

FOOD SECURITY POLICY: DOES IT WORK?  
DOES IT HELP?

Tagel Gebrehiwot Gidey

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FOOD SECURITY POLICY: DOES IT WORK?  
DOES IT HELP?

DISSERTATION

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the degree of doctor at the University of Twente,  
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born on April 29, 1974

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This thesis is approved by  
**Prof.dr. Anne van der Veen**, promoter

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Erratum: On page 47, line number 9 the following paragraph should be included before ... In addition

Abebaw et al. (2010) studied the impact of food security program on household food consumption in two villages of the Amhara region in the North-western part of Ethiopia using propensity-score matching. However, Abebaw et al. (2010) only provided the average impact of the food security program but did not attempt to analyse the sensitivity of their estimated impact to selection bias. In practice, there may be unobserved variables that simultaneously affect the outcome, and the assignment into program beneficiary. In such circumstances, a 'hidden bias' may influence the robustness of the matching estimators (Rosenbaum, 2002). As Ichino et al. (2006) have suggested, the presentation of matching estimates should therefore be accompanied by sensitivity analysis since propensity-score matching cannot fully account for selection bias. This apparent limitation of Abebaw et al. (2010) provides us with the starting point of this article.

#### Reference

Abebaw, D., Yibeltal Fentie, Kassa, B. (2010). The impact of a food security program on household food consumption in Northwestern Ethiopia: A matching estimator approach. *Food Policy* 35, 286-293.

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### **Definition of local terms**

Belg	A short rainy season usually occurring from February to April
Degua	Highland (one of the three agro-climatic zones in Ethiopia with altitude over 2300 m.a.s.l.)
Kola	Lowland (one of the three agro-climatic zones in Ethiopia with altitude less than 1500 m.a.s.l.)
Weinadegua	Midland (one of the three agro-climatic zones in Ethiopia with altitude 1500-2300 m.a.s.l.)
Dergue	The name of the military regime that ruled Ethiopia from 1974 until 1991
Hanfets	A mix of wheat and barley grown in the same crop field
Tabia	The smallest administrative unit of local government in rural Tigray
Tsimad	A plot of land that can be ploughed by a pair of oxen in a day. One tsimad approximately equals a quarter of a hectare.
Woreda	The second administrative unit above the tabia

### **Acronyms**

MoFED	Ministry of Finance and Economic Development
BoFED	Bureau of Finance and Economic Development
CBN	Cost of Basic Needs
CSA	Central Statistics Agency
ETB	Ethiopian Birr (The legal currency of Ethiopia)
FSP	Food Security Package
m.a.s.l.	meters above sea level

## **Chapter 1**

### **General Introduction**

## **1.1 Background**

Achieving food security, improving people's livelihood, and maintaining and improving the conditions of the natural resource base are central goals of policy reforms in the Sub-Saharan African (SSA) countries (Kuyvenhoven et al., 1998). This requires creating sustainable development that fulfils both economic and ecological objectives as one of the main policy concerns of governments in these low-income countries.

Food security as a concept gained momentum during the 1980s and more than ever during the implementation of structural adjustment programs in most SSA countries. Ethiopia is one of the least developed countries in SSA that faces an almost overwhelming challenge in achieving food security. Poverty is widespread and deep-rooted and constitutes the priority development challenge in the country. Since the Dergue regime that had ruled Ethiopia for nearly two decades was ousted in 1991, ensuring food security and alleviating poverty have come to represent an increasingly significant developmental concern. This echoes the international poverty agenda that gained momentum with the publication of the World Development Report 1990 and more recently the Millennium Declaration that was adopted in September 2000. Since 1991, the government of Ethiopia has embarked on extensive economic reforms focussed on market liberalization, reduction of tariff, removal of subsidies, decontrolling interest rates, and disengagement of the public sector from economic management (Diao, 2010; Webb and von Braun, 1994). Following the World Food Summit in November 1996, where 186 countries committed themselves to reducing the number of undernourished people by half by 2015, the government has been implementing policies and programs targeted at reducing vulnerability and food insecurity. Accordingly, successive national Poverty and Food Security Strategies have been designed in 1996, 2002, 2003/04 and the Plan for Accelerated and Sustainable Development to End Poverty (2005/06–2009/10). The programs aim at reducing poverty and improving food security of a large segment of the vulnerable population.

