Proceedings of the International Conference on Impact of El Niño on Biodiversity, Agriculture, and Food Security

23-24 February 2017

Haramaya University, Ethiopia

Organizers:

College of Agriculture and Environmental Sciences of Haramaya University in collaboration with the Ministry of Environment, Forest and Climate Change (MoEFCC)

Peer-reviewed and edited by:

Sintayehu Workeneh (M.Sc, PhD candidate)
Tessema Toru (M.Sc, PhD candidate)
Firew Mekbib (PhD, Associate Professor)
Nigussie Dechassa (PhD, Professor)
Kibebew Kibret (PhD, Associate Professor)
Fekadu Beyene (PhD, Professor)
Mengistu Ketema (PhD, Associate Professor)
Mengistu Urge (PhD, Associate Professor)
Abdeta Debella (MoFECC, Project Leader)
Kidesena Sebesibe (M.Sc, Lecturer)

Published by Research and Extension office of Haramaya University, Ethiopia
Website: www.haramaya.edu.et

ISBN: 978-99944-70-46-4

Articles in this conference proceeding should be cited as:

Sintayehu WD., Tessema T., Nigussie D., Firew M., Kibebew K., Fekadu B., Mengistu K., Mengistu U., Abdeta D. and Kidesena S. (Ed.) 2017. The Impact of El Niño on Biodiversity, Agriculture and Food Security. Proceedings of the International Conference, 23-24 February 2017. Haramaya University, Ethiopia.

Disclaimer

TABLE OF CONTENTS

Page No

	PREFACE	**i**
1	**INTRODUCTION**	**iii**
2	**PARTICIPANT**	**vii**
3	**WELCOMING SPEECHS**	**vii**
	WELCOMING REMARK ON BEHALF OF COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES	**vii**
	WELCOMING SPEECH ON BEHALF OF HARAMAYA UNIVERSITY	**ix**
4	**OPENING SPEECH**	**xi**
5	**KEYNOTE SPEECH**	**xiii**
6	**INTRODUCTION ABOUT THE CONFERENCE**	**xv**

THEME 1: EL NIÑO AND ITS IMPACT ON BIODIVERSITY, AGRICULTURE, AND FOOD SECURITY **1**

1	**Impacts of Various ENSO Phases on Cereal Crop Productivity in the Upper Awash Basin, Central High Land of Ethiopia** Abdisa Alemu, Dirba Korecha, and Muktar Mohamod	**3**
2	**Interconnection between El-Niño-Southern Oscillation Induced Rainfall Variability, Livestock Population Dynamics and Pastoralists Adaptation Strategies in Eastern Ethiopia** Ahmed Hassen, Tessema Zewdu, Adugna Tolera, and Diriba Korecha	**19**
3	**Evaluation of Drought Tolerance in Teff [*Eragrostis teff* (Zucc.) Trotter] Genotypes using Drought Tolerance Indices** Brikti Ferede, Firew Mekbib, Kibebew Assefa, Solomon Chanyalew, Zerihun Tadele, and Eyasu Abraha	**37**
4	**Effects of the 2015/ 2016 El Niño on Zimbabwe Rainfall** Vimbai Mamombe	**51**

THEME 2: EL NIÑO AND ITS SOCIAL AND ECONOMIC IMPACT **61**

1	**Smallholder Farmers' Adaptation to Climate Change and Determinants of their Adaptation in the Central Rift Valley of Ethiopia** Abrham Belay, John Recha, Teshale Woldeamanuel, and John F. Morton	**63**
2	**Impacts of Climate Change on Food Security and its Adaptation and Mitigation Options in Ethiopia: A Review** Tadesse Alemu and Alemayehu Mengistu	**75**

THEME 3: FORECASTING EL NIÑO AND EARLY WARNING, PREPAREDNESS, AND RESPONSE STRATEGIES 85

1 **Performance of Global Climate Models in projecting El Niño-Southern Oscillation (ENSO) in Blue Nile and Awash River Basins, Ethiopia** 87
Gebrekidan Worku, Ermias Tefferi, and Amare Bantider

2 **Modelling Impact of Climate Change on the Hydrological Response of Shaya Catchment in South-Eastern Ethiopia** 103
Sintayehu Fetene

THEME 4: POLICY AND INSTITUTIONS TO MANAGE THE IMPACT OF EL NIÑO 119

1 **Adaptations of Pastoralists to Climate Change and Variability in the Dry Land Areas of Afar, Ethiopia** 121
Amanuel Mekonnen, Desale Kidane, and Demel Teketay

2 **Climate Change Adaptation Policies in Southern and Eastern Africa** 137
Sabastiano Rwengabo and Grace-Maria Kentaro

3 **Resilience against El Nino in Borana Key Pastoral Resource Management: Do we have the right Alliances and Institutions?** 149
Zelalem Tamrat

THEME 5: CLIMATE CHANGE ADAPTATION AND MITIGATION FOR SUSTAINABLE DEVELOPMENT 155

1 **Cropping System for Food Security in the Face of Climate Change: The Case of Eastern Ethiopia** 157
Fuad Abduselam, Tamado Tana, Jamal Abdulahi, Habte Nida, and Taye Tadese

2 **Effects of Climate Change on Food Grain Production in Oromia Special Zone in the Amhara Regional State, Ethiopia** 169
Habtamu Wondemagegnehu

3 **Climate Change in Ethiopia: Its State and the Response** 207
Mensur Dessie Nuri

ABSTRACTS OF PAPER PRESENTED AS POSTERS 239

MAJOR OUTPUT OF THE CONFERENCE 255

PREFACE

Haramaya University has the triple mandates of teaching, research, and community engagement. The university is one of the pioneers of higher education in Ethiopia. It has particularly remained the epicentre of agricultural education and research in the country and produced thousands of agricultural and environmental science professionals since its establishment in 1954. During the last six decades, the university has made outstanding contributions to technology generation, popularization and disseminations, and conservation of biodiversity. Organizing this conference was a timely task for the university in the face of threats posed to agricultural production and food security by climate change. The conference provided a suitable platform for researchers, scientists, and other stakeholders to review and discuss on research findings, share lessons learned from managing El Niño impacts, connect scientific research knowledge to operational communities and develop key messages and shared recommendations for policy makers, practitioners, and the public at large. The conference was also aimed at identifying directions for future work in climate services for El Niño and conserve biodiversity as a strategy for climate change mitigation and adaptation, thereby achieving sustainable development and contributing to the sustainable maintenance of the quality of the earth's ecosystems.

This publication emanated from the International Conference on **Impact of El Niño on Biodiversity, Agriculture, and Food Security**, which was held from 23-24 February 2017 at Haramaya University, Ethiopia. The conference was organized by Haramaya University, College of Agriculture and Environmental Sciences in collaboration with the Ministry of Environment, Forest and Climate Change. Moreover, the university would like to aknowldege mainstreaming incentives for biodiversity conservation in climate resliance green economy project in Ethiopia funded by GEF/UNDP and National Disaster Risk Redaction Commision. We believe that this publication will be a source of useful information and knowledge for the scientific community and the wider public for tackling the impact of El Niño on biodiversity, agriculture, and food security. Haramaya University appreciates the efforts of all people who contributed to the realisation of the conference and the publication of the proceedings.

1. INTRODUCTION

El Niño seriously affects biodiversity, ecosystem services, agriculture and food production, development gains, water availability, soil fertility and conservation, public health and energy supplies, among others. The recent droughts due to climate change have had a profound impact on the livelihoods of agriculture as well as biodiversity-dependent households, causing millions to rely on food aid. Following El Niño, flooding, which is likely to further exacerbate their critical situation, is also expected. The situation offers a unique opportunity for scientists, humanitarian agencies, governments, development professionals and the media to share perspectives on the transformation of climate forecasts to climate services. It allows the expert community to focus attention on framing next steps in climate-services research, which are critical for achieving the sustainable development goals. Haramaya University, a premier university, and the Ministry of Environment, Forest and Climate Change jointly organized an international conference on the impact of El Niño on Biodiversity, Agriculture, and Food Security to identify priorities for enhancing climate resilience agriculture and environmental protection for sustainable development.

The conference aimed at reviewing, discussing, and sharing lessons learned from managing El Niño impacts, connecting scientific research knowledge to operational communities and developing key messages and shared recommendations for policy makers, practitioners and the public and identify directions for future work in climate services for El Niño. Authors of scientific papers, policy makers, and senior scientist made talks and presentations on the impact of El Niño and possible future prospects in climate services. This conference was also provided a platform for networking participants and stakeholders for the future team work in the sector.

2. PARTICIPANTS

More than 160 scientists, practitioners, policy makers, researchers, and public representatives from universities, ministries, NGOs, the private sector, regional sector offices, and academic and research institutions of African countries attended the conference. Twenty-three oral and nine poster presentations were made during the conference under the following broad themes:

- **Theme 1:** El Niño and its impacts on Biodiversity, Agriculture, and Food Security
- **Theme 2:** El Niño and its Social and Economic Impacts
- **Theme 3:** Forecasting El Niño and Early Warning, Readiness, and Response strategies
- **Theme 4:** Policy and Institutions to Manage the Impact of El Niño
- **Theme 5:** Climate Change Adaptation and Mitigation for Sustainable Development

Besides, panel discussions were made under the following themes:

- **Title 1:** Capacity development for climate resilient systems
- **Title 2:** Policy and strategies for climate resilient systems
- **Title 3:** Institutions for climate resilient systems
- **Title 4:** Need for coordinated biodiversity advocacy for climate resilient systems

3. WELCOMING SPEECH

3.1 Welcoming Remark on Behalf of the College of Agriculture and Environmental Sciences

Based on the programme of the conference, the welcoming remark was made by Dr. Kibebew Kibret, Dean of the College of Agriculture and Environmental Sciences (CAES). He expressed his gratitude to the organizing committee of the conference and the co-sponsoring institution, the Ministry of Environment, Forest and Climate Change (MoEFCC). Dr. Kibebew briefly highlighted the grave challenges posed by climate change in the world . He has particularly stressed on impacts of the current El Niño on the eastern and southern African countries including Ethiopia. By referring to the World Meteorological Organization (WMO), he indicated that that the 2015-16 El Niño is one of the strongest events recorded, which has been pushing people already suffering from the effects of climate change deeper into poverty and extreme vulnerability. Dr. Kibebew Kibret, in his welcoming remark, outlined his strong expectation for a stimulating scientific discussions among decision makers, academics, practitioners, researchers, policy makers and other stakeholders on the impact and the possible mitigation and adaptation strategies of El Niño and clear future directions and recommendations.

Dr. Kibebew Kibret, Dean College of Agriculture and Environmental Sciences, Haramaya University, Ethiopia

3.2. Welcoming speech on behalf of Haramaya University

Professor Nigussie Dechassa, Vice President for Academic Affairs, delivered a comprehensive and detailed welcoming speech on behalf of Haramaya University. His welcoming speech carried concrete and strong indications about the devastating impact of **El Niño** on agriculture, the environment, and survival of the human population and the possible avenues to tackle the problems. He discussed in a greater depth starting right from the definition of **El Niño** (the unusual warming of surface waters in the eastern tropical Pacific Ocean or warm phase of the larger phenomenon called the El Niño-Southern Oscillation (ENSO) and **La Niña** (a pattern that describes the unusual cooling of the region's surface waters or cool phase of ENSO) through its multifaceted impacts on socio-economics, development and environment. Among the many impacts of climate change at large and El Niño in particular, Prof. Nigussie Dechassa highlighted droughts, rising economic costs, conflicts, floods, diseases, the health of aquatic ecosystem, significant decline in livestock and crop production, loss of wildlife, loss of important germplasm (he cited Harar coffee and sorghum in Ethiopia as practical examples facing genetic erosion), loss of biodiversity, vanishing lakes (Haramaya, Langey, Adelle in eastern Ethiopia) and boreholes running dry, food insecurity, environmental degradation and livelihood challenges faced by households. In his speech, he further stated "the 2015-16 El Niño which peaked at the end of 2015, offered a unique opportunity for governments, scientists, economists, humanitarian agencies, development professionals, and the media to share perspectives on the transformation of climate forecasts to climate services". A very few of the many stimulating statements Prof. Nigussie Dechassa used in his welcoming speech are the following:

"Climate does not act in isolation!"

"Climate change knows no boundaries!"

"Together, we all have the power to chart a safer, more sustainable and prosperous path for this and future generations!"

"Together we have the power to help the most vulnerable to adapt to changes that are already underway to catalyse a new era of green growth!"

"Adaptation to climate change is indispensable for sustainable development!"

"We do not doubt our capacity to meet these demands with imaginations, innovations, and prudence that befits us if we work hard together. If we work together, we could make decisions that will affect not just our own children and grandchildren but generations yet unborn!"

His speech underlined the main tenets and expectations of the conference. He also indicated HU's commitment and ownership to take the climate service agenda including the outcomes of this conference. He also expressed his gratitude for MoEFCC, UNDP (……) and GEF (……) for their financial contributions and to all those positively responded to the call for papers and have come all the ways to Haramaya to share their experiences, He also expressed his gratitude to the conference organizing committee especially Mr, Sintayehu Workeneh and Mr. Tessema Toru for their exemplary commitment and fortitude. He concluded his speech with a motto, *"Now is our moment to act!"*

Prof. Nigussie Dechassa, Vice-President for Academic Affairs, Haramaya University, Ethiopia

4. OPENING SPEECH

The guest of honour of the conference, His Excellency Dr. Gemedo Dalle, Minister of the Ministry of Environment, Forest and Climate Change (MoEFCC) made an opening speech. His Excellency, Dr. Gemedo said that Ethiopia is an agrarian country with very rich biodiversity. He further singled out Ethiopia as one of eight Vavilov centres of crop genetic diversity and also unquestionably a critical region for floristic and faunistic species diversity. The great portion of his speech focused on the negative impact of climate change due to El Niño and La Niña on biodiversity at genetic, species and ecosystem levels and potential mitigation strategies. Dr. Gemedo said that agriculture is fundamentally dependent on biodiversity and its ecosystem services. He further stated that climate change has both direct and indirect effects on biodiversity. According to His Excellency, the links between biodiversity and climate change runs in both directions i.e. biodiversity is threatened by climate change and biodiversity can reduce the impacts of climate change. He described several consequences of climate change on the species diversity which included changes in distribution, abundance, extinction rates, changes in reproduction timings, and changes in length of growing seasons for plants. He also mentioned nature-based solutions for national and global challenges posed by climate change including El Niño and La Niña. His pointed out that maintaining and restoring native ecosystems, protecting and enhancing ecosystems services, managing habitats for endangered species, creating refuges and buffer zones, and establishing networks of terrestrial, freshwater and marine protected areas that take into account projected changes in climate are a few examples of activities that could promote mitigation or adaption to climate change. He appreciated Haramaya University for taking the initiative to organize this timely conference in collaboration with MoEFCC. Finally, he concluded his speech by saying "action is required to conserve biodiversity" and then he officially declared the opening of the two-day conference.

His Excellency, Dr. Gemedo Dalle, Minister for Ministry of Environment, Forest and Climate Change, Ethiopia

5. KEYNOTE SPEECH

The keynote speaker of the conference was Mr. Abdeta Debela from MoEFCC. He started his speech by acknowledging the organizers of the conference (HU and MoEFCC) and key partners involved in one or another way for the realization of the conference. In his speech, he raised many issues, such as a range of socio-economic impacts of El Niño including on agriculture, ecosystem services, biodiversity, food security, human and livestock migration, malnutrition of millions of rural poor, shortage of animal feeds in semi-arid and arid areas, degradation of habitats, failure of crops due to dry spells and loss of endemic species. Mr. Abdeta has particularly emphasised on the impact of the 2015/16 El Niño drought on Ethiopia's biodiversity, agriculture and food security. According to Mr. Abdeta, the 2015/16 El Niño resulted in the need to mobilize relief food aid for 8.2 million people (October 2015) and 10.2 million people (in January 2016). He indicated that 429 Woredas (districts) in Ethiopia became relief food aid areas; 821,400 people were displaced due to drought and food and 110,000 people were displaced due to conflicts on key natural resources on the stated period. In his keynote address, Mr. Abdeta noted managing the 2015/16 El Niño induced drought seriously challenged the pace of the country's fast economic growth by diverting resources meant for development to emergency response operations. He conveyed exuded confidence that the international would consolidate existing knowledge and expertise as well as generate new ideas, perspectives, approaches, and recommendations for tackling impact of El Niño and realize climate-resilient agriculture, biodiversity conservation, environmental protection, and food security. He said these would in turn lead to livelihood diversification options and decent occupational shift, highly coordinated and well aligned biodiversity mainstreaming and institutional strengthening and interpectoral synergy to enhance early warning system and climate services. He concluded his keynote address by wishing stimulating deliberations on themes s of the conference and expressing his hope of timely compiling and publishing the ensuing proceedings for dissemination to the scientific community and all other stakeholders..

Mr. Abdeta Debela, National Coordinator for GEF/UNDP Funded Mainstreaming Incentives for Biodiversity Conservation in Climate Resliance Green Economy Project in Ethiopia.

5. INTRODUCTION ABOUT THE CONFERENCE

Mr. Sintayehu Workeneh briefly explained the background of the conference and the steps they have gone through to realize the conference. Mr. Sintayehu emphasised on the negative impact of El Niño in most sub-Saharan African countries including Ethiopia for the past several decades but with little efforts having been made to tackle and mitigate the problem. With this background, the international conference on the impact of El Niño on biodiversity, agriculture and food security was initiated. According to Mr. Sintayehu, after announcing a call for papers, the committee received 87 papers from within and outside the country. However, due to limited resources, he revealed that only 23 papers were selected for oral presentation and nine papers for poster presentation. Mr. Sintayehu also stated his gratitude to MoEFCC for collaborating with Haramaya University to organize the conference. Mr. Sintayehu concluded his presentation by describing the objectives and thematic areas of the conference.

Mr. Sintayehu Workeneh, Core-organizing Committee Member, Haramaya University, Ethiopia

Theme 1: El Niño and its impact on Biodiversity, Agriculture, and Food Security

1. Impacts of Various ENSO Phases on Cereal Crop Productivity in the Upper Awash Basin, Central High Land of Ethiopia

Abdisa Alemu[1*], Dirba Korecha[2], and Muktar Mohamod[1]

[1]Haramaya University, P.O. Box 138, Dire Dawa, Ethiopia

[2]USGS/Famine Early Warning Systems Network, P.O. Box 17403, Addis Ababa, Ethiopia

*Corresponding author email: abdanne12@gmail.com

Abstract

El Niño-Southern Oscillation (ENSO) has different impacts on seasonal agricultural systems in Ethiopia. In order to characterize the effects of ENSO, this paper is aimed at determining impacts of various ENSO phases on cereal crops in Upper Awash Basin region of central Ethiopia. Rainfall data covering the period from 1980 to 2014 were used. Climatological pattern of rainfall and its variability, areal rainfall anomalies, were evaluated with respect to global sea surface temperature. Multivariate statistical methods were employed to quantify relationships between regionalized rainfall index and Sea Surface Temperature anomalies (SSTa). The results of this study revealed that SSTa as recorded over Nino regions have strong signal in explaining regional rainfall variation than other ocean fields. In particular, Nino regions SSTa have negatively correlation with kiremt rainfall and vice versa in the case of belg rains. Computed weighted average rainfall data for each homogenous zone of Upper Awash Basin and cumulative density function (CDF) with zonal cereal crop yield data, particularly for teff, wheat, maize and sorghum crops, were analysed. Risk analysis was computed against the ENSO-based approach using CDF. The results showed that, preferable yield value and less crop risk were identified during non-ENSO years both by first and second stochastic dominance senses. Hence, non-ENSO phase was, therefore, found to be the best risk efficient set identified in the Upper Awash Basin for crop productivity. In contrast, overall cereal crop yields were decreased in regionalized area three of Upper Awash Basin by 16% and 5.3% during El Niño and La Niña episodes, respectively. El Niño shocks are likely to cause a reduction in cereal crop production but it is relatively better than La Niña episodes for wheat crop production in regionalized area one. Thus, it could be concluded that having the information of ENSO phase in advance may improve agricultural practices such as selection of crop varieties and thus maximize agricultural rain-fed cereal crop productivity and minimize crop risks associated with fluctuation of seasonal rainfall under various ENSO phases. The results of this study could, therefore, be utilized by agricultural societies in the provision of alternate use of ENSO forecasts for further insightful decisions, particularly on crop risk management strategies.

Keywords: Cereal crop, ENSO, Regression, Stochastic dominance, Variability

1. Introduction

The El-Niño-Southern Oscillation (ENSO) is the most important coupled ocean atmosphere phenomenon to cause global climate variability on inter-annual time scale. Basically, the phenomenon is related to the quasiperiodic redistribution of heat across tropical Pacific region. ENSO is characterized by a varying shift between a neutral phase and two extreme phases such as El Niño and La Niña. The El Niño phase is marked by a deep layer of warm ocean water across the eastern and central equatorial Pacific region. La Niña related condition is opposed to those of El Niño a deep layer of cooler than average ocean temperatures across the east-central equatorial Pacific region. Monthly and spatially Sea Surface Temperature anomaly (SSTa) and the index values of each month has been considered over the tropical Pacific region of 5°S - 5°N and 150°W - 90°W. If the SSTa index values are 0.5 or greater, between -0.5 and 0.5, and -0.5 or less for consecutive months over central and eastern and Pacific Ocean, ENSO phase is categorized as El Niño, Neutral, and La Niña, respectively (Goddard *et al.,* 2001).

The most important feature of sea surface temperature variability that can cause large scale weather disruptions is El Niño and its counterpart La Niña (Goddard *et al*., 2001). According to Nicholls (1991) ENSO and local rainfall relationship has been made of correlation and regression methods in attempting to establish evidence of "teleconnections" that affects local rainfall patterns. According to Korecha and Barnston (2007), in Ethiopia ENSO events have strongly linked with various atmospheric system and rainfall distribution. The principal cause of drought in Ethiopia is asserted to be the fluctuation of the global atmospheric circulation, which is triggered by SSTa, occurring according to ENSO events. The phenomena have significant impact on displacement and weakening of the rain producing system in the seasons. ENSO episodes and other regional systems have impact on seasonal rainfall performance and rainfall variability over Ethiopia due to remote teleconnections system (NMSA, 1996; Tsegay, 1998; 2001; Gissila, 2001; Korecha, 2002; Korecha and Barnston, 2007). Hence, most of the drought years were recorded during *kiremt* season's El Niño episode. Since agriculture is heavily dependent on rainfall, productivity and production are strongly influenced by climatic and hydrological variability due to ENSO phases. In Ethiopia, the degree of crop yield variability over time is determined by the amount, pattern, and frequency of rainfall (Adugna, 2005). Fraisse *et al.* (2006) showed that ENSO-based seasonal climate reduces crop yield.

The Upper Awash River rises from the high plateau of central Ethiopia near Ginchi town, west of Addis Ababa and extends to Koka dam. Upper Awash Basin (UAB) is part of lands where all digital elevation maps are located about 1500 m above sea level (Taddese *et al*., 1998). The major agricultural crops grown in the area are cereals, pulses, and oil seeds (CSA, 2014). In the UAB, the rainfall is highly characterized by inter annual and inter seasonal variation. The rainfall type of UAB is bimodal type, which are two rainy seasons and one dry season. The *belg* (FMAM) rainy season extends from February to May. Major rain bearing systems during the *belg* season are the development of thermal low over South Sudan, generation and propagation of disturbances over the Mediterranean Sea, sometimes coupled with easterly waves, development of high pressure over the Arabian Sea, the interaction between mid-latitude depressions and tropical systems accompanied by troughs and the subtropical jet and occasional development of the Red Sea convergence zone (RSCZ) (NMSA, 1996; Gonfa, 1996). *Kiremt (JJAS)* main rainy season covers the period from June to September. Major rain producing systems during *Kiremt* season includes northward migration of ITCZ, development and persistence of the Arabian and South Sudan thermal low along 20°N latitude, development of quasi-permanent high pressure systems over south Atlantic and south Indian Oceans, development of tropical easterly jet and the generation of low level Somali jet that enhance low level south westerly flow (NMSA, 1996; Segale and Lamb, 2005). Under such circumstances, crop yield values of each year in Upper Awash Basin (UAB) and associated ENSO phase is needed into a simple tool that allows users to customize the output of its specific situations. Therefore, the research study was conducted with the objectives of determining the influences of ENSO on the local areal rainfall pattern, and determining impacts of ENSO phase on major cereal crop productivity.

2. Materials and Methods

2.1 Description of the Study Area

This study was conducted in the Upper part of the Awash River Basin in Ethiopia, which is located between 8°16' N - 9° 18' N and 37° 57'E - 39°17'E. It covers about 7240km² and lie between 1500m to 3419m above sea level (Taddese *et al.*, 1998). The physical settings of the study area are characterized by the heterogeneity of the large topographic systems such as orographic groups, the high plains, mountains and plateaus (Figure 1).

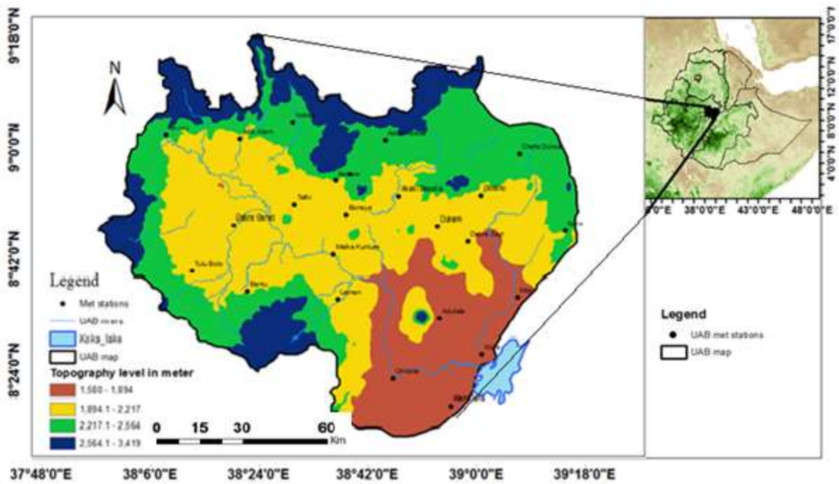


Figure 1. The Upper Awash River Basin and its topographic features.

The land use of UAB consists mainly of cultivated agricultural land, grassland and shrub land, which cover 93.2% of the total area; about 3.6% is covered by sparse trees and the remaining 3.2% comes from the other land cover types (Mussa, 2011). According to Koei (1996), the dominant soil types are Cambisols and Vertisols.

2.2. Data Collection

Various types of data were obtained from different sources in order to analyse and examine the impacts of ENSO phase on crop production. Daily rain gauge data from 1980 to 2014 were obtained from National Meteorological Agency (NMA) of Ethiopia; missing data were filled with gridded data. Major crop yield data were obtained from Central Statistical Agency (CSA). Global and regional SST data and atmospheric indices were taken from NOAA-CIRES climate diagnostics centre (http://www.cdc.noaa.gov/). SST data were taken from CPC (https://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/).

2.3. Data Analysis

Characteristics of areal rainfall analysis, rainfall pattern, and its variability as well as its relation with global SST have been analysed.

2.3.1 Climate variability analysis

The seasonal and annual spatial rainfall distributions were computed based on historical rainfall data using various spatial analysis tools in ArcGIS software version 10.1. *Kiremt* seasonal rainfall data ranging from 1980 to 2014 have been selected from the UAB. The coefficient of variation of seasonal and inter-seasonal rainfall variability and anomaly were analysed by:

$$CV = (\frac{SD}{\overline{X}}) * 100 \text{ where } \overline{X} = \frac{\sum Xi}{N} \text{ and } SD = \frac{\sqrt{(Xi - \overline{X})^2}}{N-1} \quad (1)$$

$$RAi = \frac{Xi - \overline{X}}{SD} \quad (2)$$

Where SD is standard deviation; $\overline{X}$ is long year mean; N is total number of year taken, X_i is rainfall of each month or season and RA_i is rainfall anomaly of each year. If RA_i is more than 0.5 between -0.5 and 0.5 and less than -0.5, meteorologically the season is wet, normal, and dry, respectively.

Regional level rainfall variability has been analysed and characterized (Equation 3). This computation was made for each of the three homogenous rainfall regime of UAB during the *belg* and *kiremt* seasons that enabled to show the degree of long term temporal Zonal rainfall variability. Regional rainfall index R_k is calculated using the following formula:

$$R_k = \sum_{i}^{m} Wi \, x(\frac{R_{k,i} - \overline{m}}{SD}) \quad (3)$$

Where R_k is regional level areal rain fall index, W_i is a weight applied to the i^{th} of n stations, $R_{k,i}$ is the rainfall at i^{th} station during year k, and SD are the average and standard deviation of the station's rainfall. If R_k is more than 0.5, between -0.5 and 0.5 and less than -0.5, meteorologically the zonal seasonal rainfall is categorized under wet, normal and dry season, respectively.

2.3.2. Correlation between SST and regional local areal rainfall

Local based regional rainfall index of each homogenous rainfall regime was evaluated. Canonical correlation analysis (CCA) was used to estimated patterns of correlated with pre-seasonal data between ocean fields of 40N to 40S degree extensions SST and long year's regionalized rainfall index (R_k) using R-Gui software. The predictors with a threshold correlation (r) value of ≥ |0.3| has been taken into account, and amounts to a minimum 10% of the variance being explained (Tanco and Berri, 2000). Empirical correlation between zero lead time Nino region SST anomaly and regionalized rainfall anomaly using SPSS software has been done (Landman and Goddard, 2002).

Canonical correlation is calculated by

$C = R_{yy}^{-1} R_{yx} R_{xx}^{-1} R_{xy}$ (4)

Where: C = matrix of singular value decomposition

R_{yy} = Correlations between Y variables

R_{yx} = Correlations between Y and X variables

R_{xx} = Correlations between X variables

R_{xy} = Correlations between X and Y variables

2.3.3. Cumulative Density Functions (CDFs) and Stochastic Dominance (SD) Analyses

Stochastic dominance (SD) means the cumulative density function (CDF) of the best alternative must always lie below and to the right of the CDFs of the other distribution curves (Hardaker *et al.*, 1998; Mamo, 2005). For instance, a CDF 'A' lies entirely below and to the right of another CDF 'B', then 'A' dominates 'B' in the first-degree sense (FSD). 'A' would be preferred by any individual who prefers more of the performance measure to less, regardless of whether they are risk averse. On the other hand, decisions are more difficult to resolve by FSD when the CDFs interact (cross-over) such as 'A' cross 'B'. Second degree stochastic dominance is applied based on the area under the CDF. If the area under CDF of 'A' is less than the area under CDF 'B' at every point along the x-axis, under such circumstances, neither of them totally dominates in the sense of FSD, indicating the limited discriminatory power of the FSD (McCarl, 1996). Then 'A' is said to dominate 'B' in the second-degree sense. Activity 'A' would be preferred by any individual to any risk-averse for all values of the performance measure (Levy, 1992; 1998).

Cross-over implies that one strategy could dominate the other at the lower points (bottom tail) of the distribution, but could be dominated at the upper values (top tail) in the distribution or vice versa. Crop yield and associated rainfall values for UAB were incorporated into a simple tool that allows users to customize the output to their specific situations.

Average Zonal crop yields for their specific fields with *Kiremt* homogenous Zonal rainfall data for the period from 1995 to 2013 were classified into three ENSO episodes, namely, El Niño, La Niña and Neutral, based on Oceanic Nino region index value. If ENSO phase classifications are 0.5 or greater, between -0.5 and 0.5, and -0.5 or less for consecutive months over central and eastern and Pacific Ocean during crop growing season, ENSO phase is categorized as El Niño, Neutral and La Niña, respectively. Stochastic dominance (SD) analysis of teff, wheat, maize and sorghum cereal crop with different ENSO Phase such as *El Niño, La Niña* and normal phenomena were analysed for risk analysis.

CDF was estimated for stochastic dominance rules that assume farmers should decide whether to invest crop production during la Niña phase "F" or an alternative El Niño phase "G" and Normal phase "H" as stated in Equation 6 by using R-Gui software. Decision rule of First Stochastic Dominance (FSD) is if and only if

$$G(x) - F(x) \geq 0 \ \forall x \ \varepsilon \ R \qquad (5)$$

And the cumulative density function can be calculated by:

$$F(x) = \int_0^X F(X, \mu, \delta) dx, \qquad (6)$$
$$where \ F(X, \mu, \delta) = \frac{1}{\sqrt{2\pi\delta^2}} \exp(-\frac{(x-\mu)^2}{2\delta^2})$$

Where F(x), G(x) and H(x) are crop yield cumulative density functions given during *La Niña, ElNiño* and Normal phase, respectively. Given 'X' represent crop yield in quintal per hectare during each ENSO phase and μ and δ mean and standard deviation of yield, respectively.

2.3.4. Yield reduction due to ENSO phases

A percentage crop yield deviating due to ENSO variability was calculated by the following methods;

$$R = (\frac{\Delta P}{\overline{Yn}}) * 100 \qquad (7)$$

$$\overline{Yn} = \frac{1}{i} \sum_1^i Yn \qquad \text{If and only if } -0.5 < ONI < 0.5 \text{ during crop growing season} \qquad (8)$$

$$\overline{Yla} = \frac{1}{j} \sum_1^j Yla \qquad \text{If and only if ONI} \leq -0.5 \text{ during crop growing season} \qquad (9)$$

$$\overline{Yel} = \frac{1}{k}\sum_{1}^{k} Yel \quad \text{If and only if ONI} \geq 0.5 \text{ during crop growing season} \tag{10}$$

$$OR = \frac{1}{N}\sum_{1}^{N} R \tag{11}$$

Where R and OR are reduction of each crop yield and over all crop yield reduction in %age, respectively, and whereas n is number of cereal crop grown in the same year. In this regard, four major cereal crops grown in the study area and these are teff, wheat, maize and sorghum. ΔP is change in productivity of crop yield in quintal per hectare (Qt/ha) from neutral year due to La Niña or El Niño episode. $\overline{Yn}$, $\overline{Yla}$ and $\overline{Yel}$ are the average of crop yield in Qt/ha for the entire years in Neutral, La Niña and El Niño years, respectively; i, j and k are the number of Neutral, La Niña and El Niño years, respectively whereas Y_n ,Yla and Yel are the amount of crop yield harvested in (Qt/ha) during Neutral, La Niña and El Niño years and (i+ j+ k=19 years of cropping season has been taken in this study which is from 1995 to 2013); and ONI is the Oceanic Niño Index value for the reproductive growth period of the cropping season in the respective year.

3. Results and Discussion

3.1. Rainfall climatology

Seasonally, 183 to 310mm and 465 to 906mm contribution come from Belg and *kiremit*, respectively (Figures 2a and b). The annual rainfall ranges between 649 to 1222mm of which the western mountain chains receive an annual rainfall ranging from 1000 to 1200mm, while the southern; south eastern and central regions of UAB receive between 700 to 900 mm (Figure 2c). The quantum of rainfall is found to be highest in the western highland or Zone one and lowest in the lower altitude or zone three. Therefore, the climate of UAB is influenced by undulated mountain chains and the circulatory systems that interact with Orography, cross equatorial wind system and ITCZ.

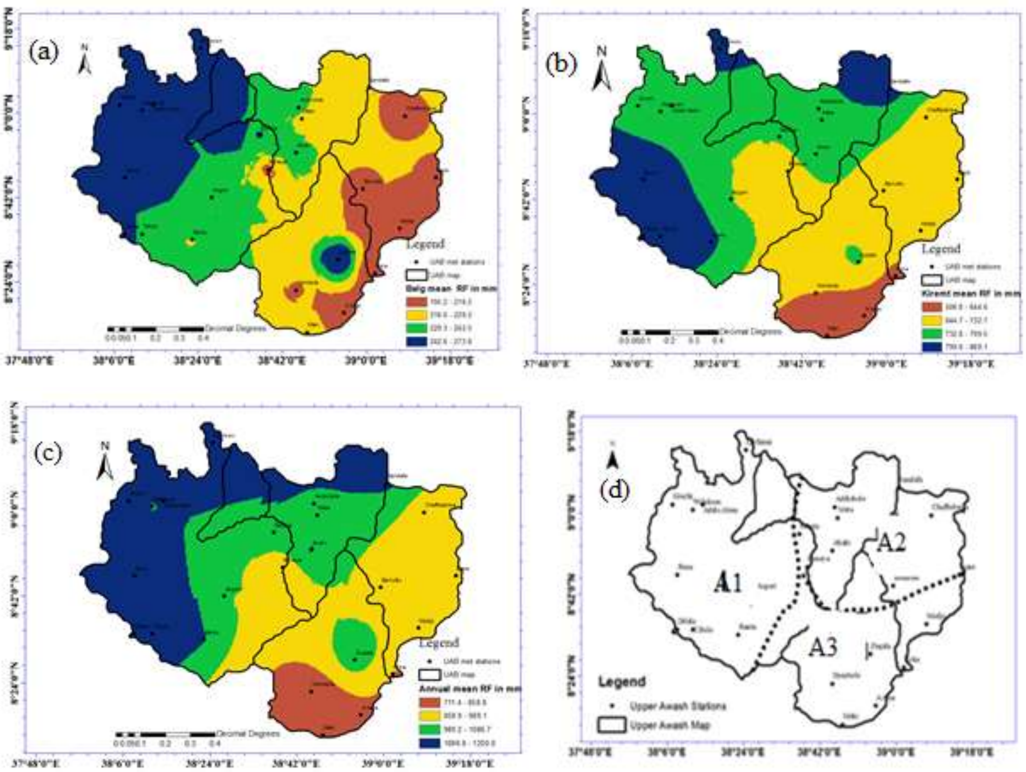


Figure 2. Rainfall distribution of Upper Awash, during Belg (a), Kiremit (b) and Annual (c).

3.2. Inter-Seasonal to Seasonal Rainfall Variability

The rainfall variability during *kiremt* season and annual totals have shown that there existed less spatial and temporal variability, while monthly and *belg* season rainfall patterns have possessed high spatial and temporal variability (Table 1). Seasonal and inter-seasonal rainfall variability information are very important for short and long term management of farming system through which cropping patterns, sowing period and selection of crop variety.

Table 1. Inter-seasonal to seasonal rainfall coefficient of variation (CV%).

Stations	Jun	July	Aug	Sep	*Belg*	*Kiremt*	Annual
Busa	42	31	38	55	55	29	28
A/Ababa bole	47	21	22	31	40	16	15
A/Tena	59	42	31	50	43	22	13
Bishoftu	48	30	28	40	55	19	19
Ginchi	35	22	25	34	43	15	16
Akaki	50	35	42	52	44	36	30

3.3. Spatial correlation between SST and regionalized rainfall index

Correlations with pre-seasonal SST data results showed that rainfall during JJAS and FMAM have strong relationship with the global SSTs such as Nino regions, the Indian Ocean dipole and (IOD). This index expresses the magnitude of excess or stress rainfall relative to normal. CCA with SSTa anomalies over most of the Pacific Ocean tend to be positively correlated with *belg* rainfall index (Figure 3a) and negatively correlated with *kiremt* season (Figure 3b).

During *belg* season, Zone one regional rainfall index was correlated with global sea surface temperature (r ≥ |0.3|) at Nino regions such as Nino 4 and Nino 3.4, part of Nino 3. It is positively correlated with North eastern Pacific Ocean and some parts of southern Atlantic and south western Indian ocean. Whereas, western Pacific and most of Eastern Indian ocean have a negative correlation with Zone one (Figure 3a).

Kiremt regional rainfall index of Zone one was correlated (r value of ≥ |0.3|) with mean of Spatial global sea surface temperature. Some part of North eastern pacific was positively correlated with Zone one (Figure 3a). The IOD phase was not correlated with *kiremt* zonal rainfall (Figure 3b).

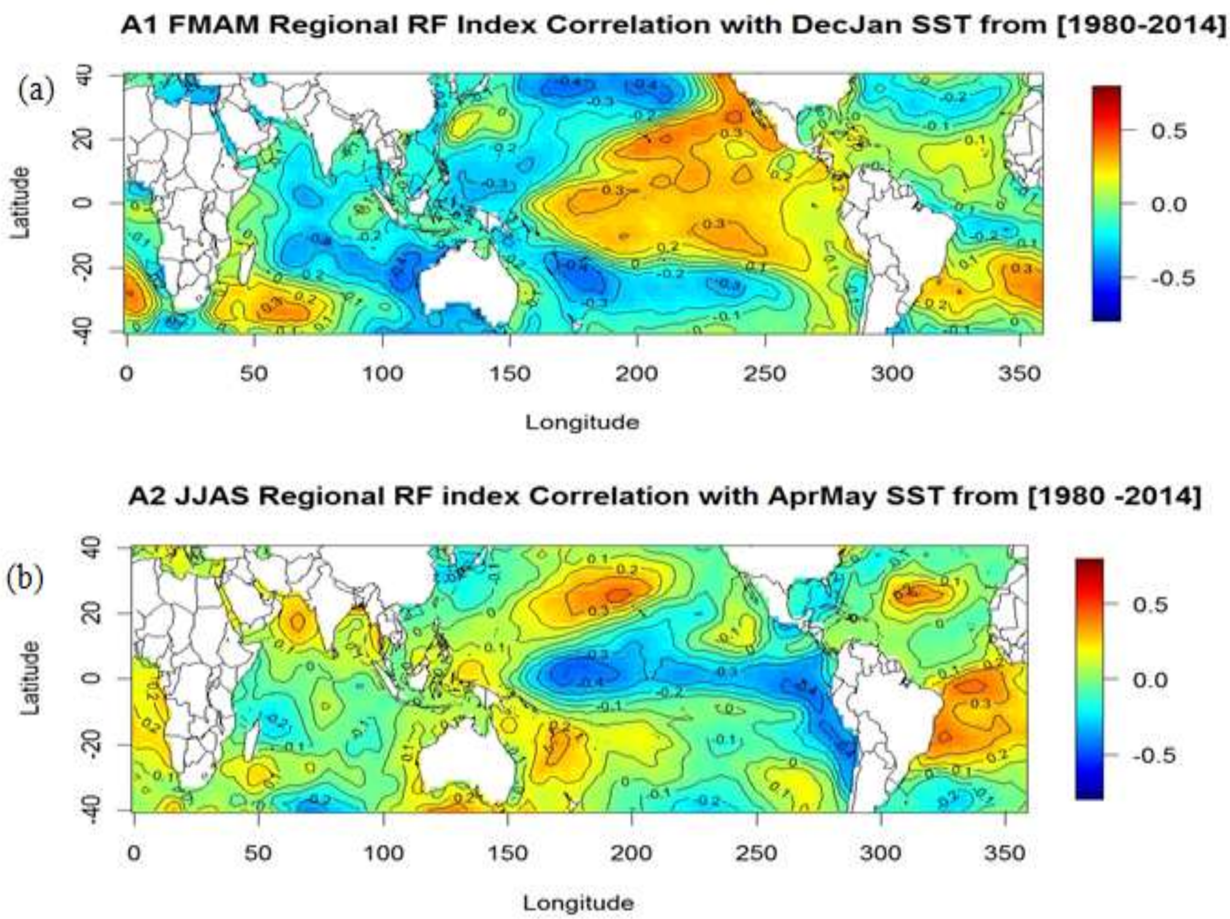


Figure 3. Regional R_K index correlation with global spatial SSTa

3.4. Relationship between zero lead time Nino regions SST with regional rainfall index

Empirical correlations between Nino regions SSTa and regionalized rainfall anomaly suggest that ENSO variability is closely linked to variability in rainfall in Upper Awash basin. According to long years' correlation analysis of zero lead time, Nino region SST and seasonal regional rainfall index for each Zone results showed that, observation described

During *belg* season rainfall anomaly and related Nino regions was positively correlated, while during *kiremt* season rainfall anomaly and SST was negatively correlated (Table 2 and 3). Positive SST anomaly is related to increasing sea surface temperature than normal while negative SST anomaly is related to coldness of sea surface than normal condition. This resulted to increase rainfall activity in the *kiremt* rainy season during La Niña -i.e., cold phase of the year (Figure 4). Zero lead time of the Nino region -SST anomaly was positively correlated with *kiremt* regional rainfall index (Table 2). All Nino regions were negatively correlated with *kiremt* rainfall index, and positively correlated with *belg* regional rainfall index (Table 3). Nino 3 and 3.4 SST regions were positively correlated with Zone one and two regional rainfalls, whereas, Nino 4 and 3.4 SST were positively correlated with Zone three *kiremt* regional rainfall index (Table 2).

Table 2. Zero lead time Nino region SSTa correlation with Zonal rainfall index of *kiremt*.

Variables	JJAS nino4	JJAS nino3.4	JJAS nino3	JJAS nino1+2	*Kiremt* A1	*Kiremt* A2	*Kiremt* A3
JJAS nino4	1.000	0.898	0.700	0.326	-0.209	-0.501	-0.341
JJAS nino3.4		1.000	0.909	0.562	-0.368	-0.610	-0.331
JJAS nino3			1.000	0.827	-0.427	-0.631	-0.251
JJAS nino1+2				1.000	-0.321	-0.502	-0.078
KiremtA1					1.000	0.695	0.390
KiremtA2						1.000	0.503
KiremtA3							1.000

Table 3. Zero lead time Nino region SSTa correlation with Zonal rainfall index of *belg*.

Variables	FMAM nino1+2	FMAM nino3.4	FMAM nino4	FMAM nino3	*Belg* A1	*Belg* A2	*Belg* A3
FMAM nino1+2	1.000	0.675	0.388	0.890	0.247	0.087	0.214
FMAM nino3.4		1.000	0.869	0.894	0.474	0.312	0.429
FMAM nino4			1.000	0.613	0.380	0.245	0.350
FMAM nino3				1.000	0.427	0.268	0.407
Belg Z1					1.000	0.787	0.799
Belg Z2						1.000	0.797
BelgZ3							1.000

3.5. Regionalized rainfall and Nino regions SST anomaly during rainy seasons

The result of regional rainfall anomaly has shown that those extreme seasons of wet or dry season, whereas value more than 0.5 and less than -0.5 with associated years of *belg* and *kiremt* seasons were extreme wet and dry season, respectively (Figure4a and b). According to the historical SST anomalies in the Niño 3 and 3.4 regions results revealed that rainfall amounts of major rainy season became very high in La Niña but low in El Niño years. Conversely, during small rainy season, comparatively high rainfall amounts were observed when El Niño was apparently established and low rainfall has been observed during La Niña episode (Figure 4b).

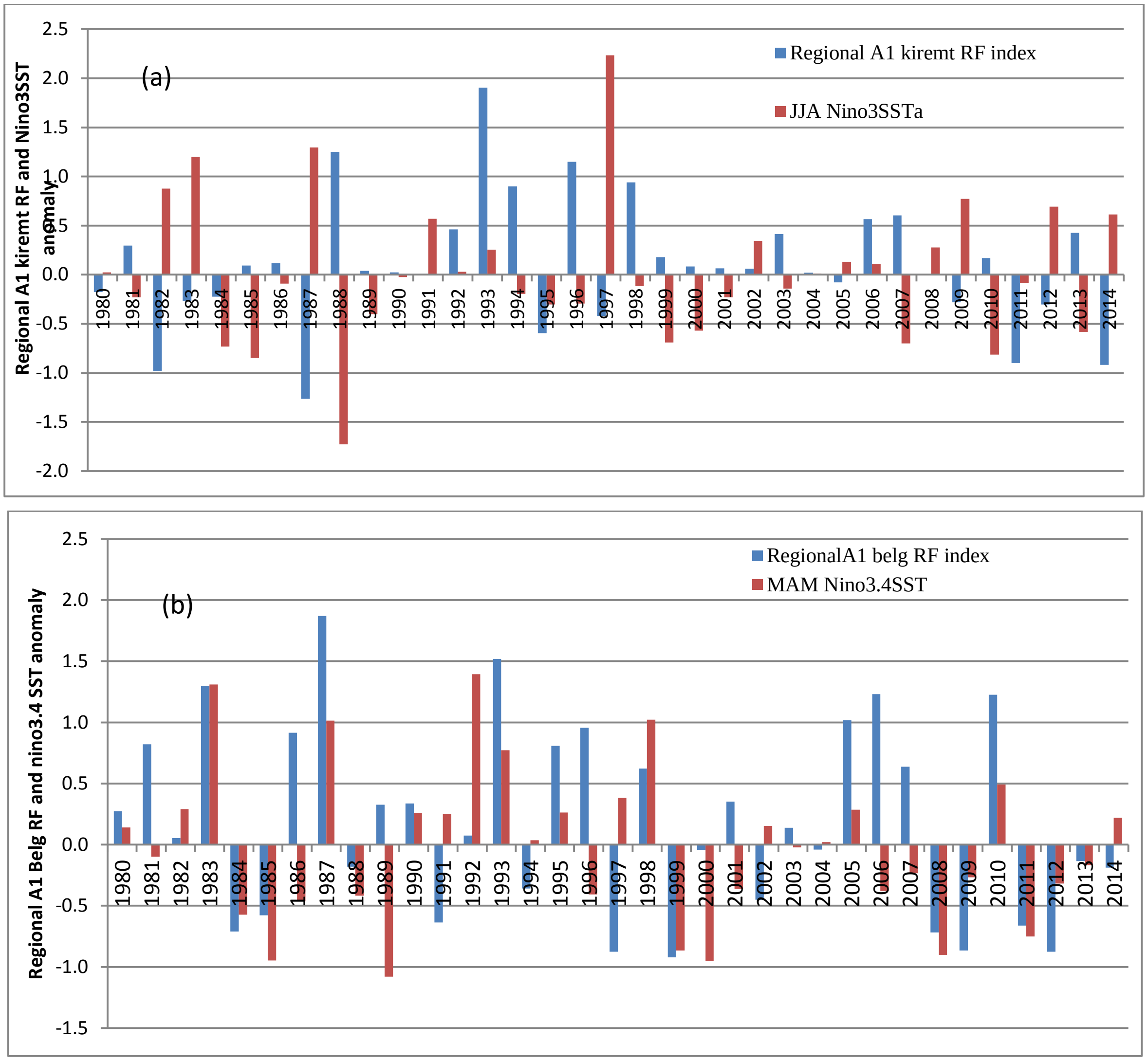
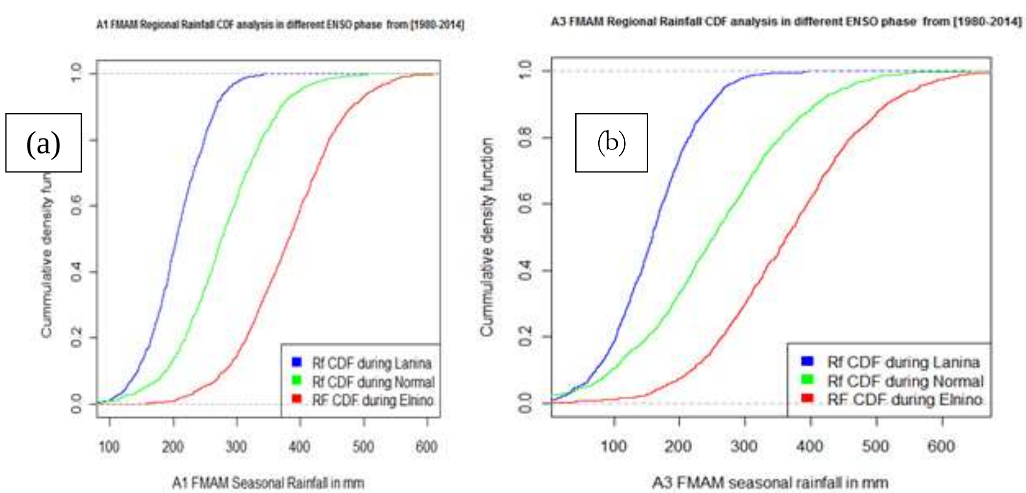


Figure 4. Regional rainfall and Nino regions SST anomaly during rainy seasons: *kiremt* (a) and *belg* (b) seasons.



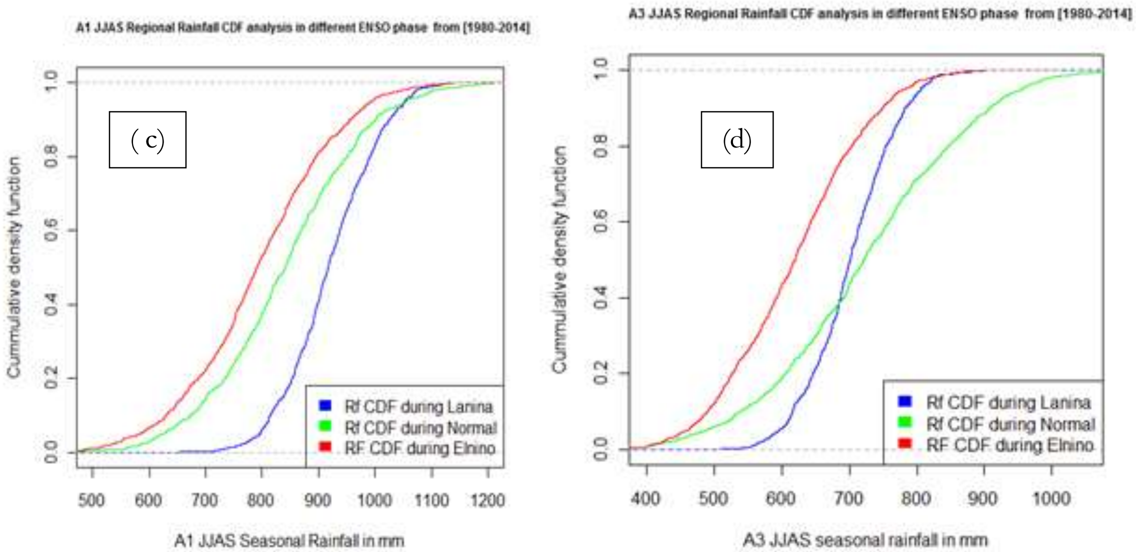


Figure 5. Comparison of cumulative seasonal rainfall at various ENSO phases.

3.6. Crop Yield Risk Analysis by using ENSO Phase

According to crop risk analysis, based on 19 years of crop data associated with seasonal ENSO phase of 4 ElNiño years, 4 La Niña years, and 11 Neutral years' result, by the First order stochastic dominance (FSD) shown that, the dominating variable would be preferred by any decision maker who prefers "more" to "less", regardless of the management of risk. CDFs of crop yield during 'Normal' SST phase and 'La Niña' SST phase were more dominant than that of 'El Niño' SST phase (Figure 6a-d; 7a-d). Zone one during 'El Niño' phase has better wheat crop yield production than during La Niña' by FSD sense (Figure 6b). The seasonal climate information may further support in the selection of crop variety/types, field allocation, and other strategic management activities with respect to less crop risks.

The cross-over between CDF during la Niña phase and CDF during Normal phase (Figure 7b) implies that curves meet the requirements for Second order stochastic dominance (SSD) and the comparison should be handled using the higher order stochastic dominance techniques to be the first choice as described by McCarl (1996). CDF of wheat crop yield during Normal phase lies to the left of CDF during la Niña at the lower level of the yield data series, meaning La Niña phase alternative is better choice in this range of the yield data distribution. CDF during La Niña lies to the left of CDF during Normal at the upper tail of the series, meaning that the Normal phase is a better and less risky choice in the upper range of the wheat yield at Zone three (Figure 7b).

Comparing the total area under the CDF (Figure 7b), during Normal phase is bigger than CDF during 'La Niña' phase at upper % ile points. SSD requires that the area under the cumulative density function during normal SST phase at lower tail is smaller than the area under the cumulative density function during La Niña phase at upper tail as described in Figure 7b. Therefore, during 'Normal' phase, standard algorithms for identifying stochastic dominance utilize pair-wise area comparisons of wheat yield in sorted series of net revenue distributions. CDF during 'La Niña' and 'Normal' phase for wheat production yield at Zone three has better performance. Every risk-averse farmer, therefore, prefers Normal phase alternative that is dominated by SSD. Therefore, Normal phase is found to have the best risk efficient set identified for each three Zones crop productions planning. Crop yield has good performance during Normal SST phase than El Niño and La Niña phases; users can make comparisons based on alternate ENSO forecasts for further insight for crop risk planning and management strategy. Farmers targeting 12Qt/ha of Teff crop yield at Zone three cropping seasons could achieve the desired quantity, but the associated risk level is of the highest order of 40% as described in Figure 7a.

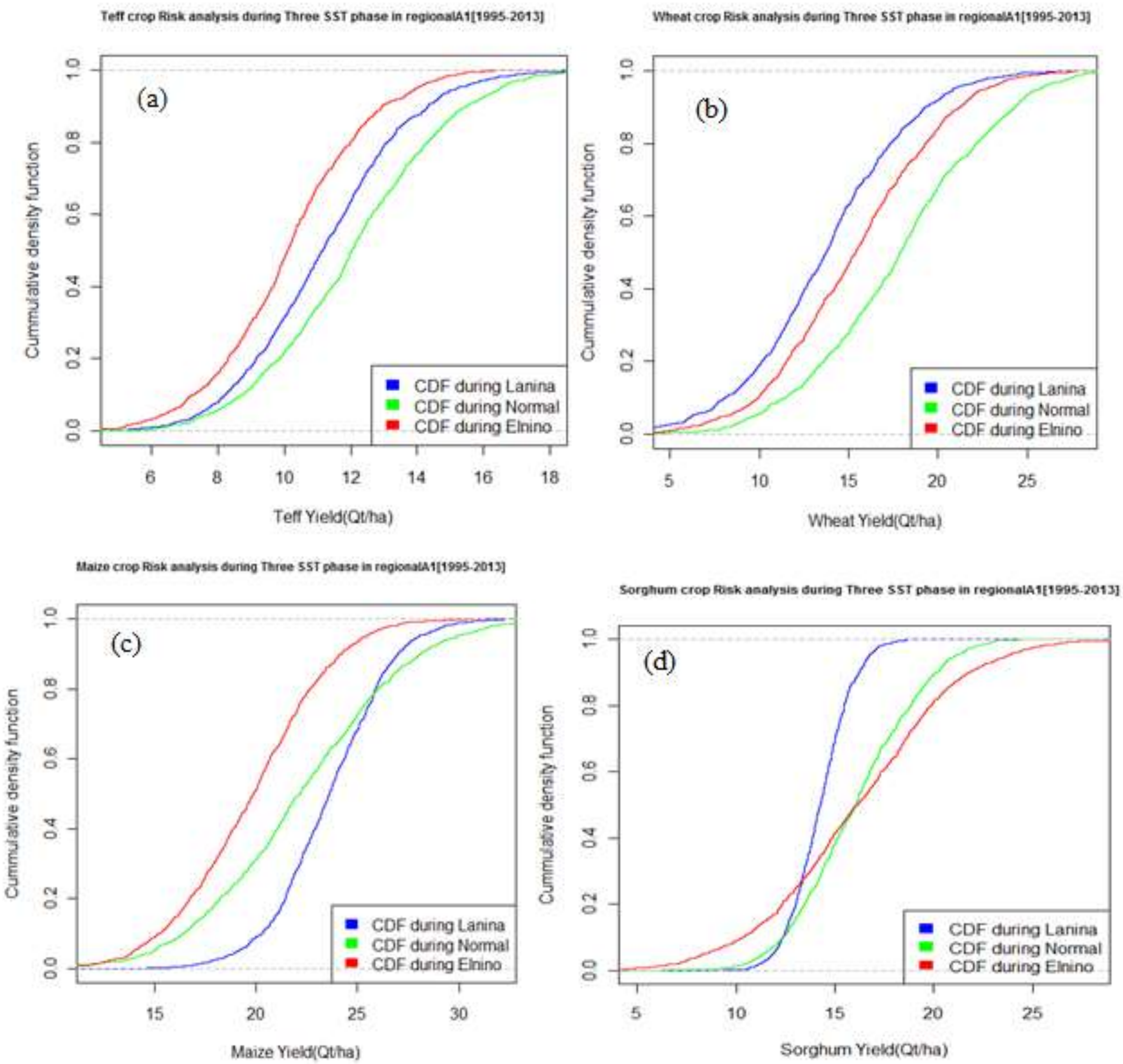


Figure 6. Cumulative density function for cereal crop yield of Zone one with three SST phase: Teff (a),Wheat (b), Maize(c) and Sorghum (d).

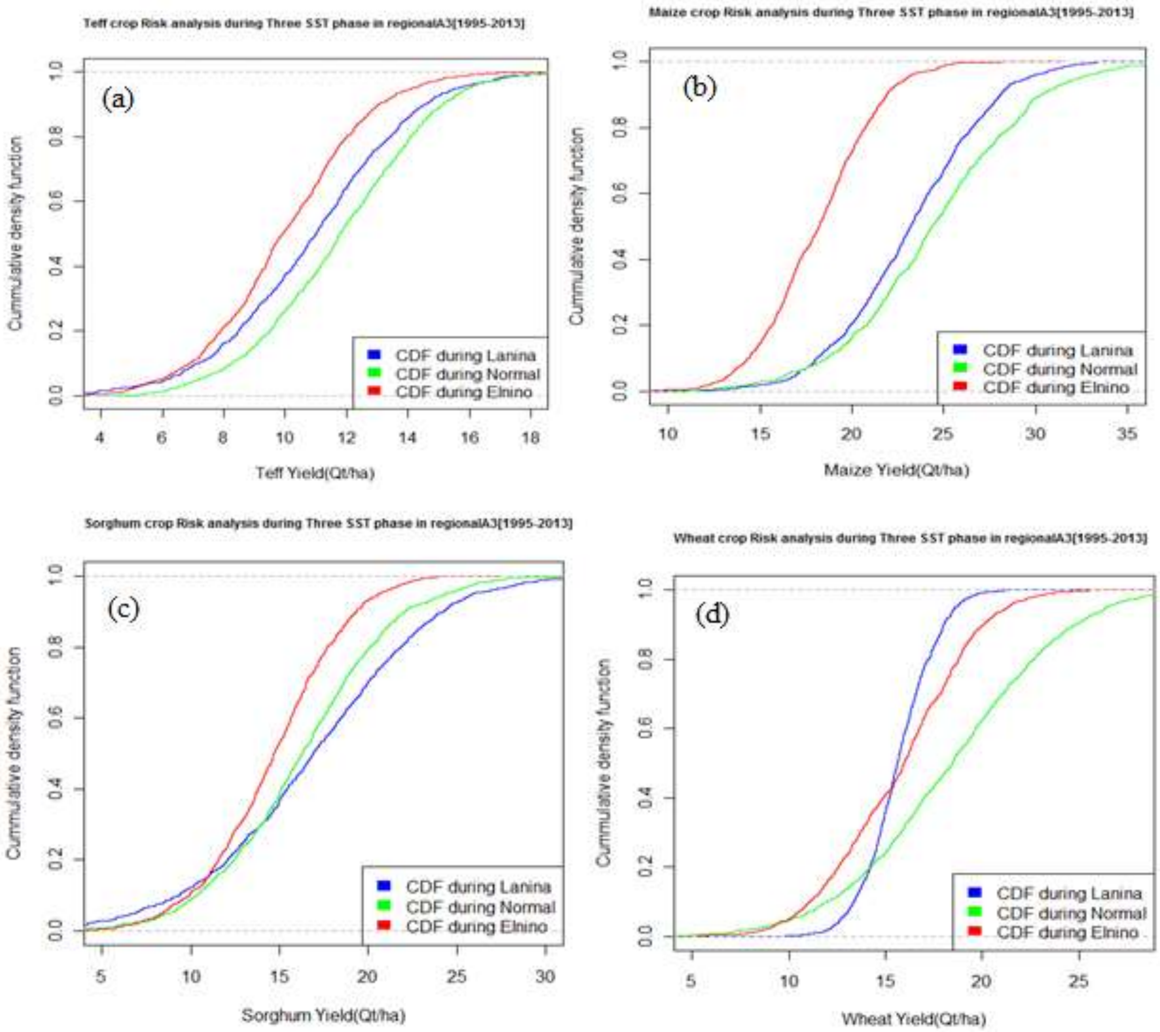


Figure 7. Cumulative density function for cereal crop yield of Zone three with three SST phase Teff (a),Wheat (b), Maize (c) and Sorghum (d).

3.7. Cereal Crop Yield Reduction due to Various ENSO Phases

In the course of ENSO phase changes from normal situation, the major cereal crop productivity has decreased for overall cereal crop yield in regionalized area one of the Upper Awash Basin by 10.1% and 9.1% due to El Niño and La Niña episode, respectively (Table 4). Overall reduction of cereal crop yield in regionalized area three of the Upper Awash Basin is by 16% due to El Niño episode and by 5.3% due to La Niña episode (Table 5). The results showed that cereal crop production in regionalized area three was more vulnerable to El Niño episode while reduction during La Niña episode is less in regionalized area three than regionalized area one. El Niño shocks are likely to cause on average a reduction in cereal crop production but it is relatively better than La Niña episodes for wheat crop production in regionalized area one (Figure 6b).

Table 4. Impact of ENSO events on crop productivity in regionalized area A1.

Cereal Crop	Average Productivity (Qt/ha)	El Niño Δ productivity (Qt/ha)	percentage change (%)	La Niña Δ productivity (Qt/ha)	percentage change (%)
Teff	12.17	-2.0	-16.49	-0.96	-7.90
Wheat	17.9	-2.47	-13.77	-4.12	-23.02
Maize	22.2	-2.60	-11.72	1.46	+6.56
Sorghum	16.13	+0.26	+1.64	-1.97	-12.19

Table 5. Impact of ENSO events on crop productivity in regionalized area A3.

Cereal Crop	Average productivity (Qt/ha)	El Niño Δ productivity (Qt/ha)	percentage change (%)	La Niña Δ productivity (Qt/ha)	percentage change (%)
Teff	11.65	-1.69	-14.50	-0.77	-6.59
Wheat	18.42	-2.53	-13.72	-2.7	-14.65
Maize	24.52	-6.42	-26.17	-1.48	-6.02
Sorghum	16.15	-1.50	-9.31	+0.97	+5.99

4. Conclusions and Recommendations

We found that SST anomalies of the Nino regions and IOD phase were positively correlated with all zonal rainfall indices during *belg* season, which indicated that Nino regions are the mostly identified effective area where upsets rain bearing system during *kiremt* season. It was also found that seasonal climate pattern in UAB is affected by the El Nino-Southern Oscillation (ENSO) phases and there is a close relationship between the increase and decrease of rainfall depending upon the warm or cold phases of the phenomenon. The rainfall amounts of major rainy season became very high in La Niña but low in El Niño years. Conversely, during small rainy season, comparatively high rainfall amounts were observed when El Niño was apparently established. Therefore, the variability of rainfall patterns during the major and small rainy seasons as well as annual total rainfall at UAB were strongly linked to ENSO phases.

A stochastic dominance analysis using cumulative density function (CDF) of crop yield for teff, maize, wheat and sorghum crops risk analysis, result showed that crop yield has good performance and was less risky during non-ENSO years than El Niño and La Niña phases. Therefore, analysis of CDF is recommended to evaluate crops yield risk analysis.

Due to ENSO phase changes from normal situation, the major overall cereal crop productivity was decreased. So, having the information of ENSO phase in advance can be used to forecast ENSO and select crop types and varieties to maximize agricultural rain fed cereal crop productivity while minimizing the crop risk associated with seasonal rainfall and ENSO phases.

5. References

Adugna Lemi. 2005. Rainfall Probability and Agricultural Yield in Ethiopia. Journal of Eastern Africa Social Science Research Review. 21: 57-96

Anderson, J. R. and J. L. Dillon. 1992. Risk Analyses in Dry land Farming Systems. FAO Farming Systems Management Series 2. FAO, Rome.

CSA (Central Statistical Agency). 2014. Agricultural sample survey Report on area and production of major crops, Central statistical Agency of Ethiopia Addis Ababa, Ethiopia V.1 statistical bulletin 532.

FAO. 1998. World reference Base for soil Resources. FAO, Rome, Ethiopian country profile.

Fraisse, C. W., N. W. Breuer, D. Zierden, J. G. Bellow, J. Paz, V. E. Cabrera, A. Garcia y Garcia, K. T. Ingram, U. Hatch, G. Hoogenboom, J. W. Jones, and J. J. O'Brien. 2006. Agclimate: A Climate Forecast Information system for Agricultural Risk Management in the South-eastern USA. *Computational and Electron Agriculture*, 53, 13-27.

Gissila, T. 2001. Rainfall Variability and Teleconnections over Ethiopia. MSc thesis (Meteorology), *University of Reading, U.K.* pp109

Goddard, L., A.G. Barnston and S.J. Mason. 2001. Evaluation of the IRI'S "Net Assessment" seasonal climate forecasts, *Bulletin of American Meteorological Society*. 84 (2003) 1761.

Gonfa, L. 1996. Climatic Classification of Ethiopia NMSA, Addis Ababa, Ethiopia

Koei, N. 1996. Feasibility Study on the Becho Plain Agricultural Development Project Ethiopia. *Final report*: 2

Korecha, D. 2002. Seasonal rainfall Prediction of Ethiopia for the Periods of September-December. DMC

Korecha and Anthony. G. Barnston. 2007. Predictability of June-September Rainfall in Ethiopia, *International research institute for climate and society. Palisades*. New York.

Landman, W.A. and L. Goddard. 2002. Statistical Recalibration of GCM Forecasts over Southern Africa using Model Output Statistics. *Journal of. Climate* 15: 2038-2055.

Levy, H. 1992. Stochastic Dominance and Expected Utility: Survey and Analysis. Management Sci. 38: 555-593.

Levy, H. 1998. Stochastic Dominance: Investment Decision Making under Uncertainty. Boston: Kluwer Academic Publishers.

Mamo G. 2005. Using seasonal climate outlook to advice on sorghum production in the central rift valley of Ethiopia

McCarl, B. A. 1996. Stochastic Dominance Notes: Risk Root programme documentation. Department of Agricultural Economics, Texas A & M University.

National Meteorological Services Agency (NMA). 1996. Climate and agro climatic resources of Ethiopia, Meteorological Research Report Series.Vol.1, No.1, Addis Ababa. pp137.

Nicholls, N. and Katz, R. W. 1991. In Teleconnections linking Worldwide Climate anomalies (Eds, Glantz, H. and Nicholls, N.) *Cambridge University Press*, *New York,* pp. 511-525.

Segale, Z. T., and P.J. Lamb. 2005. Characterization and Variability of Kiremt Rainy season over Ethiopia. *Meteorological Atmospheric physics*, 89, 153-180.

Taddese, G., E. Bekele, G. Eticha and F. Abagaz. 1998. Evaluation of Awash River for irrigation under middle Awash condition proceedings of fourth conference of the Ethiopian society of soil science, feburary 16-27, Addis Ababa, Ethiopia

2. Interconnection between El-Niño-Southern Oscillation Induced Rainfall Variability, Livestock Population Dynamics and Pastoralists Adaptation Strategies in Eastern Ethiopia

Ahmed Hassen[1*], Tessema Zewdu[2], Adugna Tolera[3], and Diriba Korecha[4]

[1]Department of Animal Science, Debre Berhan University, P. O. Box 445, Debre Berhan, Ethiopia

[2]School of Animal and Range Sciences, Haramaya University, P. O. Box 138, Dire Dawa, Ethiopia; [3]Department of Animal and Range Sciences, Hawassa University, P. O. Box 222, Ethiopia;

[4]National Meteorological Agency, P. O. Box 1090, Addis Ababa, Ethiopia

*Corresponding Author Email: hassenahmed211@gmail.com

Abstract

Extreme climatic events significantly limit livestock performance in semiarid areas. The effect of El-Niño-Southern Oscillation (ENSO) rainfall variability episodes on livestock population dynamics of pastoral communities in Shinile Zone of eastern Ethiopia was assessed. Rainfall and ENSO data from 1984-2015 were collected from the National Meteorology Agency of Ethiopia and National Oceanic and Atmospheric Administration, respectively. Rainfall trend was predicted with MarkSim (RCP 4.5 General Circulation Model). Data on livestock population was collected from Ethiopian Central Statistical Agency and the respective study zone. There was higher inter-annual rainfall variability under pastoral communities during the study years. Cattle and sheep were positively associated ($P<0.05$) with mean annual rainfall of ENSO events, whereas, the population of goat and camel were not positively associated ($P>0.05$). Cattle mortality and off-take rate had a significant negative relationship with ENSO rainfall variability thereby affected livestock population dynamics, mortality and off-take rates. Accordingly, pastoral communities are practising adaptation strategies such as settling around water points, seasonal mobility and destocking. However, the lack of information on climate change, watering points and convenient mobility pathways were major adaptation challenges under pastoral communities. Moreover, the predicted annual rainfall variability and increasing temperature (2020-2100) is expected to affect the livelihood of pastoral communities. Therefore, appropriate early warning systems and disseminate ENSO information ahead to minimize the loss of livestock that would affect the fragile livelihoods of pastoral communities are recommended.

Keywords: El-Niño; La-Niño; Livestock mortality; Off-take rate; Rainfall prediction; Rainfall variability; Trend analysis

1. Introduction

Livestock is an essential part of the biological basis for world food security, and contribute to the livelihoods of over thousand million people. Ethiopian pastoral comprises 60% of the country's land and has large grazing areas that hold half of the nation's livestock, which account for over 90% of meat and live animal exports. The total direct economic contribution of pastoralism to the Ethiopian economy through the production of milk, meat, skin, hides, etc., is estimated at about 6% of the agricultural GDP per annum (Berhanu and Feyera, 2009). Moreover, the pastoral system provides various livestock products and contributes significantly to the livelihoods of the people and to the country's economy at large. However, the level of contribution is generally much lower than the potential due to different constraints including shortage of water, low quality and quantity of feeds and poor market infrastructure as the pastoral areas experience very low rainfall and frequent droughts which are closely associated with climate change and variability (Adugna, 2012).

The most important feature of sea surface temperature (SST) variability that can cause large-scale weather disruptions is El Niño and La Niña, a near basin-wide warming and cooling of the equatorial Pacific Ocean, known as El-Niño-Southern Oscillation (ENSO) (Godderd *et al.,* 2001). NOAA (2013) defines ENSO state (e.g., El Niño or La Niña) as a departure from normal SST in the Niño 3.4 region with a magnitude of 0.5°C or more. The main ENSO signal is found during the northern summer depicting lower than normal rainfall in the years of higher SST in the eastern equatorial Pacific (i.e., El Niño years) (Camberlin, 2009). El Niño episode occurs when there are large scale atmospheric pressure differences between the eastern and western side of the Pacific which is characterized by warmer than normal temperature and covering the wide central and eastern tropical pacific. As a result, the warmer waters of the western pacific begin to flow back towards the eastern pacific which creates a large pool of the anomalously warm water that effectively cuts off the water temperature rises (by approximately 0.5°C) on the eastern side (Trenberth, 1991). On the contrary, La Niña is the counterpart to El Niño and is characterized by cooler than normal temperature across much of the equatorial eastern and central pacific. During La Niña, the easterly winds are strengthened, cooler than normal water and extend westward to the central pacific. As the same time, warmer than normal water in the western pacific is accompanied by above normal rainfall in areas which normally remain dry during that particular season (Trenberth, 1991).

In recent years, the episodes of ENSO, including El Niño and La Niña are becoming common phenomena in Shinile pastoral communities of Ethiopia and causing rainfall variability (Serigne *et al*., 2006; Korecha and Sorteberg, 2013) thereby affecting the distribution and amount of rainfall (Segele and Lamb, 2005; Diro *et al.,* 2011), which again alters livestock population and rangeland potentials. ENSO had its own impact on the wet or dry seasons, as El Niño or La Niña is a departure from normal SST (NOAA, 2013). The continuous rise of temperature also induced prolonged droughts in semi-arid environments, and such climatic variability affects negatively livestock production and productivity in pastoral communities. Rainfall is the primary important climatic element that affects the availability of feed resources and livestock performance in most parts of eastern Ethiopia and its variability becomes a problem in pastoral communities. Pastoralists are responding to climate changes by adjusting their herd composition for example by keeping more drought tolerant species i.e., camels and goats (Faya *et al.,* 2012; Megersa *et al.,* 2014).

The pastoral areas of Shinile Zone in eastern Ethiopia have been frequently affected by ENSO events, leading to lower production and productivity of livestock, as well as high livestock mortalities. However, information on ENSO episodes and other climate variability and how different livestock species respond to these extreme events and climatic shocks would be helpful for developing appropriate mitigation measures at regional, national and local levels (Best *et al.,* 2007; Korecha and Barnston, 2013). It is also critical to assess the expected future rainfall and temperature change to minimize stresses and sustain livestock potential under the changing climate and global warming (Thornton *et al.,* 2009). However, knowledge on the effects of rainfall variability during ENSO episodes on livestock population dynamics at pastoral communities in eastern Ethiopia is either lacking or limited. Therefore, the objectives of this study were to assess the impacts of rainfall variability during ENSO events on livestock population dynamics (off-take and mortality rates), as well as the perception, challenges and adaptation strategies of pastoralists in Shinile Zone of eastern Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted in Shinile Zone of the Somali region of Ethiopia (Figure 1). Pastoralism is the dominate production system in the zone, where livestock is the main livelihood of the people, dependent up on communal grazing systems on rangelands as feed resources. Cattle, sheep, goat and camel are the major livestock types owned by the pastoralists in Shinile zone. The study area was selected due to its potential in livestock population and vulnerability to frequent climate shocks. Shinile Zone is located between 9^{o}47’and 11^{o}00’N latitude and 40^{o}69’ and 42^{o}94’E longitude, at an altitudinal ranges of 500 to 1600 m above sea levels. Average annual rainfall is 447mm, ranging from 195 to 737 mm and was highly variable among years with a coefficient of variation (CV) = 35.4% (1984 - 2015). Under normal condition, the zone receives its highest rainfall amount during long rainy season (June to September) while the short rains prevail from March to May. The long term mean daily minimum and maximum temperatures from 1984 to 2015 were 19^{o}C and 32^{o}C, respectively. .

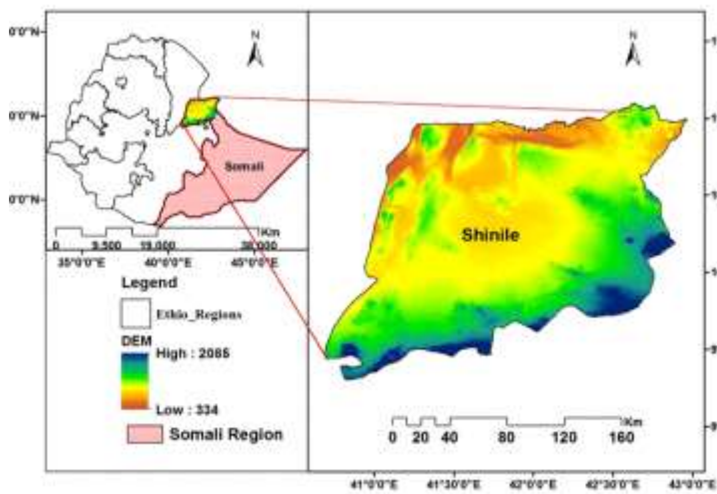


Figure 1. Location of the Shinile Zone in Somali Region of Ethiopia.

2.2. Data Collection

2.2.1. Rainfall and livestock data

Gridded (10km x 10km) rainfall data was obtained from National Meteorological Agency of Ethiopia (NMA) as the rain gage station available for the study area was not enough and has a lot of discontinuity. Moreover, a minimum of 30-year rainfall data is recommended for time series climatic change analyses (IPCC, 1999). Annual rainfall data were collected during the period 1984-2015. ENSO years was obtained from the NOAA/CPC (National Oceanic and Atmospheric Administration/Climate Prediction Centre) 2009 and 2013 and IRICS (International Research Institute for Climate Society) websites, as well as other international forecast centres (http://www.ncdc.noaa.gov/and http://www.ncep.noaa.gov/). Based on this information eight El-Niño years (i.e., 1987, 1991, 1993, 1994, 1997, 2002, 2004, and 2015), six La-Niña years (i.e., 1988, 1998, 1999, 2000, 2007, and 2008) were included for the study. The livestock population data (cattle, sheep, goats and camels) from 1991-2015 as well as mortality and off-take rates of livestock species (2001-2015) were collected from the Central Statistical Agency of Ethiopia (CSA, 1991-2015). Furthermore, IPCC reports of 2013 as well as governmental and non-governmental organizations working on livestock production in the study area were consulted for secondary information.

2.2.2. Perception and adaptation of pastoralists against rainfall variability

Semi-structured questionnaires were used to collect information related to pastoralists perception and adaptation against the effect of extreme weather condition on livestock population and productivity, water and feed resource availability. The questionnaire was pre-tested and used for the final interview after all adjustments were made. Pastoralists amounting to 260 were selected from the two *kebeles* (the smallest administrative units under district) (*kebele* I: N =116, *kebele* II: N =144) using proportional sampling to the overall livestock population size of each site. Households were randomly selected from each sample *kebele*. Among the selected pastoralists, 72 of them were females. In addition, focus group and key informant discussions, classified by sex and age groups were conducted to avoid specific group's idea dominance, as well as to include gender and household experiences. There were a total of four focus group discussions (FGD), two from each *kebele*, and each FGD consisted 15 individuals. Moreover, household heads above 50 years were purposely selected for the interview during the FGD (Bartlett *et al*., 2001). Local enumerators versatile with the area participated to administer the household survey. Data were collected between the months of September to December, 2014. Data related to livestock population, milk yield, sales (off-take rates) and herd history, impact of rainfall variability on livestock population, as well as their adaptation strategies and challenges against inter-annual rainfall variability during ENSO events were included.

2.3. Data Analyses

2.3.1. Analysis of rainfall trend and variability

Mann-Kendall's test was used for analysing the trend of rainfall (Partal and Kahya, 2006) by using XLSTAT software. Variability of rainfall was analysed using coefficient of variation (CV) (AMB, 2010; Dereje *et al.,* 2012; Gebre *et al.,* 2013). The CV was calculated as: - $CV = \frac{SD}{X} * 100$, where SD is standard deviation of rainfall and X is the long-term rainfall mean. The CV values below 20% shows less rainfall variability, while CV values between 20-30% and >30% indicate moderate and high rainfall variability (ABM, 2010), respectively. Standardized Rainfall Anomaly (SRA) was calculated from long-term rainfall data (Table 1). It is calculated from the monthly rainfall data as the difference between annual rainfall of a particular year and the long-term rainfall average divided by the standard deviation [$Z = X - X/SD$].

Table 1. Drought categories and the corresponding standardized rainfall anomaly (SRA) values.

SRA values	Drought categories
≤ -2	Extreme drought
-1.5 to – 1.99	Severe drought
-1.0 to -1.49	Moderate drought
-0.99 to 0.99	Close to normal
1.0 to 1.49	Moderate wet
1.5 to 1.99	Very wet
≥ 2	Extreme wet

Source: (http://drought.unl.edu/monitor/spi/programme/spi.programme.htm).

2.3.2. Analysis of future climate scenarios

The IPCC used four climate change scenarios known as the Representative Concentration Pathways (RCPs) to replace the previous scenarios of the Special Report on Emission Scenarios (SRES) (IPCC, 2013). Each of the RCPs defines the trajectory of the alteration or change in the net irradiance (W/m^2) of the tropopause due to an increase in the concentration of greenhouse gases (GHGs) and other forcing agents for the year 2100. The four scenarios or RCPs include a very low baseline emission scenario (RCP 2.6), a post-2100 emission stabilization scenario (RCP 6) and a very high baseline emission scenario (RCP 8.5). In the RCP4.5 scenario, which is selected for our downscaling, GHGs concentrations rise with increasing speed until the forcing is 4.5 Wm^{-2} in the year 2100. This is a moderate emission scenario of concentration rise. Future scenarios of indices of rainfall and temperature projections in Shinile Zone were done by downscaling global circulation model outputs and downloaded from http://www.ccafs-climate.org/patternscaling/ MarkSim-GCM using latitude, longitude and elevation of the study area (Jones and Thornton, 2013). Future rainfall and temperature changes were analysed for three-time slot centred in 2030 (2020-2049), 2050 (2040-2069) and 2080 (2070-2099) and compared its trend and variability with the current rainfall data (1984-2015) for the study area.

2.3.3. Relationship between ENSO rainfall and livestock population

The relationship between livestock population, mortality and off-take rate of livestock with mean annual rainfall variability during ENSO years was determined by regression analysis (Minitab 15). The data on perception of the livestock herders against the inter-annual rainfall variability were analysed using a Kruskal-Wallis rank test method (Schlotzhauer, 2009). The chi-square (X^2) test was used to compare challenges and adaptation strategies of the pastoral communities against the inter-annual rainfall variability (ENSO years).

3. Results and Discussion

3.1. Results

3.1.1. Trends and variability of rainfall during ENSO episodes

The annual and main rainy season rainfall data showed an increasing trend ($P<0.05$) whereas the short rainy season indicated decreasing trend ($P<0.05$) in Shinile Zone of Ethiopia (Figure 2; Table 2). Moreover, there was higher inter-annual rainfall variability during the study years as reflected by the high CV (35.4%) and SRA. The rainfall trend indicated that 53% of its distribution ~~was~~ deviated from the average rainfall amount. Among the El-Niño and La-Niño years identified, more than half of the events had below average rainfall distribution, leading to higher rainfall variability in the study areas (Figure 3). The SRA showed that 40% of the rainfall was near moderate to high drought. The ENSO events rainfall analysis revealed that El-Niño reduced the amount of rainfall during the long rainy season and increased its amount during the short rainy season, whereas, La-Niño suppressed the short rainy season and enhanced the long rainy season rainfall distribution in our study area (Figure 4). Furthermore, the long-term rainfall data (1984 – 2015) indicated that drought occurred during the 1984, 2000, 2002, 2009 and 2011(Figure 3), of which year 2000 and 2002 are categorized in ENSO episode and contributed to lowering of cattle and sheep population, increased mortality and off-take rates.

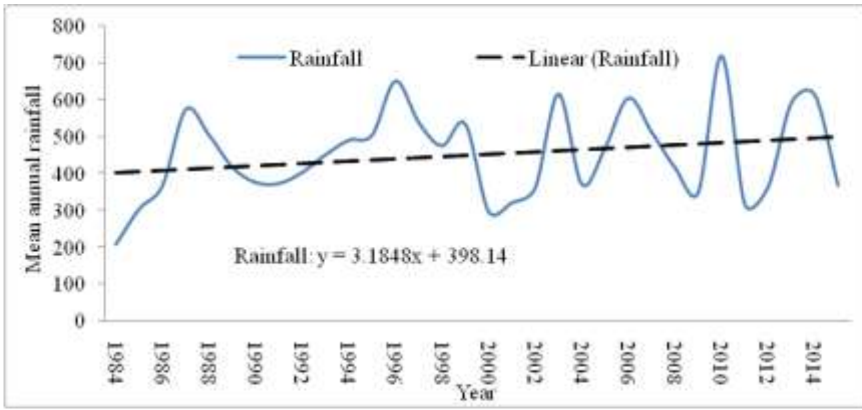


Figure 2.Trends of mean annual rainfall and its variability in Shinile Zone of Somali Region, Ethiopia, 1984-2014.

Table 2. Trends of annual and seasonal rainfall for the period of 1984-2015, in Shinile Zone of Somali Region in eastern Ethiopia.

	Annual rainfall		Long rainy season		Short rainy season	
	Z_{mk}	Slope	Z_{mk}	Slope	Z_{mk}	Slope
Pastoral	0.139ns	+3.53	0.215ns	+3.192	-0.101ns	-1.071

Z_{mk} is Mann-Kendall trend test, Slope (Sen's slope) is the change (mm)/annual; ns is non-significant at 0.05. The mean seasonal and annual rainfall trend recorded, - value is decreasing trend and + values is an indication of increasing trend.

