents significant trends at p <5% probability level.

2.3.2. Trends in precipitation extremes

2.3.2.1. Maximum 1-day (Rx1DAY) and 5-day (Rx5DAY) precipitations

Among the studied stations, seven had positive trends while four had negative trends in Rx-1DAY. However, the positive trend was significant only at Yavelo and the negative trend was significant only at Negele-Borana (Figure 2.6(a)). Trends in Rx5DAY were similar to that of Rx1DAY except that the trend at Yavelo was not significant (Figure 2.6b).

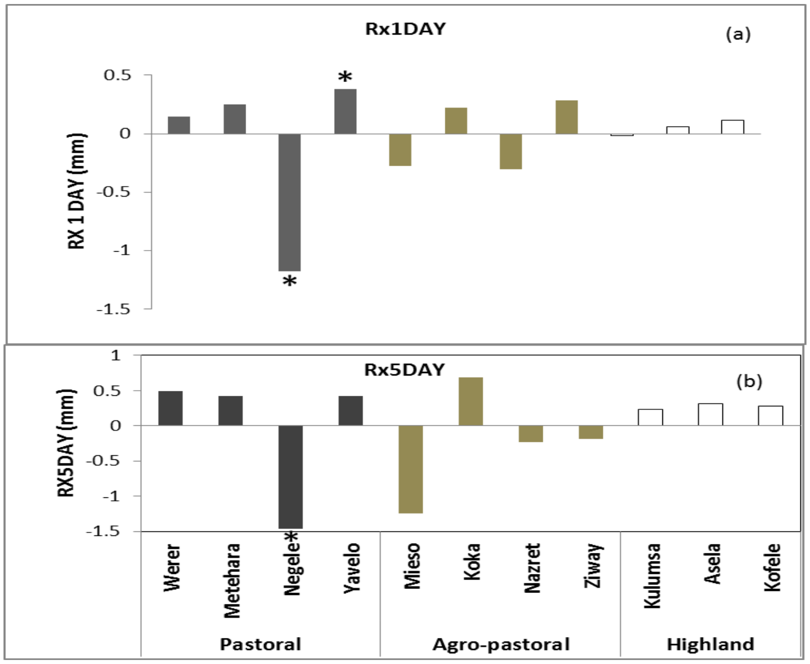

Figure 2.6. Annual trends in Rx1DAY (mm/year) and Rx5DAY (mm/year) for 1967-2008 period at different stations over the pastoral, agro-pastoral and highland eco-environments of Ethiopia. The star (*) on bar graph represents significant trends at P <5% probability level.

2.3.2.2. Daily intensity index (SDII)

Except a significant increasing trend at Koka and a significant decreasing trend at Negele-Borana, trends in SDII were not significant at the stations studied (Figure 2.7). Koka and Negele-Borena are located in the agro-pastoral and pastoral eco-environments, respectively and represent site specific and region wide differences in climate. However, the trends in other stations located in the pastoral and agro-pastoral eco-environments are not significant implying that the significant trends observed at the two stations represent isolated site-specific conditions rather than region wide events.

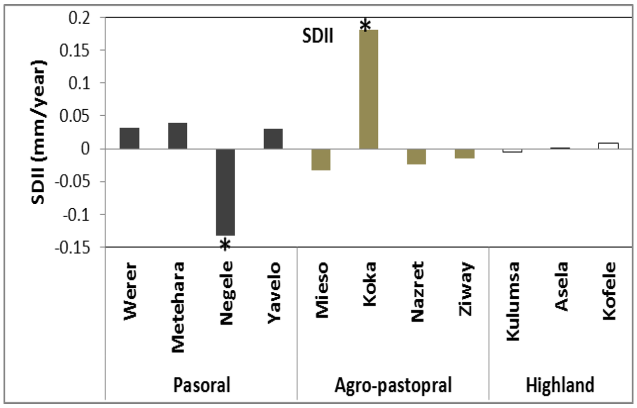

Figure 2.7. Annual trends in SDII (mm/day/year) for 1967-2008 period at different stations over the pastoral, agro-pastoral and highland eco-environments of Ethiopia. The star (*) on bar graph represents significant trends at p <5% probability level.

2.3.2.3. Number of heavy (R10mm) and very heavy (R25mm) precipitation days

Trends in R10mm and R25mm were not significant at most of the stations indicating a similar number of heavy rain days over a period of 42 years. However, some stations scattered over the study area showed significant decreasing (Negele-Borena and Asela) and increasing (Koka) trends in R10mm and R25mm (Figure 2.8a & b).

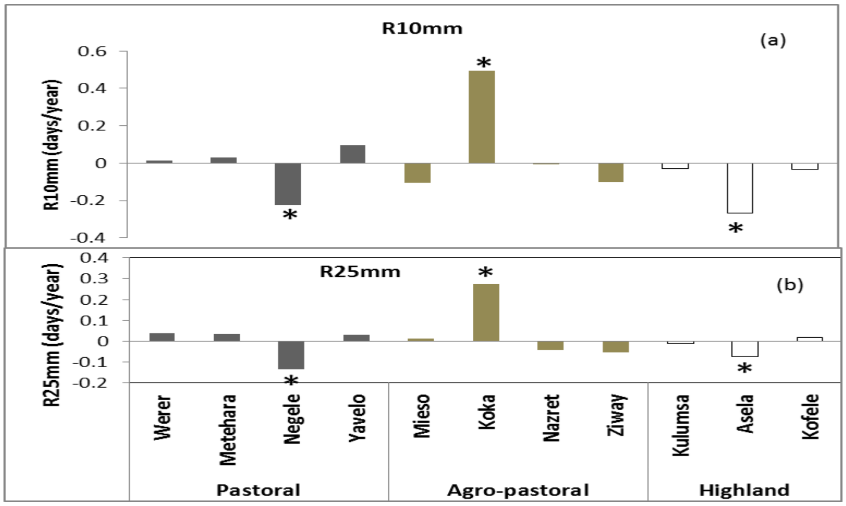

Figure 2.8. Annual trends in R10mm (days/year) and R25mm (days/year) for 1967-2008 period at different stations over the pastoral, agro-pastoral and highland eco-environments of Ethiopia. The star (*) on bar graph represents significant trends at P <5% probability level.

2.3.2.4. Very wet days (R95p), extremely wet days (R99p), consecutive wet days (CWD) and consecutive dry days (CDD)

There were no significant trends in R95P and R99p at any of the stations except Negele-Borena where a significant decreasing trend was observed. Despite lack of statistical significance, trends in R95p and R99p were negative at 5 and 3 and positive at 6 and 8 of the 11 stations, respectively (Figure 2.9a & b). Trends in CWD and CDD were not significant at any stations except at Asela where CDD showed a decreasing trend (Figure 2.9c & d) indicating a similar distribution of wet and dry spells across the study area over the study period.

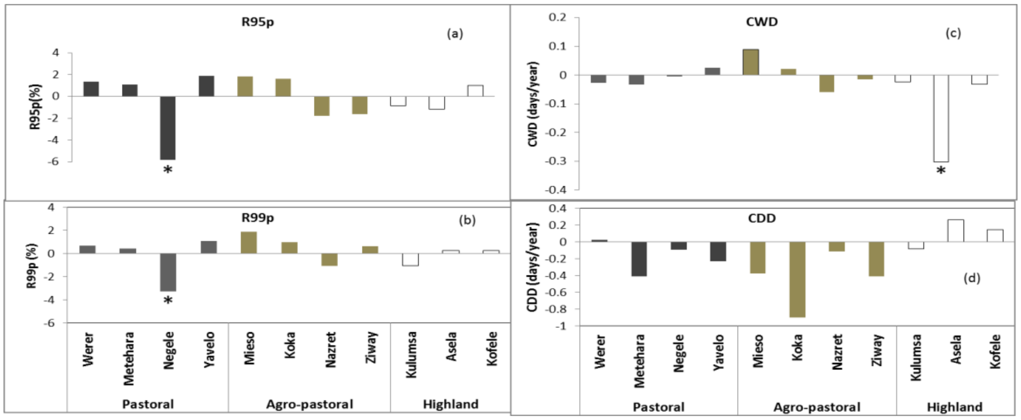

Figure 2.9. Annual trends in R95p (percent/year), R99p (percent/year), CDD (days/year) and CWD (days/year) for 1967-2008 period at different stations over the pastoral, agro-pastoral and highland eco-environments of Ethiopia. The star (*) on bar graph represents significant trends at P <5% probability level.

2.4. Discussion and conclusions

It is apparent from the results of the present study that most of the temperature and precipitation extreme indices computed at the 11 stations distributed across three major eco-environments of Ethiopia showed both positive and negative trends at several isolated stations. The TXx, TX90p, TN90p and WSDI showed positive trends at more than seven stations while the TX10p, TN10p and the CSDI revealed negative trends at more than 8 stations with trends being significant at more than four stations. This indicated a general tendency of increasing warm extremes and a decreasing tendency of cold extremes in the study eco-environments. This is in line with previous studies that indicated an increase in warm extremes and decrease in cold extremes in tropical environments (Manton *et al*., 2001 Kruger and Shongwe, 2004; McSweeney *et al*., 2010; Kruger and Sekele, 2013). The observed changes in temperature extreme could be attributed to climate change which is mainly a result of human activities such as deforestation and industrial and agricultural greenhouse gas emissions (Eltahir and Bras, 1993; Houghton, 2005; Zhou *et al*., 2007; Meinshausen *et al*., 2009).

The trends in precipitation extremes were much more variable and more inconsistent among neighboring stations. Although some indices showed positive (Rx1DAY, Rx5DAY and R99p) and negative (R10mm, CDD and CWD) trends at more than seven stations, trends were significant only at a few stations. Similar to the current results, New *et al.* (2006) also reported inconsistencies and lack of statistical significance in precipitation extreme indices computed from stations in southern and western Africa regions.

In the present study, seven of the nine precipitation extremes were exceptionally significant at one station (Negele-Borana) with a negative trend. Homogeneity test of the climate data of the station did not reveal evidence of station relocation or instrument change to contradict the observed general decline in precipitation extreme events. Negele-Borana and Yavelo stations are located in the southern part of Ethiopia and receive major rains from February to May and small rains from September to November as compared to the major rain season from June to September and small rain from March to April in the rest of the stations. Although the different results at Negele-Borena seems to be related to a different climate system that brings precipitation to the region, the results at Yavelo, a station within the same region, do not support this assertion. Therefore, the results at Negele-Borena need to be seen with caution and also require further investigation.

Most of the observed extreme trends in temperature and precipitation did not show spatial coherence among stations within eco-environments and varied among neighboring stations with some showing opposite trends. This could be due to the fact that in mountainous countries, the spatial and temporal patterns of temperature and precipitation are complex due to both regional synoptic-scale and landscape-scale physiographic controls of the climate system (Dobrowski *et al*., 2009). The spatial and temporal variability observed in the trends of both precipitation and temperature extremes could thus be related to the diverse topography and relief features of the country (Bewket and Conway, 2007; McSweeney *et al*., 2010) which affects local and regional atmospheric circulations (NMSA, 1996; Shanko and Camberlin, 1998; NMA, 2001; Segele and Lamb, 2005). Similar differences among neighboring stations were also reported in previous studies from other tropical regions (New *et al.*, 2006). However, the present study did not cover the entire relief features and geographic areas of the country because of practical limitations and hence the results of this study should not be taken as representative of the whole country but an example of the long-term trend of temperature and precipitation extremes among different eco-environments in the country. However, the study clearly indicated that trends of climate extremes could vary considerably among stations within a given eco-environment and that local climate could respond differently to global warming in physiographically diverse regions.

3. PERCEPTION OF CLIMATE EXTREME TRENDS OVER THREE ETHIOPIAN ECO-ENVIRONMENTS: COMPARISON WITH RECORDS AND ANALYSIS OF DETERMINANTS

Abstract

Understanding household perceptions of climate change and determinants of such perceptions are important for planning climate change adaptation and mitigation strategies. In this study, herding/farming households' perceptions were compared with recorded trends of extreme rainfall and temperature indicators from nearby weather stations for three seasons (major rains, small rains and dry season) across three eco-environments (pastoral, agro-pastoral and mixed crop-livestock highland system) in Ethiopia. Factors influencing household perceptions were assessed using a multinomial logit model. Results indicated that the majority of households (52.5-98.8%) across the three eco-environments perceived increasing numbers of extreme warm days and warm nights and decreasing numbers of extreme cool days and cool nights for all seasons. In most cases, the household perceptions agreed with the recorded extreme temperature trends. The perceptions of seasonal total rainfall and daily rainfall intensity varied across seasons and eco-environments. Thus, the majority (50-95.5%) of the respondents in the pastoral and agro-pastoral eco-environments perceived decreasing trends across seasons while respondents in the mixed crop-livestock highlands were almost equally divided in perceiving increasing and decreasing trends of rainfall in the major and small rainy seasons. Most of the households in the mixed crop-livestock highlands also perceived either a decreasing trend or no change in rainfall amount during the dry season. Household perceptions on the studied rainfall extreme events agreed with recorded trends in the pastoral eco-environment in all seasons. Household perceptions of the studied extreme events were significantly affected by literacy, eco-environment, contact with the agricultural extension service, and presence of relief aid. We conclude that policy programs that enhance the literacy level of household and strengthen eco-environment-based extension services may increase the level of awareness and understanding of climate change by households which could help them to better adapt to climate change.

Key words: Household perception; Recorded data; Season

3.1. Introduction

Climate change as a reality has been increasingly recognized with the advent of a growing number of scientific studies (Henry, 2000; Thornton *et al*., 2006; Trenberth *et al.,* 2007). In many cases, analysis of weather monitoring station data is a primary source of evidence (Trenberth *et al.,* 2007). In Sub-Saharan Africa, however, scientific studies based on station data lag behind other parts of the world mainly because of low station density, lack of data continuity and heterogeneity in the quality of records (Seleshi and Zanke, 2004). Similarly weather information from monitoring stations seldom reaches herders and farmers who rather rely on age old traditional knowledge and perceptions accumulated through long historical exposure to the different facets of local climate (Nyong *et al.,* 2007; Ishaya and Abaje, 2008).

Numerous studies have investigated how local knowledge and perceptions (Hansen *et al*., 2004; Viscusi and Zekhauser, 2006; Maddison, 2007; Semenza *et al,* 2008; Gbetibouo,2009**;** Deressa *et al.,* 2011; Ofuoku, 2011; Piya *et al*., 2012; Silvestri *et al*., 2012) or social awareness (Saroar and Routray, 2010; Sarkar and Padaria, 2010; Acquah, 2011; Mandleni and Anim, 2011; Akerlof *et al.,* 2013) are related to weather monitoring stations' records from climate change perspectives (Maddison, 2007; Benedicta *et al.,* 2010). Among others, studies by Maddison (2007) in eleven African countries showed that significant number of African farmers' perceptions of increased temperature and decreased rainfall are somewhat equivocal with records from weather monitoring stations. Farmers' perceptions that climate is changing were found to be consistent among neighborhoods (Maddison, 2007; Bryan *et al.,* 2013) and overwhelming in some cases (Benedicta *et al.,* 2010; Enujeke, and Ofuoku, 2012) while trends derived from weather station data were found to show a much less clear picture of climate change (New *et al.,* 2006).

The joint CCl/CLIVAR/JCOMM Expert Team (ET) on Climate Change Detection and Indices (ETCCDI) (http://cccma.seos.uvic.ca/ETCCDI) have developed and recommended 27 precipitation and temperature extreme indices for detecting climate change. Yet there are no agreed standard indices available for using human perceptions in climate change studies. Available literature to date reports perceptions based on general descriptions of temperature and rainfall trends (Hassan and Nhemachena 2008; Maddison, 2007; Deressa *et al.,* 2011). Such generalizations, however, are ambiguous to understand as they are not validated against weather station data. Secondly, people seem more able to detect and remember extreme weather events (Bento *et al.,* 2013) than more gradual changes in averages (Hulme *et al.,* 2009). Thirdly, because of media exposure, people may falsely attribute occasional but normal events such as yield reductions, changes in vegetation phenologies and/or droughts to climate change where in reality they represent extremes of a time series whose mean is stable (Byrd *et al*., 2001; Weber, 2010). However, these short comings of perception studies could be partially dealt with by matching perceptions with analysis of standard meteorological extreme indices using records from nearby weather observatory stations.

Climate change perceptions can also be shaped by psychometric, cultural, demographic, social and institutional factors (Vedwan, 2006; Dhaka *et al.,* 2010; Acquah, 2011; Hasan and Akhter, 2011; Silvestri *et al.,* 2012). For example the way in which the climate change issue is addressed in mass media, education and extension determines households' awareness. Farming experience is also highly related to experience with local climatic normal, extreme events and general environmental responses. For instance, the Borana and Guji pastoralists of southern Ethiopia have an ecologically sound range management culture. Their seasonal movements, grazing and watering resources are managed by traditional rules and regulations that have evolved in response to local climate (Coppock, 1994; Abebe, 2000; Desta, 2000; Angassa and Oba 2007; Abate *et al.,* 2010). Similarly the mixed crop-livestock farming highlanders who have adopted a sedentary life based on crop farming have also developed cropping and farming cultures in response to their local climate (Gebru, 2001; Vedwan, 2006; Lamma and Devkota, 2009). The agro-pastoral households have also developed efficient herding and farming cultures based on opportunistic use of experience from both pastoralism and farming.

Despite this rich traditional knowledge, there are few rigorous studies that relate household perceptions to weather station data in Sub-Saharan Africa. A prior understanding of these households perceptions on climate extreme trends and their relationship with weather monitoring station data and other factors at play could help to create community sensitization on climate change; such understanding could also enable policy makers and development planners to design and popularize community based climate resilient adaptation strategies. Thus this paper presents results of relating household perceptions on selected rainfall and temperature extremes indicators and comparing them with values computed from nearby daily weather station data. It also assesses major environmental, social and/or institutional factors that influenced household perceptions over three seasons and major eco-environments of Ethiopia taking the case of pastoralists in Liben, agro-pastoralists in Mieso and mixed crop-livestock highland farmers in Tiyo districts[2] of Oromia National Regional State in Ethiopia.

3.2. Materials and methods

3.2.1. Analysis of extreme rainfall and temperature trends

3.2.1.1. Data source, station selection and quality control

Long term (1967-2008) daily rainfall and temperature data from stations located at Negele-Borana in Liben district in the pastoral eco-environment, Mieso district in the agro-pastoral eco-environment, and Asela and Kulumsa in Tiyo district in the mixed crop-livestock highland eco-environments of the country were sourced from the National Meteorological Agency of Ethiopia. Prior to analysis, the data of all these stations were plotted against time in days of the year format and subjected to visual examination for quality control. Special codes for missing values were removed. Typing errors, duplicated years and outliers defined as values above or below the mean plus or minus 4 times the standard deviation (Tank *et al.,* 2009) were treated on a case by case using information from the day before and after the event and also by reference to nearby stations as indicated in Chapter Two. Missing values were also filled as stated in chapter two.

3.2.1.2. Defining the extreme parameters and trend analysis

The quality controlled data were subjected to the RClimDex package developed to run under the open source R software (R Development Core Team, 2012) to compute number of extreme cool

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[2] District is Woreda which is a higher administrative unit above the lowest administrative unit-Kebele.

days (TX10p), number of extreme cool nights (TN10p), number of extreme warm days (TX90p) and number of extreme warm nights (TN90p), seasonal total rainfall (PRCPTOT) and simple daily intensity index (SDDI) for the major rainy, small rainy and dry seasons as defined in Table 3.1 after ETCCDI's (Slightly modified from that of Tables 2.2 and 2.3 in Chapter 2) definition. The period from 1971-2000 was used as the base period in the analysis. A linear trend was then fitted (on mean values of the two station in case of Tiyo district) using Kendal's *tau* and the slope of the line was computed using the Sen's slope estimator in order to determine the rate of change in extreme events. The statistical significance of the slopes was tested at 5% probability level.

Table 3.1. Extreme precipitation and temperature indices and their definition

No	Index	Definition of the index	Unit
1	PRCPTOT	Seasonal total rainfall: determined by summing daily precipitation events in a season with daily rainfall $\geq$1 mm.	mm/day
2	SDII	Simple daily intensity index: determined as season's seasonal total rainfall on wet days (precipitation $\geq$1 mm) divided by number of rainy days with rainfall $\geq$1 mm in a season.	mm/day
3	TN10p	Cool nights: Percentage of days in a season when the daily minimum temperature is less than 10th percentile of base period (1971-2000).	Days
4	TX10p	Cool days: Percentage of days in a season when the daily maximum temperature is less than 10th percentile of base period (1971-2000).	Days
5	TN90p	Warm nights: Percentage of days in a season when the daily minimum temperature is greater than 90th percentile of base period (1971-2000).	Days
6	TX90p	Warm days: Percentage of days in a season when the daily maximum temperature is greater than 90th percentile of base period (1971-2000).	Days

3.2.2. Household perception survey

3.2.2.1. Site and household selection

A total of 217 households were selected through a mix of purposive and stratified random sampling. First, the three districts, one from each of the three major eco-environments of the country were selected purposively so as to represent the pastoral, agro-pastoral and mixed crop-livestock highland eco-environments. Once the districts are selected, the lowest administrative units (Kebeles) in each of these districts were stratified into three strata using subjective expert judgment based on relative proportion of land allocated to crops and livestock, and agro-ecological settings of the Kebeles. From each stratum one Kebele was randomly selected and household censuses conducted to collect names and ages of the household heads. Household heads above 50 years old (supposed to have rich knowledge of local environment) were identified and later sampled randomly for selection of households. The number of households surveyed was proportional to the number of households in the district; a total of 81, 44 and 92 households in the pastoral, agro-pastoral and mixed crop-livestock highland systems were randomly selected for interview.

3.2.2.2. Household interview

A structured questionnaire was prepared, pretested and administered with 217 selected household heads whose age range from 51-82 with mean of 63 years old. Data collected included household level data such as literacy level of the household head, land holding, livestock ownership, social and /or institutional responsibility of the household head, distance from market, access to extension services and relief aid (Table 3.3). The interview also included information on perceptions of the respondent about trends of rainfall amount, daily rainfall intensity, and frequency of extreme cool days, cool nights, warm days and warm nights for the major rainy, small rainy and dry seasons (Table 3.2). For ease of communication and understanding, respondents were asked to compare the extreme indicators of interest for three historical periods: the Imperial regime (before 1974), the Derg regime (1974-1991) and the current regime (from 1991 to present). Responses were then translated as increasing, decreasing or no change over the last 30-40 years.