As an agrarian economy with more than 80 per cent of the population dependent on agriculture, agriculture is seen as a point of departure and growth-engine for development. Accordingly, in Ethiopia, food security and poverty reduction policies have focused on strategies to enhance the production and productivity of smallholder agriculture through generation, adoption and dissemination of suitable farm technologies in the form of improved inputs and farming methods, provision of credit, building of infrastructure, expansion of health care services and primary education, promoting off-farm employment through diversification of the rural economy, and rural asset building (FDRE, 2000; MoFED, 2002). This has been

complemented by safety net programs, mainly targeted at food transfer either in the form of food for work (FFW) or free hand-outs, to alleviate temporary food security problems. Later the Integrated Household Food Security Package (FSP) program was introduced, which aims to provide financial support to the food insecure population in a way that assists them to participate in one or more program activities and create assets at the household level, and protect their assets.

While much has been achieved in reducing rural poverty in recent years, Ethiopia still has a high level of food insecurity, and food shortages continue to be an on-going problem in the country. Poverty and food insecurity are mutually reinforcing in Ethiopia, where over 30 per cent of the people live below the poverty line (MoFED, 2012). While many things are clear about the characteristics, causation and potential remedies of hunger in general, a thorough understanding of the causes of food insecurity at the household level is seriously lacking. One of the problems is local communities in the study region adopt different coping strategies in response to the effects of food shortages and entitlements. However, no research has been carried out to investigate the bundle of response actions employed by the rural households in response to shortages of food availability and the factors that influence their coping. Understanding the characteristics of the poor, the specific nature of a population's food security problem and the reasons why their deprivation persists is important for policy measures to tackle food insecurity and poverty. Clearly a great deal of probing investigation - analytical as well as empirical - is needed to support public policy and action to eradicate poverty, and eliminate endemic food insecurity.

It is generally researched that poor people live in environments characterized by high risk of shocks that cause loss of assets, or loss of income. In Ethiopia, policies that tackle food insecurity at household level, which stretch from making food available to the rural poor to mitigating transitory economic shocks and diversifying the income base of the rural poor, are seen as the most effective way to reduce poverty. von Braun et al. (1992) describe that the ultimate goal of an effective food security policy is to provide for individuals' adequate dietary intake through availability and accessibility of food, which are necessary for conditions for nutritional well-being. In the light of this, in Ethiopia, food security programs are widely implemented in rural areas to address the specific and complex problems and causes of food insecurity that are plaguing the rural poor. The food security program aims at enabling growth by increasing the production and productivity of smallholder agriculture in a sustainable manner and by furnishing the asset base of the poor to ensure food security through the provision of adequate and efficient financial services, training and technical assistance, and provision of improved agricultural inputs. Other specific objectives of the program include

rehabilitation and better management of natural resources and infrastructure as a precondition for the rural poor to regain their capacity for self-reliance, and diversification of employment and household income through off-farm activities to improve life for all rural people. Accordingly, the government has extensively carried out a number of program interventions to reduce the problems of widespread rural poverty and improve people's access to food. Given the large amount of money and energy spent, we still know surprisingly little about the actual impact of the FSP programs on the aggregate (macro level) and household's food security (micro level). Thus, evaluating scientifically the actual impacts of program interventions by tracking direct indicators that measure food security goals at both levels is indispensable.