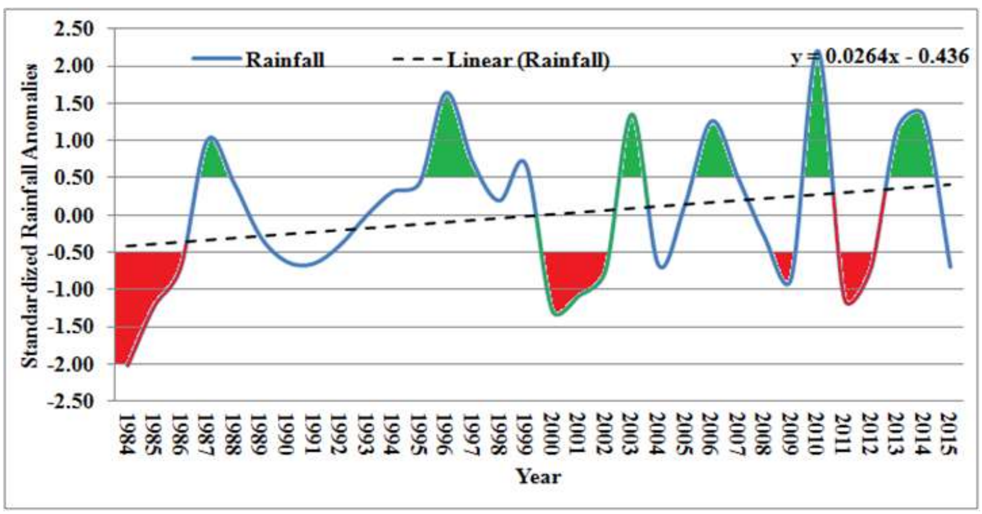


Figure 3. Standardized mean annual rainfall anomalies of Shinile Zone in Somali Region, Ethiopia, over the period of 1984–2015. The red colour indicated moderate to extreme drought periods and green showed moderate to extreme wet years

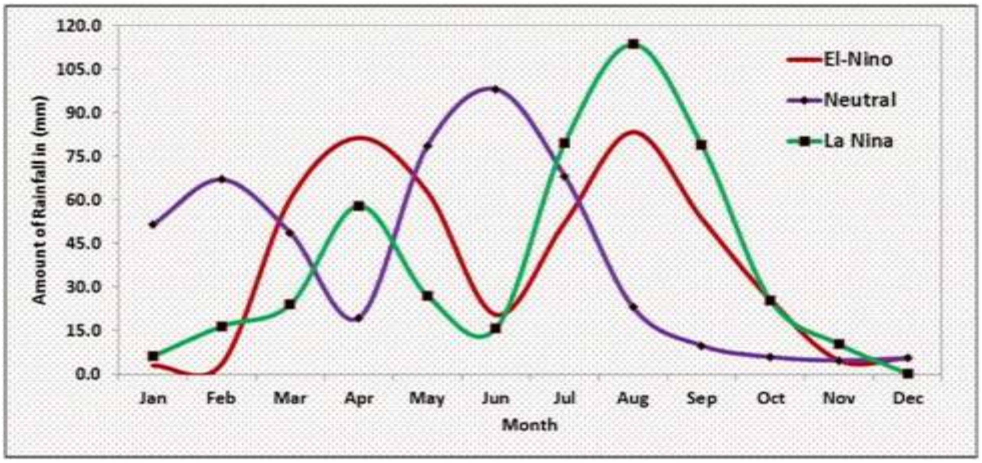


Figure 4. Mean monthly standardized rainfall anomalies observed during El-Niño, La-Niño and neutral episodes in Shinile zone of Somali region, Ethiopia during the period 1984-2015.

3.1.2. Relationships between rainfall variability and livestock population

Cattle and sheep are more affected by rainfall variability than goats and camels. Camels are more tolerant to rainfall variability which is supported by a positive relationship between cattle and sheep population and mean annual rainfall in the Shinile zone (Figure 5). The cattle and sheep population was positively correlated to sheep population ($r=0.74$, $P<0.05$). Moreover, El-Niño reduces the amount of rainfall during the long rainy season as a result of which the livestock population during this time was declined (Figure 6), whereas La-Niño suppresses the short rainy season and enhances the long rainy season rainfall distribution; as a result, reduced cattle and sheep population (Figure 7). Pastoral communities mostly depend on the rainfall during the main rainy season for availability of pasture and water resources. Hence, declining of rainfall during this period has resulted in severe livestock reduction. Cattle and sheep population was lower ($P<0.05$) during most El-Niño and La-Niño events in the study area. In addition, the population of goat and camel were also lower during ENSO events ($p>0.05$). Based on adaptability to the current rainfall variability due to ENSO events, the livestock species we studied had the following rankings: camel>goat>sheep>cattle under pastoral communities of Shinile Zone of Ethiopia.

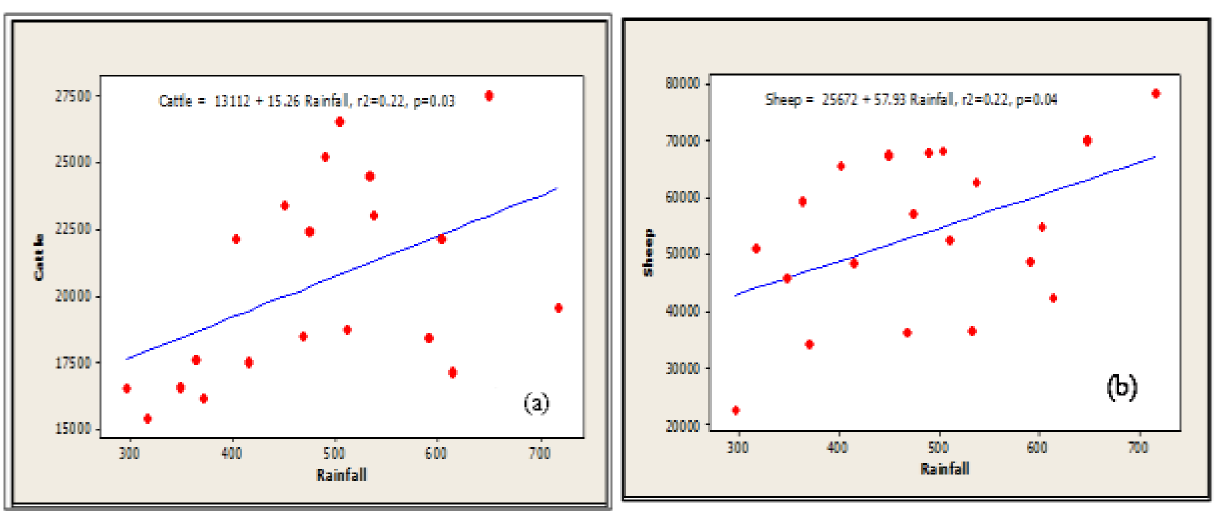


Figure 5. Relationship of mean annual rainfall to cattle (a) and sheep (b) population under pastoral communities of Shinile Zone in Somali Region of Ethiopia.

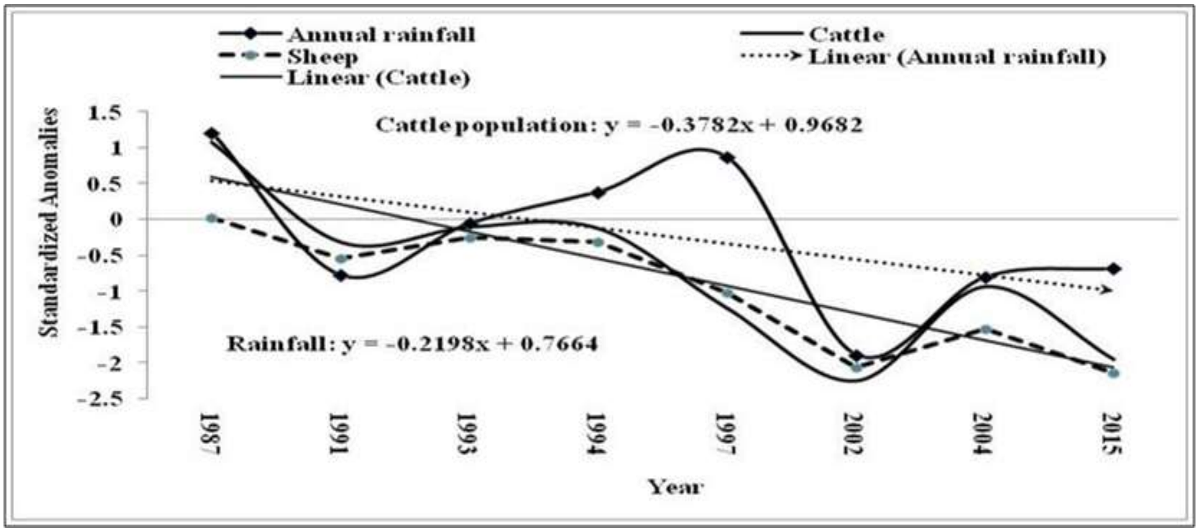


Figure 6. Trends of standardized livestock population (cattle, sheep) and rainfall anomalies observed during El-Niño episodes in Shinile Zones of Somali Region, Ethiopia, 1987 – 2015.

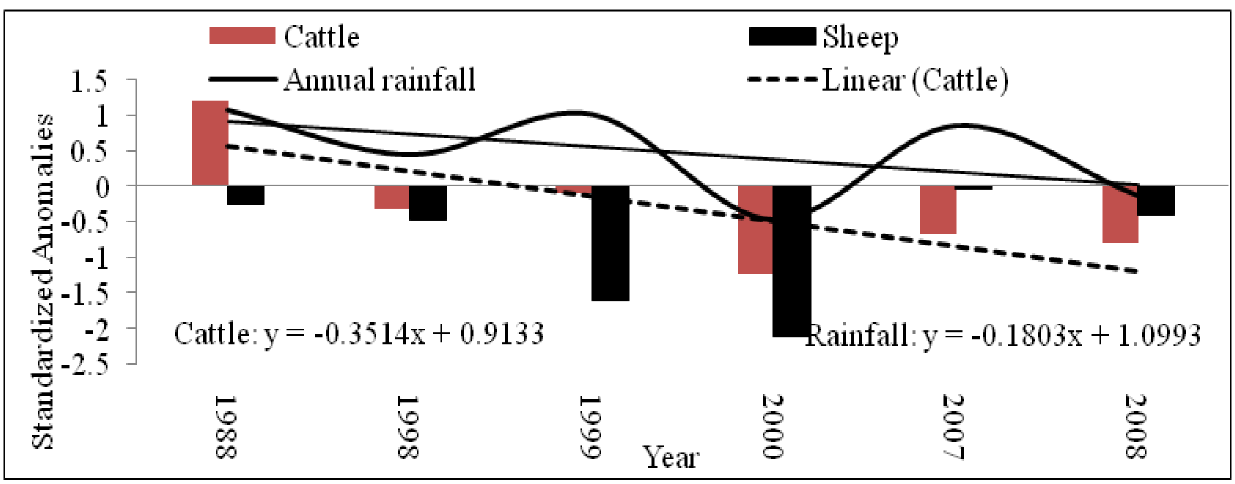


Figure 7. Trends of standardized cattle, sheep and rainfall anomalies observed during La-Niño episodes in Shinile Zones of Somali Region, Ethiopia, 1988- 2008.

Cattle mortality rate increased with decreasing mean annual rainfall lower than normal distribution during most ENSO events ($P<0.05$) in pastoral communities (Figure 8). Moreover, cattle off-take rate were higher in most La Nina episodes (Figure 9). For instance, in La-Niño years 2008, cattle mortality increased by 12.4%, sheep 26.2% and goats by 6.5% in Shinile pastoral communities.

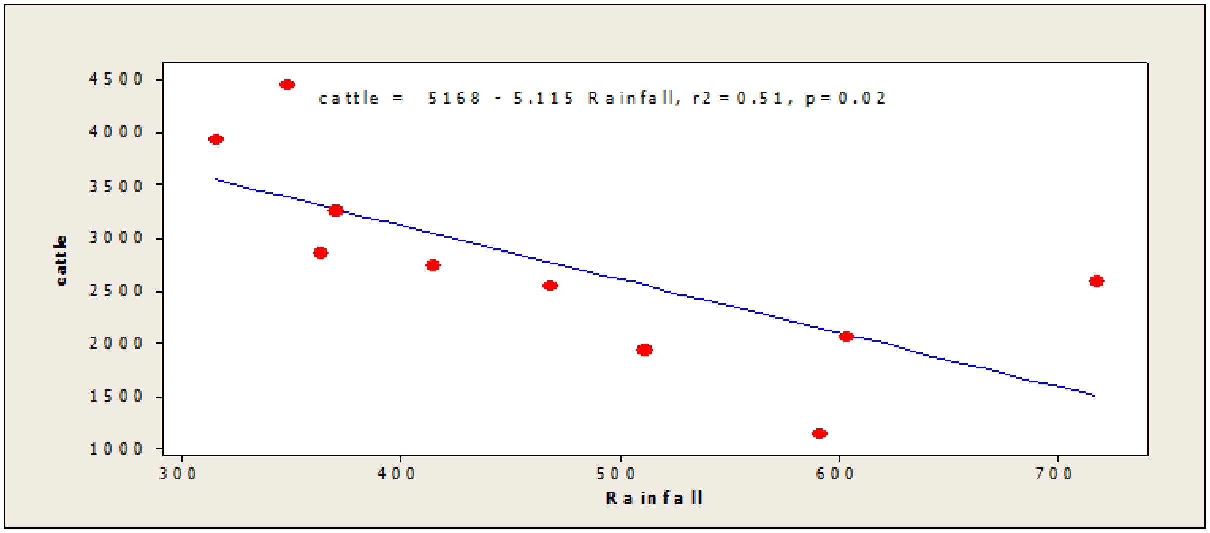


Figure 8. Relationship of mean annual rainfall to cattle mortality during El-Niño episodes under pastoral communities of Shinile Zone of Somali Region, Ethiopia.

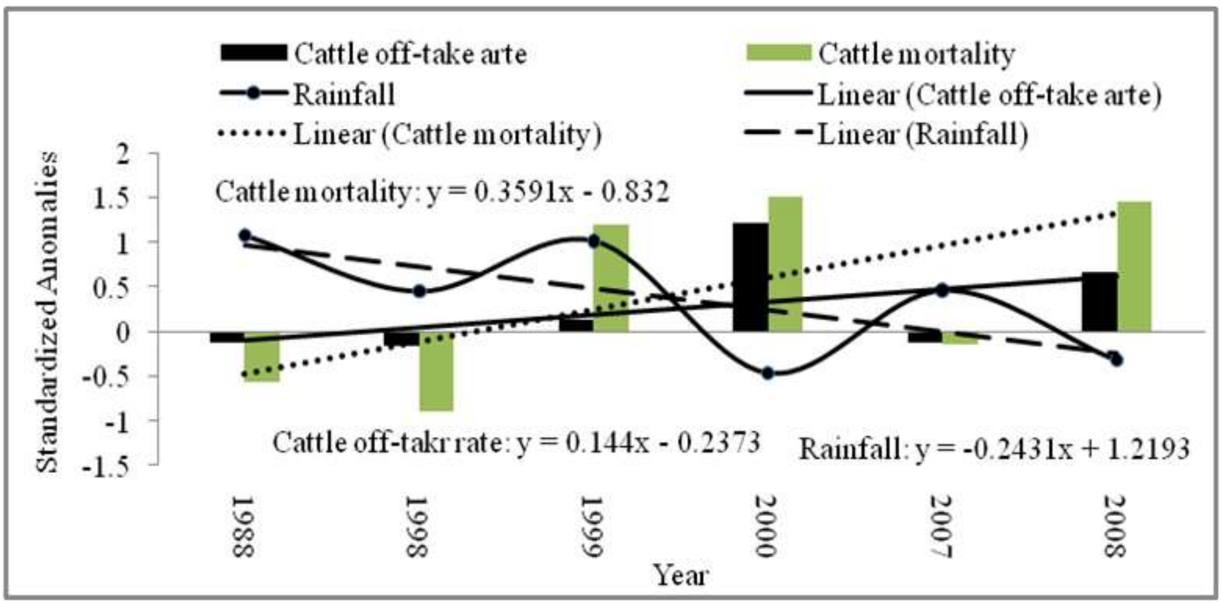


Figure 9. Trends of standardized rainfall, cattle mortality and off-take rate anomalies observed during La-Niño episodes in Shinile Zone, eastern Ethiopia.

3.1.3. Perception and adaptation of pastoralists against extreme rainfall variability

Respondents' also perceived that the patterns of rainfall distribution reduce the livestock population and increase the mortality and unwanted sales of livestock due to limited availability of pasture and water resources (Table 3). The respondents' had the knowledge that the condition of rangelands deteriorated with bush encroachment leading to reduced performance of livestock. Pastoralists' adaptation strategies towards ENSO event is indicated in Table (4). The majority of respondents (90%) settled around watering points to reduce the effect of ENSO events on livestock population and its productivity. They (86%) also practised seasonal mobility as the second option to reduce the effect of rainfall variability during ENSO events. When drought appears, non-lactating cattle moved over long distance in search of better grazing land and water which were used for reducing rangeland degradation problems. However, there are some adaptation challenges including poor climate information access and knowledge, shortage of water points, and restriction of mobility that reduced the effect of adaptation strategies (Table 5). The results showed that more than 86% of the respondents in the study areas realized that they didn't have extreme weather information access before happening.

Table 3. Possible impact of rainfall variability on livestock population and productivity as ranked by Kruskal-Wallis test according to the sampled respondents under pastoral communities (n = 260).

Perceived impact	Pastoralist
Serious shortage of water for livestock	1.16[a]
Reduced pasture availability, rangeland degradation, bush encroachment	1.56[b]
Animal disease, parasitic infestation and mortality	2.51[c]
Poor condition of livestock and unwanted sales	3.82[d]
Reduced livestock population and products	4.21[e]
Poor reproductive performance	5.13[f]
Probability value	0.00

Table 4. Adaptation strategies (%) of the sampled respondents in Shinile Zone of eastern Ethiopia to extreme climate variability [(kebelle I (n =116) and kebelle II (n =144)].

Adaptation strategies	Pastoral community		P value (X^2)
	Kebele I	Kebele II	
Settlement around watering points	91	90	>0.05
Seasonal mobility	86	87	>0.05
Livestock destocking	83	71	>0.05
Diversification of livestock species	75	50	<0.05
Feed supplementation	69	45	< 0.05

Table 5. Adaptation challenges (%) of the sampled respondents in Shinile zone of Somali region, Ethiopia to extreme climate variability [kebelle I (n =114) and kebelle II (n=116)].

Adaptation challenges	Pastoral community		P value
	Kebelle I	Kebelle II	(X^2)
Poor access to climate information	91	85	>0.05
Shortage of water points/deep water table	86	78	>0.05
Restriction of seasonal mobility	82	67	>0.05
Bush encroachment	74	52	<0.05
Human population pressure	71	41	<0.05

3.1.4. Prediction of climate scenario in Shinile pastoral areas

The amount of annual rainfall would increase by 2030, 2050 and 2080s under RCP 4.5 scenario in Shinile pastoral communities (Figure 10). The annual rainfall will increase by 11.4, 9.4 and 5.9% in 2030s, 2050s and 2080s, respectively. The annual rainfall is also predicted to be variable (CV=30.5%). The temperature tends to increase as compared to the base period. Moreover, the maximum temperature is expected to increase by an average of 0.67, 0.57 and 0.52°C in the 2030, 2050 and 2080, respectively compared to the current maximum temperature. The minimum temperature is also estimated to increase by 0.42, 0.9 and 0.63°C in the 2030, 2050 and 2080, respectively.

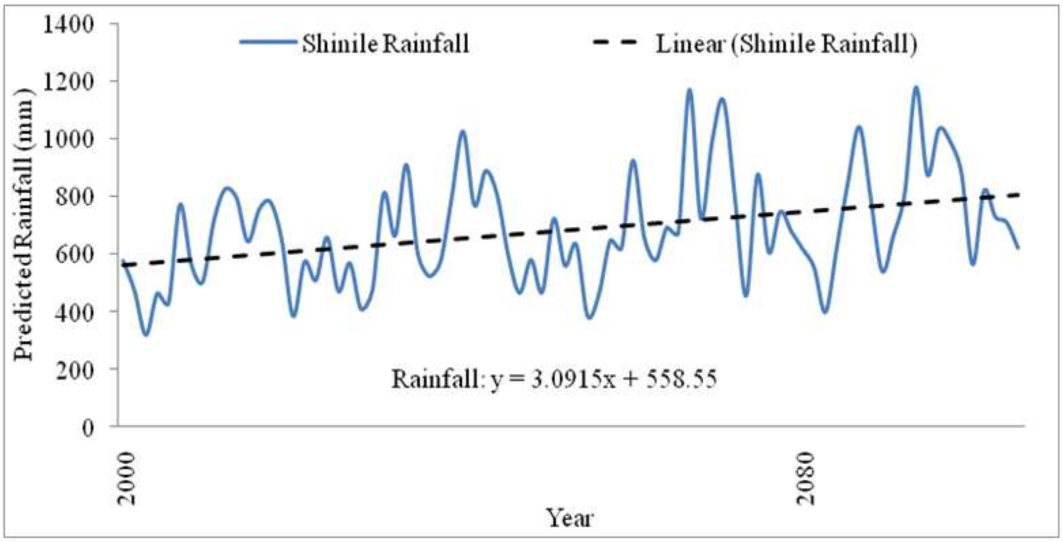


Figure 10. Trends of current mean annual rainfall and its future prediction scenarios, over the period of 1984 – 2100, for Shinile Zone of the Somali Region in eastern Ethiopia.

3.2. Discussion

3.2.1. Trends and variability of rainfall during ENSO episodes

The rainfall characteristics from 1984 - 2015 indicated that there was a clear inter-annual and seasonal rainfall fluctuation, with a higher coefficient of variation. Consequently, this rainfall variability leads to extreme drought condition causing reduced livestock population under the pastoral communities of Shinile Zone. Similarly, Omondi *et al.* (2012) indicated the existence of declining in rainfall amount as a result of climate variability in most parts of the dry lands. Moreover, declining rainfall has been documented during climate variability in southern Ethiopia (Viste *et al.,* 2013), in Amhara region (Dereje *et al.,* 2012) and in central rift valley of Ethiopia (Tsegaye *et al.,* 2015). Usually, El-Niño and La-Niño episode occur when SST deviate from normal, which might be associated with the result of ocean atmosphere variability internal to tropical Pacific Ocean (Seleshi and Zanke, 2004). Moreover, based on SRA analysis, rainfall ranged between normal to high drought which is in agreement with other studies (Sherwood 2013; Kgosikoma and Batisani, 2014). Such droughts have the potential to increase loss of livestock that would devastated the fragile livelihoods of the pastoral communities particularly women (Sherwood, 2013), where alternative livelihood options are limited (Kgosikoma and Batisani, 2014).

3.2.2. Relationships between rainfall variability and livestock population

Reduction of rainfall during El-Niño and La-Niño would create severe drought, leading to reduction of pasture and water availability that cannot support the livestock population, as a result of this phenomenon, the livestock population showed a decreasing trend. In this study, more than half of the El-Niño and La-Niño events coincided with lower rainfall distribution and reducing livestock population and higher mortality and off-take rate of cattle and sheep. Livestock mainly depends on long rainy season as the short rainy season is not mostly reliable. In addition, the long rainy season is more essential for forage production and replenishment of water resources and hence the declining trends of long rainy seasons determine the livestock population and mortality. Previous studies also suggested that drought have mostly occurred due to the failure of long rainy season (Angassa and Oba, 2007; Viste *et al.,* 2013; Megersa *et al.,* 2014). El-Niño events were more severe than La-Niño on livestock population and mortality in the study areas. Cattle and sheep population was lower during ENSO period of the study area, while the pastoralists were forced to diversify drought tolerant species such as goats and camels. Previous studies in Afar (Tilahun *et al.,* 2016) and Borana pastoral communities (Megersa *et al.,* 2014; Brigham *et al.,* 2015) testified that herd diversification were the results of shifts in vegetation from grassland to woodland. This could be due to the shortage of feed and water availability which results in reduction of conception and birth rate of livestock thereby leads to increasing mortality and unplanned livestock sales (Brigham *et al.,* 2015). However, the population of goat and camel were not significantly reduced with ENSO annual rainfall distribution indicating that goats and camels are more adapted to low rainfall distribution compared to cows and sheep. In addition, the replacement of grasses with less palatable woody plants due to climate variability might affect cattle and sheep population than goats and camels (Abebe *et al.,* 2012). Moreover, goats and camels are able to utilize the available browse and bushy species better than sheep and cattle under lower rainfall distribution. Similar studies have also supported the dependence of goats and camels rather than cattle and sheep dominance to use the available feed resources more effectively under the changing climate scenario (Teshome *et al.,* 2010; Megersa *et al.,* 2014). As reported by Tilahun *et al.* (2016) camel is more selected by the livestock herders during high rainfall variability due to relatively higher milk production abilities and market price which can be easily converted into cash and income generation than other livestock population. Hence, goats and camels could be used as an adaptation strategy against frequent extreme rainfall variability.

In our study, there was high mortality of livestock during periods of El-Niño and La-Niño episodes which could be due to traveling of long distance of pastoralists with their animals in search of better grazing and water resources under low rainfall seasons. Moreover, appropriate rainfall is highly relevant for the growth and production of forages and water resources, and hence, the variability of rainfall is a serious problem to the livestock production (Desta and Coppock, 2002). A similar finding is also reported in Borana pastoral areas by Megersa *et al.* (2014) who documented that shortage of grazing lands and climate variability are the major cause for the declining of livestock population and productivity. Similarly, the highest mortality of sheep, goat and camel was observed in year 2000 and 2002 at times of ENSO events. Most of the ENSO year caused a higher livestock mortality due to shortage of feed and water resources as due to abnormal rainfall distribution which resulted in selling of large number of animals at lower price. The off-take rate of animals was lower during neutral years which might be associated with normal rainfall distribution that minimize mortality and off-take rate and increases births, leading to increasing livestock population (Mapiye *et al.,* 2009). Hence, this could be partially explained by the importance of rainfall on vegetation and water sources for livestock (Ward *et al.,* 2004). According to Lobell *et al.* (2008) rainfall variability causes increase intensity and frequency of droughts, which affect the productivity of livestock. Moreover, Thornton *et al.* (2009) also reported that climate change affects livestock productivity by altering the quantity and quality of feed available for animals' especially in area where extreme rainfall variability occurred. Outbreak of El-Niño event in 1997 has led to a death of up to 80% of the livestock population in Somalia and northern Kenya (World Bank, 2010). Moreover, in Borana lower than average rainfall recorded during 1999-2005 caused massive die-offs of livestock (Conway and Schipper, 2010). Most of the drought years, especially years 1984, 2000, 2002, 2009 and 2011 caused a higher livestock mortality due to shortage of feed and water resources. However, lowest mortality and off-take rates of cattle, sheep, goat and camel was observed in wet years such as 1996, 2003, 2006, 2010 and 2014. Especially during the long rainy seasons that there is a strong relationship between livestock population and rainfall distribution (Desta and Coppock, 2002; Angassa and Oba, 2007; Tache and Sjaastad, 2010).

3.2.3. Perception and adaptation of pastoralists against extreme rainfall variability

Pastoralists perceived a declined trend of rainfall amount as opposed to meteorology data and leading to reducing water and pasture availability and livestock population and applied different strategies to reduce the impact of climate variability. In Shinile Zone, pastoralists settled around water points, used browse trees and look for feed supplement to save their livestock during drought periods. Mobility, splitting and destocking of herds was practiced as an additional adaptation strategy during ENSO events. However, mobility was the second option because of intra and inter-ethnic conflicts due to shortage of pasture and water resources in most parts of neighbouring rangeland. Moreover, the local government encourages settlement of pastoralists for introducing better interventions. However, such activities might lead to high human population (Berhanu *et al.,* 2013) affecting the traditional resource use and management, reduce livestock per household and cause fragmentation of communal rangelands (Tilahun *et al.,* 2016). Similar findings were also observed in Borana pastoral communities where mobility is used as an adaptive mechanism to reduce the effect of feed and water shortage in arid environment (Feye, 2007; Abebe *et al.,* 2011). Although the importance of ENSO events to Ethiopian rainfall distribution pattern is being accepted and incorporated in the National Meteorology Agency's operational forecasting policy at present, the effort to aware the impact and get readiness of the pastoral communities is very low.

3.2.4. Prediction of climate scenario in Shinile pastoral areas

Prediction of scenarios revealed an increase rainfall in Shinile pastoral area which coincide with the IPCC (2007) projection. In contrast, decreasing trend of future annual rainfall was reported by Tsegaye *et al.* (2015) in the rift valley of Ethiopia which might be due to differences in topography, altitude, and atmospheric interactions. The rainfall variability is expected to limit the availability of water and feed supply. Our results are consistent with Lobell *et al.* (2008) who indicated rainfall variability is the cause for increase intensity and frequency of droughts that would affect the productivity of feed resources and livestock. Similarly, Beier *et al.* (2008) and Kassahun *et al.* (2008) showed the consequence of decreasing rainfall on reduction of pasture, leading to sudden decline of livestock performance and condition due to health related problems (Rufael *et al.,* 2008). Prediction of rising in temperature is also expected as a major cause for reduction of livestock performance. Nardone *et al.* (2010) argue that rising in temperature may directly affect thermal stresses on animals, reduce feed intake, and impairs metabolic activities, thereby hindering their performance. Moreover, Thornton *et al.* (2009) indicated that higher temperature affect the population and productivity of livestock in the pastoral and agro-pastoral production systems through reduction of feed and water availability and increased disease incidence. Thus, the annually predicted rainfall variability and increasing temperature may affect the future livestock population, mortality and off-take rates in Shinile pastoral areas of Ethiopia.

4. Conclusions and Recommendations

The present study revealed that extreme drought events affected more the number and productivity of livestock and dominance of camels and goats herding than cattle and sheep. The mortality and off-take rate was also affected by ENSO events. Though the future rainfall trend showed an increase, its variability could result in extreme drought and be a sign of threat to the availability of enough water and grazing resources to the livestock. The increases in future minimum and maximum temperature projection are expected to increase water requirement by animals and pasture that would likely exacerbate shortages in water, feed, and biodiversity of plant species. Currently, pastoralist perceive the impact of rainfall variability on livestock population and mortality, which includes shortage of water, feed resources and livestock products. Pastoralists practice settlement around water points, seasonal mobility and destocking as their adaptation strategies. In contrast, poor climate information and knowledge on ENSO and mobility restriction are the major adaptation challenges. Although, mobility restriction aimed at improving the livelihood of Shinile pastoral communities is implemented by the government, it could not bring satisfactory changes in improving feed and water resources (e.g., Berhanu *et al.,* 2013). Hence, there is a need to design long term climate early warning systems with the participation of local community to minimize the effect of extreme drought episodes on livestock population and productivity. Proper land management and implementing basic conservation mechanisms should be crucial to minimize risks and sustain rangeland productivity under the changing climate scenario.

5. Acknowledgements

We express our sincere thanks to Haramaya University, Pastoral, and Agro-pastoral Research and Capacity Building Directorate and Somali Region Pastoral and Agro-pastoral Research Institute of Ethiopia for their financial and material support. We thank also the National Meteorology Agency and Central Statistical Agency of Ethiopia for providing the required data. Our gratitude goes to pastoral communities for giving valuable information during the study.

6. References

Abebe, A., Lars, O.E., Oyestin, H., Torrnod, A., Tolera, A. 2011. Pastoralists' perception of feed scarcity and livestock poisoning in southern rangelands, Ethiopia. *Tropical Animal Health and Production*, 44: 149-157.

Adugna, T., Alemu, Y., Alemu, A. 2012. Livestock feed resources in Ethiopia: Challenges, Opportunities and the need transformation. Ethiopian Animal Feed Industry Association, Addis Ababa, Ethiopia.

Angassa, A., Oba, G. 2007. Relating long-term rainfall variability to cattle population dynamics in communal rangelands and a government ranch in southern Ethiopia. *Agriculture Systems*, 94(3): 715–725.

Australian Bureau of Meteorology (ABM). 2010. Rainfall variability in Australia. (http:/www. Bom.gov.au/climate/data/index.shtml). Accessed on September 15, 2014.

Bartlett, E., Kotrlik, W., Higgins, C. 2001. Organizational research: determining appropriate sample size in survey research. *Information Technology Learn Performance*, 19: 43–50.

Beier, C., Emmett, B., Penuelas, J., Schmidt, I., Tietema, A., Estiarte, M., Gundersen, P., Llorens, L., Riis-Nielsen, T., Sowerby, A., Gorissen, A. 2008. Carbon and nitrogen cycles in European ecosystems respond differently to global warming. *Science of the Total Environment*, 407: 692-697.

Berhanu, A., Feyera, A. 2009. Economic values of pastoralism in Ethiopia. In: Beyne T., Bezabih E. and Degnet N. (ed). Proceedings of the 11th annual Conference of the agri- cultural economics Society of Ethiopia. Agricultural Economics Society of Ethiopia, May 2009, Addis Ababa.

Berhanu, Y., Beyene, F., Angasa, A. 2013. Influence of resettlement on pastoral land use and local livelihood in southern Ethiopia. *Tropical and Subtropical Agro-ecosystems*, 16: 103-117.

Best, S., Johst, K., Munkemuller T., Travis. J. 2007. Which species will successfully track climate change. The influence of intra-specific competition and density dependent dispersal on range shifting dynamics. *Oikos*, 116: 1531-1539.

Brigham, W., Forrest, D., Coppock, D. L., Bailey, D., Ward, A. 2015. Economic Analysis of Land and Livestock Management Interventions to Improve Resilience of a Pastoral Community in Southern Ethiopia. *Journal of African Economics*, 2015: 1-34.

Camberlin, P., Philipon, N. 2001. The East African March-May rainy season associated atmospheric dynamics and predictability over the 1968-1997 perio. *American Meteorology Society*, 15: 1002-1019.

Central Statistical Agency (CSA). (1991–2015). Agricultural Sample Survey, Report on Livestock and Livestock Characteristics, Statistical Bulletin, Addis Ababa, Ethiopia.

Conway, D., Schipper, E. 2010. Adaptation to climate change in Africa: Challenges and opportunities identifies from Ethiopia. *Global Environment Change*, 21: 227-237.

Dereje, A., Kindie, T., Girma, M., Birru, Y., Wondimu, B. 2012. Variability of rainfall and its current trend in Amhara region, Ethiopia. African Journal of Agricultural Research, 7(10): 1475-1486.

Desta, S., Coppock, D. L. 2002. Cattle population dynamics in the southern Ethiopian Rangelands, 1980-97. *Journal of Range Management*, 55: 439-451.

Diro, G.T., Grimes, D. I., Black, E. 2011. Teleconnections between Ethiopian summer rainfall and sea surface temperature: part II. Seasonal forecasting. *Climatology Dynamic*, 37(1-2): 121-131.

Faye, B., Chaibou, M., Vias, G. 2012. Integrated impact of climate change and socio-economic development on the evolution of camel farming systems. *British Journal. of Environment and Climate change*, 2: 227-244.

Feye, Y. 2007. Pastoralists perception towards range resource utilization and range condition assessment in Gewane Districts of Afar Regional state, Ethiopia. MSc thesis, School of Graduate studies, Haramaya University, Ethiopia.

Gebre, H., Kindie, T., Girma, M., Belay, K. 2013. Trend and variability of rainfall in Tigray, Northern Ethiopia: Analysis of meteorological data and farmers' perception. *Academia Journal of Agricultural Research,* 1(6): 088-100.

Goddard, L., Mason, S.J., Zebiac, S.E., Ropelewski, C.F. Bashier, R., Cane, M.A. 2001. Current approaches to seasonal to inter-seasonal climate prediction. *International Journal of Climatology*, 21: 1111-1152.

Intergovernmental Panel on Climate Change (IPCC). 1999. Guidelines on the use of scenario data for climate impact and adaptation assessment, Version 1. Prepared by Carter TR, Hulme M, and Lal M. Intergovernmental Panel on Climate Change, Task Group on Scenarios for Climate Impact Assessment, p. 69.

Intergovernmental Panel on Climate Change (IPCC). 2007. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller. United Kingdom and New York, NY, USA: Cambridge University Press, Cambridge.

IPCC. 2013. Summary for policy makers. In Climate change .The physical science basis. Contribution of Working Group 1 to the Fifth Assessment Report of the Inter-governmental Panel on Climate Change, TE Stocker, D Qin, GK Plattner, M Tignor, SK Allen, J Boschung, A Nauels, Y Xia, V Bex, and PM

Midgley (eds.), Cambridge and New York: Cambridge University Press. Htpp://www.ipcc.ch/report/ar5/wg1/.Accessed 14 Oct 2014.

Jones, P.G., Thornton, P.K. 2013. Generating downscaled weather data from a suite of climate models for agricultural modeling applications. *Agricultural Systems*, 114: 1-5.

Kassahun, A., Snyman, H.A., Smit, G.N. 2008. Impact of rangeland degradation on the pastoral systems, livelihoods and perceptions of the Somali in eastern Ethiopia. *Journal of Arid Environments*, 72: 1265-1281.

Kgosikoma, E., Batisani, N. 2014. Livestock population dynamics and pastoral communities' adaptation to rainfall variability in communal lands of Kgalagadi South, Botswana. *Pastoral Research Policy*, 4: 1-9.

Korcha, D., Sorteberg, A. 2013. Validation of operational seasonal rainfall forecast in Ethiopia. Water Resource Research, 49: 7681-7697.

Lobell, B., Burke, B., Tebaldi, C., Mastrandrea, D., Falcon, P., Naylor, L. 2008. Prioritizing climate change adaptation needs for food security in 2030. *Science,* 319(5863): 607-610.

Mapiye, C., Chimonyo, M., Dzama, K. 2009. Seasonal dynamics, production potential and efficiency of cattle in the sweet and sour communal rangelands in South Africa. *Journal of Arid Environments*, 73: 529-536.

Megersa, B., Andre, M., Angassa, A., Anne, V.Z. 2014. The role of livestock diversification in ensuring household food security under a changing climate in Borana, Ethiopia. *Journal of Food Science*, 6: 15-28.

Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M.S., Bernabucci, U. 2010. Effects of climate changes on animal production and sustainability of livestock systems. *Livestock Science*, 130: 57-69.

National Oceanic Atmospheric Administration (NOAA). 2013. United State Global change Research Programme. Available at http://www.esrl.noaa.gov/psd/ USA.

NOAA. 2009. Climate Literacy: The essential principles of climate sciences. US Global Change Research Programme. Available at: noaa.gov/education.

Omondi, P., Awange, J.L., Ogallo, L.A., Okoola, R.A., Forootan, E. 2012. Decadal rainfall variability modes in observed rainfall records over East Africa and their relations to historical sea surface temperature changes. *Journal of Hydrology,* 464-46: 140-156.

Partal, T., Kahya, E. 2006. Trend analysis in Turkish precipitation data. *Hydrological Processes*, 20: 2011-2026.

Rufael, T., Catley, A., Bogale, A., Sahle, M., Shiferaw, Y. 2008. Foot and mouth disease in the Borana pastoral system, southern Ethiopia and implications for livelihoods and international trade. *Tropical Animal Health and Production*, 40: 29-38.

Schlotzhauer, S. 2009. Elementary Statistics Using SAS®.Cary, North Carolina, USA: SAS Institute Inc. pp 210, 280.

Segele, Z.T., Lamb P.J. 2005. Characterization and variability of Kiremt rainy season over Ethiopia. *Meteorology Atmospheric Physics*, 89: 153-180.

Seleshi, Y., Zanke, U. 2004. Recent changes in rainfall and rainy days in Ethiopia. *International Journal of Climatology*, 24: 973-983.

Serigne, T., Louis, V., Jens, M. 2006. Climate Change Climate and Variability in Southern Africa: Impacts and Adaptation in the Agricultural Sector. Kenya nairobi: Word Agroforestry Centre (ICRAF), United Nations Environment Programme (UNEP), n.d.

Sherwood, A. 2013. Community adaptation to climate change: exploring drought and poverty traps in Gituamba location, Kenya. *Journal of Natural Resources Policy Research*, 5: 147-161.

Tache, B., Sjaastad, E. 2010. Pastoralists' conceptions of poverty: An analysis of traditional and conventional indicators from Borana, Ethiopia. *World Development*, 38: 1168-1178.

Teshome, A., Ebro, A., Nigatu, L. 2010. Traditional rangeland resource utilization practices and pastoralists' perception on land degradation in south-east Ethiopia. *Tropical Grasslands*, 44: 202-2012.

Thornton, P.K., Van de Steeg, J., Notenbaert, A., Herrero, M. 2009. The impact of climate change on livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems*, 101: 113-127.

Tilahun M., Ayana, A., Aster, A., Alemayahu, M. 2016. Perception and attitude of pastoralists on the use and conservation of rangeland resources in Afar Region, Ethiopia. *Journal of Ecological Processes*, 5: 18.

Trenberth, K.E. 1991. General characterstics of El Nino-Southern Oscillation. In: M.H. Glantz, R.W. Katz and N. Nichollis (eds). Teleconnections Linking Worldwide Climate Anomalies: Scientific Bases and Societal Impact. Cambridge University Press. New York, P13-42.

Tsegaye, G., Guta, W., Rao, G.N., Tessema, A. 2015. The current and future trend of rainfall and its variability in Adami-Tulu Jido-Kombolcha Woreda, central rift valley of Ethiopia. *Journal of Environmental and Earth Science*, 5: 40-49.

Viste, E., Korcha, D., Sorteberg, A. 2013. Recent drought and precipitation tendencies in Ethiopia. *Theoretical and Applied Climatology*, 112: 535-551.

Ward, D., Saltz, D., Ngairorue, B.T. 2004. Spatio-temporal rainfall variation and stock management in arid Namibia. *Journal of Range Management*, 57: 130-140.

World Bank. 2010. The social dimensions of adaptation to climate change in Ethiopia. Development and climate change discussion papers No. 14. Washington, DC. USA.

3. Evaluation of Drought Tolerance in Teff [*Eragrostis teff* (Zucc.) Trotter] Genotypes using Drought Tolerance Indices

Brikti Ferede*[1,2], Firew Mekbib[2], Kibebew Assefa[3], Solomon Chanyalew[3], Zerihun Tadele[4], and Eyasu Abraha[5]

[1]Assosa University, Department of Plant Sciences, P. O. Box 18, Assosa, Ethiopia;

[2]Haramaya University, School of Plant Sciences, P. O. Box 241, Dire Dawa, Ethiopia;

[3]Ethiopian Institute of Agricultural Research, Debre Zeit Centre, P. O. Box 32, Debre Zeit, Ethiopia; [4]University of Bern, Institute of Plant Sciences, Altenbergrain 21, 3013 Bern, Switzerland; and [5]Tigray Agricultural Research Institute P. O. Box 492, Mekelle, Ethiopia.

*Corresponding Author Email: banchialemf@gmail.com

Abstract

Drought is a wide spread problem seriously limiting crop production in dryland areas. This study was conducted to determine drought tolerance of *teff* genotypes with high yielding potential and to select the best and stable genotypes using drought tolerance indices. Sixty-four *teff* genotypes were evaluated under two field conditions i.e., under drought stress and non-stress conditions using a "8 x 8 simple lattice design" with two replications at Debre Zeit Agricultural Research Centre. Ten drought tolerance indices: drought susceptibility index (SSI), drought tolerance index (STI) geometric mean productivity (GMP), mean productivity (MP), yield index (YI), yield stability index (YSI), drought resistance index (DRI), abiotic tolerance index (ATI), stress susceptibility percentage index (SSPI) and harmonic mean (HM) were estimated. The indices were adjusted based on grain yield under drought stress (Ys) and non-stress (Yp) conditions. The highest value of grain yield in both drought and normal condition was obtained from Melko. Based on drought tolerant indices, the highest amounts of STI, GMP and MP were related to genotypes of Melko, Etsub and Ziquala. Correlation analysis revealed that grain yield was positively correlated with STI, GMP, MP, YI, DRI and HM, indicating these indices were more important for screening stress tolerant *teff* genotypes. PCA indicated that the first two components accounted for more than 98% of the total variations. First PC contributed 67.9% of the variation with strong association between STI, GMP, MP, YI, DRI, HM, Ys and Yp. Thus, the first component can be named as the yield potential and drought tolerance while second PC explained 30.2% of the total variability. Biplot analysis indicated STI, GMP, MP, YI, DRI and HM were more reliable indices to identify drought tolerant *teff* genotypes. Cluster analysis revealed that the 64 *teff* genotypes were grouped in to 7 distinct clusters. In conclusion, this study showed that selection based on indices with Ys and Yp are more reliable for breeders.

Keywords: Correlation; Cluster analysis; Principal component analysis; Tolerance indices

1. Introduction

Teff [*Eragrostis teff* (Zucc.) Trotter] is the major cereal crop in the Horn of Africa particularly in Ethiopia where it is staple food for more than 50 million people. Its resilience to extreme environmental conditions and high nutrition makes teff the preferred crop among both farmers and consumers (Plaza-Wüthrich *et al.*, 2015). Among the food crops grown in Ethiopia, teff is cultivated on about 3 million hectare producing 4.75 million tonnes (CSA, 2015). In spite of the low productivity, teff is widely cultivated by over six million smallholder farmers in Ethiopia (Assefa *et al.,* 2015*)*. It is considered to be an orphan crop because it has benefited little from genetic improvement.

Although teff is resilient to adverse climatic conditions, the national average yield is low (1.57 tonnes/ha) (CSA, 2015) which is partly due to moisture stress (Shiferaw *et al.*, 2012). Drought continues to be a major constraint to the productivity of cereal crops and moisture stress will increase in most arid and semi-arid regions under future climate change scenarios (IPCC, 2007; Wassmann *et al.*, 2009). The best option for crop production under drought stress environments is to develop tolerant varieties which will reduce yield loss due to drought stress (Richards *et al.*, 2002). Simultaneously, drought resistance in crops is probably the most difficult trait to understand (Bruce *et al.*, 2002; Ashraf, 2010).

Breeding for drought tolerance by selecting purely for grain yield is difficult, because the heritability of yield under stress environment is low due to large genotype by environment interaction variances as compared to non-stress environments (Kirigiwi *et al.*, 2004). Achieving a yield increase under these environments has been recognized to be a difficult challenge while progress in yield has been much higher in favourable environments (Richards *et al.*, 2002).

Losses in yield are the main concern of plant breeders and hence they emphasize on yield performance under drought stress conditions. Thus, drought indices which provide a measure of drought based on yield loss under drought conditions in comparison to normal conditions have been used for screening drought tolerant genotypes (Fernandez, 1992; Mitra, 2001; Sio-Se *et al.*, 2006; Talebi *et al.*, 2009). The relative yield performance of genotypes in drought stress and non-stress environments appear to be a common starting point for identifying desirable genotypes for unpredictable rainfall conditions (Mohammadi *et al.*, 2010). Fernandez (1992) stated that the best measure for selection in drought condition could be able to separate genotypes which have desirable and relatively similar yield in stress and non-tress condition from other groups and also, the best indices are those which have high correlation with grain yield in both conditions.

The indices commonly used in the study of drought tolerance are stress susceptibility index (SSI) (Fischer and Maurer 1978), mean productivity (MP) (Rosielle and Hamblin, 1981), geometric mean productivity (GMP) (Fernandez 1992), stress tolerance index (STI) (Fernandez, 1992), yield index (YI) (Gavuzzi *et al.*, 1997), yield stability index (YSI) (Bousalama and Schapaugh, 1984), harmonic mean (HM) (Schneider *et al.*, 1997) and drought resistance index (DRI) (Lan, 1998). Two new indices namely: abiotic stress tolerance index (ATI) and stress susceptibility percentage index (SSPI) were introduced by Moosavi *et al.* (2008) to identify relatively tolerant genotypes under drought stress and non-stress conditions.

Although, there are several reports on the association of the indices with drought tolerance of many other crops, reports employing teff in relation to drought tolerance indices are rare. Only Shiferaw *et al.* (2012) reported that the information on drought tolerance indices in eighteen teff genotypes with six drought tolerance indices. Evaluation of large amount of genotypes from wide range of diversity is important for exploiting the genetic variation. The present study was conducted to identify drought tolerant teff genotypes with high yielding potential as well as to select the best and stable genotypes using drought tolerance indices.

2. Materials and Methods

2.1. Experimental Site

The experiment was conducted at Debre Zeit Agricultural Research centre of the Ethiopian Institute of Agricultural Research (EIAR). It is located at 8°44N, 38°58E, at an altitude of 1900 meters above sea level with an annual average rainfall and temperature of 1100 mm and 18.6°C, respectively (EIAR, 2004).

2.2. Experimental Materials and Design

Sixty-four *teff* genotypes comprising 35 released varieties, 24 landraces obtained from different drought prone areas of Ethiopia, 2 drought tolerant candidate parents identified by induced mutagenesis and 3 recombinant inbred lines (RILs) from national variety trials were grown in two field experiments i.e., under moisture stress and non-stress conditions during February to May 2015. Genotypes in each experiment were laid in 8x8 simple lattice design with two replications. The seeding rate was 10kg/ha for each plot. Under non-stress conditions, treatments were regularly watered until physiological maturity, while in the stress treatments water was withheld for 20 days as of anthesis stage. For determining the final yield 4 rows of $1m^2$ plot was harvested at physiological maturity.

2.3. Data Analysis

Correlation among indices and grain yield in two conditions was done by Statistical Analysis System 9.1 (SAS 2004) software. A biplot derived from principal component analysis (PCA) based on the correlation matrix and cluster analysis of genotypes for Yp, Ys and drought tolerance indices using Average linkage method and Euclidian distance were computed by Minitab ver.17 software.

For screening drought tolerant genotypes, a rank sum (RS) (Farshadfar and Elyasi, 2012) was calculated by the following formula: Rank sum (RS) = Rank mean ($\bar{R}$) + Standard deviation of rank (SDR), SDR= $(S^2i)^{0.5}$.

3. Results and Discussion

3.1. Comparing *Teff* Genotypes Based on the Tolerance Indices

Mean grain yield of genotypes under stress environment varied from 215 kg/ha to 2130 kg/ha, while mean yield of genotypes under non-stressed environment varied from 325 kg/ha to 2500 kg/ha. Melko, Etsub, Gola, Gerado, Genete, Werekeya, Ziquala, Pop7R36, Menagesha and Pop9R24 had the best performance for grain yield in drought stressed conditions, while Pop12S2, Pop2R38, Pop14S4, Pop5R13, Pop11S1, Magna and Pop14R53 exhibited the least performance (Table 1).

In order to investigate suitable stress tolerance indices for the screening of genotypes under drought condition, the indices were adjusted based on grain yield under drought stress (Ys) and non-stress (Yp) conditions. Many authors (Zeynali-Khanghah *et al*., 2004, Sio-Se 2006, Sanjari Pirevatlou *et al*., 2008, Talebi *et al*., 2009, Mohammadi *et al*., 2010, Nouri *et al*., 2011, Ilker *et al*., 2011) indicated that these were the most suitable parameters for screening drought tolerant, high yielding genotypes. Genotypes which possess high values of STI, MP and GMP can be considered tolerant to drought. Therefore, Melko, Etsub and Ziquala were ranked as the first, second and third varieties based on these indices; and therefore, it was considered the most tolerant and high yielding varieties under favorable and severe drought stress conditions. Etsub and Ziquala also exhibited highest YI, DRI, HM and grain yield under the two conditions. However, Pop14S4, Pop5S13 and Pop11S1, and all landrace genotypes displayed the lowest amount for these indices (Table 1).

According to ATI and SSPI indices Dima, Workeya, and Pop8R61 were the most relatively tolerant genotypes while for these indices Dukem, Pop12R11 and Pop10R19 were the least tolerant. The two new indices namely ATI and SSPI reveal the relative tolerance of a genotype to drought. The nature of ATI and SSPI are such that they rely on crop survival mechanisms in stress conditions although these genotypes can have either high or low yields under the two conditions. The yield stability is more important than high yield for these indices; the smaller ATI and SSPI, the more relative tolerant crop which is in agreement with that of Moosavi *et al.* (2008). With regard to YSI and SSI, genotypes Workeya, Dima and Pop8R61 were the most desirable genotypes. While Pop12S2, Magna and Enatite showed the lowest value for these indices. Mohammadi *et al.* (2010) also showed YSI to be a more useful index to discriminate drought tolerant from drought susceptible genotypes. Therefore, breeders should use this index for selection of stress tolerant genotypes. SSI selected genotypes with relatively low Yp but high Ys. The greater SSI, the greater susceptibility of the genotype to stress (Fernandez, 1992).

3.2. Ranking of Genotypes

The identification of drought tolerant genotypes based on a single criterion is contradictory. Different indices selected different genotypes as drought tolerant. In order to determine the most desirable drought tolerant genotype considering all indices, mean rank, standard deviation of ranks and rank sum all indices were calculated and based on these criteria the most desirable drought tolerant genotypes were identified. Taking into account all indices, genotypes Etsub, Worekeya, Gola, Pop7R36, Gerado, Genete, Melko, Pop8R61 and Dima exhibited the best mean rank, rank sum and relatively low standard deviation of ranks. Hence they were identified as the most drought tolerant genotypes, while genotypes Pop14S4, Pop12S2, Pop5R13, Magna, Enatite, Pop2R38, Pop10R19, Pop4R56, Pop11S1 and Pop4S1 identified as the most susceptible genotypes (Table 1).

Table 1. Mean grain yield (kg/ha) under drought stress (Ys) and non-stress (Yp) conditions and measures of different drought tolerance indices for sixty four teff genotypes.

No.	Genotype	Ys	Yp	SSI	STI	GMP	MP	YI	YSI	DRI	ATI	SSPI	HM	R	SDR	RS
1	Enatite	425(56)	1595(23)	2.61(62)	0.33(50)	823(50)	1010(44)	0.412(56)	0.266(62)	0.110(61)	0.652(60)	40.8(60)	671(50)	52.83	11.10	63.91
2	Asgori	1105(29)	1535(27)	0.99(37)	0.83(29)	1302(29)	1320(30)	1.072(29)	0.720(37)	0.772(29)	0.239(41)	15.0(41)	1679(29)	32.25	5.17	37.42
3	Magna	395(59)	1550(24)	2.65(63)	0.30(52)	783(52)	973(46)	0.383(59)	0.255(63)	0.098(62)	0.643(59)	40.3(59)	606(52)	54.17	10.90	65.04
4	Wellenkomi	880(37)	1520(28)	1.50(49)	0.65(38)	1157(38)	1200(37)	0.854(37)	0.579(49)	0.494(42)	0.356(51)	22.3(51)	1324(38)	41.25	7.21	48.46
5	Menagesha	1585(9)	2180(5)	0.97(35)	1.68(6)	1859(6)	1883(5)	1.538(9)	0.727(35)	1.118(20)	0.331(48)	20.8(48)	3421(6)	19.33	17.30	36.63
6	Melko	2310(1)	2500(1)	0.27(17)	2.81(1)	2403(1)	2405(1)	2.241(1)	0.924(17)	2.071(1)	0.106(22)	6.6(22)	5718(1)	7.17	9.23	16.40
7	Tsedey	1300(20)	1600(22)	0.67(26)	1.01(17)	1442(17)	1450(18)	1.261(20)	0.813(26)	1.025(23)	0.167(30)	10.5(30)	2059(17)	22.17	4.86	27.03
8	Gibe	940(36)	1540(26)	1.38(47)	0.70(35)	1203(35)	1240(34)	0.912(36)	0.610(47)	0.557(40)	0.334(49)	20.9(49)	1433(35)	39.08	7.32	46.40
9	Dukem	1000(34)	2325(4)	2.03(54)	1.13(14)	1525(14)	1663(11)	0.970(34)	0.430(54)	0.417(45)	0.738(64)	46.2(64)	2302(14)	33.83	22.10	55.89
10	Ziquala	1595(7)	2395(2)	1.19(42)	1.86(3)	1955(3)	1995(3)	1.547(7)	0.666(42)	1.030(22)	0.446(55)	27.9(55)	3782(3)	20.33	21.80	42.16
11	Gerado	1750(4)	1820(12)	0.14(14)	1.55(7)	1785(7)	1785(7)	1.698(4)	0.962(14)	1.632(4)	0.039(16)	2.4(16)	3154(7)	9.33	4.74	14.07
12	Koye	1345(17)	1360(39)	0.04(5)	0.89(24)	1353(24)	1353(27)	1.305(17)	0.989(5)	1.290(11)	0.008(5)	0.5(5)	1811(24)	16.92	11.00	27.97
13	KeyTena	655(49)	900(56)	0.97(34)	0.29(53)	768(53)	778(54)	0.635(49)	0.728(34)	0.462(43)	0.136(26)	8.5(26)	584(53)	44.17	11.20	55.39
14	Dega Teff	1165(27)	1700(16)	1.12(39)	0.96(19)	1407(19)	1433(19)	1.130(27)	0.685(39)	0.774(28)	0.298(45)	18.7(45)	1961(19)	28.50	10.80	39.32
15	Chafe	760(46)	1785(13)	2.04(55)	0.66(37)	1165(37)	1273(32)	0.737(46)	0.426(55)	0.314(53)	0.571(58)	35.7(58)	1343(37)	43.92	13.40	57.32
16	Amarach	1005(33)	1230(44)	0.65(24)	0.60(40)	1112(40)	1118(42)	0.975(33)	0.817(24)	0.797(26)	0.125(25)	7.9(25)	1224(40)	33.00	7.91	40.91
17	Quncho	840(40)	2010(9)	2.07(56)	0.82(30)	1299(30)	1425(20)	0.815(40)	0.418(56)	0.341(51)	0.652(61)	40.8(61)	1672(30)	40.33	17.00	57.32
18	Simada	775(44)	1160(48)	1.18(40)	0.44(44)	948(44)	968(47)	0.752(44)	0.668(40)	0.502(41)	0.214(38)	13.4(38)	890(44)	42.67	3.26	45.92
19	Genete	1695(5)	1770(14)	0.15(15)	1.46(9)	1732(9)	1733(9)	1.644(5)	0.958(15)	1.575(6)	0.042(18)	2.6(18)	2970(9)	11.00	4.79	15.79
20	Zobel	1410(15)	1735(15)	0.67(25)	1.19(12)	1564(12)	1573(13)	1.368(15)	0.813(25)	1.112(21)	0.181(33)	11.3(33)	2422(12)	19.25	7.97	27.22
21	Laketch	1210(23)	1895(11)	1.28(45)	1.12(15)	1514(15)	1553(15)	1.174(23)	0.639(45)	0.749(32)	0.382(52)	23.9(52)	2270(15)	28.58	15.80	44.41
22	Mechare	845(39)	1175(47)	0.10(38)	0.48(43)	996(43)	1010(45)	0.820(39)	0.719(38)	0.589(37)	0.184(34)	11.5(34)	983(43)	40.00	4.18	44.18
23	Gola	1845(3)	1915(10)	0.13(12)	1.72(5)	1880(5)	1880(6)	1.790(3)	0.963(12)	1.724(3)	0.039(17)	2.4(17)	3498(5)	8.17	5.25	13.42
24	Boset	405(57)	1310(43)	2.46(60)	0.26(54)	728(54)	858(50)	0.393(57)	0.309(60)	0.121(59)	0.504(56)	31.6(56)	525(54)	55.00	4.75	59.75
25	Yilmana	1080(30)	1490(30)	0.98(36)	0.78(31)	1268(31)	1285(31)	1.048(30)	0.725(36)	0.759(31)	0.228(40)	14.3(40)	1593(31)	33.08	3.85	36.93
26	Etsub	2125(2)	2170(6)	0.07(8)	2.24(2)	2147(2)	2148(2)	2.061(2)	0.979(8)	2.019(2)	0.025(10)	1.57(10)	4566(2)	4.67	3.45	8.11

Table continued

No.	Genotype	Ys	Yp	SSI	STI	GMP	MP	YI	YSI	DRI	ATI	SSPI	HM	R	SDR	RS
27	Guduru	1360(16)	1390(36)	0.08(9)	0.92(21)	1375(21)	1375(23)	1.319(16)	0.978(9)	1.291(10)	0.017(9)	1.1(9)	1872(21)	16.67	8.26	24.93
28	Dima	1415(14)	1420(34)	0.01(2)	0.98(18)	1418(18)	1418(21)	1.373(14)	0.996(2)	1.368(9)	0.003(1)	0.2(1)	1989(18)	12.67	10.10	22.79
29	Kena	635(50)	985(50)	1.26(44)	0.30(51)	791(51)	810(53)	0.616(50)	0.645(44)	0.397(47)	0.195(36)	12.2(36)	619(51)	46.92	5.81	52.72
30	Ajora	1450(13)	1670(20)	0.47(21)	1.18(13)	1556(13)	1560(14)	1.407(13)	0.868(21)	1.221(13)	0.123(24)	7.7(24)	2398(13)	16.83	4.71	21.54
31	Gemechis	1075(31)	1410(35)	0.84(31)	0.74(32)	1231(32)	1243(33)	1.043(31)	0.762(31)	0.795(27)	0.187(35)	11.7(35)	1501(32)	32.08	2.27	34.36
32	Holetta Key	470(53)	975(51)	1.84(52)	0.22(56)	677(56)	723(56)	0.456(53)	0.482(52)	0.220(55)	0.281(44)	17.6(44)	454(56)	52.33	4.29	56.63
33	Ambo Toke	850(38)	945(52)	0.36(19)	0.39(47)	896(47)	898(49)	0.825(38)	0.899(19)	0.742(33)	0.053(19)	3.3(19)	795(47)	35.58	13.30	48.93
34	Kora	745(48)	940(53)	0.74(28)	0.34(48)	837(48)	843(51)	0.723(48)	0.793(28)	0.573(38)	0.109(23)	6.8(23)	693(48)	40.33	11.60	51.93
35	Worekeya	1680(6)	1685(18)	0.01(1)	1.38(10)	1683(10)	1683(10)	1.630(6)	0.997(1)	1.625(5)	0.003(2)	0.2(2)	2803(10)	6.75	5.08	11.83
36	Pop9R1	1340(18)	1385(37)	0.12(11)	0.90(23)	1362(23)	1363(25)	1.310(18)	0.968(11)	1.258(12)	0.025(11)	1.6(11)	1838(23)	18.58	8.05	26.63
37	Pop15R3	1300(21)	1350(40)	0.13(13)	0.85(28)	1325(28)	1325(29)	1.261(21)	0.963(13)	1.214(14)	0.028(13)	1.7(13)	1738(28)	21.75	8.89	30.64
38	Pop5R35	1195(26)	1215(46)	0.06(6)	0.71(34)	1205(34)	1205(36)	1.159(26)	0.984(6)	1.140(19)	0.011(7)	0.7(7)	1438(34)	23.42	14.10	37.50
39	Pop7R36	1590(8)	1605(21)	0.03(4)	1.24(11)	1598(11)	1598(12)	1.542(8)	0.991(4)	1.528(7)	0.008(6)	0.5(6)	2527(11)	9.08	4.66	13.74
40	Pop12R11	840(41)	2095(7)	2.13(58)	0.86(27)	1327(27)	1468(17)	0.815(41)	0.401(58)	0.327(52)	0.699(63)	43.8(63)	1742(27)	40.08	19.00	59.10
41	Pop1R55	1030(32)	1340(41)	0.82(29)	0.67(36)	1175(36)	1185(38)	0.999(32)	0.769(29)	0.768(30)	0.173(31)	10.8(31)	1367(36)	33.42	3.87	37.29
42	Pop13R49	1210(24)	1505(29)	0.69(27)	0.89(25)	1350(25)	1358(26)	1.174(24)	0.804(27)	0.944(24)	0.164(28)	10.3(28)	1803(25)	26.00	1.76	27.76
43	Pop10R41	1300(22)	1365(38)	0.17(16)	0.86(26)	1332(26)	1333(28)	1.261(22)	0.952(16)	1.201(15)	0.036(15)	2.3(15)	1757(26)	22.08	7.13	29.21
44	Pop2R38	265(63)	840(59)	2.43(59)	0.11(59)	472(59)	553(60)	0.257(63)	0.315(59)	0.081(63)	0.320(47)	20.1(47)	220(59)	58.08	5.45	63.53
45	Pop6R45	1485(11)	2390(3)	1.35(46)	1.73(4)	1884(4)	1938(4)	1.441(11)	0.621(46)	0.895(25)	0.504(57)	31.6(57)	3514(4)	22.67	22.40	45.04
46	Pop3R61	820(42)	1425(32)	1.51(50)	0.57(42)	1081(42)	1123(41)	0.795(42)	0.575(50)	0.458(44)	0.337(50)	21.1(50)	1157(42)	43.92	5.37	49.28
47	Pop11R11	585(51)	905(54)	1.26(43)	0.26(55)	728(55)	745(55)	0.567(51)	0.646(43)	0.367(48)	0.178(32)	11.2(32)	524(55)	47.83	8.59	56.42
48	Pop4R56	450(54)	745(60)	1.41(48)	0.16(58)	579(58)	598(58)	0.437(54)	0.604(48)	0.264(54)	0.164(29)	10.3(29)	332(58)	50.67	10.80	61.49
49	Pop14R53	405(58)	900(57)	1.96(53)	0.18(57)	604(57)	653(57)	0.393(58)	0.450(53)	0.177(57)	0.276(43)	17.3(43)	361(57)	54.17	5.47	59.64
50	Pop11S1	395(60)	440(62)	0.36(20)	0.09(63)	417(63)	418(63)	0.383(60)	0.898(20)	0.344(50)	0.025(12)	1.6(12)	172(63)	45.67	22.30	67.99
51	Pop15S3	765(45)	905(55)	0.55(22)	0.34(49)	832(49)	835(52)	0.742(45)	0.845(22)	0.627(36)	0.078(21)	4.9(21)	686(49)	38.83	13.60	52.42
52	Pop14S4	270(62)	325(64)	0.60(23)	0.04(64)	296(64)	298(64)	0.262(62)	0.831(23)	0.218(56)	0.031(14)	1.9(14)	87(64)	47.83	21.90	69.78

Table continued

No.	Genotype	Ys	Yp	SSI	STI	GMP	MP	YI	YSI	DRI	ATI	SSPI	HM	R	SDR	RS
53	Pop12S2	215(64)	900(58)	2.71(64)	0.09(60)	440(60)	558(59)	0.209(64)	0.239(64)	0.050(64)	0.382(53)	23.9(53)	192(60)	60.25	4.07	64.32
54	Pop5S1	1130(28)	1695(17)	1.19(41)	0.93(20)	1384(20)	1413(22)	1.096(28)	0.667(41)	0.731(34)	0.315(46)	19.7(46)	1896(20)	30.25	10.90	41.16
55	Pop4S1	430(55)	440(63)	0.08(10)	0.09(61)	435(61)	435(62)	0.417(55)	0.977(10)	0.408(46)	0.006(3)	0.4(3)	187(61)	40.83	25.90	66.69
56	Pop5R13	275(61)	660(61)	2.07(57)	0.09(62)	426(62)	468(61)	0.267(61)	0.417(57)	0.111(60)	0.214(39)	13.4(39)	180(62)	56.83	8.50	65.34
57	Pop8R61	1475(12)	1485(31)	0.02(3)	1.07(16)	1480(16)	1480(16)	1.431(12)	0.993(3)	1.421(8)	0.006(4)	0.4(4)	2169(16)	11.75	8.15	19.90
58	Pop9R24	1545(10)	2015(8)	0.83(30)	1.51(8)	1764(8)	1780(8)	1.499(10)	0.767(30)	1.149(17)	0.262(42)	16.4(42)	3082(8)	18.42	13.70	32.12
59	Pop10R19	490(52)	1675(19)	2.52(61)	0.40(46)	906(46)	1083(43)	0.475(52)	0.293(61)	0.139(58)	0.660(62)	41.3(62)	813(46)	50.67	12.30	62.93
60	Dtt13	785(43)	1055(49)	0.91(32)	0.40(45)	910(45)	920(48)	0.762(43)	0.744(32)	0.567(39)	0.150(27)	9.4(27)	820(45)	39.58	7.99	47.58
61	Dtt2	1315(19)	1425(33)	0.27(18)	0.91(22)	1369(22)	1370(24)	1.276(19)	0.923(18)	1.177(16)	0.061(20)	3.8(20)	1855(22)	21.08	4.36	25.44
62	RIL27	1200(25)	1225(45)	0.07(7)	0.72(33)	1212(33)	1213(35)	1.164(25)	0.980(7)	1.140(18)	0.014(8)	0.9(8)	1455(33)	23.08	13.20	36.30
63	RIL91A	985(35)	1340(42)	0.94(33)	0.64(39)	1149(39)	1163(39)	0.956(35)	0.735(33)	0.702(35)	0.198(37)	12.4(37)	1307(39)	36.92	2.78	39.70
64	RIL129A	760(47)	1545(25)	1.81(51)	0.57(41)	1084(41)	1153(40)	0.737(47)	0.492(51)	0.363(49)	0.437(54)	27.4(54)	1163(41)	45.08	8.15	53.23
	Mean	1030.8	1434.06	0.997	0.80	1199	1233	1.001	0.719	0.788	0.225	14.1	1625	32.50	9.61	42.11

The numbers in the parentheses are the ranks of the genotype for each index, Ys = Mean value of yield under water stress condition, Yp = mean value of yield under non-stress condition, SSI = Stress susceptibility index, STI = Stress tolerance index, GMP = Geometric mean productivity, MP = Mean productivity, YI = Yield index, YSI = Yield stability index, DRI = Drought resistance index, ATI = Abiotic tolerance index, SSPI = Stress susceptibility percentage index, HM = Harmonic mean, R *= Rank mean, SDR= Standard deviation of rank, RS= Rank sum.*

3.3. Correlation

In order to determine the most desirable drought tolerant criteria, the correlation coefficients between Yp, Ys and other indices of drought tolerance were calculated (Table 2). Correlation between grain yield and drought tolerance indices can be a good criterion for screening the best genotypes and indices used. A suitable index must have a significant correlation with grain yield under both conditions (Mitra, 2001). There was a positive significant correlation between Yp and Ys analyses which indicated that high yield performance under favourable condition resulted in relatively high yield under stress conditions.

Yield in stress condition (Ys) was significantly and positively correlated with STI, GMP, MP, YI, YSI, DRI, and HM. On the contrary, a significant and negative correlation was recorded between SSI, ATI and SSPI with Ys. As lower SSI, ATI and SSPI and higher quantities of Ys are desirable indicating with increasing Ys, these indices will decrease. Therefore, SSI, ATI and SSPI are suitable indices to identify genotypes with more drought tolerance than higher yield. In consistence with our results, Naghavi *et al.* (2013) in maize reported that STI, GMP, MP, YI, YSI and DRI were positively correlated with stress yield. Shiferaw *et al.* (2012) in teff found that there was negative correlation between SSI and yield under stress condition. The result also concurs with Moosavi *et al.* (2008) in wheat who reported that negative correlation between SSI, ATI and SSPI with Ys.

Grain yield under non-stress condition (Yp) was positively correlated with SSI, STI, GMP, MP, YI, DRI, ATI, SSPI and HM and negatively correlated with YSI. The results are in consistent with Yasir *et al.* (2013) in Chinese bread wheat who reported that positive correlation between STI, GMP, MP, YI, DRI, ATI, SSPI and HM and negatively correlated with YSI. The result coincides with Farshadfar *et al.* (2012) in bread wheat where all indices were correlated positively. In contrast, other authors reported a positive correlation between YSI and Yp which is in contrary with the current result.

Table 2. Correlation coefficients between drought tolerance indices and yield under water stress and non-stress conditions.

	Ys	Yp	SSI	STI	GMP	MP	YI	YSI	DRI	ATI	SSPI	HM
Ys	-											
Yp	0.71**	-										
SSI	-0.66**	0.01ns	-									
STI	0.94**	0.84**	-.42**	-								
GMP	0.95**	0.88**	-.44**	0.97**	-							
MP	0.92**	0.92**	-.35**	0.96**	0.99**	-						
YI	1.00**	0.70**	-.66**	0.94**	0.95**	0.92**	-					
YSI	0.66**	-.01**	-.00**	0.42**	0.44**	0.35**	0.66**	-				
DRI	0.95**	0.49**	-.80**	0.83**	0.83**	0.78**	0.95**	0.80**	-			
ATI	-.37**	0.39**	0.88**	-.11ns	-.08ns	0.012ns	-.37**	-.88**	-.59**	-		
SSPI	-.37**	0.39**	0.88**	-.11ns	-.08ns	0.012ns	-.37**	-.88**	-.59**	1.00**	-	
HM	0.94**	0.84**	-.42**	1.00**	0.97**	0.96**	0.94**	0.42**	0.83**	-.11ns	-11ns	-

*For abbreviations, see Table 1. * and** significant at 5 and 1% levels of probability, respectively, ns = not significant.*

As per the correlation matrix, it is observed that positive correlation was found between grain yield in the stress (Ys) and non-stress (Yp) conditions with STI, GMP, MP, YI, DRI and HM indicating that these criteria were more effective in identifying high yielding genotypes under different moisture regimes. The relationships were in consistent with Ashraf *et al.* (2015) in bread wheat who observed that significant positive correlation between grain yield in the stress (Ys) and non-stress (Yp) conditions with STI, MP, GMP, YI, HM and DRI. Highly correlated indices with both the Ys and Yp are most appropriate for identifying stress tolerant cultivars which agreed with Farshadfar *et al.* (2011). Khalilzade and Karbalai-Khiavi (2002) and Farshadfar *et al.* (2012) believed that the most suitable indices for selection of drought tolerant cultivars are the ones with relatively high correlation with grain yield in both stress and non-stress conditions. Therefore, the correlation between indices of stress tolerance and yield in both conditions identify the most suitable indicators for screening drought tolerant genotypes. Fernandez (1992) also illustrated that the most appropriate indicators for selection of drought tolerant cultivars are indices showing a relatively high correlation with grain yield in both environmental conditions (genotypes that express uniform superiority in both environmental conditions). In generally the observed finding were consistence with those reported by Farshadfar and Elyasi (2012) in bread wheat, Dehbalaei *et al.* (2013) in bread wheat, Toorchi *et al.* (2012) in canola and Golabadi *et al.* (2006) in durum wheat.

3.4. Principal Component Analysis

Of the principal components, the first and second components explained more than 98% of the total variation. Hence, bi-plot was drawn based on the first two components. Similarly, Golabadi *et al.* (2006), Malekshahi *et al.* (2009), Nazari and Pakniyat (2010), Mohammadi *et al.* (2011), Yarnia *et al.* (2011), Farshadfar *et al.* (2012), Rahimi *et al.* (2013) have used biplot analysis based on the first two principal components for screening drought tolerant genotypes of different crop species.

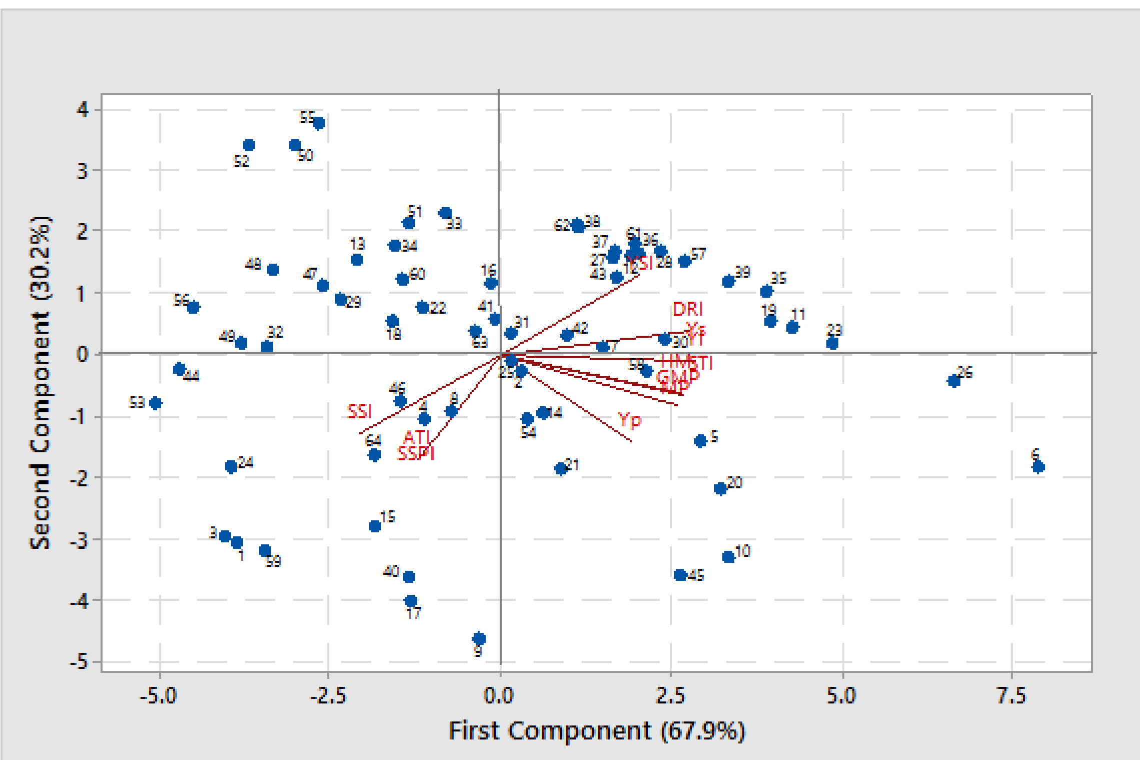


Figure 1. Biplot for drought tolerance indices based on the first two principal components axes (PC1 and PC2) for sixty-four teff genotypes in stress (Ys) and non-stress (Yp) conditions. The indices are indicated using uppercase letters and each genotype is represented with numbers (see Table 1, for abbreviations and genotypes code).

Cluster analysis based on 10 drought tolerance indices and grain yield under drought stress and non-stress conditions classified sixty-four teff genotypes into seven groups with 8, 23, 4, 2, 19, 5 and 3 genotypes respectively (Figure 2).

Cluster analysis were in agreement with the results of biplot analysis. Cluster analysis was also used by several studies to classify genotypes according to their response to drought stress. Studies conducted by Aliakbari *et al.* (2014) in rapeseed, Farshadfar *et al.* (2013) in bread wheat, Nouri *et al.* (2011) in durum wheat, Mursalova *et al.* (2015) in winter bread wheat, Subhani *et al.* (2015) in barley, Zare (2012) in Iranian barley, Yasir *et al.* (2013) in Chinese bread wheat, Menezes *et al.* (2014) in sorghum all of whom found cluster analysis based on drought tolerance indices and grain yield under drought stress and non-stress conditions to be suitable for selection of drought tolerant crops.

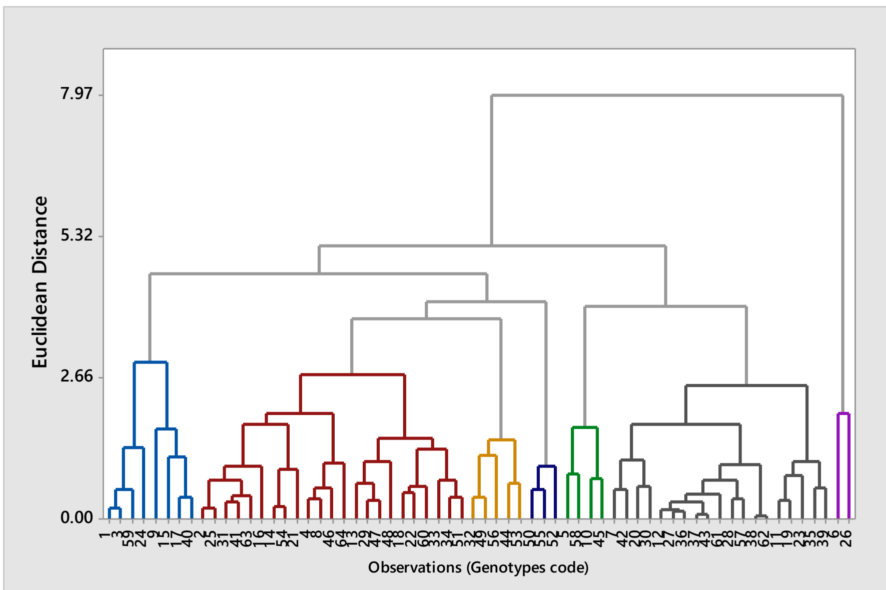


Figure 2. Dendrogram of *teff* genotypes using average linkage method (between groups) based on drought tolerance indices.

4. Conclusions and Recommendations

Drought stress significantly reduced the yield of some genotypes while some other genotypes were tolerant to drought. Selection based on a combination of indices can be useful for improving drought tolerance of teff genotypes with desirable yield under both stress and non-stress conditions. In consideration to all indices using rank some method, genotypes Etsub, Worekeya, Gola, Pop7R36, Gerado, Genete, Melko, Pop8R61 and Dima exhibited relatively the lowest rank sum respectively, hence they were identified as the most drought tolerant genotypes, while genotypes Pop14S4, Pop12S2, Pop5R13, Magna, Enatite, Pop2R38, Pop10R19, Pop4R56, Pop11S1 and Pop4S1 as the most sensitive.

Yp and Ys have positive and significant association with STI, GMP, MP, YI, DRI and HM indicating that these indices were appropriate indices to select drought tolerant genotypes. Based on PCA and biplot analysis the indices of STI, GMP, MP, YI, DRI and HM exhibited strong correlation (acute angles) with Ys and Yp, therefore separated drought tolerant genotypes with high grain yield. Hence, breeders can select suitable genotypes based on these indices for drought stress. Cluster analysis also showed that the genotypes based on tolerance indices tended to cluster into seven groups. Cluster IV had an outstanding performance than any other genotypes tested in this study. Genotypes in cluster V were characterized by moderate to high grain yield in both conditions next to cluster IV.

In conclusion, the multiple indices and statistical methods which have been used in this study showed that STI, GMP, MP, YI, DRI and HM were more reliable indices and recommended to select genotypes with stable and high grain yield in both stress and non-stress conditions.

5. References

Akcura, M. and S. Ceri. 2011. Evaluation of drought tolerance indices for selection of Turkish oat (Avena sativa L.) landraces under various environmental conditions. *Zemdirbyste Agriculture*, 98 (2): 157-166.

Ali, M.B. and A.N. El-Sadek. 2016. Evaluation of drought tolerance indices for wheat (Triticum aestivum L.) under irrigated and rainfed conditions. *Communications in Biometry and Crop Science*, 11: 77-89.

Aliakbari, M., H. Razi and A. Kazemeini. 2014. Evaluation of drought tolerance in rapeseed (*Brassica napus* L.) cultivars using drought tolerance indices. *International journal of advanced biological and biomedical research*, 2 (3): 696-705.

Ashraf, A., A. El-Mohse, M.A. Abd El Shafi, E.M. Gheith, H.S. Suleiman. 2015. Using different statistica procedures for evaluating drought tolerance indices of bread wheat genotypes. *Advances in agriculture and biology*, 4 (1): 19-30.

Ashraf, M. 2010. Inducing drought tolerance in plants: Recent advances. *Biotechnology Advances*, 28: 169-183.

Assefa, K., G. Cannarozzi, D. Girma, R. Kamies, S. Chanyalew, S. Plaza-Wüthrich, R. Blösch, A. Rindisbacher, S. Rafudeen and Z. Tadele. 2015. Genetic diversity in teff [*Eragrostis teff* (Zucc.) Trotter]. *Frontiers in Plant Science*, 6: 1-13.

Bouslama, M., W.T. Schapaugh. 1984. Stress tolerance in soybean. Evaluation of three screening techniques for heat and drought tolerance. *Crop Science*, 24: 933-937.

Bruce W.B., G.O. Edmeades and T.C. Barker. 2002. Molecular and physiological approaches to maize improvement for drought tolerance. *Journal of Experimental Botany*, 53 (366): 13-25.

CSA (Central Statistics Authority). 2015. Agricultural Sample Survey report on Area and production of major Crops (Private peasant holdings "meher" season), Volume I Addis Abeba, Ethiopia.

Dehbalaei, S., E. Farshadfar and M. Farshadfar. 2013. Assessment of drought tolerance in bread wheat genotypes based on resistance/ tolerance indices. *International Journal of Agriculture and Crop Sciences*, 5 (20): 2352-2358.

EIAR (Ethiopian Institute of Agricultural Research). 2004. A document prepared for Research strategy for teff commodity research programme. Addis Ababa, Ethiopia.

Farshadfar, E. and P. Elyasi. 2012. Screening quantitative indicators of drought tolerance in bread wheat (Triticum aestivum L.) landraces. *European Journal of Experimental Biology*, 2 (3): 577-584.

Farshadfar, E., B. Jamshidi and M. Aghaee. 2012. Biplot analysis of drought tolerance indicators in bread wheat landraces of Iran. *International Journal of Agriculture and Crop Science*, 4: 226-233.

Farshadfar, E., M.M. Poursiahbidi and S.M. Safavi. 2013. Assessment of drought tolerance in land races of bread wheat based on resistance/ tolerance indices. *International Journal of Advanced Biological and Biomedical Research*, 1: 143-158.

Farshadfar, E., V., Rasoli, J.A., Teixeira da Silva and M. Farshadfar. 2011. Inheritance of drought tolerance indicators in bread wheat (Triticum aestivum L.) using a diallel technique. *Australian Journal of Crop Science,* 5 (7): 870-878.

Fernandez, G.C.J. 1992. Effective selection criteria for assessing plant stress tolerance. Proceedings of the International Symposium on Adaptation of Vegetables and other Food Crops in Temperature and Water Stress. Asian Vegetable Research and Development Centre, Shanhua, Taiwan, pp: 257-270.

Fischer, R.A. and R. Maurer. 1978. Drought resistance in spring wheat cultivars. I. Grain yield response. *Australian Journal of Agricultural Research*, 29:897-912.

Gavuzzi, P., F. Rizza, M. Palumbo, R.G. Campaline, G.L. Ricciardi and B. Borghi. 1997. Evaluation of field and laboratory predictors of drought and heat tolerance in winter cereals. *Canadian Journal of Plant Science,* 77 (4): 523-531.

Golabadi, M., A. Arzani and S.A. Maibody. 2006. Assessment of drought tolerance in segregating populations in durum wheat. *African Journal of Agriculture Research*, 5: 162-171.

Ilker, E., O. Tatar, F. Aykut Tonk, M. Tosun and J. Turk. 2011. Determination of Tolerance Level of Some Wheat Genotypes to Post-Anthesis Drought. *Turkish Journal of Field Crops*, 16 (1): 59-63.

IPCC (Intergovernmental Panel on Climate Change). 2007. Climate change: impacts, adaptation and vulnerability: contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Jafari, A.A., F. Paknejad and M. Jamial-Ahmadi. 2009. Evaluation of selection indices for drought tolerance of corn (Zea mays L.) hybrids. *International Journal of Plant Production*, 3: 33-38.

Jalilvandy, A. and M. Rozrokh. 2013. Assessment of Drought Tolerance Indices in Wheat Genotypes. *International Journal of Agriculture and Crop Science*, 6 (7): 370-374.

Kaya, Y., R. Topal, A.E. Gonulal and R.Z. Arisoy. 2002. Factor analyses of yield traits in genotypes of durum wheat (Triticum durum). *Indian Journal of Agriculture Science*, 72: 301-303.

Khalilzade, G.H. and H. Karbalai-Khiavi. 2002. Investigation of drought and heat stress on advanced lines of durum wheat. Seventh Iranian Congress of Agronomy and Plant Breeding. Agricultural Education Publishing. Gilan,Iran, pp:563-564.

Kirigiwi, F.M., M. Van Ginkel, R. Trethowan, R.G. Sears, S. Rajaram and G.M. Paulsen. 2004. Evaluation of selection strategies for wheat adaption across water regimes. *Euphytica*, 13: 361-371.

Kristin, A.S., R.R. Serna, F.I. Perez, B.C. Enriquez and J.A. Gallegos. 1997. Improving common bean performance under drought stress. *Crop Science*, 37: 51-60.

Lan, J. 1998. Comparison of evaluating methods for agronomic drought resistance in crops. *Acta Agriculturae Boreali-occidentalis Sinica*, 7: 85-87.

Malekshahi, F., H. Dehghani and B. Alizadeh. 2009. A study of drought tolerance indices in Canola (Brassica napus L.) genotypes. *Journal* of *Science* and *Technology* of Agriculture and *Natural Resources*, 13: 77-90.

Menezes, C.B., C.A. Ticona-Benavente, F.D. Tardin, M.J. Cardoso, E.A. Bastos, D.W. Nogueira, A.F. Portuga, C.V. Santos and R. E. Schaffert. 2014. Selection indices to identify drought-tolerant grain sorghum cultivars. *Genetics and Molecular Research*, 13 (4): 9817-9827.

Mitra, J. 2001. Genetics and genetic improvement of drought resistance in crop plants. *Current Science,* 80: 758-762.

Mohammadi, M., F. Karimizadeh and M. Abdipour. 2011. Evaluation of drought tolerance in bread wheat genotypes under dry land and supplemental irrigation conditions. *Australian Journal of Crop Science*, 5: 487-493.

Mohammadi, R., M. Armion, Kahrizi D and A. Amri. 2010. Efficiency of screening techniques for evaluating durum wheat genotypes under mild drought conditions. *Journal of Plant Production*, 4:11-24.

Moosavi, S.S., B. Yazdi-Samadi, M.R. Naghavi, A.A. Zali, H. Dashti and A. Pourshahbazi. 2008. Introduction of new indices to identify relative drought tolerance and resistance in wheat genotypes. *Desert*, 12: 165-178.

Mursalova, J., Z. Akparov, J. Ojaghi, M. Eldarov, S. Belen, N. Gummadov and A. Morgounov. 2015. Evaluation of drought tolerance of winter bread wheat genotypes under drip irrigation and rain-fed conditions. *Turkish Journal of Agriculture and Forestry*, 39: 1-8.