3.2.3. Perception analysis: Theoretical framework

According to the Oxford dictionary perception is defined as the way in which something is regarded, understood, or interpreted. In the climate literature models two perception theories emerge prominently (Tansey and O'riordan, 1999). These are the psychometric and cultural theories. The psychometric theory is all about individualism and perception is treated as an exclusive property of individuals (Tansey and O'riordan, 1999). The cultural theory on the other hand is about people. It focuses on what is shared by people who form their outlook through their interaction in the social world (Tansey and O'riordan, 1999). According to Tansey and O'riordan (1999) culture is a shared interpretative framework for such groups or the common way that a group of persons make sense of the world. They share common sets of plans, laws, rules, regulations, customs, belief, norms and rituals to which individuals abide. According to the psychometric theory a human being uses close observation to assess his local climate and makes day to day decisions about farming, travel, clothing and others to match his local weather conditions. Thus, from experience *per se* human beings can assess significant changes in local climate.

Table 3.2. The dependent variables and definition used for the study

No	variable	Definition of the variable	Unit
1	TR	Seasonal total rainfall: Perceived amount of rainfall in a season.	polycotomous: 1= increasing; 2, decreasing; 3= no change
2	IR	Intensity of rainfall: Perceived strength of rainfall during raining time in a season.	Polycotomous: 1= increasing; 2, decreasing; 3= no change
3	CD	Frequency of cool days: number of days with extreme coolness of the day time hours in a season.	Polycotomous: 1= increasing; 2, decreasing; 3= no change
4	CN	Frequency of cool nights: number of days with extreme coolness of the night time hours in a season.	Polycotomous: 1= increasing; 2, decreasing; 3= no change
5	HD	Frequency of warm days: number of days with extreme warmness of the day time hours in a season.	Polycotomous: 1= increasing; 2, decreasing 3= no change
6	HN	Frequency of warm night: number of days with extreme warmness of the night time hours in a season.	Polycotomous: 1= increasing; 2, decreasing; 3= no change

Those who oppose this theory, however, say that "the deviations in the long term mean termed climate change is difficult to recognize unless one uses certain statistical analysis and that climate change is a constructed issue" (Storch, 2011). According to this group there are different classes of constructions (Stehr and Storch, 1995; Pasquaré and Oppizzi, 2012). One is through objective analysis of observations and interpretation by theories and the other is what is maintained and transformed by the public media (Stehr and Storch, 1995; Pasquaré and Oppizzi, 2012). Thus, according to this theory farmers' and herders' perceptions of changes in the extremes of rainfall and temperature indices might be derived from external sources such as extension services or mass media. According to Weber (2010); Frank *et al.* (2011) and Akerlof *et al.* (2013) knowledge of local climate is derived from personal experiences, local sources of knowledge and external sources of techno-scientific information. This indicates that herding/farming household perceptions of changes in those indices could be a result of personal experiences and influences from external agents. Based on these theories we used empirical models to identify what might be responsible for the observed household perceptions of rainfall and temperature extremes from sets of given environmental, social/ institutional and personal variables as given below.

3.2.3.1. The empirical model and model specification

A multinomial logit (MNL) model commonly used for climate change adaption studies (Deressa *et al*., 2009, Hassan and Nhemachena, 2008; Bryan *et al*., 2013) and adoption decision studies involving multiple choices was used to identify the determinants of household perceptions of rainfall and temperature extreme indicators. The model was estimated based on households' responses using three choices namely increases (j=1), decreases (j=2) and no change (j=3) in specified climate extreme variables. Each household head was asked to give as single perception choice (j=1…J) to each rainfall and temperature extreme indicator denoted as y=1…Y. Thus for each extreme indicator taking one perception choice with sets of conditioning factors and household characteristics, the MNL model takes the following form:

$$P(y = j \setminus x) = \frac{\exp(x\beta j)}{1 + \sum_{h=1}^{J} \exp(x\beta h),\ j = 1,\ldots J}$$

The MNL model requires assumption of independence of irrelevant alternatives (IIA) to hold which states that the probability of choosing a certain perception alternative by a given household needs to be independent from the probability of choosing another perception alternative (that is, Pj/Pk is independent of the remaining probabilities).

The parameter estimates of the MNL model offer only the direction of the effect of the independent variables on the dependent (response) variable, and estimates do not signify either the actual magnitude of change nor probabilities. Hence differentiating the equation above with respect to the explanatory variables provides marginal effects of the explanatory variables given as:

$$\frac{\partial Pj}{\partial x_k} = Pj(\beta_{jk} - \sum_{J=1}^{J-1} P_j \beta_{jk})$$

Where X is a vector of perception characteristics (specified in Table 3.3), β is a set of estimated parameters and J is a number of choices.

The marginal effects or marginal probabilities are functions of the probability itself and measure the expected change in probability of a particular choice being made with respect to a unit change in an independent or explanatory variable (Greene, 2000).

3.2.3.2. Dependent variables

A total of six dependent variables (indicated in Table 3.2) which included household perceptions of trends in seasonal total rainfall, intensity of rainfall, frequency of extreme cool days, frequency of extreme cool nights, frequency of extreme warm days and frequency of extreme warm nights were identified. Six independent MNL models were run to regress these dependent variables on sets of environmental and social and/or institutional factors hypothesized to affect household perceptions.

3.2.3.3. Independent variables

Nine independent variables namely, household head characteristics (literacy level, land holding and livestock ownership), access to institutional services (social and /or institutional responsibility, distance from market**,** access to extension and relief aid services), environmental factors (eco-environment and season) were used in the model to assess the effect of changes in the above response variables on household perceptions (Table 3.3).

3.2.3.3.1. Household characteristics

According to Hidalgo and Pisano (2010) environmental perceptions in relation to climate change are related to knowledge of the respondents. In line with this studies have shown that education increases climate change perception and awareness (Maddison, 2007; Deressa *et al.,* 2009; Acquah 2011; Hasan and Akhter, 2011; Enujeke and Ofuoku, 2012; Tesso *et al.*, 2012). Hence literate household heads might have more access to information and also analysis of environmental factors than their illiterate or uneducated counterparts. Literate household heads are expected to perceive changes in rainfall and temperature extreme indicators more than the illiterate household heads.

Land and livestock holdings represent wealth and farm activities. The size of these holdings influences farmers planning and execution of activities which could be affected by climate (Deressa *et al.,* 2009). Studies have shown that livestock ownership is positively related to climate change perception and adaptation decisions (Deressa *et al*., 2011; Silvestri *et al*., 2012; Mandleni and Anim, 2011).We hypothesize that farming and herding households with large land and livestock holding sizes have a better idea about climate change than those with few livestock for several reasons. On the one hand they have more social interactions and communications with neighbors for the management of their land and livestock. Secondly, they need to adjust their farming and herding practices and operational calendars in response to the changing local level climate extremes. Thirdly, they may be wealthier through sale of their farm produce and livestock and this wealth can improve access to communication media.

3.2.3.3.2. Household access to institutional services

Household heads with social and /or institutional responsibilities such as serving the community as religious leaders, arbitration, and involvement in various capacities within the 'Kebele' administration gives opportunity for communication with various people who might include those informed about climate change. Hence, we hypothesis that household heads with social and /or institutional responsibility could perceive rainfall and temperature extremes changes better than others with fewer responsibility.

Distance from input markets has been found to positively affect household perceptions of climate change and adaptation to the changes (Mandleni and Anim, 2011). In contrast, studies by Tesso *et al*. (2012) showed that distance from market was negatively related to farmers' perceptions of climate change. We hypothesize that households close to market outlets may have more awareness about climate change than distant ones. Those household heads close to market centers have a tendency to frequent market areas where they meet many people and share ideas about changes in rainfall and temperature extremes.

Extension services are an important source of information on climate and climate related issues (Deressa *et al*., 2009, 2011; Hassan and Nhemachena, 2008). Access to information on rainfall and temperature has been found to positively relate to climate change awareness and hence adaptation measures (Deressa *et al*., 2009; Dhaka *et al*., 2010; Mandleni and Anim, 2011; Enujeke and Ofuoku, 2012; Tesso *et al.*, 2012). In contrast, studies by Silvestri *et al.* (2012) showed that climate change perceptions of agro-pastoralists are negatively affected by livestock extension field visits. We hypothesize that herders and farmers close to extension services have better interaction with extension agents and hence have information on rainfall and temperature extremes. This is because extension agents themselves could teach them about climate change.

Studies have shown that food or other relief aid positively affects climate change perceptions of agro-pastoral households (Silvestri *et al.*, 2012). We hypothesize that relief aid recipient households have a better perception of rainfall and temperature extremes than the non-recipient households. This is because on the one hand relief aid recipients understand that increased frequencies of climatic extremes might expose them to repeated crop failures and livestock mortalities which lead them to be relief aid recipients. On the other hand donors and other informed relief aid workers could tell them of changes in rainfall and temperature extreme trend.

Table 3.3. Description of the independent variables

Variable	Description	Value
Household characteristics		
Literacy	Household head literacy status.	1= literate, 0= illiterate
Land holding	Household head's land holding.	hectare
Livestock ownership	Household head's livestock holding.	Tropical livestock unit (TLU)
Distance from market	Household head's residential house distance from nearby market place.	km
Institutional factors		
Social/institutional responsibility	Household head's social and / or institutional responsibility such as serving as priest, 'kebele administration, etc.	1= yes, 0=no
Access to ext. service	Household head's access to extension service including material benefits on livestock and crop over the last decades in his farm life.	1= yes, 0=no
Access to relief aid	Household head food relief aid and or safetynet assistance received over the last decades in his farm life	1= yes, 0=no
Environmental factors		
Eco-environment		
Pastoral	Household head living in pastoral eco-environment.	1 yes, 0= otherwise
Agro-pastoral	Household head living in agro-pastoral eco-environment.	1 yes, 0= otherwise
Mixed crop-livestock Highland	Household head living in mixed crop-livestock highland eco-environment.	1 yes, 0= otherwise
Season		
Major rain season	Household head's response for the major rain season	1 yes, 0= otherwise
Small rain season	Household head's response for the small rain season	1 yes, 0= otherwise
Dry season	Household head's response for the dry season	1 yes, 0= otherwise

3.2.3.3.3. Environmental factors

Ethiopia is topographically very diverse but three major eco-environments with distinct climate and land use patterns have been specified. These diverse eco-environmental settings could affect perceptions of change in patterns of rainfall and temperature extremes among households living in each eco-environment. Previous studies in the Ethiopian mixed crop-livestock highlands have shown that farmers living in different eco-environments perceive climate change and hence take certain adaptation measures (Deressa *et al*., 2011) appropriate to their conditions. However studies by Tesso *et al*. (2012) did not find a significant effect of eco-environment on farmers' perceptions of climate change. We hypothesize that households living in different eco-environment may perceive changes in frequencies of occurrence of rainfall and temperature extremes from experience. Pastoral and agro-pastoral households have developed system behaviours focusing on mobility in response to the warm dry climate of pastoral areas and have knowledge on the occurrence of climatic extremes to which they have responded with certain management strategies. This is less important among the more stable and sedentary mixed crop-livestock highlanders.

Rainfall and temperature patterns differ among seasons over the different regions of the country. The rainfall of small rainy season plays vital role for land preparation and planting of long season crops such as sorghum and maize while the major rain season is important for planting short duration crops over most parts of the country. Studies by McSweeney *et al*. (2010) indicated significant increase in frequency of hot days and hot nights and conversely significant declining trends in frequencies of cold days and nights for the different seasons of Ethiopia. Seasonal differences in duration and magnitude of occurrence of rainfall and temperature variables affect choices of adaptation options to climate change (Hassan and Nhemachena, 2008).This difference could be one factor to affect household perceptions of changes in patterns of rainfall and temperature extremes. We hypothesize that because of their agricultural significance households perceive patterns of change in rainfall and temperature extremes better for the major and small rainy seasons than the dry season in the country.

3.2.3.4. Estimation of empirical model parameters

For all response variables, the multinomial logit model was estimated by taking the no change perception response as a baseline category against which other alternatives were compared. A multicollinearity test was conducted by employing an Ordinary Least Square (OLS) model using a Variance Inflation Factor (VIF) (Myers, 1990; O'brien, 2007). The VIF was found to be less than 10 for all variables indicating multicollinearity was not a serious problem in all the cases. We then ran Hausman's test to check the validity of the models for Independence of the Irrelevant Alternatives (IIA) assumption. The Hausman's test, however, failed to reject the null hypothesis of independence of the rainfall and temperature change perception options, indicating the multinomial logit model specifications are adequate to model rainfall and temperature extreme perception of the study household. As evidenced from Table 3.4 the likelihood ratio test of the models were found to be highly significant ($P<0.0000$) indicating strong explanatory power of the models. For each of the six multinomial logit models we ran, the marginal effect and interpretations of model output are based on marginal effects of the multinomial logit. For all models the output for the increased and decreased perceptions are interpreted by comparing with the no change perception category.

Table 3.4. Model fitting diagnostic characteristics of the multinomial logit model

Diagnostics	**TR**	**IR**	**CD**	**CN**	**HD**	**HN**
Base category	**No change**	**No change**	**No change**	**No change**	**No change**	**No change**
Number of observation	651	651	651	651	651	651
Wald X^2	375068.67	248.16	61251.05	107282.83	1116.16	574.34
$P>X^2$	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Pseudo R^2	0.3918	0.326	0.2555	0.2869	0.3236	0.2651
Log pseudo likelihood	-375.6573	-424.9048	-349.1884	-427.9930	-268.6830	-416.2042

Note TR=Seasonal total rainfall; IR = Intensity of Rainfall; CD=number of extreme cool days; CN= number of extreme cool night; HD= number of extreme warm days, HN=number of extreme warm night

3.3. Results and discussion

3.3.1. Household perception of extreme weather events vis-à-vis observed records

3.3.1.1. Pastoral eco-environment

In the pastoral eco-environment, the majority of households perceived an increasing number of extreme warm days (WD) and warm nights (WN), and conversely a decreasing number of extreme cool days (CD) and cool nights (CN) across all seasons. The perceptions were in line with recorded significant increasing trends in WD and WN across seasons. The decreasing trends from observed data were significant only for the major and small rainy seasons but were broadly in line with the decreasing trends in CD and CN perceived by the household. The majority of pastoral households (61.0-94.0%) also perceived decreasing trends in seasonal total rainfall (TR) and daily rainfall intensity (IR) across all seasons. Perceptions on IR were in line with observed data which also showed decreasing trends in all seasons. On the other hand, the observed data for TR showed a significant decline only in the major rainy season (Table 3.5).

3.3.1.2. Agro-pastoral eco-environment

Similar to the pastoral eco-environment, in the agro-pastoral eco-environment, the majority of households perceived increasing numbers of extreme warm days (WD) and warm nights (WN), and conversely decreasing numbers of extreme cool days (CD) and cool nights (CN) across all seasons. However, the station data for CD indicated significant decreases only in the major rainy and dry seasons while the observed decrease was significant only in the major rainy season. Contrary to household perceptions, the recorded trends in WD revealed significant decreasing trends in the small rainy season. The majority of agro-pastoral households also perceived decreasing seasonal total rainfall (TR) and daily rainfall intensity (IR) across all seasons. However, the recorded trends showed no significant change in these parameters across all seasons (Table 3.6).

3.3.1.3. Mixed crop-livestock highland eco-environment

In the mixed crop-livestock highland eco-environment, most of the households perceived increasing numbers of extreme warm days (WD) and warm nights (WN), and conversely decreasing numbers of extreme cool days (CD) and cool nights (CN). The perceptions for the major rainy and dry seasons agree with the recorded station data for WN which also showed increasing trends. For the small rainy season, however, station data indicated that only WD showed significant increasing trends. On the other hand, the recorded station data did not significant changes in CD and CN except for the small rainy season where a decrease was seen in the small rainy season. With regard to rainfall extremes (TR and IR), households were equally divided between perceiving these to be increasing and decreasing in the major rainy seasons plus also the small rainy season in case of TR. Similarly for dry season, the respondents were equally divided between perceiving decreasing trends and no change (Table 3.7).

From the above results it is evident that households from the three eco-environments perceived increasing numbers of extreme warm days and warm nights, and conversely decreasing numbers extreme cool days and cool nights. The perceptions on rainfall extremes, however, were variable across season and eco-environments in such a way that majority of households in the pastoral and agro-pastoral eco-environments perceived decreasing total rainfall and intensity of rainfall, whereas the respondents were equally divided between perceiving increases and decreases for the major and small rainy seasons in the mixed crop-livestock highland eco-environment. The results are in line with other reports from similar environments (Dhaka *et al.*, 2010; Acquah and Onumah, 2011). On the other hand, the relationship between household perceptions and station data were not systematic; in the pastoral eco-environment household perceptions were in line with recorded data, but in the agro-pastoral or mixed crop-livestock highland eco-environment the relationship was not clear. Maddison (2007) also found similar inconsistences for rainfall and temperature between farmers' perceptions and recorded weather station data across many African countries. The results also revealed more inconsistences among recorded data than household perception across eco-environments. This is in line with results of Chapter Two which indicated considerably varied trends of climate extremes among neighboring stations within a given eco-environment.

Table 3.5. Comparison of recorded and perceived trends of rainfall and temperature extremes for three distinct seasons in a pastoral eco-environment.

Climate extreme event	Recorded	Perceived		
		Increasing (%)	Decreasing (%)	No change (%)
Major rainy season				
Seasonal total rainfall	Decreasing (-1.47* mm/year)	6.2	93.8	0
Daily rainfall intensity	Decreasing (-0.16* mm/day/year)	24.7	75.3	0
number of extreme warm days	Increasing (0.39* days/year)	97.5	2.5	0
number of extreme warm nights	Increasing (1.22* days/year)	75.3	24.7	0
number of extreme cool days	Decreasing (-0.23* days/year)	8.6	91.4	0
number of extreme cool nights	Decreasing (-0.29* days/year)	32.1	67.9	0
Small rainy season				
Seasonal total rainfall	No change(-0.83 mm/year)	4.9	91.4	3.7
Intensity of Rainfall	Decreasing (-0.064* mm/day/year)	23.5	74.1	2.4
number of extreme warm days	Increasing (0.39* days/year)	98.8	1.2	0
number of extreme warm nights	Increasing (0.70* days/year)	72.8	27.2	0
number of extreme cool days	Decreasing (-0.21* days/year)	8.6	91.4	0
number of extreme cool nights	Decreasing (-0.34* days/year)	34.6	64.2	1.2
Dry season				
Seasonal total rainfall	No change(-0.99 mm/year)	4.9	81.5	13.5
Intensity of Rainfall	Decreasing (-0.092* mm/day/year)	4.9	82.7	12.3
number of extreme warm days	Increasing (0.43* days/year)	96.3	2.5	1.2
number of extreme warm nights	Increasing (0.89* days/year)	72.8	27.1	0
number of extreme cool days	Decreasing (-0.21*)	9.9	90.1	0
number of extreme cool nights	Decreasing (-0.36* days/year)	38.3	60.5	1.2

* Trends are significant P <5% probability level

Table 3.6. Comparison of recorded and perceived trends of rainfall and temperature extremes for three distinct seasons in an ago-pastoral eco-environment.

Climate extreme event	Recorded	Perceived		
		Increasing (%)	Decreasing (%)	No change (%)
Major rainy season				
Seasonal total rainfall	No change (-0.40 mm/year)	4.5	95.5	0
Intensity of Rainfall	No change (-0.038 mm/day/year)	9.1	88.6	2.3
Number of extreme warm days	No change (0.13 days/year)	68.2	29.5	2.3
Number of extreme warm nights	No change (0. 14 days/year)	68.2	29.5	2.3
Number of extreme cool days	Decreasing (-0. 16* days/year)	29.5	65.9	4.6
Number of extreme cool nights	Decreasing (-0.29* days/year)	29.5	63.6	6.8
Small rainy season				
Seasonal total rainfall	No change (-0.93 mm/year)	11.4	86.4	2.3
Intensity of Rainfall	No change (-0.066 mm/day/year)	9.1	86.4	4.6
Number of extreme warm days	Decreasing (-0.17* days/year)	72.7	27.3	0
Number of extreme warm nights	No change (0.102 days/year)	68.2	29.5	2.3
Number of extreme cool days	No change (-0.069 days/year)	29.5	65.9	4.5
Number of extreme cool nights	No change (-0.053 days/year)	25	68.2	6.8
Dry season				
Seasonal total rainfall	No change (-0.14 mm/year)	25	50	25.0
Intensity of Rainfall	No change (-0.046 mm/day/year)	17.7	65.5	21.8
Number of extreme warm days	No change (0.29 days/year)	65.9	29.5	4.5
Number of extreme warm nights	No change (0.054 days/year)	65.9	25	9.1
Number of extreme cool days	Decreasing (-0.16* days/year)	38.6	52.3	9.1
Number of extreme cool nights	No change (0.020 days/year)	13.6	79.5	6.8

* Trends are significant at P <5% probability level

Table 3.7. Comparison of recorded and perceived trends of rainfall and temperature extremes for three distinct seasons in a mixed crop-livestock highland eco-environment.

Climate extreme event	Recorded	Perceived		
		Increasing (%)	Decreasing (%)	No change (%)
major rainy season				
Seasonal total rainfall	Decreasing (-1.202* mm/year)	47.8	51.1	1.1
Intensity of Rainfall	No change (0.012 mm/day/year)	48.9	51.1	0
Number of extreme warm days	No change (0.051 days/year)	77.2	14.1	8.7
Number of extreme warm nights	Increasing (0.094* days/year)	66.3	26.1	7.6
Number of extreme cool days	No change (-0.032 days/year)	18.5	77.2	4.4
Number of extreme cool nights	No change (0.062 days/year)	29.3	65.2	5.5
Small rainy season				
Seasonal total rainfall	No change (0. 147)	47.8	47.8	4.4
Intensity of Rainfall	No change (0.027 mm/year)	28.3	67.4	4.4
Number of extreme warm days	Increasing (0.109* days/year)	65.2	29.3	5.4
Number of extreme warm nights	No change (0.071 days/year)	71.7	22.8	5.4
Number of extreme cool days	Decreasing (-0.238* days/year)	35.9	62.0	1.1
Number of extreme cool nights	No change (0.070 days/year)	30.4	66.3	3.3
Dry season				
Seasonal total rainfall	No change (-0.137 mm/year)	13.0	45.7	41.3
Intensity of Rainfall	No change (0.013 mm/day/year)	16.3	44.6	39.2
Number of extreme warm days	No change (0.016 days/year)	90.2	6.5	3.3
Number of extreme warm nights	Increasing (0.276* days/year)	67.4	31.5	1.1
Number of extreme cool nights	No change (-0.021 days/year)	42.4	54.3	3.3
Number of extreme cool days	No change (-0.038 days/year)	27.2	69.6	3.3

* Trends are significant P<5% probability level.

3.3.2. Determinants of household perceptions

Results of the estimated marginal effects of the multinomial logit models are presented in Tables 8-10. The results show that most of the explanatory variables have statistically significant explanatory power at less than 10%, 5% or 1% probability level and discussed below.