As in other developing countries' economies, especially in SSA, the Ethiopian economy is mainly agricultural-based. The agricultural sector is almost totally dependent on rainfall with irrigation covers only less than three per cent of agricultural crop areas (Diao, 2010). Most of the crops are grown in the longer rainy season, Kiremti, and Ethiopian agriculture largely depends on this rain, which is characterized by high spatial variation (Block and Rajagopalan, 2007). This heavy dependency on rain-fed agriculture renders the majority of Ethiopians powerless in the face of irregular and unpredictable rainfall. As a result of the erratic nature of precipitation in Ethiopia which is highly affected by the monsoon climate in the Indian Ocean, the country in general and the study region in particular have faced recurrent drought over the past decades with the frequency of recurrence increasing in recent years. From 1970 onwards, drought hit the country at least once in every ten years but during the past years the event is becoming even more frequent (Ferris-Morris, 2003). In the past 15 years, for instance, Ethiopia has been hit by different disasters (natural and human-induced) about 15 times (FAO, 2010). As a result of the subsistence nature of Ethiopian agriculture, recurring droughts and the complex interplay of socioeconomic factors, the majority of the households who derive their livelihoods from farming are vulnerable to poverty and food insecurity. Food production is highly vulnerable to the influence of adverse weather conditions such as drought. Accordingly, rural livelihoods and agricultural systems in the study region are subject to continuous and widespread disequilibrium dynamics (van der Veen and Tagel, 2011). Thus, in the absence of accurate drought early warning information support systems, farmers risk aversion behaviour can be an obstacle to the realization of food security. Hence, there is a need for empirical research in identifying the most effective tool for initiating drought response actions at regional and local level.

Climate change and variability pose an enormous threat to Ethiopia. A recent study by UNDP (2008) indicates that climate change in Ethiopia could lead to

extreme temperatures and rainfall events, as well as more heavy and extended droughts and floods. Consequently, considering the fact that more than 80 per cent of Ethiopians are engaged in subsistence rain-fed agriculture, climate change and associated risks will have serious consequences for the country's economic growth, agriculture and food security in particular. According to Dercon (2004), in Ethiopia a season with starkly reduced rainfall depressed consumption even after four to five years. Studies further show that rainfall is expected to decline in the future (Funk et al., 2005) and also become more irregular. Rain-fed agriculture remains susceptible to environmental changes and a significant portion of the population remains vulnerable to slight changes in rainfall patterns or amounts. Notwithstanding the high economic significance of agriculture to the overall economy, the sector has been facing serious challenges through climate change induced natural and man-made disasters. Left unmanaged, climate change and variability will reverse development progress made and compromise the well-being of the people, particularly the rural farmers', whose livelihoods depend largely on rain-fed agriculture. Research along these lines is also important for identifying the vulnerable or hotspot areas, farmer's perceptions and choice of adaptation measures in response to the changing climate, which ultimately guide policymakers regarding alternative adaptation measures to be employed to stabilize and ensure food security in the face of anticipated changes in climate.

Motivated by the need to understand the dynamics of drought, food insecurity and the impact of public policies on household welfare, this research is conducted in the northern Ethiopia, Tigray region, one of the most severely affected regions in the well-known famine of 1983–84. In addition, to the best of my knowledge no comprehensive attempts have ever been made to scientifically evaluate the impacts of government program interventions on ensuring food security both at macro and micro levels; no attempts have been made to scientifically quantify the spatial and temporal characteristics of drought in the study region despite the fact that climate variability forms the major uncertainty that farming households have to deal with; and no attempts have been made to examine farm sectors' vulnerability and the factors influencing farmers' choice of adaptation measures to climate change and variability in the study region. These apparent limitations further provide us with the starting point of the thesis. Using macro and micro level socioeconomic data, monthly precipitation and temperature data for the period 1954 to 2009, and datasets from satellite imagery for the period 1999 to 2009, the study explores the factors influencing household food insecurity, impact of food security program interventions, spatial and temporal aspects of drought, farming sector's vulnerability, and farm level adaptation options to changes in climate.