Naghavi, M.R., A. Pouraboughadareh and M. Khalili. 2013. Evaluation of drought tolerance indices for screening some of corn (*Zea mays* L.) cultivars under environmental conditions. *Notulae Scientia Biologicae,* 5: 388-393.

Nazari, L. and H. Pakniyat. 2010. Assessment of drought tolerance in barley genotypes. *Journal of Applied Science*, 10: 151-156.

Nouri, A., A. Etminan, A. Jaime, S. Teixeira and R. Mohammadi. 2011. Assessment of yield, yield-related traits and drought tolerance of durum wheat genotypes (*Triticum turjidum var. durum* Desf.). *Australian Journal of Crop Science*, 5: 8-16

Plaza-Wüthrich, S., R. Blösch and Z. Tadele. 2015. Efficiency of In Vitro Regeneration is Dependent on the Genotype and Size of Explant in Teff [*Eragrostis teff* (Zucc.) Trotter]. Advance in Crop Science and Technology, 3: 179. doi:10.4172/2329- 8863.1000179.

Rahimi, M., H. Dehghani, B. Rabiei and A.R. Tarang. 2013. Evaluation of rice segregating population based on drought tolerance criteria and biplot analysis. *International Journal of Agriculture and Crop Science*, 5: 194-199.

Richards, R. A., G.J. Rebetzke, A.G. Condon and A.F. Herwaarden. 2002. Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals. *Crop Science,* 42: 111-121.

Rosielle, A.A. and J. Hamblin. 1981. Theoretical aspects of selection for yield in stress and non- stress environment. *Crop Science*, 21: 943-946

Sanjari, P.A. and A. Yazdansepas. 2008. Evaluation of wheat (Triticum aestivum L.) Genotypes under Pre and Post anthesis drought stress conditions. *Journal of Agricultural Science and Technology,* 10: 109-121

SAS (Statistical Analysis System). 2004. SAS guide for personal computers, file version 9.1. SAS Institute, Kary, NC, USA.

Schneider, K.A., R. Rosales-Serna, F. Ibarra-Perez, B. Cazares-Enriquez, J.A. Acosta-Gallegos, P. Ramirez-Vallejo, N. Wassimi and J.D. Kelly. 1997. Improving common bean performance under drought stress. *Crop Science,* 37: 43-50.

Shiferaw, W., Balcha A. and Mohammed H. 2012. Genetic variation for grain yield and yield related traits in teff [*Eragrostis teff* (Zucc.) Trotter] under moisture stress and non-stress environments. *American Journal of Plant Sciences*, 3: 1041-1046.

Sio-Se, M., A. Ahmadi, K. Poustini and V. Mohammadi. 2006. Evaluation of drought resistance indices under various environmental conditioning. *Field Crops Research,* 98: 222- 229.

Subhani, G.M., J. Abdullah, J. Ahmad, J. Anwar, M. Hussain and A. Mahmood. 2015. Identification of drought tolerant genotypes of barley (*hordeum vulgare* l.) through stress tolerance indices. *The Journal of Animal & Plant Sciences*, 25 (3): 686-692.

Talebi, R., F. Fayaz and A.M. Naji. 2009. Effective selection criteria for assessing drought stress tolerance in durum wheat (*Triticum durum* Desf.). *General and Applied Plant Physiology*, 35: 64-74.

Toorchi, M., R. Naderi, A. Kanbar M.R. Shakiba. 2012. Response of spring canola cultivars to sodium chloride stress. *Annals of Biological Research*, 2 (5): 312-322.

Wassmann, R., SVK. Jagadish, S. Heuer, A. Ismail, E. Redona, R. Serraj, R.K. Singh, G. Howell, H. Pathak and K. Sumfleth. 2009. Climate change affecting rice production: the physiological and agronomic basis for possible adaptation strategies. *Advances in Agronomy*, 101: 59-122.

Yarnia, M., N. Arabifard, F. R. Khoei and P. Zandi. 2011. Evaluation of drought tolerance indices among some winter rapeseed cultivars. *African Journal of Biotechnology*, 10: 10914-10922.

Yasir, T.A., X. Chen, L. Tian, A.G. Condon and Y. Hu. 2013. Screening of Chinese bread wheat genotypes under two water regimes by various drought tolerance indices. *Australian Journal Crop Science*, 7 (13): 2005-2013.

Zare, M. 2012. Evaluation of drought tolerance indices for the selection of Iranian barley (*Hordeum vulgare*) cultivars. *African Journal of Biotechnology*, 11 (93): 15975-15981.

Zeinali-Khanghah, H., A. Izanlo, A. Hosseinzadeh and N. Majnoun-Hosseini. 2004. Determine of appropriate drought resistance indices in imported soybean cultivars. *Iran Journal of Agriculture Science*, 354: 875-885.

4. Effects of the 2015/ 2016 El Niño on Zimbabwe Rainfall

Vimbai Mamombe

Meteorological Services Department of Zimbabwe Corner Bishop Gaul Avenue/ Hudson Street Box BE 150, Belvedere, Harare, Zimbabwe,

Corresponding Author Email: vmamombe@gmail.com

Abstract

This study was aimed at investigating the effects of the 2015/2016 El Niño event on Zimbabwe rainfall. Rainfall data from the meteorological services department was used to compare the mean monthly, onset and cessation dates and deviation of rainfall for the 2015/2016 season with that of 1981 to 2010. Although the season had started earlier than usual in some places, an anomalously dry peak of the rainy season (December, January and February) and prolonged intra-season dry spells resulted in crop failure. Rainfall received higher than the mean during the month of November which contributed significantly to the early onset of the rainfall. However, there are some places where the rainfall distribution failed to meet the requirements for onset of the season. The El Niño events brought erratic rainfall pattern which resulted in the month of March being wetter than January. However, January is usually the wettest month because of the position of the Inter tropical convergence zone in the southern hemisphere. Above normal rainfall received during the month of March resulted in spatial variations in the mean end of season, even if the season ended earlier than usual in most parts of the country. The 2015/2016 seasonal forecast issued in August 2015 had projected drier than usual conditions over a large portion of the country. In conclusion, the seasonal forecast should be considered as a significant tool for planning in order to enhance risk aversion, disaster preparedness and food security.

Keywords: Disaster preparedness; El Niño; Rainfall; Seasonal characteristics

1. Introduction

The start of the 2015/2016 rainy season over Zimbabwe coincided with an El Niño event which could be regarded as one of the strongest El Niño events on record. The El Niño event had great influence on the global weather patterns. The less than usual rainfall which was received during the early season extending from October to December prompted the government of Zimbabwe to declare the 2015/2016 agricultural season a national state of emergency in February 2016. The poor rainfall received during the first half of the rainy season resulted in crop failure due to delayed planting and unfavourable conditions for early crop establishment. Record breaking temperatures were also recorded in November 2015 in most parts of the country (Table 1). The anomalously high temperatures exacerbated the shortage of water and pasture. The El Niño induced drought resulted in many communal farmers losing their cattle which will stifle animal drawn ploughing capability in future.

Zimbabwe rainfall is highly variable both in space and time, hence, reliable seasonal forecasts are of great importance in alleviating the impacts of extreme weather events and in water resource management (Manatsa and Mukwada, 2012; Mamombe *et al.,* 2016). The South African Development Community (SADC) Climate

Services Centre coordinates the seasonal climate outlook forum for southern African countries before the beginning of each rainy season. The intensity, duration and frequency of large-scale atmospheric systems are the major causes of rainfall variability across the region (Torrance, 1981; Nicholson, 1986; Muchuru *et al.,* 2014). By influencing the major rainfall bearing systems and the atmospheric circulation, the El Niño Southern Oscillation (ENSO) has wider influence on climate variability over southern Africa (Richard *et al.,* 2000; Landman *et al.,* 2001; Manatsa *et al.*, 2011; Mason, 2001; Meque and Abiodun, 2015). Therefore, this study was aimed at investigating the effects of the 2015/2016 El Niño event on Zimbabwe rainfall.

2. Materials and Methods

Rainfall data from the meteorological services department was used to compare the mean monthly rainfall for the 2015/2016 season with that of 1981 to 2010; the mean onset and cessation dates for the 2015/2016 rainfall season and their deviation from the mean of 1981 to 2010. In order to establish the contribution of the 2015/2016 seasonal outlook in informed decision making, the 2015/2016 seasonal outlook was compared with the observed rainfall for the season.

Table 1. Record temperatures during the month of November in Zimbabwe.

Station	Previous record ^{0}C	Date	New record ^{0}C*
Chivhu	35.5	8 November 1981	36.5
Goetz Observatory	37.4	14 November 1990	37.7
Gweru	36.4	4 November 1998	36.7
JM Nkomo Airport	37.7	13 November 1990	38.6
Kezi	40.5	9 November 1997	41.1
Makoholi	37.2	23 November 1994	38.2
Marondera	32.9	25 November 1976	33.4
Nyanga	30.7	20 November 1994	30.9
Plumtree	37.5	9 November 1997	37.7
Rusape	34.8	14 November 1955	35.2
Tsholotsho	40.4	12 November 2011	40.5

**All the temperatures for the new record were recorded on 12 November 2015.*

3. Results and Discussion

3.1. Mean Monthly Rainfall

Extending from October to March and sometimes well into April, the rainfall season over Zimbabwe has its peak from December to February with January being the wettest month (Figure 1a). The peak of the rainy season coincides with the period when the intertropical convergence zone will be over the country (Beilfuss, 2012; Ziegler *et al.*, 2013). It is important to note that for the 2015/2016 rainfall season, the highest amount of rainfall was received during the month of March (Figure 1b). It is also worth noting that November and December had more rainfall than January which implied that the El Niño phenomenon disturbed the usual movement of weather systems over the region.

With the exception of the extreme eastern parts of Mashonaland and north of Manicaland provinces which received significant rainfall, the majority of the country was under dry conditions during the month of October (Figure 2a). Comparing the rainfall received for the 2015/2016 season during the month of October with the long term average, wetter than usual conditions were realized over parts of Mashonaland East and north of Manicaland provinces, however, the rest of the country experienced drier than usual rainfall conditions (Figure 2b). El Niño induced atmospheric anomalies had negative impacts on the frequency, intensity and general movement of the weather systems that bring rainfall to the country during the month of October.

During the month of November, a large portion of the country received high amount of rainfall (Figure 3a). The majority of the country received the usual to above the mean rainfall. Wetter than usual conditions were experienced over the eastern and extreme northern parts of the country during the month of November. However, drier than usual conditions were experienced over the Zambezi Valley and some parts of Masvingo province. In the month of December, with the exception of the extreme southern parts of the country, most part of the country was under drier than normal conditions (Figure 4) which is the period of high amount of rainfall are expected in the country. The El Niño event disrupted the spatio-temporal distribution of rainfall across the country.

In January, only the eastern and parts of the northern half of the country received high amount of rainfall (Figure 5a), whereas, the rest of the country was under drier than usual conditions (Figure 5b). It implies that the El Niño event altered the duration, intensity and general movement of the intertropical convergence zone which usually brings significant amounts of rainfall over the country during December, January and February (Schefub *et al*., 2011; Schneider *et al*., 2014). Drier than usual rainfall conditions were experienced over a most of the country during the month of February. Only the western part of the country received rainfall within the long term mean (Figure 6). With the exception of the south eastern parts of the country, the whole country received significant rainfall during the month of March (Figure 7a). Also the majority of the country had wetter than usual conditions during the month of March (Figure 7b). The season was characterised by anomalously dry conditions during December, January and February. Ironically, when the season was supposed to come to an end it received highest rainfall and when high rainfall amounts were expected dry conditions prevailed. The El Niño phenomenon resulted in erratic rainfall patterns across Zimbabwe during the 2015/2016 season which affected negatively the rain-fed agricultural activities.

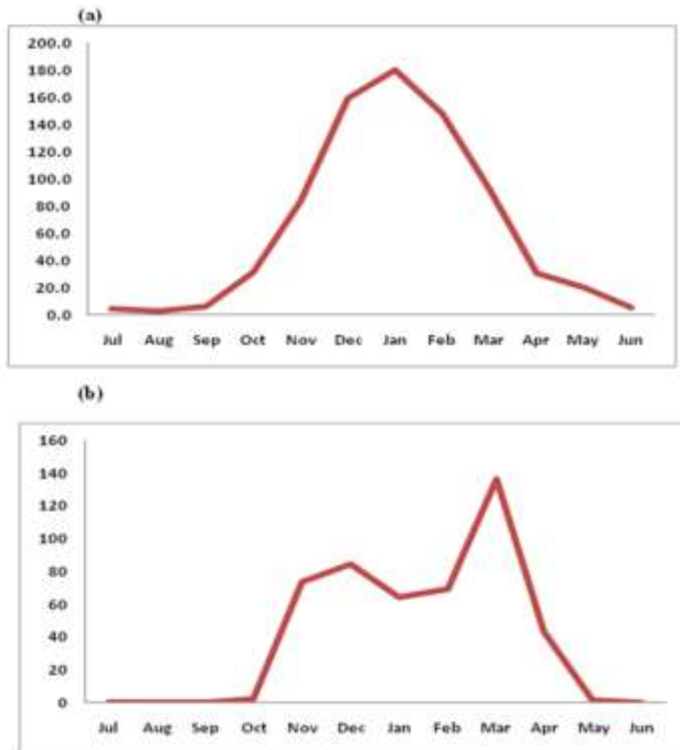


Figure 1. Mean monthly rainfall over Zimbabwe for (a) 1981 to 2010 climate period and (b) 2015/2016 season.

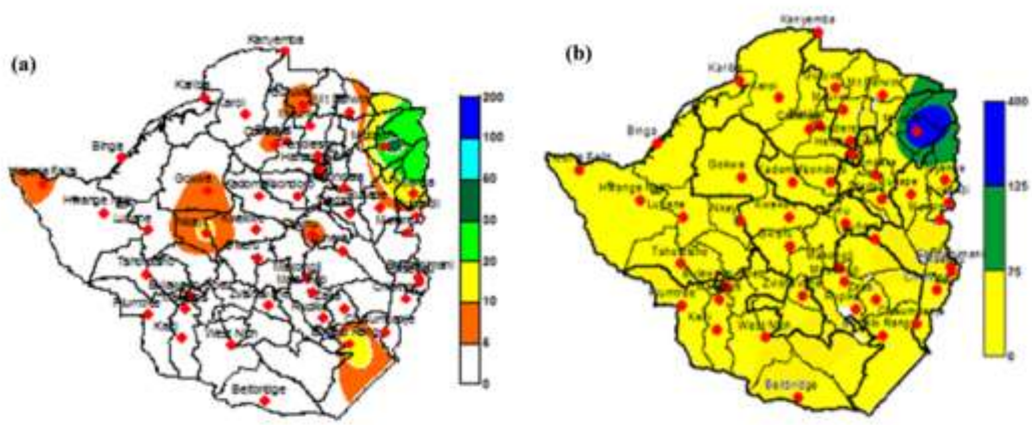


Figure 2. Spatial distribution of rainfall for October 2015 showing (a) the accumulated rainfall and (b) percentage of normal.

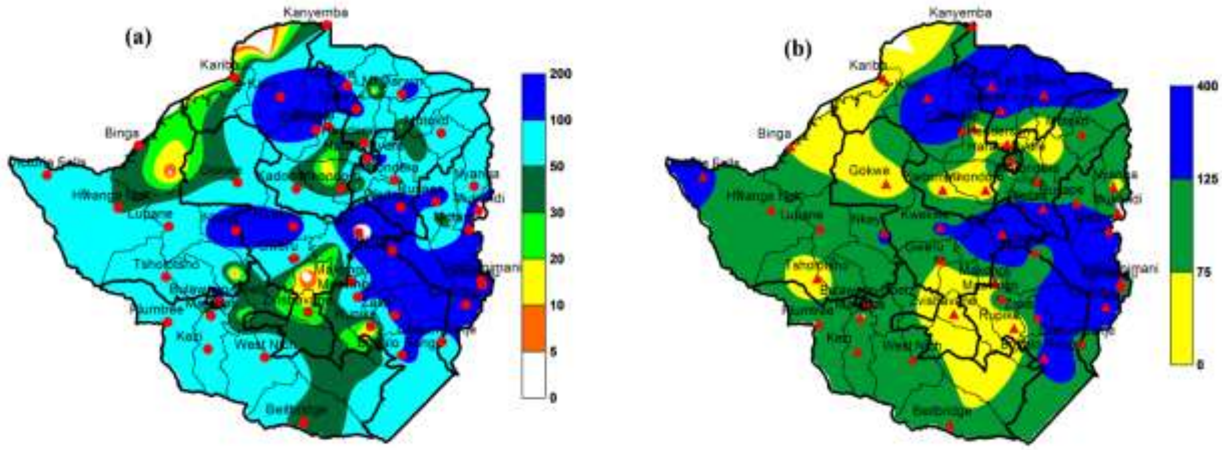


Figure 3. Spatial distribution of rainfall for November 2015 showing (a) the accumulated rainfall and (b) percentage of normal.

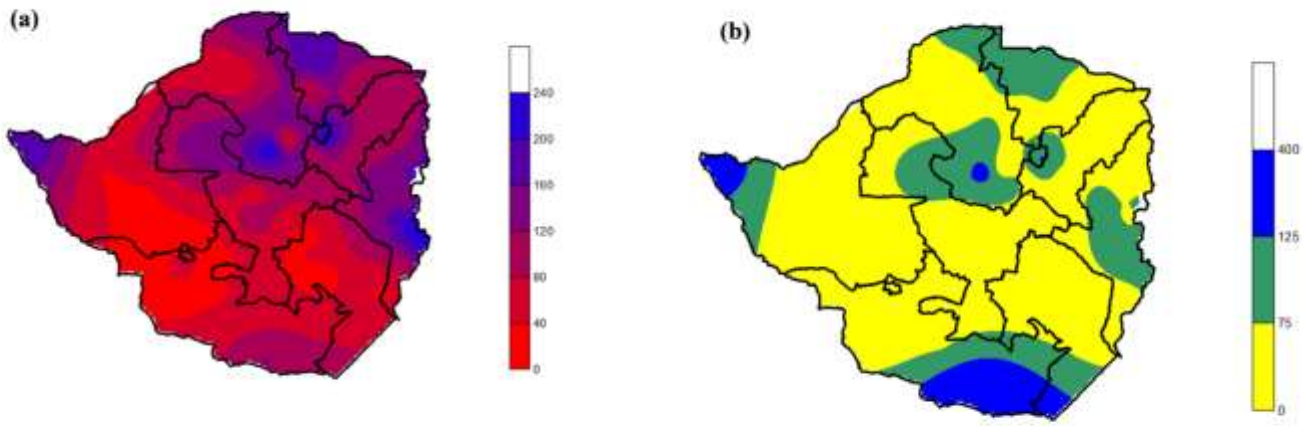


Figure 4. Spatial distribution of rainfall for December 2015 for (a) the accumulated rainfall and (b) percentage of normal

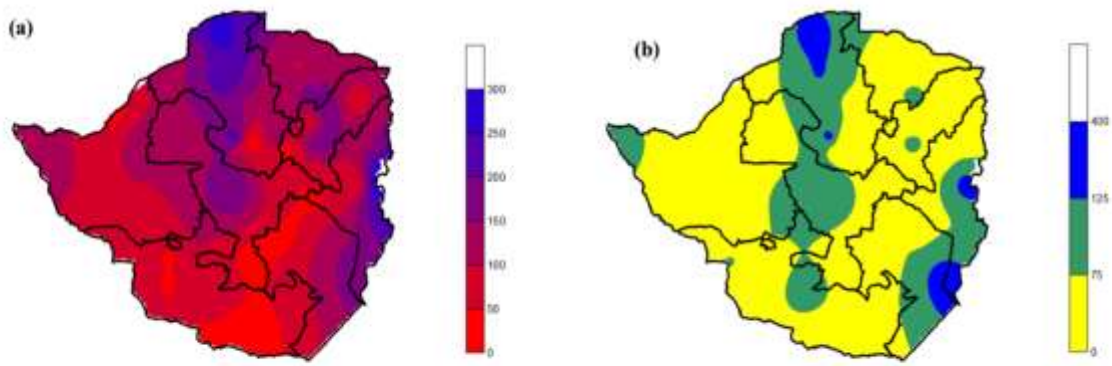


Figure 5. Spatial distribution of rainfall for January 2016 for (a) the accumulated rainfall and (b) percentage of normal.

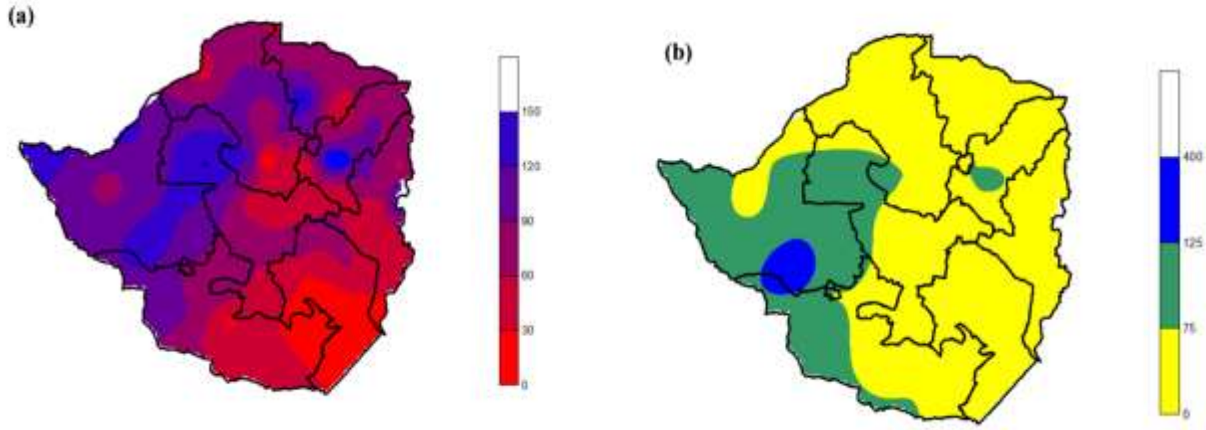


Figure 6. Distribution of rainfall across Zimbabwe for February 2016 for (a) the accumulated rainfall and (b) percentage of normal.

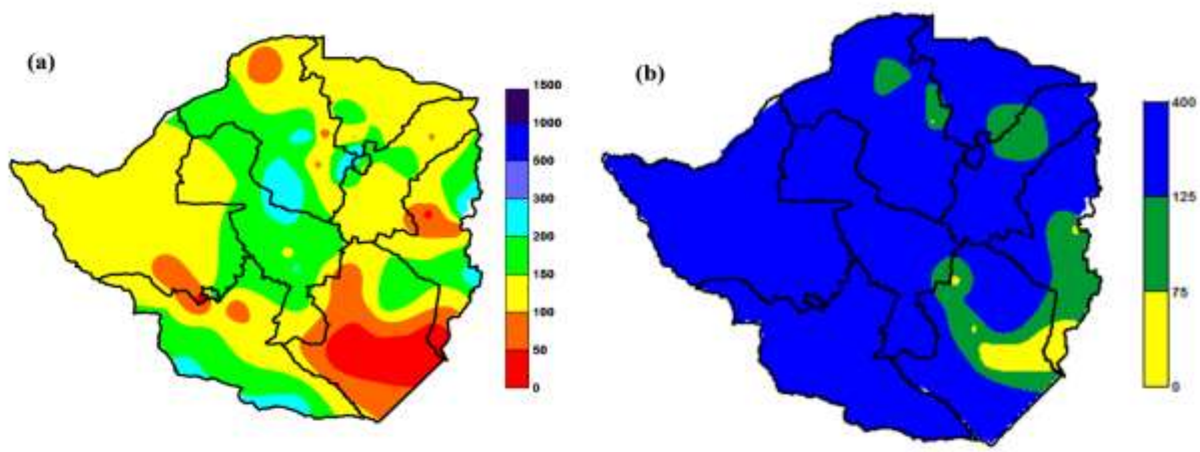


Figure 7. Distribution of rainfall across Zimbabwe for March 2016 showing (a) the accumulated rainfall and (b) percentage of normal

3.2. Rainfall Season Characteristics

The influence of El Niño on the onset and cessation of the rainy season as well as the frequency of dry spells are of paramount importance for agricultural activities (Amekudzi *et al.,* 2015). The types of crops to grow and the planting dates depend on the onset and length of the rainy season as well as the frequency of dry spells within the season. The season started early in most parts of the country especially in the southern parts of the country where it normally starts around 5 December but started around 15 November (Figure 8a). There are areas where the start of the season was never declared (white circles; Figure 8b). In this study, the start of season is defined as when an area receives 20mm or more of rainfall in one or two days and there is no dry spell of more than ten days in the subsequent thirty days. An early onset of the season in the country happens when average to above average rainfall is received in the month of November. However, the early onset was of little importance to agriculture as it was interrupted by drier than usual conditions during December, January and February.

Most of the country had longer than usual intra season dry spells with a maximum dry spell of over twenty days (Figure 9), which resulted in withering of the crops and declaring the national state of emergency.

Prolonged intra seasonal dry spells are usually associated with drought and food insecurity. Even if some farmers replanted when sufficient rainfall amount was received in March, it was of no use as the season came to an end or already ended in some parts of the country.

Although the majority of the country received higher than usual rainfall during the month of March, the season ended earlier than usual in some parts of the country (Figure 10). On average, the rainy season extended to the 25th of March over the south eastern parts of the country, however, during the 2015/2016 rainfall season, the season had ended by the 5th of March. In the extreme northern parts of the country, the season usually extended well into April but the 2015/2016 season had ended by the 5th of March (Figure 10). This implies that the El Niño phenomenon caused significant variations in the rainfall characteristics across the country.

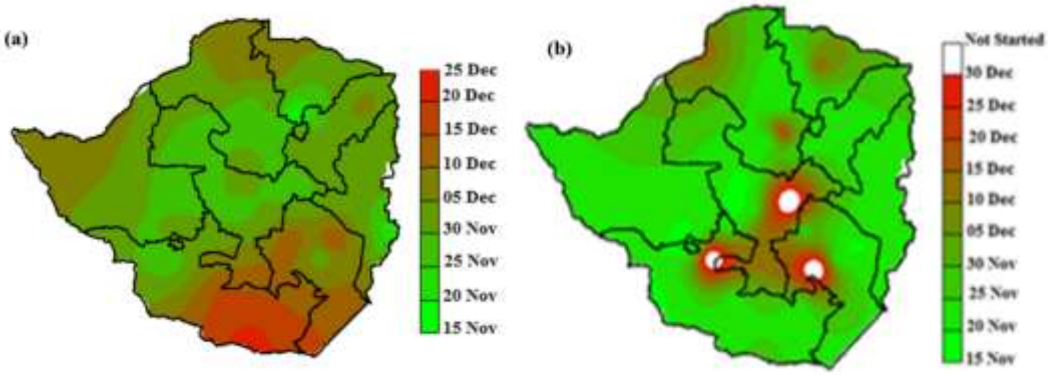


Figure 8. The mean onset dates of the rainfall season in Zimbabwe for (a) the period from 1981 to 2010 and (b) 2015/2016 season.

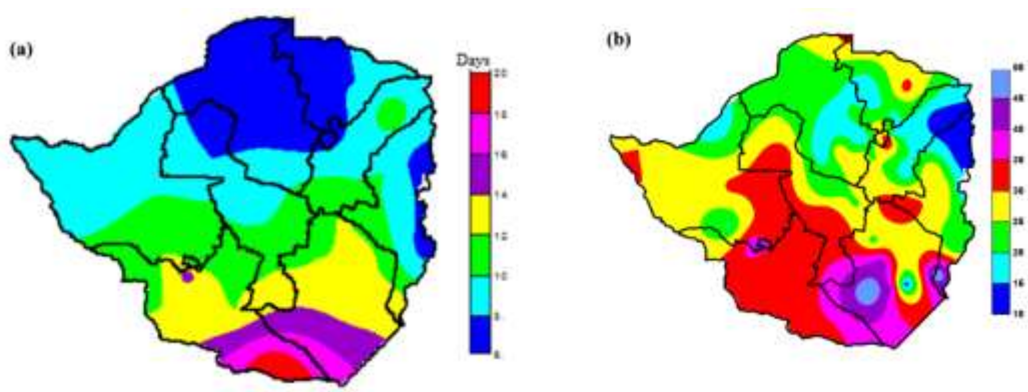


Figure 9. Dry spells in days for (a) 1981 to 2010 period and (b) 2015/2016 season.

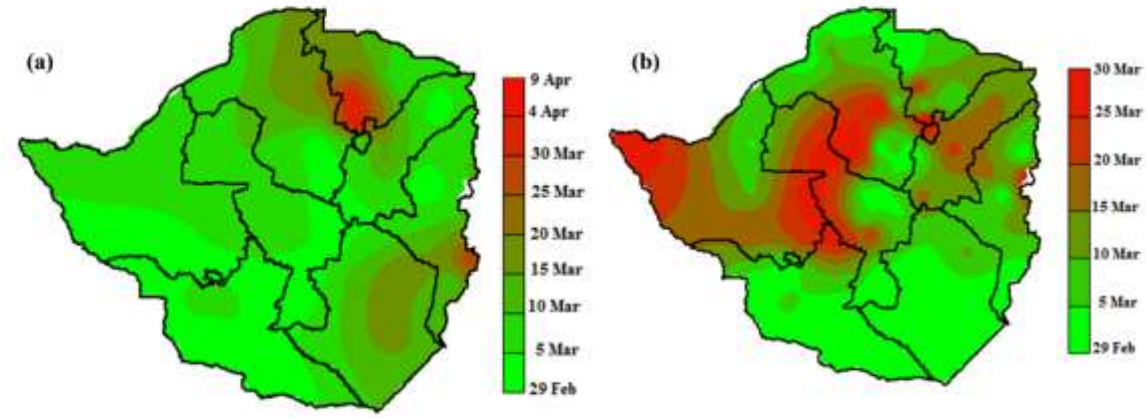


Figure 10. Mean cessation dates for (a) The 1981 to 2010 climate period and (b) the 2015/2016 season.

3.3. Seasonal Outlook

For the seasonal outlook, the country is divided into three meteorological regions. During the period from October to December, the seasonal rainfall projection had gone for greater chances of receiving below normal to normal rainfall over region 1, normal to below normal rainfall over region 2 and normal to below normal rainfall over region 3 (Figure 11a). Most part of the country was under drier than normal conditions for the same period as shown in figure (11b). This implies that the seasonal forecast was accurate and should be used for decision making. For the period from January to March, high chances of normal to drier than normal conditions were projected for the whole country (Figure 12a). With the exception of the extreme south western parts of the country which received higher than usual rainfall amounts, the whole country was in the normal to below normal category which implied that the El Niño induced drought was experienced during the year 2016 as projected through the seasonal outlook.

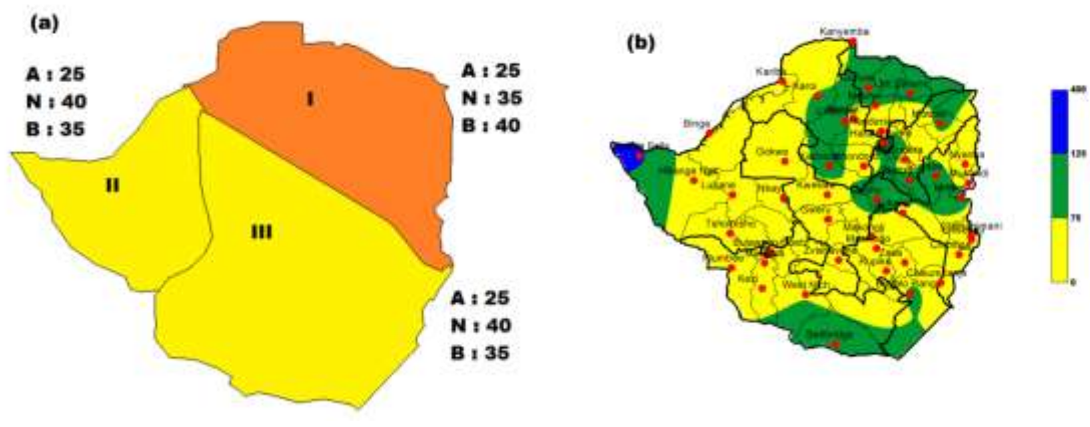


Figure 11. (a) Projections for the OND 2015 sub season. **A** is the probability of getting above normal rainfall (greater than 125% of the long term mean); **N** is the probability of getting rainfall within the normal range (75% to 125% of the long term mean); **B** is the probability of getting below normal rainfall (less than 75% of the long term mean) and (b) Accumulated rainfall for the period from October to December as a percentage of the long term mean.

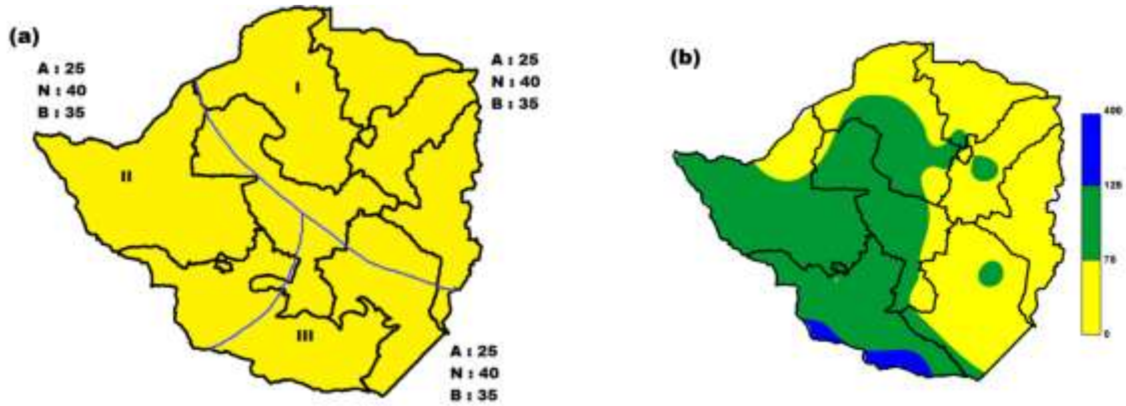


Figure 12. (a) Projections for the JFM sub season where **A, N** and **B** have the same meaning as in figure 11 and (b) Accumulated rainfall for the period from January to March as a percentage of the long term mean.

4. Conclusions and Recommendations

The impacts of the 2015/2016 El Niño event on the mean monthly rainfall, onset and cessation dates and the mean dry spell days over Zimbabwe were analysed using rainfall data from the Meteorological Services Department of Zimbabwe. Variations in the mean onset, cessation and prolonged intra season dry spells were observed. Generally, the season started earlier than usual but the prolonged intra season dry spells resulted in water scarcity and crop failure.

Normally, highest rainfall amounts are recorded during December, January and February with January being the wettest month. However, during the 2015/2016 rainy season March was the wettest month. Mostly drier than usual conditions were experienced across the country during December, January and February which is the peak of the rainy season. The drier than usual conditions lead to crop failure and loss of livestock due to the negative impacts of El Niño events.

The findings demonstrated that the seasonal forecast is of paramount importance in decision making. The 2015/2016 seasonal outlook which was issued in August 2015 had projected higher chances of receiving normal to below normal rainfall across the whole country and this agreed with the observed conditions that prevailed during the rainy season. The drought episode which was declared a national state of emergency was projected by the seasonal forecast. Therefore, the seasonal outlook should be considered when making decisions pertaining to enhance disaster preparedness, risk aversion and food security.

5. References

Amekudzi, L.K., Yamba, E. I., Preko, K., Asare, E. O., Aryee, J., Baidu, M., and Codjoe, S. N. 2015. Variabilities in rainfall onset, cessation and length of rainy season for the various agro-ecological zones of Ghana. *Climate*, **3**(2): 416-434.

Beilfuss R. 2012. A Risky Climate for southern African Hydro. Risks and Consequences for Zambezi River Basin Dams. International Rivers, Berkeley, CA. 56pp.

Landman, W. A., Mason, S. J., Tyson, P. D., and Tennant, W. J. 2001. Retro-active skill of multi-tiered forecasts of summer rainfall over southern Africa. *International Journal of Climatology*, 21(1): 1-19.

Mamombe, V., Kim, W., and Choi, Y. S. 2016. Rainfall variability over Zimbabwe and its relation to large-scale atmosphere–ocean processes. International Journal of Climatology.DOI: 10.1002/joc.4752.

Manatsa, D., Matarira, C. H., and Mukwada, G. 2011. Relative impacts of ENSO and Indian Ocean dipole/zonal mode on east SADC rainfall. *International Journal of Climatology*, 31(4): 558-577.

Manatsa D and Mukwada G., 2012.Rainfall Mechanisms for the Dominant Rainfall mode over Zimbabwe relative to ENSO and/or IODZM. The Scientific World Journal. DOI:10.1100/2012/926310.

Mason, S.J. 2001. El Niño, climate change, and Southern African climate. *Environmetrics*, 12(4): 327-345.

Meque, A., and Abiodun, B.J. 2015. Simulating the link between ENSO and summer drought in Southern Africa using regional climate models. *Climate Dynamics*, 44(7-8): 1881-1900.

Muchuru, S., Landman, W. A., DeWitt, D., and Lötter, D. 2014. Seasonal rainfall predictability over the Lake Kariba catchment area. *Water SA*, 40(3): 461-470.

Mushore TD. 2013. Uptake of the seasonal forecasts in Zimbabwe. *IOSR* J. Environ. Sci.Toxicol. *Food Technol.* 5(1): 31-37.

Nicholson, S. E. 1986. The nature of rainfall variability in Africa south of the equator. *Journal of Climatology*, 6(5): 515-530.

Richard, Y., Trzaska, S., Roucou, P., & Rouault, M. 2000. Modification of the southern African rainfall variability/ENSO relationship since the late 1960s. *Climate Dynamics*, 16(12): 883-895.

Schefuß, E., Kuhlmann, H., Mollenhauer, G., Prange, M., and Pätzold, J. 2011. Forcing of wet phases in southeast Africa over the past 17,000 years. *Nature*, 480(7378): 509-512.

Schneider, T., Bischoff, T., and Haug, G. H. 2014. Migrations and dynamics of the intertropical convergence zone. *Nature*, 513(7516): 45-53.

Theme 2: El Niño and its Social and Economic Impact

1. Smallholder Farmers' Adaptation to Climate Change and Determinants of their Adaptation in the Central Rift Valley of Ethiopia

Abrham Belay*[1], John Recha[2], Teshale Woldeamanuel[1], and John F. Morton[3]

[1]Wondo Genet College of Forestry and Natural Resources, Hawassa University, Department of Natural Resource and Environmental Studies;

[2]International Livestock Research Institute, CGIAR Research Programme for Climate Change, Agriculture and Food Security (CCAFS), Nairobi, Kenya;

[3]University of Greenwich, Department of Livelihoods and Institutions, Natural Resources, Institute, Kent, United Kingdom.

*Corresponding Author Email: abrish.z2010@gmail.com

Abstract

The agricultural sector in Ethiopia remains the main source of livelihoods for smallholders and the basis of the national economy. The sector is characterized by its heavy dependence on rainfall, traditional technology, low input, and environmental degradation. It is also a victim of climate change and variability. Therefore, identifying climate change adaptation strategies is crucial for food security and improving farmers' livelihoods. This study aimed at assessing the impact of climate change and adaptation strategies in the Central Rift valley of Ethiopia. Both primary and secondary data were used for this study. Primary data was collected from 200 randomly selected households, key informants and focus group discussants. Secondary data was collected from published literature. Descriptive statistics were employed to analyse farmers' perceptions, the impact of climate change, and the adaptation strategies. The results showed that the majority of the smallholders (90%) perceived change in temperature and rainfall and experienced associated effects. About 85% of farmers have responded to the climate risks through different mitigation and adaptation practices such as crop diversification, planting date adjustment, soil and water conservation, increasing the inputs use, integrating crop with livestock enterprises, and tree planting. Farmers in Central Rift Valley of Ethiopia need institutional and policy support and suitable technology for adaptation. Furthermore, providing climate change information, extension services and creating access to markets are crucial for enhancing farmers' livelihoods.

Keywords*:* Adaptation; Climate change; Diversification; Livelihoods; Smallholder farmers

1. Introduction

Scientific evidences indicate that the earth's climate is rapidly changing and affecting in various forms. Almost all evidences associated with the problem increases greenhouse gases emissions. The use of fossil fuel as energy source, land use change, and other anthropogenic activities are known to be major factors for increase in the concentration of the greenhouse gases (Stern, 2006; IPCC, 2014). The increased concentration of greenhouse gases has already raised the average temperature and altered the amount and distribution of rainfall globally (Cubasch *et al.,* 2001; IPCC, 2007). Climate change with multifaceted impacts has been experienced all over the world. At present no country is immune to the impacts of climate change and all have been exposed to the economic, social, and environmental impacts of climate change (Stern, 2006; Dasgupta *et al.*, 2014).

The impacts due to climate change have both spatial and temporal dimensions. On the one hand the impacts can vary between different geographical spaces with implication of differential impacts between developing and developed countries. On the other hand, the impacts vary over time. Besides, the impacts also vary between sectors. Notably, the agricultural sector is more climate prone (IPCC, 2014). In this regard, smallholder farmers in most developing countries have already faced losses in agricultural production (IPCC, 2007; Bankhoff, 1999; Anderson *et al.,* 2009; IPCC, 2014). The impact of climate change in Africa is visible on both the natural and social systems (Amsalu & Gebremichael, 2010; Mearns and Norton, 2010). Notably, in semi-arid and arid areas of Sub Saharan Africa (SSA), the impact of climate change on agricultural production has been severe (Boko *et al.,* 2007; Anderson *et al.,* 2009; Niang *et al.,* 2014). The frequent droughts experienced over the last three decades and the recent impacts of El Niño in eastern African countries in general and Ethiopia in particular have made millions of people food insecure (Otto *et al.,* 2015).

Climate change mitigation and adaptation have been challenging throughout the world (Agrawal, 2010). In this regard diverse adaptation strategies have been practiced both at individual and group level (Stern, 2006). In the case of smallholder farmers, the role of adaptation is more crucial. Smallholder farmers in developing nations have had limited resilience to droughts, floods and other catastrophes. In the West African Sahel, for instance, pastoralists have adapted strategies to cope with the extreme fluctuation of rainfall (Dasgupta *et al.,* 2014). In Ethiopia, diverse indigenous adaptation strategies have been practiced (Ababa, 2007; NMSA, 2001). Even with adaptation, there will be residual costs, for instance, switching to more climate resistant crop varieties is associated with lower productivity (McCarthy *et al.*, 2001; Adger *et al.,* 2003).

The intergovernmental panel on climate change (IPCC) found that the impacts of climate change are not evenly distributed and the people who were exposed to the worst impacts are the ones least able to cope with the associated risks. In developing countries, adaptation of the agricultural sector to the adverse effects of climate change is imperative to protect the livelihoods of the poor communities (Dasgupta *et al.,* 2014). Effective adaptation requires the involvement of various stakeholders, including policymakers, extension agents, NGOs, researchers, communities, and farmers. Besides, climate change adaptation is mostly location specific, and its effectiveness depends on local institutions and socioeconomic setting which mediate and translate the impact of external interventions to facilitate adaptation to climate change (Morton, 2007). A better understanding of how smallholder farmers perceive climate change and the adaptation strategies they use is needed to strengthen the existing adaptation practices as well as develop programmes and strategies aimed at promoting successful. A combination of factors influences the farmers' perception about climate variability and the decision to choose and practice selected adaptation strategies over other strategies (Deressa *et al.*, 2009; Nhemachena and Hassan, 2007).

In the recent decades, the impact of climate change has become pressing in agricultural sector in Ethiopia (Deressa *et al.*, 2009). Although recorded history of drought in different parts of Ethiopia dates back to 250 BC, recently it has become more frequent and omnipresent (Webb *et al.*, 1992). Meanwhile communities in different parts of the country have been known for their indigenous responses and practices in minimizing the challenges (Morton, 2007). Therefore, knowing how individuals and communities adapt to climate change is crucial as it helps to know what strategies are practiced using their own capacity (i.e. autonomous adaptation strategies) as well as the limitations of the indigenous adaptation strategies that need to be supported by policies. As Ethiopia is characterized by cultural and ecosystem diversity, hence the impacts of climate change and the types of adaptation responses can vary over small geographical area and requires location and context specific analysis. This study, therefore, was initiated to examine how the local community perceives the impacts of climate change, and identify the adaptation strategies to climate change practiced by them. The study area, Central Rift valley of Ethiopia, is evidently the hardest hit region in terms of drought (Bezabih *et al*., 2010) resulting in shortage of water, crop yield reduction and occurrence of pest and diseases to poor smallholder farmers.

2. Materials and Methods

2.1. Description of the Study Area

This study was conducted in Arsi Negelle district of West Arsi Zone, Oromia Regional State of Ethiopia. Geographically, it is located at 7°17'N to 7°66'N and 38°43'E to 38°81'E. It is located 250km south of Addis Ababa. The district is at the centre of the Central Rift valley of Ethiopia, which is characterized by frequent droughts for several decades and has three distinct agro-ecological zones that range between 1560 and 3105 m.a.s.l. The high altitude agro-ecological zone occupies the largest area followed by mid and low altitude agro-ecological zones, respectively (Gebeyehu, 2002). This helps to study the spatial dimension of climate change impacts, adaptation strategies and factors contributing for the differential variation. Moreover, the district is characterized by variation in climate parameters. For instance, the average annual temperature ranged between 10 and 25^{o}C. The annual rainfall is erratic and ranged from 500mm to 1200mm. In addition, the district has four distinct seasons including, dry season (December to February), short rainy season (March to May), main rainy season (June to August) and harvest season (September to November) (ORS,2004). Finally, the fact that lives and livelihoods in the district are based on rain fed agriculture (cereal and livestock farming) makes it more appealing for this study (CSA, 2007).

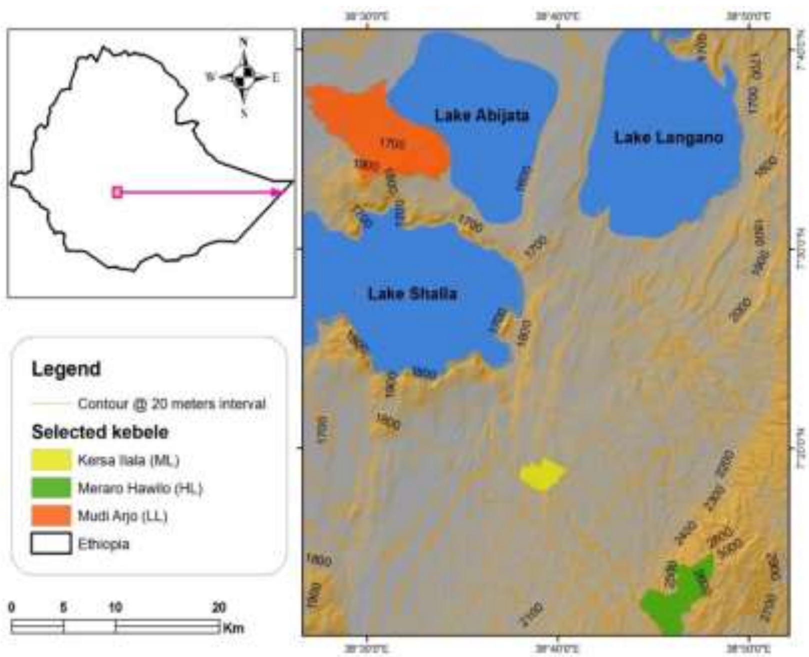


Figure 1. Map of the study area.

2.2. Sampling Design and Sample Size

This study employed a multi-staged sampling to select the *Kebeles* (the lowest level administrative unit under the Federal Democratic Government of Ethiopia) and households. In the first stage, Arsi Negelle district was selected purposely among the districts of West Arsi Zone, Oromia Regional State. In the second stage, three *Kebeles* (one from each agro-ecological zone) were selected randomly with the assumption that smallholder farmers in each agro-ecology may be different in their indigenous knowledge. In the third stage, the number of households in each target *kebele*s were selected randomly and sample size was determined proportionately across the three *kebele*s.

Table 1. Distribution of sampled households by the *Kebele*/village.

Kebele Name	Agro-ecology	Number of sampled household head	Male household Head (%)	Female household Head (%)
Meraro Hawilo	Highland	70	93	7
Kersa IIala	Midland	53	83	17
Mudi Arjo	Lowland	77	84	16
Total		200		

2.3. Data Collection

This study employed both qualitative and quantitative data both at community and household level (Neuman, 2005). The qualitative data at community level were collected through Focus Group Discussions (FGDs), key informant interviews (KIIs), and direct observations. FDGs for this study were held with separate groups of elders, youth and women comprising 6-10 individuals per group in each *Kebele*. FGD sessions were moderated by the researcher. Among the issues included in the checklist for FGD were change in climate parameters, the impacts brought due to the change, how the community is responding to the impacts autonomously, and what type of planned climate change adaptation strategies are introduced by government agencies and non-governmental organizations at different levels, and what factors affect their adaptation capacity etc., Similarly, KIIs were held with experts and administrators from government office and NGOs and knowledgeable people from the community who have access to climate information (seasonal or short term forecasting) regarding the dynamics in climatic parameters, the impacts of climate change, the responses strategies so far practiced to adapt to climate change, and constraints to the adaptation strategies in the area and etc.

The data at the household level were collected *via* household survey. For the household survey, the impacts of climate change and the adaptation strategies at individual household level were investigated. The sampling size for the households' survey was determined by using probability proportional to sampling technique (Midzuno,1951). Consequently, a total of 200 sample households were selected and interviewed: 70 from Merarow Hawilo, 53 from Kersa Elala, and 77 Mudi Arjo *kebele*s. In order to collect the necessary information, structured questionnaires were prepared. Before starting the actual survey, the questionnaires were pre-tested with nine households to check their validity and appropriateness which allowed the edition and restructuring of questions before actual data collection. The local language, Afan Oromo, was employed for both household survey, focus groups discussions and key informant interviews. Research assistants fluent in Afan Oromo with good knowledge of local tradition were used for the survey. The survey was carried out from May to October 2015.

2.4 Data Analysis

Data analysis was made using a combination of descriptive statistics (tables, minimum, maximum, frequency, percentage s, means, ratios and standard deviations) and qualitative analysis. Univariate tests such as t-test and chi-square were used in order to compare the difference among groups. Microsoft Excel and STATA version 13 were employed to analyse the data. Whereas the qualitative data collected through key informant interviews, focus group discussions, and direct observation were transcribed, categorized, looked for relationships and interpreted. Enumeration was done to identify the recurrence of themes or events. Finally, relationships were established using categories and cause-and-effect connections.

3. Results and Discussion

3.1 Smallholder Farmers' Perceptions of Climate Change

The FGDs and KIIs reflected that climate variables including rainfall and temperature had showed small variation and are almost predictable over more than two decades ago in Arsi Negele district. Rainfall was regular and generally sufficient in all seasons for crop and livestock production. Currently, changes have led to unpredictable rainfall patterns, and cropping seasons. The household survey results (Figure 2) showed that about 90% of the respondents have already experienced change in climate parameters over the last two decades. With respect to the smallholder farmers, increasing rate and frequency climate variability was evident. In the past, they used to experience drought in the range of 10 years, but now in less than 5 years. The households have diverse responses regarding temperature variability (Figure 2). More than two-thirds of the respondents (68.5%) noted that the temperature has been increasing over the last two decades while 12.3% of the households perceived the temperature has been decreasing. However,18.8% of the households revealed that they had not observed any change.

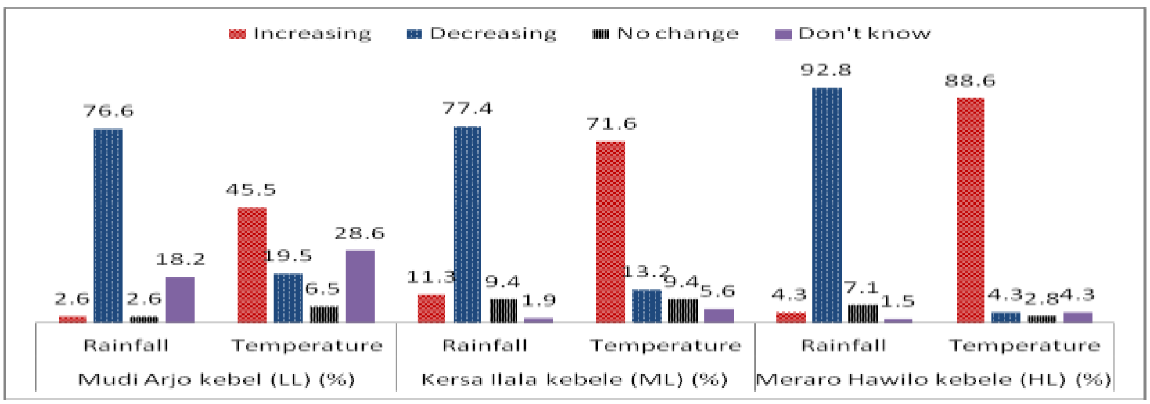


Figure 2. Smallholder farmers' perceptions about climate variability.

The variability of the climate variables has shown similar trends across *Kebeles* although there were few differences in the proportion of the sample households. In all *kebele*s the precipitation has been reported to be declining but the proportion of the households who reported the decline in precipitation vary across *Kebels*. The result shows that 93% of the households in Meraro Hawilo *Kebele* perceived declining precipitation. Whereas in the case of the remaining *Kebeles,* 77% the respondents had experienced declining precipitation. As to temperature, the impacts varied across *Kebeles*. In some *Kebele*s where more proportion of the households perceived declining temperature, they also experienced increasing temperature and variability. The difference could be due to agro-ecology. For example, Meraro Hawilo is a high land *Kebele*, majority of the households experienced and witnessed the problem in which crops and livestock production has been an old age practice in the highlands *Kebele*s with sufficient precipitation before. However, currently the declining precipitation experienced by smallholders is a new scenario. In the case of lowland *Kebele*s, however, minority of farmers experienced for the variability of rainfall in which smallholder agriculture is a recent practice. Both the FGD and KII results showed that the frequency and magnitude of the variation in climatic parameters have also been increasing over the last two decades, which indicated that climate change is a problem across space and over time as stated by Stern (2006).

The majority of the respondents (40%) realized the climate variability and its impact from their own understanding (Table 2). The respondents indicated that over the two decades they noticed early or late onset of rainy seasons, unexpected rainfall, declining rainfall, and extreme day and night temperature. They also indicated that the decline in productivity of some of the crops. In this regard, in the highland agroecology, crops like barely, field peas and beans have been performing poorly as a result some farmers reduced the amount of land allocated for cultivation and others stopped the production of those crops. On the contrary, the majority of the farmers are shifting to crops like teff and Maize due to their climate resilience. Nevertheless, the productivity of the new crops that are now being cultivated in highland was reported to be low as compared to midland which indicated that the trade-off adaptation strategies (Yesuf *et al.*, 2008).

In the district, the role of governmental and non-governmental organizations as sources of information regarding climate change and its impacts have been considerable. The role of formal communication from research institutions, mass media especially the report from national meteorological agency, and government extension services through its development agents and seminars and workshops was important however their coverage is minimal. Informal communication (5%) among the smallholders themselves was also reported as a source of information (Table 2).

Table 2. Primary sources of information about climate change and its impacts .

Climate change information Sources	Number of respondents	Respondents in %
Own understanding	80	40
Research institutions	20	10
Mass media	36	18
Development agents	30	15
Seminar/meeting	24	12
Other farmers	10	5
Total	**200**	**100**

3.2. Impact of Climate Change on Smallholder Farming

It is not only the variability of climate parameters but also its impacts have been perceived by smallholder farmers. Prolonged drought, incidence of pests and disease, livestock and crop production, seasonal flooding, and scarcity of water were underlined as climate change impacts (Figure 3). Both livestock and crop production have been severely affected which led to food insecurity among smallholder farmers. Notably 31% of the respondents clearly indicated that climate change and variability has brought reduction in crop and livestock productivity. They indicated that the reduction of crops yield is associated with late onset and early cessation of the rainy season makes the smallholders not to cultivate the crops properly. With respect to livestock, productivity has become often low due to extended drought and scarcity of water and feed.

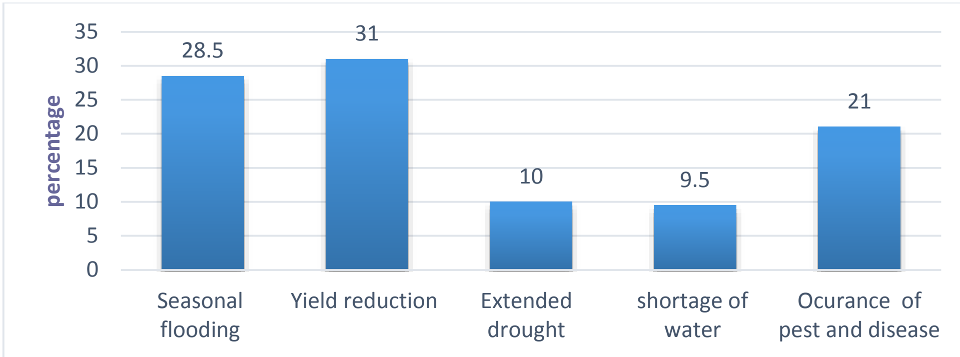


Figure 3. Perceived Impact of climate change on smallholder farming activities in the study area.

3.3 Climate Change Adaptation Strategies by Smallholder Farmers

Smallholders have been practicing diverse strategies to adapt to climate change. Among the adaptation strategies practiced by smallholder farmers in the study area, crop diversification stands first (Table 3). About 23% of the households have been practicing crop diversification as a response strategy, whereas only a few respondents (5%) have been practicing irrigation as an adaptation strategy. The fact that majority of the households practice crop diversification as an adaptation strategy is due to the help of extension services. Farmer-to-farmer communication was also reported as an important source of information for diversification of adaptation strategies. In contrast, the minority (3%) of the households used irrigation for adaptation of climate change due to limited access, capital and technology to ground and surface water. Next to crop diversification, on farm tree planting is practiced for providing natural shades and source of fodder for livestock. Soil and water conservation has been practiced for long and now the extent is increasing from time to time which is used to avoid the risk of flooding as well as improving soil moisture retention.

Table 3. The proportion of respondents that practised primary adaptation strategies to climate change.

Adaptation strategies	Number of households	% of households
Change in planting date	20	10
Crop diversification	45	23
Intensive use of agricultural inputs	29	14
Crop and livestock integration	16	8
Supplementary irrigation	5	3
Soil and water conservation	23	11
Tree planting	32	16
No adaptation strategy	30	15
Total	200	100

The adaptation strategies practiced in Arsi Negele district were both self-directed and planned (Table 3). The self-directed climate change adaptation strategies are those that were initiated by the smallholders and practiced using indigenous knowledge (Stern, 2006). For instance, farmers practiced crop diversification, planted trees using their indigenous knowledge and changing planting dates based on their experience. However, only few farmers have practiced irrigation autonomously. On the contrary, policy driven climate change adaptation strategies were those planned interventions organized by the government and NGOs (Measham *et al.*, 2011).

In this regard, the role of government and NGOs in supporting soil and water conservation activities, tree planting, providing improved varieties and agricultural inputs, providing information on weather forecasts is exemplary.

The adaptation strategies practiced vary across agro-ecologies. The results showed that the lowland part of Arsi Negelle district was more vulnerable to climate variability and change as manifested through water scarcity and extended drought period. Integrating crop and livestock production, changing planting dates, and changing crop varieties/short rotation crop were practiced as adaption strategy. In the case of extreme drought, the farmers also commonly make temporary migration to the highlands areas. In rare cases, irrigation was also being practiced. Similarly, in the highlands, smallholder farmers have used various adaptation strategies such as intensification of agricultural production, fruit and fodder tree planting, soil and water conservation, using crop residues as livestock feed and introducing Enset (*Ensete ventricosum*) crops for both source of food and feed which is in line with other studies (Adger *et al*., 2003; Melka *et al*., 2015; Mukheibir and Ziervogel, 2007; McCarthy *et al*., 2011; Belay *et al*., 2013; FAO, 2013).

Farmers faced constraints for climate change adaptation. For instance, 11% and 17% of the respondents reported shortage of money and low level education as their constraints to adapt climate change, respectively. Lack of climate forecasting information, limited irrigation, poor extension services and shortage of land and labour were primary constraints for climate change adaptation (Table 4).

Table 4. Farmers primary constraints to climate change adaptation.

List of constraints	Total number of respondents	Respondents in %
Lack of climate forecasting information	18	9
Poor potential for irrigation	22	11
Lack of contact with extension personnel	10	5
Shortage of farm land	14	7
Shortage of labour to implement adaptation	28	14
Exposure or access to mass media	26	13
Shortage of necessary farm inputs	26	13
Low level of education	34	17
Shortage of money	22	11
Total	200	100

4. Conclusion and Recommendations

The study examined how smallholder farmers in Arsi Negelle district experienced climate change and how they adapt to the risks. The majority of the smallholders have already perceived change and experienced impacts owing to increase in temperature and decline in precipitation. Across the agro-ecologies, extended dry periods and declining precipitation were more frequent as a result, both livestock and crop production have been adversely affected. It was found that coping with extreme climate conditions in the study area has been practiced over two decades and diverse climate change adaptation strategies have been identified. Tree planting, soil and water conservation, adjustment of planting period, crop diversification, and intensification of agricultural inputs were practiced as adaptation strategies. At present, however, the extent of the problem has been severe which needs institutional, policy, and technology support. Moreover, creating opportunities for non-farm income sources is important to enhance income generation. Furthermore, providing climate change information, extension services and creating access to markets are important. Therefore, including these adaptation strategies in the existing formal extension channels of the Ministry of Agriculture and other line ministries will be useful to farmers.

5. Acknowledgment

The authors are grateful for the financial support from the Department for International Development (DfID) under the Climate Impact Research Capacity and Leadership Enhancement (CIRCLE) programme. They are also grateful to the International Livestock Research Institute (ILRI), for hosting the CIRCLE Fellow within the CGIAR Research Programme for Climate Change, Agriculture and Food Security (CCAFS). Wondo Genet College of Forestry and Natural Resource, Hawassa University are also acknowledged for providing support during the field work.

6. References

Ababa, A. 2007. Climate Change National Adaptation Programme of Action (NAPA) of Ethiopia. National Meteorological Services Agency, Ministry of Water Resources, Federal Democratic Republic of Ethiopia, Addis Ababa.

Adger, W. N., Huq, S., Brown, K., Conway, D., & Hulme, M. 2003. Adaptation to climate change in the developing world. Progress in development studies, 3(3), 179-195.

Agrawal, A. 2010. Local institutions and adaptation to climate change. Social dimensions of climate change: Equity and vulnerability in a warming world. The world bank, 173-198.

Amsalu, A., & Gebremichael, D. 2010. An Overview of Climate Change Impacts and Responses in Ethiopia in 2009. In Forum for Environment: Addis Ababa, Ethiopia.

Anderson, S., Morton, J., & Toulmin, C. 2010. Climate change for agrarian societies in drylands: implications and future pathways. Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World. *The world Bank*, 199-230.

Bankoff, G. 1999. A history of poverty: the politics of natural disasters in the Philippines, 1985–95. *The Pacific Review*, 12(3): 381-420.

Belay, A., Bekele, T., & Ewunetu, Z. 2013. Analysis of climate variability and its economic impact on agricultural crops: The case of Arsi Negelle District, Central Rift Valley of Ethiopia. Open Science Repository Agriculture, doi:10.7392/openaccess.70081993.

Bezabih E, Hadera G and Nigatu R. 2010. Impacts of Improved Seeds and Agrochemicals on Food Security and Environment in the Rift Valley of Ethiopia: Implications for the Application of an African Green Revolution: Dry lands Coordination Group Report No. 56 02, 2010, DCG c/o, MiljøhusetG9. Norway. Oslo.

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R., Yanda, P. 2007. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Africa. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge UK, pp. 433–467.

CSA. 2007. Summary and statistical agency report of population and housing census: Addis Ababa, Ethiopia.

Dasgupta, P., J.F. Morton, D. Dodman, B. Karapinar, F. Meza, M.G. Rivera-Ferre, A. Toure Sarr, and K.E. Vincent, (2014) Rural areas. In: Climate Change. 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 613-657.

Deressa, T.T., Hassan, R.M., Ringler, C., Alemu, T., and Yesuf, M. 2009. Determinants of Farmers' choice of adaptation methods to Climate change in the Nile Basin of Ethiopia. Global Environmental Change19, doi: 10.1016/j.gloenvcha.2009.01.002.

Gebeyehu, S. M., Mwilawa, K., Rijal, A., Subramaniam, K., & S Weili, L. 2002. Food insecurity in a bread basket. Food security among households in the different agro-ecological zones in Arsi Negele Woreda, Ethiopia. ICRA, Wageningen (Países Bajos) Ethiopian Agricultural Research Organization, Nazareth, Ethiopia.

IPCC. 2007. Metz, B.; Davidson, O.R.; Bosch, P.R.; Dave, R.; and Meyer, L.A., ed. Climate Change. 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

IPCC. 2014. Field, C.B., *et al.*, ed., Climate Change. 2014. Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II (WG2) to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press.

McCarthy, N., Lipper, L., & Branca, G. 2011. Climate-smart agriculture: smallholder adoption and implications for climate change adaptation and mitigation. Mitigation of Climate Change in Agriculture Working Paper, 3, 1-37.

Measham, T. G., Preston, B. L., Smith, T. F., Brooke, C., Gorddard, R., Withycombe, G., & Morrison, C. 2011. Adapting to climate change through local municipal planning: barriers and challenges. Mitigation and Adaptation Strategies for Global Change. *Springer*, 16(8), 889-909.

Mearns, R., & Norton, A. (Eds.). 2010. Social dimensions of climate change: equity and vulnerability in a warming world. World Bank Publications.

Melka, Y., Kassa, H., Ketema, M., Abebaw, D., & Schmiedel, U. 2015. The effect of drought risk perception on local people coping decisions in the Central Rift Valley of Ethiopia. *Journal of Development and Agricultural Economics*, 7(9), 292-302.

Midzuno, H. 1951. On the sampling system with probability proportionate to sum of sizes. Annals of the Institute of Statistical Mathematics. *Springer*, 3(1), 99-107.

Morton, J. 2007. "The impact of climate change on smallholder and subsistence agriculture" Proceedings of the National Academy of Sciences 104:19680-19685.

Mukheibir, P., & Ziervogel, G. 2007. Developing a Municipal Adaptation Plan (MAP) for climate change: the city of Cape Town. *Environment and Urbanization*, 19(1), 143-158.

Neuman, W. L. 2005. Social research methods: Quantitative and qualitative approaches (Vol. 13, pp. 26-28). Boston, MA: Allyn and bacon.

Nhemachena and Hassan, C. 2008. Determinants of African farmers' strategies for adapting to climate change: multinomial choice analysis. African Journal of Agricultural and Resource Economics, 2 (1), 83–104.

Niang, I., O.C. Ruppel, M.A. Abdrabo, A. Essel, C. Lennard, J. Padgham, and P. Urquhart. 2014. Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1199-1265.

NMSA. (2001) Initial National Communication of Ethiopia to the UNFCCC. National Meteorological Service Agency (NMSA), Addis Ababa, Ethiopia.

ORS. (The Oromia Regional State government). 2004. Socio Economic Profile of East Shoa Zone. Addis Ababa, Ethiopia.

Otto, F. E., Boyd, E., Jones, R. G., Cornforth, R. J., James, R., Parker, H. R., & Allen, M. R. 2015 Attribution of extreme weather events in Africa: a preliminary exploration of the science and policy implications. Climatic Change. *Springer*, 132(4), 531-543.

Stern, N. H. 2006. Stern Review: The economics of climate change (Vol. 30). London: HM treasury.

Webb, P., Von Braun, J., & Yohannes, Y. 1992. Famine in Ethiopia: policy implications of coping failure at national and household levels (Vol. 92). Intl Food Policy Res Inst.

Yesuf, M., Di Falco, S., Deressa, T., Ringler, C., & Kohlin, G. 2008. The impact of climate change and adaptation on food production in low-income countries: evidence from the Nile Basin, Ethiopia. Intl Food Policy Res Inst.

2. Impacts of Climate Change on Food Security and its Adaptation and Mitigation Options in Ethiopia: A Review

Tadesse Alemu[1]* and Alemayehu Mengistu[2]

[1]Center for Environmental Science, Addis Ababa University, Ethiopia

[2]Pasture and Range Scientist, P. O. Box, 62291, Urael Branch, Addis Ababa, Ethiopia

*Corresponding Author Email: tadese07@yahoo.com

Abstract

Climate change affects the rainfall pattern, rises temperature, increases the potential for soil erosion, reduces soil quality, lowers agricultural productivity, and hence negatively affects food security. The poorest and most vulnerable people are the worst affected by climate change. Systematic analysis of published articles showed that African countries like Ethiopia are vulnerable to climate change because their economies largely depend on climate-sensitive agriculture. Environmental changes, such as changes in water availability and land cover change, and altered nitrogen availability and cycling have increased concerns about achieving food security. Growth and Transformation Plan (GTP) recognized climate change as one of the threats and opportunities for Ethiopia. GTP stipulates the country's ambition to build a climate resilient green economy by 2030. Climate change impacts on agriculture in Ethiopia depends on changes in temperature, precipitation, and climate variability (such as erratic rainfall, floods and droughts). The complex interaction of these factors makes it difficult to predict the impacts of climate change at regional level. Achieving food security and reducing poverty in Ethiopia has been a major challenge for both government and development agencies. Ethiopia's Programme of Adaptation to Climate Change (EPACC) identifies adaptation and mitigation strategies in the various sectors including cloud seeding, crop and livestock insurance mechanisms, grain storage, societal reorganization, renewable energy, gender equality, factoring disability, research and development, and capacity building. The policies and strategies emphasized on the need to integrate the different sectors depending on water-rain fed and irrigated agriculture, livestock, fisheries, forestry, water and soil conservation and biodiversity management. An integrated, evidence-based and transformative approach to address food security and climate resilience at all levels requires coordinated actions.

Keywords: Adaptation and mitigation options; Climate change; Greenhouse gases; Livestock technologies

1. Introduction

Evidence from the Intergovernmental Panel on Climate Change (IPCC) is now overwhelmingly convincing that climate change will become worse, and that the poorest and most vulnerable people will be the worst affected (IPCC, 2007). The IPCC (2014) predicts that by 2100 the increase in global average surface temperature may be between 1.8°C and 4.0°C. With increases of 1.5°C to 2.5°C, approximately 20 to 30 % of plant and animal species are expected to be at risk of extinction (FAO, 2007) with severe consequences for food security in developing countries (IPCC, 2007; Shigdaf *et al*., 2014). The Fifth Assessment Report (AR5) produced by IPCC and the COP 24 recommendations also call from action not only from the government, but also from various stakeholders.

Climate change affects agriculture and food production in complex ways. It affects food production directly through changes in agro-climatic conditions (e.g., changes in rainfall leading to drought or flooding, or warmer or cooler temperatures leading to changes in the length of growing season), and indirectly by affecting growth and distribution of incomes, and thus demand for agricultural products (Gregory *et al*., 2008). Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (IPCC, 2007). Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases: the average temperature rose by about 0.3°C during the first half of the 20^{th} century, and by another 0.5°C in the second half up to the beginning of the 21^{st} century. Most of the observed increase in global average temperatures since the mid-20^{th} century is very likely due to the observed increase in anthropogenic GHG concentrations.

Food security is a situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 2002). The links between climate change and food security have, to date, largely been explored in relation to impacts on crop productivity and hence, food production. For instance, Gregory *et al.* (2002, 2008) reported on wheat and rice which indicated decreased crop duration (and hence yield) of wheat as a consequence of warming and reductions in yields of rice of about 5% $°C^{-1}$ rise above 32°C.

Climate change will act as a multiplier of existing threats to food security; it will make natural disasters more frequent and intense, land and water more scarce and difficult to access, and increases in productivity even harder to achieve. The implications of climate change for people who are poor and already food insecure and malnourished are immense (Gregory *et al*., 2008; UNFCCC, 2009).

It is clear that the magnitude and rate of projected changes will require adaptation. Actions towards adaptation fall into two broad overlapping areas: (1) better management of agricultural risk associated with increasing climate variability and extreme events, for example using climate smart agriculture, improving climate information services, and safety nets, and (2) accelerated adaptation to progressive climate change over decadal time scales, for example integrated packages of technology, agronomy and policy options for smallholder farmers and food systems (Leslie, 2015). Maximization of agriculture's adaptation and mitigation potential will require, among others, investments in technological innovation and agricultural intensification linked to increased efficiency of inputs, and creation of incentives and monitoring systems that are inclusive of smallholder farmers. A systematic review was used to analyse the published articles, policy documents, and international climate change reports. This paper was initiated to review the impacts of climate change on food security and adaptation and mitigation options in Ethiopia.

2. Results and Discussion

2.1. Impacts of Climate Change in Africa

Africa is the continent that has been hardest by climate change. Unpredictable rains and floods, prolonged droughts, subsequent crop failures, and rapid desertification, among other were signs of global warming, have in fact already begun to change the face of Africa (Gregory *et al.,* 2008; Thornton *et al*., 2008). We can no longer consider climate change is a threat that is yet to hit us; all over the world, we see its impact (Aklilu and Dereje, 2009). The predictions showed that Africa will face serious challenges given the expected climate change impacts. Temperatures are expected to increase across the continent, which will lead to increased plant stress and increased risks of drought. Over the past 130 years, the mean global temperature appears to have risen 0.6 to 1.2°F (0.3 to 0.7°C) (Figure 1). Rainfall is expected to decline significantly in southern Africa, and the North African region, including the Sahara Desert (Aklilu and Dereje, 2009). East Africa is expected to become wetter, with the rains falling in more intense storms, causing greater risks of flooding. The models show mixed results for what is likely to happen to West Africa's rainfall (Aklilu and Dereje, 2009). Although climate change is a threat to all countries, developing countries are most vulnerable. The World Bank (2006) estimates that they will have to shoulder some 75 to 80% of the costs of damages caused. A global 2°C warming above pre-industrial temperatures could result in permanent reductions in GDP of 4 to 5% for Africa. The African continent has been warmed by about 0.5°C in the last century. This century, average annual temperatures are projected to rise by 3 to 4°C (IPCC, 2007). Climate models predict that many arid areas will become drier and humid areas wetter.

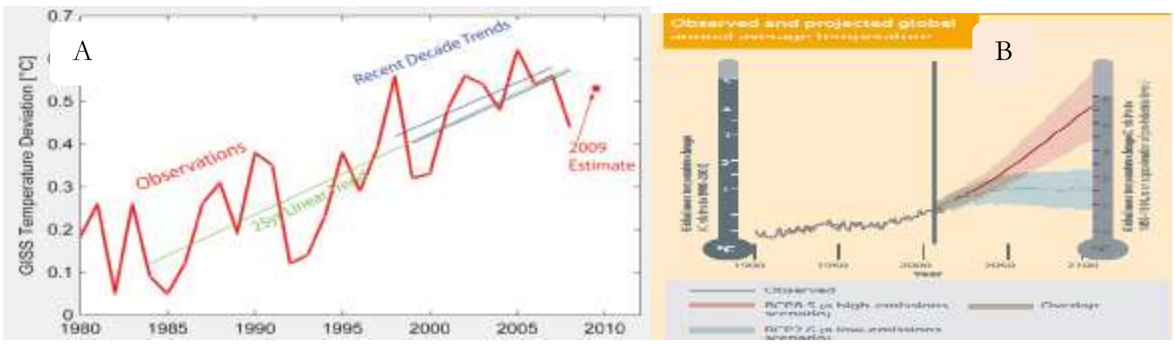


Figure. 1. Global temperature A) 0.2 °C increase in each decades B) future scenarios.

The impacts of climate change across Africa will vary**:** At mid to high latitudes, crop productivity may increase slightly for local mean temperature increases of up to 1 to 3°C, depending on the crop; while at lower latitudes, crop productivity is projected to decrease for even relatively small local temperature increases (1-2°C) (IPCC, 2007). In the tropics and subtropics in general, crop yields may fall by 10–20% by 2050 because of warming and drying; but there are places where yield losses may be much more severe (Thornton *et al.*, 2008). Climate change affects productivity of agricultural products and as a result, major changes can be anticipated in livestock systems, related to livestock species mixes, crops grown, and feed resources and feeding strategies (Anderson *et al.,* 2010).

There are 300 million poor people in sub-Saharan Africa. Africa's population is projected to grow from 0.9 billion people in 2005 to nearly 2 billion by 2050. Projections indicate an increase of arid and semiarid lands, and, in some countries, yield reductions in rain-fed agriculture of up to 50 % by 2020; but some parts will also get wetter (Anderson *et al.,* 2010). Therefore, failure to manage agricultural climate change adaptation will cause a sharp decline in food production, increments in famine, and unprecedented setbacks in the fight against poverty in developing countries. Adapting agriculture to climate change is the key to food security in the 21st century in Africa.

2.2. Climate Change in the Context of Ethiopia

2.2.1. Influence of climate change on temperature and rainfall

In Ethiopia, climate change is already taking place now. Thus, past and present changes help in indicating possible future changes. Over the last decades, the temperature in Ethiopia increased by about 0.2°C per decade. The increase in minimum temperatures is more pronounced with roughly 0.4°C per decade (Alemayehu, 2008; Daniel, 2008). The temperature will very likely continue to increase for the next few decades with the rate of change as observed (Daniel, 2008; Alemayehu, 2008; Alemayehu and Shigdaf, 2014; IPCC, 2014).

The average annual volume of rainfall over the previous 50 years (from 1951-2000) remained more or less constant for the whole country (NMSA, 2001). However, Koresha (2014) concluded that mean annual rainfall showed a slightly decreasing trend and an increasing year to year variation was observed in 1951 to 2010. Rainfall distribution across the country showed a marked difference. There was a tendency for less rain to fall in the northern part of the country where there is already massive environmental degradation. The same trend can be observed in the southeast and northeast of the country, both often affected by drought. However, in central Ethiopia where most of the population and the country's livestock are located and the soil is severely depleted and degraded, more rain fell. The western and north-western parts of the country also received more rain (Alemayehu, 2008; UNDP, 2009). Farmers and pastoralists are experiencing that the rain is becoming more unpredictable or is failing to appear at all. In some places, the rain falls more heavily and the degraded soil is unable to absorb this rain which falls over a shorter period of time. According to Daniel (2008), the farmers in the central part of the country have lost up to 150 tons of soil per hectare. In the central part of the country, more rain will mean further erosion of the soil and lower crop yields for smallholder farmers, leading to flooding in the more low lying areas. Ethiopia loses three billion tons of top soil annually due to erosion caused by heavy rainfall.

It is not only the rainfall distribution that has changed but also the temperature that has become warmer in the last 55 years. The minimum temperature has increased by approximately 0.37^{O}C per decade between 1950 and 2006 (Daniel, 2008). The rise in temperature and fluctuations in rainfall create many problems for the pastoralists who live in the already drought-stricken areas which are receiving less and less rain. They have already switched from cattle to goats and camels since the latter are able to endure long periods of drought than the former. Climate change can affect how long the farmers have to grow their crops. In addition, warmer weather provides better growing conditions for emerging pests and diseases that attack crops and destroy farmers' harvests (Alemayehu, 2008; Daniel, 2008; Temesgen *et. al*, 2008). Therefore, these situations have created high demands for improved crops and varieties that are more drought resistant, and early maturing as the rains have become more unpredictable and shorter in some places.

2.2.2. Impacts of climate change on various sector

Today the forest cover is very low. As a result, the soil has become more vulnerable to erosion. People cut down the forest to expand farmland and to harvest firewood for cooking. Ethiopia's explosive population growth is aggravating the situation. If population growth continues at the same pace, Ethiopia's current population of 90 million people will double by 2045. Population growth will put pressure on the already degraded soil, and hence marginal plots will be brought into use worsening the situation (Alemayehu, 2008; Temesgen *et. al*, 2008; Alemayehu and Shigdaf, 2014).

Table 1. Sectoral Impacts of Climate Change in Ethiopia

Sector	Potential impacts
Crop farming	• Shortening of maturity period, crop failure and expanding crop diseases
Livestock	• Change in livestock feed availability and quality • Effect on animal health, growth, and reproduction • Impact on forage crops quality and quantity • Change in distribution of diseases, decomposition rate, income and price • Contracting pastoral zones in many parts of the country
Forests	• Expansion of tropical dry forests and bushland • Loss of indigenous species and expansion of toxic weeds
Water resources	• Decrease in river run-off and energy production • Flood and drought impacts
Health	• Expansion of malaria and other diseases to highland areas • Threat from expanding endemic diseases and newly emerging diseases of human, plant, and livestock
Wildlife	• Shift in physiological response of individual organisms • Shift in species distribution and biomass • Shift in genetic make-up of populations • Out migration, of endemic and threatened species
Environment	• Reduced productive capacity from degradation of forests, range, and water recourses • Desertification • Loss of key wetland and breeding sites

Source: Alemayehu (2008) and Alemayehu and Shigdaf (2014)

2.3. Implications of Climate Change on Agriculture and Food Security

The impact of climate change was assessed in terms of its effect on crop and livestock farming and how these effects extend throughout Ethiopia. According to IPCC's 5th report, climate change impacts in East Africa will increase risk of food insecurity and leads to a breakdown of food systems, increase risks of loss of rural livelihoods and income due to insufficient access to drinking and irrigation water and reduced agricultural productivity, particularly for farmers and pastoralists with minimal capital in semi-arid regions. Risks due to extreme weather events leading to breakdown of infrastructure networks and critical services such as electricity, water supply, and health and emergency services are also linked to these areas of concern (IPCC, 2013).

The overall effect of climate change on yields of major cereal crops in the African region is very likely to be negative, with strong regional variation (Niang *et al.,* 2014). At even relatively low levels of warming of 1 to 2^{0}C, many unique natural systems are threatened and food productivity, human health and water resources could be negatively impacted. "Worst-case" projections (5th %ile) indicated losses of 27–32% for maize, sorghum, millet and groundnut for a warming of about 2^{0}C above pre-industrial levels by mid-century. The IPCC concluded that large-scale warming, of around 4°C or above, will increase the likelihood of severe, pervasive, and irreversible impacts to which it will be difficult to adapt.

Achieving food security and reducing poverty in Ethiopia has been a major challenge for both governments and development agencies due to the result of many factors, some of which are: (1) land degradation and nutrient depletion; (2) rapid population growth (3) low and inappropriate use of technologies such as improved varieties, fertilizers, mechanization and irrigation that have stimulated agricultural development elsewhere in the world (Daniel, 2008; Mekuriaw *et al.*, 2008). According to Zenebe (2011) the no-total factor productivity (TFP) growth scenarios, the outcome is considerably bleaker (Figure 2). Since the effects of climate change on agriculture is positive in the main moisture sufficient regions to begin with, income increases faster with climate change than without it. However, as the effects of climate change on agriculture become negative, incomes drop off considerably. At the end of the projection period, because of climate change, average incomes will be lower than at the beginning of the period, despite the capital accumulation, which takes place in the meantime. In the no-TFP-growth scenario, climate change also leads to a loss of 30% of income, compared to the no-climate-change baseline.

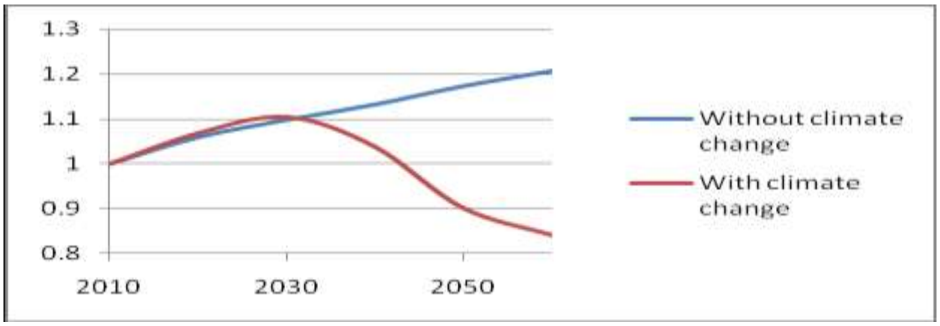


Figure 2. GDP per Capita with No TFP Growth Scenarios (Zenebe *et al.,* 2011).

According to the World Bank (2006), droughts and floods are very common phenomena in Ethiopia with significant events occurring every three to five years. The country has experienced six major national droughts since the 1980s, along with dozens of local droughts. Over the years, the frequency of droughts and floods has increased in many areas resulting in loss of lives and livelihoods (Mesfin, 1984). Climate change is expected to exacerbate the problem of rainfall variability and associated droughts and flood disasters in Ethiopia (NMA, 2006; Aklilu and Alebachew, 2009; World Bank, 2009; UN-ISDR, 2010).

2.4. Climate Change Adaptation and Mitigation in Ethiopia

2.4.1. The need for mainstreaming climate change issues in Ethiopia

Ethiopian Programme of Adaptation to Climate Change (EPACC) strategy adequately understood climate change as a growing threat in Ethiopia and clearly elaborate the need to mainstream climate change in all spheres of development policy making, planning, and implementation processes. There are a number of reasons why Ethiopia should be concerned about climate change. The country's vital natural resources, namely, water, forest, rangeland, agricultural land, biodiversity, energy, etc., are very much the reflection of the historical climate. Agriculture and agro-forestry, which are the main sources of livelihood to rural majority and the backbone of the country's economy, are sensitive to climate variations. Recurrent drought, unseasoned flooding and livestock and crop diseases are also the main challenges in the country. Climate changes have already started appearing in Ethiopia in the last 50 years (NMA, 2006). Hence, addressing current and future climate vulnerabilities in development planning and programming should be an immediate priority to Ethiopia (Alemayehu, 2008; Alebachew and Woldeamlak, 2011).

As a party to the UNFCCC, Ethiopia is obliged by the convention to address climate change through the preparation of a national adaptation document and the integration of climate change into its sectoral development plans, policies, and strategies. The National Adaptation Programme of Action **(**NAPA), prepared in 2007, represents the first step in coordinating adaptation activities across government sectors, but was not intended to be a long-term strategy in itself. Ethiopia's NAPA projects are currently 'on hold' whilst international adaptation funding mechanisms are under negotiation (Alebachew and Woldeamlak, 2011).

2.4.2. Ethiopia's programme of adaptation to climate change (EPACC)

The Federal Environmental Protection Authority (EPA) of Ethiopia developed a separate programme for action on adaptation to climate change. The document interlinks climate change adaptation strongly with the economic development and physical survival of the country. The main objective of Ethiopia's Programme of Adaptation to Climate Change (EPACC) is to create the foundation for a carbon-neutral and climate-resilient path towards sustainable development in the country. According to this programme, climate change will be implemented by the communities at local and district levels (NMA, 2006; Alebachew and Woldeamlak, 2011). The climate risks identified by EPACC are broadly in the areas of human, animal and crop diseases, land degradation, loss of biodiversity, decline in agricultural production, dwindling water supply, social inequality, urban waste accumulation, and displacement due to environmental stress and food insecurity. The programme identifies adaptation strategies and options in the various socioeconomic sectors including cloud seeding, crop and livestock insurance mechanisms, grain storage, societal reorganization, renewable energy, gender equality, factoring disability, climate change adaptation education, capacity building, research and development, and enhancing institutional capacity and the political momentum (NMA, 2006). The programme clearly explains the need to mainstream climate change in all spheres of development policy making and planning at all phases and stages of the planning and implementation process and the urgency of taking practical adaptation and mitigation actions in the various sectors.

2.4.3. Climate resilient green economy (CRGE) of Ethiopia

Although international climate negotiations have made little progress, Ethiopia has started the race towards low-carbon development. Low-Carbon Development Plans (LCDPs) have been developed to lay foundations for overall sustainable development planning of the country. In fact, aggregate climate change mitigation commitments are still far apart from a level of ambition that effectively creates a realistic chance of limiting global warming to a maximum of 2°C or possibly even lower. Many developing countries including Ethiopia seem to have already begun this process. In this regard, Ethiopia can be an example for implementing a new national strategic framework for a smooth transition to a climate resilient green economy by 2030. A CRGE is a long-term ambition of Ethiopia. The mission statement developed to facilitate the development of the Ethiopian CRGE strategy sets out a five-step roadmap for moving towards a climate resilient low carbon economy. The roadmap identified the need for more work on Ethiopia's climate change institutions, monitoring and finance systems and sectoral and regional action plans. When combined, the work is expected to enable the EPA to draft a CRGE Strategy which will identify a clear path to the goal of a climate resilient green economy by 2030 (Alebachew and Woldeamlak, 2011).