3.3.2.1. Household characteristics

Literacy of the head of the household significantly affected perceptions of trends in seasonal total rainfall, daily rainfall intensity and number of extreme warm days among others. Being literate significantly decreased the probability of perceiving increased seasonal total rainfall, daily rainfall intensity and number of extreme warm days by 9.2%, 9% and 7.8%, respectively and significantly increased the likelihood of increased perception of the number of warm days by 10.5%. These are in line with the recorded trends especially for the pastoral and agro-pastoral environment and imply that education enables household heads to be aware of changes in climate extremes as expected.

The size of farmland owned by households is related to perceptions on number of extreme cool days and warm nights. A unit increase in households' land holding size significantly increased the probability of increased perception of the number of extreme cool days by 1.9%. It significantly decreased the increased perception of the number of extreme warm nights by 2.9% and significantly increased the likelihood of decreased perception by 2.3%. However, these perceptions are not in line with the observed trends indicating that it is not the size of the farm, but the specific characteristics of the farm that may dictate household perceptions of changes in rainfall and temperature extremes trend.

A unit increase in livestock holding of the household significantly increased the probability to perceive increased seasonal total rainfall and daily rainfall intensity by 0.3% and 0.1%, respectively. It however, decreased the likelihood of decreased perception of seasonal total rainfall and daily rainfall intensity by 0.3% and 0.2%, respectively. Moreover, a unit increase in livestock ownership of the household significantly increased the probability of decreased perception of number of extreme warm days by 0.2% and significantly decreased the increased perception of the number of extreme warm nights by 0.2%. These perceptions are not supported by the observed trends. This might be due to better rainfall and temperature conditions in recent years that might result in better availability of pasture and water for livestock production.

Table 3.8. Marginal effects of explanatory variables from the multinomial logit perception models on seasonal total rainfall and intensity of rainfall.

	Seasonal total rainfall (TR)			**Daily rainfall intensity(IR)**		
Explanatory variable	**Increase**	**Decrease**	**No change**	**Increase**	**Decrease**	**No change**
Literacy	0.0280	-0.0915***	0.0635***	0.0240	-0.0896**	0.0240
Land holding	-0.0055	0.0096	-0.0041	0.0122	-0.0026	0.0123
Livestock ownership	0.0025***	-0.0025***	-1.60E-05	0.0013**	-0.0017**	0.0013**
Social/institutional responsibility	-0.0579***	0.1185***	-0.0606**	-0.0431	0.1063**	-0.0431
Distance from market	0.0012	-0.0021	0.0009	-0.0005	0.0002	-0.0005
Access to ext. service	0.0978*	-0.0789	-0.0189	-0.2040***	0.1905***	-0.2040***
Access to relief aid	-0.2355***	0.2272***	0.0083	0.1098**	-0.1258**	0.1098**
Pastoral	-0.2143*	0.2320**	-0.0177	0.1936**	-0.1476	0.1936**
Agro-pastoral	-0.4866***	0.5983***	-0.1117**	0.1064	-0.0008	0.1063
Major rainy season	-0.16456***	-0.1623***	0.3268***	-0.1682***	-0.1505**	-0.1682***
Small rainy season	-0.1323***	-0.0414	0.1737***	-0.0717**	-0.1062**	-0.0717**

*, **, ***significant at < 10%, <5% and < 1% P level, respectively

3.3.2.2. Household access to institutional services

Having social and /or institutional responsibility significantly increased the probability of perceiving decreased seasonal total rainfall and daily rainfall intensity by 11.8% and 10.6%, respectively and increased the likelihood of perceiving decreased seasonal total rainfall by 5.8%. This indicates that as expectations social and/ or institutional responsibility enables farmers and herders to be more aware of climate extreme trends and that their perceptions on rainfall extremes may have been influenced by interactions with other peoples.

Contrary to expectations, a unit increase in distance from market center significantly increased the likelihood of decreased perception of number of extreme cool days by 0.3% and decreased the likelihood of increased perception by 0.2% and significantly decreased the probability of increased perception of the number of cool nights by 0.2%.This implies that though households far away from input centers have less access to information from market centers, they can perceive from experience the changes in number of extreme cool days and night better than those nearby to market centers.

As expected access to extension services significantly increased the probability of perceiving increased number of extreme warm nights by 16.3%. It significantly decreased the probability of increased perception of daily rainfall intensity and number of extreme cool nights by 20.0% and 18.9%, respectively. Moreover, access to extension services significantly decreased the likelihood of perceiving decreased number of extreme warm nights by 10.3%, respectively. It also significantly increased the probability of decreased perception of number of cool nights by 21.5%. However, unlike expectations access to extension services significantly increased the probability of perceiving increased seasonal total rainfall by 9.8% and decreased the likelihood of perceiving decreased daily rainfall intensity by 19.0%. Relief aid assistance also significantly increased households' likelihood of perceiving decreased seasonal total rainfall and number of extreme cool days by 22.7% and 17%, respectively. It significantly decreased the likelihood of increased perception of seasonal total rainfall and number of extreme cool days by 23.6% and 12.7%, respectively. Access to relief aid significantly increased the probability of perceiving increased number of warm days by 11%, but significantly decreased the likelihood of perceiving decreased number of extreme warm days by 8.6%. However, access to relief aid significantly increased the probability of perceiving increased daily rainfall intensity by 11.0% and decreased the likelihood of perceiving decreased daily rainfall intensity by 12.6%. This indicates that herding/farming households close to extension and relief aid services for information, advice and material benefits perceived as expected especially on number of extreme warm and cool days and nights. The results emphasize the importance of extension and relief aid services in climate change perception.

Table 3.9. Marginal effects of explanatory variables from the multinomial logit perception models on number of extreme cool days and cool nights.

	Number of cool days (CD)			**Number of cool nights (CN)**		
Explanatory variable	**Increase**	**Decrease**	**No change**	**Increase**	**Decrease**	**No change**
Literacy	-0.0071	-0.0106	-0.0033	0.0317	-0.0339	0.0022
Land holding	0.0178**	-0.0135	-0.0075	0.0057	-0.0025	-0.0031
Livestock ownership	-0.00013	-0.0007	-0.0005	0.00013	-0.00056	0.00042
Social/institutional responsibility	-0.0212	-0.0019	0.0491*	-0.0517	0.0537	-0.0020
Distance from market	-0.0024**	0.0029**	0.0023**	-0.0022**	0.00154	0.00065
Access to ext. service	-0.0606	0.0694	0.0083	-0.1886***	0.2149***	-0.0263
Access to relief aid	-0.1270***	0.1706***	-0.0377	-0.0609	0.0693	-0.0084
Pastoral	-0.2591**	0.4812***	-0.0682	-0.2090**	0.3324***	-0.1234**
Agro-pastoral	-0.1682	0.4166***	-0.1222	0.0545	0.0656	-0.1201**
Major rainy season	0.0317	-0.0216	0.0663	0.0996**	-0.0925**	-0.0071
Small rainy season	-0.0385	0.0358	0.0669	0.0812**	-0.0787**	-0.0025

*, **, *** significant at <10%, 5% and 1% P level, respectively

3.3.2.3. Eco-environmental factors

Compared to being in the mixed crop-livestock highland eco-environment, being in the pastoral eco-environment significantly increased the probability of perceiving decreased seasonal total rainfall, number of extreme cool days and number of extreme cool nights by 23.2%, 48.0% and 33.0%, respectively. It also significantly decreased the likelihood of perceiving increased rainfall and number of extreme cool days by 21.4% and 25.9%, respectively. Moreover, being in the pastoral eco-environment significantly increased the probability of increased perception of intensity of rainfall, number of extreme warm days and number of extreme warm nights by

19.4%, 36.0% and 40.0%, respectively. It significantly decreased the likelihood of increased perception of number of extreme cool nights by 20.9% and significantly decreased the likelihood of decreased perception of number of extreme warm days and number of extreme warm nights by 31.7% and 39.0%, respectively. Except for the intensity of rainfall, these are in line with the recorded trends and indicate that households in the pastoral eco-environments perceive climate extreme trends better than households in the mixed crop-livestock highland eco-environment. This might be related to the fact that pastoral areas are located in areas of high climate variability and frequent crop failures and livestock mortality to drought. As a result climate change is of major concern to them.

Similarly compared to being in the mixed crop-livestock highland eco-environment, households being in the agro-pastoral eco-environment significantly increased probability of perception of decreased number of extreme cool days by 41.7 % and significantly decreased the likelihood of increased perception by 16.8%. It however, significantly increased the probability of perceiving increased rainfall and number of extreme warm days by 59.8% and 59.8%, respectively. It also significantly decreased the likelihood of perceiving decreased rainfall and number of warm days by 48.7% and 21.7%. This shows that unlike expectations agro-pastoralists are not better in perceiving recorded trends in climate extremes than the mixed crop-livestock highland farmers.

Compared to the dry season, the major rain season significantly decreased the probability of household perceptions of increased seasonal total rainfall and daily rainfall intensity by 16.0% and 16.8%, respectively. It significantly decreased the likelihood of perceiving decreased seasonal total rainfall by 16.0%, daily rainfall intensity by 15.0%, and number of extreme cool nights by 9.3%, and number of extreme warm days by 7.0%. It also significantly increased the probability of increased perception of number of extreme cool nights and number of extreme warm days by 10.0% and 8.8%, respectively.

Table 3.10. Marginal effect of explanatory variables from the multinomial logit perception models on number of extreme warm days and warm nights.

	Number of warm days (HD)			Number of warm nights (HN)		
Explanatory variable	**Increase**	**Decrease**	**No change**	**Increase**	**Decrease**	**No change**
Literacy	0.1045**	-0.0777**	-0.0275	0.0302	-0.0363	0.0061
Land holding	-0.0099	0.0112	-0.0012	-0.0294***	0.0232**	0.0062
Livestock ownership	-0.0013	0.0016**	-0.00033	-0.0017**	-0.00076	0.0025**
Social/institutional responsibility	-0.0029	-0.0263	0.0291	0.0219	-0.0586	0.0367
Distance from market	0.0024	-0.00012	-0.0023**	0.00065	0.00024	-0.00088
Access to ext. service	-0.0477	0.0729	-0.0252	0.1629***	-0.1028*	-0.0602***
Access to relief aid	0.1123**	-0.0861**	-0.0261	0.0216	0.0104	-0.0319
Pastoral	0.3607***	-0.3171***	-0.0436	0.4042***	-0.3944***	-0.0098
Agro-pastoral	0.3074**	-0.2172**	-0.0902**	0.1185	-0.0268	-0.0917*
Major rainy season	0.0878**	-0.0709**	-0.0169	-0.0095	0.0342	-0.0247*
Small rainy season	0.1137**	-0.1156**	0.0019	-0.0266	0.0423	-0.0157

*, **, *** Significant at < 10%, 5% and 1% P level, respectively

Similarly compared to the dry season, the small rain season significantly decreased the likelihood of increased perception of seasonal total rainfall and daily rainfall intensity by 13% and 7% respectively. It also significantly increased the probability of increased perception of number of extreme cool nights by 8.2%; decreased the likelihood of decreased perception of intensity of rainfall, number of extreme cool nights and number of extreme warm days by 10.6% 7.9% and 11.6 % respectively. Moreover, it significantly increased the probability of perceiving increased number of extreme warm days by 11.0% and significantly decreased the likelihood of decreased perception of number of extreme warm days by 11.6 %. These show that though seasons have agricultural significance, its effect on household perceptions are not clearly defined.

3.4. Conclusions and policy implications

From the results of the present study it is apparent that large percentage of households across the three eco-environments and seasons perceived increasing number of extreme warm days (WD) and warm nights (WN), and conversely decreasing number of extreme cool days (CD) and cool nights (CN). The perceptions variably comply with recorded significant trends from nearby weather stations across eco-environments and seasons. In the pastoral eco-environment household perceptions positively comply with recorded significant increasing trends in WD and WN across seasons. The decreased perception of CD and CN also agree with recorded significant decreasing trends for the major and small rain seasons. In the agro-pastoral eco-environment household perceptions agree with recorded significant decreasing trends in CD and CN for major rain season, whereas the perception on increasing WD contradicts the recorded significant decreasing trend. In the mixed crop-livestock highland eco-environment household perceptions agree with significant increasing trends in WN for major rain and dry seasons.

The perceptions on rainfall extremes varied across eco-environments and seasons. In the pastoral and agro-pastoral eco-environment the majority of households perceived decreasing seasonal total rainfall (TR) and daily rainfall intensity (IR) across all seasons, whereas respondents in the mixed crop-livestock highlands almost equally divided on increasing and decreasing trends of rainfall in the major and small rainy seasons. Most of the households in the mixed crop-livestock highlands also perceived either a decreasing or no change in rainfall amount during the dry season.

Household perceptions agreed with recorded significant trends of IR across all seasons in the pastoral-eco-environment while the perception on TR agrees with the significant decreasing trends recorded only for the major rain season. In the agro-pastoral eco-environment no significant trends were recorded in TR and IR to comply with household perceptions. While the perceptions in TR comply with the significant decreasing trends recorded for the major rainy season in the mixed crop-livestock highland eco-environment.

Herding/farming household perceptions on rainfall and temperature extremes are significantly affected by a number of factors and the factors affecting each extreme variable may not be the same. Generally literacy, eco-environment, distance from market, social/institutional responsibility, access to extension and relief aid services caused/helped the majority of households to perceive increasing number of extreme warm days and warm nights, and conversely decreasing number of extreme cool days , cool nights, daily intensity rainfall and seasonal total rainfall as expected. However, Farm land size, and livestock holding size of households could not help perceive such changes

We concluded that herding/farming household perceptions of extremes of climate are similar for temperature extremes trend across eco-environments and seasons, whereas the perceptions on rainfall extremes vary with eco-environments and seasons. Moreover, household perceptions are sometimes at variance with recorded significant trends across eco-environments and seasons. Households in the pastoral eco-environment perceive changes in climate extremes better than households either in the agro-pastoral or mixed crop-livestock highland eco-environments. Household perceptions of the studied extreme events were significantly affected by a number of factors. Policy programs that enhance the literacy level of households and eco-environment based extension services may increase the level of awareness and understanding of climate change by households which help them better adapt to climate change.

4. INTER-CONNECTION BETWEEN LAND USE/LAND COVER CHANGE AND HERDERS'/FARMERS' LIVESTOCK FEED RESOURCE MANAGEMENT STRATEGIES: A CASE STUDY FROM THREE ETHIOPIAN ECO-ENVIRONMENTS

(Published in Agriculture, Ecosystems and Environment)

Abstract

We assessed land use/ land cover changes from remotely sensed satellite imagery and compared this with households perceptions on availability/use of livestock feed resources and feed deficit management strategies since the 1973 in three districts representing the pastoral, agro-pastoral and mixed crop-livestock eco-environments of Ethiopia. We found that land use/land cover changes are proceeding in all eco-environments and that transitions are from grasslands, and forest lands to bush/shrub lands and crop lands in the pastoral site (Liben), from bush/shrub lands and grasslands to crop lands in agro-pastoral site (Mieso) and from bush/shrub lands, forest lands and grasslands to crop lands in the mixed crop-livestock site (Tiyo). The changes significantly affected livestock feed resources and feed deficit management strategies available to households. Over the last 30-40 years, grazing resources available to livestock keepers have been declining with resultant increase in the contribution of crop residues and other feeds from crop lands (weeds and crop thinnings) as compared to feeds from grasslands. The feed deficit management strategies of households are also changing significantly from mobility to herd management and feed conservation in the pastoral areas; from mobility to feed conservation and purchasing of feed in the agro-pastoral areas and from transhumance to feed conservation and purchase of feed in the mixed crop-livestock areas. Hence feed resources and their availability vary with time and eco-environments indicating the need for the development of eco-environment/site specific feed management strategies in order to support productive stock in the study areas and similar eco-environments.

Key words: Eco-environment; Feed availability; Feed deficit management; Land use/ land cover

4.1. Introduction

Ethiopia while located in the tropics has wide eco-environmental settings that range from arid and semiarid tropical lowlands to cool afro alpine highlands and mountains. The warm and drier lowlands in the south east, eastern and north eastern part of the country are constrained by low and erratic rainfall for reliable crop production and are thus used for extensive pastoral livestock production (Coppock, 1994). On the other hand, the highland plateau and mountains above 1500 m asl constitute less than 40% of the total land mass of the country and are under extensive mixed crop-livestock production. In between these two systems there are transitional areas known as agro-pastoral areas that share the properties of both pastoral and mixed crop-livestock systems.

Across these eco-environments, numerous studies have been carried out to identify land use/land cover changes in relation to drought vulnerability (Biazin and Sterk, 2013) and community perceptions (Oba and Kotile, 2001; Oba and Kaitira, 2006; Beyene, 2009; Garedew *et al*., 2009). Many of these studies, however, focused on analysis of drivers of the changes (Reid *et al*., 2000; Amsalu *et al.*, 2007; Tsegaye *et al*., 2010; Meshesha *et al*., 2012; Biazin and Sterk, 2013), and only a few studies have dealt with consequences (Reid *et al*., 2000; Meshesha *et al*., 2012) and none have dealt with land use/land cover change in relation to availability and management of livestock feed resources.

Feed is an important component of livestock farming. The supply of feed both in quantity and quality determines productivity and profitability of farms (Sarwar *et al*., 2002). In Ethiopia, livestock feeds are derived mainly from annual foraging over large areas of grazing lands. Substantial amounts of feeds are also derived from crop residues, agro industrial by-products and other non-farm and farm products (Ibrahim, 1999; Habte, 2000; Mengistu, 2005; Tolera *et al*., 2012). The proportional contribution of these feed resources, however, is subject to variations in agro-ecosystem, farming system, and the type of animals reared (Aregheore, 2000**;** Rahman *et al*., 2008). Largely irreversible human activities over land surfaces including the clearing of forest, cultivation, overgrazing, settlements, industrialization, urbanization and other forms of land management (Meyer and Turner II, 1992; Reid *et al*., 2000; McCusker, 2004; Luoga *et al*., 2005; VanWey *et al.,* 2007; Garedew *et al*., 2009; Lambin and Meyfroid, 2011) are causing changes in land use and land cover patterns (Homewood *et al*, 2001; Feddema *et al.*, 2005) with resultant change in livestock feed resource composition, feed deficits and feeding management strategies. Because of these dynamic changes, traditional feed resources, and existing feeding management strategies are no longer adequate to sustain a productive livestock population (Benin *et al*., 2002; Sarwar *et al*., 2002).

In many areas, the traditional rangeland-based nomadic pastoral systems where livelihoods are based on extensive movements over vast areas of land are under threat (Coppock, 1994; Bollig and Schulte, 1999; Gebru *et al.*, 2003; Muller *et al*., 2007; Elias, 2008). Increased use of limited land for competing interests occasionally flares into conflicts among neighbours (Yemane, 2003; Beyene, 2009; Gizachew, 2012). As a result, as grazing resources decrease and the availability of by-products from farmland increase, changes are expected from grazing based feed deficit management strategies (mobility, transhumance, wet and dry season grazing) to non-grazing-based feed use and conservation strategies (purchase of feed, feeding of crop residues, use of agro industrial by-products) (Aerts *et al*., 2009, Dikshit and Birthal, 2010; Sarwar *et al*., 2002). In line with this, a study conducted in northern Ethiopia revealed that availability and use of communal grazing lands, private pastures, woodlots and forest areas as feed sources has significantly declined over the past decades and that this was mirrored by an increase in availability and use of crop residues and purchased feeds (Benin *et al*., 2002). Purchasing of feeds include agro-industrial by-products from market, crop residues, pastures and others from neighbouring farmers who have no animals to feed or sales of feed to obtain cash for various purpose.

The inter-connections of changes in feed resource with land use/land cover change, however, is less understood. On the one hand, long-term monitoring of land use /land cover from remotely-sensed satellite imagery and GIS gives quantitative information on the surface coverage of different land use/land cover categories or classifications. Combining satellite and GIS based land use/land cover information with household observations and practices on the ground could give a fuller picture of the effects of land use /land cover changes on feed resource availability and herders' and farmers' practices of feed deficit management. Therefore, this paper firstly, presents results of a land use/land cover monitoring exercise since the 1973 over three districts located in the three major eco-environments in Ethiopia. Secondly, household perceptions on the relative availability of different feeds and feed deficit management strategies in response to changes in land use/land cover over the last 30-40 years were assessed. Thirdly, we discussed implications of the temporal change in availability of different feeds and feed deficit management strategies on capacity of land to support productive stock.

4.2. Materials and methods

4.2.1. Description of the study areas

This study was carried out across three eco-environments in Ethiopia. These were the pastoral, agro-pastoral and the mixed crop-livestock systems. The pastoral eco-environment constitutes a significant part of the low lands below 1500 m asl. It covers extensive areas of, Oromia, Afar, Somali and the Southern Nations Nationalities and Peoples Region (SNNPR) regional states of the Federal Democratic Republic of Ethiopia. The pastoral eco-environment is not suitable for reliable rainfed crop production unless supplemented with irrigation (Coppock, 1994; Abebe, 2000; Desta, 2000). It is inhabited by about 12 % of the human and 24% of the livestock populations of the country (TECHNIPLAN, 2004). The highlands - dissected by the great Rift Valley into western and eastern highlands - constitute the central part of the country where precipitation is sufficient both in amount and distribution for good crop production. Thus the major land use in the highlands is extensive smallholder mixed crop-livestock production (Gebru, 2001). The highlands with less than 40% of the land mass of the country is populated by over 60% of the human and 70% of the livestock population of the country. The agro-pastoral eco-environment on the other hand, is intermediate between the more livestock-based pastoral and the crop-dominated highland systems. It is fairly widely distributed in a number of Ethiopia’s regional states without having the clear spatial coherence and boundaries characterizing the pastoral and mixed crop-livestock eco-environments.

From each of these eco-environments, one district typical of the respective eco-environment was randomly selected. Accordingly Liben, Mieso and Tiyo districts were selected from the pastoral, agro-pastoral and the mixed crop-livestock eco-environments, respectively.

Liben district is found in Guji Zone of the Oromia National Regional State to the south east of Addis Ababa (Figure 4.1). The district’s capital, Negele-Borana, is located at 610 km south of Addis Ababa. The district lies between 4°38’55” and 5°33’7” N latitude, and 39°9’25” and 39°58’37” E longitude. It has a semiarid climate with two wet and two dry seasons a year. The main rainy season lasts from March to May followed by a dry season in June, July and August and then by a small rainy season in September, October and November followed by another main dry season in December, January and February. It is sparsely populated with a typical pastoral livestock production system where herding is the main livelihood. The climatic conditions are summarized in Table 4.1.