## **1.2 Objective and research questions**

The general objective of this research is to assess the issue of drought and food insecurity; to examine the effect of government program interventions on enhancing the food security conditions of the rural poor and reducing natural resource degradation; and to identify the factors influencing farmer's decision making regarding the choice of adaptation measures in response to changes in climate. The study addresses this general objective by addressing three broader issues.

The first issue relates to understanding the situations of food insecurity. It starts with issues related to conceptual evolution of the term food security and analysis of food security. This is crucial to know what the situation is and to understand the factors determining the situation. It also investigates the impact of food security program interventions upon regional and household food security, and rehabilitating the degraded lands.

The second issue of this research deals with the characteristics of drought risks in the region. An attempt is made to provide a detailed analysis of seasonal drought dynamics in order to identify the spatial and temporal characteristics of drought over the past decade. In addition, the research addresses the implications of using meteorological and remote sensing drought monitoring tools in providing better real time and spatially continuous data that can be used for rigorous analysis of drought proneness over large areas. This ultimately aids in drought monitoring, early warning and mitigating the effects of drought disaster.

The third issue that this study addresses relates to the assessment of farming sector's vulnerabilities to the expected changes in climate and farm level adaptation options. The study seeks to identify farmer's vulnerability at district level by employing socioeconomic and biophysical factors. The research also attempts to examine the factors that influence farmer's decision making regarding the choice of adaptation measures in response to changes in climate. It aims to identify the hotspot rural areas most exposed to climate variability, and the policy required to promote successful and sustainable adaptation measures in the face of anticipated changes in climate in the study area.

These three issues are intended as illustrative cases of policy and institutional elements that need to be addressed in order to promote sustainable agricultural development where 80 per cent of the population currently makes its livelihood. The analyses in relation to the three issues dealt with in this study provide insights into the factors influencing household food security, impact of government interventions upon regional food self-

sufficiency and household's food security, farming sector's vulnerabilities to the expected changes in climate, and the factors influencing farmer's choice of adaptation measures and practices.

The following sequence of research questions aims at clarifying the above mentioned issues.

- a) Who is food insecure? What influences rural household's food insecurity? What are the main household coping mechanisms employed during times of food shortage?
- b) How effective are program interventions in the Tigray region in reducing food insecurity both at regional and household levels, and at enhancing the recovery degraded lands?
- c) How does the spatial and temporal characteristic of drought vary across the region? Which drought monitoring tool offers the possibility to effectively detect regional drought evolution in time and space?
- d) Where do the vulnerable farming communities locate?
- e) What determines farmer's choice of possible adaptation measures?

To answer these questions the thesis is divided into three parts: the first part of the thesis deals with food security analysis and policy impacts analysis. To empirically test the factors influencing household food security and coping behaviour a study is conducted in which household food insecurity and coping behaviour is investigated through data collected from focus groups and a household survey of 400 rural farmers in three districts of Tigray. To investigate the effect of policy interventions targeted at improving regional food self-sufficiency, data on indicators of regional food availability: data on annual agricultural crop production, population, fertilizer and improved seed supply, irrigation coverage, and data on the quantity of food aid distributed for the period 2000-2011 is collected. The impact of program interventions upon household food security is investigated through data collected from a survey sample of 400 farm households randomly drawn from 9 *tabias*. In addition, datasets from satellite imagery for the period 2001-2009 was used to detect the change in vegetation induced due to the governmental policy intervention of area enclosures.

To answer the second issue of the thesis, spatiotemporal characteristics drought, historical records of monthly precipitation data for the time period 1979-2009 from 25 weather stations is collected. In addition, a geo-referenced SPOT vegetation ten day composite Normalized Difference Vegetation (NDVI) images (S10 product) with spatial and temporal resolution of 1km×1km and 11 years respectively were used.