2.4.4. Climate change adaptation and mitigation options

Climate Smart Agriculture (CSA) is an approach that helps to guide actions needed to transform reorient agricultural system to effectively support development and ensure food security in the changing climate. CSA aims to tackle three main objectives: increase agricultural production and income sustainably; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions, where possible (IPCC, 2013). The proposed CSA practices are aimed at promoting efficient use of land, water, soil & other environmental resources. CSA promotes coordinated actions by farmers, researchers, private sector, civil society, and policymakers towards climate-resilient pathways through four main action areas: (1) building evidence; (2) increasing local institutional effectiveness; (3) fostering coherence between climate and agricultural policies; and (4) linking climate and agricultural financing.

CSA differs from 'business-as-usual' approaches by emphasizing the capacity to implement flexible, context-specific solutions, supported by innovative policy and financing actions. It emphasizes agricultural systems that utilize ecosystem services to support productivity, adaptation, and mitigation. Examples include integrated crop, livestock, aquaculture and agroforestry systems; improved pest, water and nutrient management; landscape approaches; improved grassland and forestry management; practices such as reduced tillage and use of diverse varieties and breeds; integrating trees into agricultural systems; restoring degraded lands; improving the efficiency of water and nitrogen fertilizer use; and manure management, including the use of anaerobic bio-digesters (Leslie *et al.,* 2015).

Enhancing soil quality can generate production, adaptation and mitigation benefits by regulating carbon, oxygen and plant nutrient cycles, leading to enhanced resilience to drought and flooding, and to carbon sequestration (Leslie *et al.,* 2015). Building resilience means reducing the risk of becoming food insecure and increasing the adaptive capacity to cope with risks and respond to change (Gitz and Meybeck, 2012). Transformative changes can involve major shifts in agricultural production (for example from crops to livestock) or sources of livelihoods (increased reliance on non-farm income) (Leslie *et al.,* 2015).

3. Conclusions and Recommendations

Many studies indicated that climate change is real, that it will become worse, and that the poorest and most vulnerable people will be the worst affected. Agriculture dominates Ethiopia's economy and any climate-change impacts on agriculture will be considerable in the coming decades. Climate change affects agriculture and hence food security directly through changing agro-climatic conditions and indirectly by affecting growth and distribution of incomes. Environmental changes, such as changes in water availability and land cover, altered nitrogen availability and cycling has increased concerns about achieving food security. These problems are further intensified by climate change. Shifts in rainfall and rise in temperature will bring major impacts in terms of crop and livestock feed yields, water availability, disease incidence and flood damage. CSA strategies for adaptation and mitigation options such as carbon-sequestration practices involving reduced tillage, increased crop cover, including agro-forestry, and use of improved rotation systems are needed. This transition to CSA will have to be improved by active adaptation policies on the part of the government and will surely need outside support. The countries Green Economy Policies and Strategies integrate the different sectors depending on water-based integrated agriculture, fisheries, forestry, water and soil conservation and biodiversity management. An integrated, evidence based and transformative approaches to addressing food security and climate resilience at all levels require coordinated actions from national to local levels, from research to policies, and investment and across private, public and civil society sectors to achieve the sale and rate of change required. With the right site specific practices, policies and investments, the agriculture sector can move on to CSA pathways resulting in improved food security and decrease in poverty in the short term while contributing to reducing climate change as a threat to food security over a longer term.

As a final recommendation, urgent action from public, private and civil society stakeholders at all levels is required in four areas: (1) building evidence and assessment tools; (2) strengthening national and local institutions; (3) developing coordinated and evidence-based policies; and (4) increasing financing and its effectiveness. The current evidence base is inadequate to support effective decision-making, and largely inaccessible to decision-makers at the national and local levels. The spatial and temporal scales of much work addressing climate change impacts on agriculture are not appropriate for national and local level planning. Tools are needed for evaluating the adaptation and mitigation potential of different policies and technologies, covering the impacts of both extreme events and slow-onset changes on agriculture and food security, assessing means of increasing resilience in agriculture and food systems, and identifying options for, and costs of reducing emission growth.

4. References

Aklilu Amsalu & Alebachew Adem. 2009. Assessment of climate change-induced hazards, impacts and responses in the southern lowlands of Ethiopia. *Forum for Social Studies (FSS) Research Report No. 4*. Addis Ababa, Ethiopia.

Aklilu Amsalu & Dereje Gebremichael. 2009. An overview of climate change impacts and responses in Ethiopia.

Alebachew Adem and Woldeamlak Bewket. 2011. Climate Change Country Assessment, Ethiopia, Epsilon International R&D.

Alemayehu Mengistu. 2008. Climate Variability and Change. *Eth. J. Anim. Pro.* 8 (1): 94-98.

Alemayehu Mengistu and Shigdaf Mekuriaw. 2014. Challenges and Opportunities for Carbon Sequestration in Grassland System: A Review. *International Journal of Environmental Engineering and Natural Resources* 1 (1): 1-12.

Anderson S., Gundel S. and Vanni M. 2010. The impacts of climate change on food security in Africa: A synthesis of policy issues for Europe.

Daniel Kassahun. 2008. Impacts of climate change on Ethiopia: a review of the literature, pp 9–35. In: Green Forum (ed.), Climate change – a burning issue for Ethiopia.

FAO. 2002. The State of Food Insecurity in the World 2001, Food and Agriculture Organization, Rome.

FAO. 2007. Viale delle Terme di Caracalla, 00153 Rome, Italy.

Gitz, V. & Meybeck, A. 2012. *Risks, Vulnerabilities and Resilience in a Context of Climate Change*.

Gregory P.J, *et al.* 2002. Environmental consequences of alternative practices for intensifying crop production. *Agric. Ecosyst. Environ.* 88: 279–290. doi:10.1016/S0167-8809(01)00263-8.

Gregory, P.J, Ingram J.S.I. and Brklacich M. 2008. The impacts of climate change on food security in Africa.

IPCC. 2007. Climate Change: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge Univ Press, Cambridge, UK), in press.

IPCC. 2013. Climate-Smart Agriculture Sourcebook Executive Summary (Food and Agriculture Organization of the United Nations)

IPCC. *2014a*. Summary for Policymakers *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectorial Aspects* (eds Field, C. B. *et al.*) (Cambridge Univ. Press, 2014).

IPCC. 2014b. *Climate Change: Mitigation of Climate Change* (eds Edenhofer, O. *et al.*) 29, note 4 (Cambridge Univ. Press, 2014)

Leslie L., Philip T., Bruce M.C., Tobias B., Ademola B., Martin B. *et al.* 2015. Climate-smart agriculture for food security. *Nature Climate Change Perspective.* doi:10.1038/nclimate2437.

Mekuriaw S, Tegegn F, Mengistu A. 2008. A review on reduction of greenhouse gas emission from ruminants through nutritional strategies. *Acad. J. Environ. Sci.* 2(1): 006-014.

Mesfin W. 1984. Rural vulnerability to famine in Ethiopia 1958 – 1977. New Delhi: Vikas Publisher.

Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J., Urquhart, P. 2014. Africa. In: Climate change 2014: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

NMA. 2006. National Adaptation Programme of Action of Ethiopia (NAPA). Addis Ababa.

NMSA (National Meteorological Services Agency). 2001. Initial national communication of Ethiopia to the UNFCCC. Addis Ababa.

Shigdaf Mekuriaw, Firew Tegegn and Alemayehu Mengistu. 2014. A Review on Reduction of Greenhouse Gas Emission from Ruminants through Nutritional Strategies. *Acadamia Journal of Environmental Science,* 2(1): 006-014.

Temesgen Deressa, R. Hassan & C. Ringler. 2008. Measuring Ethiopian farmers' vulnerability to climate change across regional states, IFPRI (International Food Policy Research Institute), Washington DC.

Thornton PK, Jones PG, Owiyo T, Kruska RL, Herrero M, Orindi V, Bhadwal S, Kristjanson P, Notenbaert A, Bekele N and Omolo A. 2008. Climate change and poverty in Africa: Mapping hotspots of vulnerability, African Journal of Agricultural Research and Extension Vol 2 No 1 March 2008.

UNFCCC. 2009. Climate Change, Food Insecurity and Hunger. Technical Paper of the IASC Task Force on Climate Change.

UN-ISDR. 2010. International Strategy for Disaster Reduction (Africa). Country information Ethiopia. http://preventionweb.net/english/countries/africa/eth/.

World Bank. 2006. Ethiopia: Managing water resources to maximize sustainable growth. Country water resources assistance strategy. Washington, DC.

Zenebe Gebreegziabher, Jesper Stage, Alemu Mekonnen, and Atlaw Alemu. 2011. Climate Change and the Ethiopian Economy. A Computable General Equilibrium Analysis.

Theme 3: Forecasting El Niño and Early Warning, Preparedness, and Response Strategies

1. Performance of Global Climate Models in projecting El Niño-Southern Oscillation (ENSO) in Blue Nile and Awash River Basins, Ethiopia

Gebrekidan Worku[1*], Ermias Tefferi[1], and Amare Bantider[2,3]

[1]Center for Environment and Development, Addis Ababa University, Addis Ababa

[2]Center for Food Security Studies, Addis Ababa University, Addis Ababa

[3]Water and Land Resources Centre, Addis Ababa, Addis Ababa

*Corresponding Author Email: gebrekidanw12@gmail.com

Abstract

Evaluation of the performance of Global Climate Models (GCMs) in simulating large-scale patterns and inter-annual variability of precipitation associated with El Niño-Southern Oscillation (ENSO) is pertinent to build robust climate change resilience. Regional and local level projection of precipitation remains difficult requiring due consideration during choice of GCMs. In this study, the performance of IPCC AR5 models in capturing El Niño-Southern Oscillation (ENSO) effects on the precipitation of Blue Nile and Awash River basins was evaluated and better performing GCMs were identified. To maintain the spatial difference, each river basin was divided into three. High spatial resolution (0.5 × 0.5) gridded monthly observed precipitation data was acquired from CRU TS 3.1, the Climatic Research Unit, University of East Anglia for the period 1960–2014. Ensemble of CMIP5, CCSM4, CNRM CM5, CSIRO-Mk3.6 and GFDL-CM3 models outputs were used for evaluation. The observed precipitation and models output were compared and statistically tested using correlation, BIAS and the Root Mean Square Error (RMSE). The results indicated that ensemble of CMIP5 and CNRM-CM5 models were better in capturing ENSO related variability of precipitation, frequency of extremes and inter-annual variability of precipitation of the Blue Nile and Awash River basins. CSIRO-Mk6-0 and CCSM4 models were found to be weak in simulating the observational precipitation of the basins. Regionally, Lower Awash is characterized by large bias by most of the models than regions in the basin.

Keywords: Climate; CMIP5; Error Measures; ENSO and Models

1. Introduction

In climate science, Global Circulation Models (GCMs) are instrumental to assess the relative change in climate system due to an increase in greenhouse gases and make predictions and projections of future climate (IPCC, 2013). Many Global Climate Models were developed by different climate research centres since the 1950s. The Geophysical Fluid Dynamics Laboratory and National Centre for Atmospheric Research (NCAR) of United States, Britain's Hadley Centre, Germany's Max Planck Institute, Japan's Earth Simulator Centre and the Goddard Institute for Space Studies in the United States are the most active climate modelling centres (Blackmon *et al.*, 2001). The establishment of Earth System Modelling Framework (ESMF) which couples atmosphere–ocean GCMs with land surface, the cryosphere, hydrology and vegetation processes is another proliferation in climate modelling (Edwards, 2010).

Since the IPCC AR4, the performance of GCMs in simulating large-scale patterns of precipitation has showed somewhat improvement. The correlation between GCMs and observed annual precipitation has increased from 0.77 during the time of the AR4 to 0.82 for CMIP5 models. Still, simulation of precipitation is simulated less by GCMs and remains difficult at regional scales (Flato *et al.*, 2013). As a result, due concern needs to be given in choosing GCMs for climate change impact assessment. The ability of GCMs to accurately simulate past and current climate is required (Daniels *et al.*, 2012). There are different methods to control climate models uncertainty. Systematic comparison of model output with observed data is considered as a prerequisite to confidently use climate models (Flato *et al.*, 2013; Randall *et al.*, 2007). Beside to this, using multi-model ensemble mean and multiple downscaling methods are the prime strategies to reduce uncertainty (Flato *et al.*, 2013). It is also pertinent to consider the ability of models to simulate inter-annual variability associated with natural climate processes like El Niño-Southern Oscillation (ENSO) is pertinent (Achuta Rao and Sperber, 2006). Since the performance of GCMs in simulating the observed climate varies from place to place, it is needed to calibrate GCMs for each place and time (Masanganise *et al.*, 2013).

In order to use GCMs with greater confidence and less uncertainty, model performance should be evaluated systematically (Perez *et al.*, 2014). Using GCM global-scale simulated variables such as temperature, precipitation, radiation, and others comparison to observations is the simplest technique to assess model performance. Better than this method, there are different statistical approaches ranging from simple descriptive statistics to most robust techniques that are used to test the skill of GCMs in simulating regional and local climate. Masanganise *et al.* (2013) used coefficient of determination (R^2), root mean square error (RMSE) and model efficiency (ME) to evaluate the performances of five GCMs in simulating monthly rainfall, minimum and maximum temperatures in North-eastern Zimbabwe. A Root-mean-square error (RMSE) was used to assess the performance of 15 GCMs in Alaska and Greenland and it is concluded that the root-mean-square errors of single models are much larger than the biases of the ensemble models output (Walsh *et al.*, 2007).

The Blue Nile and Awash River Basins of Ethiopia cover large area and the topography is very diverse. In the region of these river basins, there is little consistency in the relative performance of models in simulating the amount and seasonality of precipitation, inter-annual precipitation variability, precipitation teleconnections, and continental scale climate patterns (Bhattacharjee and Zaitchik, 2015). It is difficult to get single model which properly simulates each of these basins. Therefore, it is important to select GCMs which simulate the climate of Blue Nile and Awash River Basins. This study divided each river basin in to three and models performance evaluation was performed for each region. This study was aimed to identify robust GCMs for each subdivision of river basins and imperfect GCMs that are unable to simulate distinct regional climate characteristics, either spatially or temporally.

2. Materials and Methods

2.1. Description of the Study Area

Blue Nile and Awash River Basins are the major river basins in Ethiopia especially in terms of the total population and agricultural production. These Basins of Ethiopia cover wide climatic zones (from humid subtropical to arid) and many hydroelectric and irrigation development projects are going on with in the basins. The Blue Nile Basin covers an area of 176,000 km^2, while Awash River Basin covers an area of 113 700 km^2 (Hailemariam, 1999; Figure 1).

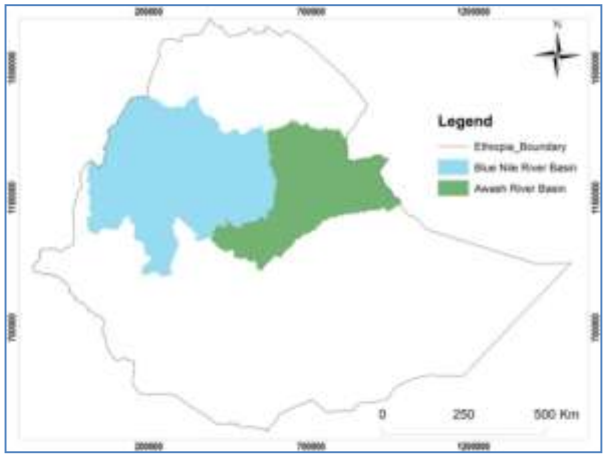


Figure 1. Blue Nile and Awash River Basins in Ethiopia.

2.2. Data Collection

High spatial resolution (0.5 × 0.5*)* gridded monthly observed rainfall data was acquired from CRU TS 3.1, the Climatic Research Unit, University of East Anglia for the period 1960–2014. From the monthly data, seasonal and annual rainfall totals were computed for analysis of the temporal variability. Ensemble of CMIP5 model outputs and five CMIP5 climate models outputs were acquired from Climatic Research Unit, University of East Anglia. RCP4.5 and RCP 8.5 scenarios of all models were considered. For each model, 'historical' daily simulations were used. The daily data was aggregated into monthly, seasonal (June–September (JJAS) and March to May (MAM) and annual rainfall data.

Models used in this study were ensemble of CMIP5, CCSM4 (NCAR, USA), CNRM CM5 of France, CSIRO-Mk3.6 of Australia and GFDL-CM3 of United States. The models have course spatial resolution which ranges from 1^0 to 3^0. The observed rainfall and the GCMs output was compared and statistically tested using correlation, bias and the Root Mean Square Error (RMSE). The RMSE and bias calculations were performed for each five models for each region and each season.

3. Results and Discussion

3.1. Rainfall Characteristics of Basins and GCMS Model Comparison

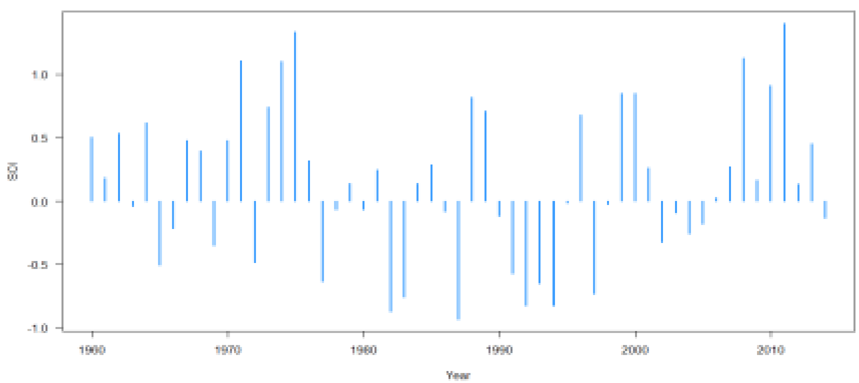
The rainfall characteristics of the two river basins are depicted in Table 1. Comparing Global Climate Models outputs with observation and observational based estimates are the most straightforward approach to evaluate GCMs' performance (Flato *et al*, 2013). The consistency of prediction across time and space is another method to evaluate the performance of GCMs (Dessai *et al,* 2005). There are different statistical techniques used for GCMs evaluation, but no individual technique is superior to others. In this study, BIAS, Root Mean Square Error (RMSE) and Correlation analysis which compare different GCMs out puts with observational based estimates CRU TS 3.1.

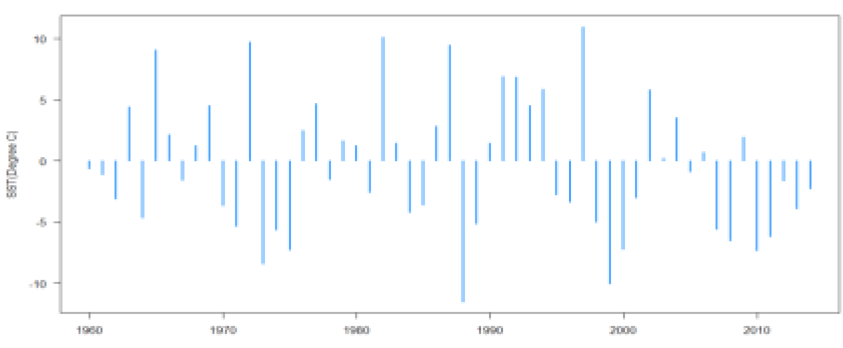
Table 1. Location and observed rainfall (1960-2014) characteristics of study regions

S. No.	Region	Location		Annual rainfall			
		Lat. (°)	Lon. (°)	Mean	SD	Maximum	Minimum
1	Eastern Blue Nile	9-11	38 - 39	1171	346.70	2323.90	620.32
2	Middle Blue Nile	9-11	36-37	1373	275.2	2163.90	912.00
3	Western Blue Nile	9-11	34 -35	1300	357.5	2382.82	628.00
4	Upper Awash	8-9	38 -40	1068	144.37	1357.81	729.11
5	Middle Awash	9 -10	40-41	532	97.73	733.99	319.24
6	Lower Awash	11-12	41-42	298	95.55	605.36	116.96

3.2. Correlation between ENSO and Rainfall of Blue Nile and Awash River Basins

Multi-decadal ocean–atmosphere interactions are the drivers of variability of rainfall. In the Blue Nile and Awash River basins, the linkages between rainfall and large scale ocean–atmosphere interactions were analysed using correlation analysis. The correlation among the indices of ENSO themselves was strongly negative (-0.86), and the impact on the rainfall of Blue Nile and Awash River basins was quite opposite. In years when an increase of SST (El Nino) is observed in SOI, a negative anomaly of SST (La lina) was observed in NINO 3.4 (Figure 2).





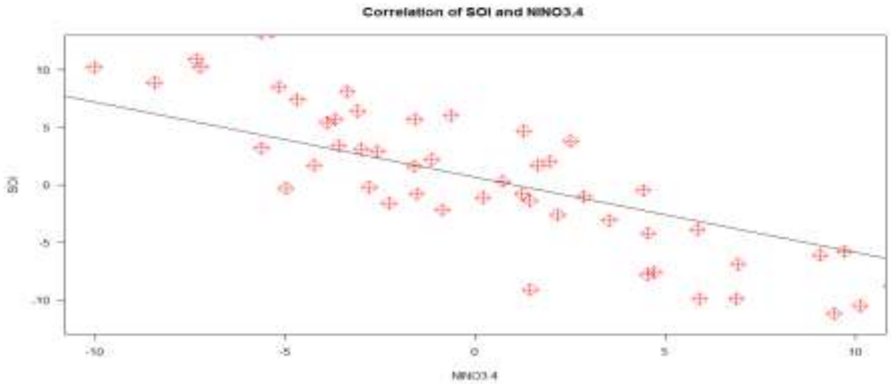


Figure 2. SOI variability, NINO3.4 variability and the correlation between SOI and NINO3.4.

The correlation between seasonal and annual rainfall of the study area with NINO 3.4 and SOI values is presented in Figure 3 and Table 2. More than the temporal difference, the spatial difference as the drivers of precipitation variability (teleconnections) is explored. Annual and *Kirmet* (JJAS) rainfall has better correlation with NINO 3.4 and SOI in Eastern and Western Blue Nile regions than other regions. The correlation with teleconnections and rainfall in other regions at all seasons is comparable. The correlation of rainfall of the study area with NINO 3.4 was negative while SOI has positive impact.

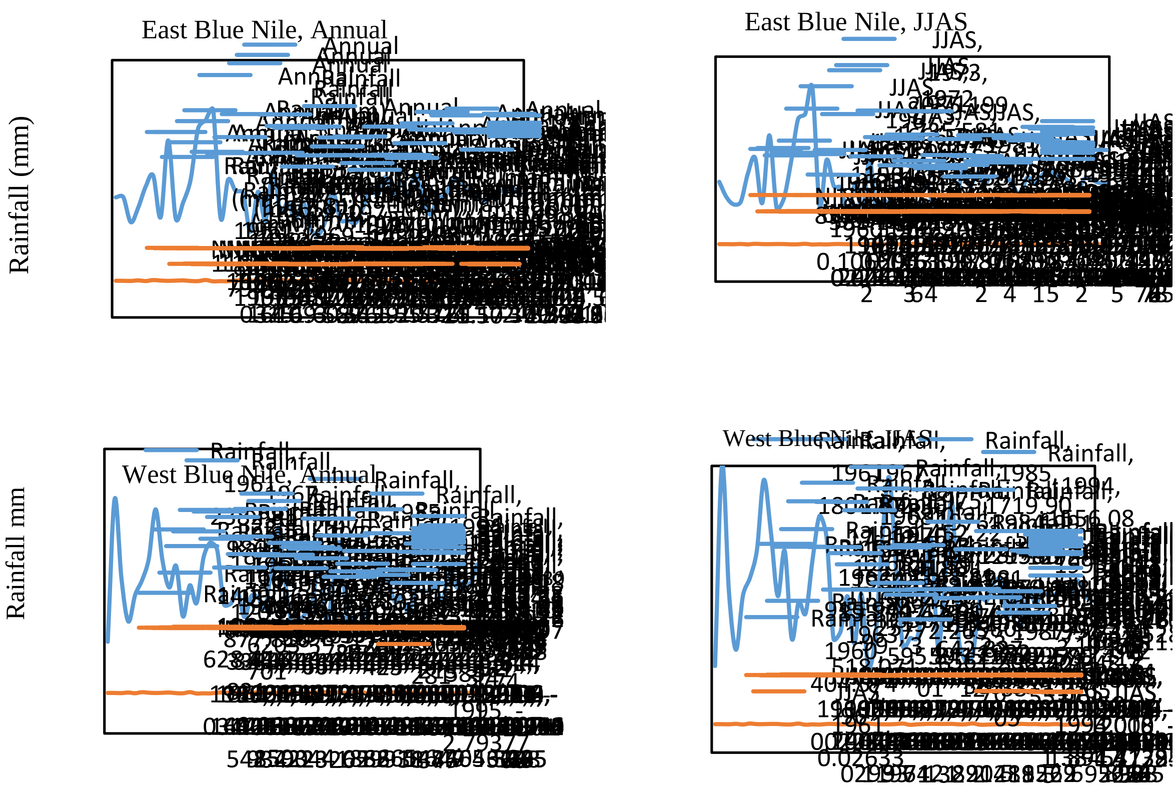


Figure 3. Pattern of rainfall and NINO 3.4 in some regions of Blue Nile river basin (1960-2014).

Table 2. Correlation between rainfall and El Nino Southern Oscillation indices (NINO 3.4 and SOI) (1960-2014).

Region	Annual		JJAS		MAM		OND	
	NINO 3.4	SOI	NINO 3.4	SOIL	NINO 3.4	SOI	NINO 3.4	SOI
Eastern Blue Nile	-0.24	0.33	-0.25	0.28	0.01	0.07	0.12	-0.14
Middle Blue Nile	-0.15	0.19	-0.15	0.18	-0.05	0.11	0.15	-0.15
Western Blue Nile	-0.37	0.40	-0.38	0.38	-0.31	0.27	-0.03	0.12
Upper Awash	-0.00	0.01	-0.25	0.02	0.18	0.03	0.17	-0.17
Middle Awash	0.07	-0.03	-0.30	0.29	0.19	-0.10	0.29	-0.3
Lower Awash	-0.06	-0.02	-0.26	0.03	-0.00	0.04	0.30	-0.33

The correlation analysis between rainfall of Blue Nile and Awash River basins with El Nino Southern Oscillation shows the negative impact of El Nino (NINO 3.4) on the annual and June, July, August and September (JJAS) rainfall of Blue Nile and Awash River basins. In contrast, the positive La Nina (SOI) could trigger positive impact on the rainfall of Blue Nile and Awash River basins. In agreement with this result, Abtew *et al. (*2009) explored the positive correlation of La Nina with rainfall and stream flow and negative correlation of El Nino with rainfall and stream flow in Blue Nile River Basin. Similarly, Diro *et al.* (2011) have also investigated the influence of SST anomalies by dividing Ethiopia into six homogeneous rainfall zones. The results revealed that the sea surface temperature of the equatorial Pacific, the mid-latitude northwest Pacific and the Gulf of Guinea has an influence on the summer rainfall of different parts of Ethiopia.

3.3. Global Climate Models Performance in Projecting Rainfall

The performance of GCMs in capturing mean rainfall and variability due to El Nino is quite different and vary from region to region. In this study, the difference between the observed rainfall and rainfall of GCMs showed relative difference in performance of GCMs. Ensemble of models (CMIP5) and CNRM-CM5 models are characterized by relatively low bias in most of the study regions than other models. The correlation between GCMs outputs of rainfall and observed rainfall also showed better correlation of observed rainfall and CMIP5 and CNRM-CM5 models (Figure 4).

Regionally, lower Awash is characterized by large bias by most of the models as compared to the other regions. Upper Awash and East Blue Nile are regions where bias is low in all seasons. This indicates that the rainfall of Upper Awash and East Blue Nile is better simulated by the GCMs while it is hardly possible to use the GCMs evaluated in this study for climate change evaluation in Lower Awash Basin. In RMSE, this is only in Upper Awash where there was better simulation of rainfall by the GCMs used. RMSE also identified GCMs which deviate from observational rainfall. The difference between observational and CSIRO-Mk6-0 and CCSM4 rainfall was large in most of the regions.

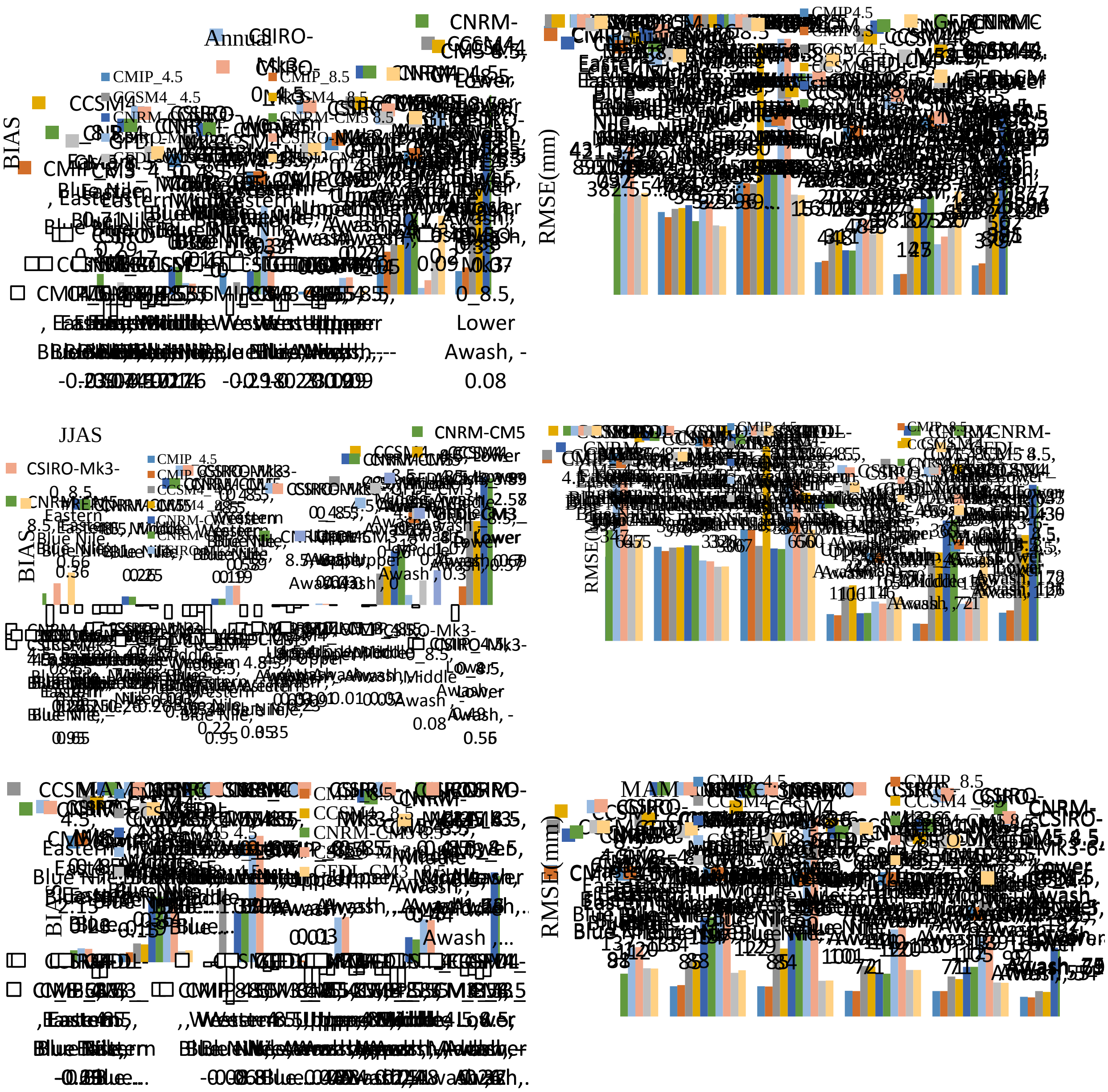
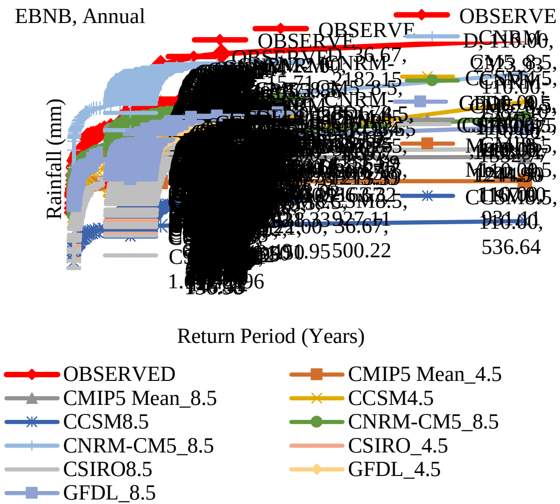
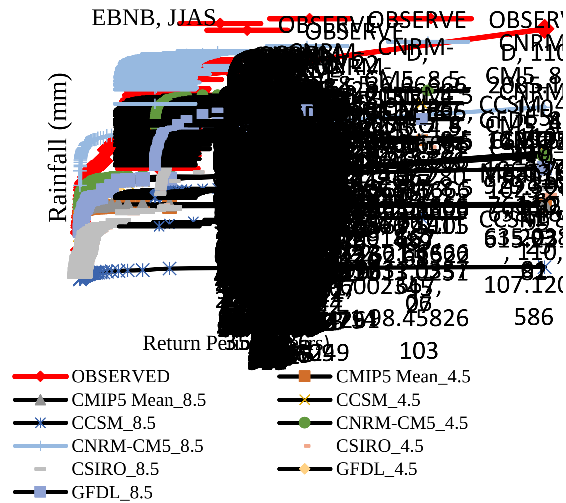


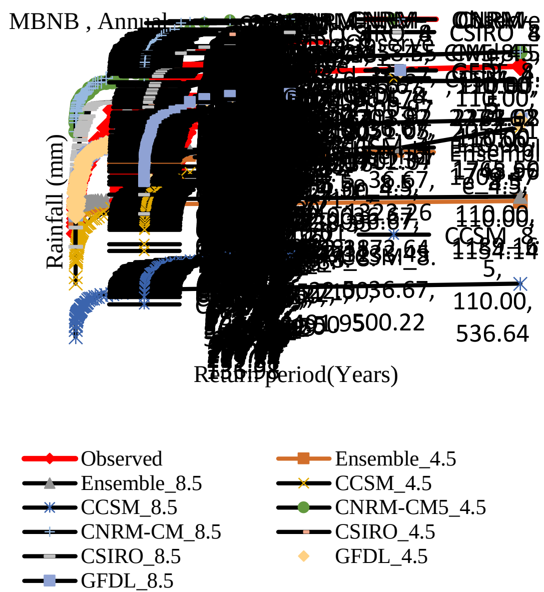
Figure 4. Bias and RMSE between observed and different models outputs (1960-2014).

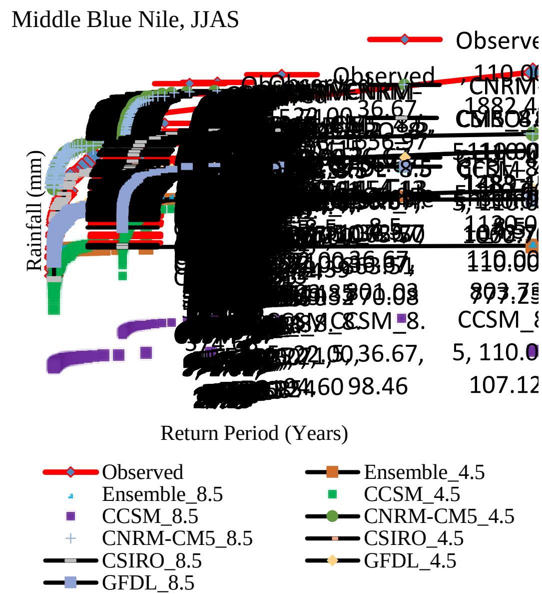
3.4. Frequency Distribution of Observed and Different GCMs' Rainfall

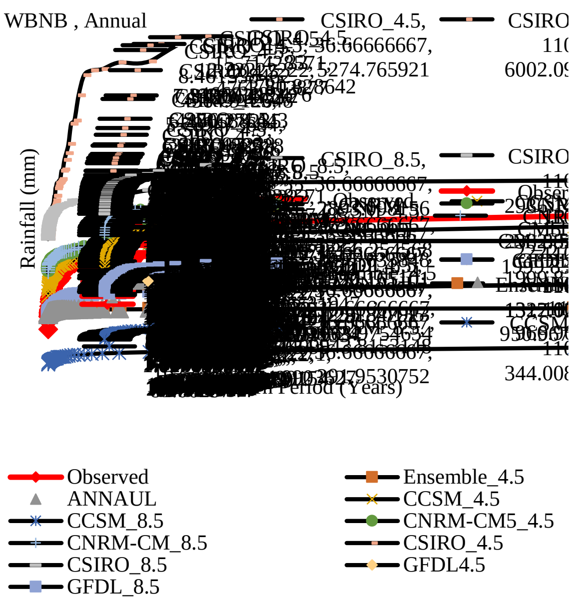
The performance of GCMs in capturing climate variability and extremes due to ocean atmospheric interaction is important evaluation method. Skill of GCMs in capturing extreme values is valuable since extreme rainfall values are responsible for flooding and drought assessment. In this study, return period of observed and different GCMs' rainfall was compared (Figure 5).

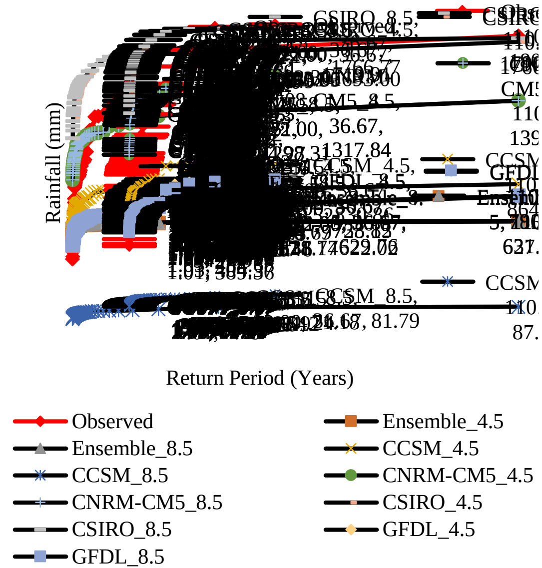

EBNB, Annual
Rainfall (mm)
Return Period (Years)
OBSERVED
CMIP5 Mean_4.5
CMIP5 Mean_8.5
CCSM4.5
CCSM8.5
CNRM-CM5_8.5
CNRM-CM5_8.5
CSIRO_4.5
CSIRO8.5
GFDL_4.5
GFDL_8.5

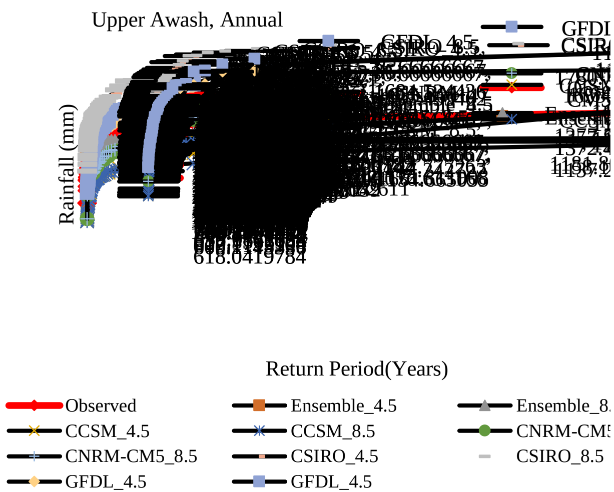

EBNB, JJAS
Rainfall (mm)
OBSERVED
CMIP5 Mean_4.5
CMIP5 Mean_8.5
CCSM_4.5
CCSM_8.5
CNRM-CM5_4.5
CNRM-CM5_8.5
CSIRO_4.5
CSIRO_8.5
GFDL_4.5
GFDL_8.5

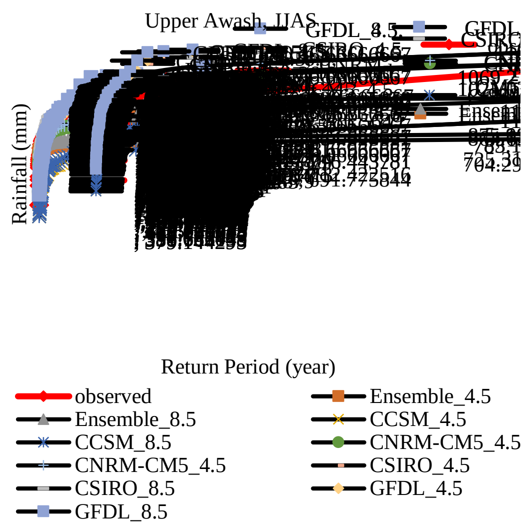

MBNB , Annual
Rainfall (mm)
Observed
Ensemble_4.5
Ensemble_8.5
CCSM_4.5
CCSM_8.5
CNRM-CM5_4.5
CNRM-CM_8.5
CSIRO_4.5
CSIRO_8.5
GFDL_4.5
GFDL_8.5


Middle Blue Nile, JJAS
Rainfall (mm)
Return Period (Years)
Observed
Ensemble_4.5
Ensemble_8.5
CCSM_4.5
CCSM_8.5
CNRM-CM5_4.5
CNRM-CM5_8.5
CSIRO_4.5
CSIRO_8.5
GFDL_4.5
GFDL_8.5


WBNB , Annual
Rainfall (mm)
Observed
ANNAUL
CCSM_8.5
CNRM-CM_8.5
CSIRO_8.5
GFDL_8.5
Ensemble_4.5
CCSM_4.5
CNRM-CM5_4.5
CSIRO_4.5
GFDL4.5


Rainfall (mm)
Return Period (Years)
Observed
Ensemble_8.5
CCSM_8.5
CNRM-CM5_8.5
CSIRO_8.5
GFDL_8.5
Ensemble_4.5
CCSM_4.5
CNRM-CM5_4.5
CSIRO_4.5
GFDL_4.5


Upper Awash, Annual
Rainfall (mm)
Return Period(Years)
Observed
Ensemble_4.5
CCSM_4.5
CCSM_8.5
CNRM-CM5_8.5
CSIRO_4.5
CSIRO_8.5
GFDL_4.5
GFDL_4.5


Rainfall (mm)
Return Period (year)
observed
Ensemble_8.5
CCSM_8.5
CNRM-CM5_4.5
CSIRO_8.5
GFDL_8.5
Ensemble_4.5
CCSM_4.5
CNRM-CM5_4.5
CSIRO_4.5
GFDL_4.5

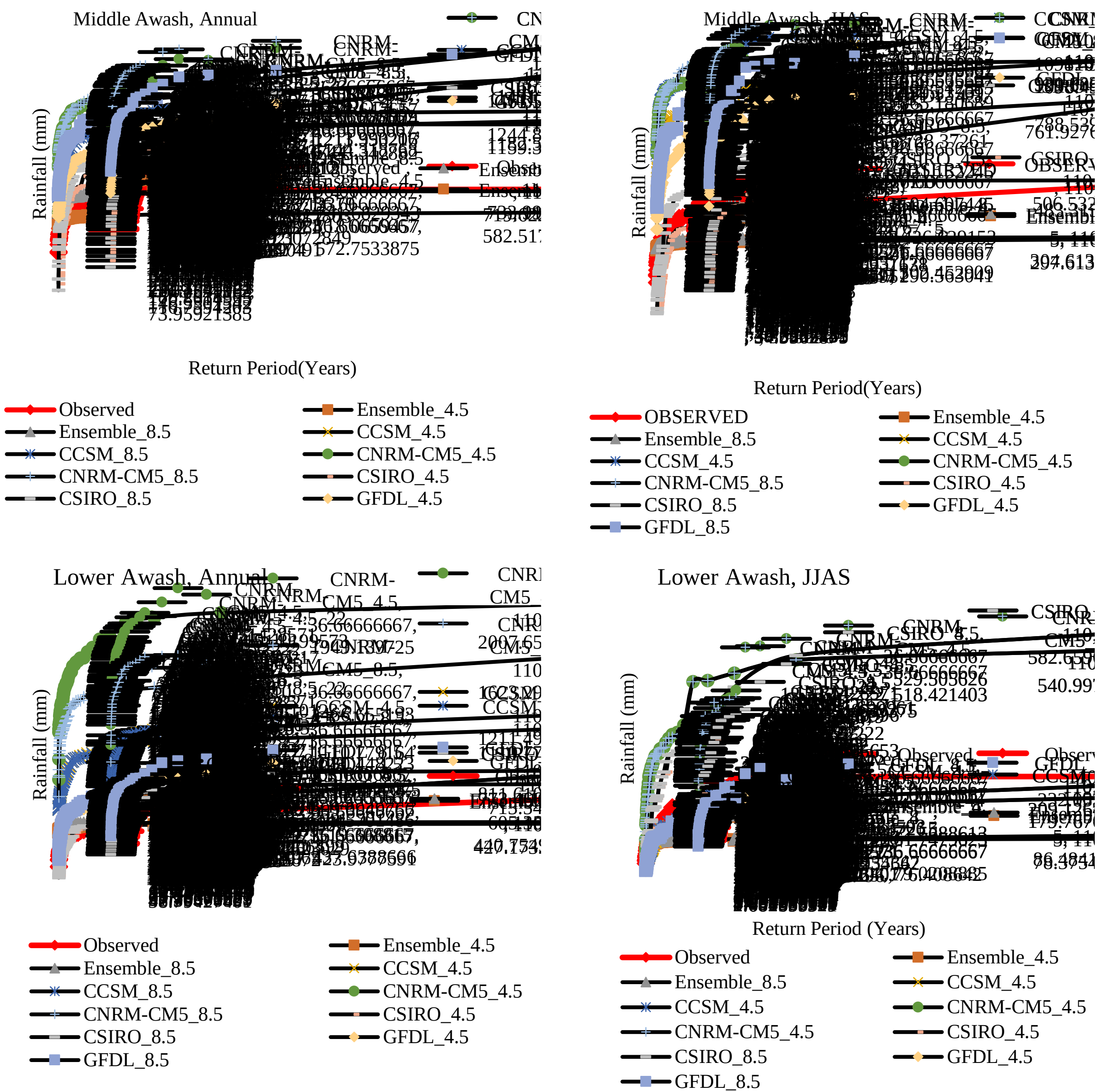


Figure 5. Observed and Different GCMs Rainfall Frequency Distribution

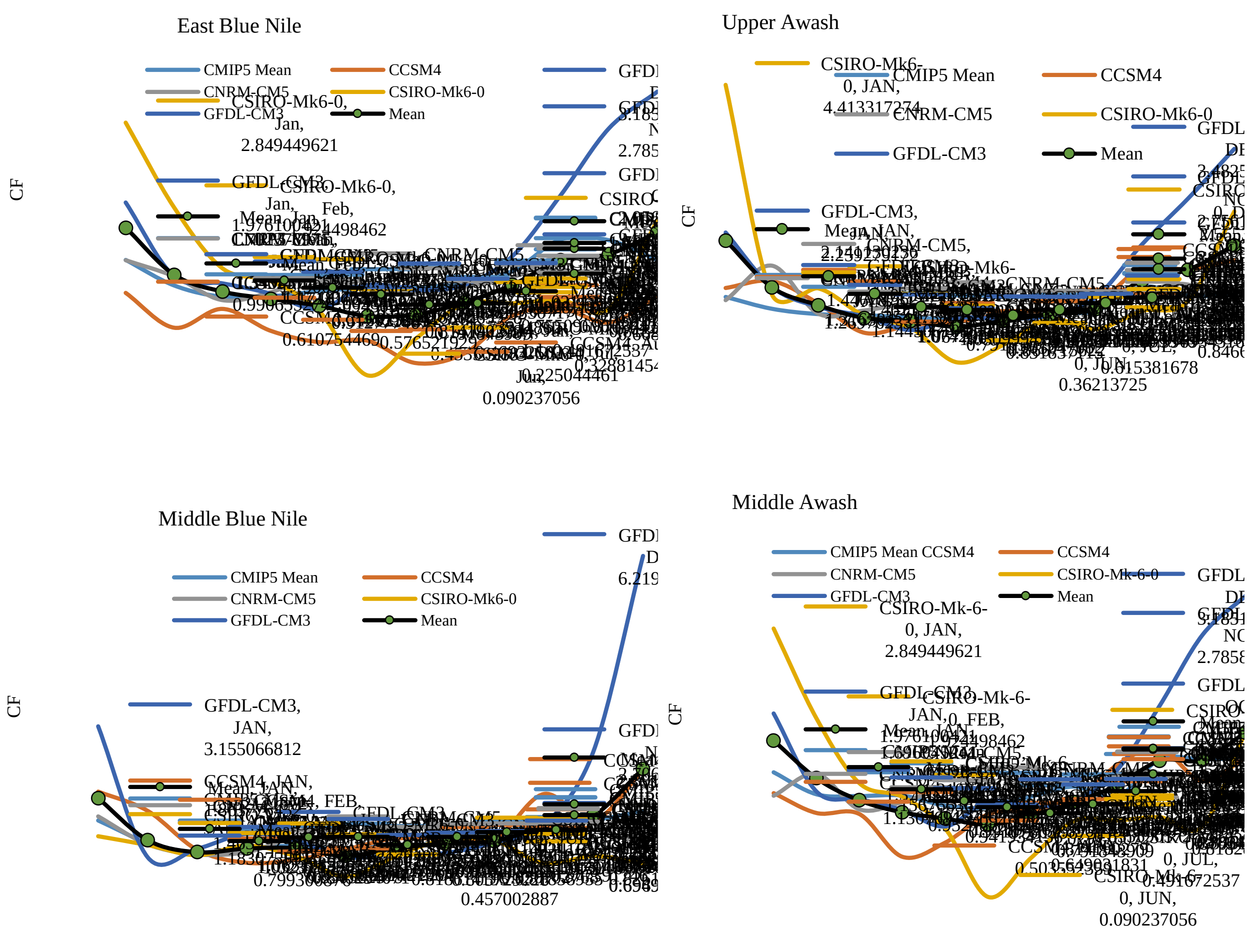
In East and Middle Blue Nile, all models did not capture the extreme rainfall events which can happen within even 10 years return period. This means these models cannot be used for mitigation and adaptation measures for flood. Relatively, recurrence interval of rainfall magnitudes was well represented by the GCMs in the Upper Awash basin. In most regions of the study, CNRM-CM5 showed similar recurrence interval with observed rainfall.

3.5. Statistical Transformation of Global Climate Models Outputs

Statistical transformation and dynamical downscaling methods are the two major downscaling methods used in climate change impact studies. In Statistical transformation methods, there is a function h which equates the modelled (Pm) and observed variable (Po). This can be expressed as Po = h (Pm) (Piani *et al.*, 2010).

Gudmundsson *et al.* (2012) has developed different parametric transformation methods to equate the distribution of modelled and observed precipitation. In this study, the change factor method was used to estimate the change between historical and future projection of precipitation. The relative change in precipitation (a_m) is estimated as the mean of Pm^{RCMFut} divided by the mean of Pm^{RCMCon}.

The change factor (CF) of some CMIP5 GCMs was computed in Blue Nile and Awash River Basins. The models output (RCP8.5) for the period 1960-2014 was taken as Pm^{RCMCon} while the models output (RCP8.5) of 2071- 2100 was taken as Pm^{RCMFut}. The result indicates by what factor precipitation will increase or decrease in the future (2071-2100).



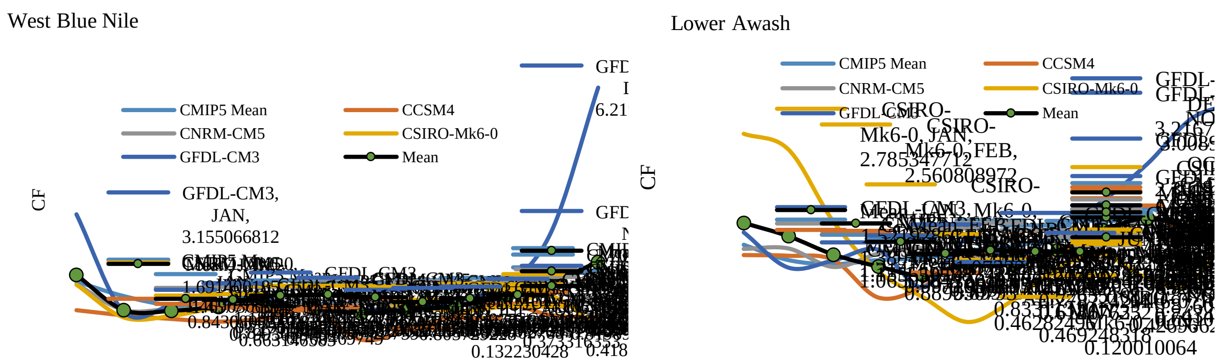


Figure 6. Change factors of CMIP5 GCMs in Blue Nile and Awash River basins.

All models indicated an increase in precipitation in dry months in all regions of the study area. In all regions of the study, in most of the GCMs, a decrease in rainfall in the main rain season (June and July) was projected. This will have multifarious impact on agricultural activities and natural ecosystem at the end of this century. The change factor of some models particularly, GFDL-CM3, CSIRO-Mk-6-0 in most regions and CCSM4 in East Blue Nile deviates from both CMIP5 mean and statistical mean of the models used. Large difference among the models is found in Eastern Blue Nile and Middle Awash than other regions. So, it is important to use other GCMs as well to reduce uncertainty in these regions.

3.6. Comparison of the Downscaled and Observed GCMs outputs

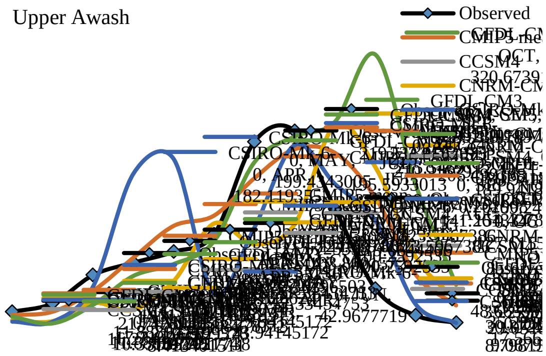
The change factor was used to downscale GCMs future rainfall in each region of the study and showed significant improvement. The downscaled rainfall from the GCMs has strong similarity and seasonal pattern with the observed rainfall. Then downscaled precipitation for the future period is;

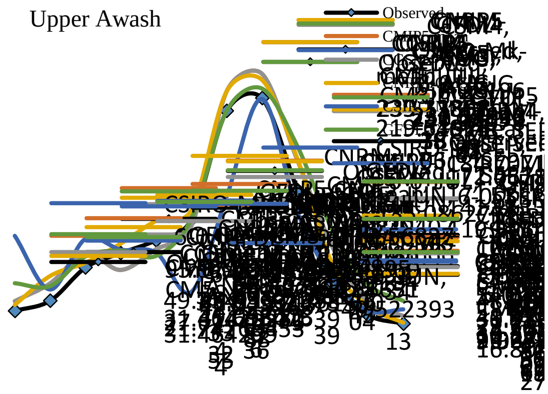
$P^{Fut} m;t = amP^{Obs} m;t$

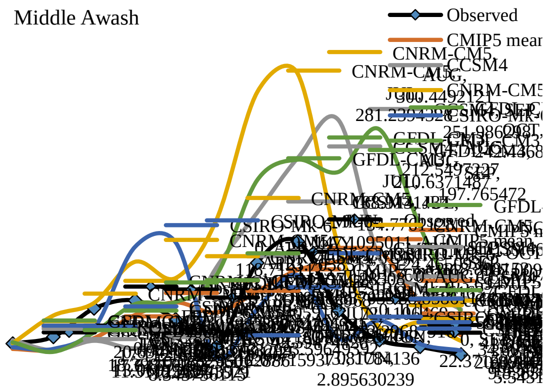
Where P^{Obs} is observed precipitation P^{Fut} is precipitation for the future period, m refers to the month and *t* to each time step in the observations; *am* is the relative change in the precipitation mean for month *m* (Sunyer *et al*, 2015). The following figure shows monthly rainfall distribution of (2071-2100) under RCP8.5 in each GCM before and after downscaling in each study region. The observed rainfall (1960-2014) is also presented.

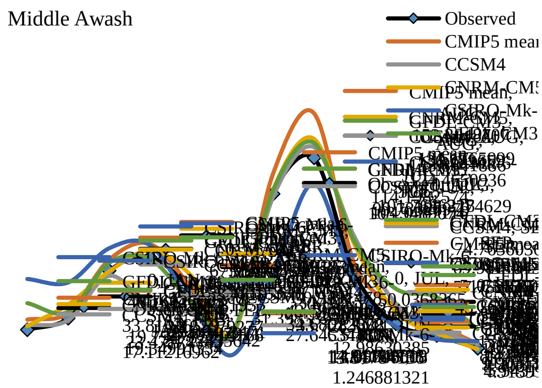
Rainfall of Raw GCMs

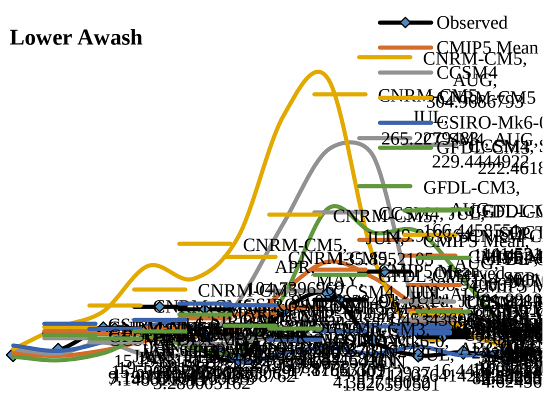
Rainfall of GCMs after Statistical transformation

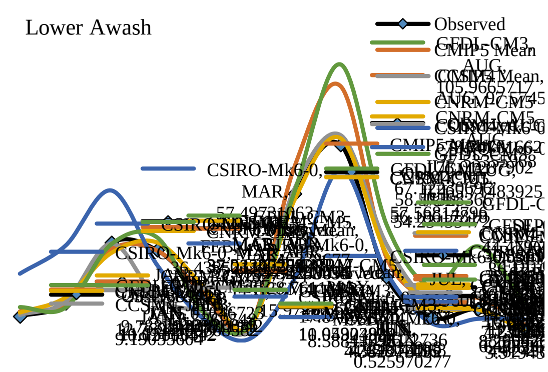












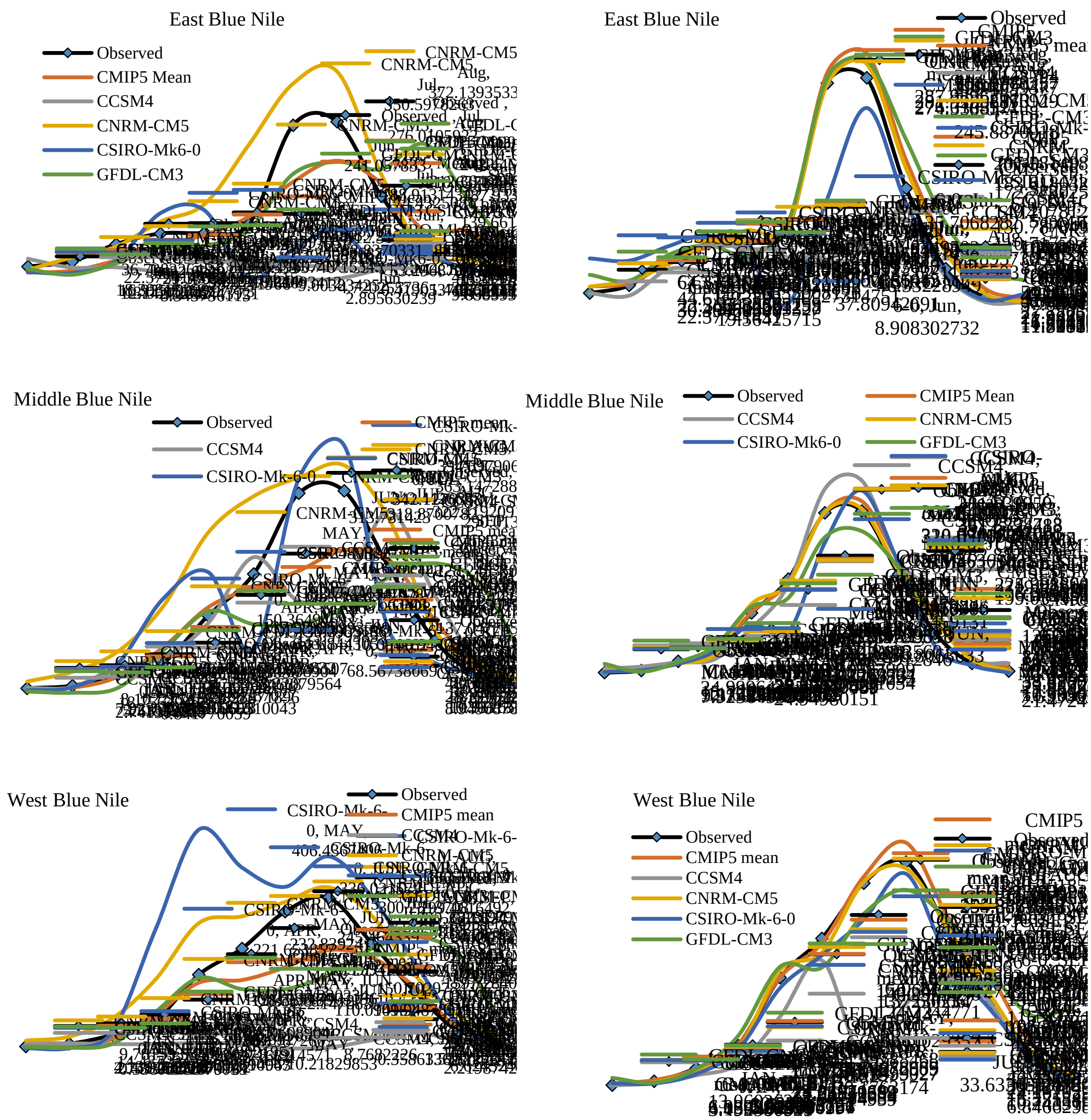


Figure 7. Comparisons between Raw GCM rainfall and Downscaled rainfall

Significant improvement on the pattern of rainfall is found after downscaling using change factor method. The monthly pattern of rainfall between observed, CMIP5 mean and most of the GCMs used was very similar. Larger difference between CSIRO-Mk6-0 and CCSM4 models and CMIP5 was evident. Change factor method brought better improvement on GCMs values in Awash River Basin than Blue Nile River Basin.

4. Conclusions and Recommendations

Global climate models performance in representing the mean and variability of rainfall due to ENSO and other biophysical drivers is critical for long term adaptation decision analysis and for short term weather forecasting.

The lateral boundary conditions of models are critical to further downscale the outputs of GCMs into lower spatial scale. This study showed that the GCMs evaluated in general were weak in projecting the rainfall of Blue Nile and Awash River Basins. Among the GCMs evaluated, CMIP5 and CNRM-CM5 were relatively good in most of the study regions and can be used for further downscaling and seasonal forecasting. This is hardly possible to use CSIRO-Mk-6-0 and CCSM4 outputs for any adaptation decisions in the study regions. The performance of CSIRO-Mk-6-0 and CCSM4 is not improved even after statistical transformation. Regional Climate Models which used the outer boundary of CMIP5 and CNRM-CM5 could better represent the mean and variability of rainfall of these regions. This study recommends evaluation of the performance of other GCMs in projecting rainfall of Blue Nile and Awash River Basins.

4. References

AchutaRao, K. and Sperber, K. 2006. ENSO Simulation in coupled ocean–atmosphere models: are the current models better? *Clim Dyn,* 27: 1-15.

Awulachew, S. B.; McCartney, M., Steenhuis, T. S, Ahmed, A. A. 2008. A review of hydrology, sediment and water resource use in the Blue Nile Basin. Colombo, Sri Lanka: International Water Management Institute. 87p. (IWMI Working Paper 131).

Bhattacharjee, P. and Zaitchi, B. 2015. Perspectives on CMIP5 model performance in the Nile River headwaters regions. *Int. J. Climatol.* 35: 4262-4275.

Dessai, S., Lu, F. and Hulme, M., 2005. Limited sensitivity analysis of regional climate change probabilities for the 21st century. *Journal of Geophysical Research-Atmospheres*, 110.

Edwards, P. 2010. History of climate modelling.*WIREs Clim Change,* 2011 2 128-139.

Flato, G., Marotzke, J., Abiodun, B., Braconnot, P., Chou, S., Collins, W., Cox, P., Driouech, F., Emori, S., Eyring, V., Forest, C., Gleckler, P., Guilyardi, E., Jakob, C., Kattsov, V., Reason, C. and Rummukainen, M. 2013. Evaluation of Climate Models. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Gudmundsson, L., Bremnes, J., Haugen, J. and Engen-Skaugen, T. 2012. Technical Note: Downscaling RCM precipitation to the station scale using statistical transformations – a comparison of methods. *Hydrol. Earth Syst.* Sci., 16, 3383-3390.

Hailemariam, K. 1999. Impact of climate change on the water resources of Awash River Basin, Ethiopia. *Climate Research*, Vol. 12: 91-96.

IPCC. 2013. Climate Change. 2013. The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the IntergovernmentalPanel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Masanganise, J., Chipindu, B., Mhizha, T., Mashonjowa, E.and Basira, K. 2013. An evaluation of the performances of Global Climate Models (GCMs) for predicting temperature and rainfall in Zimbabwe. International Journal of Scientific and Research Publications, Volume 3, Issue 8.

Piani, C., Weedon, P., Best, M., Gomes, S., Viterbo, P., Hagemann, S. andHaerter, J. 2010. Statistical bias correctionof global simulated daily precipitation andtemperature for the application of hydrologicalmodels. *Journal of Hydrology,* 395.

Randall, D.A., R.A. Wood, S. Bony, R. Colman, T. Fichefet, J. Fyfe, V. Kattsov, A. Pitman, J. Shukla, J. Srinivasan, R.J. Stouffer, A. Sumi and K.E. Taylor. 2007: Climate Models and Their Evaluation. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Sunyer, M., Hundecha, Y., Lawrence, D., Madsen, H., Willems, P., Martinkova, M., Vormoor, K., Bürger, G., Hanel, M., Kriauciunien, J., Loukas, A., Osuch, M. and Yücel, I. 2015. Inter-comparison of statistical downscaling methods for projection of extreme precipitation in Europe. *Hydrol. Earth Syst. Sci.,* 19, 1827-1847.

Walsh, J.. Chapman, W., Romanovsky, V., Christensen, J. and Stendel, M. 2007. Global Climate Model Performance over Alaska and Greenland. *Journal of Climate,* Vol, 21, 6156-6174.

2. Modelling Impact of Climate Change on the Hydrological Response of Shaya Catchment in South-Eastern Ethiopia

Sintayehu Fetene

Kotebe Metropolitan University, College of Natural and Computational Science, Addis Ababa, Ethiopia, Corresponding Author Email: demessie1986@gmail.com

Abstract

Prediction of the impacts of climate change at small watershed level is required for solving site-specific water management problems. The study was aimed at analysing the impact of climate change, particularly temperature and precipitation, on water resources variability of the Shaya Watershed. The HadCM3A2a and HadCM3B2a outputs of GCM scenarios of climate change were used for predicting the climate of the study area. Climate change scenarios of precipitation and temperature were divided into three time windows of 30 years. The SWAT model was used to assess the hydrological responses of Shaya River due to climate change. The period from 1977-2000 was taken as a base period against which a comparison was made. The SWAT calibration and validation results showed a good agreement between observed and predicted with R^2= 0.89 for calibration and 0.69 for validation, whereas the NSE was 0.86 and 0.63 during calibration and validation, respectively. The monthly flow volume did not show systematic trends. Generally, the overall results for total flow volume of Shaya River showed a decreasing trend for both A2a and B2a scenarios as compared to the base period. The decrement in the flow volume ranged from 2.02 to 12.47 % for A2a and 7.41 to 30.11 % for B2a scenarios. It could be concluded that the change in the amount and distribution of rainfall and level of temperature would affect the agricultural productivity and water utilizations in the region.

Keywords: A2a Scenario; B2a scenari; Climate change; GCM; Shaya River; SWAT

1. Introduction

The climate change impact has the potential to undermine and even, undo progress made in improving the socio-economic well-being of human livelihood. This is compounded by many factors, including widespread poverty, human diseases, and high population density, estimated to double the demand for food, water, and livestock forage within the next 30 years (Davidson *et al.*, 2003). Water resource is also one of the main sectors that will be adversely affected by climate change. Many of the most critical impacts of global climate change will manifest themselves through the hydrologic system. There is already strong evidence that climate change is having an impact on the world's water resources. These impacts include changing precipitation and temperature patterns that may result in more severe drought or floods, changing snow pack amount and elevation, varying stream flow patterns, and rising sea levels along the coasts.

Even though Africa is widely held to be highly vulnerable to climate change, Ethiopia is often cited as one of the most extreme examples. Both instrumental and proxy records have shown significant variations in the spatial and temporal patterns of climate in Ethiopia. The United Nations' Development Programme (UNDP) Climate Change profile for Ethiopia shows that the mean annual temperature increased by 1.3°C between 1960 and 2006, at an average rate of 0.28°C per decade, while rainfall behaviour showed no marked emergent changes (Conway and Lisa, 2010).

The results of Intergovernmental Panel on Climate Change (IPCC's) mid-range emission scenario showed that, compared to the 1961-1990, average mean annual temperature across Ethiopia will increase from 0.9 and 1.1°C, 1.7 to 2.1°C and 0.5°C to 3.6°C by the years 2030, 2050 and 2080 respectively and annual precipitation showed a change of between 0.6 and 4.9% and 1.1 to 18.2% for 2030 and 2050, respectively (NMA, 2006).

Conway and Lisa (2010) reported that Ethiopia's economy, which is dominantly relying on rain-fed agriculture, is highly exposed to climate variability. Current estimates showed that the agriculture sector supports roughly 42% of the Gross Domestic Product (GDP) and 85% of the employment. Over the years, the most devastating Ethiopia's droughts are associated with late onset, early offset or due to failure of rainfall during the growing season. Despite this situation, fundamental understanding of the patterns and causes of the seasonal-to-inter-annual variability of the rainfall seasons, which is crucial for Ethiopia's food security, has remained conspicuously absent (Degefu, 1987; Gissila *et al.*, 2004). Moreover, Sweeney *et al.* (2008) argued that climate change will be a major challenge against the country's efforts towards achieving sustainable development goals.

Although the influence of different climate change scenarios is projected at a global scale, the exact type and magnitude of the impact at a small watershed scale remains untouched in most parts of the world. Hence, identifying localized impact of climate change at a watershed level and quantitative estimates of hydrologic effects of climate change are essential for understanding and solving the potential water resource management problems. Future water resource planning, reservoir design and management, and for protection of the natural environment with the changing environment, such information is highly required. All this gives an opportunity to define the degree of vulnerability of local water resources to climate change and plan appropriate adaptation measures that must be taken upfront. The objectives of this study were to downscale the Global Circulation Model (GCM) output, particularly temperature and precipitation, and to a watershed level for analysing the impact of climate change on stream flow variability of Shaya River.

2. Materials and Methods

2.1. Description of the Study area

Shaya Watershed is located in south-eastern part of Ethiopia in Oromia Regional State, Bale Zone (Figure 1). The Watershed is situated in Genale-Dawa basin at the upper most parts of the Weyb basin, between 6°52'-7° 15'N and 39°46'-40°02'E.

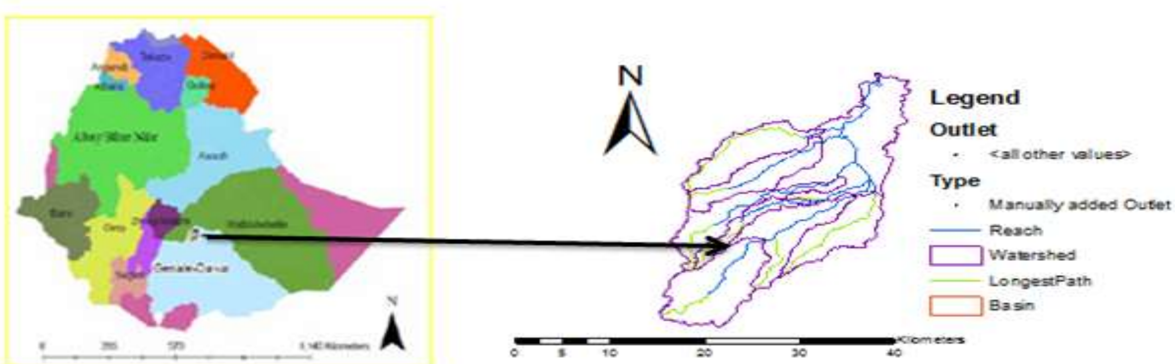


Figure 1. Location map of the Shaya Watershed.

2.2. Modelling Approaches

The modelling approaches were divided into two major sections. The first part was climate change modelling approach, and the second was hydrological modelling approach.

2.2.1. Climate change modelling approach

2.2.1.1. General circulation model (GCM) outputs

Global Circulation Model (GCM)-derived scenarios of climate change were used for predicting the future climates of the study area based on criteria proposed by the Intergovernmental Panel on Climate Change (IPCC). Among the wide range of GCM models, HadCM3 (Hadley Centre for Climate Prediction and Research, England), was selected for the climate impact study. Besides, the HadCM3 GCM output was chosen since the model is widely used for climate change impact assessment and the results of HadCM3 can be easily downscaled using SDSM (Dile *et al.*, 2013). For HadCM3 the model result was available for A2 (medium-high) and B2 (medium-low) emission scenarios. For this study the ensemble "a" was considered for A2a and B2a experiments (the "a"in A2a and B2a refer to the ensemble member in the HadCM3 A2 and B2 experiments).

2.2.1.2. Downscaling techniques

A decision support tool, SDSM 4.2, for the assessment of regional climate change impacts developed by Wilby and Dawson (2007), was used to downscale large scale predictors and it was freely downloaded from http://www.sdsm.org.uk. SDSM develops statistical relationships, based on multiple linear regression techniques, between large-scale (predictors) and local (predictand) precipitation, and maximum and minimum temperature, which were then used as inputs for hydrological modelling.

2.2.1.3. Predictor variables

Large-scale predictor variable information was freely obtained from the Canadian Climate Impact Scenario Group (http://www.cics.uvic.ca/scenarios/sdsm/select.cgi/). The National Centre for Environmental Prediction (NCEP_1961-2001) reanalysis data and HadCM3 predictor variables for the A2a and B2a were downloaded for grid boxes representing the watershed area. Large-scale predictor variable information, i.e. National Centre for Environmental Prediction(NCEP_1961-2001), reanalysis data set were used for the calibration and validation of SDSM with the observed precipitation, maximum and minimum temperature at Robe station and HadCM3 (Hadley centre Climate Model 3) GCM (H3A2a_1961-2099 and H3B2a_1961-2099, data were used for the baseline and climate scenario generation.

2.2.1.4. Screening predictor variables

Identifying the empirical relationships between gridded predictors and single site predictands (such as station precipitation, maximum, and minimum temperature) are central to all statistical downscaling methods, and is often the most time consuming step in the process (Wilby and Dawson, 2007). Several analyses were made by selecting a maximum of six out of 26 predictor variables at a time till best predictor-predictand correlations were found even though up to 12 predictors were possible to select at a time. The strength of the individual predictors varied on a month by month basis. Hence, the most appropriate combination of the predictors with the predictand was chosen by looking at the analysis output of all months. A simple correlation analysis was done to investigate inter–variable correlations for annual sub–periods to identify the amount of explanatory power that was unique to each predictor.

2.2.1.5. SDSM calibration, weather generator and validation

The calibration was done for the period of 10 years (1977-1986) at a monthly model type in order to see the monthly temporal variations. The downscaling process was 'Unconditional' for daily temperature value and 'Conditional' for precipitation. For conditional processes in which the distribution of predictand values is skewed, the Fourth root transformation was applied.

Ensembles of synthetic daily weather series were produced using NCEP re–analysis atmospheric predictor variables and regression model weights were produced by the 'Calibrate Model' operation. The 'Weather Generator' can also be used to reconstruct predictands or to fill-in missing data. Independent set of predictand variables from 1977-2000 at Robe station were used for model validation.

2.2.1.6. Scenario generation and bias correction methods

The HadCM3A2a and HadCM3B2a were the two GCM output files used for scenario generation. The regression weights produced during the calibration process were applied to the time series outputs of the GCM model. This is based on the assumption that the predictor - predictand relationships under the current condition will remain valid for future climate conditions as well. Twenty ensembles of synthetic daily time series data were produced for each of the two SRES scenarios for a period of 139 years (1961 to 2099). Finally, the mean of the twenty ensembles for the specified period was produced for maximum and minimum temperature, and precipitation. The period from 1977-2000 was considered as a base period, whereas the period from 2011-2099 was considered as future period. The future period was divided into three time horizons from 2011-2040, 2041-2070, and 2071-2099 and analyses were made for each time horizon.

Linear Scaling (LS) method was adopted to correct the model errors due to its simplicity. Precipitation was typically corrected with a multiplier and temperature with an additive term on a monthly basis. The correction factors derived during the base period (1977-2000) were applied for the future period (2011-2099).

2.3.2. SWAT hydrological modelling approach

The main reasons for the selection of SWAT model for this study were the model's moderate input data requirement which uses readily available inputs, ability to simulate the major hydrological processes, and its availability.

2.3.2.1. Watershed delineation

Shaya Watershed was delineated based on the automatic procedure using digital elevation models (DEM) data. A digital elevation model (DEM) tile of 30m resolution was used. Based on the manually added outlets, the Watershed was partitioned into eight hydrologically connected sub-basins and the final outlets found at the gauging station were used for comparison of measured and predicted flows.

2.3.2.2. Hydrological response unit definition

After watershed delineation was completed, the Hydrologic Response Units (HRU) were defined in ArcSWAT by overlaying soils, land use and slope classes that enable the model to reflect differences in evapotranspiration and other hydrologic conditions for different land cover/crops and soils which increases) the accuracy of load predictions and provides a much better physical description of the water balance (Neitsch *et al.*, 2009. In this research threshold values of 5% for land use, 5% for soils and 15% for slope classes were used to reduce those very small HRUs. Based on the threshold percentage values, the Shaya Watershed was partitioned into 46 HRUs.

2.3.2.3. Weather *generation*

In order to fill the missing data, daily rainfall, temperature, wind speed, solar radiation and relative humidity data from Robe, Dinsho and Sinana weather stations were used as an input to calculate statistical monthly weather generator parameters, which were calculated by 'Weather Parameter Calculator' programme. Using the three stations, the SWAT model generates representative weather variables for Shaya Watershed using Thiesen polygon method to fills the missed values.

2.3.2.4. SWAT model setup, calibration and validation approach

After running the sensitivity analysis, the mean relative sensitivity (MRS) of the parameters were used to rank the parameters, and their category of sensitivity were also defined based on the Lenhart *et al.* (2002) classification i.e. small to negligible ($0 \leq MRS < 0.05$), medium ($0.05 \leq MRS < 0.2$), high ($0.20 \leq MRS < 1.0$), and very high ($MRS \geq 1.0$). Based on these classifications, sensitive parameters with mean relative sensitivity value of medium to very high were selected for calibration of the simulated flows for Shaya River.

The manual calibration was adopted until the model objective functions reached a satisfactory level (i.e. $D < 15\%$, $R^2 > 0.6$ and $ENS > 0.5$) of accuracy. Stream flows measured at Shaya River gauge station from 1995-1999 were used for calibrating the model including the first two years of warm up period.

Validation of Shaya River flow was done using an independent data set without making further adjustments to the calibration parameters. Stream flows measured at Shaya River gauge station from 2000-2004 were used for the validation process to evaluate the model accuracy. The major spatially distributed and temporally varied data that were collected for hydrological modelling were digital elevation model (DEM) data, weather data, soil data, land use data and river flow data.

3. Results and Discussion

3.1. SWAT Hydrological Model Outputs

3.1.1 Sensitivity analysis outputs

Even though 27 parameters were used for the sensitivity analysis, only twenty-one of them were found to be relatively sensitive with the sensitivity category ranging from very small or negligible to high. Sensitive flow parameters, relative sensitivity values, parameter ranking and their categories are presented in Table 1.

Table 1. Results of sensitivity analysis of flow parameters.

Flow Sensitive Parameters	Rank	Mean Relative sensitivity	Category of sensitivity	Lower and upper bound
Deep aquifer percolation fraction; Rchrg_DP	1	1.840	Very High	0.0 to 1.0
Initial curve number (II) value; Cn2	2	1.060	Very High	±25.0
Base flow alpha factor [days]; Alpha_Bf	3	0.689	High	0.0 to 1.0
Soil evaporation compensation factor; Esco	4	0.319	High	0.0 to 1.0
Maximum potential leaf area index; Blai	5	0.230	High	0.0 to 10.0
Channel effective hydraulic conductivity [mm/hr]; Ch_K2	6	0.166	Medium	0.0 to 150.0
Threshold water depth in the shallow aquifer for flow [mm]; Gwqmn	7	0.132	Medium	±1000.0
Soil depth [mm]; Sol_Z	8	0.127	Medium	±25.0
Available water capacity [mm water / mm soil];Sol_Awc	9	0.121	Medium	±25.0
Threshold water depth in the shallow aquifer for "revap" [mm]; Revapmin	10	0.106	Medium	±100.0
Maximum canopy storage [mm]; Canmx	11	0.097	Medium	0.0 to 10.0
Surface runoff lag time [days]; Surlag	12	0.081	Medium	0.0 to 10.0
Average slope steepness [m/m]; Slope	13	0.072	Medium	±25.0
Manning's n value for main channel; Ch_N	14	0.067	Medium	0.0 to 1.0
Saturated hydraulic conductivity [mm/h]; Sol_K	15	0.066	Medium	±25.0
Groundwater Delay [days]; Gw_Delay	16	0.062	Medium	±10.0
Groundwater "revap" coefficient; Gw_Revap	17	0.034	Small	±0.036
Plant uptake compensation factor; Epco	18	0.005	Small	0.0 to 1.0
Moist soil albedo ; Sol_Alb	19	0.004	Small	±25.0
Average slope length [m]; Slsubbsn	20	0.0002	Small	±25.0
Maximum potential leaf area index; Biomix	21	0.0002	Small	0.0 to 10.0

3.1.2. SWAT Model calibration outputs

The model was run for a period of five years from 1 January 1995 to 31 Decembe 1999. However, the first two years of the recording period were used for stabilization of model runs (warm up period). The calibration was therefore performed for a period of three years on monthly and daily bases (Table 2).

Table 2. Finally calibrated flow parameter values and variation methods (imet).

Flow Parameters	Bounds/Ranges	Calibrated values	imet
Alpha_Bf	0.0 to 1.0	0.96	1
Blai	0.0 to 1.0	0.27	1
Canmx	0.0 to 10.0	7.55	1
Cn2	±25.0	-15.90	3
Esco	0.0 to 1.0	0.16	1
Gw_Delay	±10.0	5.47	2
Gwqmn	±1000.0	854.02	2
Revapmin	±100.0	92.71	2
Rchrg_Dp	0.0 to 1.0	0.48	1
Sol_Awc	±25.0	15.43	3
Sol_K	±25.0	21.66	3
Sol_Z	±25.0	6.17	3
Surlag	0.0 to 10.0	5.09	1

Note from the above Table 2, 1 stands for Replacement of initial parameter by value, 2 for Adding value to initial parameter and 3 for Multiplying initial parameter by value (in %age).

Model parameters were first calibrated manually which was very time consuming process, followed by automatic calibration using ParaSol (Parameter Solutions), an auto calibration tool which is embedded in SWAT 2005. The calibration processes considered 13 flow parameters (Table 2) and their values varied iteratively within the allowable ranges until satisfactory agreement between measured and simulated stream flow was obtained. The auto calibration processes significantly improved model efficiency.

The statistical results of the model performance for calibration periods, and final calibrated and fitted values on monthly time steps are summarized in Table 3. The results from different statistical method of model performance evaluation met the criteria of ENS > 0.5, r^2> 0.6 and D ≤ ±15%. The calibration showed a good agreement between the simulated and measured monthly flows. % of error of the observed and simulated monthly flows at Shaya gauge station is 4.037% which is well within the acceptable range of ±15%. Further, a good agreement between observed and simulated monthly flows are showed (R^2=0.887) and the Nash-Suttcliffe simulation efficiency (ENS=0.863) and thus fulfilled the requirements suggested by Santhi *et al.* (2001) for R^2 > 0.6 and ENS > 0.5. The graphical representation of the simulated and observed monthly flows (Figure 2) shows a reasonable agreement.

Table 3. Calibration statistics for measured and simulated flows at Shaya flow gauge station.

Period 1995-1999	Total flow (m^3/s)		Mean monthly flow (m^3/s)		% difference	R^2	ENS
	Observed	Simulated	Observed	Simulated			
	336.11	322.54	3.50	3.36	4.04	0.89	0.86

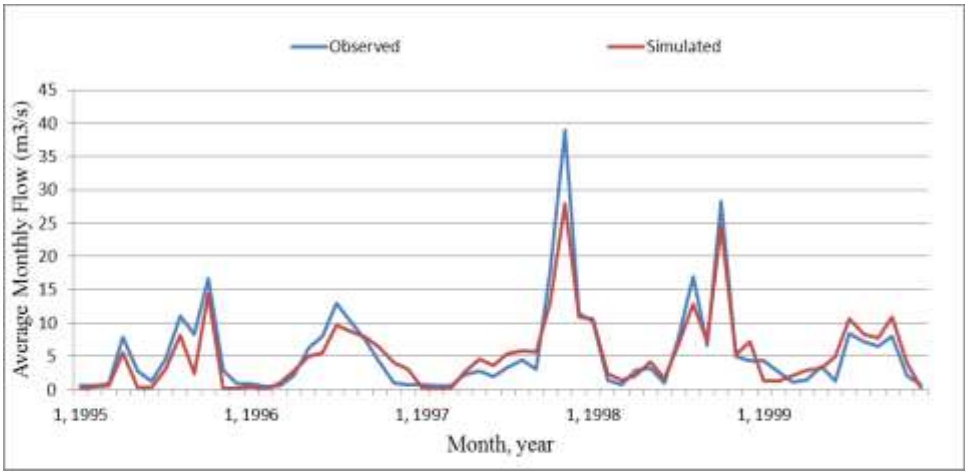


Figure 2. Calibration results of average monthly simulated and observed flows at Shaya River gauge station.

Even though the model slightly over estimated the peak values in the year 1997 and 1999, and under estimated the remaining part of the calibration period, the overall flow was well simulated and the trend showed good patterns. The observed and simulated flows and the equations showed positive relations between observed and simulated flows (Figure 3).

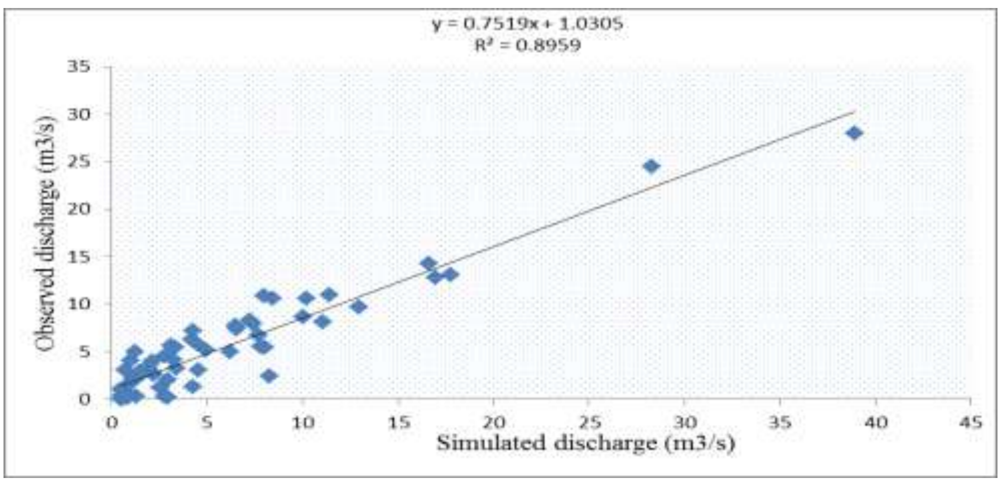


Figure 3. Monthly simulated versus observed flow at Shaya River gauge station after calibration.

3.1.3. SWAT Model validation of flow outputs

Validation of the model was carried out using an independent data set for five years from 2000- 2004 without making further adjustments of sensitive parameters. There is good agreement between monthly observed and simulated flows at Shaya River gauge station. The coefficient of determination (R^2) and Nash-Suttcliffe simulation efficiency (ENS) were 0.69 and 0.63, respectively which showed a very good correlation of the simulation results with the observed values (Table 4). The % of error between the observed and simulated monthly flow was 2.69% and found to be within the tolerable range of ±15%.

Table 4. Calibration statistics for measured and simulated flows at Shaya flow gauge station.