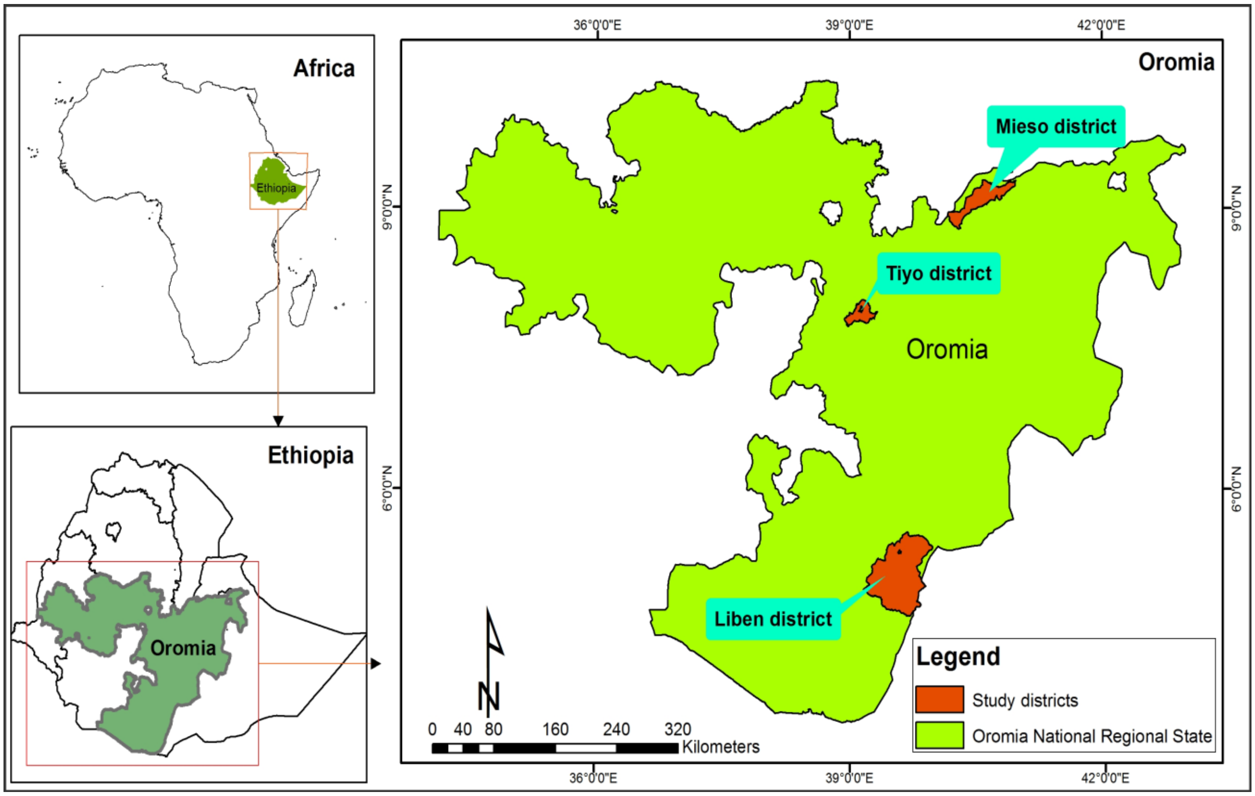

Figure 4.10 Geographic location of study districts with respect to Oromia National Regional State in Ethiopia.

Mieso district is found in the west Hararge Zone of the Oromia National Regional State in eastern Ethiopia within the Rift Valley system of the country (Figure 4.1). The district’s capital, also called Mieso is located 325 km to the east of Addis Ababa. The district is situated between

8°47’33” and 9°19’15” N latitude, and 40°9’20” and 40°58’8” E longitude. It has two rainy and one dry season in a year. The main rainy season lasts from June to September followed by dry harvesting season from October to January and the second small rainy season from February to May. It has a semiarid climate with highly erratic rainfall. Due to unreliable weather conditions, crop production is an opportunistic activity complementing livestock husbandry. Farmers in the district grow sorghum, maize and haricot bean as major crops. The climatic conditions are summarized in Table 4.1.

Tiyo district is located in Arsi Zone of the Oromia National Regional State. The district’s capital, Asela, is located 175 km south east of Addis Ababa (Figure 4.1). The district is bound between 7°45’13” and 8°2’26” N latitude, and 38°56’6” and 39°19’33” E longitude. It has two rainy seasons and one dry period in a year. The main rainy season lasts from June to September followed by dry crop harvesting season from October to January and the second small rainy season from February to May. The district is subtropical highland in climate, densely populated and is known for production of cool season crops such as wheat, barley, faba bean and field peas. The climatic conditions are summarized in Table 4.1.

Table 4.1. Surface area, elevation and summary of climatic variables in the study districts computed from data provided by National Meteorological Agency of Ethiopia(NMA) for Negele-Borana, Mieso and Asela weather stations located in Liben, Mieso and Tiyo districts, respectively for the period 1967-2008.

Description	**District**		
	Liben	**Mieso**	**Tiyo**
Surface area of the district (km^2)	5057	1457	605
Elevation range in the district (mamsl)	614-1639	823-2475	1653-3855
Mean annual rainfall (mm)	762.4	793.9	1149.0
Mean annual minimum temperature range (°C)*	10.0-19.5	4.2-21.6	4.9-10.3
Mean annual maximum temperature range (°C)*	18.4-31.4	21.6-37.1	18.3-24
Annual rainfall trend (mm/decade)**	+7.7	+1.9	+6.0
Mean annual temperature trend (°C/decade)**	+0. 64	+0. 13	+0. 67

* The minimum and maximum mean annual temperatures recorded during 1967-2008; ** is the increasing (+) or decreasing (-) annual trend during 1967-2008.

4.2.2. Satellite image interpretation

4.2.2.1. Data source and image pre-processing

For the purpose of this study, satellite images from different time periods were used for the interpretation of land use/land cover in the three districts. The images were from 1973, 1986, 2000 and 2007 and were downloaded from the Global Land Cover Facilities web site (http://www.glcf.umd.edu/data/landsat; http/glovis.usgs.gov/). The satellite images from different periods have different spatial and radiometric resolution. The 1973 Landsat (Multispectral Scanner (MSS) images have a spatial resolution of 60 m while the 1986 Landsat Thematic Mapper (TM), 2000 and 2007 Landsat ETM (Enhanced Thematic Mapper) have a spatial resolution of 30 m (Table 4.2). The images from the four years were geometrically rectified and registered to a common projection using Universal Transverse Mercator (UTM), Clarke 1880 Spheroid, and Adindan Zone 37 North datum. For compatibility purposes all the TM and ETM images were resampled, using the nearest neighborhood technique, to the spatial resolution of MSS image. The 1973 images have four bands and the 1986, 2000 and 2007 images have 7 bands hence image stacking was carried out. District boundaries also cover more than one pane image hence image mosaicing was carried out between adjacent panes and subsequently image subsetting was conducted based on district boundaries.

Table 4.2. Type of Landsat mapper, spatial resolution and image acquisition date.

Location	Path	Row	Type of Mapper	Resolution (m)	Acquisition date
Mieso	180	054	MSS	60	30 January, 1973
	179	054	MSS	60	12 December, 1973
	167	054	TM	30	30 January, 1986
	167	054	ETM	30	28 November,2000
	167	054	ETM	30	18 December, 2007
Tiyo	180	055	MSS	60	30 January,1973
	168	054	TM	30	21 January, 1986
	168	055	TM	30	21 January, 1986
	168	054	ETM	30	05 December, 2000
	168	055	ETM	30	26February, 2000
	168	054	ETM	30	09 December, 2007
	168	055	ETM	30	26 January, 2007
Liben	180	057	MSS	60	30 January, 1973
	180	056	MSS	60	30 January 1973
	179	057	MSS	60	29 January 1973
	179	056	TM	30	30November, 1975
	167	057	TM	30	14 January, 1986
	167	056	TM	30	16 December, 1986
	168	056	TM	30	21 January, 1986
	167	057	ETM	30	31 January, 2000
	167	056	ETM	30	28 December, 2000
	168	056	ETM	30	05 February, 2000
	167	057	ETM	30	05 March, 2007
	167	056	ETM	30	05 March, 2007
	168	056	ETM	30	07 January , 2007

ETM= Enhanced Thematic Mapper, MSS = Multispectral Scanner, TM= Thematic Mapper

4.2.2.2. Sampling design, image interpretation and accuracy assessment

For the purpose of this study stratified random sampling design was used. First district map was overlaid by high resolution Google Earth images (Spot 4 and 5 with spatial resolution of 10 m and 2.5 m, respectively). The images were then classified into six land use/land cover classes following the classification used to develop the land cover map of Africa (Mayaux *et al.*, 2004) with minor modification made to address the objectives of the present study (Table 4.3).

Table 4.3. Land use/land cover description in the three study eco-environments.

Ser.no.	LULC types	Description
1	Bare land	Rock outcrop with or without vegetation coverage <4 %, coarse fragments, /bare soil/loose and shifting sands, eroded lands, water bodies. No feed is expected to be available
2	Bush land	Open trees with open shrubs and open herbaceous, closed to open medium to high shrub land, closed to open medium tall herbaceous vegetation with low trees and shrub. The expected feed type is bush/shrub land grazing
3	Crop land	Rain fed herbaceous crop fields, surface irrigation herbaceous crop fields, herbaceous small fields with sparse trees. Expected feed type is crop residue and aftermath grazing
4	Forest land	Forest plantation or forestation, closed trees (dense forest) with a closed cover > 65%. The expected feed type is litter and under forest grazing
5	Grassland	Herbaceous closed to open medium tall vegetation (closed to open grassland). The expected feed type is open grazing
6	Settlement	Urban areas, any type of vegetated areas inside the urban areas, and rural villages, built up lands, roads. The expected feed type is food and beverage processing by-products usable as feed.

The land use/land cover classes were then divided into 60 m x 60 m pixels, and 300 sampling points (identified good enough to represent the study area after iteratively trying 250, 300 and

350 sampling points) were divided among the six land use/ land cover classes proportional to its area (Table 4.4), and randomly assigned to the 60 m x 60 m pixels (Appendix Figures 8.2.1, 8.2.2 & 8.2.3). The random seeded sampling points were then given independent identification numbers from 001 to 300.

Table 4.4. Area coverage and number of sampling points proportionally allocated to each land use/land cover classes.

Land use/land cover class	Area (km^2)*			# of allocated sampling points		
	Liben	**Mieso**	**Tiyo**	**Liben**	**Mieso**	**Tiyo**
Bare land (BRL)	252.8	34.0	6.1	15	7	3
Bush land (BUL)	3270.2	816.0	68.6	194	168	34
Crop land (CRL)	556.3	306.0	409.6	33	63	203
Forest land (FOL)	67.4	29.0	54.5	4	6	27
Grass land (GRL)	741.7	238.0	38.0	44	49	19
Settlement (ST)	168.6	34.0	28.3	10	7	14
Total	5057.0	1457.0	605.1	300	300	300

*Source: district offices of Agriculture

For change analysis, according to Loveland *et al.* (2002) the traditional automated to semi-automated change detection techniques which are based on spectral change information alone do not consider important change detection such as texture, shape, size and patterns. However, these components can be incorporated by a skilled analyst making visual interpretations of imagery (Loveland *et al.*, 2002). Hence instead of the classical resource and time extensive boundary based segmentation strategy commonly in use in the classical automatic classification schemes, we used an object based segmentation strategy (Loveland *et al.* 2002; Plourde and Congalton, 2003) in which point level on screen visual observation, classification of observations and manual coding of the classified observations were made on the randomly seeded observational points. The tagged sampling points were used as fixed reference points and the land use /land cover to which they refer was visually observed and classified into one of the land use/land cover classes. The process of visual observation and interpretation was carried out beginning with the Google Earth images (which served as land cover baseline template) and then switching backward to classify images of the 2007, 2000, 1986 and 1973 displayed by different windows.

Accuracy assessment was carried out on data of 2007 images by comparing with pseudo-ground-truthed data from the high resolution (2.5 m x 2.5 m for SPOT5 and 10 m x 10 m for SPOT4) Google Earth image. Error matrices that describe the patterns of mapped class relative to the reference data were generated, from which the overall accuracies, user's and producer's accuracies, and Kappa statistics were derived to assess the accuracies of the classification maps (Table 4.5).

Table 4.5. Accuracy assessment of classified image in to different land use/ land cover classes (comparing classification 2007 and Google Earth images).

Land use/cover class	**Accuracy %**					
	Liben		**Mieso**		**Tiyo**	
	Producer's	User's	Producer's	User's	Producer's	User's
Bare land (BRL)	66.67%	76.92%	57.14%	80.00%	66.67%	100.00%
Bush land (BUL)	98.45%	96.95%	95.24%	95.81%	58.82%	74.07%
Crop land (CRL)	81.82%	81.82%	90.48%	79.17%	98.52%	91.32%
Forest land (FOL)	75.00%	60.00%	66.67%	100.00%	62.96%	62.96%
Grass land (GRL)	79.55%	85.37%	77.55%	80.85%	52.63%	71.43%
Settlement (ST)	90.00%	81.82%	71.43%	100.00%	64.29%	81.82%
Over all accuracy	91.67%		89.33%		86.00%	
Kappa coefficient	0.86		0.83		0.71	

The land use/land cover output of the four periods were converted to dbf format and imported to Microsoft excel for further processing. The data were presented as percentage of the different land use/land cover classes and change detection matrix was derived to identify land use/ land cover transitions between 1973 and 2007 (Appendix Tables 8.1.1,8.1.2 & 8.1.3).

4.2.3. Household survey

4.2.3.1 Questionnaire preparation

Following the satellite image interpretation, a human centered survey was conducted in the three districts to understand the effect of the observed land use/land cover change on availability of feeds and feed deficit management strategies. Following initial level literature search and discussions with experts, check lists were prepared and used in group discussions with herders and farmers to elicit information on changes in availability and use of various feeds and management strategies over the last 30-40 years. Based on feedback, semi-structured questionnaires were prepared and tested with 10 randomly selected herders and farmers from each site. Questionnaires were then further refined and fully structured for the final interview.

4.2.3.2. Sample size determination

The ‘kebeles’ (the smallest administrative units below district) at the three districts were classified into three strata based on relative similarities in land use, agro ecology and farming system with the help of district level experts. From each stratum one kebele was randomly selected and a household census was conducted to gather information on household size, age and location (’got’) with the help of development workers at each kebele. Got is a cluster of houses in a given area within a kebele; sometimes it is synonymous with village. Household heads above 50 years old (assumed to have rich local knowledge) were identified as the study population and each was assigned a serial number which was later used for random selection of the interview households from each village/got. From a total of 1669 households across the study areas, 217 households with household heads above 50 years were selected for interview (Bartlett *et al*., 2001). The numbers of respondents per site were designed to be proportional to the overall population in each site (81, 44 and 92 from Liben, Mieso and Tiyo, respectively).

4.2.3.3. Household interview

The interviews were conducted either in houses of the respondent, at public meeting places, at livestock watering points or occasionally in other places. In case a household head could not be reached for various reasons or where they refused to be interviewed or had left the village for a time longer than the survey period, a replacement was selected by randomly selecting from the list of households in the same village/ got. During the interview, each respondent was provided with 100 maize seeds to share among different response options to show relative contribution of each feed type or management strategy to the total amount of feed or management strategies available to him/her both at present and 30-40 years ago. This was done for the major rainy, small rainy and dry seasons separately and later average values were taken for the analysis. The time taken to interview a respondent was recorded and found to vary from 1:00 to 1:30 h.

4.2.4. Data analysis

The data on households' response on relative contribution of each feed type (grazing, crop residue, agro industrial by-product, cultivated forage crops and other feeds from croplands), and the feed deficit management strategies (mobility, transhumance, feed conservation, herd management, purchase of feed and other supplementations) were subjected to a paired T test analysis to compare mean differences between past (30-40 years ago) and present (2011) conditions using SPSS for each site separately. Paired T test is chosen to be appropriate since the two sets of data to be compared are taken from same household heads and are thus paired. Significant differences were tested at 5% probability levels.

4.3. Results

4.3.1. Land use/land cover change for the period 1973-2007

The dominant land use/land cover type at Liben district is bush/shrub lands followed by grasslands (Figure 4.2). However, changes have occurred in land use/land cover over the study period. During the study period the area under bush/shrub land, bare land, crop land and settlements have shown positive changes. Between 1973-2007 bush/shrub land expanded most by 12% followed by cropland which has increased by 8.3% with rapid expansion since 1986. The areas under settlement and bare lands have shown the least increase at 3.3 and 2.2%, respectively. This indicates that bush/shrub land is the major source of livestock feed as the availability and use of grasslands and forest lands as feed sources have declined over the last decade. There has also been an increase in the area of crop lands along with bush/shrub lands and presumably an accompanying increase in livestock feed derived from crop sources.

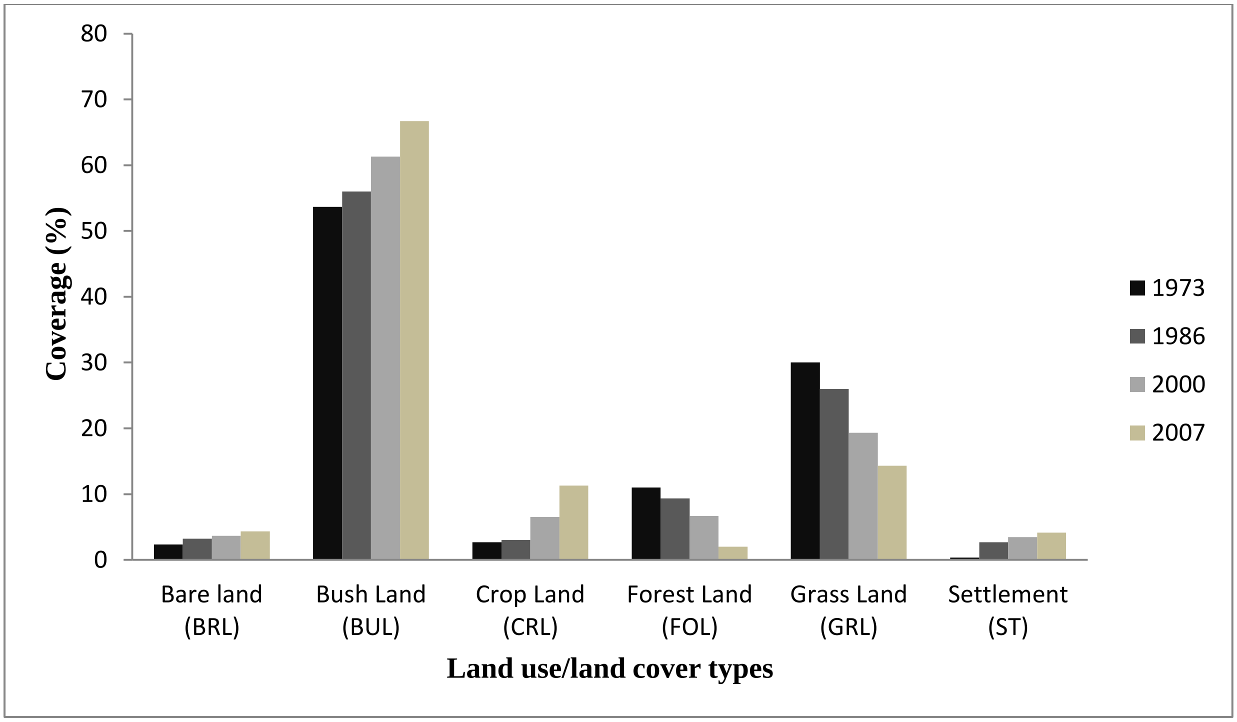

Figure 4.2. Land use/land cover changes in Liben district over the period 1973 and 2007.

Similar to Liben district, the landscape at Mieso has been dominated by bush/shrub coverage (Figure 4.3). Over the study period, however, crop land has expanded by 13.0%. Settlement and bare lands have also shown positive change each by 1.3%. On the other hand, the area under bush/shrub land and grasslands retracted by 12.3 and 3.3%, respectively. The area under forest coverage is small (1.3%) and remained almost unchanged over the study period. Similar to the results in Liben district, bush/shrub land is found to be the major source of feed in Mieso district. However, the availability and use of bush/shrub land and grasslands as feed sources have declined over the last decade leading to an increase in availability and use of feeds from crop lands.

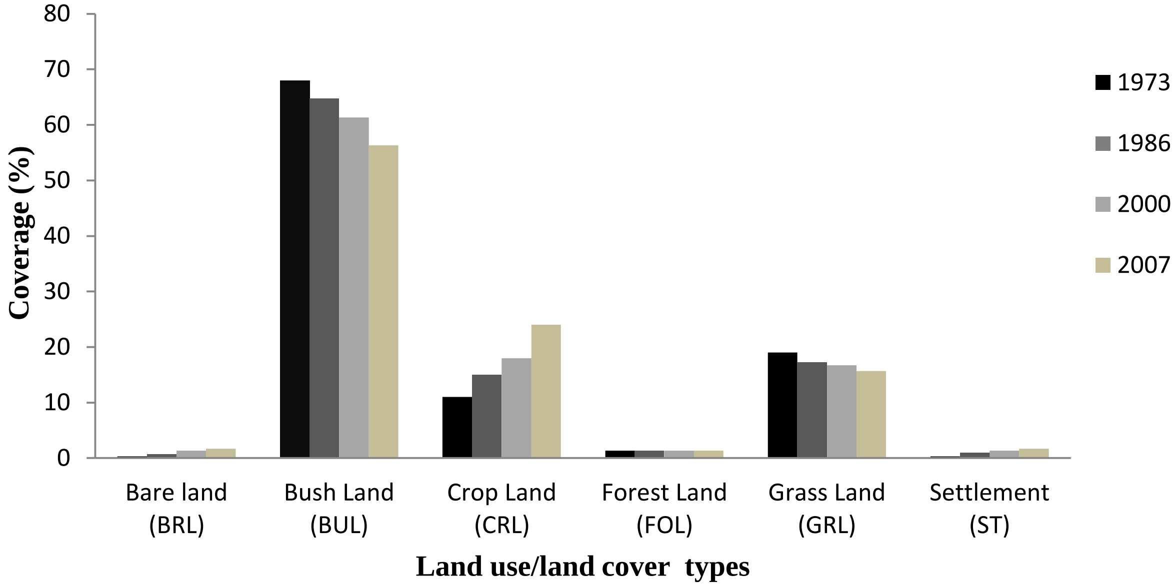

Figure 4.3**.** Land use/land cover changes in Mieso district over the period 1973 and 2007.

Unlike the situation in the pastoral and agro-pastoral districts, the landscape in Tiyo district has been dominated by crops (Figure 4.4). The area under crop land has expanded by 21.3%, whereas the area under settlements and bare lands increased by 3.0 and 0.3%, respectively. On the other hand, bush/shrub land, forest and grasslands have decreased throughout the study period. The area under grasslands contracted greatly by 15.0%. Bush lands and forest lands have decreased by 7.0 and 2.7 %, respectively. The results in general indicate that crop land has become the major source of feed in Tiyo district while there has been a rapid decline of feeds from bush/shrub land, forestland and grasslands.