To address the third issue of the thesis on farming level vulnerability to climate change and variability, data on socioeconomic and biophysical factors, and data on frequency of drought occurrence for the period 1978 to 2010 is collected for 34 rural districts. The same sample of 400 farm households is used to empirically test the factors influencing farm level adaptation measures in response to changes in climate.

## **1.3 The Study area**

### *1.3.1 Tigray Regional State*

Tigray region is located in the chronically food insecure part of northern Ethiopia, one of the most severely affected regions in the well-known famine of 1983–84 (Little, 2002; Webb et al., 1992). Geographically the region is located between 12°15'N and 14°57'N, and 36°27'E and 39°59'E covering a total land area of 53,000 square kilometres. The state is divided into 6 administrative zones and 34 rural districts (locally called *Woreda*-the second administrative level below the zone). It has the autonomy to manage its overall political, social, and economic development. The total population of the region exceeds 4.3 million, about 83.9 per cent of whom live in rural areas (CSA, 2008).

Climatically, the region belongs to the sub-tropics and monsoon weather prevails throughout the year. The regional climate is characterized by large spatial and temporal variations in rainfall, and frequent drought. The main rainy season starts in June, peaks in August and trails off in September. Average rainfall varies from about 1000-1300 mm yr<sup>-1</sup> in some areas in the southwest to less than 260 mm yr<sup>-1</sup> in the north-eastern lowlands, with a unimodal pattern, except in the southern part of the region where a second (smaller) rainy season locally allows growing two successive crops within one year. The mean annual monsoon rainfall of the region is estimated to be 473 mm, 84 per cent of the annual rainfall, but with quite large differences across the region (Gebrehiwot et al., 2011). The regional agriculture largely depends on this rain, characterized by a high coefficient of variation (38%) compared to the national figure of 8 per cent (Gebrehiwot et al., 2011).

The region has a diverse topography, with an altitude that differs from about 500 meters above sea level (m.a.s.l) in the northeast to almost 4000 m.a.s.l in the southwest. The main agro climatic zones of the region are Kolla ,Weina-degua, and Degua. About 53 per cent of the land is lowland (kolla – less than 1500 m.a.s.l.), 39 per cent is medium highland (Weinadegua – 1500 to 2300 m.a.s.l.), and 8 per cent is upper highland (Degua – 2300 to 3000 m.a.s.l.) (Hagos et al., 1999). Altitude and topography play major roles

in determining climate in general and temperature in particular (Tesfay, 2006).

Like the rest of Ethiopia, the economy of Tigray is mainly agriculture based. Agriculture and allied activities constitute the largest component of the regional gross domestic product (GDP), nearly 40 per cent of the total (Table 1.1). In 2010/11, real GDP in Tigray grew by 11.7 per cent and this growth was mainly driven by agriculture and forestry which had grown by 12.5 per cent, followed by the industry sector with a growth rate of 12 per cent and finally service which had grown by 10.8 per cent. The tremendous importance of this sector to the regional economy can be gauged by the fact that it directly supports about 80 per cent of the population in terms of employment and livelihood. Agricultural systems are rain-fed and dominated by small-scale farmers with an average land holding of less than one hectare per family. These farmers have been adopting low input and output rain-fed mixed farming with traditional technologies based entirely on animal traction. In addition, the agricultural sector is highly susceptible to climate variability, seasonal shifts in rainfall, resulting in drought, which has a direct impact on food security. Almost every year, the region experiences localized drought disasters causing crop failure and jeopardizing development activities. As a result, rural livelihoods and agricultural systems in the region are subject to continuous and widespread disequilibrium dynamics.