Period	Total flow (m^3/s)		Mean monthly flow (m^3/s)		% difference	R^2	ENS
2000-2004	Observed	Simulated	Observed	Simulated			
	201.12	206.54	3.35	3.44	2.69	0.69	0.63

The hydrograph of monthly observed and simulated flows id indicated in figure (4). Even though the model slightly overestimated the peak values in the year 2003 and underestimated from the year 2000- 2001, the general trend was more or less similar.

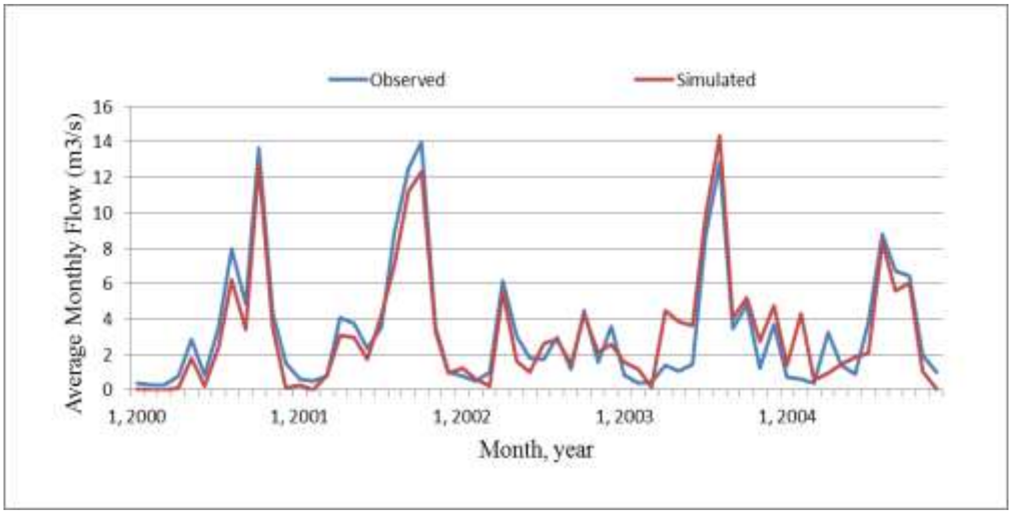


Figure 4. Validation results of average monthly simulated and observed flows at Shaya River gauge station.

Generally, there is a good fit between measured and simulated output and a slight over estimation of the low flows and under estimation of the peak flows were observed at the validation period. Since the model performed as well in the validation period as for the calibration period, the set of optimized parameters are listed in table (3). During calibration process for Shaya Watershed can be taken as the representative set of parameters for the Watershed. The relationship between simulated and observed flows was positive (Figure 5).

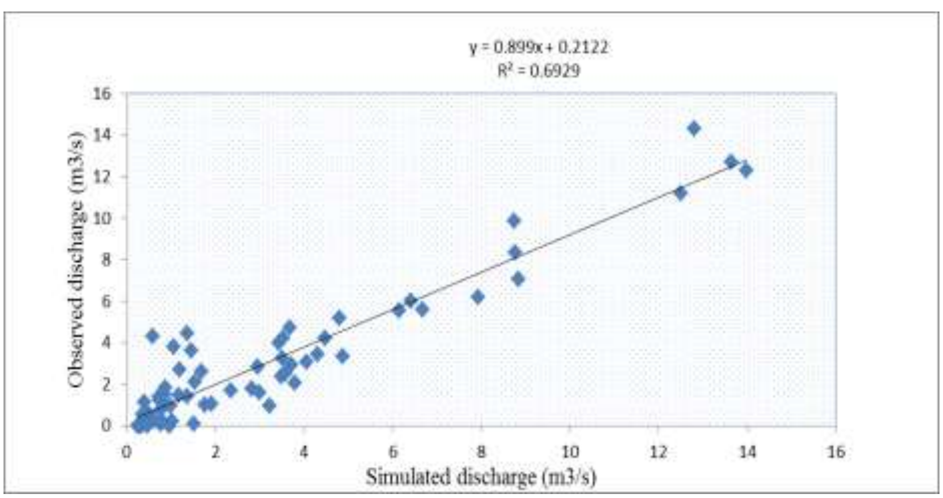


Figure 5. Monthly simulated versus observed flow at Shaya River gauge station after validation.

The validation check illustrates the accuracy of the model for simulation time-periods outside of the calibration period. The model performed as good in the validation period (2000- 2004) as for the calibration period (1995-1999) at Shaya gauge station. Hence, the set of optimized parameters used during calibration process can be taken as the representative set of parameter to explain the hydrologic characteristic of the Shaya Watershed. Further simulations using SWAT model can be carried out by using these parameters for any period of time.

3.2. Impact of Climate Change on Shaya River Flow Volume

Stream flow is largely dependent on the amount of precipitation falling on the catchment, and the amount of evapotranspiration released from that catchment. The change in the amount of precipitation and minimum and maximum temperature obviously changes Shaya River flow volumes. The period from 1977 – 2000 were used as a base period against which the climate change impact was assessed. The daily precipitation, and minimum and maximum temperature used for impact assessment were adjusted using bias-corrected SDSM model results for the future three data periods of 30 years (2011-2040, 2041-2070 and 2071-2099) and SWAT hydrologic model was re-run for each data periods and the SWAT parameters identified during the calibration period also remained valid.

Other climate variables, such as wind speed, solar radiation, and relative humidity, were assumed constant throughout the future simulation periods, which are not possible in actual case. Even though it is definite that in the future land use changes will also take place, this was also assumed to remain constant. The impact of climate change on stream flow was predicted based on conditional temperature and rainfall changes on a monthly and annual basis. The simulation for the future three time horizons in terms of monthly and annual average total flow volume and percentage change of these average total flow volumes as compared to the base period are summarized in table (5 and 6) and figure (6 and 7) for the two scenarios.

Table 5. Monthly and annual average total flow volumes (MCM).

A) A2a Scenarios				
Month	Base period (1977-2000)	2011-2040	2041-2070	2071-2099
January	4.98	2.87	1.36	1.82
February	4.28	2.97	1.67	2.13
March	10.49	3.38	4.04	5.69
April	27.35	13.35	11.00	8.42
May	37.05	11.61	14.06	11.48
June	21.76	8.49	8.53	7.50
July	12.00	6.31	2.78	2.56
August	35.73	11.19	8.78	11.71
September	26.68	7.41	9.07	10.06
October	10.20	4.86	3.53	3.17
November	8.68	2.84	1.83	2.20
December	7.49	1.65	2.04	2.38
Annual	17.23	6.41	5.72	5.76

Table 6. Monthly and annual average total flow volumes (MCM).

B) B2a Scenarios				
Month	Base period (1977-2000)	2011-2040	2041-2070	2071-2099
January	4.98	1.38	1.37	1.33
February	4.28	2.44	1.64	1.28
March	10.49	3.18	5.27	0.86
April	27.35	13.35	11.45	4.00
May	37.05	16.00	14.03	3.98
June	21.76	9.13	8.33	2.18
July	12.00	3.73	2.64	5.73
August	35.73	9.60	8.46	9.88
September	26.68	8.63	8.17	6.50
October	10.20	3.02	2.65	10.78
November	8.68	1.01	1.13	5.41
December	7.49	1.24	1.51	2.68
Annual	17.23	6.06	5.56	4.55

As it can be seen from table (5 and 6) the overall results (2011-2099) for average annual total flow volume showed a decreasing trend for both A2a and B2a scenarios as compared to the base period. The percentage decrement of total average annual flow volume ranged from 2.02% (2011-2040) to 12.47% (2041-2070) for A2a scenario and for B2a scenario the decrement ranged between 7.41% (2011-2040) and 30.11% (2071-2099) as shown in figure (6 and 7). Decrease in average total annual flow volume was observed for the periods which showed a corresponding decrease in mean annual precipitation during scenario developments. As compared to the base period, the mean annual flow volume results of this study were in consent with the findings of Alemayehu *et al.* (2013) on Modelling Impacts of Climate Change on the Hydrology of Weyb in which the mean annual stream flow decreased in the Weyb basin as compared to the base period.

On monthly basis in the month of January (2050-2080), February (2050), March (2020), April (2080), May (2020-2080), June (2080), July (2050-2080), August-September, October (2050-2080) and November-December, the average monthly total flow volume decreased for A2a scenario as compared to the base period. While in B2a scenario, in the month of January (2020-2080), February (2040-2080), March (2020 and 2080), April (2080), May (2080), June (2080), July (2040-2050), August-October (2050), November (2020-2040) and in December, the average monthly total flow volume decreased as compared to the base period.

In the month of November, the total flow volume decreased by 45.43 % (2050) which is the highest percentage change while in the month of January it decreased by 1.98% (2080) and it is the lowest percentage change forA2a scenario. For B2a scenario, the percentage decrease ranged between 4.08% (2080) in the month of December to 77.99% (2080) in the month of March. The decrease in percentage of average monthly total flow volume corresponds to the decrease in precipitation which was shown during scenario development.

In the month of January (2020), February (2020 and 2080), March (2050-2080), April (2020-2050), May (2050), June (2020-2050), July (2020) and in October (2020) the average monthly total flow volume was found to be increasing in A2a scenario and the increment was most dramatic in February (67.64%), which is one of the rainy seasons that contributed the biggest portion of inflow volumes. The range of increment varied between 1.15% (2020) in the month of June to 67.64% (2020) in the month of February for A2a scenario. Moreover, for B2a scenario, it ranged between 1.46% (2050) in the month of May to 183.23% (2080) in the month of October. The largest increment in percentage of average monthly total flow volume occurred in the month of October, while the smallest increment was found in the month of May. The percentage increment of the flow volume here also corresponded to the increment of precipitation.

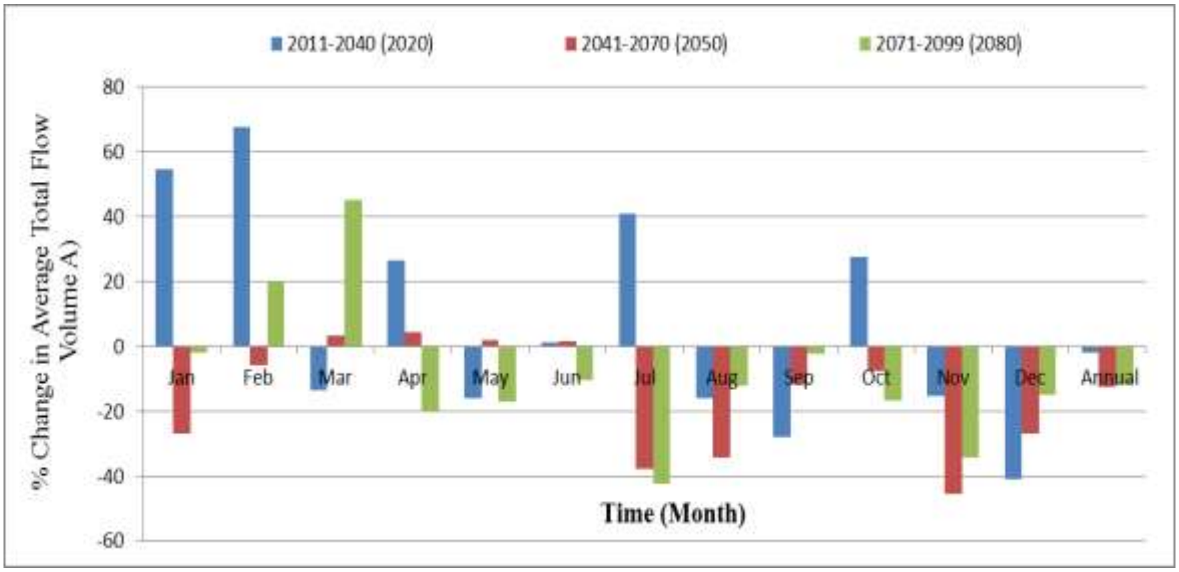


Figure 6. percentage change in average monthly and annual total flow volume for the period 2011-2099 as compared to the baseline period (1977-2000) at Shaya River gauge station for A2a scenario

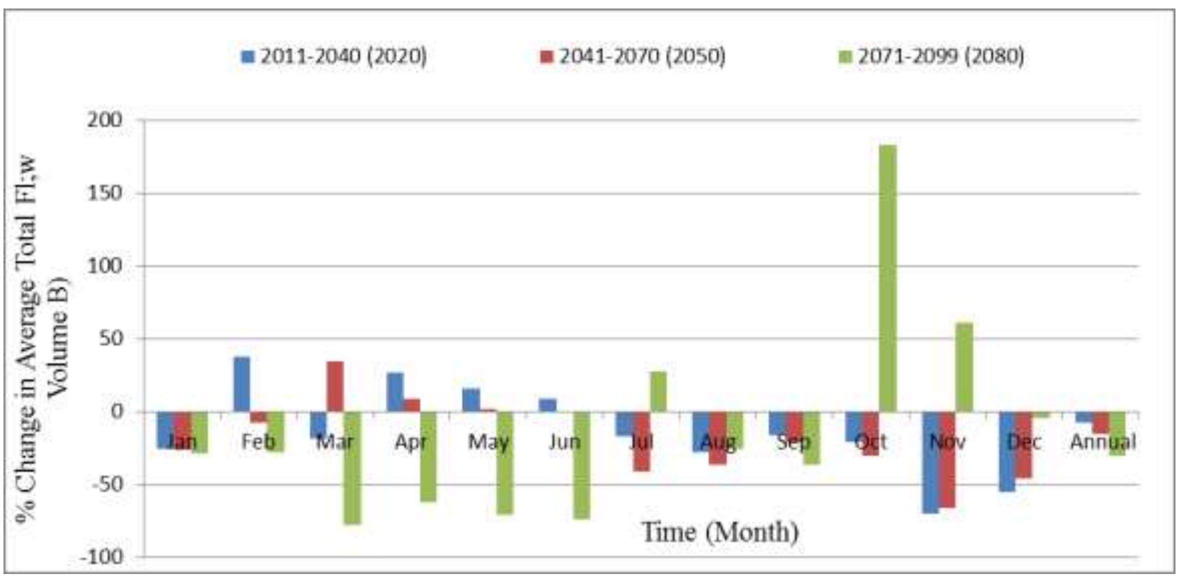


Figure 7. Percentage change in average monthly and annual total flow volume for the period 2011-2099 as compared to the baseline period (1977-2000) at Shaya River gauge station for B2a scenario.

In general, climate change results in an increase and decrease in flow volumes on Shaya River, which is one of the major tributaries of Weyb River. The increase in flow volume might have positive as well as negative implications on the sub-basin. The surplus water can be used for irrigation activities in dry season. Meanwhile, the increase in flow will feed significant amount of inflows for the proposed irrigation dam on Shaya River.

However, the increase in inflow volume of Shaya River was higher in the month of February and some months which may cause flooding problems. The runoff of in Shaya River, with climate change, may become much more seasonal and, as a result, the flow of the River may decrease considerably in some months, while the flow might increase during some part of the year.

It has been reported by Faramarzi *et al.* (2013), Alemayehu *et al.*, (2013) and Setegn *et al.* (2011) that the stream flow is sensitive to the rainfall variability. Similarly, our study showed that the increase in rainfall during the dry season has resulted in increase of stream flow at the same season. Variability of the stream flow, which will result from climate change in the Bale highlands, not only affects the livelihood of people in the Bale zone but also all habitats at the far downstream areas in Somalia whose livelihood is attached to the flow of the river. Drought has been one of the most frequent climate related phenomenon occurring across large portions of the African continent, often with devastating consequences for the agricultural production and food security (Rojas *et al.*, 2011). Particularly the downstream parts of the study area in Southeastern Ethiopia and Somalia have experienced a frequent drought. As projected in this study, the reduction of stream flow in some months may cause water scarcity in the region, and larger increment of stream flow from the baseline scenario may cause flooding to some flood plains. It is crucial to consider and implement integrated water resources management to meet the increasing water demand due to high population growth rate.

4. Conclusion and Recommendation

Predicting the level of climate change impact on water resources is a prerequisite for planners and decision makers to reduce, prevent and/or to find the possible adaptation measures. Against this background, the impact of climate change on Shaya River was assessed to address part of the global problem by showing the possible indicative predictions of climate change.

The study confirmed that the Statistical Downscaling Model (SDSM) is able to simulate climatic events reasonably well. The calibration and validation results of SDSM showed that the model is able to simulate the climatic variables (precipitation and temperature) which follow the same trend with the observed one. Even though the precipitation is a conditional process with high spatial variability, the overall result from SDSM is well correlated with the observed precipitation. Hence, SDSM can predict the future climatic events under changing conditions based on the assumption that the predictor-predictand relationships under the current condition remain valid for future climate conditions.

The downscaled precipitation trend was slightly decreasing but not statistically significant for both scenarios. Generally, increase of rainfall was comparatively higher in some season (dry) which might have positive impact on pastoral region of the study area and it might affect the highland areas negatively due to this season is specifically main crop harvesting period.

The models and model outputs used in this study possessed a certain level of uncertainty. The model simulation considered land use changes and other climatic variables such as wind speed, sunshine hours, and relative humidity will remain constant for the future time horizons although it is not true in the actual case. Hence, the results of this research should be taken carefully and be considered as indicative prediction of the future and further researches should be extended by considering the future land use changes and other climatic variables.

Therefore, it is recommended to use different GCM outputs and emission scenarios to compare the results of different models and explore a wide range of climate change scenarios that would result in different hydrological impacts. Meanwhile, the GCM was downscaled to a catchment level only using statistical downscaling model which is a regression based model, even though other methods exist which are used for impact assessment. Thus, this research should be extended in the future considering other downscaling methods.

Water resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems. Precipitation and temperature are highly affected by climate change and in turn, the change of these climatic variables affects the stream flows, the recurrent floods and droughts. Hence, it is recommended to intensify such kind of researches at the catchment level to give insight for decision makers, planners and stakeholders. As the Shaya River is one of the tributary River feeding the Weyb River and then join Genale and Dawa River, any change in the River flow is likely to affect the people whose life is attached to the flow of the river as well as the Genale and Dawa basin. Hence, future research should consider the impact of climate change on the Genale and Dawa River basins.

5. References

Bale Mountains National Park General Management Plan (BMNP GMP). 2007. Bale Mountains National Park General Management Plan.(Frankfurt Zoological Society, eds.), Ethiopia.

Conway and E. Lisa. 2010. Adaptation to climate change in Africa: Challenges and opportunities identified from Ethiopia, a School of International Development, University of East Anglia, UK Tyndall Centre for Climate Change Research, University of East Anglia, UKc Stockholm Environment Institute, Bangkok, Thailand.

Davidson, O., K. Halsnaes, S. Huq, M. Kok, B. Metz, Y. Sokona, and J. Verhagen. 2003. The development and climate nexus: the case of sub-Saharan Africa. Climate Policy 3S1: S97-S113

Degefu, Workineh. 1987. 'Some aspects of meteorological drought in Ethiopia.' In Michael H. Glantz (Ed), *Drought and Hunger in Africa*. Cambridge: Cambridge University Press.

Dile, YT, R. Berndtsson, Setegn SG. 2013. Hydrological Response to Climate Change for Gilgel Abay River, in the Lake Tana Basin - Upper Blue Nile Basin of Ethiopia. PLoSONE 8(10): e79296. Doi: 10.1371/journal.

Dilnesaw Alamirew, 2006. Modelling of Hydrology and soil Erosion of Upper Awash River Basin. PhD Thesis, University of Bonn.

Faramarzi M., Abbaspour K. C., Vaghefi S. A., Farzaneh M. R., Zehnder A.B., Srinivasan R. and Yang H. 2013. Modeling impacts of climate change on freshwater availability in Africa. *J. of Hydrology* 480 (2013) 85–101.

Farm Africa-SOS Sahel Ethiopia. 2007. Participatory Natural Resource Management Programme and Oromia Bureau of Agriculture and Rural Development, Six Months Report. 45p.

Gissila, E. Black, D. I. F. Grimesc and J. M. Slingo. 2004. Seasonal forecasting of the Ethiopian summer rains, a National Meteorological Services Agency, Addis Ababa, Ethiopia, b Centre for Global Atmospheric Modelling, University of Reading, Reading, UK, c Department of Meteorology, University of Reading, Reading, UK.

Hailemariam Kinfe. 1999. Impact of climate change on the water resources of Awash River Basin, Ethiopia. *Climate Research Journal*, 12: 91-96.

Lijalem Zeray. 2006. Climate change impact on Lake Ziway watershed water availability, Ethiopia. MSc Thesis. University of applied sciences Cologne, Germany. 123p

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J. & White, K. S. 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change.

Neitsch S.L., J.G. Arnold, J.R. Kiniry, J.R. Williams. 2009. Soil and Water Assessment Tool (SWAT). Theoretical Documentation, Version 2009, Grassland Soil and Water Research Laboratory, Agricultural Research Service, Black land Research Centre, Texas Agricultural experiment Station.

NMA. 2006. National Adaptation Programme of Action of Ethiopia (NAPA). National Meteorological Agency, Addis Ababa.

Shawul A. Alemayehu, Alamirew, T., and Dinka, M. O. 2013. Calibration and validation of SWAT model and estimation of water balance components of Shaya mountainous watershed, Southeastern Ethiopia, Hydrol. Earth Syst. Sci. Discuss., 10, 13955-13978, doi:10.5194/hessd-10-13955-2013.

Wilby, R.L. and Dawson C.W. 2007. Statistical downscaling model (SDSM 4.2) – A decision support tool for the assessment of regional climate change impacts, version 4.2, user's

Theme 4: Policy and Institutions to Manage the Impact of El Niño

1. Adaptations of Pastoralists to Climate Change and Variability in the Dry Land Areas of Afar, Ethiopia

Amanuel Mekonnen[1], Desale Kidane[1*], and Demel Teketay[2]

[*1]Samara University, Department of Geography and Environmental Studies P. O. Box 132, Samara, Ethiopia;
[2]Botswana College of Agriculture, Department of Crop Science and Production, Private Bag 0027, Gaborone, Botswana.
*Corresponding Author Email: kidanedesu@gmail.com

Abstract

Pastoralists throughout the Horn of Africa are the most vulnerable group to the impacts of climate change. This study assessed pastoralist adaptation to climate change in Dubti, Asaita, and Mille districts of Afar National Regional State. A total of 250 randomly-selected participants were included for this study. Descriptive statistics, binary and multinomial logit models were integrated with qualitative data analysis techniques to analyse the data collected through household surveys, focus group discussions, interviews and document analysis. The majority of the respondents perceived an increase in temperature (85.2%), a decrease in rainfall (79.6%) and increasing occurrence of drought (78.6%) over the last 30 years. The actual climate data analysis also indicated similar trends. The majority (86.4 %) of the respondents have taken adaptation measures to these perceived changes in climate. The Binary Logit Model revealed that pastoralists perception of increasing temperature and drought, ownership of radios, levels of education, farming experience and extension services have a positive influence on the decision of pastoralists to adapt to climate change; while, gender and nearness to river banks have a negative influence. Afar pastoralists have generally used four major adaptation strategies to climate change: mobility (49.6%), livelihood diversification (19.2%), herd management (12%) and fodder management (5.6%). The Multinomial Logit Model indicated that the choice of pastoralists between major adaptation strategies has been significantly influenced by pastoralist's perception of climate change components (increasing temperature, decreasing rainfall and recurrent drought), ownership of radios, distance from river banks, level of education, the household head's gender and access to extension services. Hence, future interventions to enhance adaptation of pastoralists to climate change should be in line with these factors. More integrated extension services, establishment of climate data centres and more focus on livelihood diversification and herd management systems are recommended.

Keywords: Adaptation strategies; Afar; Binary logit models; Climate change

1. Introduction

Climate change is one of the biggest environmental threats facing the world. Climate change refers to a permanent shift in the state of climate components manifested by changes in the mean and/or the variability of its properties persisting for an extended period of time, typically decades or longer. It occurs either due to natural variability or as a result of human activity (IPCC, 2007). The most common manifestation of climate change are variabilities in temperature and precipitation as well as occurrences of extreme climatic events, especially drought, flooding, sea level rise and storms (hurricanes, tornado, typhoons, etc.). Empirical studies have confirmed that climate change poses direct negative impacts on agriculture, livelihood assets, water resources and the nutrition and health status of people (Henson, 2006; IPCC, 2007; Boko *et al*., 2007). The most adverse impacts of climate change are predicted to hit hardest poor people in the countries of the developing world because of their geographic exposure, already fragile environments, dominance of climate sensitive sectors in their economy and low adaptive capacity (IPCC, 2007; Deressa and Hassan, 2010).

Pastoralism is a way of life based primarily on mobile raising of livestock, particularly small ruminants, cattle and camels, and is one of the climate-sensitive livelihood systems. However, it has been negatively affected by climate variability (Koocheki and Gliessman, 2005; Anderson *et al*., 2008). Many studies indicate that climate change is posing significant adverse impacts on the life of pastoralists (Koocheki and Gliessman, 2005; Anderson *et al*., 2008), such as the death of livestock (due to water shortages and heat stress), conflict over resource utilization and ownership, loss of land to agricultural encroachment, increase in frequency of flooding, spread of human and livestock diseases thriving in the wet season and the weakening of social institutions.

Pastoralists have a high degree of exposure to climate change due to their location in vast arid and semiarid areas all over the world. Compared to highland areas, these areas are characterized by marked rainfall variability, fast return rate of drought cycles and associated uncertainties in the spatial and temporal distribution of water resources and grazing for animal feeding (Conway and Schipper, 2010). Pastoralists are also highly sensitive to such exposure to climate change due to their location which is isolated, remote and underdeveloped. These areas are often highly conflict prone, food insecure and have poor basic service provision, with health and education indicators that are lower than national average (IPCC, 2007; Deressa and Hassan, 2010). Moreover, increasing population growth, unresolved land tenure issues, poor market access, encroachment of large-scale state and private investment and all forms of prevailing political and socioeconomic marginalization make pastoralists more sensitive to the impacts of climate change. That also implies low adaptive capacity to climate change impacts (GebreMichael and Kifle, 2008).

Pastoralists have developed management systems based on diverse adaptation measures, which are well adapted to difficult conditions. Mobility is a common feature of pastoralist's adaptation to changes in climate and scarcity of resources (Hesse and MacGregor, 2006). In addition to mobility, pastoralists have been adapting to climate change thought strategies such as keeping animals that can endure seasonal feed shortages and long intervals between drinking; keeping large herds in the hope that some animals will survive a period of feed shortage; diversification into cropping, engaging in non-pastoralist activities, like trade, etc. (Hesse and MacGregor, 2006; Coppock *et al*., 2009; Niamir-Fuller, 1999). While studies about sedentary agricultural farmers' adaptation to climate change are abundant, studies on pastoralist's adaptation to climate change and variability are very limited which is particularly true at local level analysis (Deressa *et al*., 2008). Hence, the objectives of the study were to identify whether pastoralists in Afar region recognize climate change, examine factors that influence the decision of pastoralists whether or not to adapt to climate change and variability, and assess factors that determine pastoralists' choice of different adaptation strategies to climate change.

2. Materials and Methods

2.1 Description of the Study Area

The study was conducted in Mille, Dubti and Asaita Districts in Zone One of Afar National Regional State in north-eastern Ethiopia (Figure 1). The altitude of the study sites ranged from 424 to 600 m above sea level. The study area is characterized by arid and semi-arid climate with low and erratic rainfall.

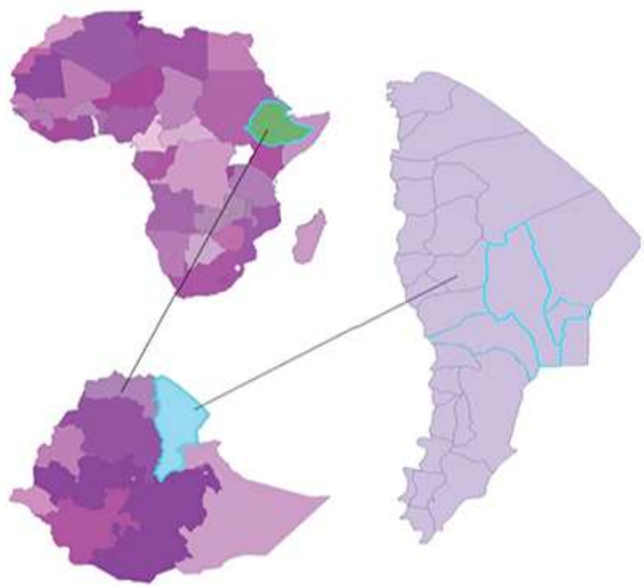


Figure 1. Location of Mille, Dubti and Asaita Districts of Afar National Regional State, Ethiopia.

The mean maximum temperature ranged from 32.1 to 42.1^{0}C and the mean minimum temperature ranged from 15.5 to 24.9^{0}C. The hottest months are March to October and the coldest months are November to February. Mean monthly rainfall ranged from 3.9 to 57.7mm. March, April, July and August receive the most rainfall. Distractive high winds accompanied by dust are very common every day in the afternoon. As a result, the region is a drought-prone area, with major shocks and hazards associated with a recurrence of drought that disrupts the livelihoods of the population.

2.2 Data Collection

A total of 250 households from the three districts were randomly selected. Structured questionnaires (open-ended and close-ended) were developed to gather pertinent information about the awareness of pastoralists to climate change and adaptation decisions and factors that determine a pastoralist's choice of adaptation strategies. The questionnaire was pre-tested for consistency, logical flow, coding and length, and amended accordingly. Training was provided for enumerators who understand and speak the local language (Afaraf) to facilitate successful data collection. In addition to the household surveys, focus group discussions and key informant interviews were carried out with pastoralists and other government authorities to supplement the survey data. In order to ascertain if pastoralists' perceptions of climate change corresponded to actual long term climatic records, 30 years of climatic data from 1981 to 2011 were collected from the Ethiopian National Meteorological Service Agency.

2.3. Data Analysis

Data collected from both household surveys and meteorological stations were quantitatively analysed by using SPSS version 17 and STATA version 12 software. Descriptive statistical techniques, such as frequency, mean, percentage and standard deviation, were employed to compare perception of agropastoralists to climate changes. The Binary Logit (BNL) Model was employed to examine a pastoralist's decision to undertake any adaptation measure. Finally, the Multinomial Logit (MNL) Model was used to analyse a pastoralist's choice of the different adaptation strategies.

2.3.1. The binary logit model

In order to determine whether adaptation is undertaken in response to observation of climate change, a probability model was used, in which the binary dependent variable is a dummy for undertaking any adaptation at all (i.e., Yi) and has only two possible values, 1 or 0, for either adapting or not adapting to climate change.

Thus,

$$Y_i = X_i \alpha + \varepsilon \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

It was assumed that the probability of observing pastoralist *i* undertaking any adaptation at all (Y_i=1) depends on a vector of independent variables (X_i), unknown parameters (α), and the stochastic error term (ε_i) (Gujarati 2003). Assuming that the cumulative distribution of ε_i is logistic, the probability that the pastoralist adapts to climate change is estimated using the logistic probability model specified as (Woodridge, 2001):

$$P(Y = 1|X) = \Lambda(x'\alpha) = \frac{e^{x'\alpha}}{1+e^{x'\alpha}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Then the corresponding log likelihood function for the probability is:

$$ln\ L = \sum_{i=1}^{N} \mathrm{I_i} \ln[\Lambda(x'\alpha)] + (1 - \mathrm{I_i})\ln[1 - \Lambda(x'\alpha)] \ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where I_i is the dummy indicator equal to 1 if the pastoralist *i* undertakes any adaptation at all to climate change and 0 otherwise. The marginal effect for each variable on the probability level is given by:

$$\frac{\partial P(Y=1|X)}{\partial X_k} = \frac{\partial \Phi(Y=1|X)}{\partial X_k} = \Lambda(X'\alpha)[1 - \Lambda(X'\alpha)]\alpha_k \ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

while the marginal effect for a dummy variable, say X_k , is the difference between two derivatives evaluated at the possible values of the dummy i.e. 1 and 0, Thus,

$$\frac{\partial P(Y=1|X)}{\partial X_k} = [\Lambda(X'\alpha)[1 - \Lambda(X'\alpha)]\alpha_k]X_k = 1 - [\Lambda(X'\alpha)[1 - \Lambda(X'\alpha)]\alpha_k]X_k = 0 \ldots\ldots\ldots \ldots\ 5$$

2.3.2. The multinomial logit model

In order to determine factors influencing pastoralists' choice of particular adaptation methods to climate change, Multinomial Logit (MNL) Model was used where the dependent variable is multinomial with as many categories as the number of adaptation methods to climate change. The use of the MNL Model is needed because pastoralists have to choose from many adaptation methods which are unordered and nominal in character (Bartels *et al.*, 1999; Greene, 2000; Wooldridge, 2001; Gujarati 2003). The MNL Model assumes Independence of Irrelevant Alternatives (IIA) (Wooldridge, 2001).

$$P(Y = j\,|\,X) \frac{\exp(X\beta_j)}{1+\sum_{j=0}^{J} exp(X\beta_j)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where β_j is a Kx1 vector and j=0, 1, 2, . . . , J. Equation 6 can only provide the direction of the effect of contextual background on choosing a particular adaptation method. The marginal effects are obtained by differentiating equation 6 with respect to independent variables of interest. The marginal effect for a typical independent variable is given as:

$$\frac{\partial P(Y=j|X)}{\partial X_k} = P(Y = j|X)\left(\beta_{jk} - \sum_{j=1}^{J-1} P_j\, \beta_{jk}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

2.4.3 Description of variables

The dependent variable (DV) is whether a pastoralist takes adaptation at all and it is coded 1 for taking adaptation or 0 for not taking adaptation. Literature states that there are limited studies on the adaptation of pastoralism to climate change and variability, while there are considerable studies on adaptation of sedentary crop farmers to climate change and variability (Hassan and Nhemachena, 2008). Hence, many of the explanatory variables (Table 1) employed in this study are selected with reference to such studies. The explanatory variables are as given below.

Household head's gender: As much empirical evidence indicates, this study hypothesized that pastoralist households headed by males will adapt to changes in climate better than their female counterparts.

Household's annual income: The total annual income of a given household which is expected to have a positive relationship to taking adaptation measures. Since many of the adaptation strategies require financial investment, pastoralists with higher annual income will adapt better to changes in climate and variability.

Farm experience: It is assumed that the more experienced a pastoralist is, the more successful he or she will be in adaptation to climate change and variability. This is because pastoralists know how and when climate changes and what strategies should be followed to respond to such changes.

Level of education: The level of formal education the household head has attained is hypothesized to have a positive significant effect on decisions regarding a pastoralist's adaptation to climate change.

Pastoralist's observation of changes in local climate variables: Local climate variables are increasing temperature, decreasing rainfall and recurrent occurrence of drought. This study hypothesizes that the observation of increased incidence of drought, increasing temperature and decreasing rainfall will positively influence pastoralists' decisions to adapt to climate change.

Location of a pastoral around a river bank: The presence of the Awash River valley in the study area forced the researchers to include this variable in the model. This is due to the assumption that pastoralists near the Awash River valley in different parts of the region will find it easy to get water and animal feed, while the reverse is true for those in remote areas away from the river bank. Hence, it was hypothesized that the proximity of a pastoralist to the river bank will have a negative effect on decisions to adapt to climate change.

Ownership of a radio: Access to timely information is fundamental to adaptation efforts to climate change and variability. Radio is one of the most commonly owned sources of media information by pastoralists. This study hypothesizes a positive relationship between a pastoralist's ownership of a radio and decisions to adapt to climate change, as well as to choose a given adaptation strategy.

Availability of extension services: It is hypothesized that pastoralists who receive extension services and visits tend to adapt to climate change. Here, extension services are expected to have a positive effect on a particular pastoralist's decision to adapt to climate change and to choose specific adaptation strategy.

Pastoralist's major herd: It is a well-established fact that all herd species do not have the same resistance to climate change and variability. The ability of a herd animal to withstand climate change stress varies from type to type. Pastoralists with cattle as their major herd are hypothesized to decide to quickly adapt to shortages of water and pasture caused by climate change and variability.

Table 1. Description of the explanatory variables used in the models.

Variable	Type	Modalities (description)
Household head sex	Dummy	0=Female; 1=Male
Household's annual income	Continuous	Amount in Ethiopian birr
Farming experience	Continuous	Number of years stayed in Pastoralism
Level of education	Continuous	Number of years attended in school
Frequency of drought occurrence	Dummy	0=No; 1=Yes
Increase in temperature	Dummy	0=No; 1=Yes
Decrease in rainfall	Dummy	0=No; 1=Yes
Located along river banks	Dummy	0=No; 1=Yes
Access to media (ownership of radio)	Dummy	0=No; 1=Yes
Receive extension service	Dummy	0=No; 1=Yes
Rear cattle as major herd animal	Dummy	0=No; 1=Yes

3. Results and Discussion

3.1. Demographic Characteristics of the Respondents

Pastoralists in the study area have low education levels. The majority (88.8%) were illiterate and the remaining can only read and write. Moreover, 82% of the respondents were categorized into wealth rank. As far as the gender of the respondents is concerned, 64.6% were male (Table 2).

Table 2. Demographic characteristics of respondents (n=250).

Variables	Frequency	percentage (%)
Education		
Illiterate	222	88.8
Read and write	28	11.2
Wealth status		
Poor	207	82.8
Medium	30	12
Rich	13	5.2
Sex		
Male	161	64.6
Female	89	35.4
Total		100.0

3.2. Pastoralists' Perception on Climate Changes

The majority of pastoralists in the study area have perceived an increase in temperature (85.2%), decrease in rainfall (79.6 %) and increased frequency of drought occurrence (78.6%) within the last three decades (Table 3). The perception of pastoralists is found to be in line with actual climate data as recorded by the Ethiopian National Meteorological Service Agency (ENMSA). All the stations in the study area experienced total annual rainfall amounts of less than 700 mm. The maximum total annual rainfall of Dubti, Mille and Asaita Districts was 255.1, 324.4 and 662.4 mm, respectively. The lowest minimum total annual rainfall in the last thirty years was recorded in Asaita (45 mm). As expected, there is a wide range of variability in totals rainfall i.e., 59.8 to 662.4 mm with a mean of 286.2 mm and standard deviation of 126.76 mm (Figure 2).

Table 3. Pastoralist's perception to changes in selected climate elements (n=250).

Variables	Frequency	Percentage (%)
Increasing Temperature		
Yes (1)	213	85.2
No (0)	37	14.8
Decreasing Rainfall		
Yes (1)	199	79.6
No (0)	51	20.4
Frequent Drought		
Yes (1)	196	78.4
No (0)	54	21.6

The rainfall distribution is bi-modal throughout the region and interruptions in the performance of any rainy season will have an impact on the availability of pasture and water, as well as the overall food security situation of agro-pastoral communities. Rainfall amounts and distribution are of paramount importance to rain-fed agriculture in less developing countries, including Ethiopia (Deressa *et al*., 2009). Research on the climate of Africa by the Intergovernmental Panel on Climate Change (2007) revealed that the amount of total annual precipitation and distribution are highly variable both spatially and temporally.

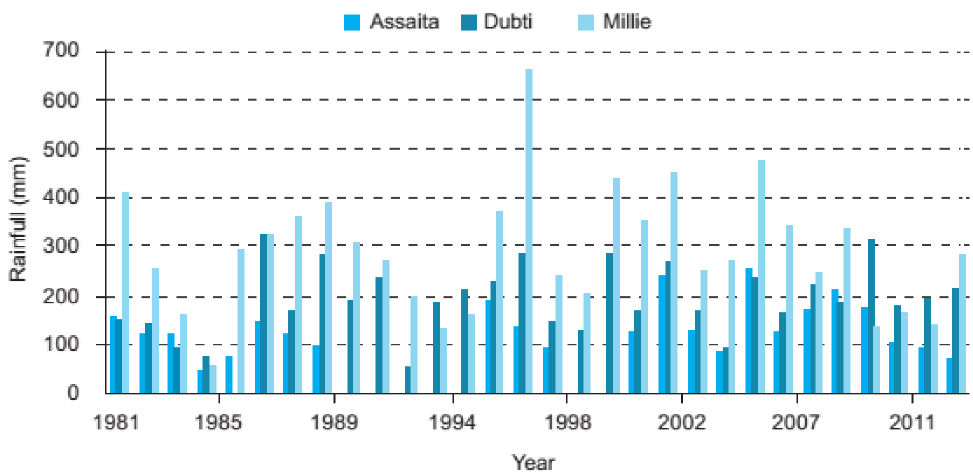


Figure 2. Rainfall trends in Dubti, Mille and Asaita districts.

3.3. Trends of temperature changes and variability

The maximum mean annual temperature recorded over the 30 years was 37.5 ± 1.22, 38.08 ± 0.91 and 38.12 ± 1.09°C, while the minimum mean annual temperature was 34.5 ± 1.27, 37 ± 0.91 and 37°C ± 1.09 in Dubti, Mille and Asaita Districts, respectively (Figure 3). The mean annual temperature of Dubti, Mille and Asaita Districts was 37.5 ± 1.22, 38.08 ± 0.91 and 38.12°C ± 1.09, respectively. As the climate record showed, the temperature changes has increased regularly over the years.

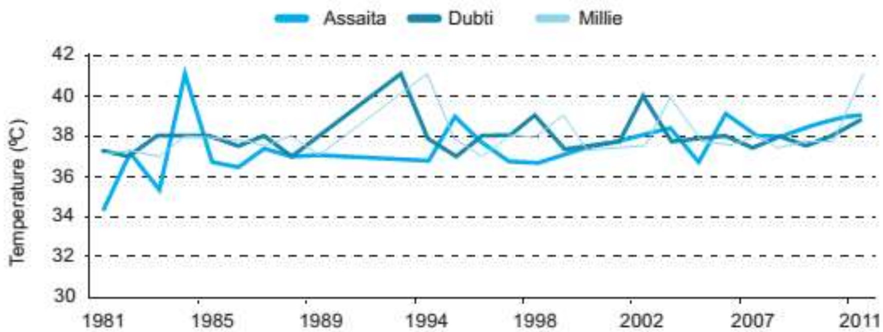


Figure 3. Temperature trends in Dubti, Mille and Asaita districts (1981-2011).

Similarly, Legesse *et al.* (2013) reported that temperatures have been increasing annually at a rate of 0.2°C over the past five decades in the highland of Ethiopia, which has already led to a decline in agricultural production. Climate simulation model showed that in Africa in all seasons the median temperature increased and lied between 3°C and 4°C, roughly 1.5 times the global mean (Herrero *et al.*, 2010).

3.4. Adaptation to Climate Change and Variability

3.4.1. Adaptation strategies

Mobility from area of scarce water and fodder to other areas was practiced by half (49.6 %) of the respondents (Table 4). Such movement was made to areas that border the neighbouring regional states of Tigray, Amhara and Oromia. Pastoralists also stated that this adaptation strategy enabled them to temporarily settle around water points and grazing lands with abundant pasture for their livestock. Mobility has served pastoralists as a successful adaptation method to climatic and environmental hazards, as well as to adapt to the difficult nature of the arid environment. However, the effectiveness of this adaptation strategy is facing increasing pressure due to natural resource-based conflicts. Participants in this study's focus group discussions explained that before the establishment of a federal system in the country they could move to central parts of adjacent regions of Tigray, Amhara and Oromia, but this has become more difficult in the current era.

Table 4. Adaptation strategies by pastoralists (n=250).

Adaptation strategy	Frequency	percentage (%)
Herd management	30	12.0
Fodder Management	14	5.6
Mobility	124	49.6
Livelihood Diversification	48	19.2
No adaptation	34	13.6
Total	250	100.0

The second most important adaptation strategy to climate change by pastoralists was livelihood diversification (Table 4). Pastoralists have been engaged in different sources of livelihood, such as selling of charcoal (Figures 4a and 4b), selling camel milk (Figure 4c), selling tooth brushes, small-scale trade, selling fish products from irrigated areas around the Awash River and selling maize from irrigation projects.

Figure 4. Prosopis that evaded the study area (a), charcoal produced from Prosopis (b) and camel milk being sold by pastoralists on the street (c).

Pastoralists stated that such livelihood diversification activities enabled them to be much more successful in other trade activities. The third adaptation strategy to climate change in their locality (12%) was herd management. Most pastoralists have reduced the number of cattle herds, and increasingly replacing cattle with goats and camels.

The last adaptation strategy practiced by 5.6% of pastoralists was fodder management. Pastoralists in the study areas have begun to make hay and to purchase crop residues from adjacent sedentary farmers and agro-pastoralists. As confirmed by focus group discussion, fodder management has been integrated with the cut and carry system, in which pastoralists cut pasture from protected areas, like the Awash National Park, and carry it to an area where they can store and feed their livestock.

3.5. Factors Influencing Pastoralists' Decision to Adapt to Climate Change

The log-likelihood ratio test of the full model with all its predictors was -80.69671 and makes the overall x^2 was 61.73 ($P<0.0005$). Hence, it is concluded that the variables included in the model explain the variation adequately. Binary Logit Model (Table 5) indicated that location or proximity of a pastoralist to the river bank of the Awash River has a significant negative influence on the decision to adapt to climate change. A one unit change in the proximity of a pastoralist to the river bank will decrease the probability of deciding to adapt to climate change by 10.2% ($p<0.005$) could be due the relative abundance of water and fodder along the river bank. Studies have confirmed that farmers in different environments make different decisions in adapting to climate change (Seo *et al.*, 2009; Nhemachena and Hassan, 2007).

Pastoralists who received extension services have an 8.5% higher probability of adapting to climate change and variability ($p<0.005$). Similarly, results of other studies (Nhemachena and Hassan, 2007; Gbetibouo, 2009;

Deressa and Hassan, 2010; Etwire *et al.*,2013) ascertained the positive relationship between receiving extension services and the decision to adapt to climate change. This is due to the fact that pastoralists who have contact with extension workers will have better knowledge and support in their efforts to adapt to climate change.

The probability of a pastoralist who owns a radio adapting to climate change was 21.59 % ($p<0.001$) higher than those who do not own a radio. The information broadcast on radio about climate change impacts, adaptation strategies and market information induces pastoralists to decide to adapt to climate change (Deressa and Hassan, 2010); Mandleni and Anim , 2011).

Pastoralists who were not illiterate had 6.34% ($p<0.05$) higher probability of adapting to climate change. The more educated they are, the more capable they are to adapt to climate change. Similar studies found that education and knowledge are crucial elements of climate change adaptation measures and natural resource management practices (Glendinning *et al.*, 2001; Hassan and Nhemachena, 2008; Deressa and Hassan, 2010). The level of education of farmers was found to be positively associated with decisions to adapt climate change (Hassan and Nhemachena, 2008). Others found the negative association between level of education and adaptation capacity (Okeye, 1998; Gould *et al.*, 1989).

Table 5. The binary logit model of a pastoralist's decision to undertake adaptation to climate change.

Explanatory variable	Coefficients	Marginal effect (dy/dx)
Pastoralist's perception to increase in temperature #	1.8580***	0.2254*
	[0.6848]	[0.1165]
Pastoralist household owning cattle as a major herd #	0.9533**	0.0688**
	[0.4412]	[0.0336]
Pastoralist's perception to decreasing rainfall #	0.9676	0.0518*
	[0.6563]	[0.0281]
Ownership of radio #	2.1866***	0.2159***
	[0.4913]	[0.0571]
Household head's level of education	1.1701**	0.0634**
	[0.5392]	[0.0257]
Pastoralist who has got extension services #	1.4076***	0.0850***
	[0.5411]	[0.0284]
Pastoralist's perception to increasing drought occurrences#	1.4797***	0.0841***
	[0.5655]	[0.0288]
Household heads Sex #	-0.4108	-.0274
	[0.4590]	[0.0293]
River bank #	-1.5307***	-0.1021***
	[0.5029]	[0.0339]
Farming experience	2.7612***	0.1749***
	[0.6365]	[0.0398]
Livelihood system #	0.1012	0.0071
	[0.4226]	[0.0296]
Constant	8.4363**	
	[1.4622]	
Observation	250	
LR $\chi^2(11)$	61.73	
(p-value)	0.0000	

*Note: Dependent variable is undertaking adaptation to climate change by a particular pastoralist; Standard errors in brackets; *, **, and *** imply 10%, 5% and 1% level of significances respectively; (#) dy/dx is for discrete change of dummy variable from 0 to 1*

Pastoralists who have perceived increasing trends in temperature and increasing frequency of drought were found to have 22.54% ($p<0.1$) and 8.4% ($p<0.01$) higher probability of adapting to climate change, respectively. However, whether a pastoralist had noticed the decreasing amount of rainfall over the last three decades was found to have no effect on decision to adapt to climate change. Similarly others reported that farmers who experience increased incidence of drought, increasing temperatures and reduction in rainfall are more likely to adapt to climate change (Komba and Muchapondwa, 2012; Nhemachena and Hassan, 2007; Gbetibouo, 2009; Deressa and Hassan, 2010). Pastoralists with farming experience was found to have higher probability, 17.49% ($p<0.001$) to adapt climate change. However, studies concluded that farm experience has no effect (Bekele and Drake, 2003; Hassan and Nhemachena, 2008), some reported a negative impact (Lapar and Pandy, 1999; 2006; Nyangena, 2007; Anley *et al*., 2007) and others found positive effects (Okeye, 1998; Bayard *et al*., 2007) on adaptation to climate change.

Pastoralists who rear cattle as their major livestock herd to adapt to climate change was 6.88% ($p<0.05$) higher than those who rear other types of livestock as their major heard (mainly camel and goats). Finally, the model showed that gender of the household head, the type of livelihood system and household income were found to have non-significant effect in predicting the decision of respondents to adapt to climate change.

3.6. Factors Determining Pastoralists' Choice of Adaptation Strategies to Climate Change

Model output indicates a Log likelihood ratio of -261.0722 and x^2 (153.76; p-value < 0.0001), which implied that the model fits significantly better than a model without predictor variables.

3.6.1 Herd management

Cattle as a major herd increases the probability of herd management by 13.16% ($p<0.01$) as opposed to the rearing of other types of herds, such as camel and goats (Table 6). Pastoralists who own radios have a 6.72% ($p<0.05$) higher probability of adapting to climate change through herd management than those who do not (Deressa *et al*., 2008). One-year increase in farming experience increases the probability of using herd management as an adaptation strategy by 6.11% ($p<0.01$). As the level of education increases by one year, the probability of using herd management as an adaptation strategy increased by 5.49% ($p<0.05$).

Table 6. The multinomial logit model marginal effects for a pastoralist's choice of specific adaptation strategy to climate change.

Explanatory variable	Adaptation strategies			
	Herd Management	Fodder Management	Mobility	Livelihood diversification
Pastoralist's perception to increase in temperature #	0.0847 [0.062]	-0.0004** [0.022]	-0.1548 [0.144]	0.0356* [0.081]
Pastoralist household owning cattle as a major herd #	0.1316*** [0.002]	0.0273** [0.033]	-0.0185 [0.791]	-0.0567 [0.213]
Pastoralist's perception to decreasing rainfall #	0.0384 [0.297]	1.02e-07 [0.783]	-0.0177** [0.037]	0.0755* [0.067]
Ownership of radio #	0.0672** [0.041]	-3.79e-07 [0.217]	-0.3024*** [0.000]	0.0291** [0.046]
Household head's level of education	0.0549** [0.042]	0.0001** [0.024]	-0.0886 [0.446]	0.1291 [0.227]
Pastoralist who has got extension services #	0.1137*** [0.001]	0.0533*** [0.003]	-0.0376** [0.038]	0.1718*** [0.006]
Pastoralist's perception to increasing drought occurrences#	0.1382** [0.022]	6.67e-08 [0.851]	-0.0198** [0.037]	0.0283** [0.027]
Household heads Sex #	0.0737** [0.018]	-1.69e-07 [0.585]	0.2596*** [0.000]	-0.4285*** [0.000]
River bank #	-0.0043* [0.070]	-2.79e-07 [0.471]	-0.1205* [0.079]	-0.0104** [0.020]
Farming experience	0.0611*** [0.003]	0.0172** 0.043	-0.0081* [0.090]	0.0805* [0.055]
Number of observations using each adaptation strategy	30	14	124	48

*Note: Base category for adaptation methods is "No adaptation" ; P values are in brackets; *, **, *** imply significance level at 10%, 5%, and 1% respectively; (#) dy/dx is for discrete change of dummy variable from 0 to 1.*

Pastoralists who have perceived increasing frequency of drought in their locality were found to have a 13.82% ($p<0.05$) higher probability of using herd management as an adaptation strategy. Receiving extension services from nearby farmer training centres (FTC) increases the probability of using herd management by 11.37% ($p<0.01$). Households headed by males were found to have a 7.37% ($p<0.05$) higher probability of adapting to climate change and variability through herd management compared to female headed households. Being located near the banks of the Awash River has resulted in a 0.43% ($p<0.1$) lower probability of using herd management as adaptation strategy.

3.6.2 Fodder management

Pastoralists who have perceived increasing temperature in their locality have a 0.04% ($p<0.05$) lower likelihood of using fodder management as an adaptation to climate change and variability compared to those who have not. pastoralists who rear cattle as their major herd have a 2.73% ($p<0.05$) higher probability of using fodder management due to the fact that fodder is mostly used by cattle compared to other herd types. It was also found that a one-year increase in the level of education of the household head increases the probability of using fodder management as an adaptation strategy to climate change and variability by 0.01% ($p<0.05$) (Table 6). The argument behind this is that fodder management requires considerable skill and some behavioural change. Pastoralists who have received extension services were found to have a 5.33% ($p<0.01$) higher likelihood of using fodder management as an adaptation strategy than those who have not received extension services. The likelihood of using fodder management as an adaptation strategy is 1.72% ($p<0.05$) higher for more experienced pastoralists than those who are less experienced. This indicates that when pastoralists have a higher level of education and more farming experience they tend to use fodder management, because with education and experience they acquire the necessary knowledge on how to manage fodder for their livestock.

3.6.3. Mobility

Pastoralists who have perceived a decreasing amount of rainfall have a 1.77% ($p<0.05$) lower likelihood of using mobility as an adaptation strategy. Owning a radio decreases the probability of using mobility as an adaptation strategy by 30.23% ($p<0.05$). These days, the government is encouraging pastoralists to permanently settle and to benefit from public service infrastructures, rather than to move across the region. This policy direction of the government is frequently discussed in the mass media and pastoralists are increasingly becoming aware of it. Receiving extension services was found to decrease the probability of using mobility as an adaptation strategy by 3.76% ($p<0.05$). Pastoralists explain that extension service experts and development agents usually encourage and train them on how to manage their herd and fodder and how to diversify their livelihood. Households headed by males were found to have a 25.96% ($p<0.001$) higher probability than those headed by females to use mobility as an adaptation strategy to climate change.

3.6.4. Livelihood diversification

Increasing temperatures, decreasing trend in rainfall, and increasing frequency of drought have increased the probability of using livelihood diversification as an adaptation strategy by 3.56 % ($p<0.1$), 7.55% ($p<0.1$), 2.83 % ($p<0.05$), respectively. Ownership of a radio, having received extension services and farming experience has increased the probability of using livelihood diversification by 2.91 % ($p<0.05$), 17.18 % ($p<0.01$) and 8.05 % ($p<0.1$), respectively. The focus group discussion participants stated that the government regularly transmits radio programmes that explain the importance of livelihood diversification and how to get involved in it. Such radio programmes have a considerable effect on creating awareness and motivating pastoralists to use livelihood diversification as an adaptation strategy.

Respondents also stated that development agents and other workers that provide extension services are always encouraging pastoralists to diversify their livelihood to other sources of income. In the focus group discussions, pastoralists reported that as their farming experience increased, they had come to understand the lack of productivity of livestock keeping and therefore are gradually shifting to some other livelihood sources, such as irrigation based farming and petty trade. Households headed by males have a 42.85 % ($p<0.001$) lower likelihood of using livelihood diversification than those headed by females. This implies that females are more successful in livelihood diversification, especially in petty trade and commercial activities. The nearer a pastoralist is located to the Awash River bank also increased the probability of using livelihood diversification as an adaptation strategy by 8.05 % ($p<0.1$) over those who are farther away.

4. Conclusions and Recommendations

In order to enable successful adaptation of pastoralists to climate change and variability, extension services should be provided. First, it should be made available to all pastoralists. Extension services need to be adjusted to the mobile nature of the pastoral communities (for instance, by distributing sources of media, like radios, or by arranging mobile posts for extension services). Secondly, extension services should not only focus on improving productivity, but should also integrate dissemination of climatic information. Thirdly, the indigenous way of information dissemination of the Afar people, called Dagu, should be harnessed.

Establishment of a climatic data centre for the Afar National Regional State to record, analyse and disseminate climate related information relevant to pastoral production systems. A special focus should be given to promoting education among pastoralists. Currently, mobility is the major adaptation strategy to climate change, which might be no longer effective because of border and ownership issues with neighbouring regions as well as the villagization programme of the government. Hence, pastoralists should be encouraged to use other strategies, like livelihood diversification and herd management, as well as fodder management to a lesser extent. When pastoralists diversify their source of livelihoods, they will decrease their dependence on livestock which is a highly climate sensitive sector. This is also in line with the settlement programme of the government.

5. Acknowledgements

We wish to express our gratitude to the Ethiopian National Meteorological Services Agency for their support with climate data. We would thank enumerators, development agents, participating agro-pastoralists and clan leaders for their unreserved collaboration. We are also grateful to Samara University, the Afar Region Land Administration and Environmental Protection Bureau and Mille, Asaita and Dubti Agriculture and Livestock Development Offices for all rounded support.

6. References

Anderson *et al.* 2008. "Climate change for agrarian societies in drylands: Implications and future pathways. "Presentation for the World Bank Social Development Division, Conference on the Human Dimension of Climate Change.

Anley Y. and Ayalneh Bogale, Abebe Haile-Gabriel. 2007. "Adoption decision and use intensity of soil and water conservation measures by smallholder subsistence farmers in Dedo District, Western Ethiopia." *Land Degradation and Development,* 18, pp. 289–302.

Bartels, K., Y. Boztug and M. Müller.1999. "Testing the Multinomial Logit Model." Sonderforschungsbereich 373 Humboldt Universitaet Berlin.

Bayard, B. and C. M. Jolly, D. A. Shannon. 2007. "The economics of adoption and management of alley cropping in Haiti.*" Journal of Environmental Management,* 84, pp.62–70.

Bekele, W. and L. Drake. 2003. "Soil and water conservation decision behaviour of subsistence farmers in the Eastern Highlands of Ethiopia: a case study of the Hunde-Lafto area." Ecological Economics 46, pp. 437-51.

Boko, M. *et al*. 2007. "Africa climate change 2007: Impacts, adaptation and vulnerability." Contribution of Working Group II to the 4th Assessment Report of the IPCC, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.), Cambridge University Press, Cambridge, UK, pp. 433-467.

Conway, Declan and E. L. F. Schipper. 2011. "Adaptation to climate change in Africa: Challenges and opportunities identified from Ethiopia." *Global Environmental Change*, 21 (1), pp. 227-237.

Coppock D. L. and S. Desta, S. Tezera, G. Gebru. 2009. "An innovation system in the rangelands: using collective action to diversify livelihoods among settled pastoralists in Ethiopia." Innovation Africa:

Enriching Farmer's Livelihoods, Waters-Bayer A., and C. Wettasinha, J. Njuki, P. Sanginga and S. Kaaria (eds.) *London: Earthscan*, pp. 104-119.

Deressa, Temesgen and R. Hassan. 2010. "Economic impact of climate change on crop production in Ethiopia: Evidence from cross section measures." *Journal of African Economies*, Volume 18, number 4, pp. 529–554.

Deressa, Temesgen and R. Hassan, C. Ringler. 2008. "Measuring Ethiopian farmers' vulnerability to climate change across regional states." IFPRI Discussion Paper 00806.

Deressa, Temesgen and C. Ringler, R. Hassan. 2009. "Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia." *Global Environmental Change,* 19 (2009), pp. 248–255.

twire, M. P. and M. R. Al-Hassan, K. M. Kuwornu, Y. Osei-Owusu. 2013. "Determinants of choice of indigenous climate-related strategies by smallholder farmers in Northern Ghana." *British Journal of Environment and Climate Change*, Vol.5 (6), pp.121-129.

Gbetibouo, A.G. 2009. "Understanding farmers' perceptions and adaptations to climate change and variability: The case of the Limpopo Basin, South Africa." IFPRI Discussion Paper No. 00849. International Food Policy Research Institute, Washington, D.C. p. 36.

GebreMichael, Yohannes and Mebratu Kifle. 2008. "Local innovation in climate adaptation by Ethiopian pastoralists." Prolinnova-Ethiopia and Pastoralists Forum Ethiopia (PFE), Intermediate Report, Addis Ababa.

Glendinning, A. and J. Mahapatra, C. P. Mitchell. 2001. "Modes of communication and effectiveness of agroforestry extension in eastern India." *Human Ecology,* 29 (3), pp. 283–305.

Gould, B.W. and W. E. Saupe, R. M. Klemme. 1989. "Conservation tillage: The role of farm and operator characteristics and the perception of soil erosion." *Land Economics,* 65, pp. 167-182.

Greene, William H. 2000. Econometric Analysis, 4th edition. New Jersey: Prentice Hall.

Gujarati, Damodar N. 2003. Basic Econometrics. New York: McGrawHill. Hassan, R. and Nhemachena, C. (2008). "Determinants of climate adaptation strategies of African farmers: Multinomial choice analysis."*African Journal of Agricultural and Resource Economics,* 2(1), 83 104.

Henson, R. 2006. The Rough Guide to Climate Change: the Symptoms, the Science and the Solutions. London: Rough Guides, Ltd.

Hesse, C. and J. MacGregor. 2006. 'Pastoralism: Drylands' invisible asset?' Issue Paper No. 142. IIED.

Intergovernmental Panel on Climate Change (IPCC), (2007). "Impacts, adaptation and vulnerability." Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Komba, C. and E. Muchapondwa. 2012. "Adaptation to climate change by smallholder farmers in Tanzania." Economic Research of South Africa (ERSA).

Koocheki, A. and R. Gliessman. 2005. "Pastoral nomadism: A sustainable system for grazing land management in arid areas". *Journal of Development Agriculture*, Vol. 25, Issue 4.

Lapar, M. L. A. and S. Pandely. 1999. "Adoption of soil conservation: The case of Philippine uplands." Agricultural Economics 21, pp. 241-256.

Legesse, Belaineh and Y. Ayele, W. Bewket. 2013. "Smallholder farmers' perceptions and adaptation to climate variability and climate change in Doba District, West Hararghe, Ethiopia.". *Asian Journal of Empirical Research*, 3(3), pp.251-265.

Mandleni, B. and F. D. K. Anim. 2011. "Climate change awareness and decisions on adaptation measures by livestock farmers,"85thAnnual Conference of the Agricultural Economics Society, Warwick University, Coventry, UK, p. 26.

Nhemachena, C. and R. Hassan. 2007. "Micro-level analysis of farmers' adaptation to climate change in southern Africa" IFPRI Discussion Paper 00714.

Niamir-Fuller, M. 1999. Managing mobility in African rangelands: the legitimization of transhumance. London: Intermediate Technology Publications.

Nyangena, Wilfred. 2007. "Social determinants of soil and water conservation in rural Kenya," *Environment, Development and Sustainability*, 10(6), pp. 745-767.

Ofuoku, A. U. 2011. "Rural farmers' perception of climate change in central agricultural zone of Delta state, Nigeria." *Indonesian Journal of Agricultural Science,* 12 (2), pp. 63–69.

Okoye, C. U. (1998). "Comparative analysis of factors in the adoption of traditional and recommended soil erosion control practices in Nigeria." Soil and Tillage Research 45, pp. 251–263.

Seo, S. N. and R. Mendelsohn, A. Dinar, P. Kurukulasuriya. 2009. "Adapting to climate change mosaically: An analysis of African livestock management across agro-ecological zones." *The BE Journal of Economic Analysis and Policy,* 9 (2).

Wooldridge, Jeffrey M. 2002. Econometric Analysis of Cross Section and Panel Data. Cambridge and London: The MIT Press.

Yegbemey, N. R., *et al*. 2013. "Farmers' decisions to adapt to climate change under various property rights: A case study of maize farming in northern Benin (West Africa). " *Land Use Policy,* 34 (2013) 168– 175.

Session on dryland ecosystem management

2. Climate Change Adaptation Policies in Southern and Eastern Africa

Sabastiano Rwengabo[1*] and Grace-Maria Kentaro[2]

[1]Plot 96, Kanjokya Street–Kamwokya, P. O. Box 29836, Kampala–UGANDA.;

[2]School of Women and Gender Studies, Makerere University, Uganda. P. O. Box (0256) 7062, Kampala, Uganda

*Corresponding Author Email: s.rwengabo@acode-u.org

Abstract

Despite scientific and political consensus on the threat of climate change, conflicting priorities, limited awareness, and states' institutional and resource weaknesses impasse the development of effective policy strategies for climate change adaptation. Africa is torn between the current obsession with fossil-fuel-driven development on one hand and meeting adaptation costs in a world of unequal development on the other hand. This paper underscores the underdevelopment of climate change adaptation policies in southern and eastern Africa taking South Africa and Ethiopia as an example. The two countries are chosen because of their stable policy environs, stronger economies, dynamic economic-growth patterns, and their relatively more activeness in global climate change processes than their regional peers. Scholarly work and policy documents in each of these countries were examined in order to underline climate change policy priorities and progress made in climate change adaptation strategies. Both countries have attempted to develop policy responses to the problem, and have joined regional and international climate-change adaptation efforts. Ethiopia has made greater strides than South Africa through its Climate-Change Resilient Green Economy (CRGE) Strategy. However, both countries' adaptation strategies lack strong institutional coordination, suffer capacity and resource limitations and limited public awareness, and are affected by competing development priorities, mainly fossil-fuel-driven industrialization. These limitations have vital ramifications for the countries' agriculture, food security, and the effectiveness of their climate-response strategies. We suggest interventions in institutional capacity-development, concurrent with awareness creation and streamlining of national development priorities and engender effective adaptation policy responses.

Keywords: Fossil-fuel-driven development; Policy engagement; Public awareness

1. Introduction

Climate change is one of the greatest challenges affecting the world today. Climate continues to change at rates unprecedented in recent human history, the impacts and risks generated by these changes are increasingly becoming insurmountable. Global warming is one such outcome, and is causing average temperatures to increase in most parts of the world including Africa. This will affect everyone and will have serious impacts on our health, environment and food and water supplies. Warmer temperatures are already changing rainfall patterns, causing snow and ice to melt in some places and droughts in others. Around the world, storms, heat waves, droughts and floods are worsening. Flooding and drought cause soil erosion. Flooding and landslides increase when the soil is dry. An increasing population and deforestation combine to make impact of climate change worse in agrarian society (IPCC, 2007). Despite these realities, climate change responses remain less articulated in policy and technical platforms in Africa and responses to the problem remain less exhaustive than is needed.

Climate change is expected to adversely affect agriculture in Africa. Agriculture remains the main source of income for most rural communities. Making the agricultural sector more adaptive to climate change is imperative to protect the livelihoods of the poor and ensure food security. A good understanding of farmer's perceptions of climate change, farmers' awareness about on-going adaptation measures and decision making process, are important for policy designs such as use of climate-resistant crop varieties, tree planting, soil conservation, changing planting seasons, and irrigation.

Climate change entails large-scale and long term shift in the weather patterns. It involves modification in concentration of atmospheric constituents (mainly greenhouse gases, radiations, particles and many others) though not exclusively due to greenhouse gas (GhG) emissions that increase atmospheric carbon dioxide (CO2), resulting in global warming across time and space. It is not synonymous with-but may be reflected and sometimes exacerbated by sporadic, short term weather changes, artificial weather alterations (like cloud seeding), weather hazards (cyclones, tsunamis, storms), or GhG emissions. Climate Change is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. This alteration calls for adaptive response.

Climate change adaptation involves devising coping strategies to survive extreme weather conditions like droughts, floods, extreme heat, heat waves, wild fires, extreme frost and the bio-ecological impact of these extremes. Adaptation policies are aimed at coping with the negative impact of climate change through adjustments in ecological, social and economic governance systems to reduce climate change vulnerability. They entail developing practical interventions, like National Adaptation Action Plans (NAAP), in order to improve societies adaptive capacity, reduce vulnerability, and develop societal characteristics that enable people to cope with environmental changes born of climate change. As policies are statements of purpose by governments, they indicate what countries intend to make their societies more adaptive to climate change. An assessment of these policies requires an understanding of the possible competing policy options as well as institutional capacity to translate policy pronouncements into practical actions with visible impact.

South Africa and Ethiopia have yet to develop effective adaptation strategies due to capacity limitations in financing, institutionalization, skills development and especially prioritization. The two countries were chosen because they embraced consensus on climate change, joined international efforts on mitigation and adaptation, and have been developing policy responses to the problem. This is not to say that other countries in their respective regions have done nothing, but in addition, the two countries have stable policy environs, stronger economies than their regional peers, dynamic economic-growth patterns, and relative activeness in global climate change processes. Therefore, they can provide sufficient representative information on the basis of which one can draw conclusions about their respective regions. This is useful for drawing lessons for other African countries.

2. Results and Discussion

2.1. Climate Change Adaptation in Africa

The impacts of climate change in Africa have grave implications on livelihood and economic development. In addition, the destruction of properties by extreme weathers like droughts and floods makes the affected communities even more vulnerable. These communities have limited capacity to adapt to the impacts of climate change due to general underdevelopment and lack of sufficient infrastructure for adaptive responses. There is inadequate access to information (in relation to weather and climate, environmental rights, policies and laws) by the communities, thereby limiting their preparedness for adaptation and coping mechanisms to climate change. Additionally, there is limited knowledge and varied understanding of climate change issues and their implications to livelihood and economic development among different stakeholders at various levels. Also worthwhile to note is the inadequate information flow and networking among stakeholders on issues of climate change at local, national, regional and international levels. Indeed climate change threatens to undo many decades of development efforts thereby frustrating poverty eradication programmes and undermining the achievement of Sustainable Development Goals (SDGs; UN, 2016).

2.2. South Africa's Adaptation Policies

For many years South Africa had no clearly-specified climate change adaptation policy, since the development of National Climate Change Response Strategy in 2004 (RSA, 2004). However, before and after the strategy, several relevant policy strategies were made. The White Paper on Environmental Management Policy for South Africa, 1997; the White Paper on Integrated Pollution and Waste Management, 2000; the National Climate Change Response White Paper, 2011; and the Climate Change Response Green Paper, 2010 are some of them (RSA, 2010). In 2011, the country launched its National Climate Change Response Policy with the aim of making a fair contribution to the global effort to achieve the stabilisation of greenhouse gas concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system; and ensuring effective climate change adaption strategy that will build and sustain South Africa's social, economic and environmental resilience and emergency response capacity (Mgquba, 2016).

Realising its vulnerability to climate change, South Africa embarked on an extensive climate change adaptation, institution building, implementation and compliance strategy. While the climate change response policy is not yet implemented. Our analysis underlines the elements of South Africa's climate change adaptation, assessment, planning, implementation, monitoring and evaluation as reflected in the country's policy documents. None of these elements can be delinked from the other as the elements are intricately entwined in all policy processes.

Observation, assessment, and planning elements of South Africa's policy can be traced from 1997. South Africa faced challenges related to bulk energy supply, household energy needs and concerns related to "indoor air pollution and the negative health effects of burning coal and wood fuel", and the emission of "noxious gases" by the petro-dependent transport sector (Debbie, 2006). Petroleum-related pollution, transport pollution, use of kerosene as fuel, coal production and use, radioactive waste from nuclear energy plants, and other problems increased the country's greenhouse gas (GhG) emissions. South Africa, one of the highest GhG emitters in Africa, emits higher levels of GhG than many European economies, due to its high carbon-intensive, energy-intensive economy. This calls for the use of wind, solar, hydroelectric, and other clean energy sources in conformity with global concerns about GhG emissions (Debbie, 2006). Indeed, Odeku and Meyer observe a surge in "Stringent Mitigation and Adaptation Strategies in South Africa" by 2010. Previous laws related to climate change mitigation (NEMA, 1998) were not sufficient to a coordinated response to climate change adaptation. While policy documents (NEMA, 1998) had been developed, the 2011 White Paper indicated the most clear high-policy attention to climate change adaptation in South Africa.

In 1997, the country ratified the United Nations Framework Convention on Climate Change (UNFCCC). It also issued an Environment Management White Paper, and then hosted the World Summit on Sustainable Development in 2002, putting itself on the global map. The UNFCCC requires countries to reduce, control, if possible stop, their sources of GHG emissions. By 2010, the country had realized the need for stringency on climate change adaptation by involving all sectors, central and local government to reduce GhG emissions

(Odeku and Meyer, 2010). The multi-phase integrated strategy culminated in the Climate Change White Paper of 2011. Operationalization of this White Paper entails legal and policy measures addressing rural, coastal, and urban settlements. It also involves responses to regional vulnerabilities through "climate change adaptation strategies based on risk and vulnerability reduction, in collaboration with its neighbours where appropriate, and seek to share resources, technology and learning to coordinate a regional response. A regional approach that achieves climate resilience will have significant socio-economic benefits for South Africa, including a smaller risk of unmanaged regional migration" (RSA, 2004). The White Paper stresses flexible planning for a range of possible responses over the medium-to long-term, monitoring and evaluation systems, continuous scientific knowledge acquirement and application, and effective early warning and forecasting for disaster risk reduction, and mitigating environmentally hazardous industry long-term projections of future climate conditions, climate forecasting to identify potential resource challenges, sustainable management of water, forestry, lands, biodiversity and ecosystems, and human settlements.

South Africa places emphasis on renewable energy (RE) but remains far from reaching the desired destination. The promotion of clean RE echoes global increases in RE research and investment, which is generally, aimed at addressing the triple problem of dependence on fossil fuels for energy, reducing energy poverty, and controlling GhG emissions. While South Africa's strategy lacks "an umbrella statute comprehensively dealing with the promotion of renewable energies", laws such the National Energy Act (2008), and administrative measures by the National Energy Regulator of South Africa (NERSA), were designed and are slowly coordinating the Strategy as the policy and regulatory environment evolves (Lüdemann, 2012).

The final strategy of South Africa's climate change adaptation is hinged on research. Although the 2011 White Paper "has yet to translate into policy that mainstreams adaptation in everyday practice and long-term planning in all spheres and levels of government" (Ziervogel *et al.*, 2014). The country's well developed in earth science research underpins the climate change response scenarios that were developed for the entire region. This endeavour is hardly inconsistent with South Africa's regional commitments as spelt out in the White Paper. The country has research programmes on the biophysical impacts of climate change on sectors like water, agriculture, and biodiversity. This programme integrates climate change scenarios, and appreciates the importance of further research and evidence based interventions in climate change resilient planning and development. South Africa's climate change adaptation policy requires institutional coordination and targeted capacity development, as well as going beyond such rhetoric. Despite a strong national policy making and legislative process with respect to climate change adaptation and mitigation, and recognition for the vulnerability of the poor and marginalized populations, responses to weather related disasters require institutional coordination. There is a growing awareness of the need to quantify the costs of climate-related disasters, and a growing awareness by the private sector of its role (and the opportunities) in mitigation and adaptation (RSA, 2011).

Besides strong institutional coordination, there is policy underdevelopment. It is one thing to have a policy document. It is another to establish the political environment in which such policy commitments can be realised on the ground. The policy is not yet operationalised since 2011. It is doubtful that implementation has begun despite Odeku and Edson Meyer's observations by 2010. To understand the current challenge facing the development and operationalization of South Africa's climate change adaptation policy, one needs to appreciate the longevity of these measures. An array of policy documents and pronouncements on climate change adaptation had not been integrated since 1997. Institutional development and coordination remains underdeveloped. These challenges stymie the establishment of the necessary institutional infrastructure for climate change adaptation as inter-agency coordination remains an administrative burden. The legal framework is also inadequate for climate change adaptation measures, especially in a liberalised economy: laws may sometimes contradict with economic freedoms of investors and entrenched interests of industrial capitalists. A climate change response policy is not an adaptation policy, but also mitigation, which may scatter the country's ability to focus its attention to the consequences of climate change that affect day-to-day lives of South Africans.

In terms of international commitment, South Africa submitted the Intended Nationally Determined Contribution (INDC) to the UNFCCC, indicating its priorities, assumptions, financial commitments, and undertakings until 2013. The likely setback to adaptation is the transition to fossil fuel independent development. Unless the country develops and implements an "industry-policymakers interplay" in which "national policies and other initiatives are taken up for implementation and for a collective mitigation of global CO_2 emissions" (Olivier *et al.*, 2015) by industry players, sub national governments and non-governmental initiatives, high-value industrial production and green energy research and development may stagnate. The country has to directly point its policy focus for addressing the impact of climate change on agriculture, biodiversity, hydrology, urban settlements, public health, energy, food security and funding. The National Adaptation Fund, managed by the South African National Biodiversity Institute (SANBI), does indicate institutional responsibility, but the policy and legal mandate remains less well coordinated and specified. This presents serious challenges for food security and livelihood as will be elaborated after briefly assessing the Ethiopian policy landscape.

2.3. Ethiopia's Adaption Policy Issues

Ethiopia suffers some of the greatest impacts of climate change owing to its greater reliance on climate-dependent natural resources, lack of finance and infrastructure for adaptation, and capacity limitations (McSweeney *et al.*, 2010). The country needs policy interventions that might address these adaptation challenges, a task that the government has recently embarked upon.

The country's environmental objectives are contained in Article 92 of the Constitution. They include: ensuring that all Ethiopians live in a clean and healthy environment; design and implementation of programmes and projects of development shall not damage or destroy the environment; protection of people's right to full consultation and to the expression of views in the planning and implementation of environmental policies and projects that affect them directly; and Government-Citizens' joint duty to protect the environment. The country appreciates the increasing consumption and drain upon natural resources such that" in many areas of highland Ethiopia, the present consumption of wood is in excess of unaided natural sustainable production. Estimates of deforestation, which is mainly for expansion of rain fed agriculture, vary from 80,000 to 200,000 hectares per annum" – hence the country's major goal is to "to improve and enhance the health and quality of life of all Ethiopians and to promote sustainable social and economic development through the sound management and use of natural, human-made and cultural resources and the environment as a whole so as to meet the needs of the present generation without compromising the ability of future generations to meet their own needs" (FDRE, 2011).

An Ethiopian climate-change adaptation policy would need to deal not only with deforestation, farming and food security, and livestock, water access and quality management, waste management, the energy sector (energy security and safety, and renewable energy), but green development as well. The principles of the country's environmental policy do address climate change adaptation elements. The emphasis on sustainable development through the use and management of renewable resources; minimization of use of non-renewable resources and where possible extension of their availability (for example through recycling); adoption, adaptation, development and dissemination of technologies which efficiently use renewable and non-renewable resources; minimizing the degrading and polluting impacts of development activities on the ecological and life support systems.

The policy further stresses that environmental and social costs (or benefits foregone or lost) of damage to environmental resources, as a result of degradation or pollution, "shall be incorporated into public and private sector planning and accounting, and decisions shall be based on minimizing and covering these costs". This reflects the view that conditions should be developed that support community and individual resource users to sustainably manage their own environment and resources, and equal treatment of all users of environmental resources regardless of gender, creed, or identity, during programme and project design, decision making and implementation. The government undertakes regular, and hopefully accurate, assessments and monitoring of environmental conditions, and disseminates this information to the population. The resulting awareness creation, multi-sectoral and multi-level integration of environmental protection issues, and care for biodiversity ecosystems are hoped to, in the long-run, strengthen the country's adaptive capacity (FDRE, 2011). The policy also demands sectoral policies that recognize and protect the varied environmental resources and riches of the country, while also working to protect them from degradation and ensuring appropriate responses. The policy is focused more on mitigation than adaptation.

The observation, assessment, and planning elements in Ethiopia's policy documents reflect the view that the economy highly depends on natural resources, the sustainable use of which may generate great economic benefits in the short term. Unsustainable exploitation of these natural resources increases environmental degradation, decreases economic growth, and erodes livelihood opportunities for especially the vulnerable which makes them susceptible to drought, flooding, temperature increases and more. The key climate change concerns in Ethiopia are related to "environmental health concerns related to malnutrition, polluted water and indoor air pollution; vulnerability to natural disasters and [other] climate change [problems]; lack of secure tenure to land and other natural resources; and unreliable access to food and water" (César and Ekbom, 2013).

Policy processes relevant to climate change adaptation are reflected in the legal and policy pronouncements contained in:

(a) The Constitution of FDR of Ethiopia, 1931/1995 (Art. 44, 43, 51, 92);
(b) Energy Policy, 1994;
(c) Environment Policy of Ethiopia, 1997;
(d) Climate Change National Adaptation Programme of Action (NAPA, 1997);
(e) Climate-Resilient Green Economy Strategy, 2011 (NAPA, 2011); and
(f) Commitments to international climate change instruments, such as convention on biodiversity, Ramsar Convention on Wetlands, UNFCCC, and others.

The most relevant policy to climate change is the environment policy. The policy is vigorous on the necessary observation, assessment, planning and implementation at all levels. It indicates the country's political and technical appreciation of the threats of climate change to the country.

Ethiopia's Green Economy Strategy, in contrast, does pronounce that "If Ethiopia were to pursue a conventional economic development path–represented in a business-as-usual scenario, greenhouse gas emissions would more than double to 400 million tonnes of CO_2 equivalents (Mt CO_2 e) in 2030." In order to build the GRCE, Ethiopia has identified several initiatives, and prioritised 60 of them, based on their local relevance, feasibility, contribution to reaching GTP targets, and significant potential for GhG emission reduction, in order to limit per capita emissions. The Strategy is also focused more on mitigation than adaptation. In terms of adaptation, the NAPA stresses identification of priority projects, institutional arrangements, and information management.

Ethiopians have developed coping mechanisms, such as changes in cropping and planting practices, reduction of consumption levels, collection of wild foods, use of inter-household transfers and loans, increased petty commodity production, migration, grain storage, sale of assets, livestock and agricultural tools, mortgaging of land, credit from merchants and money lenders, use of early warning system, and food appeal/aid (NAPA, 2011). These coping strategies are consistent with scholarly findings that farmers living in the high-climate-risk region, in the lowland savannahs and arid zones of the Sahel region, adapt by switching to integrated agricultural systems involving combinations of crops and livelihood agriculture (NiggolSeo, 2012). In other regions, seed flow within and between communities ensure access to seeds that are adapted to drier or wetter conditions, suggesting important historical and social factors informing farmers' adaptation to risks of climate change and variability (Mwongera *et al*., 2014).

In terms of international responsibility, Ethiopia cooperates with Norway and UK in a strategic partnership that promotes collaboration on international climate change policy. The partnership was crafted during the November 2010 Sixteenth Session of the conference of parties (COP16) in Cancun, Mexico. It seeks to strengthen forest conservation efforts; reinforce climate adaptation in agricultural and pastoral livelihoods; ensure food security and disaster risk management; and support renewable energy development and increase energy efficiency. This would be concurrent with reducing biodiversity loss and supporting capacity building efforts aimed at enhancing institutional responses to climate change. In its initial national communication to the UNFCCC, Ethiopia proposed adaptation options which include: crop, grassland, and livestock interventions; adjustments in agricultural practices; capacity building and institutional strengthening; efficient management of water resources; and management of human health through health surveillance and response systems. Ethiopia also held national consultative workshops through which adaptation options were proposed on agriculture, environmental resources, food security and human health.

Some of Ethiopia's adaption options have synergy with Multi-lateral Environmental Agreements (MEAs), such as instruments related to: community-based development and commercialization of non-timber forest products; community-based rehabilitation of degraded ecosystem for carbon sequestration and trading; propagation and commercial-scale cultivation of crops; establishment of a centre for propagation and commercialization of traditional herbal medicinal plants; and establishment of a national R&D centre for Rio Conventions. Other MEA-relevant options and undertakings include: incentive schemes for farmers (hill-farming communities) to reforest degraded hill areas in the northern region; participatory rehabilitation of degraded hills/ecosystem in northern Ethiopia; and institutional reinforcement for biodiversity conservation. Others include: establishment of National Environment Education Programme (NEEP); reforestation for fuel in Ethiopian highlands; regional capacity building for monitoring and inventorying of biodiversity; promotion of legume-based agro-forestry systems and home-garden agriculture; and development of new and rehabilitation (upgrading) of the existing watering sites in pastoral areas. Proposed measures on aquaculture development for efficient harvest of commercial spirulina species in the lakes of the Ethiopian rift valley system; and reorganization of drought affected community, among others (NAPA, 2001), also fall in this category.

The problem with Ethiopia's climate change adaptation approach is that neither the NAPA nor the Green Economy Strategy is a climate change adaptation policy. Without a policy specifically targeted at climate change adaptation, it remains difficult for the government, regional and international partners, researchers, and other analysts to isolate the climate-change-specific and non-climatic factors that define different communities' vulnerability and adaptive capacity. A good understanding of communities' vulnerability to climate change is important for three reasons: first, vulnerability to climate change, whether it be at family, community, national or global level, "does not exist in isolation of other processes of change", thereby putting into question "the usefulness in assessing climate change impacts solely through endpoint approaches as inputs for informing strategy, policy, and planning" (Carolina *et al*., 2011) that sectoral policies may emphasize. Second, despite the UNFCCC's funding for NAPAs in the developing world, the emergence of adaptation as an important component of climate change responses, especially its emphasis on local benefits accruing from adaptation activities, necessitates that adaptation become a policy and research issue at national and other levels: "Effective climate change adaptation will require informed policy making, which in turn will require research paradigms to evolve toward an integration of natural and social science approaches" (Amanda *et al.*, 2008). This is helpful for addressing immediate risks, intermediate obstacles and long-term threats. The final reason why proper understanding of vulnerability to climate change is a stand-alone policy issue relates to both the local and regional cost and politics of climate change vulnerability. A stand-alone governance framework (policy, operational laws, regulations, guidelines) is needed to inform the costly, sometimes technology- and capital-intensive, research on the different possible climate change adaptation strategies available to different communities across rural-urban, livelihood, and socio-identity divides in a certain socio-political context. Besides, climate change will progressively be associated with intra-state and inter-state conflicts over water, pasture, forced migrations, and food security, as water shortages and droughts cause refugees, competition over access to and control over water resources, and food exacerbate security concerns.

2.4. General Challenges Facing Climate Change Adaptation Policies

Stakeholder engagement, knowledge management, and coordination remains limited when climate change adaptation polices remain scattered in different sectoral policies with differing, sometimes competing priorities. Policy incoherence is at the centre of this challenge. The inadequacies of these policy measures relate more to lack of direct policy on adaptation than in appreciation of the nature, extent, threats, and need to respond to, climate change. Climate change adaptation requires multi-stakeholder responses. Sometimes policymaking and implementing officials may not be the first direct victims of climate change occurrences, whether these occurrences are abrupt, such as weather-storms, or slow, such as changes in average temperatures, agricultural failures, water shortages, or breakout of diseases. The policy, in this scenario, would help in coordinating efforts and resources to address climate change impacts that may be side-lined by sectoral constraints and priorities. It follows that mainstreaming climate change adaptation in other sectors should be a coordination issue, based on an independent policy-institutional framework, not a scattered obligation of government agencies. Besides, government agencies, such as environment management agencies, are more likely to place greater emphasis on mitigation than adaptation.

Institutional-capacity weaknesses, within government and civil society, prevent officials from appreciating the need to develop separate policy documents on climate change adaptation. Susan Rice and Stewart Patrick indicate that the countries under study, save for South Africa, have some of the weak states in the developing world, despite the fact that these states are relatively stronger than their counterparts in their respective regions (Susan and Stewart, 2008). South Africa itself is riddled with corruption and the marauding HIV/AIDS scourge that demands national attention (Hennie, 2004). The policy, making process entails observation, assessment, planning, multiple stakeholder engagement, and implementation of activity-plans. This requires human and non-human resources which may be limited in most of these countries. Other challenges, such as political and bureaucratic corruption gnaw at the marrow of institutional resilience and problem synthesis capacity despite engagement with the UNFCC and other international organizations in which emphasis is put on climate change response.

African countries have their priorities in socioeconomic transformation and poverty reduction, infrastructure development, building state capacity and national security. Ethiopia faces serious challenges of internal security and national cohesion and democratic consolidation as does South Africa. With these immense obligations, states may find it difficult to rake climate change adaptation as a priority despite appreciation of its importance. Response to climate change is a political issue. Democracies need prudent, long term, consistent and justifiable policy agendas to manage climate change risks. They also need to build consensus around the agenda as opposed to attending to other important issues like national security, HIV/AIDS, development. Market-orientated development approaches need to be balanced with state-centric ones in coping with climate change adaptation, by undertaking sometimes contradictory measures like carbon pricing, regulation of CO_2 emissions, promoting energy efficiency, regulating transport and land use, promoting specific technological innovations and promoting and enforcing lifestyle and behavioural changes among the populations. These choices are not easy for developing societies which not only believe they contribute negligibly to global warming, but also have strong need for industries and limited internal consensus on policy priorities.