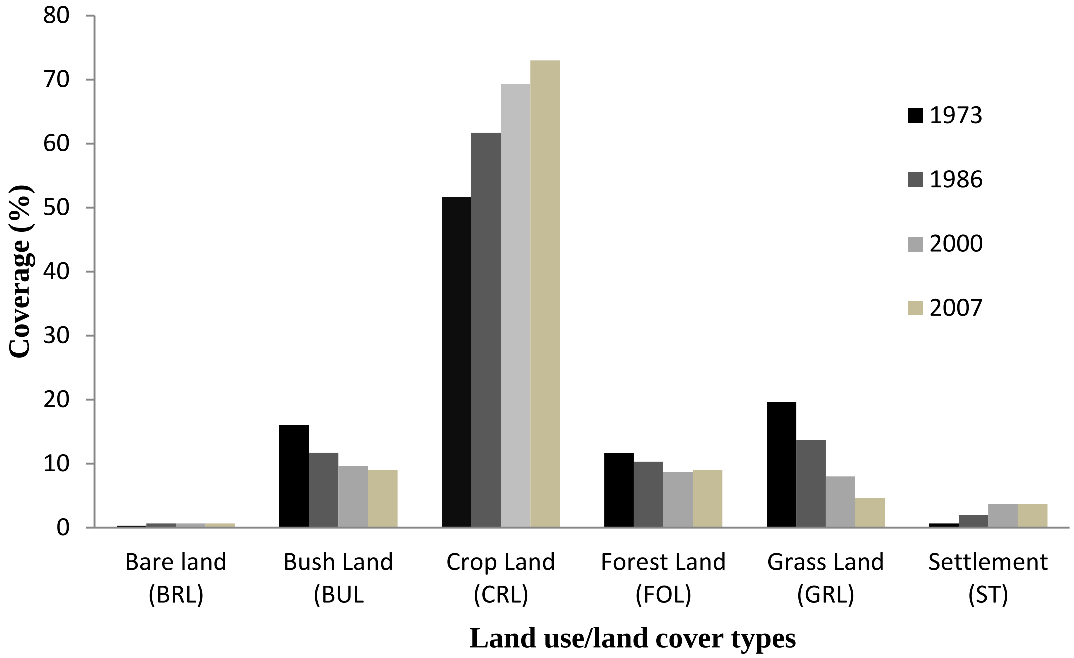

Figure 4.4 Land use/land cover changes in Tiyo district over the period 1973 and 2007.

4.3.2. Effect of land use/land cover change on availability of feeds

As shown in Table 4.6, the available feeds identified during discussion with household heads include grazing, crop residues, agro-industrial by-products (flour mill by products, oil seed mill by products, etc.) cultivated forage crops and other categories of feeds from crop lands. The relative contribution of these different categories of feed resources, however, differed between past (30-40 years ago) and present conditions with a significant difference between the two periods. In the past, grazing was the most available feed for households accounting for 100% of the total feeds available to households in Liben, 95.0% in Mieso and 70.0% in Tiyo. However, the contribution of feed from grazing has significantly decreased over the last 30-40 years by about 16.3% in Liben, 63.3% in Mieso and 37.3% in Tiyo. On the other hand, the contribution of crop residues and other feeds from crop lands have significantly increased and become the major feed available to the households at present in Mieso and Tiyo. The contribution of crop residues increased from nil to 9.4% in Liben, by 32.9 % in Mieso and by 29.5% in Tiyo. Similarly, the contribution of other feeds from crop lands increased by 6.6, 30.3 and 2.9% in Liben, Mieso and Tiyo districts, respectively. The use of agro industrial by-products has also significantly increased over the past 30-40 years in Tiyo. In Liben it increased from nil to 0.3% and in Tiyo from 6.2% to 10.8%. This shows that grazing resources have been diminishing over the years with conversion of large areas of grazing resources such as bush/shrub lands, forestlands and grasslands to croplands. As a result, availability of feeds from crop lands such as crop residues and others such as weeds and thinnings have increased in importance as feeds available to the households (Table 4.6).

4.3.3. Effect on feed deficit management strategies

During group discussion, herders and farmers identified a list of management strategies employed to overcome seasonal and long term shortages of feed (Table 4.7). These include mobility where herds are continually moved in search of pasture; transhumance (’godantu’) where the entire herd or selected animals are seasonally sent with an attendant to a specified grazing area for a short period of time; feed conservation where feeds are reserved or conserved for use during certain periods of the year; herd management/destocking where certain animals are removed from the herd and or the type of animal changed; purchase of feed where a certain feed type is purchased from market or neibhouring farmers. As was the case for feed availability and use, the contribution of these different categories of feed deficit management strategies differed across location and time.

In Liben district, salt supplementation and mobility were the major strategies, followed by feed conservation and herd management both in the past and present times. However, the contribution of mobility as a coping strategy significantly decreased by 8.8% over the last 30-40 years. On the other hand, there has been a significant increase in herd management by 7.4% and feed conservation by 3.3% in the same district (Table 4.7).

In Mieso, mobility was the major strategy 30-40 years ago accounting for 70.5% of all the feed deficit management strategies available to the households followed by transhumance (18.6%) and feed conservation (6.8%). Over the years, however, the use of mobility as a strategy has significantly decreased by 58.5%. Presently, feed conservation (64.5%) followed by transhumance (15.6%) and mobility (12.0%) have become the major strategies used by households in the district. Over the last 30-40 years, feed conservation and purchase of feeds significantly increased by 57.7% and 6.3%, respectively (Table 4.7).

In Tiyo district, feed conservation was the major strategy used by the household, both in the past and present. Over the years, the use of conserved feed and purchase of feeds has significantly increased by 7.0% and by 11.9%, respectively. On the other hand, the use of transhumance as strategy significantly decreased by 14.9% (Table 4.7).

Table 4.6. Types of available feed resources and relative contribution of each to the total feed resource available to households 30-40 years ago and at present time (2011) in Liben, Mieso and Tiyo districts in Ethiopia as reported by respondents.

Type of feed resource	**Liben(Pastoral)**			**Mieso(Agro-pastoral)**			**Tiyo(Mixed crop livestock highland)**		
	30 -40 years ago	**Present (2011)**	**Significance**	**30 -40 years ago**	**Present (2011)**	**Significance**	**30 -40 years ago**	**Present (2011)**	**Significance**
Grazing	100	83.7	*	94.7	31.4	*	69.7	32.4	*
Crop residue	0	9.4	*	5.0	37.9	*	19.1	48.6	*
Agro industrial by-products	0	0.3	*	0	0		6.2	10.77	*
Cultivated forage crops	0	0.1	ns	0	0		0.6	0.9	ns
Other feeds from crop lands (weeds, thinnings)	0	6.6	*	1.3	31.6	*	5.1	8.0	*
Total	100	100		100	100		100	100	

Note values are means of n=81 for Liben; n=44 for Mieso and n=92 for Tiyo;* Significant at 5% probability level; ns = non-significant at 5% probability level.

Table 4.7. Types of available feed deficit management strategies and relative contribution of each strategy to the total coping strategies available to households 30-40 years ago and at present time (2011) in Liben, Mieso and Tiyo districts in Ethiopia as reported by respondents.

Type of feed deficit management strategy	**Liben(Pastoral)**			**Mieso(Agro-pastoral)**			**Tiyo(Mixed crop livestock highland)**		
	30-40 years ago	**Present (2011)**	**Significance**	**30-40 years ago**	**Present (2011)**	**Significance**	**30-40 years ago**	**Present (2011)**	**Significance**
Mobility (nomadism)	34.0	25.2	*	70.5	12.0	*	2.6	0.1	ns
Transhumance (‘godantu’)	10.7	10.4	ns	18.6	15.6	ns	15.1	0.2	*
Feed conservation	13.9	17.2	*	6.8	64.5	*	65.8	72.8	*
Herd management/ destocking/	11.2	18.6	*	3.3	0.9	ns	6.9	6.5	ns
Purchase of feed	0.3	1.5	ns	1.2	7.5	*	1.7	13.6	*
Other supplementations (salt, grain)	29.9	28.8	ns	0.5	0.5	ns	7.9	6.8	ns
Total	100	100		100	100		100	100	

Note values are means of n=81 for Liben; n=44 for Mieso and n=92 for Tiyo ; * significant at 5% probability level; ns non-significant at 5% probability level.

4.4. Discussion

4.4.1. Land use/land cover change

During the 34 year study period (1973-2007) the three study sites have experienced persistent land use/ land cover changes as in many parts of the country (Reid *et al*., 2000; Mesele *et al*., 2006; Amsalu *et al.,* 2007; Tsegaye *et al*., 2010; Meshesha *et al*., 2012; Biazin and Sterk, 2013) and the rest of the sub-Saharan Africa region (Petit *et al*., 2001; Serneels *et al*., 2004; Mengistu and Salami, 2007; Baldyga *et al*., 2007; Kiage *et al*., 2007). Among the studied major land use/land cover categories, crop lands have generally increased throughout the period complementing global reports (Goldewijk and Ramankutty, 2004) while those of grasslands and forest lands have decreased. On the other hand, the area under bush/shrub lands has increased in Liben and decreased in Mieso and Tiyo. These changes could be related to biophysical and socioeconomic dynamics at local, national, regional and/or global level. Social factors such as human and livestock population pressure, land tenure arrangements and poverty and natural conditions such as climate are common causes of land use/land cover changes (Mengistu and Salami, 2007; Zak *et al*., 2008; Tsegaye *et al*., 2010; Meshesha *et al*., 2012; Biazin and Sterk, 2013).

In the past three decades, both the mixed crop-livestock and pastoral and agro-pastoral eco-environments experienced rapid increase in human population with concomitant need for subsistence crop and livestock production systems (Thornton, 2010; Tolera *et al.,* 2012). As a result forest lands, bush/shrub lands and grasslands are increasingly brought under heavy pressure to feed the ever increasing human population (Garedew *et al*., 2009; Biazin and Sterk, 2013) and the remaining grazing lands are subject to over stocking (Tessema *et al*., 2011).The net effect of these changes is land degradation and increased coverage of bare lands. Due to repeated cycles of drought and famine episodes (Udessa, 2001, Desta and Coppock, 2004; NMA, 2007), herders and farmers are forced to adopt new systems of livelihood diversification based on unreliable crop cultivation (in pastoral areas) and clearing of woody vegetation for charcoal and lumber making and wood logs to sell in urban areas and for home use (Garedew *et al*., 2009; Tsegaye *et al*., 2010).

At the same time use of fire to clear vegetation was banned by government in the 1970’s which led to encroachment of undesirable bushes and shrubs on the rangelands at the expense of grasslands (Angassa and Oba, 2008; Mesele *et al.,* 2006; Haile *et al*., 2010) contributing to the observed increase in bush/shrub land in Liben. The different land tenure systems adopted by successive governments in Ethiopia and lack of policy and regulation enforcements during transition times also aggravated land use/ land cover changes (Beyene, 2009; Meshesha *et al*., 2012; Rashid and Negassa, 2012; Biazin and Sterk, 2013) in the study areas.

4.4.2. Effect of land use/land cover change on availability of feeds to households

The perceived decline in contribution of grazing to the total feed available to the households is in line with the observed decrease in areas of bush/shrub land, grasslands and forestlands among the mixed crop-livestock (Tiyo) and agro-pastoral (Mieso) districts, but in contradiction with the observed increasing bush/ shrub land coverage in the pastoral (Liben) district. This could be because of increase in density and area coverage of thorny bush and shrubs that makes the land inaccessible to grazing stock (Angassa and Oba, 2008), less grazing land productivity due to competitive decrease in population of the most palatable grass species and conversion of productive grazing lands to crop lands (Oba and Kotile, 2001; Abebe *et al*., 2012).

As grazing resources are progressively transformed into crop land, feeds of crop land products and/or by-products become major feed resources available to households in the mixed crop-livestock highland (Tiyo) and in agro-pastoral (Mieso) areas. Moreover, since crop residues are available only after harvest, farmers are increasingly relying on feeds from maize and sorghum fields (major crops of agro-pastoral areas) sown at high population density through thinning, leaf stripping and weeding (Gebremedhin *et al*., 2007; Tolera *et al.,* 2012). Presently these feed resources have become as important as grazing resources in Mieso district. On the other hand, the contribution of these feed resources at present is low in Liben although it is expected to increase with expansion of crop lands in the near future. Areas of crop production are expected to increase substantially over the coming years in all pastoral areas of the country due to the government's plan to sedentarize pastoralists with the provision of improved drought tolerant crop varieties, irrigation facilities and crop management options (Government of Ethiopia, 2001).

The availability and use of agro-industrial by-products depend on availability of food and/or beverage processing plants near to the study sites (Aregheore, 2000**;** Tolera *et al.,* 2012). In Tiyo district, farmers have long had access to several small to medium scale oil and flour processing plants. In the pastoral and agro-pastoral districts, farmers and pastoralists have been exposed to the use of agro-industrial by-products through emergency relief aid (Gizachew, 2012) although availability is limited. Similarly, efforts have been under way to promote forage crops cultivation in all eco-environments (Assefa, 2012) although the contribution of such crops to the total feed availability of households is small (Tefera *et al*., 2010) and has not changed over the last 30-40 years in any of the study sites.

4.4.3. Effect of land use/land cover change on feed deficit management strategies of the households

In the past mobility was a major means of overcoming shortages of feed in the pastoral (Liben) and agro-pastoral (Mieso) areas because of free access to large tracts of land. The observed decline in grazing resources at all sites coupled with land fragmentation due to increased crop encroachment (Desta, 2000; Reid; *et al*., 2004), privatization of communal grazing lands and fencing of the most important grazing lands (Angassa and Oba, 2008; Napier and Desta, 2011), increase in bush density in Liben (Angassa and Oba, 2008) and inter- and intra-ethnic conflicts in Mieso and Liben (Beyene, 2009; Udessa, 2001) has reduced land area available for the free movement of livestock. Moreover, repeated loss of animals to droughts and the decline in per capita livestock holdings has weakened many households (Udessa, 2001; Desta and Coppock, 2004) and reduced the need for pastoral mobility among many pastoral households. Likewise, the contribution of transhumant movements of the herd as a means to overcome seasonal shortage of feed in mixed crop-livestock highland (Tiyo) has significantly declined due to expansion of large scale commercial crop farms in the 1970's and

1980's and subsequent conversion to arable production of forest and bush/shrub land areas to which farmers used to move their herds (Clapham, 1988; Macharia and Ekaya, 2005).

On the other hand, the contribution of feed conservation strategies has increased over the last 30-40 years. Such strategies include heaping of crop residues instead of burning on threshing fields among mixed crop-livestock keepers and agro-pastoralists; standing hay preparation through fencing of grazing land for private, semiprivate and communal use instead of the traditional wet and dry season communal grazing in the pastoral and agro-pastoral areas (Scoones, 1991; Coppock, 1994; Angassa and Oba, 2008); purchase of agro-industrial by-products from nearby markets, use of neighbours crop residues and plots of grazing lands when neigbours have few or no animals. Herd management through changing the type of animals kept from cattle to camels and poultry is also common among the pastoralists (Desta and Coppock, 2004; Abebe *et al*., 2012).

4.4.4. Implications of the changes in feed resources and management to support productive stock

Many studies have shown the wide gap between current available livestock feed and demand for such feed (Benin *et al*., 2002; Sarwar *et al*., 2002; TECHNIPLAN, 2004; Berhe *et al*., 2013). Land use/land cover change induced transition from grazing to non-grazing based feed resources has led to increasing feed shortages. Crop residues which now account for over 50% of the feed resources of the country are low in nutritional value (Habte, 2000), and a substantial proportion is lost to spoilage during both storage and use (Tolera *et al.*, 2012). The energy-and protein-rich agro-industrial by-products often in use to enhance nutritional values of crop residues are also constrained by limited availability and unaffordable prices due to export of oil seed crops (Tolera *et al.*, 2012).

Moreover, the use of high yielding crop varieties with high nutrient requirement (Gebremedhin *et al*., 2007); increased removal of crop residues; increased stall feeding and back yard disposal of excreta (Haileslassie, 2007) or use of dung for fuel (Amsalu *et al.*, 2007) are increasingly removing nutrients from farm lands. These accompanied with low rates of external fertilizer application (Spielman *et al.*, 2012) disrupt nutrient cycling in cultivated lands and have led to a decline in long term productivity of land (Braimoh and Vlek, 2004; Schlecht *et al*., 2004; Biro *et al*., 2013).

In the pastoral areas around Liben, crop cultivation and rangeland fencing have become widespread since the 1983-85 droughts to deal with human food gaps created by massive cattle mortality (Angassa and Oba, 2008; Desta and Coppock, 2004; Tache and Oba, 2010). The expansion of crop cultivation and private and semiprivate fencing into the prime grazing rangelands, however, is perceived as a serious threat to livestock production and traditional resource management practices (Reid *et al*., 2004; Solomon and Snyman, 2007; Tache and Oba, 2010) because of crop failure due to unreliable rainfall (Angassa and Oba, 2008). Successful crop harvests in the pastoral areas are possible only once in every three years or so (Desta and Coppock, 2004) and the productivity is only 31% of the average national grain yield of Ethiopia (Tache and Oba, 2010). Such frequent crop failures and low productivity result in less crop residues and increased removal of valuable grass species from the land. Private or semiprivate grazing land fencing reduces free movements of livestock, limits access to other communities and increases over stocking on remaining communal lands (Angassa and Oba, 2008; Napier and Desta, 2011). This ultimately results in severe over-grazing, declining livestock productivity and greater vulnerability to drought.

The results imply the need for appropriate policy and development measures for planned and regulated land use management. Further measures such as population growth regulation, keeping fewer improved productive livestock, technical interventions to improve the nutritive value of crop residues, develop suitable crop varieties and agronomic management options to improve the quantity and quality of thinnings from cropland, increasing domestic processing and availability of by-products, minimizing feed losses and improving the efficiency of various feed conservation strategies could have potential positive effect on feed availability.

4.5. Conclusions

From the results of the present study, it is clear that land use/land cover changes are occurring in all eco-environments of Ethiopia. The changes in land use/land cover have significantly affected feed resource availability and the feed deficit management strategies of households in the study areas. The transitions in the type of the available feeds from grazing to non-grazing (crop residues, agro-industrial by-products, weeds and thinnings) resources, and the feed deficit management strategies from mobility and transhumance to feed conservation and purchase of feeds have not been able to meet growing feed demands of households in many of Ethiopians major eco-environments. Among contributing factors are low productivity of fragmented land, low availability and quality of feed and feed losses at storage and use. The results suggest the need for land use based on its capability; improving the quantity and quality of available feeds, improving the genetic makeup of animals towards efficient use of available feeds and high productivity, providing alternative means of traction as well as improving the efficiency of site-specific feed conservation strategies through research and development interventions in order to support productive stock in the respective eco-environments. Further research is required on productivity of the different land use, quantity and quality of the different feed resources and feed balance across the different eco-environments.

5. MODELING THE RESPONSE OF TROPICAL HIGHLAND HERBACEOUS GRASSLAND SPECIES TO CLIMATE CHANGE: THE CASE OF THE ARSI MOUNTAINS OF ETHIOPIA[3]

(Published in Biological Conservation)

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[3] The same with the published version but contain minor additional information on distribution of grass species by photosynthetic pathways.

Abstract

Global warming is forcing plant and animal species to respond either through pole-ward or upslope migration to adjust to temperature increases, and grassland communities are no an exception to this phenomenon. In this study, we modeled the response of herbaceous species of grasslands within the Arsi Mountains in Ethiopia under no-migration and with migration scenarios to the projected 4.2 ^{o}C increase of temperature by 2090 (under the A2 emission scenario). For 67 species of grasses and legumes, we determined the current and predicted altitudinal limits and calculated current and projected area coverage using a Digital Elevation Model. The results indicated that the projected warming significantly reduced altitudinal ranges and habitat areas of all the species studied. All the studied species faced range contraction and habitat loss with range shift gaps among forty two species under the no-migration scenario. With the migration scenario, however, the forty two species with range shift gaps are predicted to benefit from at least some habitat area retention. Between growth forms, legumes are predicted to lose significantly more habitat area than grasses under the no-migration scenario while no significant difference in habitat area loss is predicted under the migration scenario. It can be concluded that management options are required to facilitate upslope species migration to survive under the warming climate. This could involve leaving suitable dispersal corridors and assisted colonization depending on species behavior and level of extinction risk predicted under the projected warming.

Key words: Altitudinal range; Grass; Legume; Migration; No-migration; Warming

5.1. Introduction

Grasslands constitute a significant portion of the tropical environment, and the area under grasslands is contracting over time due to crop land expansion, increased intensity of grazing, and an overall environmental degradation. Grasslands are highly responsive to temperature, precipitation and grazing pressures (Adler and Levine, 2007; Anderson, 2006; Vicca *et al*., 2007; White *et al.*, 2012). The distribution of grasslands is determined by many environmental factors among which climate, mainly through temperature, determines floristic distributions along altitudinal gradients (Pausas and Austin**,** 2001; Colwell and Rangel, 2010). Among the dominant and important floristic constituents of grasslands, grass species have a wider range of adaptation to the different climatic gradients than any other family of flowering plants, while legumes have a relatively narrow range of adaptation (Gebru, 2009).

However, the current global warming in conjunction with increased grazing pressure and land use for other purposes places pressure on the distribution and floristic composition of grasslands (Klein *et al*., 2007). Under warming scenarios, climate change will induce upward species movements as long as the elevation of the landscape will allow this to happen (Colwell *et al*., 2008; Kreyling *et al.*, 2010; Laurance *et al*., 2011; McCain and Colwell, 2011; Sheldon *et al*., 2011). However, the net movement of species upslope could lead to disappearance and decline of species in the lowlands, and at lower elevations, and also lack of a source pool of species adapting to higher temperatures to fill gaps causing 'lowland biotic attrition' (Colwell *et al.*, 2008; Feeley and Silman, 2010). On the other hand, there could be extinction of mountain top species where there are no more escape routes available to move into (Colwell *et al.,* 2008; Jansson, 2009; Kreylinget *et al*., 2010).