Food insecurity in Ethiopia does not affect all individuals equally and at the same rate. Therefore, the severity of food insecurity measured as the share of the population that is food insecure, differs per region. Poverty and food insecurity are highest in the northern part of Ethiopia (Diao, 2010; Subbarao and Smith, 2003). Poverty and food insecurity has a long history in Tigray. A large numbers of rural households in Tigray remain mired in poverty despite efforts being made and some signs of change in reducing poverty and food insecurity. Entrenched poverty, misdirected policy during the military regime, three decades of civil war, dependency on rain fed agriculture and long term economic stagnation has led to the high levels of malnutrition and other indicators of food insecurity (Gebremedhin, 2006; Keller, 1992). Accordingly, reducing poverty and food insecurity are at the forefront of government policy. The government designed a long-term strategy to address the dire situation of smallholder farmers and eventually alleviate its food deficiency. In Tigray, conservation based agriculture is seen as point of departure and growth-engine within the long-term development strategy of the government. Accordingly, increasing agricultural production and ensuring food security is one of the top regional priorities and forms the cornerstone for the sustainable economic growth and poverty reduction strategy in the region. In addition, the strategy gives priori focus to the conservation and rehabilitation of natural resources.

Table 1.1: Real gross domestic product of Tigray regional state by economic sectors at a constant factor cost in 2009/10 and 2010/11, in Ethiopian Birr

Economic indicators	Real gross value (in ETB)		Growth rate (%)
	2009/10	2010/2011	
Agriculture and forestry	3,445,244	3,876,625	12.5
Agriculture	3,314,607	3,701,561	11.7
Crop	2,670,014	2,966,586	11.1
Livestock	644,593	734,975	14.0
Forestry	130,637	175,063	34.0
Industry	1,723,166	1,929,374	12.0
Mining and quarrying	114,203	139,265	22.0
Manufacturing	493,878	510,117	3.3
Construction	975,452	1,137,407	16.6
Water and electricity	139,633	142,585	2.1
Services	3,710,041	4,109,180	10.8
Distributive service	1,462,087	1,542,096	5.5
Transport and communication	609,980	663,353	8.7
Other services	1,637,974	1,903,731	16.2
Total Regional GDP	8,878,452	9,915,180	11.7
Total population	4,682,000	4,806,000	2.6
Real GDP per capita	1,899	2,063	8.6

Source: Regional Bureau of Finance and Economic Development (BoFED).

### 1.3.2 The Study *tabias*

The household level study was made in three *Woredas*, namely Hintalo Wajirat, Enderta and Kilde-Awelaelo, each district consisting of three villages (locally called *Tabia*) (Figure 1.1). Hence, the study is conducted in a total of nine *tabias*. The study *tabias* are situated within a 100 km radius from Mekelle, the capital city of the regional state.

Agriculture, predominantly mixed farming with crop production and livestock holding, is the main economic stay. The farming season is dependent on the 'Kiremt' rains that start in June and last until September. Rainfall in the study sites is low and highly variable and there exist frequent drought periods.

The lack of suitable farming land and declining soil fertility, caused by extensive land degradation diminishes the prospects of food production in the areas. The main crops produced in the areas are barley, wheat, teff, pulses, hanfe'ts, sorghum and maize. Oxen are the main traction power and are considered to be an important production resource in the *tabias*. Population

pressure and erratic rainfall patterns coupled with a lack of suitable lands for crop cultivation are among the factors that contribute to food insecurity in the study tabias. The Woredas to which these tabias belong are among the 16 Woredas identified by the regional government as chronically food insecure.