Inadequate policy implementation and enforcement, even good policies remain on paper and are not translated into practical actions to address climate change issues. Furthermore, weak governance, associated with corruption, failure to account for public resources by implementing institutions, means that support will never trickle down to the vulnerable and most affected sections of society. Rural and marginalized communities remain endangered as available opportunities are stocked in the pockets of a few individuals. Consequently, this will result in further degradation of the environment and natural resources because the communities have to directly depend on the natural resources for livelihood and meeting their basic needs. Climate change is likely to open up various funding mechanisms from within and without for adaptation and mitigation (World Bank, 2010). But without a framework for effective policy implementation and good governance, all these resources would go to waste thus not **a**ddressing the real issues but end up in pockets of a few individuals. One need not delve in the corruption issues in South Africa and Ethiopia to demonstrate the possible link between governance and adaptive effectiveness in these countries.

Climate change adaptation capacity at all levels among various stakeholders is very weak. This is partly due to limited options for livelihood; lack of support to climate change adaptation actions (community, local and national levels) in policies and programme implementation; limited knowledge on climate change adaptation options; and poor planning in the usual way without consideration of the current climate change variability and impacts. The impacts climate change brings are so extreme as to result in loss of property, lives and livelihood. Poor rural and urban communities are very vulnerable to these impacts and hence are most affected when food process rise and floods swallow their environs. None of the countries under assessment has been effective in addressing these issues. The same can be said of other African countries.

Most policies across sectors are 'climate change blind', that is, they are implemented in a business as usual manner despite the immensity of the problem. South Africa and Ethiopia do not have a comprehensive policy on climate change to guide all sectors to mainstream and or become climate sensitive, for while policy documents exist the emphasis given on the threat of climate change is not as strong as other national priorities like industrialization and national security. The possible causes of this laxity include limited prioritization and appreciation, by key policy and decision makers, of the need to develop a national comprehensive policy intervention on climate change; limited funding for facilitating policy-making processes; limited participation and productive involvement of all stakeholders (including the most vulnerable categories) in the policy-making processes; limited and varied understanding of climate change by different policy makers at all levels, and the sheer obstinacy of some actors within and without these countries (UNDP, 2007).

The overall impact of this is limited conceptualization of programmes in relation to addressing climate change impacts through a holistic approach. Most programmes are developed with a mind-set that environment and climate change issues will be addressed by the appropriate lead institutions. The reality seems to be different. National efforts need to be garnered and focused on climate change. None of the countries has raised the antennae of climate change to crisis levels in order to ensure national mobilization for adaptive resilience and development of strategic cushions.

Various stakeholders (such as natural resource users, political leaders at all levels, technical leaders at all levels, communities) are at different levels in terms of understanding climate change issues like its impacts, and appropriate response actions to adapt to the impacts among other aspects. Yet at whatever level, they make decisions and undertake actions which may aggravate, address, prevent or maintain the impacts of climate change. It is therefore important to increase general and specific awareness on climate change through innovative means targeting all categories of stakeholders. This will ensure that most decisions and take actions are taken from an informed point of view in order to implant adaption to climate change impacts. For instance, due to lack of access to weather information, farming communities still plan their farming systems and management in the context of two rainy seasons per year yet they are currently receiving one long rainy season throughout the year. This partly explains the current food shortages in East Africa (Brown, 2008).

3. Conclusion and Recommendations

African countries need interventions in institutional capacity development, awareness creation and prioritization of adaptation. Presently climate change adaptation policies remain unfocused, possibly developed in response to global demands with limited national and regional appreciation of the urgency of climate change adaptation. Capacity development entails the rather obvious issue of technology development and transfer to improve Africa's climate change research and forecasting, skills and competencies development through relevant training, institutional development and support, and enhanced civic engagement of both governmental and non-governmental sectors with the view to establishing general interest.

Financing is both an African and global problem that needs to be addressed. It also underscores states' priorities *vis-à-vis* climate change responses. African states need to consider climate change adaptation as another priority. This is needed in "revitalizing agriculture" and "resolving the energy challenge" as well as "putting in place measures to drive agricultural and industrial transformation", to ensure food security and lower food prices while reducing poverty through climate change adaptation. Ethiopia's Green growth strategy is an encouraging intervention which needs awareness creation at local level and serious implementation. It is unclear whether this strategy directly informs budget priorities. The funding needed for Africa's climate change adaptation is estimated to "vary from $10-60 billion a year" depending on whether capacity building, climate resilience, social adaptation, and accelerated development, are included in estimates. Such farming must be incorporated in states' strategic plans and annual budgets. The tendency to include climate change adaptation in other sectors gives it a marginal position in African priorities which slows the rate of adaptive responses.

There is a great increase in population growth; the challenges that come with the high growth rate are overwhelming, especially in the context of climate change. Improper infrastructural planning and encroachment on wetlands in and around Africa, due to the fast population growth has resulted into severe challenges. This rapid urbanization growth coupled with unplanned settlements has exerted a lot of pressure on the current infrastructure that was designed for a smaller population. In turn the population has encroached on the surrounding environment which was reserved as either wetlands or forests positively correlated with pollution related environmental degradation hence influencing climate change.

Thus, urgent action to redirect mitigation and adaptation measures to respond to inherent problems and the emerging impacts of climate change is needed. Climate change needs interventions in institutional capacity development, awareness creation and prioritization of adaptation. Presently, climate change adaption policies remain scattered, possibly developed in response to global demands with limited national appreciation of the urgency of adaptation.

4. References

Amanda H., Lee Tryhorn, and Rebecca Abramson. 2008. 'Working at the Boundary: Facilitating Interdisciplinarity in Climate Change Adaptation Research', American Meteorological Society.

Brown LR. 2008. World facing huge new challenge on food front. Business as usual not a viable option. Earth Policy Institute, Plan B Update, http://www.earth-policy.org/plan_b_updates/2008/update72.

Carolina E., Amanda H. and Dale Dominey-Howes. 2011. 'What is the Goal? Framing the Climate Change Adaptation Question through a Problem-Oriented Approach', Weather, Climate, and Society, 3 (1):16-30 (at. P. 16).

César E. and Ekbom, A. 2013. Environmental and Climate Change Policy Brief, Gothenborg & Uppsalla: Sida's Helpdesk for Environment and Climate Change, p. 3.

Climate Change National Adaptation Programme of Action (NAPA). 2011. Addis Ababa: Environmental Protection Authority.

Debbie Sparks [with Stanford Mwakasonda]. 2006. 'Energy and the environment', in Harald Winkler, ed., Energy policies for Sustainable Development in South Africa: Options for the future, Cape Town: Energy Research Centre, pp 88-100 (at p. 88).

Fed. Dem. Rep. of Ethiopia (FDRE). 2011. Environmental Policy of Ethiopia, Addis Ababa: Environmental Protection Authority, p. 3 (online).

Hennie van Vuuren. 2004. 'Small Bribes, Big Challenge: Extent and nature of petty corruption in South Africa', SA Crime Quarterly No 9, PP 11-16.

Intergovernmental Panel on Climate Change (IPCC). 2007. A working Group II report on Impacts, Adaptation and Vulnerability. Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, UK.

Lüdemann, C. 2012. 'Renewable Energy Promotion in South Africa: Surrounding Conditions and Recent Developments', *Law and Politics in Africa, Asia and Latin America*, 45 (3): 315-323.

McSweeney, C., M. New, G. Lizcano, and X. Lu. 2010. The UNDP Climate Change Country Profiles Improving the Accessibility of Observed and Projected Climate Information for Studies of Climate Change in Developing Countries, Massachusetts: American Meteorological Society, p. 1.

Mgquba, S. 2016. National Climate Change Response Policy, Cape Town: Department of Water Affairs. [see https://www.thedti.gov.za/parliament/2013/DEA.pdf, accessed 22 April 2016).

Mwongera, C. Joseph Boyard-Micheau, Christian Baron, And Christian Leclerc. 2014. 'Social Process of Adaptation to Environmental Changes: How Eastern African Societies Intervene between Crops and Climate', *Weather, Climate, and Society*, 6 (3):341-353.

NAPA, Ethiopia. 2001, Initial National Communication of Ethiopia to the United Nations Framework Convention on Climate Change, Addis Ababa: Ministry of Water Resources National Meteorological Services Agency (at http://unfccc.int/resource/docs/natc/ethnc1.pdf, 22 Apr. 16).

National Environmental Management Act (NEMA) (No. 107 of 1998). 1998. The Atmospheric Pollution Prevention Act (No. 45 of 1965), Air Quality Act (No. 39 of 2004).

NiggolSeo, S. 2012. 'Decision Making under Climate Risks: An Analysis of Sub-Saharan Farmers' Adaptation Behaviors', *Weather, Climate, and Society*, 4 (4): 285-299.

Odeku, K. and Meyer, E. 2010. 'Climate Change Surge: Implementing Stringent Mitigation and Adaptation Strategies in South Africa'. *Journal of African Law,* 54 (2): 159-183.

Olivier, *et al*. 2015. Trends in Global CO2 Emissions, p. 55.

Republic of South Africa (RSA). 2004. A National Climate Change Response Strategy for South Africa, Pretoria: Department Of Environmental Affairs And Tourism [from https://unfccc.int/files/meetings/seminar/application/pdf/sem_sup3_south_africa.pdf, 20 April 2016).

Republic of South Africa. 2011. South Africa's Second Communication under the UNFCCC, Pretoria: Department of Environmental Affairs, p. I [from http://www.climateresponse.co.za/sites/default/files/SNC_Draft_Nov_2010.PDF, 19 April 2016).

RSA. 2010. National Climate Change Response Green Paper, Cape Town: Department of Environmental Affairs.

Susan E. and Stewart P. 2008. Index of State Weakness In the Developing World, Washington, DC: The Brookings Institution, p.

United Nations (UN). 2016. Sustainable Development Goals, New York: UN.

Ziervogel, G., Mark New, Emma Archer van Gardener, Guy Midgley, Anna Taylor, Ralph Hamann, Sabine Stuart-Hill, Jonny Myers and Michele Warburton. 2014. 'Climate change impacts and adaptation in South Africa', WIREs Climate Change 2014, 5:605–620. doi: 10.1002/wcc.295, p. 605.

3. Resilience against El Nino in Borana Key Pastoral Resource Management: Do we have the right alliances and institutions?

Zelalem Tamrat

Institute of Pastoral and Agropastoral Studies (IPAS) & Department of Gender and Development, CSSH-Haramaya University, Ethiopia.

Corresponding Author Email: zelalemtamrat@gmail.com

Abstract

Actors in key pastoral resource management (KPRM) have been shifting paradigms in Arero district. The KPRM actors' partnership, communications and their institutional arrangements are only beginning to emerge. Hence, there is a need to appreciate existence of some challenges and lessons to learn. This paper aims to explore innovative multi-stakeholder KPRM initiatives. It focuses on actors' institutions and its arrangements, roles and management paradigms. Data were collected through focus group discussions, pastoralist key informant and expert interviews with bureau officers, development agents and NGOs practitioners. Besides, qualitative data was obtained from bureau and NGOs reports and field observations and triangulated. Qualitative interpretation and cases summaries were used. There were promising recognition for pastoralists' knowledge on key resource governance at the centre of the new management paradigm, interest in the approaches of multi-stakeholder resource management and collaborations. However, there are a few limitations that might hinder the potential outcomes in KPRM partnership for effective adaptations. Therefore, action-learning and enhancing interaction of the partners and their paradigms are critical for KPRM.

Keywords: Adaptation; Alliance; Institutions of KPRM; Multi-stakeholders; Resilient pastoral systems

1. Introduction

Pastoralism is by its very nature a form of adaptation to climate change. But contemporary pastoral production systems are challenged by unclear projections of climate change and its impacts (Birch and Grahn, 2007). Strengths, weaknesses, challenges and opportunities of partnerships for key pastoral resource management (KPRM) practices and strategies in the context of resilience and adaptation to climate change at a local level should be explored. It employs the Local Adaptive Capacity Framework (LAC). LAC is composed of five interrelated characteristics, namely: the assets base; knowledge and information; institutions and entitlement; innovation; and flexible forward-looking governance (Jones *et al.*, 2010). Disparate findings have been reported on local level resilience and adaptation to climate changes (Ludi *et al.*, 2011; Zelalem, 2011; Reid, 2013; Berhanu and Beyene, 2015). These beg the questions: what are transformative "institution/institutional arrangement" for local resilience and adaptation? How do actors partner/network to solve development problems (co-learning and co-practicing)? These studies also focus on one or two elements of the LAC framework (Ludi *et al.*, 2011).

Recently, new alliances have been built in the Borana pastoral systems in southern Oromia regional State of Ethiopia. KPRM partnerships involve local actors (i.e. pastoralist communities), government offices (GOs) and non-government organizations (NGOs). The later actors may be called external stakeholders. This could be a paradigm shift in KPRM and governance that entails all LAC framework elements (Jones *et al.*, 2010).

Therefore, this study was aimed to identify, document and assess experiences of these partnership, to assesses actors' organizational practices in the partnership (institutional arrangements), links and roles in KPRM and governance, and to identify potentials and constraints of multi-stakeholders' partnership (KPRM governance) and its implications for implementations of effective resilience and adaptations policies.

2. Materials and Methods

Arero district is located in Borana Zone of Oromia regional state, Ethiopia. It has an estimated area of 10,890km^2. Its altitude ranges from 750 to 1700 meters above sea level. Arero district has three major watersheds: Dawa Basin/ Labu Watershed, Mata Wayna Basin/ Haro Dimtu and Horto Basin and 12, 6 and 3 Kebeles of the woreda, respectively are situated under these three watersheds. Total population of Arero district in year 2002 is estimated to be 73,595 out of which 33,428 are men and 40,167 are women, 93.89 % of the populations are estimated to be rural inhabitants (Birhanu and Mebratu, 2010).

This study was based on a baseline survey of KPRM issues and options that was completed in 2011. Data were collected through focus group discussions with pastoral communities from two pastoral Kebeles-*Wachalee* and *Addaa*. Eighteen individuals included as focus group discussants (FGDs) constituting elders, women and younger groups from each site. Besides, interviews with pastoralist key informant and expert bureau officers, development agents and NGOs practitioners. Furthermore, qualitative data was collected from bureaus and NGOs. Descriptive statistics was used to describe the findings.

3. Results and Discussion

3.1. Key Pastoral Resources Management

The key pastoral resources are livestock, water sources, pasture, salt creator and forest. Arero district has pastoral, agro-pastoral, and alternative livelihoods strategies with 85%, 14% and about 1%, respectively (Birhanu and Mebratu, 2010). Managing pastoral resources in Borana rangelands is not only the responsibilities of indigenous communities, but also through implementations of national development policies. Besides, numerous aid agencies have been attempting to deliver humanitarian services and still several NGOs are playing crucial roles in rangeland resource management and utilizations. Many interventions emphasised on improving food security and livelihoods. For example, pond construction was a very recent collaborative intervention between the State and NGO across the district. However, as FGDs indicated they are severely suffering from lack of water due to broken pond and inability of the community to maintain. Thus, now they are travelling eight hours to the nearest water sources for livestock watering and household consumption. Similarly, Wachalee kebele was experienced inappropriately designed water supply projects, this was because during the planning stage elders' were not consulted which lead to increased conflicts between *Abbaa Hereegha* (*Gadaa* system's water management body) and the new water supply management committee(s). As per the suggestion of the key informants, the most viable intervention would be maintaining and developing potentials already available in the traditional wells, resolving management problems and creating accountability of committee members. All these experiences indicated a critical weakness of most pastoral development interventions by the external agencies.

3.2. Actors and their roles, practices, and institutional arrangement

Currently, KPRM initiatives come from the Community and externally from state, NGOs or State-NGOs in partnership in Wachalee and Addaa kebeles. The pastoralist communities have begun voicing an account of past interventions' negative experiences to any external agency, so that the information would be input to improve practices. Subsequently, the external actors have become flexible. Both GOs and NGOs expert confirmed that all on-going development interventions use a "bottom-up" approach. Besides, the more concerned ones consult with the community from planning, implementation to the evaluation of development projects. These paradigm shifts may bring effective coordination and utilization of scarce resources and efforts efficiently which in turn lead to resilience and adaptive capacity of Wachalee and Addaa kebeles.

Elders' FGDs indicated that generally key pastoral resource governance roles of the Gadaa system is decreasing. Exclusive development intervention and paradigms (external disturbances) are weakening effectiveness of Gadaa resource governance system and hence disorganization of collective management traditions (Sabine, 2004). The important issues of KPRM in the last three Abaa Gaadaas indicated disorganization and weaker social relations leading to lower cooperation or negotiation (Table 1).

Table 1. Historical timelines of KPRM issues.

Year	Events	Remarks
Boru Medaa	Raids	If someone kills somebody, for example, the criminal is punished to pay 60 heads of cattle to the families of the deceased
Liben Jaladessaa	Inter-ethnic conflicts	Frequent conflicts between Gerii clan of Somali ethnic and Borana clan of Oromo ethnic
Guyo Roba	Bush Disease	Key informants attributed the prevailing challenges to mainly restricted mobility, conflict and biased interventions on KPRM

In addition, FGDs noted that because of less mobility and frequent drought, both livestock population and productivity are declining. These problems forced some of the pastoralists to diversify their livelihoods. However, Addaa kebele communities' efforts for land cultivation failed and has aggravated grazing land scarcity. Consequently, pastoralist communities are managing the key pastoral resources amidst confusions.

3.3. Practices of External Institutions in KPRM

The bureau of rural and pastoral development is engaging in extension services of camel production and marketing in the district. The key role of the government are coordination and facilitation in pursuing pastoral development strategies of the governments. Hence, GOs recognized the importance of collaboration and community consultation. Government organizations and NGOs intervention based partnerships in Wachalee and Addaa kebeles are indicated in Table 2. Besides, many more are planned in partnership between the offices-NGOs. Moreover, they are considering to fully involve pastoral communities from throughout the processes.

Table 2. Interventions of government and non-government organizations partnership.

No.	Practices	Actor's Role			Remarks	
		Community	State	NGOs	Strength	Weaknesses
1.	Forage Conservation	Attend-Cooperate in Postponing Current Pasture Use Individually or Collectively	Expert Help Community Identify Stage of Grasses Cutting and Techniques	-----	Increased Efficiency	Equity in Distribution of the Resource has Implication of Wealth
2.	Enclosure (Kaloo On *Lafaa Seraa)*	Initiation	Facilitating	Facilitating	Reduce Vulnerability, Drought and Conflicts	Constraints Include Lack of Labour, Grasses and Water Scarcity and Free Grazing Rangelands
3.	Soil and Water Conservation (Soil Bund)					
4.	Settlement Arrangements	------	Initiation	----	-----	Community Has Its Own Settlement Pattern, any New Intervention Need to Base From the Perspective of Maximizing Key Pastoral Resource Utilization and Management
5.	Water Resources Development (Pump, Motorized Pond and Wells)	Fee Contribution Per Single Species	Funding From Safety Net Programmes	Cistern Construction in Few Kebeles	Increased Water Sources for Community	Poor Community Organization and Mobilizations, Unsustainable (Like The Case of Broken Pond in *Addaa Kebele*)
6.	Experimentation of Bush Clearing	Participate	Initiate	Initiate	Improve Pasture Quality	-------
7.	Researchable Problems	Ideas	Prioritize	Do/Funding	Addresses Urgent Resource Management Problems	-----

3.4. Linkage among KPRM Actors

Currently, pastoral communities seem to be practicing KPRM in controversy. External actors are intervening with contradictory principles and actions. The existence of disarrays between internal and external actors in operationalizing practices of KPRM (Table 2). However, the external actors are changing their approaches and perspectives on the pastoral communities and their development challenges. Although pastoral communities do not seem to be ready to accept the external actors' ways of KPRM, the external actors seem to integrate basic assumptions and guides from pastoral resource governance, at least in principle. This is key positive beginning for a multi-stakeholder approach in KPRM.

4. Conclusion and Recommendation

Recognition of pastoralists' knowledge on key resource governance should be at the centre of the new management paradigm, interest in multi-stakeholder approach and collaborations. In order to reduce the numerous challenges of KPRM, community, GOs and NGOs must strengthen existing linkage and partnership. It also should integrate contemporary technical management practices. Current multi-stakeholder partnership need to get momentum. Partnership among internal and external institutions is expected to increases positive interaction and the capacity to reduce vulnerabilities. Therefore, action learning and revisiting interaction among partners and their paradigms are critical for KPRM which would enable to develop effective procedures and increase actors' capacity for successful adaptation of the pastoral system.

5. Acknowledgement

I am highly indebted to Pastoralist Forum Ethiopia (PFE)-wfd PFE for partnership and financial support. I duly thank all those participated in the data collection.

6. References

Berhanu W, Beyene F. 2015. Climate Variability and Household Adaptation Strategies in Southern Ethiopia. Sustainability, 7(6):6353-6375.

Birch, I.; Grahn, R. Pastoralism-Managing Multiple Stressors and the Threat of Climate Variability and Change. Available online: http://hdr.undp.org/sites/default/files/birch_isobel_and_grahn_richard.pdf (accessed on 10 April 2015).

Ludi, E., Getnet, M., Wilson, K., Tesfaye, K., Shimelis, B., Levine, S. and L. Jones. 2011. Preparing for the future? Understanding the Influence of Development Interventions on Adaptive Capacity at Local Level in Ethiopia. Africa Climate Change Resilience Alliance (ACCRA) Ethiopia Synthesis Report. Overseas Development Institute, London.

Birhanu Worku and Mebratu Kefale. 2010. Baseline Information and General Profile of ARERO Woreda, Pastoralist Food Security Partnership Project (Borana and Gujji Zones of Oromia National Regional State – South Ethiopia). Action for Development (AFD) and SOS Sahel Ethiopia, Co-Funded by EU, TROCAIRE, CAFOD and Christian Aid, Addis Ababa, Ethiopia.

Reid, H., Faulkner L. and Weiser A. 2013. The role of community-based natural resource management in climate change adaptation in Ethiopia: Assessing participatory initiatives with pastoral communities. IIED Climate Change Working Paper No. 6, July 2013.

Zelalem T. Gebreyohannes, 2011.Baseline Study of Key Pastoral Resource Management, Borana Zone of Oromia State: The case of Arero. In 28th Annual Research and Extension Review Proceedings of

Haramaya University. 22-25 October, 2010, Annual Review of Research, Extension, and Community Outreach Services. Lecture theatre I, Haramaya University, Ethiopia.

Theme 5: Climate Change Adaptation and Mitigation for Sustainable Development

1. Cropping System for Food Security in the Face of Climate Change: The Case of Eastern Ethiopia

Fuad Abduselam[1]*, Tamado Tana[1], Jamal Abdulahi[1], Habte Nida[2] & Taye Tadese [2]

[1]Haramaya University, School of Plant Sciences, P. O. Box 138, Dire Dawa, Ethiopia

[2]Melkasa Agricultural Research Centre, Ethiopia

*Corresponding Author Email: abduselamfuad@gmail.com

Abstract

Research was undertaken on a cropping system that can make farmers less vulnerable to changing climate. It was conducted at Fedis Research Station and Mieso sub-station of Melkasa agricultural research centre (ARC) during the 2015/2016 season with two sowing time (April & July) in RCBD. The objective of the study was to evaluate double cropping on yield, and yield components of sorghum and compare its productivity with the single cropping system. Twelve and seven treatments in 2015 and 2016, respectively were evaluate. The preceding crops showed highly significant ($p < 0.01$) difference on days to 50% flowering, days to maturity, grain yield and above ground dry biomass at Fedis and non-significant difference on yield at Mieso. The highest above ground dry biomass was obtained from lablab (var. 147)-6116kg/ha and the highest economic benefit was from mung bean (var. N-26)-30315ETB/ha. During succeeding crops days to 50% emergence, days to 50% flowering, days to maturity, grain yield and thousand kernel weight were highly significantly ($p < 0.01$) affected by the preceding crop while above ground dry biomass and harvest index were significant ($p < 0.05$) at Fedis. Total crop failure occurred at Mieso in 2015 due to prolonged dry spell. Highest grain yield was obtained from local sorghum followed by common bean (var. Batu)-Gubiye, common bean (var. Awash melka)-Gubiye and mung bean (var. N-26)-Gubiye sequences with 3369, 2342, 2107 and 2094kg/ha, respectively at Fedis in 2015. Total above ground dry biomass, monetary value of grain and biomass of double cropping, grain and biomass monetary value of preceding crops and monetary value of grain and biomass of succeeding crops were highly significant ($p < 0.01$) at Fedis. The highest total above ground dry biomass (10417kg/ha) was recorded from the sequences of lablab (var. 147)-Gubiye and pearl millet (var. Kola-1)-Gubiye with 10417 and 9842kg/ha respectively. The highest positive marginal rate of return was shown when practicing double cropping sequence of mung bean (var. N-26)-Gubiye sequence with (+2945.2 ETB/ha). All crops performed very well at both locations during both preceding and succeeding cropping time in 2016. The adoption of these treatments in the cropping system as methods for diversifying farm products would give an additional income. The Mung bean (var. N-26)-Gubiye cropping sequence can be considered profitable and recommended with due attention to pest problems. Further investigation is needed to determine the amount of fertilizer required at which production of both crops can be optimum and economically feasible.

Keywords: Cropping Sequence; Diversification; Double cropping; Sorghum

1. Introduction

Rain-fed agricultural areas of East Africa are often food insecure due to rainfall variability and ongoing soil degradation that negatively impacts crop yields. Agricultural activities and consequently the livelihoods of people reliant on agriculture will be affected by changes in temperature and precipitation conditions in large parts of Sub-Saharan Africa (SSA) (Muller *et al*., 2011). The most influential climatic variables for crop production in East Africa including Ethiopia are temperature and rainfall. Low and unreliable rainfall prevalent in many parts of the lowland areas of Hararghe means a high incidence of drought and crop failure, further contributing to food insecurity and poverty. Small land holdings and shortage of assets of the poor people in the area further limit the choice of crop. The majority of smallholder farmers must plant sorghum to have a chance of providing enough food for their family as sorghum is known to be "camel crops of cereals" though during harsh seasons even total crop failure can occur.

Mono-cropping of sorghum whether it is long or early maturing is their usual practice which aggravates the infestation of striga in case of susceptible varieties and has risk of crop failure in most cases due to erratic and unreliable rainfall (Samuel *et al.,* 2013). Basically, the farming system should be revised in the cropping areas of Fedis, and similar dry lowlands of Hararghe. Since eight-month-cycle sorghum being rain-fed, is simply late maturing and too vulnerable to pests and dependent on rainfall patterns. A re-orientation towards shorter cycle crops like early maturing sorghum, pulses and oil crops would help farmer's better cope with the climatic hazards of the area.

However, farmers in Fedis area are accustomed to sow the local varieties from end of March to the middle of April even if they know the advantage of using improved sorghum varieties reduce risk of striga and yield. This is because farmers do not want to leave their land idle when the rain starts early in March/April until the right planting time of the early maturing striga resistant sorghum varieties. Whereas, these improved varieties are sown after the local varieties from middle of June to the beginning of July and farmers who are adopting improved sorghum varieties are forced to leave their land idle to synchronize its maturity with long maturing sorghum varieties to reduce the high bird infestation prevailing in the area. As a consequence, farmers in a dilemma whether to sow early at the onset of rainfall or leave their land idle until the time of sowing for improved and striga resistant sorghum varieties. In order to alleviate this problem, to use effectively the rainfall before the middle of June, to reduce the infestation of striga, to diversify risk of crop failure and to intensify production of farmers, it is important to undertake research on cropping system. This practice is believed to provide more biomass and yield for the growers. Therefore, this study was done to evaluate the effect of double cropping on yield, and yield components of the sorghum and to compare the productivity of the double cropping system with the single cropping system.

2. Materials and Methods

2.1. Description of the experimental site

The experiment was conducted at Fedis Agricultural Research Centre at Fedis district, Eastern Hararghe zone of Oromia and Mieso sub-station of Melkasa Agricultural Research centre at Mieso district, western Hararghe zone of Oromia. Fedis is 24km far from Harar town in the south direction While Mieso is 25km from Chiro town. Fedis site is located at latitude between 8^{o} 22' and 9^{o} 14'N and longitude between 42^{o} 02' and 42^{o} 19'E, in middle and lowlands areas and the altitude ranges from 500 to 2118 meters above sea level, with a prevalence of low lands. Fedis district receives average annual rain fall of 400 - 804mm; the minimum and maximum air temperature of 20 – 25^{o}c and 30 – 35^{o}c, respectively (Samuel *et al.,* 2013).

Commonly sorghum is the staple crops cultivated by farmers, in the vicinity of the sites. Vertisols and Afilsols soil type are common to the area (Fedis Woreda Profile, 2011). Soil is loam in texture with pH of 7.4 (FARC, 2012). Two rainy seasons characterize Fedis woreda's climate. The first named 'Belg' is the shortest one and takes place between March and May, while the second and the most important is 'Meher' between July and October. The rainfall distribution during the year is bi-modal, with a dry-spell period during the months of June and July which, depending on its duration, may affect crop growth.

2.2. Description of the Experimental Materials

Experimental materials were divided into two; preceding and succeeding crops. The preceding crops were selected on the basis of their current and potential importance and mainly for their early maturity. The succeeding crop was sorghum variety 'Gubiye'. The crops selected as a preceding crop were: mung bean and common bean each with two varieties from pulses; pearl millet, sorghum and bread wheat each one variety from cereals; lablab, cowpea and buckwheat each with one variety and one fallow and local sorghum (var. Muyra) were included as farmers practice or control, while sorghum variety 'Gubiye' was used as succeeding crop.

Diammonium Phosphate (18% N and 46% P_2O_5) was used as a source of nitrogen and phosphorus at planting and Urea (46% N) was used as source of nitrogen after one month of planting during both preceding and succeeding crop. The recommended fertilizer rates of phosphorus and nitrogen were used for all crops in the experiment.

2.3. Treatments and Experimental Design

A field experiment was laid out in Randomized Complete Block Design (RCBD) with three replications and twelve treatment combinations consisting of two control of farmers practice as sole cropping system which are early planting in April and late planting in July. Overall the treatments for this experiment were grouped into two consisting of mung beans (N-26 and MH-97-6), haricot beans (Awash melka and Batu), pearl millet (Kola-1), sorghum (76T1#23), bread wheat (Jafferson), Buck wheat, Lablab, cowpea and controls from farmers' practices of mono cropping (early planting and late planting) as a preceding crops and sorghum variety gubiye as a succeeding crop.

2.4. Data Collection

2.4.1. Data collected for preceding crops

Data collected for phenology and growth were the same for all crops. The parameters were days to 50% emergence, days to 50% flowering and days to physiological maturity. The remaining parameters of yield components and yield: grain yield and aboveground dry biomass yield were collected for all preceding crops in the experiment.

2.4.2. Data collected for succeeding crop

Data collected for phenology and growth and yield components and yield were: Days to 50% emergence, Days to 50% flowering, days to maturity, Plant height, Panicle length, Crop stand count, Thousand kernel weights (g), Grain yield (kg ha^{-1}), Aboveground dry biomass yield (kg ha^{-1}), Harvest Index, Total Above Ground Biomass of the Cropping System.

2.5. Data Analysis

Analysis of variance for the design was carried out using Genstat 15th edition software for the parameters studied following the standard procedures outlined by Gomez and Gomez (1984). When the treatment effects were found to be significant, the means were separated using the least significant difference (LSD) at 5% level of probability.

3. Result and Discussion

3.1. Preceding Crops

Days to 50% flowering and days to 50% maturity were highly significantly varied at (p<0.01) among the preceding crops used in the study on both locations (Table 1). Days to 50% flowering and days to maturity were not recorded for the local sorghum variety since the local sorghum variety was still at its vegetative growth stage. Similarly, days to maturity was not recorded for the lablab as it was at flowering stage when the succeeding crop was planted. Days to 50% flowering was earliest (25.67 days) for buckwheat, but it stayed for long time before it started to set seed and matured. Buckwheat grows in the shortest time period of all cover crops (Bjorkman and Shail, 2010) flowering within 3 to 6 weeks and completely maturing within 11 to 12 weeks and flower continuously for several weeks (Bjorkman *et al.,* 2008). Similarly, common bean (var. Batu), mung bean (var. Borada), mung bean (var. N-26) and common bean (var. Awash Melka) took 36, 38, 38.33 and 42.33 days to 50% flowering, respectively. The wide variation in days to flowering was due to differences among the species.

Table 1. Days to 50% flowering, days to maturity, above ground dry biomass and grain yield of preceding crops grown during *"belg"* season at Fedis and Mieso in 2015/16.

Treatment	DF		DM		YLD(Kg/ha)	
	Fedis	Mieso	Fedis	Mieso	Fedis	Mieso
Lablab	100.67^{a}	100.00^{a}	128.67^{a}	150.0^{a}	NH	NH
76T1#23	67.67^{b}	60.00^{b}	111.00^{b}	106.0^{bc}	BA(9)	433.
Cowpea	65.67^{b}	46.67^{c}	126.67^{a}	107.0^{b}	1647^{a}	345.
Wheat	50.00^{c}	NEAA	78.00^{f}	NEAA	BA(9)	NEAA
Kola1	47.33^{cd}	46.00^{c}	107.7^{c}	103.0^{d}	BA(9)	31.
A/melka	42.33^{de}	47.00^{c}	107.7^{d}	102.0^{d}	1519^{ab}	209.
N-26	38.33^{ef}	33.67^{e}	78.00^{f}	77.0^{f}	1213^{c}	225.
Borada	38.00^{ef}	43.33^{cd}	80.00^{f}	77.0^{f}	1188^{c}	382.
Batu	36.00^{f}	39.33^{d}	83.70^{e}	81.7^{e}	1375^{bc}	197.
B/wheat	25.67^{g}	25.00^{f}	127.33^{a}	105.0^{c}	385^{d}	53.
Local	VS	VS	VS	VS	VS	VS
Fallow	NCAA	NCAA	NCAA	NCAA	NCAA	NCAA
F test	**	**	**	**	**	Ns
SE(±)	3.671	2.472	1.652	0.962	114.5	182.2
LSD (0.05)	6.298	4.279	2.834	1.666	208.2	319.1
CV (%)	7.2	5.0	1.6	1.0	9.4	77.7

***= significant at P = 0.01LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation, DF=Days to 50% flowering, DM= Days to Maturity, YLD= Yield per Hectare, Means in column followed by the same letter(s) are not significantly different at 5% level of significance.*

Similarly, common bean varieties Awash Melka and Batu matured early with 101.67 and 83.67 days, respectively, while cowpea and buckwheat were late with days to maturity of 126.67 and 127.33, respectively (Table 1). Pearl millet and mung bean varieties were also early maturing. At the same time forage lablab was also at flowering stage while the other legumes and cereals were ready to harvest during preceding crop however, it was harvested at vegetative stage. The early maturity of legumes especially common bean and mung bean will make them preferable for double cropping system especially where they can be used as food during annual hungry gap as also reported by Dereje *et al.* (1995) and also can be used as cash crop.

Overall, days to maturity were highly significantly ($p<0.01$) different among the species at both locations during the study. Crops that can fit for double cropping were identified in general though the crops are different and their uses also differ. Grain yield obtained were highly significantly ($p<0.01$) different among the treatments at Fedis and non-significant at Mieso.

The highest grain yield was obtained from cowpea (var. #12688) 1736kg ha^{-1} followed by common bean (var. Awash Melka) 1519kg ha^{-1} and common bean (var. Batu) 1397kg ha^{-1} (Table 1). However; yields of sorghum variety 76T1#23, pearl millet (var. Kola-1) and wheat (var. Jafferson) were not included in the analysis due to bird damage on the plots and lablab also did not have any grain yield since it was late in starting flowering and did not get time to complete its cycle and its above ground biomass was harvested at the time of planting of the succeeding crop.

In a similar study, it was reported that on double cropping of common bean varieties followed by main season early maturing striga resistant sorghum varieties at Boko, common bean variety Awash Melka was the highest yielder with a yield of 1862.8 kg ha^{-1} (FARC, 2013). In another study conducted in South Omo Zone of Southern Ethiopia, mung bean variety MH-97-6 (Boreda) produced 257 kg ha^{-1} followed by mung bean (var. N-26) (Rasa) which produced210 kg ha^{-1} whereas the variety Shewarobit produced 207 kg ha^{-1} (Wedajo, 2015). The better yield obtained might be due to the suitability of the agro-ecology and different agronomic practices followed. However, the yield obtained in this study was far below the potential of the varieties which is 1350 kg ha^{-1} and 800-1500kg ha^{-1} for mung bean (var. Borada) and mung bean (var. N-26), respectively, on research fields (MoARD, 2008 and 2011). The yield obtained from mung bean is promising as the crop has high market demand, high price, and drought tolerance attributes.

The lowest yield was obtained from buckwheat (385 kg ha^{-1}) which was very low compared to its potential of 1400-2000 kg ha^{-1} (MoARD, 2010). The reduction in its yield might be due to continuous flowering and seed set combined with continuous shattering. Pavek (2014) reported buckwheat seeds mature 10 days after flowering and shatter soon after maturing, which reduces yields and potentially causes the problem of emergence of volunteer buck wheat plants in the following year.

3.2. Succeeding Crop

3.2.1. Phenological parameters

The experiment at Mieso failed due to drought during the cropping season which pushed farmers to be supported by emergency aid. Days to 50% flowering was also highly significantly ($p<0.01$) affected by the preceding crops which could be due to the differences in nutrient utilization. Local sorghum varieties were late (160.67 days) in reaching its 50% flowering. The earliest days to 50% flowering were recorded in the sequence of mung bean (var. N-26)-Gubiye and common bean (var. Batu)-Gubiye with 63.33 days followed by Buckwheat-Gubiye, Common bean (var. Awash melka-Gubiye), Bread wheat-Gubiye and mung bean (var. Borada)-Gubiye sequence with 64, 64.33, 64.67 and 64.67 days, respectively (Table 2). The latest 50% flowering were recorded in the sequences of local sorghum, sorghum (var. 76T1#23)-G and lablab (var. 147)-G with

160.67, 67.67 and 67.33 days respectively. The high variation that occurred between treatments consisting Gubiye and local sorghum varieties could be attributed to genetic differences while the variations that occurred among treatments consisting Gubiye were slight, which could attributed to the effect of their respective preceding crops.

Table 2. Phenological, growth parameters and Yield components and yield of succeeding sorghum variety Gubiye grown in double cropping system during 'Meher' at Fedis in 2015.

Crop sequence	DE	DF	DM	PH(cm)	PL(cm)	SCH	TKW(g)	Grain yield (kg ha^{-1})	AGDBM (kg ha^{-1})	Harvest Index (%)
Local sorghum	10.00^{a}	160.67^{a}	221.0^{a}	225.37^{a}	13.07^{d}	85.0	20.68^{a}	3369^{a}	6119^{a}	55.05^{a}
MB(var. Borada)-G	8.00^{b}	64.67^{bcd}	123.3^{bc}	89.47^{b}	25.33^{abc}	83.7	9.50^{bcd}	1826^{bc}	3719^{bc}	49.46^{abc}
MB (var. N-26)-G	8.00^{b}	63.33^{d}	122.3^{c}	88.20^{b}	25.80^{abc}	95.7	11.26^{bc}	2094^{b}	3912^{bc}	53.60^{ab}
CB (var. Batu)-G	8.00^{b}	63.33^{d}	122.3^{c}	87.93^{b}	25.47^{abc}	87.0	12.35^{b}	2342^{b}	4265^{bc}	55.17^{a}
Lablab (var. 147)-G	7.33^{c}	67.33^{bc}	125.0^{bc}	87.93^{b}	27.20^{a}	82.7	10.76^{bc}	2049^{b}	4251^{bc}	48.63^{abc}
Wheat (Jafferson)-G	8.00^{b}	64.67^{bcd}	123.7^{bc}	87.27^{b}	25.47^{abc}	89.3	10.85^{bc}	2052^{b}	3924^{bc}	52.53^{ab}
PM (var. Kola-1)-G	8.00^{b}	65.67^{bcd}	124.0^{bc}	86.20^{bc}	23.60^{bc}	93.7	10.33^{bc}	1961^{bc}	4846^{ab}	41.62^{cd}
CB (var. Awash Melka)-G	8.00^{b}	64.33^{bcd}	122.7^{bc}	85.00^{bc}	25.20^{abc}	99.3	10.91^{bc}	2107^{b}	4716^{abc}	44.78^{abcd}
Cowpea (var. #12688)-G	7.33^{c}	66.00^{bcd}	125.0^{bc}	84.80^{bc}	26.13^{ab}	83.0	9.47^{bcd}	1753^{bc}	3545^{bc}	49.10^{abc}
Fallow-G	8.00^{b}	65.00^{bcd}	124.3^{bc}	83.87^{bc}	23.87^{bc}	96.0	10.64^{bc}	1912^{bc}	3961^{bc}	47.98^{abc}
Sorghum (var. 76T1#23)-G	8.00^{b}	67.67^{b}	125.7^{b}	81.87^{bc}	25.67^{abc}	82.7	8.81^{cd}	1711^{bc}	3912^{bc}	43.89^{bcd}
Buckwheat-Gubiye	7.33^{c}	64.00^{cd}	122.3^{c}	79.40^{c}	23.33^{c}	83.3	6.19^{cd}	1196^{c}	3289^{c}	36.03^{d}
P	**	**	**	**	**	ns	**	**	*	*
LSD (0.05)	0.49	3.61	3.13	7.861	2.770	-	3.400	780.2	1451.7	10.77
CV (%)	3.6	2.9	1.4	4.8	6.8	13.6	18.3	22.7	20.4	13.2

***= significant at P = 0.01, ns= not significant, LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation, DE= Days to 50% emergency, DF= Days to 50% flowering, DM= days to physiological maturity, PH= plant height, PL= panicle length, SCH= stand count at harvest, TKW= thousand kernel weight, AGDBM= Above ground dry biomass, MB= mung bean, CB= common bean, PM= pearl millet and G=gubiye Means in column followed by the same letters are not significantly different at 5% level of significance.*

The days to flowering of the variety Gubiye (63.33-67.67 days) was higher than the one reported by Samuel *et al.* (2013) which was 59 days at Boko. This might be due to the fact that, during the year the drought stress which occurred at the area had a negative effect on growth, phenology, yield and yield related parameters of sorghum. Days to maturity of the sorghum was highly significantly ($P < 0.01$) affected by the preceding crop. Except the local sorghum cultivar, there was no significant difference between the treatments where Gubiye was used as succeeding crop. The days to maturity recorded in this study was higher than that of Samuel *et al.* (2013) who reported 111 days for variety Gubiye.

3.2.2. Growth parameters

Plant height and panicle length were significantly ($P < 0.01$) affected by the preceding crops while the stand count at harvest did not show significant differences among the treatments. The tallest plant was observed by local sorghum (225.37 cm). The main reason why local sorghum is more preferred by farmers is also related with its length of stalk and as the local sorghum cultivars have plant height ranging from 2-3m (personal observation). From the treatments consisting Gubiye relatively taller plants were observed from the sequences mung bean (var. Borada)-Gubiye, mung bean (var. N-26)-Gubiye, common bean (var. Batu)-Gubiye, lablab-Gubiye and wheat (var. Jafferson)-Gubiye with 89.47, 88.20, 87.93, 87.93 and 87.27cm respectively (Table 2). The shortest plant was recorded in the sequence of Buckwheat-Gubiye (79.40cm) which might be due to P scavenging nature.

In experiment conducted at Kako, southern Ethiopia during main cropping season of 2006 Gubiye's height was 118.867cm (Tekle and Zemach, 2014). Similarly, Zerihun (2016) reported plant height 106.91cm for Gubiye in Kile-Bisidimo plain, Harari region during main cropping season of 2014. The difference in results of the two experiments was due to the weather condition during the study and effects of the preceding crops as it was seen in the sequence followed by buckwheat which was negative.

Panicle type of the treatments of local sorghum and '*Gubiye*' are of different types. The local sorghum was '*Muyra*' whic has compact panicle type and length (13.07cm) while variety Gubiye's head is erect and semi loose. The highest panicle length (27.2cm) was observed from the sequences of lablab-Gubiye followed by cowpea-Gubiye and mung bean (var. N-26)–Gubiye with panicle length of 26.13 and 25.81cm, respectively (Table 2). However, the lowest panicle length (23.33cm) was recorded from the sequence of Buckwheat-Gubiye which has significant difference between the six sequences listed above was due to buckwheat effect on its succeeding crop has also seen in other growth parameters (Table 2). In experiment conducted at Kako, southern Ethiopia during main cropping season of 2006 gubiye's panicle length was 20.467 cm (Tekle and Zemach, 2014). Similarly, Zerihun (2016) reported 25.74 cm of panicle length for Gubiye in Kile-Bisidimo plain, Harari region during main cropping season of 2014 which is in the same range to the result obtained in almost all the sequences followed by Gubiye of this study.

3.2.3. Yield components and yield

Thousand kernels weight was highly significantly ($P < 0.01$) affected by the preceding crops. However, local sorghum was significantly different over all other treatments. Thousand kernel weight were highest in the sequences of local sorghum (20.68g) followed by common bean (var. Batu)-Gubiye (12.35g) and mung bean (var. N-26)-Gubiye (11.26g) while the lowest thousand kernel weight were observed in the sequences of buckwheat-Gubiye (6.19g) and sorghum (var. 76T1#23)-Gubiye (Table 2). The differences observed among treatments consisting Gubiye were due effects of their preceding crops and weather condition during experimentation period. This result is lower compared to previous studies conducted on Gubiye in different parts of the country. For instance, Samuel *et al.* (2013) has reported 32.60g at Boko research station, similarly 24.667g of thousand kernel weight were reported by Tekle and Zemach (2014) and Zerihun, (2016) reported 25.29g of thousand kernel weight which were all superior to this study. The main factors that contributed to these low thousand kernel weight could be the overall the low rainfall (249mm) received during succeeding crop. Moreover, the rainfall was erratic and ceased at grain filling stage which had significant effect on kernel weight and even yield during succeeding crop (FARC Metrology, 2015). However, apart from the local sorghum which was sole cropping system the treatments practicing of sequential cropping involving Gubiye as succeeding and different crop types as preceding crops were also influenced by their preceding crops. The sequence of fallow-Gubiye is adopted by Fedis farmers growing early maturing striga resistant sorghum varieties.

The yield obtained for Gubiye is quite good compared to studies of Tekle and Zemach (2014) which was 1654kg ha^{-1}. However, yield obtained for Gubiye were low when considering its yield potential in research fields 4000kg ha^{-1} (EARO, 2004) and compared to previous studies reported by Samuel *et al.* (2013) which was about 3478kg ha^{-1} during 2012 cropping season. Similarly, Zerihun (2016) reported grain yield of 2965.56kg ha^{-1} for Gubiye at Kile-Bisidimo plain. The rainfall pattern during succeeding crop was 249 mm which was less by 160.025mm compared to the last four years in the area (FARC Metrology, 2015).

The lowest grain yield (1196kg ha^{-1}) of the succeeding sorghum variety Gubiye was obtained from the sequence buckwheat-Gubiye which is by far low which might be due to high depletion of nutrients by preceding crop buckwheat in the sequence. In line with this it was known that buckwheat is scavenging P which in turn can take up more soil phosphorus efficiently than other plants. In its growing stage, the roots of buckwheat exude substances that help to solubilize P that may otherwise be unavailable to succeeding plants (Pavek, 2014).

The improvement of soil structure following legume (Wani *et al.,* 1995) and breaking of the cycle of pests and diseases and allelopathic effect of legume crop residue (Sanford and Hairston, 1984) may be an additional reason for the extra yield from the sequences of common bean (var. Batu)-G, common bean (var. Awash Melka)-G, mung bean (var. N-26)-G and lablab (var. 147)-G with 2342, 2107, 2094 and 2049kg ha^{-1} grain yield respectively, compared to the lowest yield of 1196kg ha^{-1} obtained in the sequence of buckwheat (var. Shashe)-G. These results were in line with earlier studies of Singh *et al.,* (1996) and Sharma *et al.,* (2004), which showed that the addition of a legume in the sequence resulted in higher yield and profitability. Inclusion of legumes in the rotation hastened the N and P transformation (Wani *et al.,* 1995; Kannaiyan, 2000) and also increased root growth and N use efficiency of cereal crops, resulting in greater productivity of cereal-based production system (Buresh and De Datta, 1991; Yadav *et al.,* 1998).

Above ground dry biomass yield was significantly ($p<0.05$) affected by the preceding crops. The highest above ground dry biomass obtained was (6119 kg ha^{-1}) from local sorghum which was directly related to plant height as it known local sorghum was taller than early maturing sorghum varieties Gubiye. In treatments consisting Gubiye higher above ground dry biomass were recorded from the sequences of pearl millet (var. Kola-1)-Gubiye and common bean (var. Awash Melka)-Gubiye with values of 4846 and 4716 kg ha^{-1}, respectively which were statistically at par with local sorghum (Table 2). The lowest above ground dry biomass in this study was obtained from the sequence of Buckwheat-Gubiye (3289kg ha^{-1}). As also in other parameters the negative effect of buckwheat in this sequence was due to the nature of buckwheat voracious use of nutrient from the soil. It is to be noted that the highest above ground dry biomass yields of local sorghum cultivar obtained during the cropping season does not mean; farmer's practice of mono cropping of local sorghum cultivar is superior to the remaining double cropping system. Thus, there is a need to consider the overall productivity of the double cropping system.

Harvest index were significantly ($p<0.05$) affected by the preceding crops. Harvest index were highest in the sequences of common bean (var. Batu)-Gubiye (55.17%t) followed by local sorghum (55.05%), mung bean (var. N-26)-Gubiye (53.60%) and bread wheat (var. Jafferson)-Gubiye (52.53%) which are all at par (not significant) between them while the lower harvest indices was observed in the sequences of buckwheat-Gubiye (36.03%), pearl millet (var. koa-1)-Gubiye (41.62%) and sorghum (var. 76T1#23)-Gubiye (43.89%) which are also at par (Table 2). The main reason for high values of harvest indices were due to defoliation of leaves at later stages of the plant developments compounded with the stress occurred during reaching maturity which have direct influence on the above ground dry biomass of the crop which intern increase the value of harvest index.

High harvest index in the sequence of common bean (var. Batu)-Gubiye may be due to the presence of good partitioning of dry matter to grain yield which might have benefited from nitrogen fixation and decomposition of root and some other parts of common bean (var. Batu). Lowest harvest index of the sequence of buckwheat-gubiye might be due to poor crop growth of Gubiye which was affected by its preceding buckwheat as its above ground dry biomass was also lowest than others (Table 2) and which in turn have negative effect on partitioning of dry matter to grain yield. As reported by Tekle and Zemach (2014) harvest index for Gubiye were 20.47% which is very low compared to this study. In another study, Berhane *et al.* (2015) reported harvest index of 51.1% which is the same range with some of the treatments in this study of sequences (Table 2). Regarding variety, Gubiye has lower harvest index (33.93%) compared to Teshale and Hormat with 54.51 and 39.67%, respectively (Zerihun, 2016).

4. Conclusions and Recommendations

Mung bean (var. N-26)-Gubiye sequence can be considered as profitable cropping sequence and recommended with due attention of pest problems.

However, further investigation is required to determine the amount of fertilizer required at which production of both crops can be optimum and economically feasible and experiment must be repeated over years and locations focusing on legumes as preceding crops and considering the forage on its quality attributes such as palatability and crude protein values of the preceding crops.

5. References

Berhane Sibhatu, Ketema Belete and Taye Tessema. 2015. Effect of Cowpea Density and Nitrogen Fertilizer on a Sorghum-Cowpea Intercropping System in Kobo, Northern Ethiopia. *International Journal of Agriculture and Forestry*, 5(6): 305-317 DOI: 10.5923/j.ijaf.20150506.02

Bjorkman, T. and Shail J.W. 2010. Cover Crop Fact Sheet Series: Buckwheat. Available at http://covercrops.cals.cornell.edu/pdf/buckwheatcc.pdf (accessed 7 Jan 2016). Cornell University Cooperative Extension, Ithaca, NY.

Bjorkman, T., R. Bellinder, R. Hahn, and Shail J.W., Jr. 2008. Buckwheat Cover Crop Handbook. Available at http://www.hort.cornell.edu/bjorkman/lab/covercrops/pdf/ bwbrochure. pdf (accessed 7 Jan 2016). Cornell University Cooperative Extension, Geneva, NY.

Buresh R. J and De Datta S. K. 1991. Nitrogen dynamics and management in rice-legume cropping systems. *Adv Agron.,* 45: -59.

Dereje Negatu, Teshome Girma and Amare Abebe. 1995. Lowland pulses improvement in Ethiopia. pp.41-47. In: Twenty-five years of research experience in lowland crops. Proceedings of the 25th Anniversary of Nazreth Research Center.22-23 September 1995. Melkassa, Ethiopia.

EARO (Ethiopian Agricultural Research Organization). 2004. Directory of Realesed Crops and their Recommended Agricultural Practices. Addis Ababa, Ethiopia.

Fedis Agricultural Research Center (FARC). 2015. Metrological report of climatic condition of Fedis station. Harar, Ethiopia.

Fedis Agricultural Research Center (FARC). 2013. Soil Chemical Analysis: Regional Review, Zeway, Ethiopia.

Fedis Woreda Profile. 2011. Socio-economic Profile of Fedis District. East Hararghe, Ethiopia.

Gomez, K.A. and Gomez, A.A. 1984. Statistical Procedures for Agricultural Research, 2nd edition, John Wiley and Sons, New York, p.680.

Kannaiyan S. 2000. Integrated nutrient management strategies in wetland rice eco-system. In: Kannaiyan S, Thiyagarajan TM, Mathan KK, Savithiri P, Selvakumari G, Murugappan V, editors. Theme papers on integrated nutrient management. Tamil Nadu: Tamil Nadu Agricultural University, and Department of Agriculture. p. 1–20.

MOARD (Ministry of Agriculture and Rural Development). 2008. Animal and Plant Health Regulatory Directorate: Crop Variety Register Issue, No. 12. Addis Ababa, Ethiopia

MOARD (Ministry of Agriculture and Rural Development). 2010. Animal and Plant Health Regulatory Directorate: Crop Variety Register Issue, No. 14. Addis Ababa, Ethiopia

MOARD (Ministry of Agriculture and Rural Development). 2011. Animal and Plant Health Regulatory Directorate: Crop Variety Register Issue, No. 15. Addis Ababa, Ethiopia

Mu¨ ller, C., Cramer, W., Hare, W.L., Lotze-Campen, H. 2011. Climate change risks for African agriculture. Proceedings of the National Academy of Sciences of the United States of America 108, 4313–4315.

Pavek, P.L.S. 2014. Evaluation of Cover Crops and Plantings Dates for Dryland Eastern Washington Rotations. Plant Materials Technical Note No. 25. United States Department of Agriculture – Natural Resources Conservation Service. Spokane, WA.

Samuel Tegene, Birhanu Atomsa, Amsalu Ayana, Asrat Zewidie, Alemayehu Biri,Gabisa Banti, Solomon Ayele and Fikadu Taddesse. 2013. Efforts towards solving the disasterous effect of extreme *striga hermontica* infestation and shortage of rain on sorghum production in the lowlands of eastern Ethiopia. Open American Journal of Agricultural Research Vol. 1, No. 1: PP: 01-15

Sanford J.O. and Hairston J.E. 1984. Effects of N fertilization on yield, growth and extraction of water by wheat following soybean and sorghum. *Agronomy J.,* 76: 623-627.

Sharma P.R, Pathak S.K, Haque M, Raman K.R. 2004. Diversification of traditional rice (*Oryza sativa*)-based cropping system for sustainable production in South Bihar alluvial plains. *Indian J Agron.,* 49: 218-222.

Singh Y, Chaudhary D.C, Singh S.P, Bhardwaj A.K, Singh D, Singh D. 1996. Sustainability of rice-wheat sequential cropping through introduction of legume crops and green manure crop in the system. *Indian J Agron.,* 41: 510-514.

Tekle Yoseph and Zemach Sorsa. 2014. Evaluation of Sorghum (*Sorghum bicolor (*L.) Moench) Varieties, for Yield and Yield Components at Kako, Southern Ethiopia. *Journal of Plant Sciences,* Vol. 2, No. 4, 2014, pp. 129-133. doi: 10.11648/j.jps.20140204.12

Wani S.P, Rupela O.P, Lee K.K. 1995. Sustainable agriculture in the semi-arid tropics through bilogical nitrogen fixation in grain legumes. *Plant Soil,* 174: 29-49.

Wedajo Gebre, 2015. Adaptation study of improved mung bean (*Vigna radiate*) varieties at Alduba, south Omo, Ethiopia. *Research Journal of Agriculture and Environmental Management*, Vol. 4(8): pp. 339-342.

Yadav R.L, Dwivedi B.S, Gangwar K.S, Prasad K. 1998. Overview and prospects for enhancing residual benefits of legumes in rice and wheat cropping systems in India. In: Kumar Rao JVDK, Johansen C, Rego TJ, editors. Residual effects of legumes in rice and wheat cropping systems of Indo-Gangetic Plain Patancheru: International Crops Research Institute for the Semi-arid Tropics. p. 207–225.

Zerihun Sarmiso. 2016. Effect of Nitrogen Fertilizer on Striga Infestation, Yield and Yield Related Traits in Sorghum [(*Sorghum Bicolor* (L.) Moench] Varieties at Kile, Eastern Ethiopia. *Journal of Biology, Agriculture and Healthcare*, Vol.6, No.2.

2. Effects of Climate Change on Food Grain Production in Oromia Special Zone in the Amhara Regional State, Ethiopia

Habtamu Wondemagegnehu

[1]Department of Geography & Environmental Studies, Samara University
*Corresponding Author Email: whabtamu@gmail.com

Abstract

Despite its negligible emission of GHGs, Ethiopia has been affected by the adverse impacts of climate change and variability, which affected different sectors among which the agricultural sector is of a critical focus of this study. The general objectives were to assess the vulnerability of food grain production to climate change and variability in Oromia zone of Amhara region, Ethiopia. The researcher employed least squares method, Spearman's rho test, CV, PCI, standardized anomalies, arithmetic mean, correlation and regression to assess the climate variability of the study area over the last three decades and to find out their relation with food grain production. Accordingly, Kiremt rainfall had positive trends in all stations except Jille-Timuga. The rainfall in the area was characterized by alternation of wet and dry years in a periodic pattern. Dry years recorded as low as 45.9% below the long-term average. maize, teff, and Sorghum production show considerably high correlations with the kiremt rainfall. SDSM was also used to downscale the present and future monthly precipitation and temperatures from the UK Hadley Center GCM- HadCM3. A2 and B2 future emission scenarios considered for the periods 2030s, 2060s and 2080-99. The downscaled future climate showed that the mean daily minimum and maximum temperatures increase by 0.01^{0}C/0.05^{0}C (2030s), 0.06^{0}C/ 0.1^{0}C (2060s) and 0.15^{0}C /0.2^{0}C (2080-99) and annual precipitation also expected to increase up to 2%/4% compared to base period. The output of downscaled data provided for the Aqua Crop model to estimate yield considering different levels of CO_2 concentration. The simulated result indicated that crop yield could be sensitive to CO_2 fertilization, changes in rainfall pattern and temperature. Hence, to overcome such climate related effects, building regional level climate modelling capacity, providing timely information, and employing climate smart agricultural practices is important.

Keywords: Aqua Crop; Climate change; Crop yield; SDSM

1. Introduction

A recent study by the World Food Programme estimates that globally, 10-20% more people will be at risk of hunger by 2050 than would be without climate change. Of these, almost all will be in developing countries, with 65% expected to be in Africa (FAO, 2010).

The risk of hunger resulting from climate change impacts are the result of both direct impacts on food systems, and indirect impacts that affect the different dimensions of food security, such as change in climate increased the frequency and severity of extreme weather events which lead to crop failure/reduction of yield, loss of livestock, increase cost of marketing and distributing food and rising temperature result in reduced soil moisture, increased crop pest, shifting agricultural seasons and erratic rainfall (CARE, 2013).

Agriculture remains by far the most important sector in the Ethiopian economy. The sector is dominated by small-scale mixed crop-and-livestock production with very low productivity. The major factors responsible for this low productivity include: reliance on obsolete farming techniques; soil degradation caused by overgrazing and deforestation; poor complementary services such as extension services, credit, markets and infrastructure; and climatic factors such as drought and flood (Deressa, 2007). These factors reduce the farmers' adaptive capacity and/or increase their vulnerability to future changes, negatively affecting the performance of the already weak agricultural sector. Agriculture is mostly rain fed, whereas inter-annual and seasonal rainfall variability is high and droughts are frequent in many parts of the country. Rainfall variability has historically been a major cause of food insecurity and famines in the country (Woldeamlak, 2006). The current government of Ethiopia has given top priority to agricultural sector and has taken steps to increase its productivity. However, various problems are holding this back. One major cause of under production is climate change, which often causes droughts and floods that lead to famine. This climate related disasters make the nation dependent on food aid. The amount and temporal distribution of rainfall is generally the single most important determinant of inter annual fluctuations in national crop production levels (Mulat *et al.*, 2004). Even though rainfall variability and droughts are not a new phenomenon in Ethiopia, its frequency of occurrence has reportedly increased during the past few decades (Ketema, 2006). In addition, these years of drought and famine (1984/1985, 1994/1995, 2000/2001) are associated with very low contributions, whereas years of good climate (1982/83, 1990/91) are associated with better contributions.

United States Agency for International Development-Livelihood Integration Unit, (USAID-LIU, 2007) final report pointed out that South Wollo and Oromia eastern lowland sorghum and cattle livelihood zone, where Artuma-Fursi, Dewa-Chefa, Jille-Timuga, Bati and Dewa-Harewa woredas of Oromia nationality zone are located, are one of the most vulnerable regions to climate change impacts. The authors acknowledged that the economy is based on crop production but livestock rearing has a special importance amongst wealthier farmers. Crop production is highly dependent on rainfall. Hence, it is the frequency of irregular precipitation and rain shortage that make the zone chronically food insecure. Therefore, this study is intended to fill this gap through examining local scale rainfall variability and trend, evaluating the future food grain production and food security in the face of changing climate for A2 and B2 scenario, and estimate yield response for future changes in temperature, precipitation and CO_2 fertilization.

2. Materials and Methods

2.1. Description of the Study Area

Location: Oromia Zone is one of the nationality zones in Amhara Regional state of Ethiopia. It was established in 1986 E.C. Oromia is named for the Oromo people, who settled along the edge of the Ethiopian highlands that form this Zone. It has two town administrations (Kamisse is the administrative centre of the Zone; the other town is Bati) and five rural Woredas. The zone's capital, Kamisse, is found at about 325 kilometres northeast of Addis Ababa along the highway to Dessie and 555 kilometre of Bahir Dar, the capital of Amhara region. Geographically, Oromia nationality Zone lies between $10^0$5' and $11^0$26' north latitudes, and between 39^0 48' and 40^0 25' east longitudes. The zone shares boundaries with South Wollo Zone in the west, North Shewa Zone in the south and Afar Region in the east and northeast Oromia nationality zone administration office (ONZA, 2012).

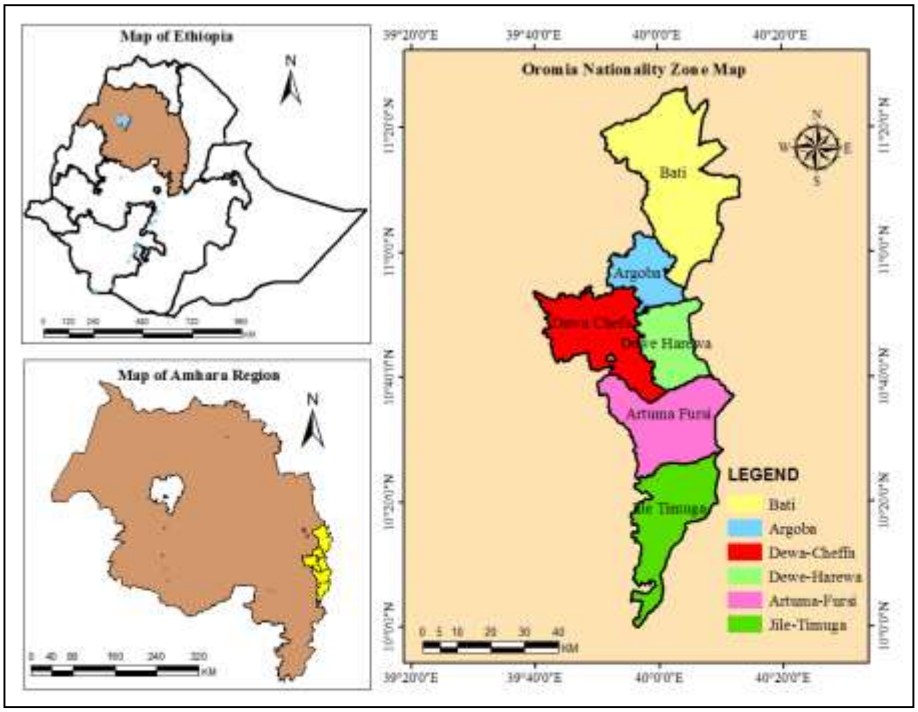


Figure 1. Map the study area as bounded by CSA for 2007 population and housing census (CSA, 2008).

Relief and Agro-ecology: According to ONZA (2012), the altitude of Oromia Zone ranges between less than 600m and about 3000m above sea level. It consists of three agro-climatic zones: degas, weyna-dega and kolla, which comprise about 2.6%, 26.2% and 71.2% of the area of the zone, respectively. Oromia Zone has 399,432 hectors of land. From the total, 6,431 ha of it is suitable to crop farming, 22,601 ha covered with bushes, 2,997 ha are covered with forest and 15,259 ha are used for grazing. It is 1000-2500-meter-high from the sea level (Ibid, 2012).

Population Size and Density: Based on the 2007 Census conducted by the Central Statistical Agency of Ethiopia (CSA, 2008), Oromia nationality zone has a total population of 457,278 of whom 227,328 are men and 229,950 women. Oromia zone has a population density of 131.78. While 51,728 or 11.31% are urban inhabitants, a further 2,005 or 0.44% are pastoralists. A total of 101,442 households were counted in this zone, which results in an average of 4.51 persons to a household, and 97,957 housing units.

Economy: The economy is based on crop production but livestock rearing has a special importance amongst wealthier farmers. Crop production is highly dependent on rainfall and the main rain is received in the *kirem*t (July-September). The main cereals grown are sorghum, teff and maize, and vetch is the main pulse crop. Cattle, goats and sheep are the major livestock in order of importance, but there are also a few camels kept by wealthier people for transport. The zone is particularly known for its cattle population, due to favourable pasture quality but supplemented by crop residues (USAID-LIU, 2007).

2.2 Data Sources and Methods of Analysis

The data used for this study was historical rainfall records and time series data on area coverage, and production of cereals during the *kiremt* and/or *meher*[1] season. The station data were collected from the Ethiopian National Meteorological Agency. Station records and years with missing data were included in the analysis through spatial interpolation and averaging. The agricultural statistics, aggregated at the level of Administrative zone, were collected from the Central Statistical Authority. The study considered more emphasis on the Meher season because over 90% of the total cultivated land of the area is cropped during this season.

Various methods of data analysis employed in the study. Analysis of the rainfall data involved characterizing long-term mean values, and calculation of indices of variability and trends at monthly, seasonal and annual time steps. The Coefficient of Variation (CV) and the Precipitation Concentration Index (PCI) used as statistical descriptors of rainfall variability. The coefficient of variation is calculated using the formula;

$$\mathrm{CV} = \frac{\sigma}{\bar{\mathrm{X}}} \qquad 1$$

Where: CV =Coefficient of Variation, σ = Standard deviation, $\bar{\boldsymbol{x}} =$ Mean

According to Cherkos (2001) and NMSA (1996), the rainfall variability of an area with coefficient of variation, where;

CV < 20% less variable,

CV 20% - 30% moderately variable and

CV >30% highly variable.

The PCI values are calculated on annual scale as given by Oliver (1980);

$$\mathrm{PCI}_{annual} = \left[\frac{\sum_{i=1}^{12} \mathrm{Pi}^2}{(\sum_{i=1}^{12} \mathrm{Pi})^2}\right] * 100 \qquad 2$$

Where, PCI = Precipitation Concentration Index,

Pi = is the rainfall amount of the i^{th} month; and

Σ = summation over the 12 months.

The seasonal scale of Precipitation Concentration Index was calculated using equation (3)

$$\mathrm{PCI}_{seasonal} = \frac{100}{3} * \left[\frac{\sum_{i=1}^{3} \mathrm{Pi}^2}{(\sum_{i=1}^{3} \mathrm{Pi})^2}\right] \qquad 3$$

According to Oliver (1980), If PCI values are:

< 10 = indicate uniform monthly distribution of rainfall;

11-15 = indicates moderate precipitation concentration;

16-20 = indicates irregular distribution, and

> 20 = indicate a strong irregularity (i.e., high precipitation concentration).

[1] ***Meher*** *- Meher season is defined as any crop harvested between September and February or It is crop seasons in Ethiopia which receive rainfall from June to October, respectively.*

The least squares regression technique used to quantify trend in annual and seasonal rainfall and the Spearman's rho test was used to test the statistical significance of trend. Standardized anomalies of rainfall calculated and used to assess frequency and severity of droughts, as in Agnew and Chappel (1999);

$$S = \frac{[P_t - P_m]}{\sigma} \quad (4)$$

Where, S= standardized rainfall anomaly.

P_t = annual rainfall in year "t".

P_m= long-term mean annual rainfall, over a given period of observation.

σ = standard deviation of rainfall over the period of observation.

The drought severity classes are extreme drought ($S< -1.65$), severe drought ($-1.28>S> -1.65$), moderate drought ($-0.84 > S> -1.28$), and no drought ($S> -0.84$).

The monthly rainfall series of all the stations were used to calculate an aerial average rainfall as per (Nicholson, 1985) for the area as follows:

$$R_j = I_j^{-1} \Sigma X_{ij} \quad (5)$$

Where, R_j = is areally integrated rainfall for year "j";

X_{ij} = is rainfall at station "i" for year "j" and

I_j = is the number of stations available for year "j".

Variability and trend in the areal rainfall also examined using the same methods.

Correlation and regression were used to examine relationships between monthly and seasonal rainfall and crop production. The patterns of inter-annual rainfall variability and fluctuations in cereal production are also presented graphically to gain a better insight into rainfall-crop production relationships in the area. It is important to note here that consideration of production of cereals are more appropriate than yield in investigating the influence of rainfall variability, because the latter can miss out impacts of extreme climatic conditions involving severe droughts that might lead to abandonment of planted areas prior to harvest. In other words, total production aggregates impact of climate on both production and yields and harvested areas and thus has greater economic relevance than yield. Further, amount and temporal distribution of rainfall also had influence on area cultivated in a given year.

2.2.1. Statistical Downscaling

SDSM which was designed to downscale climate information from coarse-resolution of GCMs to local or site level applied here to downscale the daily, monthly and annual precipitation, maximum and minimum temperatures for the study area. The SDSM was used in the downscaling of baseline period and future emission scenarios, A2 and B2. The SDSM was chosen because it can provide local scale climatic variables from GCM scale output, which is required in climate change impact studies of this nature. SDSM uses linear regression techniques between predictor and predictand to produce multiple realizations (ensembles) of synthetic daily weather sequences to check climate change. The predictor variables provide daily information about large scale atmosphere condition, while the predictand described the condition at the site level. On the contrary, HadCM3 were employed to simulate the two emission scenarios A2 and B2.

The future simulation was divided in to three periods namely the 2030s (2020-2049), 2060s (2050-2079), and 2080-99 (2080-2099) based on the mean of 20 ensembles which was then used for analysis purpose. To evaluate the performance of the downscaling, the mean of the downscaling data was compared with observed data.

A. Parameter Setting in SDSM downscaling

The following setting was adopted for SDSM downscaling of precipitation and temperature.

- **Model Transformation**: the fourth root transformation was used for downscaling precipitation while the default (None) was used for temperature.
- **Event Threshold**: this parameter was set at 0.5 mm/day during the calibration of daily precipitation to treat trace rain days and dry days. For temperature it was set at 0(zero).
- **Variance Inflation**: controls the amount of variance in the downscaled daily weather variables, with large values increasing the variance of downscaled properties. So this parameter was set at 12 (which is the default normal variance) for precipitation and temperature.
- **Bias Correction**: compensates any tendency to overestimate the mean of conditional processes by downscaling model. Different values of bias correction and variance inflation adjustment were tried and the best combination of these parameters were 1(one), which gave a calibrated model with maximum coefficient of determination (R^2), minimum standard error (SE) and identical standard deviation in the comparison of observed and simulated data.

B. Model Calibration

The SDSM model was calibrated for each month for precipitation, minimum and maximum temperature using the set of selected National Centre for Environmental Prediction (NCEP) predictors and observed data. The goodness of a calibration is measured by values of the percentage of explained Variance (R^2) and Standard Error (SE). Results of the calibration indicating specific predictors used for downscaling each parameter are presented in table1.

C. Predictors

During the screen variables stage of SDSM downscaling the following predictors were chosen.

Table 1. Large scale predictor variables selected for SDSM downscaling.

	Large Scale Predictors	Precipitation	Minimum Temperature	Maximum Temperature
ncepp_faf	Surface airflow strength		✓	✓
ncepp_uaf	Surface zonal velocity		✓	✓
ncepp_zaf	Surface voracity		✓	✓
ncepp_zhaf	Surface divergence		✓	✓
ncepp5_zaf	500 hpa vorticity		✓	
ncepp5zhaf	500 hpa divergence	✓		
ncepp8_faf	850 hpa airflow strength	✓		
ncepp8_uaf	850 hpa zonal velocity	✓	✓	
ncepp8zhaf	850 hpa divergence	✓		✓
ncepr500af	Relative humidity at 500 hpa	✓		
ncepr850af	Relative humidity at 850 hpa	✓		
Nceprhumaf	Near surface relative humidity	✓		
Ncepshumaf	Surface specific humidity	✓		
Nceptempaf	Mean temperature at 2m		✓	

D. Validation

In order to evaluate the performance of any downscaling process it is important that the synthesized data should closely replicate observed data. Usually part of the observed data series is used for calibrating the model while the data which was not used for calibration is used for independent model verification. In this study data for 1983-1997 was used for calibrating the model while the data for 1998-2012 was used for model validation.

E. Downscaling Present and Future Climate

SDSM was used to downscale the present climate from NCEP using HadCM3 A2 and B2 predictors. The results obtained were then compared with the observed values.

The future climate was downscaled using the HadCM3 predictors. Changes in mean daily precipitation and temperature were analyzed for the 2030s, 2060s and 2080-99 for the A2 and B2 scenarios by comparing with the baseline period (1983-2012).

2.2.2. Aqua Crop

The Aqua Crop model was run after preparing the input data files consists of climatic data; precipitation, maximum temperature and minimum temperature, yearly atmospheric CO_2 concentration in (ppm), reference evapotranspiration, irrigation (none), crop data (Maize, Sorghum and Teff), field management and soil information for growing season 2008 to 2012 were used for calibration and validation of the model to simulate for the period 2020-2049

Climatic Data: yearly atmospheric CO_2 concentration in (ppm) used from the- IPCC: SRES scenario A2 and B2 (provided in to Aqua Crop version 4.0 August 2012 model) for the period 2030s (2020-2049) to evaluate the effect of carbon dioxide fertilization in line with the downscaled HadCM3-A2 and B2 scenario outputs of mean monthly maximum and minimum air temperature and average monthly reference evapotranspiration (ETo) estimated from temperature data using CROPWAT version 8.0. Besides this for validation purpose global average atmospheric CO_2 concentration observed at Manoal loa and observed weather data for the period 2008-2012 was used.

Cultural Management: observed sowing dates for the *kiremt* seasons that were decided based on information from Oromia nationality zone agricultural office, were June-8, June-5, and July-2 for Maize, Sorghum and Teff respectively. Hand sowing is practiced on the well cultivated field in the Kiremt season resulting in a plant density of 75,000; 74,000 and 10, 000,000 plants/ha for Maize, Sorghum and Teff, respectively. Hand weeding was practiced twice. Harvesting was done manually 15 and/or above 25 days after cutting. Yield for the total field was determined from total weight of field grain maize harvested and dried to 12.5% moisture content.

Crop Data: the generalized model input parameters for maize reported by Davis, Bush land Texas 1991 Sorghum 25 June 1991 and Dejen teff 2010 were used for all simulations. Parameters considered to vary with cultivar were considered for adjustment depending on availability of data about the parameters. The parameters that were specified during calibration include; maximum canopy cover, plant density, maximum rooting depth and sowing date based on rainfall criteria-onset based (cumulative rainfall = 80mm) from season that the crop did not experience water stress. In some cases, such as upper and lower thresholds for canopy expansion, canopy senescence stress coefficient and upper threshold for stomata closure, the recommended default values by model guidelines, was considered.

Model evaluation: the model was evaluated against the observed data of 2008 to 2012 growing season. The grain yield was simulated for these different periods by adjusting crop parameters. To evaluate the goodness of fit between observed yield and simulated outputs, the statistical indicators such as coefficient of determination (R^2), coefficient of efficiency (E), root mean squared error (RMSE), and index of agreement (d), were used to compare simulated and observed values of the parameters as suggested (Hamidreza Salemi, *et al.*, 2011; and Ngetich, , *et al.*, 2012). The R^2, E, d and RMSE are defined as:

$$R^2 = \frac{\sum_{i=1}^{n}(O_i-\bar{O})(S_i-\bar{S})}{\sqrt{\sum_{i=1}^{n}(O_i-\bar{O})^2}\sqrt{\sum_{i-1}^{n}(S_i-\bar{S})^2}} \quad 6$$

$$E = 1 - \frac{\sum_{i=1}^{n}(O_i-S_i)^2}{\sum_{i=1}^{n}(O_i-\bar{O})^2} \quad 7$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - O_i)^2} \quad 8$$

$$d = 1 - \frac{\sum_{i=1}^{n}(S_i-O_i)^2}{\sum_{i=1}^{n}(|S_i-\bar{O}|+|O_i-\bar{O}|)^2} \quad 9$$

Where; Si is simulated and O_i is Observed value. R^2 (Eq. 6) shows the discrepancy of simulated and observed values and E (Eq. 7) indicate efficiency of the model in simulation of the parameters. The index of agreement d (Eq. 9) is a measure of relative error in model estimates. It is a dimensionless number and ranges from 0 to 1.0, where 0 describes complete disagreement and 1.0 indicates that the estimated and observed values are identical. The RMSE (Eq. 8) represents a measure of the overall, or it is the mean value of Oi. Mean, deviation between observed and simulated values, that is, a synthetic indicator of the absolute model uncertainty. It takes the same units of the variable being simulated. Values of mean residual and mean relative error close to zero indicate small differences between simulated and observed mean thus indicating little systematic deviation or bias in the entire data set, hence, the better the model's fit. Values of RMSE close to zero rather express precision and reliability of the simulation for observed estimation points.

3. Results and Discussion

3.1. Annual and Seasonal Rainfall Variability and Trends

The annual total rainfall in Oromia nationality zone varies from slightly over 896 mm in Dewe-Harewa to more than 1159 mm in Artuma-Fursi (Table 1). Only two stations (Argoba and Artuma-Fursi) experience annual rainfall amounts of greater than 1000 mm. Much of the rainfall is concentrated in the four months of the Kiremt season. The rainfall shows less inter annual variability as shown by the coefficients of variations (Table 1). Generally, the Belg (March-May) and the Bega (October-February) rainfalls are much more variable than the Kiremt (June-September) rainfall. A similar conclusion - that Belg and Bega rainfalls are more variable than *kiremt* rainfall- was arrived at by Woldeamlak (2009) in his study that analysed rainfall data from 12 stations throughout the Amhara regional state. He also reported that rainfall variability is higher in areas of low annual rainfall.

The contribution of Kiremt rainfall to the annual total ranged from 63% in Artuma-Fursi to nearly 67% in Argoba. Belg rainfall makes a considerable contribution to the annual total in stations of Jille-Timuga, and Dewe- Harewa. The extreme concentration of rainfall can also be seen from the contribution of the single largest monthly total to annual total rainfall at each of the stations. The calculated PCI shows that rainfall in the Oromia nationality zone is generally characterized by higher concentration (PCI values ranged from 19% in Artuma-Fursi, Dewa-Chaffa, Dewe- Harewa and Jille-Timuga to 20% in Argoba and Bati).

Table 2. Annual and seasonal rainfall (mm), coefficient of variation and the Precipitation Concentration Index (PCI), 1985-2012.

Station	Annual			Kiremt			Bega			Belg		
	Mean	CV	PCI	Mean	CV	PCI	Mean	CV	PCI	Mean	CV	PCI
Bati	928	0.10	20	568	0.21	13	122	0.27	17	238	0.22	14
Argoba	1038	0.10	20	690	0.20	12	99	0.25	16	249	0.20	13
Dewa-Chaffa	933	0.10	19	582	0.20	13	121	0.27	18	230	0.22	14
Dewe-Harewa	896	0.10	19	533	0.20	13	112	0.30	19	251	0.21	14
Artuma-Fursi	1159	0.10	19	730	0.20	12	139	0.24	16	289	0.19	13
Jille-Timuga	963	0.09	19	350	0.26	16	196	0.24	18	417	0.25	15

For the period 1985-2012, annual rainfall shows negative trend in two out of the six stations and positive trend in four of the stations (Table 2). The positive trends at Dewe-Harewa (21.56 mm/decade) and at Jille-Timuga (20.18 mm/decade) are significant at less than 0.05 levels. The positive trends in annual rainfall at Artuma-Fursi and Dewa-Chaffa are not significant due to large inter-seasonal fluctuations. Kiremt rainfall had positive trends in all stations except Jille-Timuga and significant at less than 0.05 levels with the exception of Argoba (at < 0.1 level). The other significant trends are the decreasing Belg rainfall at Argoba (at < 0.05 significance level) and the increasing Belg rainfall at Jille-Timuga (at < 0.01 significance level). Temperature also showed a similar trend except Jille-Timuga in all stations within the zone had a positive trend ranging from 0.345^{0}C to 0.747^{0}C per decade.

Table 3. Annual and seasonal rainfall trend during 1985-2012.

Station	Annual		Kiremt		Belg	
	Trend	*Rho*	Trend	*Rho*	Trend	*Rho*
Bati	-2.03	0.122	9.67	0.426**	-14.17	0.020
Argoba	-17.52	-0.042	13.35	0.331*	-39.37	-0.435**
Dewa-Chaffa	1.65	0.258	4.58	0.389**	-21.06	-0.119
Dewe- Harewa	21.56	0.473**	32.06	0.389**	-30.76	-0.207
Artuma-Fursi	0.78	0.097	20.26	0.425**	-36.57	-0.272
Jille-Timuga	20.18	0.390**	-42.76	-0.199	44.61	0.696***

Table 4. Mean annual Temperature trend during 1985-2012.

Stations	Trend	*Rho*
Argoba	0.646	0.701***
Artuma-Fursi	0.619	0.732***
Bati	0.345	0.397***
Dewa-Chaffa	0.747	0.631***
Dewe-Harewa	0.392	0.360***
Jille-Timuga	-0.15	-0.111

**Significant at p<0.1 level; **Significant at =p<0.05 level; ***Significant at p<0.01 level*

Trend: in mm & ^{0}C /10 years; Rho: Spearman's rho

The annual average areal rainfall in the Oromia nationality zone is 1010 mm, with a standard deviation of 71.6 mm and coefficient of variability of 7%. The anomalies in the annual and seasonal areal rainfalls are shown in Figure 2. The rainfall in the area is characterized by alternation of wet years and dry years in a periodic pattern. Of the 28 years of observation, 12 years (45.9%) recorded below the long-term average annual rainfall amount while 16 years recorded above average. Most of the negative anomalies have occurred during the 1980s (5 of 12). Between 1985 and 1994 the annual rainfall has been below the long-term mean, excepting the years of 1989, 1992, and 1993 when rainfall was slightly above the mean, and 1991 for which no records were available at many of the stations because of the political instability in the country in that year. The 1990 rainfall amount emerges as the lowest on record in the area, showing the worst drought year in combination with the pre 1991 instability in the country and in the nationality zone. It was a culmination of droughts that started in 1985. Rainfall has shown some recovery since the 1990s, from the low values of the 1980s, but drier conditions have been experienced in 2002 and 2003. Accordingly, there have been four drought years during 1985-2012 in the Oromia nationality zone, with varying severity. There were six extremes (1987, 1990, 2002, 2004, 2008 and 2011), and three moderate (1985, 1986, and 2009) drought years, which together represent 32.1% of the total number of observations. Once again, the year 1990 stands out as the worst year, with a standardized rainfall anomaly of -5.35. In contrast, 2000 was the wettest year in the zone over the period of record following the year 1995.

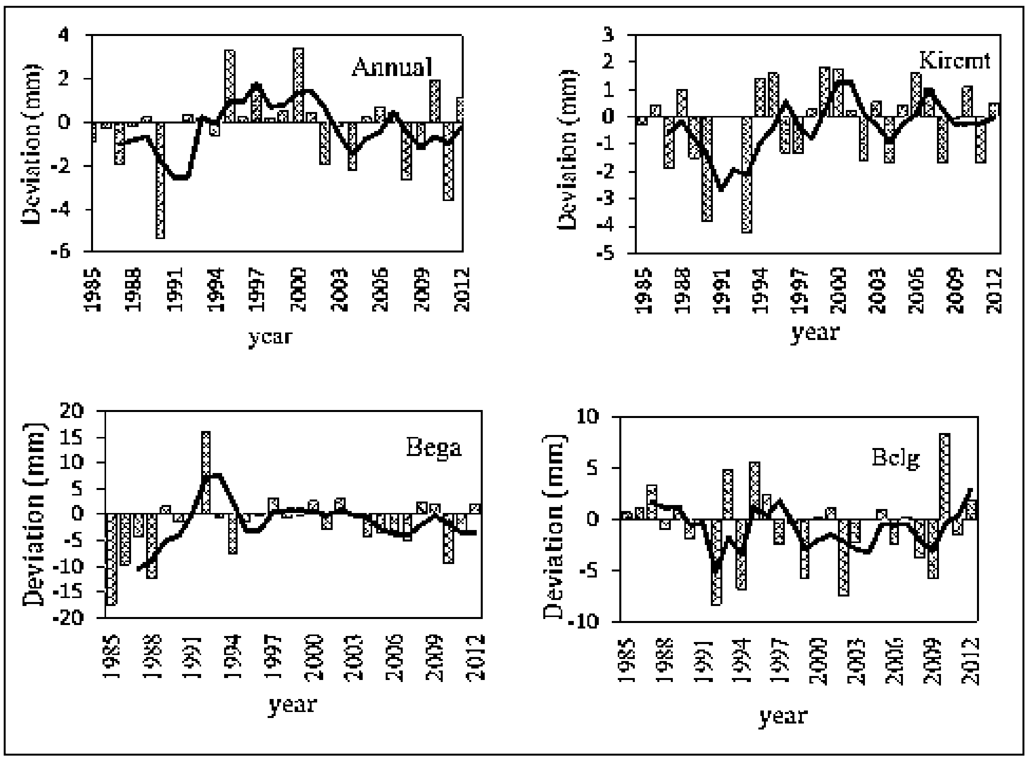


Figure 2. Deviations of annual and seasonal rainfalls from long-term averages (bold line- 3-years moving average).

3.2. Rainfall and Crop Production Relationships

The summary statistics on cereal production and area cultivated in the Oromia nationality zone during the period 1995-2012 are presented in Table 3. Sorghum, teff, and Maize are the staple food crop in many parts of the nationality zone, and these crops are most important cereals in terms of area cultivated as well as total production. In terms of production, Sorghum exhibits the largest and followed by teff and Maize, respectively. Teff production had the largest year-to-year variability in terms of total production compared to the other cereals. This high inter-annual variability is caused mainly by inter-annual variability in rainfall amount. As sorghum is cultivated in semiarid and arid parts of the zone, it is particularly vulnerable to the vagaries of weather. During agro-meteorologically drier years, both area planted and yield per unit of cultivated land become lower than average.

Table 5. Production of cereals ('000 Qt) and area cultivated ('000 ha) in Oromia nationality zone, 1995-2012.

	Maize	Sorghum	Teff	Total
Annual Production				
Maximum	142.76	738.93	143.18	1024.87
Minimum	62.29	281.68	0.16	308.13
Mean	85.80	480.40	92.14	658.34
CV (%)	35	29	53	26.4
Area				
Maximum	12669	34255	14142	61066
Minimum	95.41	842.26	164.07	1101.74
Mean	4016.74	13254.92	5422.35	7564.67
CV (%)	10.8	11	11.4	11.1

Source: CSA (2013) and Oromia nationality zone agriculture and rural development office.