The response to the observed and predicted climate change, however, is species and mountain range specific (Pauli *et al.,* 1996; Klanderud, 2008). Some species are unable to shift into a newly suitable geographic range due to dispersal barriers and/ or insufficient dispersal capabilities related to species differences, altered species interactions, phenology, resource availability, loss of dispersal vectors and other factors causing extinction risks without species range shift (Feeley and Silman, 2010, Larsen *et al*., 2011; Friggens *et al*., 2012; Urban *et al*., 2012). Many mountain plant species are slow growers with narrow habitat bounds. They tend to be intolerant to competition from the incoming fast-growing lowland species which are therefore more likely to expand into new regions because of their wider range of adaptation (Cochrane, 2011; Angert *et al.,* 2011; Hoiss *et al.,* 2013). As a result, range differences between present and future ranges- 'range shift-gaps' develop earlier for narrow-ranged species (Colwell *et al.,* 2008). Furthermore, human-induced disturbances through land fragmentation and heavy grazing pressure in many tropical mountain areas, including in Ethiopia, have left very narrow strips of road side, farm boundaries, river banks, very steep slopes and very isolated patchy area closures or refugia as dispersal corridors available for species redistribution. The opportunities for a species to move freely elsewhere are limited. Thus because of climate-driven habitat loss, increased physiological stress, extreme climatic events, changes in fecundity and other factors (Pauli, 1996; Feeley and Silman, 2010, Larsen *et al.,* 2011), the chance for extinction or population decline at a given site is high (Colwell *et al.,* 2008).

Thus a priori knowledge of which species are likely to exhibit range shift-gaps, range contractions, habitat area loss, habitat area gain or extinction risk under global warming would be of great benefit to resource managers and others (Angert *et al*., 2011). An effective response to these threats requires reliable information on which species are likely to be threatened (Akcakaya *et al*., 2006) under two scenarios. The first scenario is where the species will not have the chance to shift its current upper range limit due to lack of dispersal corridors or suitable habitat to move into while there will be climate forced shift in its lower altitudinal range limit. The second scenario is where each species is not subjected to anthropogenic barriers and has suitable dispersal corridors to shift both its upper and lower altitudinal limits. Hence, this paper presents predicted responses of economically and environmentally important herbaceous grassland species of the Ethiopian highlands to the two scenarios, taking the case of the Arsi Mountains. We use the model developed by Colwell *et al*. (2008) which has also been used for similar studies by Kreyling *et al.* (2010) and Feeley and Silman (2010).

5.2. Materials and methods

5.2.1. Description of the study area

The study area is located in the Arsi Zone of the Oromia National Regional State, Ethiopia and extends from 7^{o}27$^{’}$46.048’’N to 8^{o}24’54.605’’N latitude and 38^{o}59’32.009’’E to 39^{o}37’55.082’’E longitude within the central highlands of Ethiopia. The landscape is generally sloped with increasing altitude from the lowest point in the Central Rift Valley (less than 1500m) to the highest point at Chilalo Mountain (4036 m) (Figure 5.1).

Modified by altitude, the climate of the study area varies from warm tropical conditions in the Rift Valley to cool Afro-alpine highland conditions in the mountains. The area has three annual seasons: the dry season - October to January, the small rainy season- February to May and the main rainy season-June to September. The mean annual rainfall varies from 663 mm (1967-2008) at Koka (1595 masl) in the Rift Valley to 817 mm (1967-2008) at Kulumsa (2200 masl) and 1149 mm (1967-2008) at Asela (2350 masl). The mean daily maximum to minimum temperature range also varies from 29.8 - 14.9^{o}C (1967-2008) at Koka to 23.1-10.0^{o}C (1967-2008) at Kulumsa and 21.5 - 9.0^{o}C (1967-2008) at Asela.

The vegetation of the study area varies from the Acacia-wooded grassland in the Central Rift Valley to the degraded montane and Afro-alpine forests and associated grassland in the highlands (White, 1983; Friis, 1992). The lowlands in the Rift Valley were once dominated by Acacia woodland but much of the land is now under cultivation with beans, maize, sorghum, teff and wheat. The mid altitudes to highland areas are dominated by plantations of exotic *Eucalyptus* species. The native montane tree species such as *Cordia africana, Juniperus procera, Hagenia abyssinica, Olea africana* and *Podocarpus fulcatus* have steadily disappeared with small remnants scattered in agricultural fields and small uncultivated areas (personal observation). A large area of land is under extensive cultivation of barley, faba bean, field pea, flax, rapeseed and wheat. The upper region, above 3000 masl is home for the endemic Mountain Nyala (*Tragelaphus buxtoni*) and is dominated by Hagenia-Juniperus vegetation types. The upper extremes (above cultivation limit) are covered by species of

Artemisia, Erica and Hypericum (Friis, 1992; Evangelista *et al.*, 2007) while the upper most extremes are covered by *Helichrysum*, *Lobelia*, *Alchemilla*, etc (Zerihun personal communication). At present much of the Afro-montane forest has been cleared and replaced by cultivation of cereal crops. It is common to see barley cultivated at above 3400m asl extended beyond the 3200m limit reported in 1989 (Evangelista *et al*., 2007). Such progressive encroachment of cultivation although primarily due to increasing human demographic pressure, might also be a sign of rising temperatures opening up higher areas for cultivation.

5.2.2. Sampling

A total of 60 observational plots, each 50m by 50m, were surveyed at the end of the main rainy season when the majority of grasses and legumes come into flower. Sampling thus took place between August in the Rift Valley and October 2010 in the mountains. Sampling was done along an altitudinal gradient from Rift Valley starting at 1342m southward upto 3410 m altitude on the Chilalo Mountain. Beyond this limit we were not able to sample on moorlands because of heavy grazing pressure by domestic animals during the main rainy season and intensive Giant mole-rat foraging and damage leading to an absence of vegetation cover to sample.

The major part of the land in the study area is kept under extensive cultivation and hence sampling was conducted on plots scattered along an altitudinal gradient on lands not cultivated for a minimum of five years. Sampling sites included un-grazed sanctuaries, farm land boundaries, hill sides, road sides, river and stream sides, enclosures, school yards, church yards and other institutional compounds and grazing lands. For each sampling plot a quadrat of 1m^2 was thrown and the central point was used as a reference point. Specimens of grasses and legumes located within 25m radii to the north, south, east and west of the reference point were collected and identified at the International Livestock Research Institute (ILRI) Addis Ababa Herbarium facility and the National Herbarium of Addis Ababa University. Identification and nomenclature of voucher specimens followed Hedberg and Edwards (1989) and Phillips (1995). For each plant species we recorded geo-references and altitudes with GPS.

5.2.3. Estimation of current and future altitudinal range of plant species

The altitudinal range was assigned to be zero for species recorded only at one sampling plot and these were excluded from the analysis. All the noted ranges were interpolated by assuming continuous ranges from lowest to the highest occurrence in the data set. The current range of occurrence for each species was determined as 2.5% and 97.5% quintiles of the actual observed lower and upper altitudinal limit, respectively for each species as indicated by Feeley and Silman (2010) rather than range estimate downslope or upslope half-way to the nearest plot and extrapolating halfway to the altitude of the lowest and the highest points (Colwell *et al*., 2008 and Kreyling *et al*., 2010). This was to minimize the influence of outliers that can arise from geo-referencing errors particularly at the lowest and the highest points.

The future range limits for 2090 were projected under two scenarios. The first scenario is termed the no-migration scenario where the species will not have the chance to shift its current upper limit due to lack of suitable dispersal corridors or suitable habitat to move upslope while there will be a shift in its lower altitudinal limit.

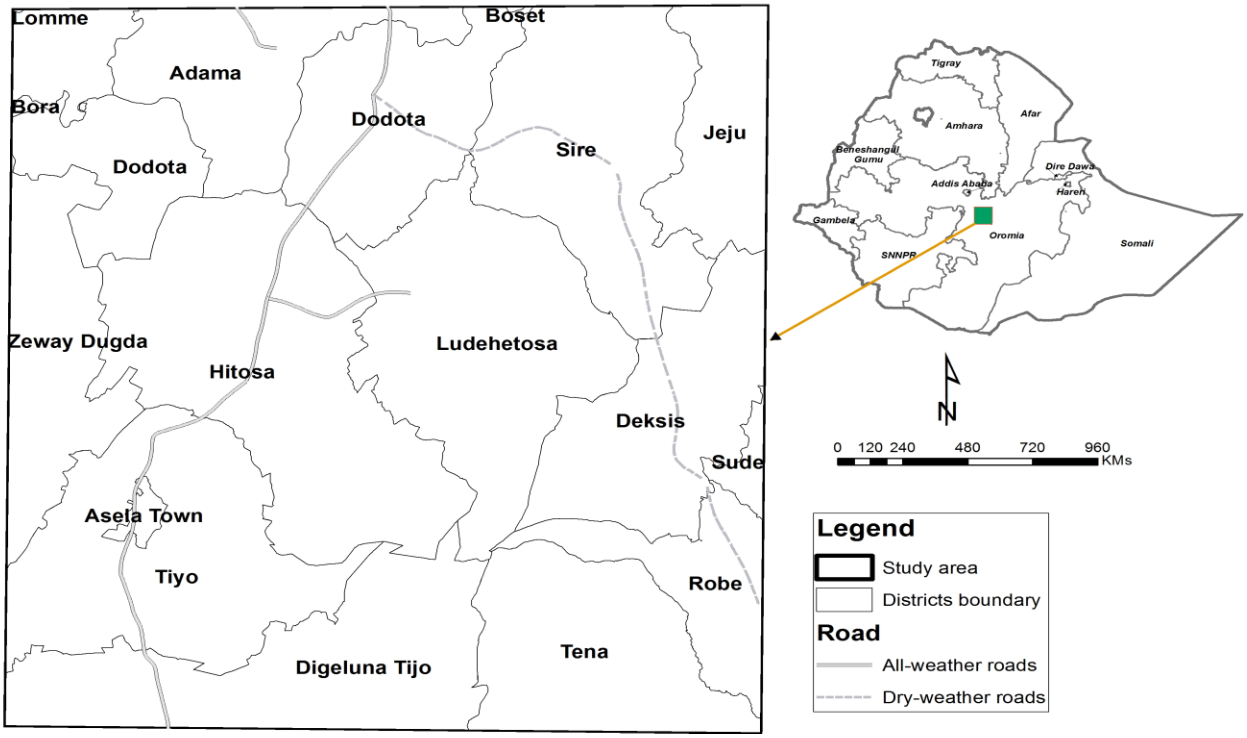

Figure 5.1. Map showing location of the study area in Ethiopia.

The second scenario, termed the migration scenario is where each species has no anthropogenic barriers and has suitable dispersal corridors left to shift both its upper and lower altitudinal limits. The range limits for these two scenarios were estimated by adding 700m to both the current upper and lower range limits in case of the second scenario and by adding 700m only to the current lower limits while the current upper limit remain unchanged for the no-migration scenario. The 700m estimate of altitudinal shift is a predicted response of species to 4.2^{o}C increase of temperature estimated for Ethiopia for 2090 (McSweeney *et al.,* 2010) under the A2 emissions scenario with the adiabatic lapse rate of 0.6^{o}C/100 m (Kreyling *et al.,* 2010). Species range shift gaps, area, attrition, range contraction and extinction risks were estimated as follows under both scenarios:

A range shift gap is expected to occur when there is a physical gap between the upper limit of a species' current altitudinal distribution and the lower limit of its predicted altitudinal distribution under a future climate scenario (Colwell *et al.,* 2008). Lowland biotic attrition is expected to occur as local species disappear from lower elevations due to upslope range movement (Colwell *et al.,* 2008). Range and/or habitat contraction is expected to occur when there is habitat and /or range loss (Colwell *et al*., 2008).

5.2.4. Estimation of change in habitat area

It is evident that mountains, because of their natural cone shape, have a wider area at their bottom which declines with increase in altitude, and the available habitat for species is negatively correlated with altitude. The current and future predicted area of each species along altitudinal gradient (bound between the lower and upper altitudinal limits) were determined by using a Digital Elevation Model (DEM) and the percentage change in habitat area, as a measure of relative risk of extinction, was determined by the following index as explained in Feeley and Silman (2010) under both scenarios:

Change in area= $100 \times (A_{F} - A_{C}) / A_{C}$

Where,

A_C= current area

A_F = future area

The implication is that species that lose a greater percentage of habitat area are under greater risk of extinction (Feeley and Silman, 2010).

5.2.5. Data analysis

Data on current and projected lower and upper altitudinal limits, range of altitude, habitat area, and projected area change (scenarios 1 and 2) were described for each species. Relationship between species richness and altitude, altitudinal range of species and altitude, area coverage of species and altitude, and area coverage and altitudinal range of species were explored using x-y graphs using altitude as a predictor and number of species, altitudinal range and area of species as response variables.

The species were sorted into possible genera, growth forms, life forms, mode of propagations and photosynthetic pathways according to descriptions given by Hedberg and Edwards (1989) and Phillips (1995). Comparisons were made among genera, growth and life forms and mode of propagation for current and projected scenarios' altitudinal range and area using the general linear model (GLM) procedure of SAS Institute (2002) which assumes normal distribution of the error term. Significant differences among genera, growth forms, life forms and mode of propagations were separated by employing the Duncan Multiple Range Test at the five percent level of significance.

5.3. Results

5.3.1. Current species distribution

A total of 53 grass and 14 legume species belonging to 30 grass and six legume genera were collected from the field. Eight grasses and three legume genera were represented by two or more species and accounted for 62.7% of the data set (Appendix Table 8.1.4). The grassland species of the grass growth for is dominated by C_4 photosynthetic pathway while that of the C_3

form are few in number (Table 5.1) and consist species of the genus *Avena, Phalaris, Lolium and Poa*.

From the results of the regression analysis it is apparent that, the number of species sampled showed a clear tendency of higher concentration at intermediate altitudes (Figure 5.2a) where most species have a wider altitudinal range (Figure 5.2b). The current area available for each species showed a decreasing tendency with altitude (Figure 5.2c) but increased with available altitudinal range for some species (Figure 5.2d).

Among the 67 studied species, *Cynodon dacylon, Eleusine floccifolia, Medicago polymorpha, Pennisetum schimperi, Pennisetum trisetum, Sporobolus natalensis, Sporobolus consimilis and Trifolium burchellianum* are some of the species with wide altitudinal ranges. On the other hand, *Eragrostis welwitschii, Harpachne schimperi, Hyparrhenia rufa, Indigofera spicata and Panicum maximum* are some of the species with narrow altitudinal ranges (Appendix Table 8.1.4).

With regard to current habitat area, *Cenchrus ciliaris, C. dacylon, Eragrostis tenuifolia, Pennisetum schimperi, S. consimilis and S. natalensis* are among the species with extensive habitat area. On the contrary, *Eragrsostis botryodes, E. welwitschii, Eulalia polyneura, Hyparrhenia rufa, H. schimperi, Lolium temulentum, Panicum calvum, Pennisetum. clandestinum and Trifolium. cryptopodium* are among the species covering relatively limited habitat area (Appendix Table 8.1.4).

Among the 11 genera, *Hyparrheni*a, *Indegofera, Panicum*, and *Vicia* showed significantly narrower altitudinal range compared to the genus *Sporobolus* which showed the highest altitudinal range. Between the two growth forms (legume and grass), life forms (annual and perennial) and mode of propagations (clonal and non-clonal) no significant differences were noticed with respect to the current altitudinal range, while the grass growth form revealed significantly higher mean habitat area than the legume growth form (Table 5.1). With respect to current area available for the genus, the habitat area available for the genus *Trifolium* was significantly lower than that available for *Chloris*. No significant differences were found among the other genera (Table 5.1). Between the two growth forms, the grass growth form showed significantly higher habitat area available than the legume growth form, whereas there was no significant difference between the annual and perennial life forms nor between the clonal and non-clonal modes of propagation. Generally, species of the C_4 photosynthetic pathway have relatively a wide altitudinal range and are abundantly found in the low to mid altitudinal areas (1925 m – 2531 m) while the C_3 forms are dominantly found in the mid to higher altitudinal areas (2300 m – 2700 m) of the study site with relatively narrow habitat area bounds (Table 5.1).

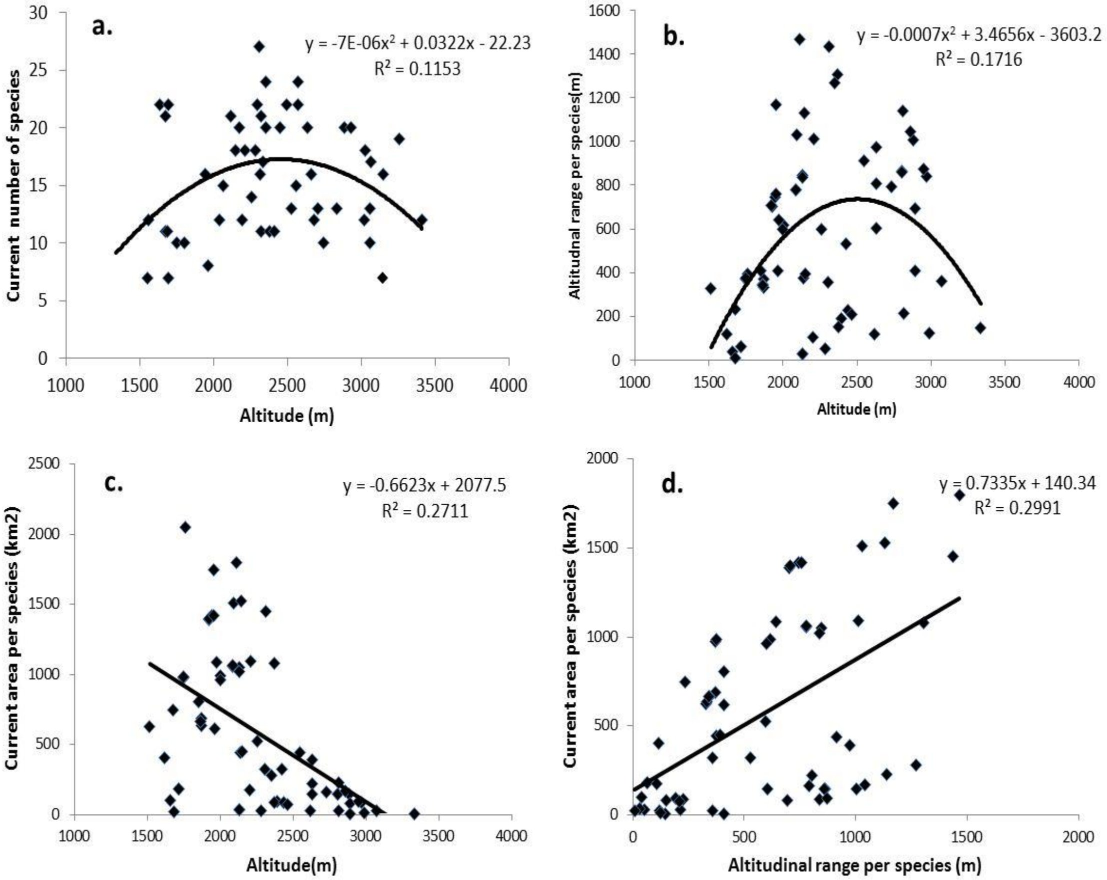

Figure 5.2. Current number of species per altitudinal gradient (a), altitudinal range of species per altitudinal gradient (b), current area of each species per altitudinal gradient (c) and current area of each species per altitudinal range of species (d) determined based on GPS reading and digital elevation model of the current altitudinal range for each species.

5.3.2. Projected species distribution under future climate (Scenario 1)

All species are predicted to face range contraction under Scenario 1 (Appendix Table 8.1.4). At the species level, forty two species, among which 10 legume species (71%) and 30 grass species (60%) are predicted to face physical gaps between the projected lower altitudinal limit and the current upper altitudinal limit of the species (Appendix Table 8.1.4). Among the 11 genera, a range shift gap is predicted to affect the genera *Chloris*, *Indigofera*, and *Vicia*. No significant differences were observed between the grass and legume growth forms or between the annual and perennial life forms or between the clonal and non-clonal modes of propagation (Table 5.1).

For all species, the predicted change in altitudinal range corresponds to changes in habitat area (Figure 5.3). The 42 species with range shift gaps (representing 63 % of the data set) are predicted to lose their entire current range and habitat area. Hence, these species are predicted to face certain local extinctions. The remaining 25 species are predicted to lose on average 91 % of their current habitat area. Among the 11 genera complete habitat loss is predicted to occur among the genera *Chloris, Indegofera* and *Vicia* (Table 5.1). Ten of the fourteen legume species are predicted to face complete loss of habitat with expectations of extinction, while the remaining four species (*M. polymorpha, T. burchellianum, Trifolium simense and Trifolium semipilosum*) are predicted to lose about 84% of their current habitat area (Appendix Table 8.1.4). Between the two growth forms, the legume growth form is predicted to show significantly higher loss of habitat than the grass growth form while no-significant differences were recorded neither between the annual and perennial life forms nor between the clonal and non-clonal modes of propagation (Table 5.1). The grass species of the C_3 photosynthetic pathways will lose relatively more altitudinal range and habitat area than the C_4 species (Table 5.1).

5.3.3. Projected species distribution under future climate (Scenario 2)

Under Scenario 2 all species are predicted to maintain their current altitudinal range since they are allowed by the model to proportionally shift the current lower and upper altitudinal limits.

Table 5.1. Current condition and projected response of the common grass and legume genera of the study area to the projected 4.2^{o}C warming by 2090 under no-migration and with migration scenarios.