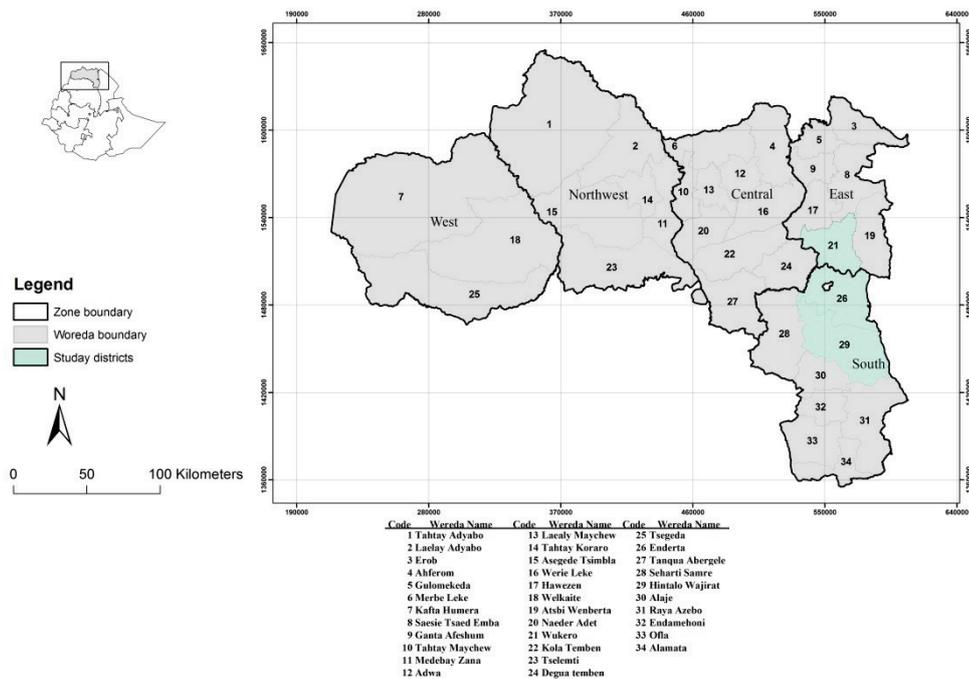


Figure 1.1: Geographic location of the study *woredas* and Tigray region, Ethiopia

The study on the effect of policy interventions upon rehabilitating the degraded lands was conducted in a randomly chosen *woreda*, Enderta Woreda, which is geographically located between 13<sup>0</sup>-14<sup>0</sup> North and 39<sup>0</sup>-40<sup>0</sup>30' East in the southern zone of Tigray region (Figure 1.2). The area is densely populated. According to the classification given by Pichi-Sermolli (1957), a great portion of Enderta *woreda* falls in the 'Weyna Degua zone' or mid-altitude while a smaller portion in the eastern and western parts lay in the 'Kolla zone' or lowland.

In addition to the fragile environment, the land resource has been excessively exploited. Exploitative land use practices such as relentless land cultivation have resulted in most of the land being severely degraded. The dominant soil types include Arenosols, Calcisols, Cambisols, Kastanozems, Leptosols, Luvisols, Phaozems, Regosols, Vertisols and Fluvisols. The natural vegetation cover of the study area is made up of grasses and scrubs with

short trees. This area had once been densely forested with the most representative species such as *Juniper procera* and *Olea Africana* (Darbyshire et al., 2003). As in many parts of the Ethiopian highlands, vegetation clearance to provide additional areas for cultivation, fuel wood and house construction has been a common practice in the Enderta Woreda.

The study was conducted over a total area of 49,255 hectares currently enclosed for the enhancement of natural vegetation and 16,932 hectares of unprotected land which are located in the western part of the *woreda* respectively. The research sites were carefully selected from the same *woreda* in order to prevent the influence of agro-ecology on the analysis of vegetation cover. Moreover, the two study sites have homogeneous land use, mainly covered with natural vegetation mainly scrubs, which is relatively better for vegetation change analysis than the mixed land uses. Ultimately it is assumed that the study sites will exemplify the rest of area enclosures in the region.