The correlation analysis between monthly, seasonal and annual areal average rainfalls and cereal production are given in Table 6. Teff production showed considerably high correlation with the *kiremt* rainfall. Belg rainfall is weakly correlated with production of cereals, compared with annual and *kiremt* correlations; hence, it is a poor predictor of cereal production. At the monthly time scale, correlation between areal rainfalls during May to September and cereal production are all positive. May to September covers the period from preparation of fields and sowing to maturity stage of crops. The production of teff shows high correlation with July and August rainfalls. Sorghum production show better correlation with May, June, and August rainfalls than with the others. Maize production show high correlation with June and July rainfall.

Even though correlation coefficients are positive, most are non-significant. This is not unexpected given the short length of the production data used and the non-linear nature of relationships between crop production and rainfall amount.

Table 6. Correlations between production of cereals and areal monthly, seasonal and annual rainfall in Oromia nationality zone.

	Maize	Sorghum	Teff
May	0.329	0.416*	0.260
June	0.475**	0.453*	0.566**
July	0.703***	0.221	0.659***
August	0.396	0.595***	0.663***
September	0.332	0.020	0.319
Annual	0.630***	0.514**	0.507*
Kiremt	0.585**	0.506**	0.776***
Belg	0.382	0.306	0.0.283

**Significant at the 0.1 level; **Significant at the 0.05 level; ***Significant at the 0.01 level.*

In recognition to this, the general patterns of inter-annual rainfall variability and fluctuations in cereal production are presented graphically (Figure 3) to gain a better insight into rainfall-production relationships in the area.

As it can be seen from Figure 3, production of each cereal crop has shown negative anomaly in 1996 and 2002. This was due to high negative anomalies in seasonal rainfalls. The *kiremt* rainfall in 2002 was at its lowest for the period 1995-2012 (21% below the 17-year mean). In consequence, total cereal production reached its lowest for the record period (16% below its 17-year mean) in the same year (2002). In 1996, both *kiremt* and annual rainfall were below their respective decadal averages; and correspondingly total cereal production in the same year was 10% below its 17-year average. In addition to these two years (1996 and 2002), the production of Maize, Sorghum and *teff* recorded negative anomalies in 2004 and 2009 as well, which contributed to the below-average total cereal production in the nationality zone (5% and 7% below the 17-year mean respectively). The number of relief food assisted population in the nationality zone was around 18,633 and 52,310 in 2002-03 and 2004-05, respectively (Oromia nationality zone food security and disaster risk management office, 2006).

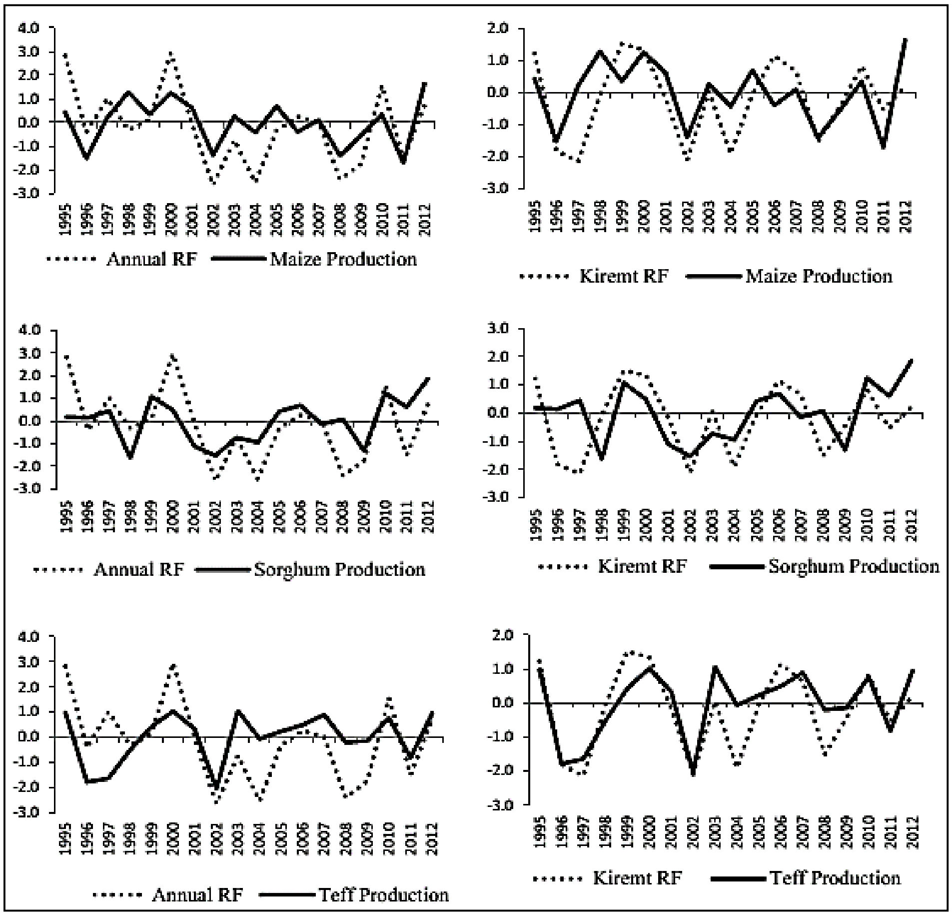


Figure 3. Standardized anomalies of production of cereals and seasonal and annual rainfall amount in Oromia nationality zone, 1995-2012.

3.3. Downscaling GCM Outputs

Model calibration: The results of calibration indicate that values of R^2 were greater for temperature than for precipitation. This indicates the difficulty in finding significant climate variables from the NCEP data that could explain well the variability of daily precipitation (Collen, 2011). In general, daily precipitation amounts at individual sites are poorly resolved by regional scale predictors. Doyle (1997) noted that both the rain occurrence and the amount of precipitation are stochastic processes which make the downscaling of precipitation a difficult problem. These results are, however, comparable to those obtained by other researchers elsewhere. In a study to test the ability to simulate daily precipitation (Collen, 2011), Value of R^2 obtained are presented in Table 7.

Table 7. Model calibration result.

	Precipitation	Minimum Temperature	Maximum Temperature
R^2	0.340	0.792	0.795
Standard Error (SE)	0.083	0.0235	0. 222
Variance Inflation	12	12	12
Bias Correction	1	1	1

Validation: The mean daily precipitation and temperature were used to test model performance during the validation period. The results are shown in Figure 4.

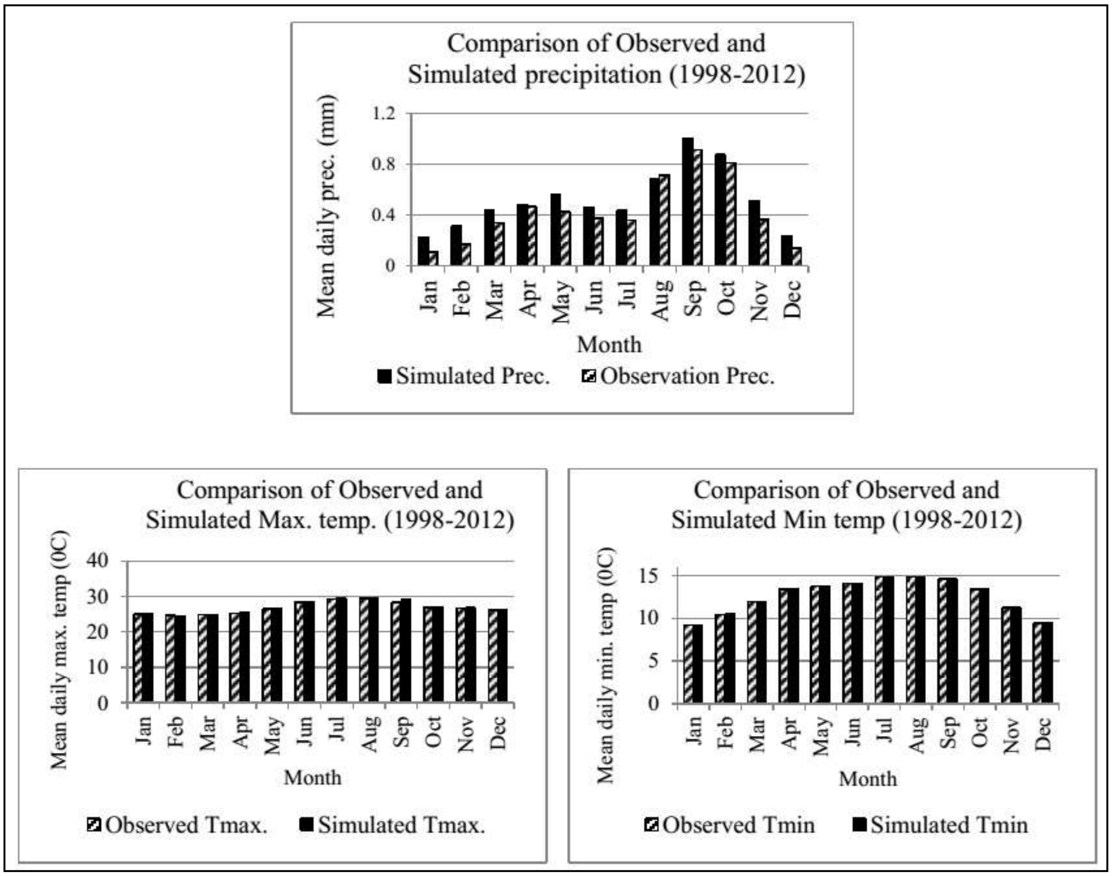


Figure 48. Validation results of SDSM downscaling at Oromia nationality zone.

The performance of the downscaling model for temperature and precipitation during validation are shown in Figure 4. The graphs show a good agreement between the simulated and observed mean daily minimum and maximum temperature for all the months. There is also good agreement for observed and simulated mean daily precipitation in terms of its pattern for all months with a small deviation where the model underestimates the observed values. Values of R^2 were 0.156, 0.21.3 and 0.350 for precipitation, minimum and maximum temperatures respectively.

3.3.1. Downscaling Present (Observed) Climate

The results obtained from downscaling the present climate using NCEP and HadCM3 predictors are shown in Figure 5.

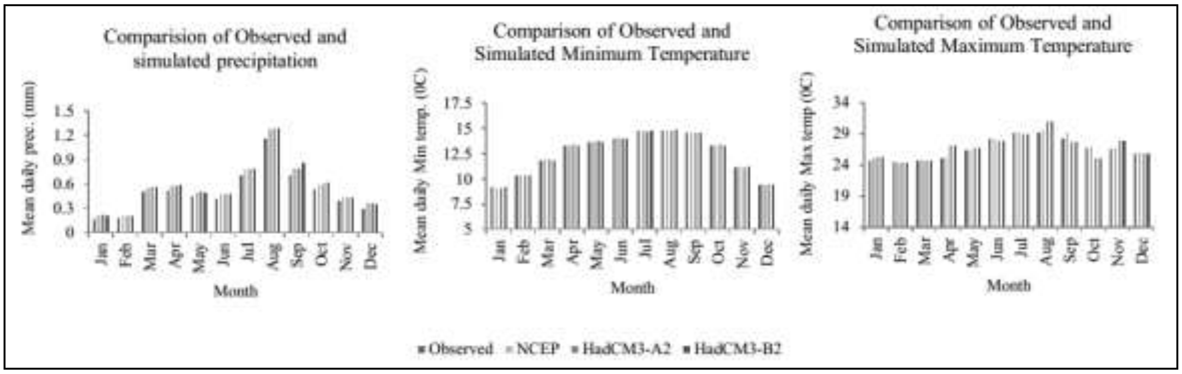


Figure 5. Observed mean daily precipitation, minimum and maximum temperature (1983-2012) and simulated data (1983-2001 for NCEP).

There was a satisfactory agreement between the observed and simulated temperature and precipitation. HadCM3-A2 and HadCM3-B2, however, overestimate August and underestimate October maximum temperature and overestimate precipitation keeping the pattern similar.

3.3.2. Downscaling Future Climate

Precipitation

The results of downscaling the future precipitation for 2030's, 2060s and 2080-99 using HadCM3 are presented in Figure 6, along with the current (1983-2012) observed values for comparison.

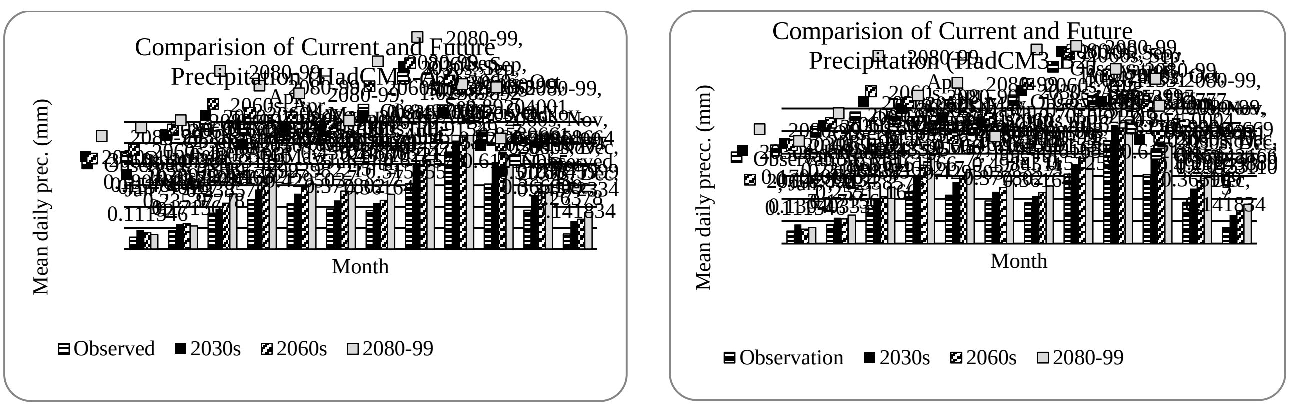


Figure 69. Comparison of the current (1983-2012) mean daily precipitation with future HadCM3simulated precipitation for A2 and B2 scenarios.

There is an increase of mean daily precipitation for 2030s, 2060s and 2080-99 for both A2 and B2 scenarios, with largest increase in late *belg* and *kiremt* seasons. Largest increase is projected in April, May August, September and October. In general, when compared to the base period, the increase in the mean annual predicted rainfall is greater under B2 scenario than A2 scenario, except for the 2080-99 (Table 8).

Table 8. Mean annual predicted values and relative changes of rainfall.

Scenarios	Base period (1983-2012)	2030s	% Change	2060s	% Change	2080-99	% Change
HadCM-A2	996	1018	2	1007	1	1007	1
HadCM-B2	985	997	1	1022	4	1002	2

As shown in Table 8, the predicted annual rainfall shows an increasing trend with a change of 2% (2030s) and 1% (2060s, 2080-2090) for A2 scenario with respect to the baseline period and 1% (2030s), 4% (2060s) and 2% (2080-90) for B2 scenarios. The above results thus indicate that the increasing annual rainfall in the future, is somewhat greater for B2 than A2 and also that the increases are higher in Kiremt and lower in Belg.

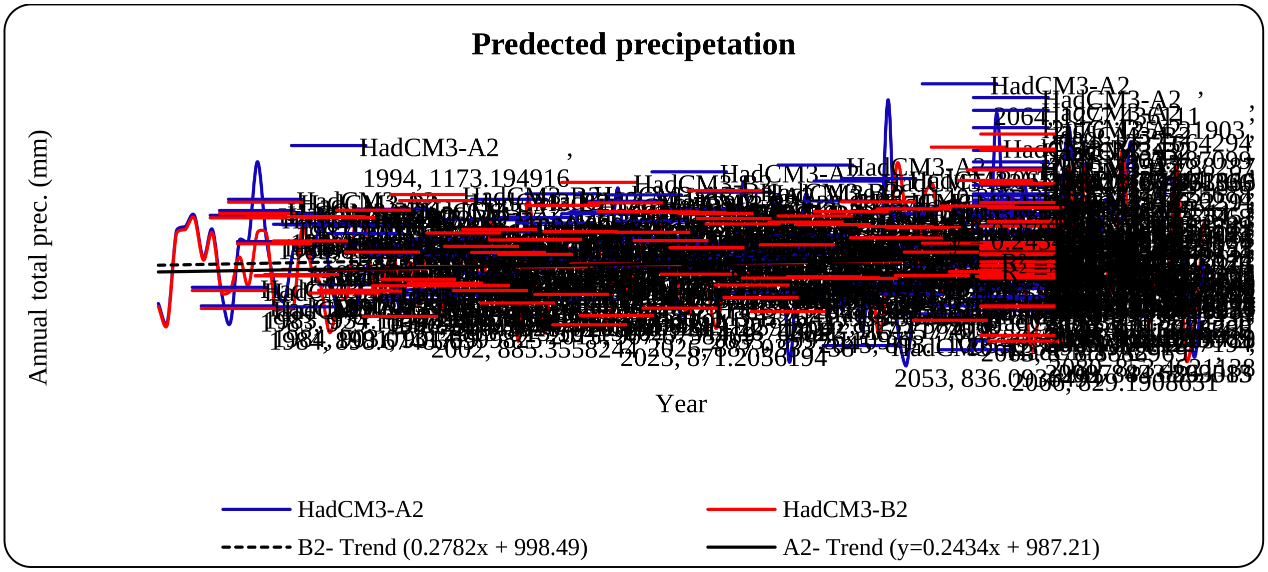


Figure 7. Projected HadCM3-A2 and HadCM3-B2 scenarios precipitations on yearly bases.

The projected annual rainfall (Figure 7), with A2 and B2 scenarios for the period 1983-2099 shows a continuous increase in the trend of annual rainfall generated for future climate scenario for the coming decades. Both scenarios predicted future rainfall in a similar trend and the variation in predicted rainfall is greater in the B2 scenario than A2 scenario.

Temperature

Minimum Temperature: Mean daily minimum temperatures (Figure 1) are projected to increase by 0.01^{0}C to 0.1^{0}C in the 2030s, 0.15^{0}C to 0.21^{0}C in the 2060s and 0.29^{0}C to 0.37^{0}C in the 2080-99 for much of the year with greater increases for A2 than B2 scenario. The increases become progressively bigger from 2030s to 2080-99. Great increases are projected in *belg* and *bega*. There minimum temperatures are projected to decrease by 0.04^{0}C to0.91^{0}C on the onset of *kiremt* season for both A2 and B2 scenario when compared to the baseline.

Maximum Temperature: Increases in the mean daily maximum temperature of between 0^{0}C to 0.02^{0}C, and 0.01^{0}C to 0.03^{0}C are projected for the 2030s and 2080-99 respectively. The A2 scenario shows higher increases than the B2 scenario. The greater increases are also projected for Belg. There is a decrease of 0.04^{0}C in the mean daily maximum temperatures for 2060s in the B2 scenario. There are also a decreases of 0.01^{0}C in

September, 0.12^0C in May and 0.09^0C in August and July for the A2, and 0.15^0C in January and February, 0.19^0C and 0.07^0C May and July respectively for B2 scenario for the period 2030s when compared to the baseline.

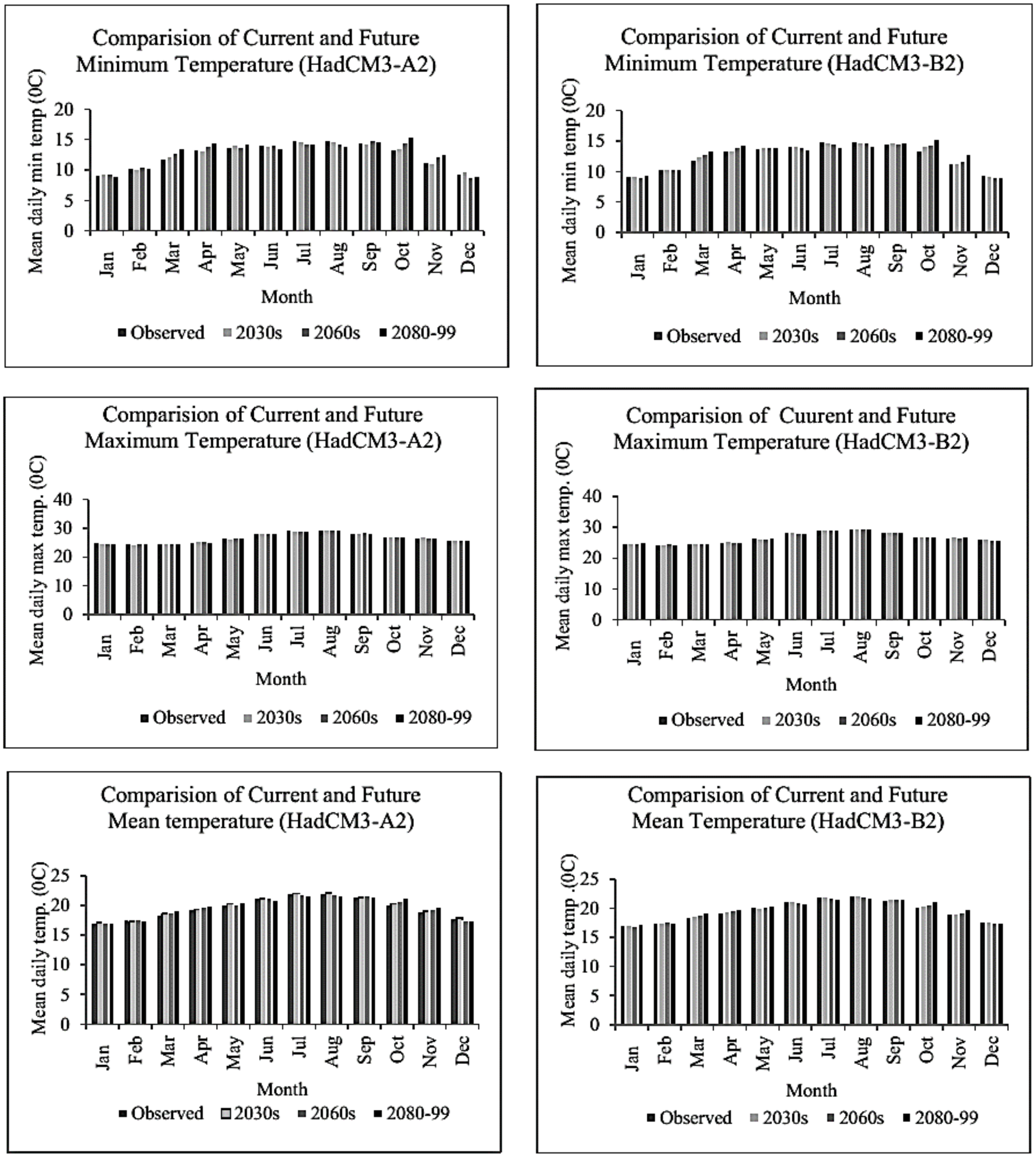


Figure 8. Comparison of Current (1983-2012) mean daily precipitation, mean temperature, minimum and maximum temperature with future HadCM3 simulated data for A2 and B2 scenarios.

Mean Temperature: Mean temperate are also projected to increases (Figure 2) by 2030s (0.01^0C to 0.05^0C), 2060s (0.06^0C to 0.1^0C) and 2080-99 (0.15^0C to 0.2^0C) compared to base period for both the A2 and B2 scenarios in their respective order. A decrease of 0.2^{0}C in the mean daily temperature is predicted in A2 for 2030s for February. More warming is projected for Bega than *kiremt*. A similarly, scenario analysis on mean annual temperature shows an increasing trend for both A2 and B2 scenarios.

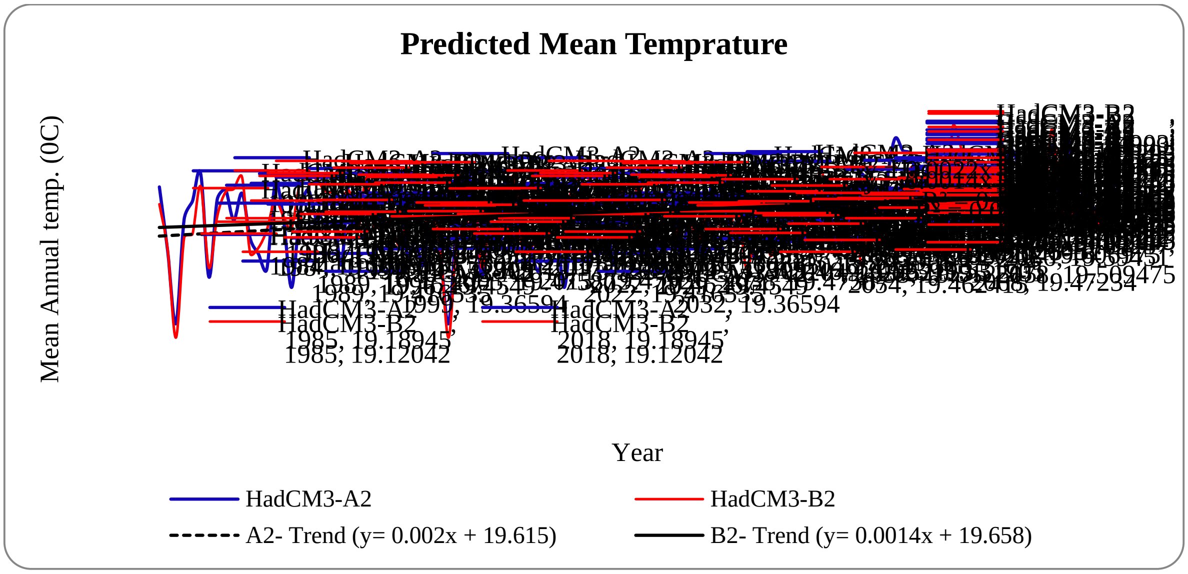


Figure 9. Projected HadCM3-A2 and HadCM3-B2 scenarios mean temperature on yearly bases.

3.4. Results from Aqua Crop model

3.4.1 Model validation

The results are presented for each crop, and comparisons have been made between simulated and observed values of the final grain yields, for the *kiremt* growing season. The observed grain yields are plotted against the Aqua Crop model simulation results under rain-fed conditions (Fig 3) and the statistical indices derived for evaluating the performance of the Aqua Crop model are given in Table 9.

As shown in the Figure 6 and Table 9, there is a remarkable match between the simulated and observed grain yields in Oromia nationality zone with an RMSE of 0.115, 0.073, and 0.144, E of 0.929, 0.998 and 0.984, d of 0.983, 1.0 and 0.996 and $R^2$of 0.963, 0.612 and 0.852 in ton/ha for Maize, sorghum and teff, respectively. Noticeable deviations found between simulated and observed Maize, Sorghum and teff yield were 3%, 5% and 6% for the *kiremt* season and model simulation result overestimate teff yield compared to the observed yields for the period.

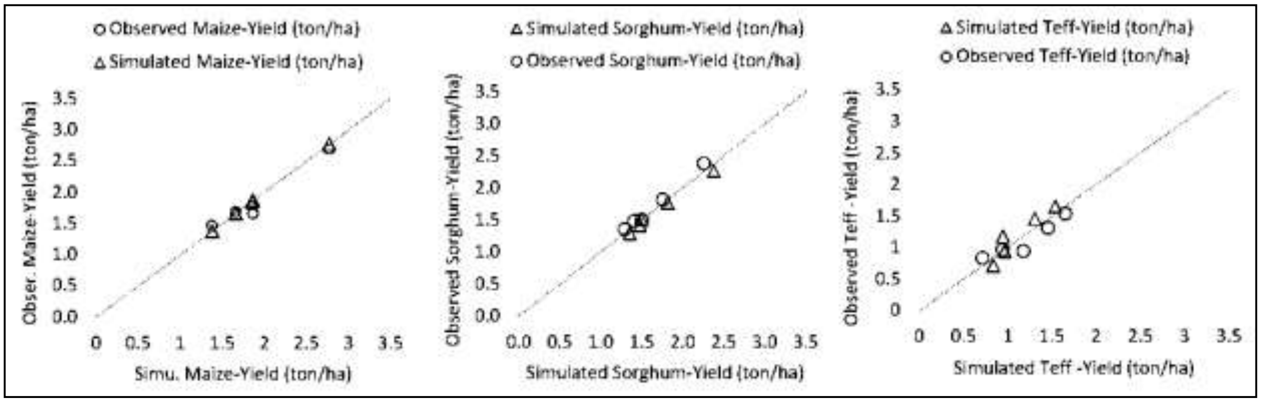


Figure 100. Comparison between simulated and observed values of Maize, Sorghum and teff yield (ton/ha) for the rain-fed agriculture at Oromia nationality zone (2008-2012) used for model validation.

Table 9. Statistical indices derived for evaluating the performance of the Aqua Crop model in simulating Maize, sorghum and teff yield (ton/ha) for *kiremt* season.

Statistical index	RMSE	E	*d*	R^2
Maize	0.115	0.929	0.983	0.977
Sorghum	0.073	0.998	1.000	0.612
Teff	0.171	0.984	0.996	0.891

3.4.2. Yield response for future Climate

Many climatologists predict significant global warming in the coming decades due to increasing concentration of CO_2 and other greenhouse gases in the atmosphere. Higher temperature could negatively impact on crop production directly through heat stress. The projected time-series data for the underlined period (2020-2049) showed that there will be an increasing trend of temperature and rainfall for the *kiremt* season. The grain yield of Maize, Sorghum and teff is found to be influenced by precipitation, temperature, reference evapotranspiration, and increments in atmospheric CO_2 concentration. The Aqua Crop model simulations (Figure 4) showed that changes in rainfall pattern will adversely affect Maize and teff yield. For sorghum the effect is not much due to its high correlation with soil moisture condition at its seed germination stage.

Maize: as shown in Appendix-I Maize appears to require a more even distribution of rainfall throughout the *kiremt* seasons, as it is illustrated in Figure 4. The anomalies of maze production have higher correlation with the *kiremt* rainfall than the annual total rainfall. The predicted Maize yield will have positive anomalies in 23 out of the 30 years, for B2 scenario and 18 out of 30 years for A2 scenario which are accompanied by positive anomalies in the *kiremt* rainfall. Likewise, 7 for B2 and 12 years for A2 scenarios will have negative maize yield are accompanied by negative anomalies in the *kiremt* rainfall. Consequently, Maize yield will face higher loss in the year 2038 (21%), 2043 (18%), 2046 (32%), and 2049 (24%) for B2 scenario and 2028 (13%) and 2046(12%) for A2 scenarios.

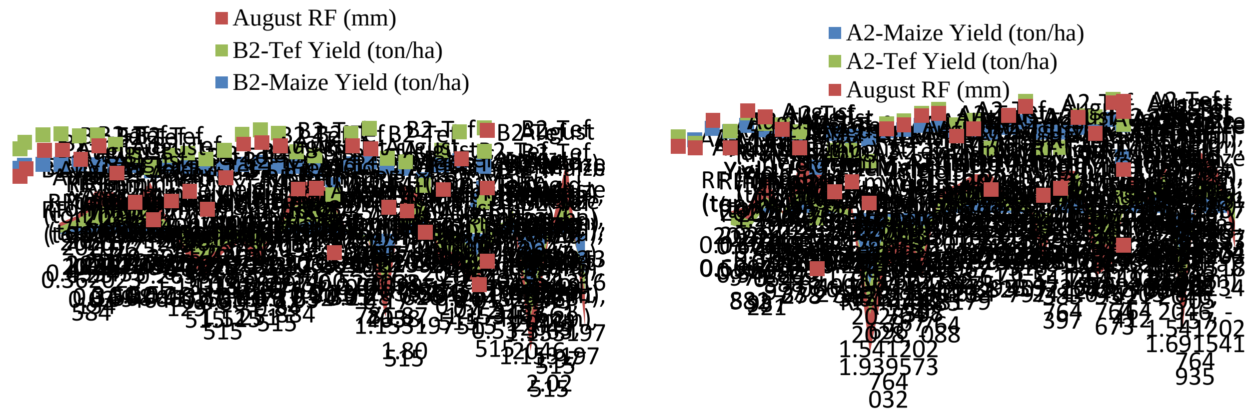


Figure 2. Maize and teff Yield relationship with *kiremt* Rainfall (August).

Teff: As shown in Appendix-I, teff production is more strongly correlated with the August rainfall than with the June and July rainfalls. Fluctuations in teff production generally follow the patterns of inter-annual variability of the August rainfall (Figure 4). Over the 30-year period for A2 scenario, teff production is predicted to be above average in 21 years following above-average August rains, while in the remaining 9 years the production has been low due to below-average August rains. For B2 scenario, the teff production is projected to be above-average in 19 years following above-average August rains, whereas in 11 years teff production has been below the average following below average August (*kiremt*) rains.

Teff production fell below the average following below-average August (*kirem*t) rains. In the late 2020s, both teff production and *kiremt* rainfall will contribute to very high yield loss ranging from 71% to 89% ton/ha for A2 scenario and 72% to 88% ton/ha for B2 scenario in their respective order.

In addition to this, the model simulation projected yield loss of teff in the late 2030s and in the first quarter of 2040s with the value range from 86% to 89%, ton/ha under A2 scenario and 78% to 90% lose for B2 scenario, respectively. It is due to below mean rainfall during that year and partly due to temperature contrast teff production will fall to achieve its growing degree day.

Sorghum: Sorghum production is particularly related to the late *belg* rains. This is because of the fact that sorghum is sown in early May or even late May, which makes the *belg* rainfall critically important. The result for sorghum yield shows there will be yield increment due to favorable soil moisture condition at its seed germination stage and for its drought resistance nature which can allow better sorghum yield per hectare of cultivated land compared to maize and teff yield. However, there will be a minor loss in yield for the period 2028 and 2046 (6% and 4%) for A2 scenario and 2038 (7%), and 2046 (12%) and 2049 (9%) for B2 scenario output.

In general, for the production of both sorghum and maize, which are long-cycle crops sown early from the *kiremt* rains. During the *kiremt* season, not only that rainfall occurrence is likely to become more common, but also that soil moisture reserves will be sufficient to support plant growth during any dry spell. Sorghum in particular has a good tolerance for water stress caused by dry spell occurrences. Similarly, sorghum tolerates end-of- season dry spells (rainfall shortage in September) than maize, so it is more sensitive to rainfall in *belg*, while maize is more sensitive to dry spells throughout its growing period beginning in *belg* and until end of *kiremt*.

Temperature also has a considerable effect on crop yield as the simulation result indicates in Appendix-I. Maize yield is projected to face an average temperature stress ranging from 11% to 25%, and the temperature stress for teff will range between 0% to 1% for both A2 and B2 scenario for the period 2030s. Sorghum could not experience significant temperature stress.

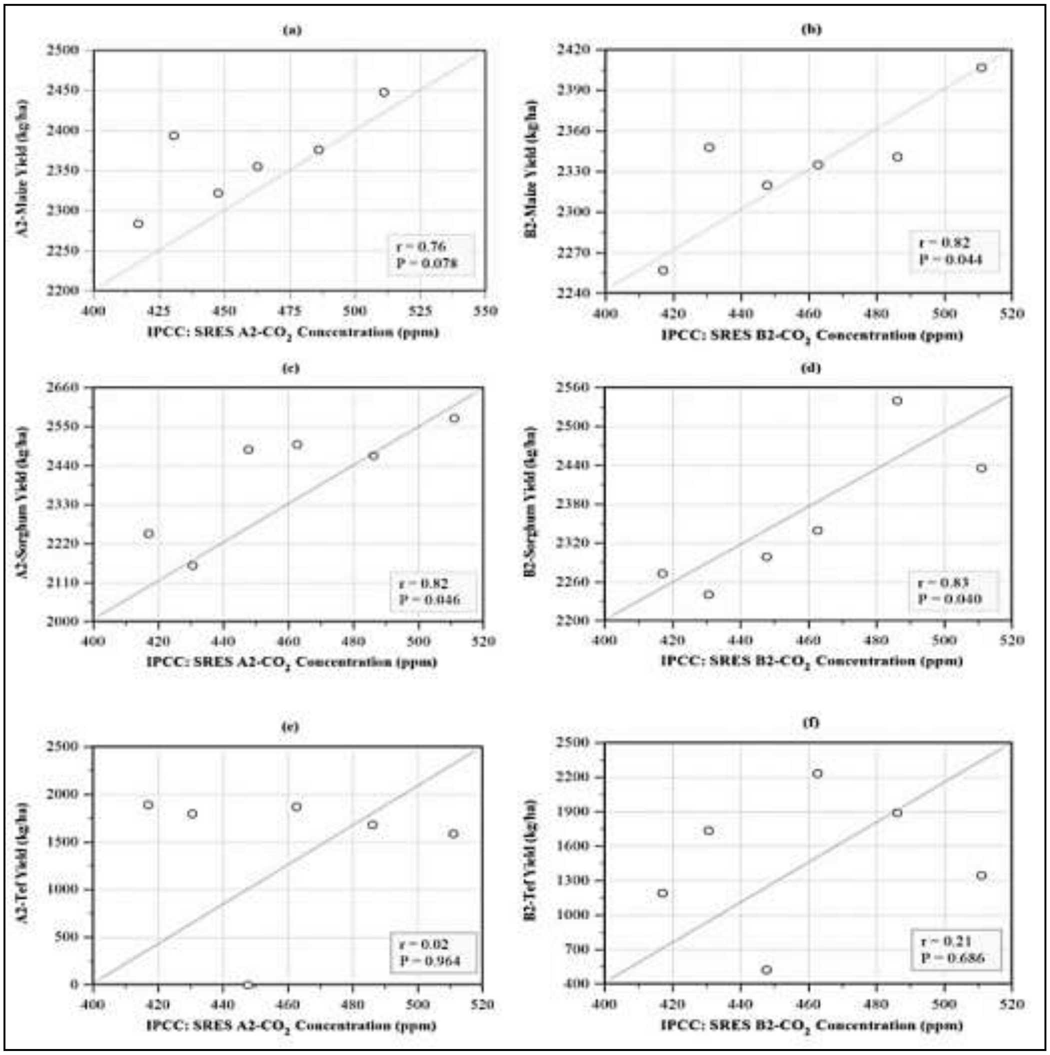


Figure 11. Correlation of simulated Maize yield (a & b), Sorghum yield (c & d) and teff yield (e & f) with atmospheric CO_2 fertilization under A2 and B2 emission scenarios using MedCalc statistical software.

The simulated result in Figure 5 indicates how much food grain productions are sensitive to CO_2 fertilization. As it is shown, low CO_2 fertilization has a positive impact on Maize and Sorghum yield for both A2 and B2 scenarios. Even though, its effect on A2-Maize is insignificant because of maize yield vulnerability to rainfall variability. Whereas, its impact on Teff yield is positive but insignificant for both scenarios. Although higher CO_2 levels in the future would balance the detrimental effects of increased temperatures to some extent but it would not be able to offset them.

4. Conclusions and Recommendations

The annual total rainfall in Oromia nationality zone varies from slightly over 896 mm in Dewe- Harewa to more than 1159 mm in Artuma-Fursi. Only two stations (Argoba and Artuma-Fursi) experience annual rainfall amounts of greeter than 1000 mm. The contribution of Kiremt rainfall to the annual total ranged from 63% in Artuma-Fursi to nearly 67% in Argoba. Rainfall in the Oromia nationality zone is generally characterized by higher concentration (PCI values ranged from 19% in Artuma-Fursi, Dewa-Chefa, Dewe- Harewa and Jille-Timuga to 20% in Argoba and Bati). For the period 1985-2012, annual rainfall shows negative trend in two out of the six stations and positive trend in four of the stations. *Kiremt* rainfall had positive trends in all stations except Jille-Timuga and significant at less than 0.05 levels. The annual average areal rainfall in the Oromia nationality zone was 1010 mm, with a standard deviation of 71.6 mm and coefficient of variability of 7%. The rainfall in the area is characterized by alternation of wet years and dry years in a periodic pattern. Of the 28 years of observation, 12 years (45.9%) recorded below the long-term average annual rainfall amount while 16 years recorded above average. Temperature also showed an increasing trend in five of the stations except Jille-Timuga woreda.

Sorghum, teff, and Maize are the staple food crop in many parts of the nationality zone, and these crops are most important cereals in terms of area cultivated as well as total production. In terms of production, Sorghum exhibits the largest and followed by teff and Maize, respectively. teff production had the largest year-to-year variability in terms of total production compared to the other cereals. This high inter-annual variability is caused mainly by inter-annual variability in rainfall amount. As sorghum is cultivated in dryland parts of the zone, it is particularly vulnerable to the vagaries of weather. During agro-meteorologically drier years, both area planted and yield per unit of cultivated land become lower than average. At the monthly time scale, correlations between areal rainfalls during May to September and cereal production are all positive. May to September covers the period from preparation of fields and sowing to maturity stage of crops. The production of teff shows high correlations with July and August rainfalls. Sorghum production show better correlations with May, June, and August rainfalls than with the others. Maize production also showed high correlation with June and July rainfall.

Oromia nationality zone is found to be sensitive to climate change. Temperature shows an increasing trend. Hence, mean temperate increases by 2030s (0.01^{0}C to 0.05^{0}C), 2060s (0.06^{0}C to 0.1^{0}C) and 2080-99 (0.15^{0}C to 0.2^{0}C) compared to base period for both the A2 and B2 scenarios in their respective order. Annual precipitation will increase by 1% to 2%, the increment is greater in B2 scenario than A2 and increases are higher in *kirem*t and lower in *belg*. Therefore, yield of maize, sorghum and teff will be influenced by changes in precipitation, temperature, and increments in atmospheric CO_2 concentration. Carbon fertilization would have a positive impact on A2 and B2-maize, A2 and B2-sorghum yield and insignificant positive impact on A2 and B2-teff yield. Changes in rainfall pattern also adversely affect maize and teff yield. Maize yield will face an average temperature stress ranges from 11% to 25%, likewise, temperature stress for teff will range between 0% to 1% for both A2 and B2 scenario for the period 2030s and sorghum could not experience that much significant temperature stress. Generally, Maize yield will face higher loss in the year 2038 (21%), 2043 (18%), 2046 (32%), and 2049 (24%) for B2 scenario and 2028 (13%) and 2046(12%) for A2 scenarios. In the coming the 30-year period, teff production also predicted to be below average in 9 years, for A2 scenario and 11 years, for B2 scenario.

According to the findings of this study there will be considerable climate change in the future in Oromia nationality zone. Hence the following recommendations are made based on the findings of the study to improve agricultural development and reduce the risks faced by the sector related to climate change and variability.

- **Build regional capacity for climate modelling and prediction:** climate modelling and prediction, especially the downscaling of information for agricultural uses and addressing issues related to dynamical and probabilistic products, especially with respect to the specific requirements of users such as amount of rainfall, onset date, wet/dry spells etc. that are required by many users. Which can Promote the development of climate/weather-agro models and new products of climate forecast, bearing in mind the needs expressed by farmers; adapting cropping to the ongoing rainy season by guidance of agronomic practices; using past experiences, including meteorological interpretations; and traditional knowledge.
- **Review the works of in-country experts:** In order to identify the most effective and locally appropriate ways of conducting this kind of analysis, the experience of in-country experts already working on climate change, food security, household livelihood security, and disaster risk reduction should be handle, and existing literature and data on vulnerability should be used to support farmers' decisions to adopt yield-enhancing adaptation strategies
- **Better access to basic extension services and facilitating infrastructure:** Farmers need appropriate and timely information on predicted changes in climate to empower them to take appropriate steps to adjust their farming practices. Therefore, local government and NGO, extension workers working in the zone should understand climate risks and promoting adaptation strategies. Since, averting the negative effects of climate change and achieving food security have become major priorities for development agencies, policymakers, and related stakeholders. Given that adaptation measures have a positive effect on crop yields, the adoption of yield-related adaptation strategies could significantly support these goals. Consequently, adaptation not only enables farmers to cope with the adverse effects of climate change and variability, but also increases the agricultural productivity of poor farm households.

The community should managing risk by planning for and investing in the future, employ climate-smart agricultural[2] practices, and diversify livelihoods, including non-agricultural strategies.

[2] Climate-smart agriculture is a pathway towards development and food security built on three pillars: increasing productivity and incomes, enhancing resilience of livelihoods and ecosystems and reducing and removing greenhouse gas emissions from the atmosphere.

5. References

Agnew, C. T. and Chappel, A. 1999. Drought in the Sahel. *GeoJournal*, 48: 299-311.

Anna, R., and Richa, S. 2012. Impact of Climate change on Agriculture and Food security. ICRIER Policy Series, No.16(1-33).

Calzadilla, A, Rehodanz, K and Tol, R. 2009. "Climate Change Impacts on Global Agriculture,". *Draft version*.

CARE- Climate change Information Center. 2013. Growing disruption:Climate change, food, and the fight against hunger.

Carter, T. R. 2007. General Guidelines on the use of scenario data for Climate Impact and Adaptation Assessment. .Helsinki, Finland: Finnish Environmental Institute.

CEEPA (Center for Environmental Economics and policy in Africa). 2006. *Climate change and African agriculture*. Policy Note No. 25, (online) at:http:// www.ceepa.co.za/ docs/ POLICY%20 NOTE%2025.pdf [Accessed 26 Nov, 2013],. .

Cherkos, 2001 and NMSA, 1996, the rainfall variability of an area with coefficient of variation. CSA 2006/7 National Statistics, Tables B.3 and B.4.

Collen, M. 2011. Impacts of climate change on groundwater resource: a case study of the serdon catchment spain. 37.

CSA (Central Statstical Agency). 2008. Summary and Statistical Report of the 2007 Population and Housing Census Results. Available at: www.cia.gov/library/publications/the-worldfactbook/print/et.html[Accesed 12 Aug, 2013].

CSA (Central Statstical Agency). 2013. Agricultural sample survey 2011/12. Area and Production of crop (private pesant holdings, Meher season), Addis Abeba.

Deressa, T. 2007. Measuring the economic impact of climate change on Ethiopian agriculture: Ricardian approach. World Bank Policy Research Paper(No. 4342).

Doyle, J. D. 1997. The Influence of Mesoscale Orography on a Costal Jet and Rainband. *Monthly Weather Review*, 125(7): 1465-1488.

Egnonto, M. and Madou, K. 2008. "Modeling Climate Change and Agricultural production in SubSaharan Africa (SSA): In quest of Statistics,". African Economic Research Consortium (AERC) Conference Paper. Nairobi, Kenya.

FAO (Food and Agricultural Organization). 2007. Climate change and Food Security: A framework document. Rome: FAO.

FAO (Food and Agricultural Organization). 2008. Climate change and food security: a framework document. available at: www.fao.org/clim/index_en.htm.[Accesed 7 sep,2013], p.9.

FAO (Food and Agricultural Organization) .2010. The state of food inseccurity in the world: addressing food insecurity protracted crises. Retrieved December 12, 2013, from www.fao.org/docrep/013/i1683e/i1683e.pdf.

Hamidreza , S, Mohd A, Mohd S, Teang , S.L., Sayed , F.M., Arman , G., Mohd , K.Y. 2011. Application of Aquacrop model in deficit irregation management of winter wheat in arid region. *African Journal of Agricultural Research,* (610): 2204-2215

Houghton, J. T. 2001. Climate Scenario Development. In: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on

Climate Change. (J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, . . . C. A. Johnson, Eds.) Cambrige and New York: Cambrige University Press.

ILO (International Labour Organization). 2007. In Key indicators of the labour market (KILM). In Chapter 4: Employment by sector (5th ed.: Available at: www.ilo.org/public /english/employment /strat/kilm/download/kilm04.pdf.[Accesed 5 Oct, 2013] IPCC. (2001). Climate change: The scientific basis. http://www.ipcc.ch/[Accesed 16, Jun 2013].

IPCC (Intergovernmental Panel on Climate Change). 2007a. "Summary for Policymakers. Climate Change 2007: The Physical Science Basis,". Working Group I Contribution to IPCC Fourth Assessment Report: Climate Change 2007, Geneva.

IPCC (Intergovernmental Panel on Climate Change). 2007b. WG II Available at http://www.ipcc.ch/[Accesed 6, Jun 2013].

Jury, M. R. 2013. Climatic trends over Ethiopia: regional signals and drivers. *International Journal of Climatology*, 33(8): 1924-1935

Kabubo-Mariara, J., and Karanja, F. 2006. "The economic impact of climate change on Kenyan crop agriculture: a Ricardian approach,". CEEPA Discussion Paper No. 12 Centre for Environmental Economics and Policy in Africa, University of Pretoria(No. 12).

Ketema, T. 2006. The characterisation of rainfall in the arid and semi-arid regions of Ethiopia. *Water SA*, 32(3): 429-436.

Kurukulasuriya, P., and Mendelsohn, R. 2008. "A Ricardian analysis of the impact of climate change on African cropland,". *African Journal of Agricultural Resources and Economics*, 2(1): 1-23.

MoA/FAO. (1984). Land-use and land cover map of Ethiopia, 1:1,000,000. Addis Abeba.

Mulat, D., Fantu, G., and Tadele, F. 2004. Agricultural development in Ethiopia: are there alternatives to food aid? FAO working paper 02.

Nakićenović, N., Fenhann, J., Davis, G., Alcamo, J., de Vries, B., Gaffin, S., Gregory, K., Grübler, A., Jung, T.Y., Kram, T., La Rovere, E.L., Michaelis, L., Mori, S., Morita, T., Pepper, W., Pitcher, H., Price, L., Raihi, K., Roehrl, A., H.H., Rogner, A., and Sankovski, M. 2000. Emissions Scenarios. A Special Report of Working Group III of theIntergovernmental Panel on Climate Change. Cambridge, UK and New York NY, USA,: Cambridge University Press.

Nelson, G.C., Rosegrant, MW., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R., Tokgoz, S., Zhu, T., Sulser, T.B., Ringler, C., Msangi, S., and You, L. 2011. "Climate change: impact on agriculture and costs of adaptation and food security, farming, and climate change of adaptation and food security, farming, and climate changeof adaptation and food security, farming, and climate change to 2050.". Washington, DC: International Food Policy Research Institute, .

Ngetich, K.F., Raes, D., Shisanya, C.A., Mugwe, J., Mucheru-Muna, M., Mugendi, D.N., and Diels, J.2012. Calibration and validation of AquaCrop model for maize in sub-humid and semiarid regions of central highlands of Kenya. Third RUFORUM Biennial Meeting 24 - 28 September 2012, (pp. pp. 1525-1548). Entebbe, Uganda.

Nicholson, S. 1985. Sub-Saharan Rainfall 1981-84. *Journal of Climate and Applied Meteorology,* 24: 1388-1391.

NMSA (National Meteorological Services Agency).1996. The rainfall Variabilty of an area with Coefficent of Variation.

NMSA (National Meteorological Services Agency). 2001. Initial National Communication of Ethiopia to the United Nations Framework.NMSA, Convention on Climate Change (UNFCCC). National Meteorological Services Agency, Addis Ababa, Ethiopia.

Oliver, J. E. 1980. Monthly precipitation distribution: a comparative index. *Professional Geographer*, 32: 300-309.

ONZAO (Oromia Nationality Zone Administration Office). 2012. Tourism in Oromia zone (un published).

Pankhurst, R., and Johnson, D. 1988. The great drought and famine of 1888-92 in northeast Africa. (Johnson, D and Anderson, D. Eds.) The ecology of survival: case studies from northeast African history, pp. 47-72.

Strzepek, K., and McCluskey, A. 2007. "The impacts of climate change on regional water resources and agriculture in Africa,". Policy Research working paper (No. 4290 World Bank, Washington, DC.).

The Hague Conference on Agriculture, Food Security. 2010. The Hague Conference on Agriculture, Food Security and Climate Change. Chair's summary.

UNDP (United Nations Developemnt Programme). 1994. Human development report: new dimensions of human security. Oxford (online): Oxford University Press.

UNFCCC (United Nations Framework Convention on Climate Change). 2008. Nairobi work programme on impacts, vulnerability and adaptation to climate change. In FCCC/SBSTA/2008/ (Ed.), Revised draft conclusions proposed by the Chair, Rev. 1 L. 13.

USAID-LIU. 2007. South Wollo & Oromia eastern lowland sorghum and cattle livelihood zone profile, Amhara region, Ethiopia. United States Agency for International Development-Livelihood Integration Unit. prepared by FEG.

von Braun, J. 1991. A policy agenda for famine prevention in Africa. Food Policy Statement (No.13).

Woldeamlak, B. 2006. Adapting to rainfall variability in the drought-prone areas of the Amhara region of Ethiopia: rainwater harvesting as a livelihood strategy.

Woldeamlak, B. 2009. Rainfall variability and crop production in Ethiopia case study in the Amhara region. In Sveia Ege, Harald Aspen, Birhanu Teffera, & Shiferaw Bekele (Ed.), preceedings of the 16th International Conference of ethiopian studies. Trondheim.

Wood, A. 1977. A preliminary chronology of Ethiopian droughts. (D. Dalby, R. Church, & F. Bezzaz, Eds.) Drought in Africa: *International African Institute*, 2: 68-73.

World Bank. 1986. Poverty and hunger : issues and options for food security in developing countries. A World Bank policy study.Washington DC: World Bank. http://documents .worldbank.org/curated/en/1986/07/440681/poverty-hunger-issues-options-food-security-developing-countries[Accesed 26, Nov 2013].

Yusman, S. 2011. The Impact of Climate Change on Food Production and Security and Adaptation Programs in Indonesian. *International Society for Southeast Asian Agricultural Sciences*, 17(1): 40-51.

Zhai, F., and Zhuang, J. 2009. "Agricultural Impact of Climate Change: A General Equilibrium Analysis with Special Reference to Southeast Asia,". ADBI Working Paper(131 Asian Development Bank Institute, Tokyo.).

Appendix-I

Aqua Crop 4.0 (June 2012) - Output created on (date) : 3/27/2014 at (time) : 7:57:48 AM
Simulation run (A2-Maize)

RunNr	Year1	Rain mm	ETo mm	GD ^{0}C.day	CO_2 Ppm	E mm	E/Ex %	Tr mm	Tr/Trx %	Cycle days	TempStr %	BioMass ton/ha	Brelative %	HI %	Yield ton/ha
1	2020	719	899	1702	417	169	57	549	100	189	22	4.745	98	48	2.284
2	2021	621	867	1705	420.4	145	51	530	100	178	18	4.697	98	48	2.26
3	2022	659	860	1706	423.8	158	55	528	100	178	14	4.928	98	48	2.367
4	2023	586	872	1703	427.2	156	52	522	100	182	16	4.845	97	48	2.334
5	2024	693	862	1704	430.6	173	58	523	100	178	13	4.988	99	48	2.394
6	2025	702	854	1701	434	135	47	518	100	176	14	4.894	98	48	2.349
7	2026	579	852	1702	437.4	138	46	513	100	173	12	4.865	98	48	2.341
8	2027	731	914	1703	440.8	202	68	552	100	193	24	4.819	99	48	2.315
9	2028	676	919	1700	444.2	217	61	498	96	195	25	4.169	87	48	2.017
10	2029	746	891	1701	447.6	177	57	526	100	189	21	4.817	97	48	2.322
11	2030	707	876	1702	451	177	60	523	99	183	19	4.755	97	48	2.293
12	2031	645	885	1702	454.9	195	62	519	99	183	18	4.700	95	48	2.272
13	2032	687	894	1703	458.8	166	53	527	100	189	20	4.881	98	48	2.344
14	2033	629	852	1706	462.7	164	58	518	100	172	13	4.893	99	48	2.355
15	2034	741	838	1704	466.6	175	61	509	100	171	11	4.977	99	48	2.39
16	2035	591	871	1706	470.5	175	58	523	100	179	14	4.991	98	48	2.401
17	2036	709	874	1700	474.4	181	61	524	100	180	17	4.879	98	48	2.348
18	2037	628	878	1705	478.3	173	60	528	100	181	18	4.877	98	48	2.351
19	2038	677	844	1702	482.2	174	57	491	99	172	12	4.814	96	48	2.33
20	2039	722	846	1701	486.1	168	59	511	100	172	13	4.944	98	48	2.376
21	2040	624	871	1705	490	157	53	519	100	182	15	5.036	98	48	2.423
22	2041	590	857	1700	494.2	170	56	498	98	177	14	4.789	94	49	2.333
23	2042	641	867	1701	498.4	171	57	508	99	180	17	4.816	96	48	2.332
24	2043	649	862	1704	502.6	145	49	507	100	177	15	4.942	98	48	2.375
25	2044	704	861	1703	506.8	178	59	506	100	177	14	4.969	98	48	2.389
26	2045	674	885	1705	511	174	59	525	100	186	17	5.092	99	48	2.448
27	2046	652	907	1703	515.2	197	57	488	97	192	23	4.363	88	48	2.11

28	2047	685	877	1702	519.4	140	46	516	100	182	16	5.026	98	48	2.412
29	2048	756	906	1704	523.6	178	58	523	100	191	21	4.997	98	48	2.398
30	2049	652	879	1703	527.8	198	66	517	100	185	17	5.033	98	48	2.437

AquaCrop 4.0 (June 2012) - Output created on (date) : 3/27/2014 at (time) : 9:05:29 AM
Simulation run (B2-Maize)

RunNr	Year1	Rain mm	ETo mm	GD ^{0}C.day	CO_2 ppm	E mm	E/Ex %	Tr mm	Tr/Trx %	Cycle days	TempStr %	BioMass ton/ha	Brelative %	HI %	Yield ton/ha
1	2020	648	900	1705	408	188	56	527	99	184	17	4.657	94	48.5	2.257
2	2021	612	863	1702	410.1	159	56	527	100	183	19	4.790	98	48.2	2.309
3	2022	731	888	1700	412.2	172	55	530	100	182	16	4.855	97	48.1	2.336
4	2023	600	876	1705	414.3	149	49	527	100	180	14	4.850	96	48.2	2.336
5	2024	641	855	1701	416.4	182	61	518	100	175	12	4.863	97	48.3	2.348
6	2025	654	880	1704	418.5	158	55	540	100	185	18	4.857	98	48	2.332
7	2026	543	852	1703	420.6	171	56	511	99	171	11	4.762	96	48.5	2.308
8	2027	713	887	1706	422.7	193	64	534	100	186	19	4.800	98	48.2	2.314
9	2028	725	925	1702	424.8	206	62	521	97	189	22	4.520	93	48.7	2.201
10	2029	679	917	1701	426.9	212	62	527	99	189	20	4.785	96	48.5	2.320
11	2030	670	866	1705	429	187	58	508	99	171	12	4.697	95	48.6	2.283
12	2031	724	912	1703	431.4	219	66	522	98	183	17	4.680	94	48.7	2.280
13	2032	708	935	1700	433.8	193	57	540	99	197	25	4.660	96	48.2	2.246
14	2033	613	873	1704	436.2	177	60	532	100	177	15	4.857	98	48.1	2.335
15	2034	689	861	1706	438.6	172	60	530	100	174	12	4.925	98	48.2	2.374
16	2035	628	893	1701	441	187	57	523	100	181	17	4.762	96	48.2	2.297
17	2036	653	877	1706	443.4	202	63	511	99	174	13	4.743	96	48.5	2.299
18	2037	660	874	1702	445.8	230	68	492	98	170	12	4.575	92	48.6	2.223
19	2038	723	900	1705	448.2	240	65	431	91	178	15	3.974	79	48.8	1.938
20	2039	701	855	1705	450.6	165	57	515	100	172	13	4.864	97	48.1	2.341
21	2040	635	883	1704	453	163	54	531	100	184	17	4.937	98	48.2	2.379
22	2041	641	871	1705	455.5	170	53	503	99	175	14	4.706	95	48.7	2.292
23	2042	580	873	1705	458	167	56	528	100	186	20	4.676	97	48.2	2.253
24	2043	623	913	1702	460.5	228	57	449	94	185	16	4.171	82	48.7	2.031

25	2044	680	899	1704	463	185	61	532	99	188	20	4.809	97	48.3	2.324
26	2045	609	863	1701	465.5	187	63	518	100	176	13	4.974	98	48.4	2.407
27	2046	710	900	1705	468	256	62	365	88	183	18	3.374	68	48.7	1.642
28	2047	694	887	1702	470.5	176	49	491	99	178	14	4.729	93	48.4	2.291
29	2048	755	913	1702	473	178	55	537	100	186	18	4.966	98	48	2.384
30	2049	622	926	1706	475.5	267	68	429	92	196	21	3.841	76	48.6	1.866

AquaCrop 4.0 (June 2012) - Output created on (date) : 3/27/2014 at (time) : 7:57:48 AM
Simulation run (A2-Sorghum)

RunNr	Year1	Rain mm	ETo Mm	GD ^{0}C.day	CO_2 Ppm	E mm	E/Ex %	Tr mm	Tr/Trx %	Cycle days	TempStr %	ExpStr %	BioMass ton/ha	Brelative %	HI %	Yield ton/ha
1	2020	339	517	1410	417	136	54	291	100	89	0	8	4.741	99	47	2.249
2	2021	324	523	1479	420	124	47	290	100	89	0	12	4.718	98	48	2.244
3	2022	373	514	1398	424	135	52	283	100	89	0	9	4.743	98	46	2.194
4	2023	307	513	1400	427	121	47	283	100	89	0	13	4.734	98	49	2.333
5	2024	394	512	1356	431	138	55	286	100	89	0	6	4.771	99	45	2.159
6	2025	387	517	1418	434	110	43	286	100	89	0	9	4.741	98	46	2.179
7	2026	320	524	1428	437	113	43	287	100	89	0	11	4.738	98	48	2.259
8	2027	397	515	1392	441	163	65	288	100	89	0	2	4.813	99	45	2.185
9	2028	280	515	1399	444	146	56	272	97	89	0	24	4.563	94	55	2.486
10	2029	311	508	1383	448	131	52	282	100	89	0	7	4.791	99	49	2.338
11	2030	350	519	1441	451	143	55	286	100	89	0	10	4.794	99	50	2.384
12	2031	327	521	1408	455	152	60	291	100	89	0	15	4.799	99	52	2.5
13	2032	346	512	1366	459	131	52	285	100	89	0	12	4.803	99	48	2.307
14	2033	364	523	1459	463	141	55	291	100	89	0	9	4.809	99	47	2.268
15	2034	392	517	1419	467	148	58	288	100	89	0	4	4.833	99	45	2.179
16	2035	340	518	1379	471	142	56	288	100	89	0	8	4.825	99	47	2.247
17	2036	368	523	1430	474	150	59	292	100	89	0	8	4.836	99	48	2.31
18	2037	330	521	1450	478	146	57	287	100	89	0	8	4.833	99	48	2.297
19	2038	303	515	1433	482	137	54	283	100	89	0	15	4.824	98	51	2.468
20	2039	386	526	1454	486	147	56	286	100	89	0	9	4.832	99	47	2.246
21	2040	316	509	1374	490	122	48	278	100	89	0	7	4.833	99	47	2.254

22	2041	262	519	1420	494	131	51	283	100	89	0	11	4.830	98	51	2.47
23	2042	297	518	1437	498	134	52	283	100	89	0	15	4.833	98	51	2.47
24	2043	326	514	1411	503	113	45	285	100	89	0	11	4.829	98	48	2.296
25	2044	363	518	1407	507	142	56	283	100	89	0	5	4.860	99	47	2.258
26	2045	343	510	1353	511	142	56	277	100	89	0	8	4.863	99	46	2.243
27	2046	270	515	1399	515	133	51	272	99	89	0	23	4.725	96	55	2.574
28	2047	362	514	1370	519	109	43	279	100	89	0	9	4.833	98	46	2.219
29	2048	388	510	1370	524	135	53	275	100	89	0	4	4.865	99	45	2.185
30	2049	310	509	1375	528	157	63	278	100	89	0	6	4.887	99	48	2.354

AquaCrop 4.0 (June 2012) - Output created on (date) : 3/27/2014 at (time) : 9:09:29 AM
Simulation run (B2- Sorghum)

RunNr	Year1	Rain	ETo	GD	CO2	E	E/Ex	Tr	Tr/Trx	Cycle	TempStr	BioMass	Brelative	HI	Yield
		mm	mm	C.day	ppm	mm	%	mm	%	days	%	ton/ha	%	%	ton/ha
1	2020	307	512	1391	408	127	51	289	100	89	0	4.337	99	48	2.273
2	2021	322	517	1453	410	134	52	288	100	89	0	4.333	98	48	2.266
3	2022	375	507	1374	412	131	51	281	100	89	0	4.344	99	46	2.177
4	2023	329	508	1370	414	111	44	283	100	89	0	4.336	98	47	2.22
5	2024	347	507	1387	416	141	57	286	100	89	0	4.368	99	47	2.241
6	2025	382	512	1403	419	132	52	287	100	89	0	4.360	99	46	2.161
7	2026	315	519	1430	421	134	52	288	100	89	0	4.352	98	48	2.293
8	2027	367	510	1402	423	153	61	287	100	89	0	4.386	99	49	2.316
9	2028	324	510	1409	425	152	60	285	100	89	0	4.384	99	51	2.421
10	2029	339	503	1362	427	148	60	283	100	89	0	4.391	99	48	2.299
11	2030	365	513	1437	429	137	54	286	100	89	0	4.376	99	49	2.324
12	2031	361	517	1396	431	161	65	294	100	89	0	4.406	99	51	2.431
13	2032	346	508	1379	434	131	53	286	100	89	0	4.386	99	48	2.293
14	2033	380	519	1431	436	144	57	291	100	89	0	4.397	99	45	2.171
15	2034	402	513	1409	439	142	57	288	100	89	0	4.403	99	46	2.22
16	2035	342	514	1414	441	137	54	288	100	89	0	4.399	99	47	2.224
17	2036	359	517	1432	443	149	60	293	100	89	0	4.410	99	49	2.34
18	2037	337	515	1452	446	148	58	287	100	89	0	4.410	99	48	2.319

19	2038	301	510	1408	448	151	59	268	96	89	0	4.147	93	55	2.458
20	2039	368	520	1449	451	136	52	286	100	89	0	4.402	99	46	2.212
21	2040	345	504	1390	453	133	54	281	100	89	0	4.420	99	46	2.218
22	2041	302	514	1440	456	131	52	284	100	89	0	4.404	98	51	2.434
23	2042	303	511	1394	458	142	56	282	100	89	0	4.383	98	52	2.497
24	2043	264	506	1348	461	109	44	280	99	89	0	4.329	97	54	2.54
25	2044	342	514	1416	463	145	57	285	100	89	0	4.429	99	49	2.354
26	2045	321	510	1407	466	154	61	281	100	89	0	4.445	99	47	2.247
27	2046	253	510	1412	468	137	53	251	92	89	0	3.939	88	55	2.334
28	2047	334	507	1373	471	112	45	279	100	89	0	4.410	98	49	2.367
29	2048	439	504	1371	473	135	54	277	100	89	0	4.444	99	44	2.127
30	2049	257	500	1327	476	156	63	257	95	89	0	4.109	91	55	2.436

AquaCrop 4.0 (June 2012) - Output created on (date) : 3/27/2014 at (time) : 7:57:48 AM
Simulation run (A2-Teff)

RunNr	Year1	Rain mm	ETo mm	GD ^{0}C.day	CO_2 ppm	E mm	E/Ex %	Tr mm	Tr/Trx %	Cycle days	TempStr %	BioMass ton/ha	Brelative %	HI %	Yield ton/ha
1	2020	430	470	1158	417	188	72	219	99	82	1	2.522	84	34	1.891
2	2021	388	472	1194	420	148	64	250	100	82	1	2.938	98	28	1.785
3	2022	450	461	1130	424	146	65	245	100	82	1	2.946	98	27	1.742
4	2023	376	463	1145	427	213	69	169	98	82	0	2.016	66	32	1.426
5	2024	458	464	1123	431	156	71	251	100	82	0	3.039	99	27	1.797
6	2025	504	468	1176	434	150	67	250	100	82	0	3.046	99	27	1.801
7	2026	402	471	1177	437	150	66	250	100	82	0	3.029	98	28	1.855
8	2027	462	467	1152	441	217	81	202	96	82	0	2.453	79	32	1.704
9	2028	382	467	1166	444	278	64	30	88	31	0	0.346	11	0	0.000
10	2029	436	463	1169	448	311	76	41	85	38	0	0.484	15	0	0.000
11	2030	468	467	1171	451	290	74	75	91	82	0	0.909	29	28	0.547
12	2031	403	474	1177	455	309	71	32	85	32	0	0.366	11	0	0.000
13	2032	443	466	1159	459	142	62	243	100	82	0	3.071	96	28	1.871
14	2033	419	476	1201	463	156	67	249	100	82	0	3.117	97	28	1.911
15	2034	469	469	1181	467	169	77	253	100	82	0	3.197	99	27	1.897

16	2035	369	470	1150	471	156	69	242	98	82	0	3.079	95	30	2.032
17	2036	442	475	1187	474	209	72	196	99	82	0	2.477	76	31	1.682
18	2037	371	472	1170	478	180	70	211	96	82	1	2.664	82	35	2.039
19	2038	402	469	1198	482	308	72	34	86	35	0	0.415	13	0	0.000
20	2039	460	472	1186	486	149	65	247	100	82	0	3.238	98	27	1.914
21	2040	378	461	1133	490	157	71	242	100	82	0	3.200	97	32	2.259
22	2041	341	468	1146	494	299	70	33	86	32	0	0.404	12	0	0.000
23	2042	378	469	1171	498	308	72	34	86	35	0	0.418	13	0	0.000
24	2043	413	471	1185	503	143	63	247	100	82	0	3.262	97	27	1.949
25	2044	467	469	1175	507	230	78	177	97	82	0	2.358	70	31	1.587
26	2045	388	461	1111	511	146	66	242	100	82	1	3.282	98	27	1.965
27	2046	384	469	1156	515	284	65	30	88	32	0	0.382	11	0	0.000
28	2047	478	469	1136	519	148	66	246	100	82	0	3.342	99	27	1.976
29	2048	485	461	1128	524	167	77	243	100	82	1	3.343	99	27	1.977
30	2049	349	462	1124	528	304	75	37	84	34	0	0.484	14	0	0.000

AquaCrop 4.0 (June 2012) - Output created on (date) : 3/27/2014 at (time) : 9:12:33 AM
Simulation run (B2-Teff)

RunNr	Year1	Rain mm	ETo mm	GD °C.day	CO_2 ppm	E mm	E/Ex %	Tr mm	Tr/Trx %	Cycle days	TempStr %	BioMass ton/ha	Brelative %	HI %	Yield ton/ha
1	2020	368	469	1130	408	235	70	139	94	82	1	1.557	53	35	1.194
2	2021	372	471	1182	410	235	71	150	96	82	1	1.722	58	35	1.299
3	2022	461	461	1126	412	148	66	243	100	82	1	2.874	97	27	1.706
4	2023	404	463	1106	414	144	63	243	100	82	1	2.838	95	29	1.808
5	2024	403	464	1142	416	210	71	179	97	82	0	2.087	70	33	1.513
6	2025	436	467	1150	419	142	63	250	100	82	1	2.938	98	27	1.738
7	2026	352	471	1168	421	248	71	128	94	82	0	1.482	49	34	1.118
8	2027	438	467	1162	423	316	77	40	84	36	0	0.442	15	0	0.000
9	2028	409	467	1165	425	301	72	35	84	33	0	0.395	13	0	0.000
10	2029	403	463	1139	427	307	76	45	85	42	0	0.51	17	0	0.000
11	2030	454	466	1164	429	292	75	74	90	82	1	0.864	28	28	0.524
12	2031	435	475	1158	431	314	73	34	85	32	0	0.37	12	0	0.000

13	2032	424	466	1141	434	242	70	141	97	82	1	1.689	55	30	1.123
14	2033	398	476	1176	436	147	64	254	100	82	1	3.013	98	27	1.781
15	2034	467	469	1137	439	161	69	244	100	82	1	2.94	95	28	1.824
16	2035	382	470	1170	441	161	68	242	100	82	1	2.933	94	35	2.234
17	2036	410	475	1182	443	302	74	67	89	82	1	0.778	25	29	0.497
18	2037	395	472	1194	446	266	72	105	93	82	0	1.261	40	32	0.873
19	2038	411	469	1162	448	272	63	30	88	31	0	0.353	11	0	0.000
20	2039	431	471	1177	451	144	63	247	100	82	0	3.069	97	27	1.823
21	2040	403	461	1130	453	196	76	205	98	82	1	2.555	81	34	1.890
22	2041	386	469	1179	456	308	72	33	86	32	0	0.384	12	0	0.000
23	2042	342	467	1136	458	293	68	31	86	32	0	0.36	11	0	0.000
24	2043	342	466	1113	461	287	66	29	86	32	0	0.339	11	0	0.000
25	2044	404	468	1139	463	303	74	58	88	82	1	0.692	22	29	0.432
26	2045	347	464	1160	466	222	74	141	88	82	0	1.764	55	35	1.345
27	2046	365	469	1177	468	256	58	27	91	30	0	0.325	10	0	0.000
28	2047	460	467	1168	471	277	72	85	92	82	0	1.076	33	28	0.648
29	2048	490	460	1125	473	164	76	246	100	82	1	3.207	99	27	1.897
30	2049	307	461	1088	476	257	60	29	89	31	0	0.361	11	0	0.000

Legend

RunNr :Number simulation run;
Year1 :year of simulation run
Rain :Rainfall
ETo :Reference evapotranspiration
GD :Growing degrees
CO_2 :Atmospheric CO2 concentration
E :Soil evaporation
E/Ex :Relative soil evaporation (100 E/Ex)
Tr :Crop transpiration
Tr/Trx :Relative crop transpiration (100 Tr/Trx)
Cycle : Length of crop cycle: from germination to maturity (or early senescence)
TempStr :Average temperature stress (affecting biomass)
Biomass :Cumulative biomass produced
Brelative :Relative biomass (Reference: no water, no soil fertility, no soil salinity stress)
HI :Harvest Index adjusted for failure of pollination, inadequate photosynthesis and water stress
Yield :Yield (HI x Biomass)
DayN :End day of simulation run
MonthN :End month of simulation run
YearN :End year of simulation run

Appendix-II

Table 10: User specific parameters (calibrated) for Oromia nationality zone for Maize (a), Sorghum (b) and Teff (c) in AquaCrop.

(a)

Parameters	Value	Units	Interpretation
Maximum effective rooting depth	0.85	(m)	
Effect of canopy cover in late season	50		CC effect on soil evaporation
Soil surface covered by an individual seedling	6.5	(cm^2)	At 90 % emergence
Number of plants per hectare	75,000	ha^{-1}	
Canopy growth coefficient (CGC):	0.1682	days	per day CC increase
Maximum canopy cover (CCx)	0.88	(%)	depends on plant spacing
Canopy decline coefficient (CDC):	0.1003	days	per day CC decrease
Time from sowing to emergence	7 6	days	Calendar days
Time from sowing to maximum rooting depth	55	days	Calendar days
Time from sowing to start senescence	104	days	Calendar days
Time from sowing to maturity	130	days	Calendar days
Time from sowing to flowering	60	days	Calendar days
Length of the flowering stage	18	days	
Building up of Harvest Index	65	days	From flowering
Reference Harvest Index (HIo) (%)	48	%	

(b)

Parameters	Value	Units	Interpretation
Base temperature	12	^0C	
Upper temperature	30	^0C	
Soil surface covered by an individual seedling (CC_0)	3	(cm^2)	At 90 % emergence
Number of plants per hectare	74,000	ha^{-1}	Farily covered
Canopy growth coefficient (CGC)	0.16	days	fraction per day
Maximum canopy cover(CCx)	65	(%)	
Canopy decline coefficient (CDC)	0.01	day^{-1}	
Time from sowing to maturity	102	days	Calendar days
Time from sowing to flowering	65	days	Calendar days
Length of the flowering stage	20	days	Calendar days
Maximum effective rooting depth	1.30	(m)	
Reference harvest index (HIo)	65	(%)	
Building up of Harvest Index	45	(%)	From flowering

(C)

Parameters	Value	Units	Interpretation
Canopy cover per seedling at 90% emergence (CC_O)	0.15	(cm)	
Canopy growth coefficient (CGC)	9.9	(%)	Increase in CC relative to existing CC per day
Maximum canopy cover (CC_X)	80	(%)	well covered
Maximum crop coefficient	0.95	-	At max. canopy
Canopy decline coefficient (CDC) at senescence	16	(%)	Decrease in CC relative to CC_X per day
Upper threshold for canopy expansion	0.2	-	Above this leaf growth is inhibited
Lower threshold for canopy expansion (Plower)	0.5	-	Leaf growth stop completely at this Pvalue
Leaf expansion stress coefficient curve shape	3.5	-	
Upper threshold for stomatal closure	0.7	-	Above this stomata begins to close
Stomata stress coefficient curve shape	4.5	-	
Canopy senescence stress coefficient (Pupper)	0.79	-	Above this canopy senescence begins
Senescence stress coefficient curve shape	3.5	-	Moderately convex
Reference harvest index (HI)	25	(%)	Common for good condition
Duration of flowering	16	days	
Duration of yield build-up	35	days	
Total growing period	85	days	Emergence to maturity
Coefficient, adjustment of HI to water stress during flowering	0.85	-	Upper threshold to failure of pollinations
Coefficient, HI increased due to inhibition of leaf growth after flowering	1.0	-	Maximum HI increased by inhibition of leaf growth after flowering
HI decreased caused by water stress during yield formation	5.0	-	HI reduced by inhibition of stomata at yield formation

NB:- Conservative parameters (left unaltered) for all crops.

3. Climate Change in Ethiopia: Its State and the Response

Mensur Dessie Nuri

Ministry of Environment, Forest and Climate Change (MEFCC), Addis Ababa, Ethiopia,
*Corresponding Author Email: mensurdes2012@gmail.com

Abstract

This paper aims to serve as a springboard for research in areas of climate change in Ethiopia. While there have been critical issues that merit intellectual attention, very little has so far been done in the area. The paper reviews literatures using DPSIR model as recommended by UNEP. The results of the assessment depict that the driving forces of climate change in Ethiopia is linked with ENSO. Human–related GHG emissions are responsible for the observed temperature increase. Ethiopia become warmer over the past century where it is 0.25% temperature increase per decade since 1960s and it is projected between 1.4^{o}C and 2.9^{o}C by 2050s in all seasons. The inter annual rainfall variation in Ethiopia for the period 1951-2010 shows the fluctuations of the total annual rainfall, with some years experiencing above normal rainfall, others below normal and still others around the average value. From 1900-2016, at least 17 droughts, 22 epidemic diseases and 50 flood events with 415,959 deaths and about 88,501,534; 2,447,438 and 169,659 total affected by drought, diseases and flood respectively with damages of USD 117.083 million are recorded. CRGE with its 60 mitigation and/or adaptation options, among others, is one of the main strategic responses reacted for climate change in the country. Since climate change is inevitable, a lot is expected from the scientific world including the universities by conducting site specific and problem-oriented research on each element of DPSIR of climate change in Ethiopia. On the contrary, MoEFCC and National Planning Commission, as coordinating organs for design and implementation of climate smart strategies in general, have to take the responsibility of bridging the scientific gaps to the government policies, projects and programmes in the respective sectors of the country through establishment of systems and institution.

Keywords: Climate change; DPSIR framework; El Nino; Temperature; Rainfall

1. Introduction

The climate system is made up of a multitude of interlinking environmental components, and therefore can be viewed as the status of the entire Earth system, including the atmosphere, land (geosphere), water (hydrosphere), snow and ice (cryosphere) and living things (biosphere) – as shown in Figure 1. The conditions of these components of the climate system form the background conditions for the occurrence of certain weather patterns.

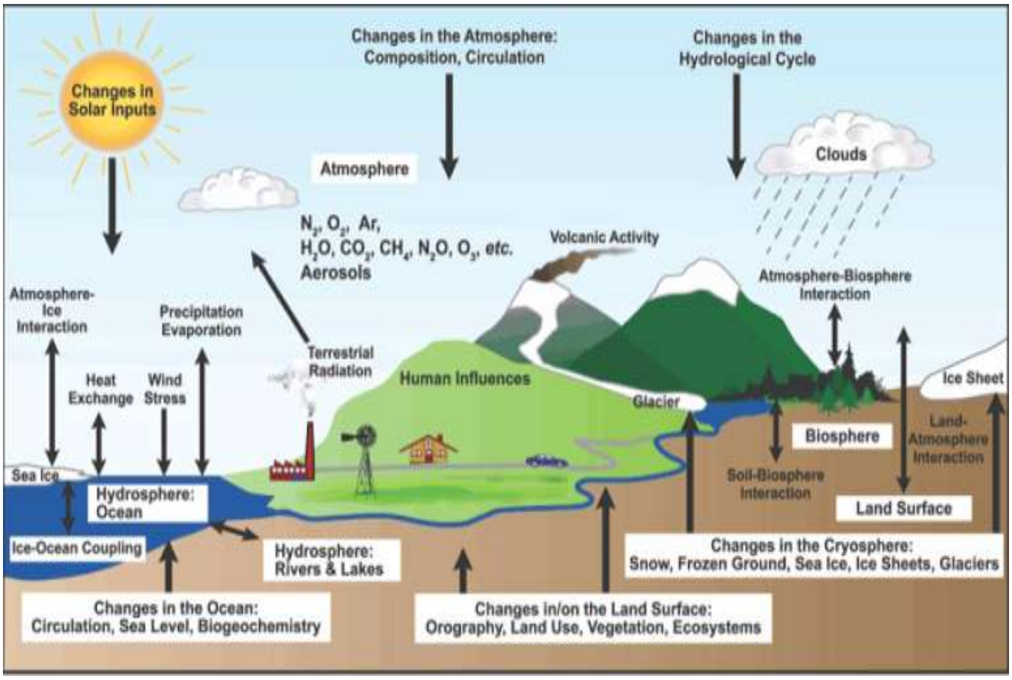


Figure 1: The Climate System.

Source: UNITAR, 2015

Concentrations of greenhouse gases have dramatically increased during recent decades as a result of a growing global population and resource intensive lifestyles. The expansion of human activities has resulted in increased consumption of energy (mostly produced by fossil fuels) and natural resources, through manufacturing and industrial activities, as well as biomass burning and agriculture, which has resulted in increased emissions of greenhouse gases such as carbon dioxide and methane.

Although the conditions of the climate system evolve over time under the influence of changes within its own natural dynamics, anthropogenic pressures on the climate system are now acknowledged virtually unanimously concluded to be a major factor in determining our current changing climate and for making projections of climate in the future.

Results of IPCC (2014) over the period 1880 to 2014 showed that global mean surface temperature has increased by approximately 0.85 [0.65 to 1.06] °C. These temperature changes since the middle of the 20th century can only be explained by scientists with reference to the increased emissions of greenhouse gases due to anthropogenic activity since the (Western) industrial revolution.

Developing countries are among the most vulnerable to the effects of climate change. Changing weather patterns, particularly severe floods and droughts increase the exposure of millions of people in developing countries to poverty, hunger and disease. Vulnerability is a result of a country's reliance on climate-sensitive sectors such as agriculture, geographical location, poverty levels, and institutional capacity. Developing countries are burdened more by climate-related natural disasters than industrialized countries.

Warming throughout the African continent is very likely to be greater than the global annual mean warming during all seasons, with drier subtropical regions warming more than the wetter tropical regions. Unlike to other parts of Africa, there is however likely to be a significant increase in annual mean rainfall over East Africa (IPCC, 2007).

The climate of Ethiopia is largely controlled by the seasonal movement of the Inter-Tropical Convergence Zone (ITCZ) and it's associated with atmospheric circulations, however, the complex and rugged topography of the country and its geographical location modifies the local weather system. The ITCZ normally makes a zone of rising moist air and heavy rainfall. The ITCZ normally makes a zone of rising moist air and driving most of the seasonal rainfall in Ethiopia. The ITCZ changes its precise position over the course of the year, while oscillating across the equator from its northernmost position over northern Ethiopia in July and August, to its southernmost position over southern Kenya in January and February.

The amount and pattern of rainfall and temperature varies across the country. The average annual rainfall in the lowland areas in the south, southeast, east, and north eastern is below 500 mm, whereas some areas of the highland receive over 2000 mm (Figure 2). In addition to spatial variability rainfall in Ethiopia, it is highly variable over seasonal and inter annual time scales.

In most areas of the country, there are two rainy seasons-the short spring rains (February-May) locally known as *Belg*, and the main rainy season (June-September) locally known as *Kiremt*. In between the rainy seasons there is dry spell locally known as *Bega*. In the western part of the country, however, there is only one rainfall peak during the year. The March and April rain originate from the Indian Ocean and are brought by the Easterly Wind; while the heavy rains in the wet season come from the Atlantic Ocean by wind known as Equatorial Westerly Wind or the Guinea Monsoon.

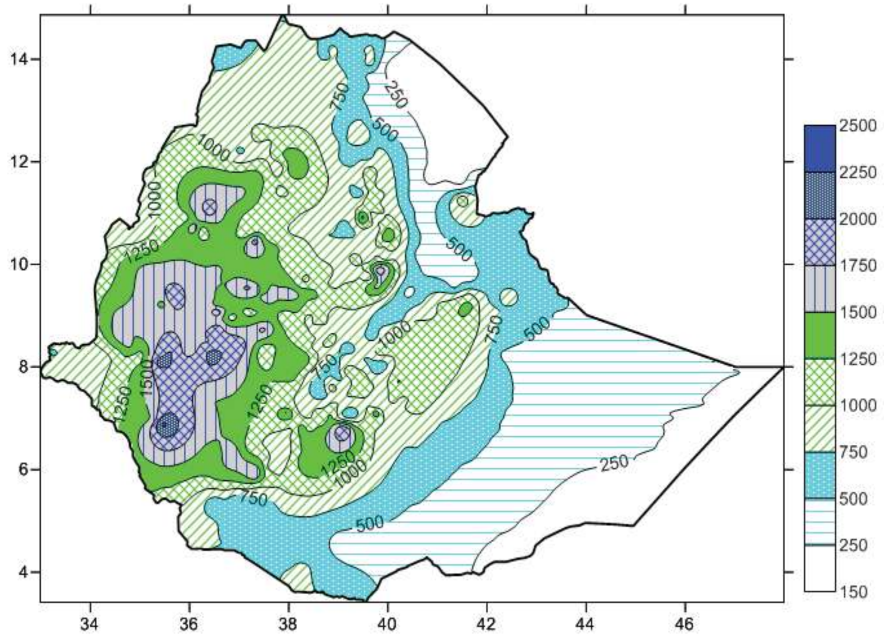


Figure 2. Spatial Distribution of Mean Annual Rainfall (mm).

Like that of rainfall, temperature is also very much modified by the varied topography of the country. Mean annual temperature of the country varies between 10^{o}C and 35^{o}C. The minimum mean temperature is manifested over the northwest, central and southeast highlands of the country and the maximum occurs over north-eastern lowlands, which is part of the Great Rift Valley. Daily maximum temperature ranges between 37^{o}C over the lowlands of Northeast (Afar Triangle) and Southeast (Ogaden) and 15^{o}C over the highlands of central and northern Ethiopia (Figure 3).

Generally, in most parts of the country, the hottest months are from March to May and the coldest periods occur in July and August. Over the highlands, particularly between November and January the temperature experiences its lowest value and reaches frost point.

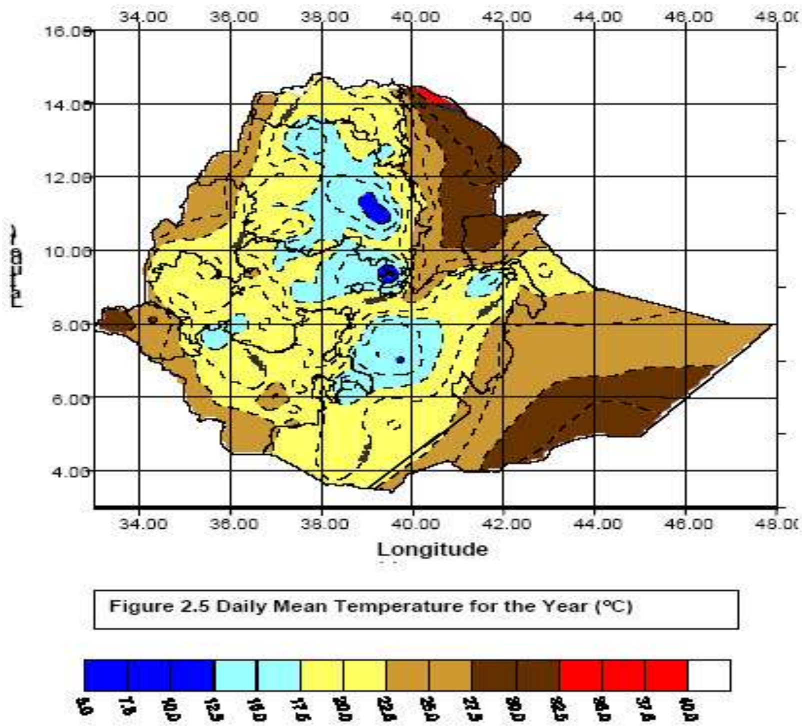


Figure 3. Daily Mean Temperature (^{o}C).