		Current distribution		Scenario 1 (no-migration)			Scenario 2 (migration)		
Description	**No species**	**Altitudinal range (m)**	**Area (km^2)**	**Altitudinal range (m)**	**Area (km^2)**	**Area change (%)**	**Altitudinal range (m)**	**Area (km^2)**	**Area change (%)**
Genus									
Andropogon	3	880.3^{ab}	253.0 ^{ab}	180.7^{ab}	14.33 ^{b}	-94.7 ^{ab}	880.3^{ab}	30.44 ^{b}	-87.4^{a}
Chloris	2	659.8 ^{ab}	1188.4^{a}	0.0 ^{b}	0.0 ^{b}	-100^{b}	659.8 ^{ab}	152.5 ^{ab}	-87.2^{a}
Eleusine	2	856.9 ^{ab}	943.6^{ab}	302.0 ^{ab}	52.0^{b}	-95^{ab}	856.9 ^{ab}	120.8 ^{ab}	-87.0^{a}
Eragrostis	5	429.1 ^{ab}	544.3 ^{ab}	81.2 ^{ab}	33.2^{b}	-97^{ab}	429.1 ^{ab}	70.1 ^{b}	-87.2^{a}
Hyparrhenia	3	406.5 ^{b}	678.5 ^{ab}	9.3 ^{b}	5.4^{b}	-99.7^{b}	406.5 ^{b}	88.9 ^{ab}	-87.3^{a}
Panicum	3	336.3 ^{b}	386.0^{ab}	48.7 ^{ab}	21.6^{b}	-98.7^{b}	336.3 ^{b}	49.1 ^{b}	-85.8 ^{a}
Pennisetum	6	792.0^{ab}	565.9 ^{ab}	248.2 ^{ab}	46.4^{b}	-95.0^{ab}	792.0^{ab}	72.3^{b}	-86.9^{a}
Sporobolus	3	1097.3 ^{a}	1135.4 ^{ab}	399.0 ^{a}	114.0^{a}	-88.7 ^{a}	1097.3 ^{a}	227.7 ^{a}	-82.2^{a}
Indigofera	3	231.3 ^{b}	450.4 ^{ab}	0.0 ^{b}	0.0^{b}	-100^{a}	231.3 ^{b}	60.3 ^{b}	-83.6^{a}
Trifolium	6	679.6 ^{ab}	149.9 ^{b}	101.3 ^{ab}	5.8^{b}	-95.0^{ab}	679.6 ^{ab}	18.9 ^{b}	-73.1^{a}
Vicia	2	248.4 ^{b}	313.0 ^{ab}	0.0 ^{b}	0.0 ^{b}	-100 ^{b}	248.4 ^{b}	29.6^{b}	-91.6^{a}
Growth form									
Grass	53	586.1^{a}	663^{a}	113.2^{a}	33.7^{a}	-89.4^{a}	586.1^{a}	98.3^{a}	-78.4^{a}
Legume	14	498.2^{a}	270.2^{b}	84.07^{a}	9.71^{a}	-96.9^{b}	498.2^{a}	40.3^{b}	-85.6^{a}
Life form									
Annual	20	522.1^{a}	484.5^{a}	123.2^{a}	35.8^{a}	-96.4^{a}	522.1^{a}	77.5^{a}	-84.4^{a}
Perennial	47	587.2^{a}	622.1^{a}	69.3^{a}	12.1^{a}	-97.0^{a}	587.2^{a}	89.9^{a}	-85.9^{a}
Mode of propagation									
Clonal	27	634.6^{a}	665.2^{a}	126.0^{a}	44.7^{a}	-96.1^{a}	635.0^{a}	99.7^{a}	-85.1^{a}
Non-clonal	40	522.6^{a}	524.^{2a}	94.3^{a}	17.9^{a}	-97.0^{a}	522.6^{a}	77.1^{a}	-85.9^{a}
Photosynthetic pathway									
C$_4$ grass	46	608.5^{a}	722.1^{a}	122.5^{a}	38.1	96.7	608.5	108.11^{a}	-85.5
C$_3$ grass	4	497.8^{a}	263.0^{b}	34.8^{b}	1.0	98.8	497.8	30.0^{b}	-87.75

Means with the same letters in a column are not significantly (P> 5% probability level) different from each other.

Nevertheless, species the C_3 photosynthetic pathway occupy narrow habitat area and many of the studied species are predicted to lose a significant proportion of their current habitat area mainly due to less area available on the upper portion of the mountains to which they migrate upslope. The species are predicted to lose an average of about 84% of their current habitat area (Figure 5.3) with over 90% loss to occur among *C. ciliaris, Exotheca. abyssinica, Panicum. calvum* and *Trifolium. rueppellianum.* The lowest losses are predicted to occur among *Echinochloa colona* (44.8%) and *M. polymorpha* (55%) (Appendix Table 8.1.4).

The forty two species predicted to face range shift gaps under the no-migration scenario are predicted to do better under the full migration scenario since they retain at least some portion of their habitat areas as they move upslope (Appendix Table 8.1.4). Between the two growth forms, the grass growth form is predicted to have significantly higher habitat area than the legume growth form (Table 5.1). However, no significant differences were predicted to occur in habitat area loss among the eleven genera, between the grass and legume growth forms, between the annual and perennial life forms and between the clonal and non-clonal modes of propagation (Table 5.1).

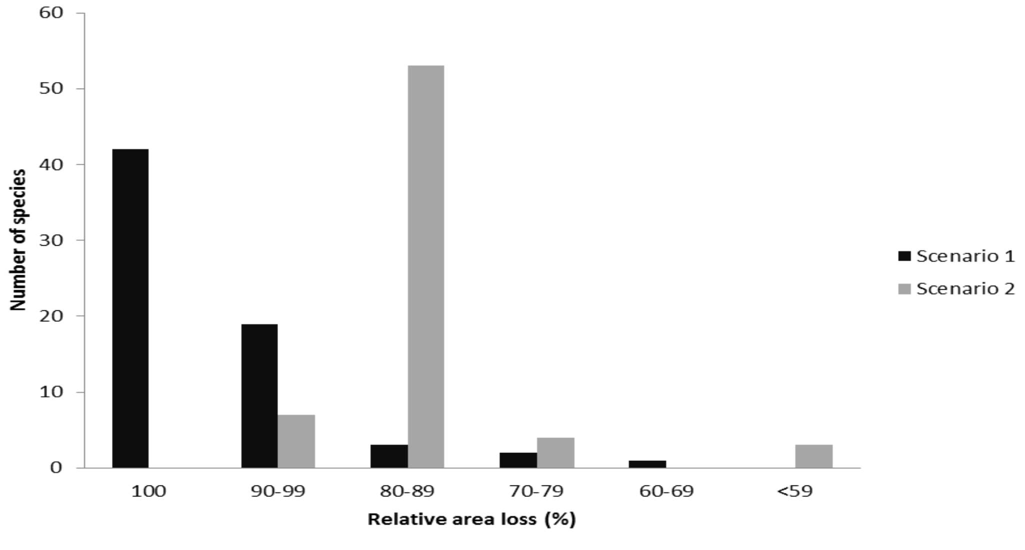

Figure 5.3. Predicted percentage change in habitat area of species determined from Digital Elevation Model and GPS readings under no-migration (Scenario 1) and migration (Scenario 2) scenarios to predicted 4.2°C increases in temperature by 2090.

5.4. Discussion

5.4.1. Current species distribution

The present study has demonstrated that a large number of the dominant grassland species are concentrated on mid-altitude areas giving a characteristic hump-shaped distribution. Similar types of plant distributions have been reported by many authors along altitudinal gradients in tropical environments (Desalegn and Beierkuhnlein, 2010; Aynekulu *et al.,* 2012; Namgail *et al.,* 2012). The hump-shaped distribution of species could be because of wider altitudinal range (Figure 5.2b) and proportionally more habitat area availability (Figure 5.2c) in the mid-altitude which provides the species with combinations of climate, water and energy dynamics that have direct effects on plant physiological performance (Desalegn and Beierkuhnlein, 2010). Although the area available for species is larger, only few species are recorded at lower altitudes (Figure 5.2a). This is because of high temperature and low annual rainfall conditions that have influenced growth, development and distribution of the species. On the other hand, the low number of species observed at higher altitudes could be due to cooler temperature conditions that limit physiological performance of species to adapt and survive in this environment (Namgail *et al.,* 2012). As a result the lower to mid altitude of the study area is dominated by species of grass of the C_4 photosynthetic pathways that are adapted to high temperature and low rainfall of the tropical environment (Mantlana *et al*., 2008) while species of the C_3 photosynthetic pathways inhabited the upper cooler part of the study area because of their low temperature requiring physiological activities (Woldu, 1991). This distribution of species by physiological difference along altitudinal gradient is in agreement with previous reports of Woldu (1991) in Ethiopia.

Although the area available for species increased with altitudinal range, some species with a wide altitudinal range did not occupy wide areas and vice versa. This could be due to the shape of the mountain and slope of land over which species exist. In mountains, the area available for species generally decreases with altitude (Figure 5.2c), and there is less area over a wider altitudinal range in the steeper part and conversely more area over a narrow altitudinal range in the gentle part of the mountain (Colwell *et al*., 2008; Kreyling *et al*., 2010).

In the present study, except among the genera and between growth forms, no differences were detected between life forms and modes of propagation in the current altitudinal range and area occupied. This shows that despite differences among legumes and grasses (in the current area), annual and perennial species as well as species propagated by clonal and non-clonal plant parts have similar altitudinal ranges and area occupation along the altitudinal gradient.

5.4.2. Projected species distribution under future climate

Human induced land use and land scape fragmentation and physiology of the species might have restricted the range of some dominant grassland species at low- to mid-altitude areas. As is evident from the weather station data described in section 2.1, the temperature is higher in the low- to mid-altitude areas and species living in such areas might be living currently under their maximum tolerance to the rising temperature. A small increase over the current temperature level may thus force them to respond to the change. One such response already seen for other species under different environments is to move upslope towards their optimum or maximum level of temperature tolerance (Pauli *et al*., 1996) or face consequences of the warming temperature (Kreyling *et al*., 2010) given the case in Scenario 1, many of the species face range shift gaps which imply complete loss of habitat with a high degree of extinction.

The range shift gaps and habitat loss caused by rising temperature, however, did not differ among species belonging to different life forms (annual vs. perennial) and modes of propagation (clonal vs. non-clonal). This could be because of similarities in altitudinal range and habitat area occupied. The legume growth form, because of naturally narrow range of adaptation (Gebru, 2009), however, is predicted to be affected significantly more by range shift gaps, and habitat area loss than the grass growth form. Loss of legumes to climate-induced extinctions from the agro-ecosystems, however, could result in instability of the whole system as it leads to reduced or lack of nitrogen fixation, and incorporation into soils. As a result, growth of the non-nitrogen fixing species in the grassland community would be impaired and consequently may lead to loss of species from the system (Pausas and Austin, 2001). On the other hand, although the mechanisms are not yet clearly understood (Kreyling *et al.,* 2010), occasional long-distance dispersal events have been found to occur among some plant species between geographically isolated Afro-alpine mountain ranges (Ehrich *et al*., 2007; Kreyling *et al*., 2010). This may help species to perpetuate even under conditions of fragmented habitat if it also holds true among the grasses and legume species under study.

It is also apparent that some species of grasses and legumes that are predicted to suffer from range shift gaps and habitat-loss induced extinctions under Scenario 1 are predicted to benefit from Scenario 2. The implication is that for narrow ranged and endangered species, modification of the current land use system through management intervention is of paramount importance (Opdam and Wascher, 2004; Brooker *et al*., 2011). The management option to be followed, however, would be better if implemented in such a way that habitats and dispersal corridors are interconnected. This is to accommodate species of different genera with different growth, life forms and modes of propagation as they face similar problems of environmental and anthropogenic effects to migrate against warming climate from the model.

Thus fragmented plots of land would need to be connected especially for creeping-type grasses propagated by rhizomes and stolons. Assisted colonization could also be a feasible solution to dispersal-limited species of grasses and legumes (Brookeret *et al*., 2011; Lunt *et al*., 2013). Since the study did not cover the full geographic range to the top of the highest summit (4036 masl) above the current limit, full geographic range of species found above the last altitudinal limit of the present study is not available to predict mountain top extinction risks. Particularly species of the C_3 photosynthetic pathway which normally occupy the upper cooler part of the mountain might more be at risk of extinction because of narrow habitat area availability and lack of escape route to move up further against warming climate. Hence intensive surveys may be required across the whole geographic range of the country to predict mountain top extinction risks. Further studies are also required using robust models that can accommodate multiple factors including at species level, edaphic, topographic precipitation and others for better prediction of species response to future climate over larger area.

5.5. Conclusions

The results of the present study show that projected warming could significantly affect grassland herbaceous plant communities. Plant species differ in their response to the projected warming both under the no-migration and with-migration scenarios. Altitudinal ranges and habitat areas of the species are predicted to be significantly affected. All species face range contraction and habitat losses with range shift gaps among forty two species – mostly legumes, representing 17.9 % of the species, recorded in the study, under a no-migration scenario. With the migration scenario, however, 63 % of the study species are predicted to benefit from retention of at least some portion of their habitat area. Between growth forms, legumes are predicted to lose significantly more range and habitat area than grasses under the no-migration scenario while no significant difference was predicted in habitat area loss between the two growth forms under the migration scenario and between the two life forms and modes of propagation. Hence it can be concluded that management options are required to help species migrate upslope to survive. These may include leaving end-to-end connected mosaic dispersal corridors along altitudinal gradients running from bottom lowlands to the top of the highest summit. This might seem difficult to implement under the current land tenure system in the study area. However, recognizing the need to maintain biodiversity of the grasslands for the benefit of mankind and functioning of eco-system, further studies are required to identify mechanisms of implementation including physiological reproductive behavior of each species in the study area and/or other similar areas of the country. Assisted colonization could also be a feasible solution to follow depending on species dispersal behavior and level of extinction risks predicted under the projected warming.

6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The livestock production system in sub-Saharan African countries such as Ethiopia has largely been based on traditional herding where animals range over extensive grazing lands with little or no supplementation. In recent decades the human population of the region has increased considerably and triggered diversification of agricultural activities in order to meet the demands for food and welfare. This has created pressure on the limited nonexpendable land which tremendously is becoming fragmented and used for various purposes. At the same time population growth and changing land use has increased greenhouse gas emissions both from agricultural and industrial activities leading to warming of the planet resulting in alteration of precipitation patterns and increasing the occurrence of climatic extremes with resulting biophysical and social impacts. Climate change affects availability of feeds by altering plant community structures, growth, productivity and quality.

This dissertation presents four empirical studies on analysis of historical climate extremes, perception of climate change, land use/land cover changes and interconnections with feed resources availability and management. This final chapter summarizes the findings and implications of these chapters to the main discussion point, followed by a concise description of the main conclusions. Subsequently, it draws recommendations for policy and future research work.

The dissertation took as a starting point an important discussion point that livestock feed resources are at a crossroads of climate and land use/land cover change. The notion is built on various studies that indicate that the currently available feed from all sources is too low both in quantity and quality to meet the requirements of a productive livestock population in the study area. This is hypothesized to be a result of a range of factors. The underlying one could be changes in climate and land use/land cover that have both temporal and spatial dimensions. All other factors in one or another way would be a subset of these. The dissertation thus examined the temporal and spatial interconnections among climate, land use/land cover and household feed resource management over three eco-environments in Ethiopia.

Over the last century, our planet has become warmer because of intensified anthropogenic activities and there is a general consensus that the amount, frequency, magnitude, intensity and duration of temperature and precipitation events have shown changes. The magnitude and trends of changes, however, vary with region and localities making local level adaptation planning difficult particularly in the sub-Saharan African region including Ethiopia where information on extremes trend is very scarce.

Accordingly, Chapter 2 assessed temporal trends in temperature and precipitation extremes at different stations and assessed whether the observed trends are uniquely differentiated among the three major eco-environments of Ethiopia. The results show that most of the indices are not significant at many stations and the significant trends are not uniquely differentiated by eco-environment. However, there is a general tendency of increasing warm extremes and a decreasing tendency of cold extremes at most stations studied over the three eco-environments. Indices such as maximum value of the maximum temperature, warm days, warm nights and warm spell duration indicators showed positive trends, whereas cool days, cool nights and cold spell duration indicators were negative at more than 8 of the 11 stations studied. The result also revealed that precipitation extreme trends are more variable and inconsistent among stations and eco-environments. However, some indices such as maximum 1-day precipitation amount, maximum 5-day precipitation amount and extremely wet days percentages showed positive trends while the number of days with precipitation ≥10mm, maximum number of consecutive days with precipitation <1mm and maximum number of consecutive days with precipitation >1mm showed negative trends at more than seven stations.

Climate extreme events are causing significant socioeconomic and environmental consequences around the world. The occurrence of extreme events is rare and in most cases has not shown significant changes as indicated in Chapter 2. However, a small increase in magnitude and frequency will cause significant damage to life, property and resources. A prior understanding of households' perception of trends of climate extremes indicators, its congruence with weather station data, and perception determinants could help create household sensitization on climate change, and enable policy makers and development actors to design and popularize community based climate resilient adaptation strategies.

The third chapter thus explains the relations between on the one hand trends of selected climate extreme indicators of significance such as the number of extreme warm days, warm nights, cool days, cool nights, seasonal total rainfall and the daily intensity of rainfall recorded and on the other hand household perceptions. In short the chapter relates household perceptions with recorded climate extreme trends across the three eco-environments and seasons. The results showed that a large percentage of households across the three eco-environments perceived increasing numbers of extreme warm days and warm nights, and conversely decreasing numbers of extreme cool days and cool nights across all seasons. The perception on rainfall extremes, however, was variable in such a way that the majority of the households in the pastoral and agro-pastoral eco-environments perceived decreasing seasonal total rainfall and daily intensity of rainfall across all seasons while there was no clear distinction between increasing and decreasing perceptions for rainy season, and between decreasing and no change for the dry season in the mixed crop-livestock highland system.

Chapter 3 also showed that household perceptions on rainfall and temperature extreme indicators mostly agreed with the recorded significant trends from nearby weather stations across eco-environments and seasons. In the pastoral eco-environment for example the perceptions positively comply with recorded significant increasing trends in warm days and warm nights, and the decreasing trends in daily intensity of rainfall across all seasons. In the agro-pastoral eco-environment significant decreasing trends were seen only in cool days and cool nights for the major rainy season and this agreed with the perceptions, whereas the perception on increasing warm days contradicts the recorded significant decreasing trend observed for the small rainy season. In the mixed crop-livestock highland system, significant increasing trends were observed only in warm nights for the major rainy and dry seasons in agreement with household perceptions.

The third chapter also revealed that households' perceptions on rainfall and temperature extremes are significantly affected by a number of factors. The results showed that factors such as literacy of household, eco-environment, distance from market, and social and / or institutional responsibility, access to extension and aid services are vital sources of information for households' understanding of climate change. On the other hand, factors such as season, increased farm land size and livestock holding size of household did not influence the climate change perceptions of households although they are vital means of adaptation to climate change.

Climate and land use/land cover changes are interrelated in many ways and synergetic effects can be strong. Land use/land cover change, however, is hypothesized to have far reaching effects over a short period of time. The fourth chapter dealt with identifying land use/land cover trajectories over the last 30-40 years from remotely sensed satellite images and related these changes to household perceptions on trends in availability of feeds and the feed deficit management strategies of household in districts identified to represent the three main Ethiopian eco-environments.

The results presented in Chapter 4 indicated that during the last 30-40 years, bush/shrub lands have come to dominate the land use/land cover in the pastoral and agro-pastoral areas whereas the mixed crop-livestock highland systems are dominated by cropland. Over the last 30-40 years, however, large areas under grasslands and forest lands have been increasingly replaced by bush/shrub and crop lands in the pastoral area (e.g., Liben). In the agro-pastoral area (e.g., Mieso) substantial areas of bush/shrub lands and grasslands have been converted to crop lands. Similarly in the mixed crop-livestock system (e.g., Tiyo) large areas of grassland, forest and bush/shrub lands have been replaced by crop lands.

Chapter 4 also revealed that households across the three eco-environments identified grazing, crop residues, agro industrial by-products and other feeds from croplands (weeds and crop thinning) as the feed resources available to them, and they employed various strategies such as mobility, transhumance, feed conservation, herd management and purchase of feed to overcome seasonal feed scarcities that they often face. Over the last 30-40 years, however, changes have occurred in the relative contribution of each of these feed resources and the feed deficit management strategies in connection to the observed land use/land cover change. From the households' perspectives, it is apparent that over the last 30-40 years, grazing resources available to livestock have been declining significantly across all eco-environments with resultant increase in the contribution of crop residues and other feeds from crop lands (weeds and crop thinning). The feed deficit management strategies of households are also changing from mobility to herd management and feed conservation in the pastoral areas; from mobility to feed conservation and purchasing of feed in the agro-pastoral areas and from transhumance to feed conservation and purchase of feed in the mixed crop-livestock systems.

The retraction of grassland areas and attendant landscape fragmentation pose a challenge to maintaining the floristic composition of grasslands. Under a warming climate, plant species are expected to move upslope along altitudinal gradients to optimum thermal zones to allow survival as long as the hypsometry of the landscape will allow this to happen. However, the observed land use/land cover change and associated land fragmentations are barriers to species redistribution. In Chapter 5 current altitudinal range and habitat area of 67 herbaceous grassland species of various growth forms, life forms and modes of propagation and evaluation of their potential response to projected 4.2^{o}C increase of temperature by 2090 under two conditions is presented. The two conditions were termed the 'no-migration scenario' and the 'migration scenario'. The no-migration scenario assumes exactly the current land use system where each species will not have the chance to shift their current upper altitudinal limit because of effective control by barriers while there will be climate warming induced upward shift in its lower altitudinal limit. The migration scenario on the other hand, assumes better land management and free movement of species upslope shifting both its current lower and upper altitudinal limits.

Results indicate that a large number of the dominant grassland species are concentrated on mid-altitude areas giving a characteristic hump-shaped distribution. The major limiting factors are high temperature and low annual rainfall in the lower altitude, and conversely cool temperature on the other end. Species with annual and perennial life forms as well as species propagated by clonal and non-clonal plant parts have similar altitudinal ranges and area occupations along altitudinal gradients while species of the grass growth form have significantly wider area occupation. Under the projected warming all species will lose a significant portion of their current habitat area because of a warming induced shift in altitudinal limits. If migration is not possible, 42 of the 67 species, equivalent to 63% of the current species complement, will face a range shift gap with 100% loss of their current habitat area. Legumes because of their naturally narrow range of adaptation will be significantly affected while no differences are expected between species of annual and perennial life forms or clonal and non-clonal modes of propagation. The chapter, however, showed that if migration is possible, all the species will have at least some habitat area left to survive indicating the need for effective management of the land use system.

In general, the results presented in Chapters 2 to 5 showed that the climate is generally warming and land use/ land cover change is occurring rapidly. The synergistic effects of the changing land use/ land cover and warming climate has placed feed resources at a cross roads in between a warming planet and changing land use across all eco-environments. The farming and herding households have already sensed this and are trying to developing coping strategies. They are forced to abandon or reduce their dependence on traditional feeds. Grazing-based feed resources are continually reducing to varying degrees across all eco-environments. Conversely, non-grazing based feeds and the associated feed deficit management strategies are becoming increasingly available to livestock and are expected to be the future feed resources. There are concerns, however, as to whether these feed resources are meeting requirements to support productive stock with respect to nutritive value of crop residues, nutrient cycling in croplands, crop expansion to fragile pastoral eco-environments, communal grazing land conversion to private use and a growing livestock population. Land fragmentation and replacement of grazing lands with lands of other use will also aggravate loss of valuable grassland species in the face of a warming climate. These changes call for integrated research and policy interventions for eco-environment/ site specific feed resources development and management strategies that ensure sustainable availability of feeds both in quality and quantity, and conservation of the biodiversity of grasslands.

Based on the results of this study, the following recommendations are drawn for policy and research: Further research is required on recorded climate extreme trends with the dense station network across the country to adequately cover the relief features and all geographic areas. There is also a need for enhancing households' literacy level and eco-environment based extension services to improve awareness and understanding of climate change and adaptation. There is a need for strengthening development measures for planned land use management such as using land according to its capability for production and biological conservation. Additional studies on plant species distribution across the whole geographic range of the country and use of robust models that can accommodate multiple factors for better prediction of species response to future climate over larger area including prediction of mountain top extinction risks. Conservation measures such as assisted colonization and establishing end-to-end connected mosaic dispersal corridors along altitudinal gradients (running from bottom lowlands to the top of the highest summit) to facilitate species redistribution under warming climate.

Further measures are required to improve nutritive value of crop residues, increasing domestic processing and availability of by-products, minimizing feed losses and improving the efficiency of various feed conservation strategies, improving the genetic makeup of animals towards efficient use of available feeds and high productivity, and providing alternative means of traction.

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8. APPENDICES

8.1. Appendix Table

8.1.1. Land use/ land cover transition matrix showing percentage changes between 1973 and 2007 at Liben district, Ethiopia.

		Year 2007							
	Land use/ land cover class	Bare land (BRL)	Bush Land (BUL)	Crop Land (CRL)	Forest Land (FOL)	Grass Land (GRL)	Settlement (ST)	Total 1973[b]	loss 1973[d]
Year 1973	Bare land (BRL)	1.33[a]	1.00	0.00	0.00	0.00	0.00	2.33	1.00
	Bush Land (BUL)	0.00	43.67[a]	1.67	0.33	6.00	2.00	53.67	10.00
	Crop Land (CRL)	0.33	0.67	1.67[a]	0.00	0.00	0.00	2.67	1.00
	Forest Land (FOL)	0.67	5.67	3.00	1.00[a]	0.33	0.33	11.00	10.00
	Grass Land (GRL)	2.00	14.67	4.67	0.33	7.33[a]	1.00	30.00	22.67
	Settlement (ST)	0.00	0.00	0.00	0.00	0.00	0.33[a]	0.33	0.00
	Total 2007[c]	4.33	65.68	11.01	1.66	13.66	3.66	100.00	
	Gain 2007[e]	3.00	22.01	9.34	0.66	6.33	3.33		
	Net change [f]	2.00	12.01	8.34	-9.34	-16.34	3.33		
	Net persistence (ratio)[g]	1.50	0.28	4.99	-9.34	-2.23	10.09		55.33[h]

a = percentage of land for each class that did not show change between 1973 and 2007 and h is the percentage sum of land use /land covers that has not undergone changes between 1973-2007; b =is the sum of figure in the row; c = is sum of figure in the column; d = is b minus a; e = is c minus a; f =is e minus d; g=is ratio of f to a (f/a).

8.1.2. Land use/ land cover transition matrix showing percentage changes between 1973 and 2007 at Mieso district, Ethiopia.

		Year 2007							
	Land use/ land cover class	Bare land (BRL)	Bush Land (BUL)	Crop Land (CRL)	Forest Land (FOL)	Grass Land (GRL)	Settlement (ST)	Total 1973[b]	loss 1973[d]
Year 1973	Bare land (BRL)	0.33[a]	0.00	0.00	0.00	0.00	0.00	0.33	0.00
	Bush Land (BUL)	0.67	48.33[a]	14.33	0.33	3.67	0.67	68.00	19.67
	Crop Land (CRL)	0.33	6.67	3.33[a]	0.00	0.33	0.33	10.99	7.66
	Forest Land (FOL)	0.00	0.00	0.33	0.33[a]	0.67	0.00	1.33	1.00
	Grass Land (GRL)	0.33	0.67	6.00	0.67	11.00[a]	0.33	19.00	8.00
	Settlement (ST)	0.00	0.00	0.00	0.00	0.00	0.33[a]	0.33	0.00
	Total 2007 [c]	1.66	55.67	23.99	1.33	15.67	1.66	100.00	
	Gain 2007 [e]	1.33	7.34	20.66	1.00	4.67	1.33		
	Net change [f]	1.33	-12.33	13.00	0.00	-3.33	1.33		
	Net persistence (ratio) [g]	4.03	-0.26	3.90	0.00	-0.30	4.03		63.65[h]

a = percentage of land for each class that did not show change between 1973 and 2007 and h is the percentage sum of land use /land covers that has not undergone changes between 1973-2007; b =is the sum of figure in the row; c = is sum of figure in the column; d = is b minus a; e = is c minus a; f =is e minus d; g=is ratio of f to a (f/a).

8.1.3. Land use/ land cover transition matrix showing percentage changes between 1973 and 2007 at Tiyo district, Ethiopia.

		Year 2007							
	Land use/ land cover class	Bare land (BRL)	Bush Land (BUL)	Crop Land (CRL)	Forest Land (FOL)	Grass Land (GRL)	Settlement (ST)	Total 1973[b]	Loss 1973[d]
Year 1973	Bare land (BRL)	0.33[a]	0.00	0.00	0.00	0.00	0.00	0.33	0.00
	Bush Land (BUL)	0.33	9.00[a]	5.00	0.67	0.00	1.00	16.00	7.00
	Crop Land (CRL)	0.00	0.00	50.00[a]	0.00	0.33	1.33	51.66	1.66
	Forest Land (FOL)	0.00	0.00	7.67	3.33[a]	0.00	0.67	11.67	8.34
	Grass Land (GRL)	0.00	0.00	10.00	5.00	4.33[a]	0.33	19.66	15.33
	Settlement (ST)	0.00	0.00	0.33	0.00	0.00	0.33[a]	0.66	0.33
	Total 2007[c]	0.66	9.00	73.00	9.00	4.66	3.66	100.00	
	Gain 2007[e]	0.33	0.00	23.00	5.67	0.33	3.33		
	Net change [f]	0.33	-7.00	21.34	-2.67	-15.00	3.00		
	Net persistence (ratio) [g]	1.00	-0.78	0.43	-0.80	-3.46	9.09		67.32[h]

a = percentage of land for each class that did not show change between 1973 and 2007 and h is the percentage sum of land use /land covers that has not undergone changes between 1973-2007; b =is the sum of figure in the row;   c = is sum of figure in the column; d = is b minus a; e = is c minus a; f =is e minus d; g=is ratio of f to a (f/a).

8.1.4. Current and projected altitudinal and habitat area response of grass and legume species of the study area to the projected 4.2^{o}C warming by 2090 under no-migration and with migration scenarios.

	Current distribution				Scenario 1 (no-migration)					Scenario 2 (migration)				
	Lower limit (m)	**Upper limit (m)**	**Altitudinal range (m)**	**Area (Km^2)**	**Lower limit (m)**	**Upper limit (m)**	**Altitudinal range (m)**	**Area (Km^2)**	**Area change (%)**	**Lower limit (m)**	**Upper limit (m)**	**Altitudinal range (m)**	**Area (Km^2)**	**Area change (%)**
Andropogon abyssinicus	2144	3118	975	393	2844	3118	275	25	-94	2844	3818	975	41	-90
Andropogon distachys	2375	3236	862	145	3075	3236	162	8	-95	3075	3936	862	20	-86
Andropogon pratensis	2231	3036	805	222	2931	3036	105	10	-95	2931	3736	805	31	-86
Aristida kenyensis	1566	1935	370	976	2266	1935	0	0	-100	2266	2635	370	144	-85
Avena fatua	2161	2690	529	321	2861	2690	0	0	-100	2861	3390	529	32	-90
Bothriochloa insculpta	1571	2316	746	1420	2271	2316	46	27	-98	2271	3016	746	191	-87
Brachiaria brizantha	1562	1795	233	746	2262	1795	0	0	-100	2262	2495	233	115	-85
Cenchrus ciliaris	1561	1955	393	2049	2261	1955	0	0	-100	2261	2655	393	150	-93
Chloris gayana	1574	2277	702	1388	2274	2277	0	0	-100	2274	2977	702	183	-87
Chloris pycnothrix	1692	2310	618	989	2392	2310	0	0	-100	2392	3010	618	122	-88
Chrysopogon plumulosus	1686	2057	371	687	2386	2057	0	0	-100	2386	2757	371	94	-86
Coelachyrum poaeflorum	1559	1676	117	403	2259	1676	0	0	-100	2259	2376	117	66	-84
Cynodon dacylon	1372	2540	1169	1748	2072	2540	469	386	-78	2072	3240	1169	469	-73
Digitaria abyssinica	1700	2299	599	963	2400	2299	0	0	-100	2400	2999	599	115	-88
Echinochloa colona	1350	1677	328	625	2050	1677	0	0	-100	2050	2377	328	345	-45
Eleusine floccifolia	1718	3023	1304	1081	2418	3023	604	104	-90	2418	3723	1304	126	-88
Eleusine multiflora	1647	2056	409	806	2347	2056	0	0	-100	2347	2756	409	116	-86
Eragrostis botryodes	2559	2679	120	25	3259	2679	0	0	-100	3259	3379	120	4	-86
Eragrostis paniciforms	2298	2489	191	93	2998	2489	0	0	-100	2998	3189	191	12	-87
Eragrostis papposa	1697	2474	776	1058	2397	2474	76	37	-97	2397	3174	776	131	-88

Appendix Table 8.1.4. Continued …

	Current distribution				**Scenario 1 (no-migration)**					**Scenario 2 (migration)**				
	Lower limit (m)	**Upper limit (m)**	**Altitudinal range (m)**	**Area (Km2)**	**Lower limit (m)**	**Upper limit (m)**	**Altitudinal range (m)**	**Area (Km2)**	**Area change (%)**	**Lower limit (m)**	**Upper limit (m)**	**Altitudinal range (m)**	**Area (Km2**	**Area change (%)**
Eragrostis tenuifolia	1578	2608	1030	1511	2278	2608	330	129	-91	2278	3308	1030	200	-87
Eragrostisis welwitschii	2119	2148	29	35	2819	2148	0	0	-100	2819	2848	29	4	-89
Eulalia polyneura	2376	3236	861	144	3076	3236	161	8	-95	3076	3936	861	20	-86
Exotheca abyssinica	3261	3407	146	4	3961	3407	0	0	-100	3961	4107	146	0	-90
Festuca abyssinica	2379	3385	1005	147	3079	3385	305	12	-92	3079	4085	1005	20	-87
Harpachne schimperi	2257	2309	51	31	2957	2309	0	0	-100	2957	3009	51	5	-83
Heteropogon contortus	1561	1935	374	986	2261	1935	0	0	-100	2261	2635	374	147	-85
Hyparrhenia anthistirioides	2297	2448	151	85	2997	2448	0	0	-100	2997	3148	151	11	-87
Hyparrhenia callina	1570	2276	707	1399	2270	2276	0	0	-100	2270	2976	707	187	-87
Hyparrhenia cymbaria	1703	2035	333	638	2403	2035	0	0	-100	2403	2735	333	79	-88
Hyparrhenia dregeana	1576	2334	758	1419	2276	2334	58	33	-98	2276	3034	758	189	-87
Hyparrhenia hirta	1653	2293	640	1083	2353	2293	0	0	-100	2353	2993	640	141	-87
Hyparrhenia papilipes	2324	2552	228	91	3024	2552	0	0	-100	3024	3252	228	12	-87
Hyparrhenia rufa	2119	2148	29	35	2819	2148	0	0	-100	2819	2848	29	4	-89
Lolium temulentum	2708	2922	215	29	3408	2922	0	0	-100	3408	3622	215	4	-87
Panicum atrosanguineum	1706	2552	846	1048	2406	2552	146	43	-96	2406	3252	846	125	-88
Panicum calvum	2929	3053	124	12	3629	3053	0	0	-100	3629	3753	124	1	-91
Panicum maximum	1637	1677	40	99	2337	1677	0	0	-100	2337	2377	40	21	-79
Pennisetum clandestinum	2891	3250	358	25	3591	3250	0	0	-100	3591	3950	358	4	-86
Pennisetum adoense	2357	2566	208	75	3057	2566	0	0	-100	3057	3266	208	10	-87

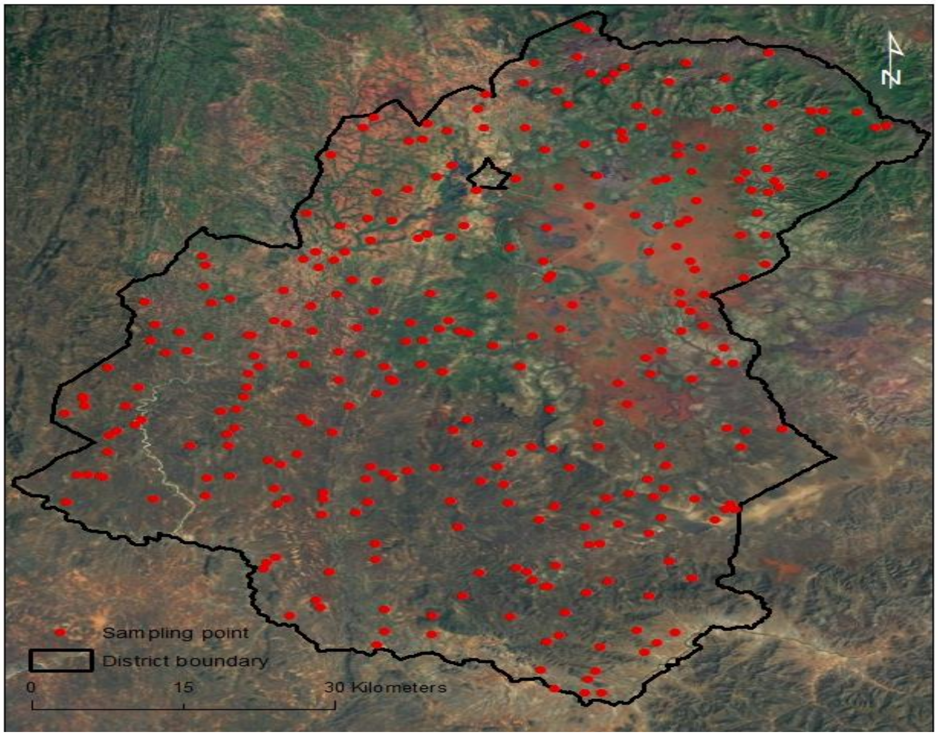
Appendix Table 8.1.4. Continued …

	Current distribution				Scenario 1 (no-migration)					Scenario 2 (migration)				
	Lower limit (m)	**Upper limit (m)**	**Altitudinal range (m)**	**Area (Km^2)**	**Lower limit (m)**	**Upper limit (m)**	**Altitudinal range (m)**	**Area (Km^2)**	**Area change (%)**	**Lower limit (m)**	**Upper limit (m)**	**Altitudinal range (m)**	**Area (Km^2)**	**Area change (%)**
Pennisetum glabrum	1703	2715	1013	1091	2403	2715	313	76	-93	2403	3415	1013	131	-88
Pennisetum schimperi	1594	3029	1435	1453	2294	3029	735	178	-88	2294	3729	1435	199	-86
Pennisetum trisetum	2240	3381	1141	228	2940	3381	441	24	-89	2940	4081	1141	32	-86
Pennisetum villosum	1959	2555	597	524	2659	2555	0	0	-100	2659	3255	597	58	-89
Phalaris paradoxa	1760	2167	408	616	2460	2167	0	0	-100	2460	2867	408	72	-88
Poa schimperara	2550	3389	839	86	3250	3389	139	4	-95	3250	4089	839	12	-86
Setaria pallidifusca	1696	2474	777	1061	2396	2474	77	37	-96	2396	3174	777	131	-88
Snowdenia polystachya	2089	3002	913	441	2789	3002	213	26	-94	2789	3702	913	48	-89
Sorghum verticilliflorum	1686	1749	64	183	2386	1749	0	0	-100	2386	2449	64	36	-80
Sporobolus africanus	2546	3241	694	83	3246	3241	0	0	-100	3246	3941	694	12	-86
Sporobolus consimilis	1380	2845	1466	1798	2080	2845	766	432	-76	2080	3545	1466	470	-74
Sporabolus natalensis	1581	2712	1131	1526	2281	2712	431	147	-90	2281	3412	1131	202	-87
Themda triandra	1715	2552	837	1021	2415	2552	137	36	-96	2415	3252	837	118	-88
Dolichos sericeus	1686	1749	64	183	2386	1749	0	0	-100	2386	2449	64	36	-80
Glycine wightii	1953	2326	373	441	2653	2326	0	0	-100	2653	3026	373	48	-89
Indigofera spicata	1677	1685	8	22	2377	1685	0	0	-100	2377	2385	8	5	-77
Indigofera arrecta	1692	2036	344	666	2392	2036	0	0	-100	2392	2736	344	88	-87
Medicago polymorpha	1717	2987	1269	281	2417	2987	569	101	-64	2417	3687	1269	126	-55
Trifolium burchellianum	2340	3384	1043	167	3040	3384	343	15	-91	3040	4084	1043	23	-87
Trifolium cryptopodium	2691	3098	408	6	3391	3098	0	0	-100	3391	3798	408	6	-87
Trifolium rueppellianum	2127	2485	357	323	2827	2485	0	0	-100	2827	3185	357	30	-91

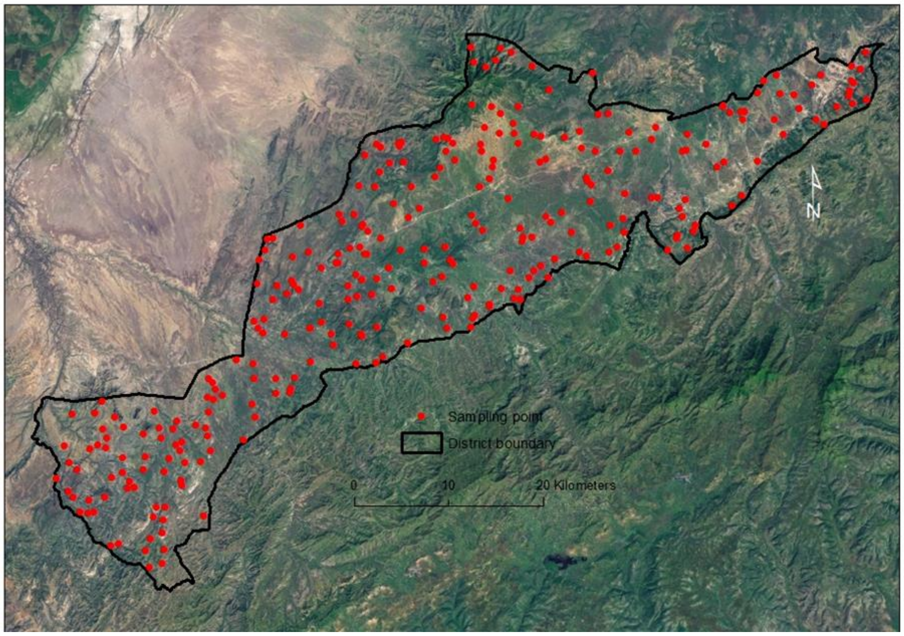
Appendix Table 8.1.4. Continued …

	Current distribution				Scenario 1 (no-migration)					Scenario 2 (migration)				
	Lower limit (m)	Upper limit (m)	Altitudinal range (m)	Area (Km^2)	Lower limit (m)	Upper limit (m)	Altitudinal range (m)	Area (Km^2)	Area change (%)	Lower limit (m)	Upper limit (m)	Altitudinal range (m)	Area (Km^2)	Area change (%)
Trifolium simense	2515	3388	873	93	3215	3388	173	15	-84	3215	4088	873	13	-85
Trifolium semipilosum	2334	3126	792	161	3034	3126	92	5	-97	3034	3826	792	21	-87
Trifolium tembense	2329	2933	604	149	3029	2933	0	0	-100	3029	3633	604	20	-86
Vicia pancifolia	2150	2255	105	178	2850	2255	0	0	-100	2850	2955	105	11	-94
Indigofera colutea	1693	2035	342	663	2393	2035	0	0	-100	2393	2735	342	88	-87
Vicia sativa var angustifolia L.	1953	2345	391	449	2653	2345	0	0	-100	2653	3045	391	49	-89

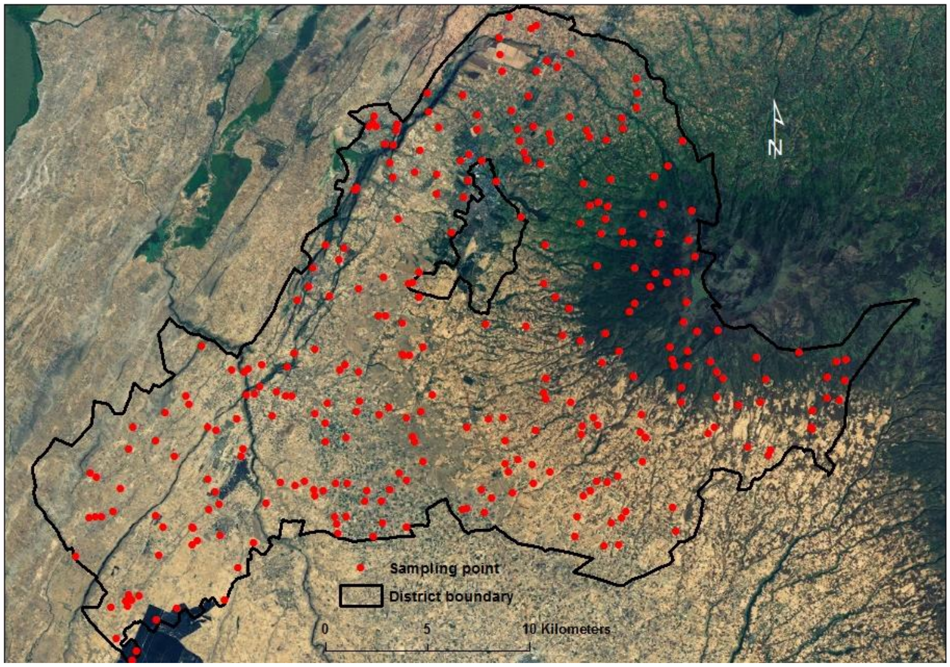
8.2. Appendix Figures



8.2.1. Map showing location of sampling points randomly seeded on recent Google Earth image in Liben district, Ethiopia.



8.2.2. Map showing location of sampling points randomly seeded on recent Google Earth image in Mieso district, Ethiopia.



8.2.3. Map showing location of sampling points randomly seeded on recent Google Earth image in Tiyo district, Ethiopia.

8.3. Appendix bibliographic details of published articles

1. Aklilu Mekasha, Kindie Tesfaye and Alan J. Duncan (2014). Trends in daily observed temperature and precipitation extremes over three Ethiopian eco-environments. *International Journal of Climatology* 34: 1990–1999.

2. Aklilu Mekashaa, Bruno Gerard, Kindie Tesfaye, Lisanework Nigatu, Alan J. Duncan (2014).Inter-connection between land use/land cover change and herders'/farmers' livestock feed resource management strategies: A case study from three Ethiopian eco-environments. Agriculture, *Ecosystems and Environment* 188: 150–162.

3. Aklilu Mekasha, Lisanework Nigatu, Kindie Tesfaye, Alan J. Duncan (2013). Modeling the response of tropical highland herbaceous grassland species to climate change: The case of the Arsi Mountains of Ethiopia. *Biological Conservation* 168 (2013) 169–175.