Crop productions of the country are based on the two rainy seasons (*Kiremt* and *Belg)* rainfalls that shares from 90-95% from the *Kiremt* season and 5-10% from *Belg* season. However, in the south and south-western parts, *Belg* production raise to 25-60% of the food production and it is also the major rainy season for south-eastern pastoral lowland areas.

Through international negotiations under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC), governments including Ethiopia are working to secure a global and comprehensive climate change agreement. This agreement will form a cooperative path for reducing the causes and responding to the impacts of climate change. In order to design a path forward that addresses the most urgent concerns and prioritizes the most vulnerable communities, developing countries need ample and reliable information as well as enough support about the current state of play.

While climate change is acknowledged and considered virtually unanimously by governments worldwide to be one of the greatest challenges of this time, understanding and finding solutions is a work in progress for the scientific, economic and technological community.

There are some documents written on climate change but they do not cover national dimensions as climate change by itself is interlinked with every activity either of both sides that may cause for climate changes or mitigating and/or adapting for the change. There are still significant gaps in the knowledge and understanding of the issue that need to be addressed. More is necessary in order to use the findings for the development of effective policy and strategy formulation and implementation and exchange of experiences and lessons learned so far.

This paper explores the issue of climate change while recognizing the broader nature of the issue, focus will be on a few important issues by selecting indicators in the context of the interlinked elements such as drivers, pressures, state and trend, impacts and responses of the ongoing climate change in Ethiopia from reviewing of archival documents and literatures.

Having drawn from archival documents and the review of literature, the general objective of this paper is to assess holistically the status of climate change in Ethiopia and to initiate researchers to conduct deep study in the subject under discussion.

Specifically this paper is intended to identify the drivers and pressures that force climate to change in Ethiopia, show the state of Ethiopia's climate change and its trends, elaborate the impacts of climate change in Ethiopia and identify the response measures taken so far to climate change in Ethiopia

2. Methodology

This paper uses Driver Pressure State Impact Response (DPSIR) framework to review the climate change in Ethiopia. The DPSIR framework originally developed by Rapport and Friend (1979) for Statistics Canada and also adopted by other bodies such as United Nations Environment Programme (UNEP) in the Global Environment Outlook (GEO) and African Environment Outlook (AEO) processes. In recommendation to the UNEP on how member states should proceed with the development of a strategy for Integrated Environmental Assessment (IEA) where it proposed the use of a framework or model, which distinguished a chain of causal links starting with driving forces, pressures, states, impacts and responses and has since been more widely adopted by the Ministry of Environment, Forest and Climate Change (MEFCC), acting as an integrated approach for state of environment reporting.

The framework is seen as giving a structure within which to present the indicators needed to enable feedback to policy makers on environmental quality and the resulting impact of the political choices made, or to be made in the future. The DPSIR framework is multi-scalable and indicates generic cause and effect relations within and among its elements such as:

DRIVERS: The drivers are sometimes referred to as indirect or underlying drivers or driving forces and refer to fundamental processes in society, which drives activities having a direct impact on the environment (e.g population, poverty);

PRESSURES: The pressure is sometimes referred to as direct drivers as in the framework. Human interventions may be directed towards causing a desired environmental change and may be subject to feedbacks in terms of environmental change, or could be an intentional or un-intentional by-products of other human activities (i.e., pollution, waste);

STATE: Environmental state also includes trends, often referred to as environmental change, which could be both naturally and human induced. One form of change, such as climate change, may lead to other forms of change such as biodiversity loss (a secondary effect of climate gas emissions) (e.g. the level of air pollution, land degradation, deforestation or waste management);

IMPACTS: Environmental change may positively or negatively influence human wellbeing through changes in environmental services and environmental stress. Vulnerability to change varies between groups of people depending on their geographic, economic and social location, exposure to change and capacity to mitigate or adapt to change. (e.g. Decline in water table, species decline, birdlife migration, human health, etc); and

RESPONSES: Responses consist of elements among the drivers, pressures and impacts which may be used for managing society in order to alter the human-environment interactions (e.g. green technologies, legislations, economic instruments).

Having recognizant that climate change is very wider theme to assess; a systematic approach has been applied in dealing with the issues by selecting indicator throughout this paper. The selected indicators are shown in the table below.

Table 1. The issue-indicator matrix in integrated environmental assessment reporting.

Issue	Indicators				
	Driver	Pressure	State	Impact	Response
Climate Variability/Change	Global and regional climate systems	Industrialization	Monthly, Seasonal and annual temperature anomalies	People affected by droughts	Level of climate prediction and weather forecasting capacity
		GHG emission contribution to global climate change	Monthly, Seasonal and annual Rainfall anomalies	People affected by Floods	National coping strategy and early warning system
			Temperature trend index	No of people affected by epidemic diseases	No. of National Mitigations/adaptation plans and actions
			Rainfall trend index		No. of Multilateral Environmental Agreements

Source: Adopted from FDRE MEF (2014).

It is hoped that this paper will indicate the intricate nature of climate change and facilitate the work of researchers, and provide stakeholders with ideas on how they can manage to this increasingly important topic on climate change in Ethiopia.

3. Results and Discussion

3.1. Drivers and Pressures of Climate Change in Ethiopia

The movements of the Inter-Tropical Convergent Zone (ITCZ) are sensitive to variations in the Indian Ocean's sea surface temperatures and vary from year to year; hence, the onset and duration of the rainy seasons vary considerably inter-annually, causing frequent drought. The ITCZ changes its precise position over the course of the year, while oscillating across the equator from its northernmost position over northern Ethiopia in July and August, to its southernmost position over southern Kenya in January and February. The best documented cause of this variability is the El Nino Southern Oscillation (ENSO). Studies made at National Metrological Agency (NMA) have also shown that there is a link between El Nino and La Nina phenomena and Ethiopian rainfall

(NAPA, 2007). Many including Funk *et. al.,* (2005) believe that Ethiopian drought is caused by ENSO.

Warm phases of ENSO have not only been associated with reduced rainfall in the main wet season (*Kiremt*) which account for 50–80 % of the annual rainfall totals over the regions having high agricultural productivity and major water reservoirs, causing severe drought and famine in north and central Ethiopia, but also with enhanced rainfalls in the earlier February-April rainy season, which mainly affects southern Ethiopia. The observed temperature increase is expected to lead to increased evapotranspiration and reduced soil moisture content and atmospheric humidity, with serious socio-economic consequences for the country. The higher warming rates for central Ethiopia could lead to serious socio-economic consequences for the country, given that this is representative of the high rainfall highland areas which accounts for the majority of the total population and for 95% of the cropped land.

Globally it's widely recognized that the main cause of climate changes is anthropogenic GHG emissions which reached 49 ± 4.5 GtCO2-equivalent in 2010 (IPCC, 2014). Fossil fuel (coal, oil and gas) and industrial processes contributed about 78% of the increase in emissions of CO2 from 1970 to 2010 (IPCC, 2014). Economic and population growth continued to be the key drivers of increases in CO2 emissions around the world (IPCC, 2014). In order to avoid exceeding the 450 ppm atmospheric concentrations of CO2e that are likely to be required to stay within the temperature rise limit of 2^{o}C, the IPCC has concluded that developed countries need to reduce emissions by 25-40 % below 1990 levels while developing countries need to reduce emissions by 15-30 % relative to business-as-usual by 2020 (IPCC, 2007). Further reductions are then required beyond 2020 to achieve the target.

Ethiopia's contribution to total global GHG emissions is marginal (146 Mt CO2e in 2013), representing less than 0.3 per cent of total global emissions in 2012. According to the UNFCCC accounting methodology, from the 146 Mt CO2e of GHG emissions in 2013, about 79 per cent came from the agriculture, forestry, and land use (AFOLU); industrial processes and product use (IPPU), of which agriculture accounted for 55 % (cropland 26 %, livestock 23 %, direct and indirect emissions from managed soils and manicure managements aggregated 6 %), while grassland produced 14 % and forestry removed 30 %. The energy and waste sectors contributed 15 % and 5 % respectively and the IPPU sector only 1 %.

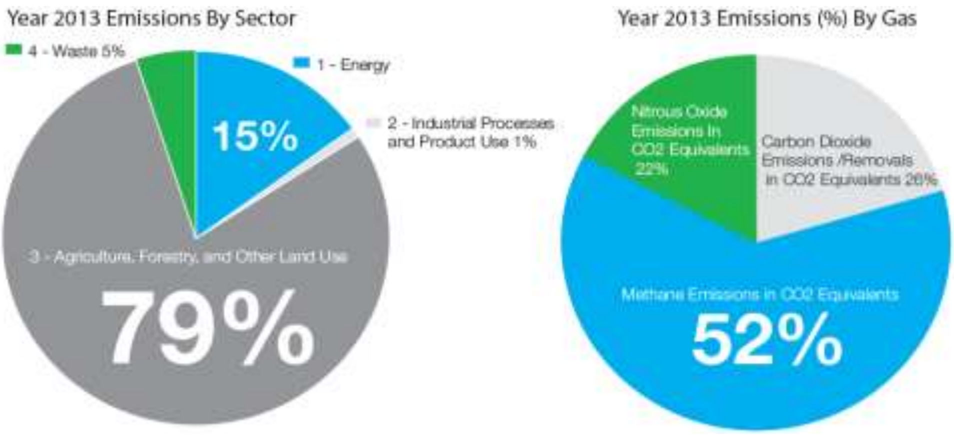


Figure 4: Emissions by Sector and by Gas, by 2013.
Source: Ethiopia's Second Communication to UNFCCC, 2015.

According to Ethiopia's Second Communication to UNFCCC (2015), net GHG emissions contribution is increased by 450 %. Energy sector emissions increased by 144 per cent, IPPU sector emissions by 396 per cent and waste sector by 297 per cent while there was a particularly large increase in emissions from AFOLU, by 657 %.

However, at sector level, there are also promising reductions in emissions at various sub-category levels. Substantial decreases in emissions were recorded in the soda ash production and grassland sub-categories, of 89 % and 76 %, respectively.

Generally, there has been a rising trend in aggregated national GHG emissions in Ethiopia. Estimated emissions in 2013 were about 447 % higher than in 1994 but 34.5 % and 24.6 % lower than in 2000 and 2010 respectively. Comparing GHG emissions in 1994, 2000 and 2010 with those in 2013 shows that total (gross) CO_2 emissions increased by an estimated 237.6 % between 1994 and 2013, but by 2013 had decreased by 66.1 % and 58.3 % from the 2000 and 2010 estimates, respectively. The 2013 methane emission estimates show significant increases from 1994, 2000, and 2010, by 96.6 %, 24.4 % and 6 %, respectively, while the nitrous oxide emissions increased by 113.5 %, 61.5 % and 3.2 % between the comparator inventory years and 2013. This is in consistent with the fast growing economy of the country as of it is one of the top ten fast growing economy in the world next to China and India (IMF; The Economist, as cited in Ethiopia's 2nd Communication to UNFCCC, 2015) .

The trend of carbon stocks of Ethiopia in the Land-Use Change and Forestry (LUCF) sub-sector which was decreasing rapidly in the period 1990-2000 is now stabilizing following the intensive afforestation and re-afforestation campaigns by the Government. This has seen the forest cover increase from well below 7 % the late 1990s to 15.5 % in 2015 (NFSDP, 2016).

Aggregation of the 2013 CO_2, CH_4 and N_2O emissions for all the national GHG inventory sectors using the IPCC methodology, Global Warming Potential (GWP)) factors over a 100 years' time horizon yields a total of about 146,160.43 Gg CO_2e, excluding emissions/removals from the categories classified as memo items. Assuming a population of 91 million for the year 2013, the estimated *per capita* emission was 1.5776 tons of CO_2e in that year (Ethiopia's 2nd Communication to UNFCCC, 2015).

a

b

Figure 5. Emission from cement factory in Inchini area (a) and Emission from steel factory from Dukem area (b).

Source: Oromia SOE, 2015.

It is also important to notice, however, that other factors threaten the livelihoods of Ethiopian communities as well. For example resource degradation and the over exploitation of natural resources such as forests and other vegetation is one of the key issues in association with the environmental decline in the country.

3.2. State and trend of climate change in Ethiopia

According to IPCC (2013), the globally averaged combined land and ocean surface temperature data showed a warming of 0.85 [0.65-1.06] °C, over the period 1880 to 2012.

The year 2014 is the 38th consecutive year (since 1977) that the yearly global temperature was above average. Including 2014, 9 of the 10 warmest years in the 135-year period of record have occurred in the 21st century. The 2014 global average ocean temperature also recorded high, at 0.57°C above the 20th century average of 16.1°C, breaking the previous records of 1998 and 2003 by 0.05°C. The 2014 global average land surface temperature was 1.0°C above the 20th century average of 8.5°C, the fourth highest annual value on record (IPCC, 2014). It is predicted to increase in east Africa under business as usual as shown in Figure 3.

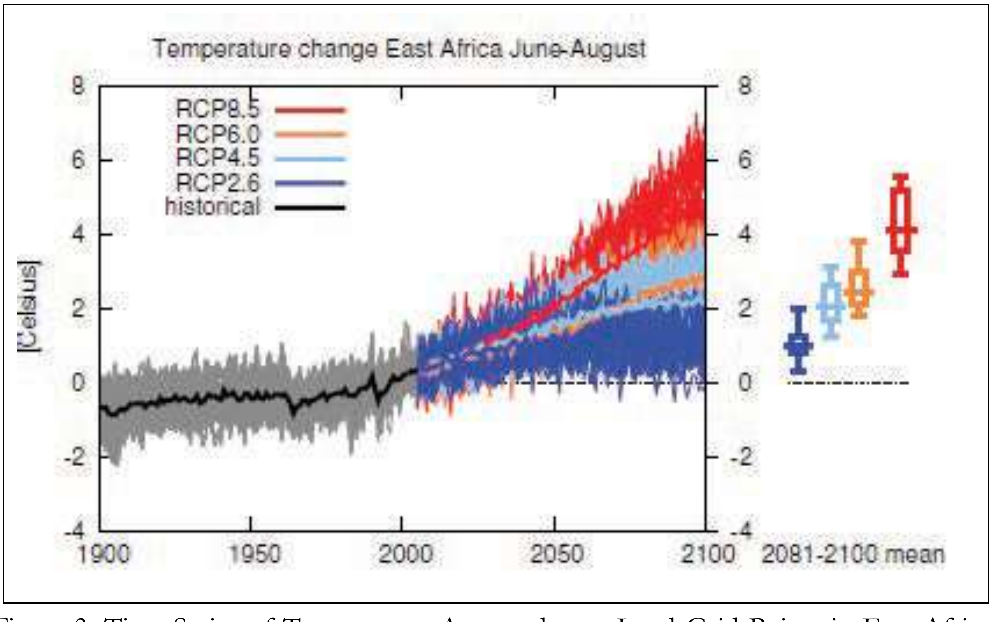


Figure 3. Time Series of Temperature Averaged over Land Grid Points in East Africa, June- August. Source: IPCC, 2014.

Like much of Africa (as in Figure 3), Ethiopia has become warmer over the past century and human induced climate change will bring further warming over the next century at unprecedented rates.

The Climate Resilient Green Economy (CRGE) analysis (FDRE, 2011a) indicates that there is an increase of temperature from 0.1 - 0.4°C per decade resulting in an average temperature increase of around 0.25°C per decade, since the 1960s. The study made in northern parts of Ethiopia (Tigray region) even much above the national average having a trend of increasing in temperature 0.1- 0.9°C (0.5°C in average) every 10 years (Tigray PPACC, 2011). It is likely that this warming will be associated with heat waves and higher evapotranspiration (CRGE Vision).

Climate models suggest that Ethiopia will see further warming in all seasons of between 0.7°C and 2.3°C by the 2020's and of between 1.4°C and 2.9°C by the 2050s (Table 2).

Table 2. Ethiopia's Changing climate.

	Temperature	Rainfall	Extreme events
Historical trend	Mean temperature increased by 1.3°C from 1960-2006 More hot days and nights, fewer days and nights	Highly variable from year to year, season to season, decade to decade No significant trend	Regular severe flood and drought events No evidence of changes in frequency or intensity of extremes
2020's	+1.2°C (0.7-2.3 °C)	+0.4%	Greater increases in rainfall in Oct-Dec, especially in the south and east
2050's	+2.2°C (1.4-2.9°C)	+1.1%	Heavier rainfall events Uncertain future El Nino behavior brings large uncertainties
2090's	+3.3°C (1.5-5.1°C)	Wetter conditions	Flood and drought events likely to increase Heat waves and higher evaporation

Source: CRGE vision.

Historically the average annual temperature in Ethiopia has a ten-year cycle increase with a pronounced hike during the second half of the 1990s. Spatially higher temperature spots are found in the northern, southern and eastern parts of the country. Rainfall in general has shown a decreasing trend since the 1990s. Extreme climate events namely drought and flood, most likely linked to climate change, have increased in intensity, frequency and geographic coverage since 2000. Particularly, drought repeats cyclically and is a common phenomenon in the country. From historical period to 2090 climate change in Ethiopia is expected to behave as it is shown in Table 2 (NAP-ETH, 2016).

As it can be seen from Figure 4, the annual maximum temperature has been rising faster than the minimum temperature. It is most probable that this is an indication of climate change. Although no significant change has been observed in rainfall during the last 30 years, there is no doubt that the temperature has increased tremendously.

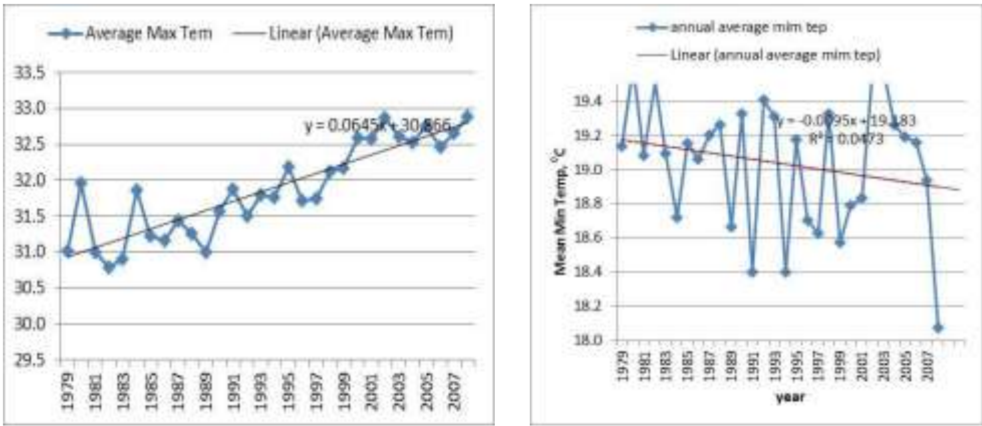


Figure 4. Annual Maximum and Minimum Temperature Trend of Dire Dawa (1980-2008)
Source: DDA SOE, 2015.

The trends in annual and seasonal mean temperature for the recent past and projected future under the Special Report on Emission Scenarios (SRES) A2 Scenario are shown in Figure 5. The projections also show substantial increases in the frequency of days considered "hot" in current climate conditions, and are consistent with other temperature projections for the country.

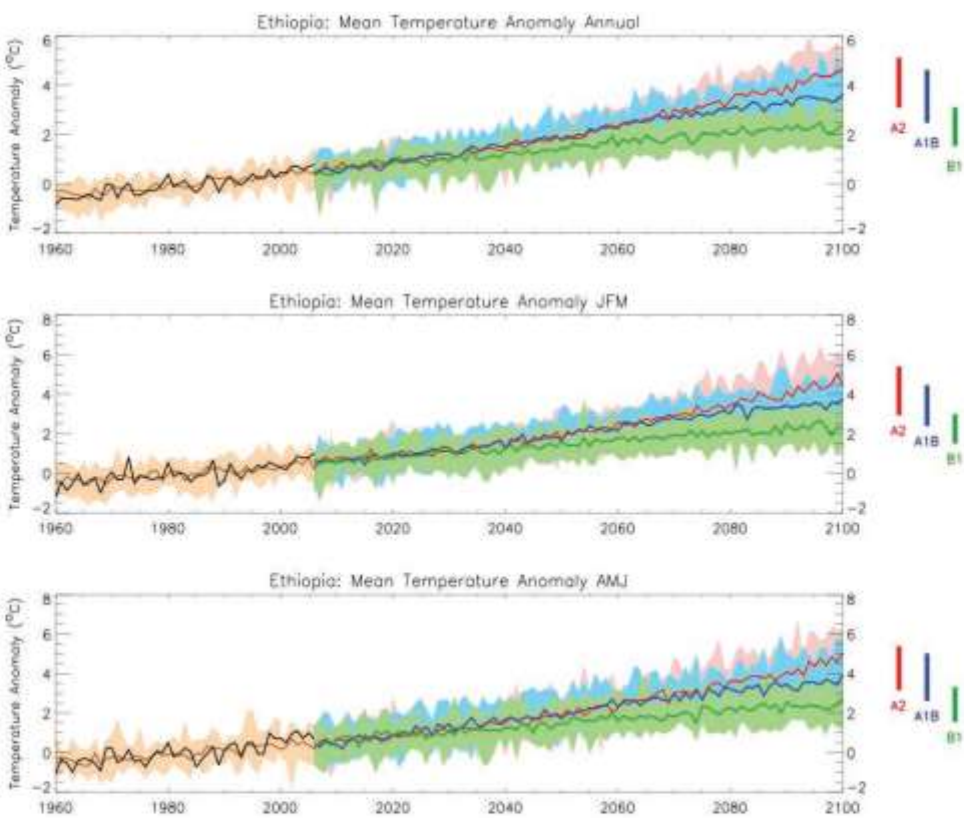


Figure 5. Trends in Annual and Seasonal Mean Temperature for the Recent Past and Projected

Future.

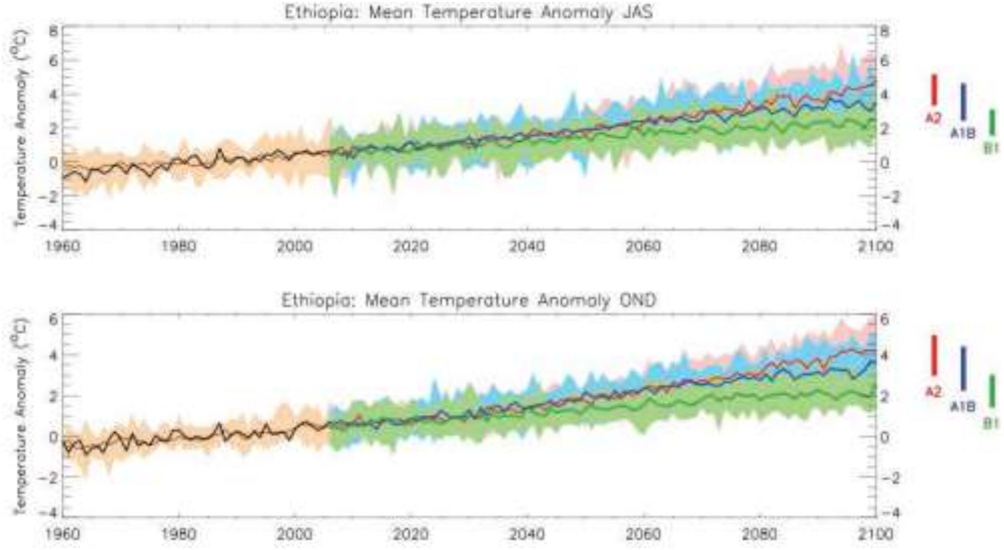


Figure 6. Trends in Annual and Seasonal Mean Temperature for the Recent Past and Projected Future.

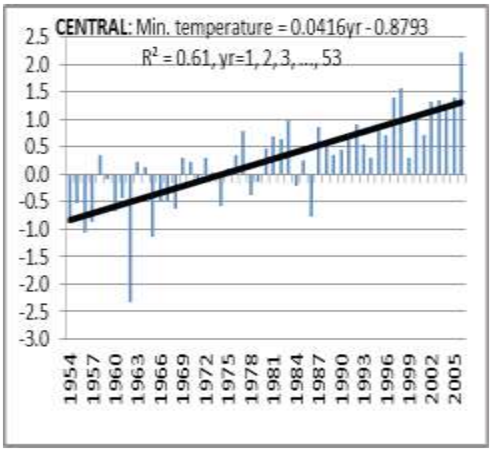
Source: McSweeney, New and Lizcano, 2014 as cited in Ethiopia's 2nd Communication to UNFCCC

Hot Day: The temperature threshold for a 'hot day' in any region or season is defined as the daily maximum temperature which is exceeded on 10% of days in the standard climate period (1970 - 99).

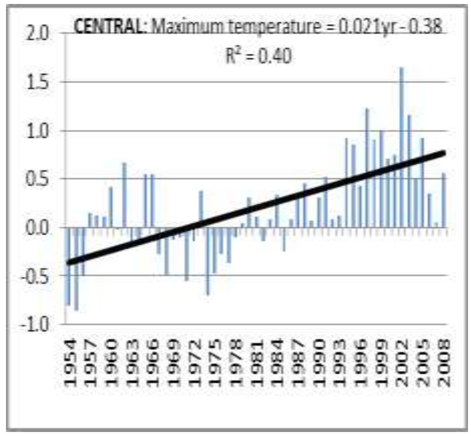
The national temperature trend analysis covering two representative areas, namely central (high rainfall highlands) and north eastern Ethiopia (the drier lowlands) is indicated in Figure 5. The trends for the central region are, however, higher, explaining up to 60 per cent and 40 per cent of the total variance of minimum and maximum temperature, respectively. The observed temperature increase is commensurate with corresponding increases in the minimum and maximum temperature, an increased frequency of hot days and nights, and decreases in the frequency of cold days and nights.

Analysis of the inter-annual variation of temperature for the period 1954-2006 reveals an increasing trend for both the minimum (night time) and maximum (day time) temperature as shown in Figure 6 below which generally provide a signal of warming of Ethiopia during this period.

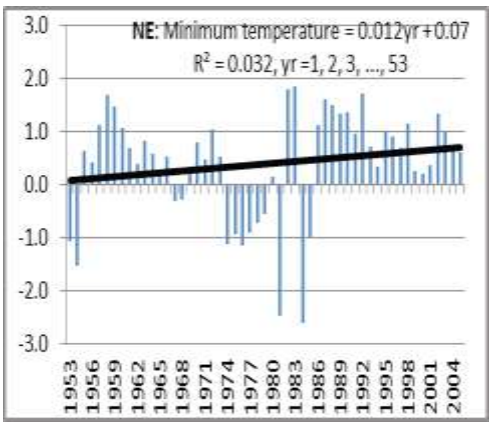
In general temperature is expected to show an increasing trend. The inter-annual variation of temperature in Central and north east Ethiopia over a 50-year period reveals a rising trend, which is an indicative of warming over the whole country.



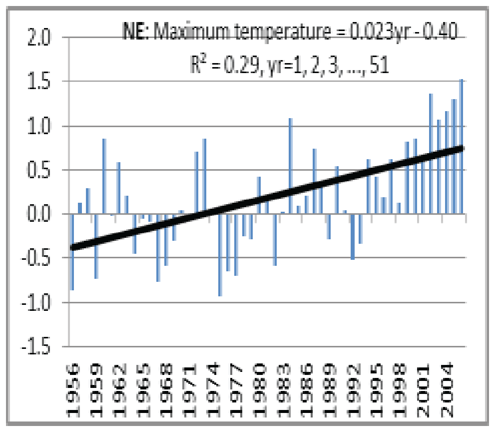
A



b



C



d

Figure 7. Year-to-year variation of Ethiopia's temperature (UNFCCC, 2015).

Analysis of the inter-annual variation of rainfall in Ethiopia for the period 1951-2010 shows the fluctuations of the total annual rainfall, with some years experiencing above normal rainfall, others below normal, and still others around the average value (Figure 7). The mean annual rainfall also shows a slight decreasing trend, indicative of a decrease in the total annual rainfall over the years.

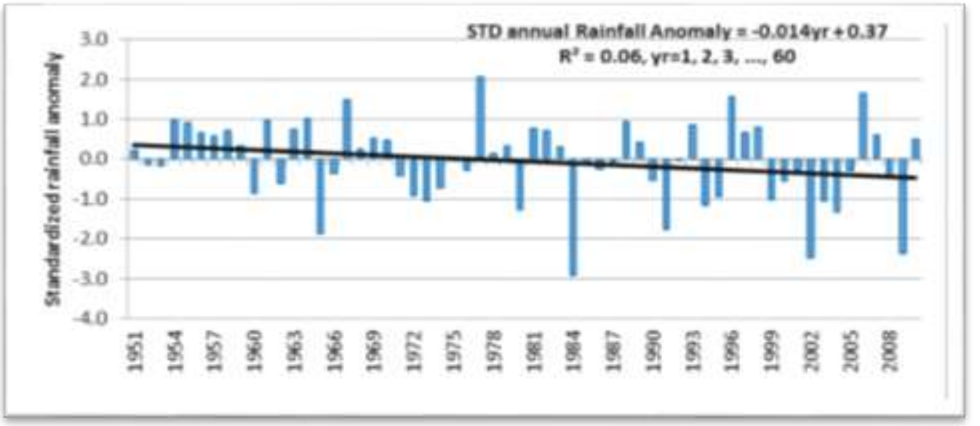
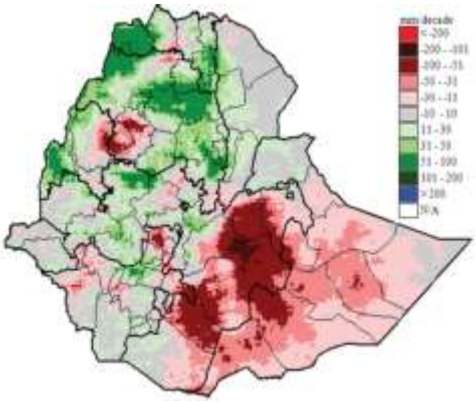


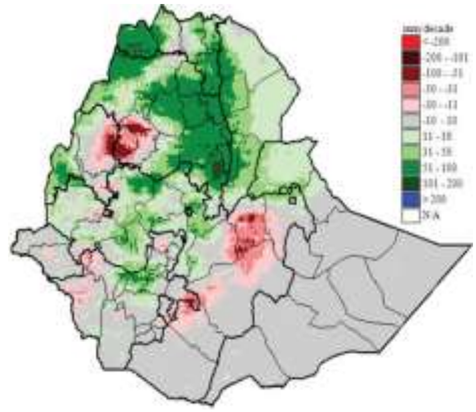
Figure 7. Year-to-year variation of Ethiopia's rainfall (1951-2010).
Source: Koresha, 2014b .

The projected warming across the entire country is likely to exacerbate the observed declining rainfall trends, leading to increased water stress. Some recent studies also indicate that the annual rainfall in southern Ethiopia has decreased from 1971 to 2010 during the March-April-May (MAM) (*Belg*) and June-July-August (JJA) (*Kiremt*) seasons, with no clear trends detected for central and northern Ethiopia. The February–May (*Belg*) precipitation has declined at the rate of 2.6 mm/year during the same period. This amounts to a reduction of 30 per cent based on the recorded values for the period 1971 to 2010. The study also showed a reduction of 2.2 mm/year in the wetter June–September (*Kiremt*) season, amounting to a reduction of more than 50 %. The total annual reduction in the spring season is 32 per cent (5.4 mm/year) (FEWS NET, 2012).

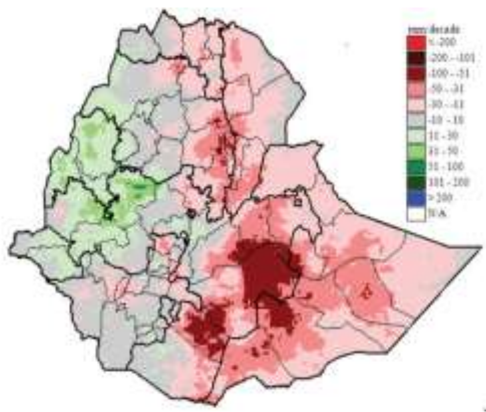
The country's total annual rainfall variability is shown in Figure 8, which indicated a close relationship between the variability and the total annual rainfall, with areas receiving the highest rainfall showing the lowest variability, while the drier areas received the lowest rainfall with highest variability. It is worth noting that some of the drier areas to the south east and north east parts of the country showed variability in excess of 50%. These are the areas with the highest vulnerability to climate change and variability, a situation expected to worsen in the future with the projected higher temperatures.

The change in the average total annual rainfall (January-December) compared with the average total annual rainfall for 1997-2013 minus 1981-1996 (a) and the deviation from the average rainfall for the period July 1981 to August 2014. The figure depicts a rainfall reduction over the hotspot areas (Figure 8).





A **B**



C

Figure 8. Annual Climate Variability and Average Differences in Rainfall, 1981-2013: a) Shows change in average rainfall over the March- September season, comparing averages for 1997-2013 with 1981- 1996 (Long Cycle Rain). b) Shows change in average rainfall over the June-September season, comparing averages for 1997-2013 with 19981-1996 (Kiremt season). c) Shows change in average rainfall over the March-June Season, comparing averages for 1997-2013 with 1981-1996 (Belg season).

Although projections of IPCC shows that rainfall will increase in some areas of East Africa as a result of climate change, evapotranspiration will also increase due to a rise in temperatures, thus reducing the benefit of the increase (IPCC, 2014).There was also a pronounced increase in the projections of the total rainfall occurring in "heavy" rainfall events, indicative of an increase in potential floods. These results are probably an indication of a potential increase in the frequency of extreme climate events in the coming years.

Heavy Rainfall Event: *A heavy rainfall event is defined by daily rainfall amount exceeded by the 5% of heaviest events in a given region or season. The total rainfall which falls in any events which are greater than this fixed threshold is then totaled, and expressed as a percentage of the total monthly rainfall in that season or year. This is then expressed as an anomaly against the total rainfall falling in 'heavy' events in the standard climate period (1970-99).*

3.3. Impact of Climate Change in Ethiopia

IPCC's Scientific Assessment indicates that in recent decades, eastern Africa in general and Ethiopia in particular, has been experiencing an intensifying dipole rainfall pattern with increased recurrence of heavy rainfall events at intervals of a decadal time-scale. The IPCC (2007) also reported that current climate variability, prolonged drought and recurrent flood, coupled with human-induced change are the main factor in aggravating the socio-economic and ecological problems of Africa.

Likewise, it is well recognized in Ethiopia that most of the disasters faced in the country so far is linked directly with the adverse effects of climate change as over 60% of the country is arid and has low resilience to moisture stresses. The insignificant irrigation coverage and poor moisture harvesting schemes in the country have compounded the plight of Ethiopian dry lands. Ethiopia has already suffered from extremes of climate, manifested in the form of frequent drought (1965, 1974, 1983, 1984, 1987, 1990, 1991, 1999, 2000, and 2002) (TSOER, 2015). Since the early 1980s, the country has suffered seven major droughts, five of which led to famines in addition to dozens of local droughts. Major floods also occurred in different parts of the country in 1988, 1993, 1994, 1995, 1996 and 2006 (World Bank, 2010; FDRE, 2011c; FDRE, 2011e). The variability of rainfall and the increasing temperature are blamed for the frequent droughts that might lead to famine and affecting people's livelihood.

Most areas in Ethiopia are climatically secure in spite of the erratic rainfall patterns. However, the *Belg* season is, becoming drier, particularly in the regions of Oromiya, Somali, and SNNP; while the *Kiremt* season continues to be wetter in some areas of Amhara. Ethiopia does not, therefore, face a catastrophic national failure of rainfall, but rather regional hotspots with a tendency towards more frequent and more intense droughts. These droughts will tend to affect most pastoralists and agro-pastoralists living in marginal climatic areas. The positive and negative changes in average rainfall over the *Belg* and *Kiremt* seasons and the region's most affected are shown in Figure 9.

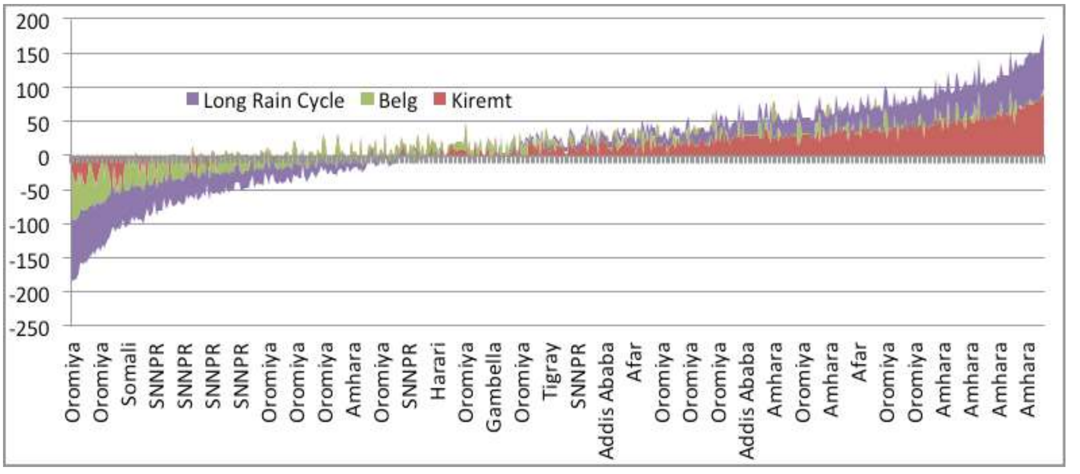


Figure 9. Regions Affected by Changes in Average Rainfall (NAP-ETH, 2016).

Agriculture is the source of livelihood to an overwhelming majority of the Ethiopian population (it employees more than 80% of the labour force) and is the basis of the national economy which takes a lion's share by contributing nine from top ten export commodities (Ethiopia's 2nd Communication to UNFCCC, 2015). Hence, a decrease in seasonal rainfall has devastating implications on agricultural production and the whole economy in general, leading to food insecurity, malnutrition and famine. The frequency and intensity of drought is likely to increase over the coming decades, which will present a serious threat to biodiversity, ecosystems, water, agricultural and human health. The following box indicates the sensitivity of agriculture to climate variability and extremes.

Box 1 (change it to Table: Climate Stresses and Key Impacts on Agriculture

Source: FDRE 2011c

Climate stresses	Key impacts
High mean temperature	Shifting agro-ecological zones
Days with a max temperature above 35°C	Heat stress for some crops
Days with a max temperature above 40 °C	Leads to heat stress on people and livestock
Lower mean rainfall	Shifts in agro-ecological zones; plus drought regimes
Higher mean rainfall	Landslides, damage to crops and livestock
Large scale floods	Damage to crops, livestock, infrastructure and people
Flash floods	Local damages to crops, livestock, infrastructure, people
High 1-hour rainfall intensity	Soil erosion and landslides, some local damages to crops
Heavy hail events	Crop damage at certain times in the growing season
Rainfall distribution (variability)	
Within season	Significant impact on some crops
10-day dry spells	Significant impact on some crops
Seasonal droughts	Significant impact on most crops
Consecutive seasonal droughts	Significant impact on livelihoods and economic growth
Later onset of rainfall season	Shortens growing period - impacts on crops, fodder
Earlier end date of the rainfall season	Shortens growing period - impacts on crops, fodder
Decreased predictability of the	

Climate change has adverse ecological, social and economic impacts. The major adverse impacts of climate variability and change in Ethiopia include:

1. Food insecurity arising from occurrences of droughts and floods;

2. Outbreak of diseases such as malaria, dengue fever, water borne diseases (such as cholera, dysentery) associated with floods and respiratory diseases associated with droughts;

3. Land degradation due to heavy rainfall;

4. Damage to infrastructure by floods;

5. Loss of life and property; and

6. Loss of biodiversity due to extensive change in land use and human intervention in ecologically reserved areas.

The country is especially vulnerable to climate change because of its geographic coverage and complexity, low income, and great reliance on climate sensitive economic sectors particularly agriculture and pastoralism. The livelihoods of many millions of people in the country are critically dependent on climate. The table below shows the extent of impacts of climate change in Ethiopia.

Table 3. Impacts of climate change in Ethiopia, 1900 – 2016.

Disaster/hazard	Type	No. of events	No. of deaths	Total affected	Damage (in 000 USD)
Drought	Drought	17	415,959	88,501,534	111,083
Earthquake (Seismic activity)	Earthquake(ground shaking)	7	24	585	7,070
Epidemic	Unspecified	4	429	32,948	-
	Bacterial infectious diseases	15	10,984	133,680	-
	Parasitic infectious diseases	1	157	2,500	-
	Viral infectious diseases	2	46	531	-
Flood	Unspecified	13	136	195,240	920
	Flash flood	6	735	436,278	9,400
	General flood	31	1,105	2,815,926	6,700

Source: IFRC, 2013; Actalliance, 2016 and OCHA, 2016.

3.4. Response of Climate Change in Ethiopia

The Government of Ethiopia has put in place national policies and legislation, strategies, and guidelines to address climate change through the mainstreaming of response measures and re-establish environmental and/or climate change safeguarding and coordinating institutions with the potential to bring about integrated rural development in a sustainable way.

Together with other institutes making research related to climate change, National Meteorological Agency (NMA) established Meteorological Research and Studies Department so as to produce and ready available to use well analysed documents and information for various stakeholders. So far, significant progress has been made in understanding the country's weather and climate. A number of research reports, publications and maps have been produced on several climate-related topics. The country has also been participating in Global Environment Facility (GEF) supported Climate Change Enabling Activities since 1998.

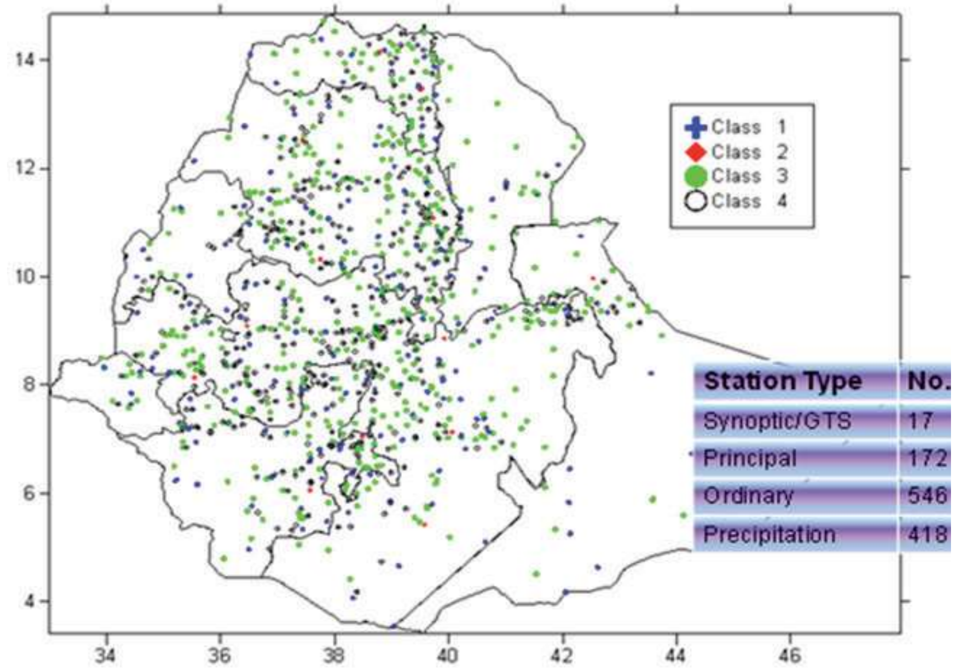


Figure 10. Distribution of Meteorological and Climatological Stations in Ethiopia (UNFCCC, 2015).

In order to respond effectively and early warn the risks of the ever increasing impacts of climate change and to make ready, climatological stations has been increasing and currently about 1,153 stations are established (Figure 10).

National Disaster Risk Management and Strategy has been under implementation since 1993 in order to facilitate the implementation of the reoriented approach and direction with participation of all concerned bodies and support of legal frameworks,

For any meaningful benefits to accrue from the different initiatives there is a need to enhance institutional coordination structures for both cross-ministerial and between national and sub-national authorities. The ideal overarching coordination could be done within the framework of the CRGE. The Federal Government is already taking action in this direction with the establishment of the Sectoral Reduction Mechanism (SRM) with the aim of enabling action on the priorities identified in the CRGE Strategies. The SRM is expected to direct sectors in their effort to reduce GHG emissions and vulnerability to climate change and compile a web-based CRGE Registry to monitor progress. The SRM is also mandated to increase public access to climate related information and initiate action to deliver the CRGE, by matching the identified needs with funding from a pool dubbed the CRGE Facility. Coupled with the new systems for monitoring, reporting and verifying impacts (MRV), and a proactive approach to knowledge management, the SRM represents a comprehensive mechanism to facilitate the country's response to climate change.

As stated above it is well recognized that climate change poses a serious threat to agricultural production, the natural resource base, and the livelihood of communities, more particularly in the dry lands. As response to the Fifth Assessment Report of the IPCC which indicated that adaptation and mitigation are underpinned by common enabling factors that include "effective institutions and governance, innovation and investments in environmentally sound technologies and infrastructure, sustainable livelihoods, and behavioural and lifestyle choices". Developing or reinforcing adaptive mechanisms to deal with the negative effects of climate change must be a high priority. It is recognizable that without addressing climate change issues, much effort in other development policy and practice will be wasted since most climate change impacts will fall predominantly on the poorest people who highly dependent on climate for their survival (lists of national policies and strategies is presented in annex I change it to table).

The following table summarizes different climate change response measures that are undertaking in Ethiopia.

Table 4. The summarized description of mitigation and adaptation plans in Ethiopia.

Programme/Strategy	Status	Type of response
Climate Resilient Green Economy (CRGE) strategy	Ethiopia's strategic document aimed at insuring middle income status and carbon neutral economy in 2025	Identified 60 climate change mitigation options with equivalent and/or adaptation co-benefits
Ethiopia's Second National Communication to the UNFCCC	A short term, project based plan prepared during the end of 2015	Climate Change Impacts, Vulnerability and Adaptation Options
National Adaptation Plan of Action (NAPA)	A short term, project based plan developed in 2007	Climate change scenarios, vulnerability levels, adaptation options
Sectoral/regional adaptation plans	Adaptation plans prepared 2010/2011 for some sectors/regions	Adaptation options specific to sectors/regions
Ethiopian Programme of Adaptation for Climate Change	Summary of programme of adaptation prepared in 2011 based on earlier plans	The 20 prioritized climate change impacts, adaptation measures, institutions, implementation measures
Intended Nationally Determined Contribution	Ethiopia's intended contribution to GHG reduction and its adaptation to climate change submitted to UNFCCC in 2015	Major adaptation options categorized under drought, flood, and cross sectoral issues

Technology Need Assessment (TNA) (draft)	A draft document addressing potential technologies need to be adopted by Ethiopia towards GHG emissions reduction prepared 2016	Mitigation and Adaptation technologies for the prioritized sectors affected by climate change

Source: NAP-ETH, 2016 (draft).

In 1992, where the first global convention on climate change was adopted, i.e. the UNFCCC, as part of the United Nations Conference on Environment and Development- the Rio Earth Summit, Ethiopia has started participation in multilateral environmental negotiations and sign UNFCCC agreement and ratify Kyoto protocol in 2005 that would set mandatory emission limits and means to achieve them. Besides, since then Ethiopia is signatory to a number of multilateral agreements that have bearing on the sustainable development efforts of the country. Ethiopia has signed and/or ratified many of the international conventions and protocols (see Table 5).

Table 5. Major treaties where Ethiopia is a party.

No.	Multilateral Environmental Agreements-Ethiopia Signed	Adoption	Ethiopia's ratification/acce-ssion/ acceptance
1	Convention on Biological Diversity (CBD)	22 May 1992	31 May 1994
2	Convention to Combat Desertification	1994	1997
3	International Treaty on plant genetic resources for food and Agriculture	Nov 2001	2003
4	Vienna Convention for the Protection of the Ozone Layer	March, 1985	1996
5	UN Framework Convention on Climate Change (UNFCCC)	10 Jun 1992	5 Apr 1994
6	Kyoto Protocol to the UNFCCC		14 Apr 2005
7	Stockholm Convention on Persistent Organic Substances	17 May 2002	2 July 2002
8	Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade	10 Sept.1998	2 July 2002
9	Basel Convention on the Transboundary Movement of Hazardous Wastes and their Disposal	1989 (adopted)	31 Feb 2000

10	Protocol on Liability and Compensation for Damages Resulting from Transboundary Movements of Hazardous Wastes and Their Disposal	10 Dec 2000	3 July 2003

International climate negotiations are handicapped by the conflicting interests of nations and special groups, particularly multinational corporations. Recently, active climate negotiations from Least Developed Countries (LDCs) including Ethiopia results in recognition of adaptation by which it appreciates need to assist those developing countries that are least capable to adapt. However, preparing for adaptation to the impacts of climate change by carrying out climate change impact assessments is one of the commitments of the Parties. Hence, there are now attempts to bring climate change into the wider development agenda. Furthermore, the interaction between adaptation and mitigation that had previously been overlooked is now receiving greater attention because of the potential synergies and trade-offs (IPCC, 2007; UNFCCC, 2015). Article 7 (2) of Paris agreement states:

Parties recognize that adaptation is a global challenge faced by all with local, subnational, national, regional and international dimensions, and that it is a key component of and makes a contribution to the long-term global response to climate change to protect people, livelihoods and ecosystems, taking into account the urgent and immediate needs of those developing country Parties that are particularly vulnerable to the adverse effects of climate change.

Even if negotiations take longer than expected at the international level, national actions should continue to move forward. As a responsible member of the world, Ethiopia is also aware of the important role that developing countries play in fighting climate change, and has consequently taken on a constructive role in international climate negotiations.

Adaptation is a critical response to the impacts of climate change because current agreements to limit emissions, even if implemented, will take a long time to stabilize the atmospheric concentrations of GHGs that are responsible for climate change. In line with this, the Government of Ethiopia has demonstrated its determination to address climate change through the mainstreaming of response measures in national and sectoral development plans.

The Ethiopian government continues to make efforts to mainstream environmental issues in development processes and in all sectors. In regions up to Woredas, preparations and implementation of environmental and/or climate change management plans is on-going through community participation.

Figure 11. Integrated watershed management as a means of reducing GHG emissions from land and forest degradation (Amhara SOE, 2015).

As a core coordinator of environmental and/or climate change issues, Ministry of Environment, Forest and Climate Change (MoEFCC) restructured in a way that it tries to well coordinate inter-sectoral plans and initiatives towards sustainable development and enabling Ethiopia to actively participate in multilateral environmental and/or climate change negotiations and implementation of the resulting agreements.

Environmental authorities in different hierarchical level are in place and many international environmental agreements have been signed (Table 5). However, there are gaps between the environmental commitments made and the actual implementation to improve environmental outcomes (Cesar and Ekbom, 2013). It seems true in Ethiopia, although progress has been made and environmental issues are stated as priority in many policies, there is lack of implementation, and enforcement needs to be strengthened. Increasing economic growth and attaining middle-income country status by 2025 might result in improvements for some environmental problems but might increase pressure on some resources (such as water an energy) and increase emissions of some pollutants, typically those linked with urban traffic, transport and industrial production. Furthermore, environmental degradation and climate change hampers Ethiopia's economic growth. To reach its vision Ethiopia needs to speed up mainstreaming of environmental issues and institutions needs to be strengthened to attain sustainable development and a green economy.

-

4. Conclusions and Recommendations

The reality of climate change is acknowledged virtually unanimously worldwide. The best documented driving forces of climate change in Ethiopia is mainly related with ENSO and global GHG emissions though Ethiopia's contribution is marginal which is about 0.3% from the global total. However, there has been a rising trend in aggregated national GHG emissions in Ethiopia that is associated with its fast economic growth in the last decades. According to Ethiopia's 2nd Communication to UNFCCC (2015), net GHG emissions contribution is increased by 450%. Agriculture, forestry, and land use (AFOLU) shares the largest one which is about 79 % from the country's total emission.

Analysis of the inter-annual variation of temperature for the period 1954-2006 reveals an increasing trend for both the minimum (night time) and maximum (day time) temperature which is an indicative of warming over the whole country. There is no doubt that the temperature has increased tremendously with a ten-year cycle increasing trend for both the minimum (night time) and maximum (day time) with a pronounced hike during the second half of the 1990s.

The projected warming across the entire country is likely to exacerbate the observed declining rainfall trends, leading to increased water stress. On the contrary, IPCC's Scientific Assessment indicates that in recent decades, eastern Africa in general and Ethiopia in particular, has been experiencing an intensifying dipole rainfall pattern with increased recurrence of heavy rainfall events at intervals of a decadal time-scale.

From 1900-2016, there are at least a total affected of 415,959 deaths and about 88,501,534 drought, 2,447,438 epidemic diseases and 169,659 flood with damages of USD 117.083 million are recorded. Ethiopia has already suffered from extremes of climate manifested in the form of frequent drought and floods as well as epidemic diseases.

As a responsible member of the world, Ethiopia is also aware of the important role that developing countries play in fighting climate change, and has consequently taken on a constructive even leading role in international climate negotiations. Locally Ethiopia is responding strategically to climate change through CRGE which aims at achieving middle income in 2025 with carbon neutral economy followed by Growth and Transformation Plan (GTP II) of Ethiopia, INDC, and different versions of national and sectoral as well as regional adaptation plans which appreciate climate smart economic activities. A number of environmental signing and ratification has been committed together with substantial international communications for the commitment. But, it seems important to notice that their implementation status is not as such promising and also not supported with scientific documents other than country's promising commitment towards climate change.

Furthermore, the Ministry of Environment, Forest and Climate Change (MoEFCC) which has lately come as an autonomous entity before two years ago where its three building blocks (Environment, Forest and Climate Change) were organized under different institutions whom working towards the same goal; a ministry that has assumed enormous responsibilities of coordinating and regulating a climate smart policies, strategies and programmes of the country to be mainstreamed along the sectors. The thrust of this recent government action has also become a higher concern, for years of experience have shown that the climate change in this country merits very special attention with a separate system and institution in place.

Hence, the way forward would be building a more vibrant and autonomous as well as well coordinating entity of environment and climate change sector that should be established upon the active partnership of all relevant actors (government and non-government) in an integrated approach. A system should be embracing strategies holistically devoted by all sectors in comprehensive understanding the driving forces of climate change, its status, to response and recovery through prevention (mitigation), resilience (adaptation) to both drought and non-drought hazards that have potentially been threats to the community and its assets in Ethiopia.

In line with this, universities and other research institutions need to conduct site specific and problem-oriented research on each elements of DPSIR of climate change in Ethiopia.

On the contrary, MoEFCC and National Planning Commission as coordinating organs for design and implementation of climate smart strategies in general, have to take the responsibility of bridging the scientific findings to the government policies, projects and programmes to the respective sector in the country through establishment of an institution for the purpose under discussion.

5. References

Actalliance. 2016. Ethiopia: Response to El Nino-caused drought emergency appeal, Geneva.

Available at www.actalliance.org

Amhara SOE. 2015. Bureau of Environmental Protection, Land Administration and Use, Ensuring Sustainable Environmental Protection Core Process.

CRGE Vision. Year??? Ethiopia's Vision for climate Resilient Green Economy, Federal Democratic Republic of Ethiopia.

Dire Dawa State of Environment (DDA SOE). 2015. Dire Dawa Administration Environment, forest and Climate Change Authority, Dire Dawa.

Emelie Cesar, E. and Ekbom, A. 2013. Ethiopia Environmental and Climate Change policy brief, Sida's Helpdesk for Environment and Climate Change, Swedish embassy, Ethiopia.

Ethiopia Environment Outlook. 2008. Federal Environmental Protection Authority (EPA).

Famine Early Warning Systems Network (FEWS NET). 2012. A Climate Trend Analysis of Ethiopia. Famine Early Warning Systems Network-Informing Climate Change Adaptation Series, Fact Sheet 2012–3053, April 2012. Available from pubs.usgs.gov/fs/2012/3053/FS12 3053_ethiopia.pdf.

Ethiopia's Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC). 2015. The Federal Democratic Republic Of Ethiopia Ministry of Environment and Forest.

Federal Democratic Republic of Ethiopia. 2011a. The Climate Resilient Green Economy, Green Economy Strategy.

Federal Democratic Republic of Ethiopia (FDRE). 2011b. Ethiopia's Climate Resilient Green Economy: Agriculture Climate Resilient Strategy, Addis Ababa.

Federal Democratic Republic of Ethiopia Ministry of Agriculture (FDRE). 2011c. Agriculture Sector Programme on Adaptation to Climate Change. Available at www.slmethiopia. info.et/attachment/ article/10/Agriculture Sector Programme of Plan on Adaptation to Climate Change.pdf.

Federal Democratic Republic of Ethiopia Ministry of Environment and Forest (FDRE MEF). 2014. Guidelines for the preparation of State of the Environment Report (SOER) in Ethiopia, Netsanet Seid Printing and Advertising.

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A.

Intergovernmental Panel on Climate Change (IPCC). 2013. Climate Change 2013. The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Available at www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf.

Intergovernmental Panel on Climate Change (IPCC). 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC. Available at www.ipcc.ch/report/ar5/syr.

International Federation of Red Cross and Red Crescent Societies (IFRC). 2013. Ethiopia: Country Case Study Report. How Law and Regulation Supports Disaster Risk Reduction.

Korecha, D. 2014a. Characterizing the Predictability of Seasonal Climate in Ethiopia. Ph.D. Dissertation, University of Bergen, Norway. Available at http://malaria.b.uib.no/files/*2014*/06/DiribaPhD.pdf.

Korecha, D. 2014b. The current methods and techniques on short, medium and long-range climate prediction in Ethiopia. Available at drought.unl.edu/Portals/0/docs/workshops/6_Dr.Diriba 2014.pdf.

McSweeney C., M. New and G. Lizcano. 2014. Ethiopia: UNDP Climate Change Country Profiles. Available at www.geog.ox.ac.uk/research/climate/projects/undpcp/UNDPreports/Ethiopia/ Ethiopia.lowres.report.pdf.

Meyer (eds); **Year** Cambridge, UK and New York: Cambridge University Press, Available at www.ipcc:ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm.

Ministry of Finance and Economic Development (MoFED). 2007. Survey of the Ethiopian Economy. Addis Ababa, Ethiopia.

NAPA .2007. Federal Democratic Republic of Ethiopia (2007):National Adaptation Plan of Action, Addis Ababa.

NAP-ETH. 2016. Ministry of Environment, Forest and Climate Change (Draft).

National Forest Sector Development Programme (NFSDP). 2016. Institutional Strengthening for Forest Sector Development in Ethiopia, United Nations Development Programme (UNDP).

Tigray Climate change Adaptation Programme (TCCAP). (February, 2011).

Tigray State of the Environment Report (TSoER). 2015. Tigray Environmental Protection, Land Administration and Use Agency, Tigray Region, Ethiopia.

United Nations Environment Programme (UNEP). 2012. Global Environment Outlook (GEO5), Progress Press Ltd, Valletta, Malta.

United Nations Framework Convention on Climate Change (UNFCCC). 2015. Paris Agreement, United Nations (UN)

World Bank. 2010. Economics of Adaptation to Climate Change: Ethiopia. Washington DC: World Bank. Available athttp://climatechange.worldbank.org/sites/default/files/ documents/EACC_Ethiopia.pdf.

ANNEX I

List of major programmes and strategies that are directly designed to respond to climate change

i. The Climate-Resilient Green Economy (CRGE) Strategy;

ii. The 5-year Growth and Transformation Plans (GTPs); and 5-year sector development plans;

iii. The Environmental Policy of Ethiopia;

iv. Ethiopia's Programme of Adaptation to Climate Change;

v. The Food Security Programme (FSP) and its components, namely, the Voluntary Resettlement

Programme; the Productive Safety Net Programme (PSNP); the Household Asset Build in Programme

(HABP); and the Complimentary Community Investment (CCI);

vi. The Water Resources Management Policy;

vii. The National Policy on Biodiversity Conservation and Research;

viii. The National Policy on Disaster Prevention and Preparedness;

ix. The Conservation Strategy of Ethiopia;

x. The Agriculture and Rural Development Policy and Strategy;

xi. Agricultural Extension Packages;

xii. Community-based Participatory Watershed Development (CPWD);

xiii. The Disaster Prevention and Preparedness programme and its Early Warning System;

xiv. Integrated Watershed Management; and

xv. Participatory Forest Management.

Abstracts of paper presented as Posters

Theme 1: El Niño and its impact on Biodiversity, Agriculture, and Food Security

1. Will El Nino affect Chickpea Production in Bishoftu Area? Or will Future Climate Change affect Chickpea Production in Bishoftu Area?

Eba Muluneh[1] and Kibebew Kibret[1]

[1]Haramaya University, College of Agriculture and Environmental Sciences, School of Natural Resources Management and Environmental Sciences,

*Corresponding Author E-mail: ashenafi54321@gmail.com

Abstract

In Ethiopia, where vulnerability to climate change and variability is high, studying the impact of climate change at a local scale is critical for designing appropriate strategies that enhance adaptive capacity. The study was conducted in Bishoftu area to examine the extent of climate change effects on the production of two chickpea varieties (Arerti and Habru) in the upcoming periods (2050's and 2080's) under two climate scenarios, RCP4.5 and RCP8.5. Future climate data were downscaled using the ensemble of two climate models (CSIRO-Mk3-6-0 and MIROC-ESM-CHEM0) with RCP4.5 and RCP8.5. Twelve years of crop data were collected from Debre Zeit Agricultural Research Center (DZARC). Soil data were also adopted from published documents of DZARC. Decision Support System for Agrotechnology Transfer (DSSAT) model was used for this study. The model employs all collected data to simulate days to flowering (DF), days to maturity (DM), and yield. Prior to simulations, the model was validated for its performance in simulating the yields of both chickpea varieties. The study revealed that yield of Arerti will increase by 22% from the baseline yield of 2846 kg/ha by 2050's under RCP 4.5. In contrast, by 2050'sunder RCP 8.5 the yield of Arerti will reduce by 33%. Moreover, the study depicted that2% yield increment of Habru from the baseline yield of 2787.5 kg/ha will be expected by 2080's under RCP 8.5. The reason for yield increment and decrement could be due to the combined effects of mainly rainfall and maximum temperature versus the tolerance of respective chickpea variety. In general, RCP 8.5 has resulted in more reduction of yield of Arerti than RCP 4.5 scenario. However, Habru variety will benefit more from RCP 8.5 scenario. Therefore, chickpea production under the changing climate is possible with appropriate variety choice fitted a given environment and a time period.

Keywords: Adaptive capacity; Climate models; Decision support system; Vulnerability

2. Breeding Opportunities for Climate Resilient and Production Challenges of Cowpea (Vigna Unguiculata L.) in Ethiopia

Tesfaye Walle*[1], Firew Mekbib[2], and Berhanu Amsalu[3]

[1*]Wolkite University, P. O. Box: 07, Wolkite, Ethiopia,

[2]School of Plant Sciences, College of Agriculture and Environmental Sciences, Haramaya University, P. O. Box: 138, Dire Dawa, Ethiopia,

[3]Ethiopian Institute of Agricultural Research (EIAR), Melkassa Agricultural Research Centre P. O. Box 436, Oromiya region, Adama town-Ethiopia

*Corresponding Author Email: tesfaye.walle@gmail.com

Abstract

Long-term food insecurity is the most common issues in our country, this issues raised by different climatic change. The dry land area of the country will face more acute challenges. Ethiopia already suffering from high/medium poverty levels due to poor land and water availability with erratic rainfall, more frequent droughts, extreme temperatures, shifting climatic zones and the arrival of new crop pests and diseases. More than 66.5% of the Ethiopian arable land falls within dry land environments where rainfall is usually inadequate, poorly distributed, and varies with years and seasons. But cowpea is an important grain legume grown and consumed in dry land areas of Ethiopia. Its ability to grow under diverse agro-climatic conditions in different cropping systems is associated with a wide range of biotic and abiotic production constraints. Major cowpea production constraints in Ethiopia are scarcity of sufficient improved varieties for climate resilient such as drought, disease, weed and insect pest attacks at field, storage and in adequate cultural practices, low soil fertility and poor technology dissemination and popularization. However, only six cowpea varieties released from 1976 up to now with recommended production packages in Ethiopia descendent one-size-fits-all fashion. Ethiopia is a centre of diversity for cowpea and there is great opportunities to improve cowpea for resistance or tolerance to biotic and abiotic stresses and there is a need for selection of drought tolerant and short-season crop varieties that fit the growing season of such areas. Currently in Ethiopia cowpea is one of climate resilient crop because of this it is a strategic crop for dry land (dry land agriculture) area of the country. Ethiopian government has given a good research attention for this crop due alleviating production and productivity of crop. It is, therefore, important to revive research in this crop and to develop more varieties for biotic and abiotic stress resistance to wide range of Ethiopia especially developing drought tolerance varieties on this crop. The current research focuses is to increase cowpea production, improve smallholder household nutrition, improve the soils and possibly increase household incomes from the sales of the cowpea. The present paper focused on the contributions for food security, changing climate and other recent challenges being addressed in these breeding programmes and future opportunities to overcome some of the cowpea production constraints.

Keywords: Climate resilient; Cowpea; Food sec-urity; Production challenges

Theme 2: El Niño and its Social and Economic Impacts

1. Rapid Agriculture Needs Assessment in Response to the "El - Niño" Impacts in Benishangulgumuz Region

Dereje Mosissa[1]*and Biresaw Mokonnon[2]

[1]Ethiopian Biodiversity Institute, Assosa Biodiversity Center, Asossa, Ethiopia

[2]Bureau of Environment Forest and Land Administration, BGRS, Asossa, Ethiopia.

*Corresponding Author Email: derament5964@gmail.com;

Abstract

The main rainy season (*kiremt*) that is vital for producing over 80 % of Ethiopia's agricultural yield-in an industry that employs 85% of the country's workforce-failed in 2015. A powerful El Niño continues to wreak havoc on children's lives and their families' livelihoods. Since 2015, it has caused serious destruction on farmer's crops, livestock and other common properties including natural resources. In response, Benishangul Gumuz Regional Bureau of Agriculture and Rural Development (BoARD) requested the Ministry of Agriculture and Rural development (MoARD), to provide an emergency support through FAO in conducting a rapid agriculture needs assessment to estimate the impact on the agricultural livelihoods of the affected population. This assessment was a useful input towards the development of mitigation and resilience plans, and assist in planning the required emergency support to the affected households and communities. The assessment used both primary and secondary tools for data collection and covered the affected region. Checklists for KIIs and FGDs were also developed to gather pre and post-disaster information. Reports, publications, newspaper articles and other secondary informative material were also collected and analysed. A combination of heavy rains followed by insufficient rain attributed to El-Niño event, > 25,000 households have been directly affected in five assessed Woreda-Kurmuk, Mengie, Sherkole, Assosa and Guba of the Benishangul Gumuz region since 2015. This had severe repercussion on the livelihood of the affected population who have lost crops, agricultural inputs and tools, animals, pasture land and biodiversity. To estimate the damages and losses occurred in the agriculture sector and sub-sectors and to come out with necessary emergency response interventions, the MoARD, the PO-RALG, the DMD, EPLAUB with technical and financial support from FAO, jointly conducted a rapid agriculture needs assessment in the affected regions. The key findings of the assessment showed that drought have been the most devastating natural hazard. Heavy rains coupled with incidences of storms and hails led to additional problems resulting in water-logging of large agricultural and pasture areas, spread of animal diseases, accumulation of debris on agricultural land, mainly silt and stones, as well as collapse of animal shelters, infrastructures and storage facilities. The crop sector followed by livestock has been the most affected with sorghum and maize cultivated areas resulted to be the most impacted. The affected areas were totally destroyed by the drought or resulted reduction of production on staple crops such as sorghum, maize, and millet leading to decreased yield by approximately 41, 57, and 38% respectively.

Keywords: Disaster, Flooding. Livelihood; Main rainy season; Waterlogging

2. Green Entrepreneurship as "One-To-All Approach" against Climate Change, Unemployment and Migration: Review of Best Practices, Practical Challenges and Possible Strategies for Rural Ethiopia

Tsegaye Molla[1]

[1]Department of Agricultural Economics, Debre Markos University, Ethiopia

*Corresponding Author Email: tsegayem4@gmail.com

Abstract

For reasons ranging to global levels, climate change yet continues to threaten human life on earth, which is more severe when it comes to the economies of the developing world. Although climate change needs macro solutions, looking for green entrepreneurship (businesses that can save earth and make money) as an integrated approach against climate change, unemployment, food insecurity, poverty and migration are needed as adaptive ways for rural lives to transform to green economy. This paper is aimed at identifying potentials, best practices and strategies of exploiting rural enterprises from African experiences to catalyse development of rural Ethiopia. Hence, green rural agribusinesses are; monetizing biodiversity, forestry enterprises, irrigation farming, value addition, and agro-forestry blended farms like fruit and vegetable, fattening, poultry, dairy, apiculture and cash crops are identified as yet untapped and potential in rural areas. Major practical challenges of enterprises include lack of irrigation water, lack of land, lack of technical skill, finance, market, lack of equipment and seasonal demand for some products. Strategies to exploit identified enterprises are expanding irrigation technologies (private and communal), climate adaptive soil and water conservation, climate-resilient crop varieties and livestock breeds, research-extension-farmer linkage, disaster-risk management schemes, biodiversity benefit sharing, holistic value-chain, holistic training, and 'institutional partnership' among financial sector, microenterprises, education/TVET institutes, agriculture sector, environment protection, physical and institutional infrastructures are critical for synergic results ranging from supplying affordable equipment to marketing. Medium and large-scale agro-processing industries should also be established for value addition to offset seasonal fluctuation of demand. In this way, it is possible to realize our quest of transforming climate-sensitive rural life to climate adaptive via greening jobs with transition from self-employment to employing others, reducing rural poverty, curbing mass migration from rural to urban areas and protecting biodiversity given that these strategies are synergistically implemented.

Keywords: Agro-processing; Biodiversity; Food insecurity; Green entrepreneurship irrigation

Theme 5: Climate Change Adaptation and Mitigation for Sustainable Development

1. Mechanisms for Successful Biological Restoration of the Threatened Juniperus Procera (Cupressaceae) on Degraded Landscape, Ethiopia

Legesse Negash[1] and Birehanu Kangew[2]*

[1]Addis Ababa University
[2]Hawassa University
*Corresponding Author Email: Birhank444@gmail.com

Abstract

Juniperus procera Hochst. ex. Endl. (Cupressaceae) is world's largest juniper, but is currently threatened owing to multiple anthropogenic factors. This paper describes mechanisms for the successful biological restoration of African pencilcedar in a degraded landscape that had been depleted of organic matter and essential nutrient elements as a consequence of relentless deforestation, soil erosion, unsustainable farming and overgrazing. We used stecklings (= planting materials derived from rooted cuttings) of *J. procera*, and deployed *Acacia abyssinica* Hochst. ex Benth. (Fabaceae) to serve as a putativefoster tree. The study was conducted for a period of 7 years, with major soil fertility indicators determined at years 0, 3 and 7. We found that mean height, crown length, crown diameter, branch length, and branch numbers of *J. procera* trees grown in association with *A. abyssinica* were significantly (p = 0.001) higher than those grown without the putative foster tree. Mean plant-available P (15 ± 2.1 ppm) and soil N-content (0.42 ± 0.04%) were approximately 3- and 2-fold higher, respectively, in the *A. abyssinica*-treated plots than in the non-treated ones. Similarly, the levels of exchangeable cations and soil organic carbon were twice higher in the *A. abyssinica*-treated plots than in the non-treated ones. Cation exchange capacity improved with restoration time, both in the 0–15 and 15–30 cm soil profiles, but the extent of improvement was significantly (p = 0.001) higher in the 0–15 cm soil profile of the *A. abyssinica*-treated plots than in the non-treated ones. We conclude that successful restoration of *Juniperus procera* in degraded landscapes and across the species' range of habitats is feasible provided that strong and well-fortified stecklings are established along with the N_2-fixing, fast-growing and drought-tolerant *Acacia abyssinica.*

Keywords: Indigenous trees; Highlands; Mountainous region; Soil fertility; Stecklings; Tulu–Korma

2. Role of Forest Management for Climate Change Mitigation and Adaptation

Meseret Woldeyohannes[1*] and Sintayehu Fetene[2]

[1]Neway Challenge Academy Addis Ababa, Ethiopia,

[2]Kotebe University College, Faculty of Natural and Computational Science, Environmental Science department, Addis Ababa, Ethiopia

*Corresponding Author Email; mesumar2013@gmail.com;

Abstract

Forest management activities play a key role through mitigation of climate change. However, it can also be influenced by the changing climate. As results of climate change global warming is basically recognized as severe risk to nature and society due to the increase concentration of GHGs. In the global carbon cycle the special role of forests that differs significantly from other components is due to the properties of carbon pools in forest ecosystems. In addition, global forest is also important for their daily livelihood activities. Therefore, the objective of this paper is to review available literature on the role of forest management to climate change mitigation and adaptation strategies so as to have a sustainable green development. Climate is changing due to several factors and it can be driven by changes in the atmospheric concentration of CO_2, N_2O, CH_4 and halocarbons. The increments of the concentration of radioactively active gases are due to human anthropogenic activity; deforestation, land use change and other natural factors. So to reduce the changing climate, forest in general primary and secondary forest in particular has great role. Therefore, forest can be considered as natural sinks of carbon. According to IPCC reports, the latest estimates for the terrestrial sink for the decade 1993-2003 are 3,300 MtCO2/year. The most likely estimate of these emissions for 1990s is 5,800 MtCO2/year. IPCC concludes that the forest sector has a biophysical mitigation potential of 5,380 MtCO2/year on average up until 2050. Reviewing on this type of topic is therefore important for researcher to undergone study on the specific topic, so as to inform and influence policy makers for the country as well as for the world sustainable developments.

Keywords: Deforestation; Forest; Global warming; Sustainable developments; Terrestrial sink

3. Determining the Ideal Climate Smart Conservation Tillage Method for Groundnut (Arachis Hypogeal L.) Production in Zimbabwe

Mutsa Muhambi*[1], Alex Kondwakwenda[1], Agness Dube[1], Dumisani Kutywayo[1], and Sakhile Kudita[2]

[1]Agronomy Research Institute, Department of Research and Specialist Services, Harare, Zimbabwe,
[2]International Crops Research Institute for The Semi-Arid Tropics (ICRISAT), Matopos, Bulawayo, Zimbabwe
*Corresponding Author Email: mutsamuhambi@gmail.com

Abstract

This study was conducted at Gwebi, Kadoma and Matopos during the 2014-2015 and 2015-2016 seasons to determine the ideal conservation tillage method for groundnut cultivars as a way to promote climate change adaptation and mitigation. One introduced cultivar CG7 and a standard check cultivar Nyanda were subjected to 4 conservation tillage methods as follows; planting on rip lines, planting on basins, planting on tied ridges and planting on open ridges. The experiment consisted of 8 treatment combinations (2 cultivars and conservation tillage method at 4 different levels) of a 2 x 4 factorial (cultivar x conservation tillage) arranged in a Randomized Complete Block Design. Agronomic data was subjected to analysis of variance (ANOVA) using Genstat statistical package software (Discovery edition 14) (VSN International UK). Mean separation for the significant means was done using Fischer protected least significant difference Test (LSD). Across-season analysis showed that there were significant differences($P<0.05$) in grain yield due to soil conservation tillage method. Highest grain yields were as a result of growing on open ridges. Grain yield did not differ significantly ($P > 0.05$) among the cultivars when planted on tied ridges and open ridges. Grain yield was reduced by 50 % due to planting on rip lines as compared to planting on ridges and tied ridges. On the basis of the two-year results obtained, it can be concluded that growing groundnuts on ridges and tied ridges are the most ideal conservation tillage methods. Ridge planting was most ideal for groundnuts probably because of more loose soil favourable for pod development and easier uprooting, higher infiltration, as well as greater soil moisture holding capacity thereby sustaining the crops during dry spells.

Keywords: Conservation tillage; Cultivar; Ridge planting; Soil moisture holding capacity; Yield

4. Climate Change and Distributions of Ethiopian Endemic Birds: Implications for Conservation

Nega Tassie [a, b], Tak Fung [a], Felix Lim [a], Beth Crase [a,] , Frank E. Rheindt [a,] , and Ryan A. Chisholm [a,]

[a]Department of Biological Sciences, National University of Singapore, 14 science Drive 4, Singapore 117543; [b]Bahir Dar University, Department of Biological Sciences, P.O.Box 79, Bahir Dar, Ethiopia

*Corresponding Author Email:negatassie@yahoo.com

Abstract

The effects of climate change on species distributions are a matter of global concern because these effects impose substantial adverse impacts on socioeconomic and ecological systems. Successful management and conservation under climate change relies on our ability to model species–habitat interactions and predict species distributions. This is particularly important in biodiversity hotspots with high number of endemic species. In this context, we performed a novel study by using the distributions of 28 endemic bird species in Ethiopia, which is part of the Eastern Afromontane biodiversity hotspot. Maximum Entropy (MaxEnt) models were developed for these species to predict distributions in 2050 and 2070 under two Representative Concentration Pathway (RCP) climate scenarios, RCP6.0 and RCP8.5. Performance of models was evaluated using area under the curve of receiver operating characteristics (AUC). Prediction performance of models was high (mean AUC 0.82 ± 0.04 SE), with the climate variables maximum temperature and annual precipitation being most frequently among the best predictors. For the 23 species whose current ranges were well reproduced by the models, mean projected range contractions were 26% by 2050 and 36% by 2070 under RCP6.0, versus 38% and 48% under RCP8.5. The models described less well the distributions of five species with restricted ranges; more work is needed to assess these species' vulnerability to climate change. One exceptional species with a very restricted range, Stresemann's bushcrow (*Zavattariornis stresemanni*) was among the 23 accurately modelled species and was projected to go extinct in future. Efforts to conserve Ethiopia's endemic birds should focus on the highlands, which our models predict will be climate refuges, providing suitable habitat for these species as regions at lower elevations become unsuitable. A focus on highlands is especially warranted because these areas currently have few conservation reserves and is subject to a high intensity of human activity.

Keywords: Biodiversity hotspots; Climate refuges; Species distribution; Ecological systems

5. Adaptation and Mitigation of Climate Change through Ethnoveterinary Medicinal Plants

Tinsae Bahru[1*], Zemede Asfaw[2], and Sebsebe Demissew[2]

[1]Central Ethiopia Environment and Forest Research Center (CEE-FRC), Addis Ababa, Ethiopia,

[2]Department of Plant Biology and Biodiversity Management, Faculty of Life Sciences, College of Natural Sciences, Addis Ababa University, Addis Ababa, Ethiopia.

[*]Corresponding Author Email: batinsae@gmail.com,

Abstract

Climate change is recognized as one of the greatest global challenges faced to human kind. Consequently, pastoralists and agro-pastoralists mainly depend on climate sensitive livelihoods are the most vulnerable. Of these challenges, various diseases and insect pest outbreaks are the major consequences of global climate change. However, ethnoveterinary medicinal plants are commonly being used for the treatment of livestock diseases so as to reduce their vulnerability and to enhance adaptation capacity. The present study aimed at investigating and documenting ethnoveterinary medicinal plants commonly being used by Afar and Oromo ethnic communities and traditional healers in and around the Awash National Park, Ethiopia. A total of 96 informants comprising 76 men and 20 women between the ages of 20 and 80 were selected. Data were collected using semi-structured interview, guided field walk, discussions, market survey and field observation. A total of 20 ethnoveterinary medicinal plants belonging to 19 genera and 15 families were documented. Of these, the Afar and Oromo ethnic communities reported 6 and 8 species, respectively. Herbs and leaves were the most widely used plant habits and parts used, respectively. *Achyranthes aspera*, *Asparagus africanus*, *Cissus quadrangularis, Grewia villosa and Rhus vulgaris* were among the most popular ethnoveterinary medicinal plants. Anthrax, Babesiosis, Black leg, Pasteurellosis, expelling the Leech and many others were treated. Documenting ethno-veterinary knowledge can serve as a basis for future investigation of modern drugs for livestock health care and hence adapt and mitigate climate change.

Keywords: Adaptation; Anthrax; Climate change; Ethno-veterinary medicinal plants

6. Status of Renewable Energy Technologies in the Rural Areas of Ethiopia and their Role in Climate Change Mitigation: A Case Study on Improved Cooking Stoves and Biogas Technologies

Yitayal Addis Alemayehu[1]*

[1]Kotebe Metropolitan University, College of Natural and Computational Sciences, Department of Environmental Science, Addis Ababa, Ethiopia
*Corresponding Author Email: yituaddis@gmail.com

Abstract

Use of alternative energy technologies is one of the key programmes of nations for climate change mitigation, environmental protection and sustainable development. The majority of Ethiopia's people (85%) reside in rural areas, deriving their livelihood from agriculture, and the energy system is characterized mainly by biomass fuel supply, with households being the greatest energy consumers. The household sector takes up nearly 94 % of the total energy supplies. Access to energy resources and technologies in rural Ethiopia is highly constrained which makes the energy supply and consumption pattern of the country to show many elements of un-sustainability. The concern on cooking practices, household economics, health, forest and agricultural resource management, and global greenhouse gas emissions has emerged as a transformative opportunity to improve individual lives, livelihoods, and the global environment. More decentralized renewable energy projects could play an important role in mitigating traditional biomass fuel use and climate change effects. Improved cooking stove (ICS) dissemination projects have been launched involving the private sector in the production and commercialization of the stoves. In doing so, about 3.7 million ICSs have been disseminated in the country so far which benefited stove users, producers (obtain a profit margin of about 48%) and the total environment as an estimation of about 30 million hectare of forest land per year could be preserved**,** and equivalently about 249 million ton of CO_2 could be stored per year. Conversion of animal waste to biogas energy to replace traditional fuel and use of the slurry as a fertilizer is the other current focus of the government of Ethiopia and installed more than 860 biogas digesters in the four regions of the country. The benefits obtained from these technologies are also considerable and promising. However, the programmes are not that much benefited the rural households where it had been intended to address. So, due attention should be given for those of the rural households in order to address the fuel wood crisis, environmental degradation and their health condition.

Keywords: Biogas; Improved cooking stoves; Renewable energy; Rural household

7. Land Restoration Projects: Implications for Climate Change Adaptation and Mitigation

Zewdie Kassa[1]

[1]Addis Ababa University, Department of Plant Biology and Biodiversity Management, Corresponding Author Email: zewdie.kasa@aau.edu.et Or zewdiekasa@gmail.com

Abstract

The purpose of this study was to present the applications of numerical methods in assessing the roles of restoration projects as among best practices contributing to sustainable agriculture in the Ethiopian highlands ecosystems, the species diversity of the area together with the associated ethnobotanical knowledge as well as its contribution to conservation agriculture, food security, health and environmental planning. Common ecological and ethnobotanical methodologies and techniques were used through numerical approaches to R integrated ArcGIS based resource mapping as a model for environmental management. About 304 plant species belonging to 216 genera and 78 families were recorded from the area within 5-10km radius from the restoration project centre. R statistical Software was used to run cluster analysis and four plant community types were identified. Ordination techniques were followed to see the major environmental variables structuring the floristic composition and plant community types and altitude was found to be the most influential environmental variable at 95% confidence interval (P = 0.005) for Canonical Correspondence Analysis (CCA) ordination followed by disturbance, aspect, grazing and slope. The Shannon-Weiner Diversity index was also calculated to see the overall diversity of the study area. The area is with relatively high plant species diverse at H'= 3.37 with overall species evenness, J= 0.61. About 12 major plant use categories were identified and the values of informants' consensus factor showed medicinal use were ranked first followed by charcoal making and shade. Comparison of historical records from literature and practical observation of the current status of the study area with regard to the trends of biodiversity changes in the area confirmed that there is an increasing trend of biodiversity and vegetation cover. The increasing trend is justified by observing the positive impacts of the project centre for indigenous trees propagation and biodiversity development for Ethiopia. Land restoration projects are among the best approaches to climate change adaptation and mitigation measures for sustainable development, biodiversity conservation as well as natural resource management.

Keywords: CCA; Cluster analysis; Conservation agriculture; Diversity; Ethiopia; Ethnobotany, Indigenous species; Multipurpose plants; Ordination; Restoration; Tulu Korma

1. Major Output of the Conference

- Cereal prices and cost of consumption basket decreased during El Niño
- Livestock price declines faster during El Niño
- Some Southern and Eastern African countries have policies for climate adaptation
- Policies are not fully focused, prioritised, operationalized and implemented
- Limited capacity was evident to negotiate on climate change, develop policy framework, and to implement adaptation and mitigation strategies
- Access to information about climate system is limited
- Climate change is reducing the yield and area of livestock and crop production
- The impacts of El Niño and La Niña on water bodies were noticed
- Linkage among institutions is limited.
- Following climate change, reduction and loss of biodiversity were reported
- Food insecurity has been aggravated by climate change in general and El Niño in particular
- The impacts of climate change are not uniform across regions and localities, moreover, the future expected to have more challenges and less opportunities especially for the poor.
- The climate change impact perception of local communities is in line with the scientific evidences.
- Drought is becoming the greatest challenge in pastoral areas.
- The climate change impact in eastern Africa, including Ethiopia, is mainly driven by ENSO.
- The combination of elevated carbon dioxide and increased temperature has significant influence agriculture, biodiversity and food security
- Various ENSO phases have different effects on different rainy seasons.

2. Policy Briefs and Recommendations

2.1. Policy Briefs and Strategic Issues

- The international climate agreements are skewed towards the North due to lack of financial, technical and diplomatic capacities in the South.
- Adaptation measures with business as usual measures such as agro forestry, soil management, and improved land management, etc will not be enough to respond

to climate change. Needs arise to explore and use all social, economic and technological options.

- Ethiopia has workable national policies, which are derived from the ratified international agreements that can support the designed CRGE. However, their implementation is limited.
- Institutional capacity development in climate system mainly in climate forecasting could be among the solution to many of the challenges in adapting and mitigating climate change impact.
- Regional institutions as well as countries must have much improved capacities to generate and interpret forecasts.
- Institutions (including international, Universities, the private sector, NGOs, and governments) are considerably more adept and active in requesting, seeking out, and using climate, as well as El Niño, information for planning, preparedness, and prevention.
- Continued improvements are needed in all areas of research – including the social sciences, data, models, stakeholder engagement, tailored products, communication and feedback, documentation and evaluation of results.
- There is a need for greater engagement by the interdisciplinary community that has extensive experience and expertise in the field of climate services.
- There is a need to complement scattered efforts with a move towards systematic support for full-suite implementation of relevant climate services (historical, tailored, multiple time scales, end-to-end), focused primarily at country level, including evaluation as part of design, demonstrating substantial improvements in climate-related outcomes, as well as identifying gaps.
- The effective use of climate information to manage risk and enhance resilience requires an iterative partnership with stakeholders.

2.2. Recommendations

- There should be South-South agreements, partnership, and communication that help develop and implement regional and national policies accordingly.
- Climate smart approaches and technologies should be encouraged and financed to the possible margin.
- The DPSIR (Drivers-Pressures-State-Impact-Response) framework is by now helpful for researches, practices, policy designs and should be implemented.
- Institutional set up should be designed in accordance with the required climate resilient system, should be stable, and should be assessed and monitored (that must include personnel, structure, finance, and property issues).

- Coordination, communication, and synergy at policy level are vital to respond to climate change and establish resilient climate system to practically achieve the growth and development goals of a nation.
- There is a need to understand the vulnerabilities and exposure of different communities and sectors and improve scientific capacity to predict the physical aspects of the El Niño phenomenon particularly as it is affected by global climate change.
- There is an urgent need to strengthen governance to manage risk and show, for instance, the role of coordination within and across sectors and how clear responsibilities and cooperation can ensure understanding of El Niño conditions, and are effectively communicated to local communities who are engaged and supported to reduce risks and respond appropriately.
- Need to strengthen disaster preparedness, including early warning and contingency planning, to manage the impacts of the current phenomena, raise the challenge of reliable sources of prediction, translate these into impacts and address the information needs of key sectors and the most vulnerable communities.
- Investments are required in long-term efforts to provide climate services that reduce the risk to extreme events and increase local and national preparedness capacity and resilience – particularly in the biodiversity, agriculture and food security, water and health sectors – in line with the Sendai Framework, the Paris Climate Change Agreements and the SDGs.
- Lessons learned on what was predicted, communicated, what were the impacts and what actions were taken in the context of the 2015/2016 El Niño phenomenon will be required, drawing on the institutions that contribute the observations, , the regional and national climate centres and key sectors and other end-users of climate information in countries.
- Sustained commitments and investments are needed to improve regional and national climate services and establish and/or strengthen multi-hazard early warning mechanisms and preparedness for effective response at all levels to reduce the effects of extreme weather and climate events, including those associated with El-Niño.
- Implementation of livelihood-based safety net programmes should be accelerated to reduce vulnerability of affected populations and enhance their resilience.
- Efforts on preparedness and response should continue, risk reduction plans and activities should be developed.
- Ensure data is available to design an effective response.