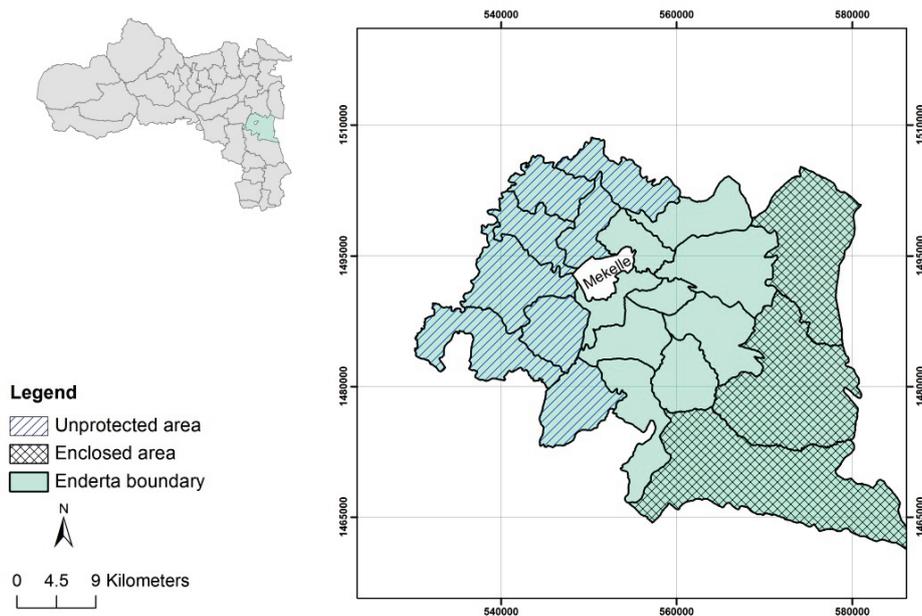


Figure 1.2 Geographic locations of the study sites in Enderta *woreda*, Southern Tigray. Mekelle is the capital city of the region and one of the administrative zones.

## **1.4 Thesis organization**

This thesis analyses food insecurity, drought, and vulnerability by looking at three broader issues: the first deals with food security analysis and policy impacts reported in chapters 2 and 3, the second deals on spatial and temporal characteristics of drought reported in chapter 4, and the third part of the thesis deals on farming community's vulnerability to climate and farm level adaptation options reported in chapters 5 and 6 respectively. Chapter 7 will provide the conclusions. The research objectives and questions raised in section 1.2 are addressed with in the subsequent chapters of this study which are organized as follows.

Chapter 2 concerns the first research question and starts with the conceptualization of the term food security and its underlying causes. The chapter contains an analysis of food insecurity and its determinants using household welfare measures of poverty line. In this study the poverty line is measured as food expenditure necessary to attain recommended nutritional requirements (food energy intake). In addition, the chapter discusses the coping behaviour of rural households employed during times of food shortages using coping strategy index. The chapter attempts to estimate a model of household food insecurity determinants by using food expenditure required to attain some minimum level of standard of living that defines the threshold to poverty.

Chapter 3 deals with the second research questions and contains an analysis of government policy interventions. Food insecurity is better understood and well-informed policy measures can be suggested if it is observed at different level of analysis. Accordingly, the chapter provides an overview of the need and conceptual definitions of policy evaluation, and government policy instruments implemented to address the problems of food insecurity and land degradation. The chapter then evaluates the impact of the widely applied intervention program in Tigray regional state –the Food Security program. The impacts on food security are assessed both at the household (micro level) and aggregate levels (macro level) by tracking direct indicators that measure food security goals at both levels. In addition, impact of interventions on rehabilitating the degraded environment is assessed by taking two exemplary study sites. Once the impact of the interventions is identified, the next three chapters focus on the main aspects of drought and climate variability that are important in the livelihood system of rural households.

Chapter 4 deals with the third research question. It provides a detailed analysis of seasonal drought dynamics in order to identify the spatial and temporal characteristics of drought over the last decade. In Tigray, drought is

the single most important climate related natural hazard impacting the region from time to time. This chapter presents an analysis of drought using meteorological and remote sensing drought monitoring tools, which ultimately suggests an effective tool that can provide better real time and spatially continuous data, which aid for early assessment and monitoring of drought impacts over large areas.

Chapter 5 addresses the fourth research questions. It thoroughly analyses farming communities' vulnerability to the changes in climate. The chapter discusses the conceptual and analytical approaches of vulnerability assessment. A range of socioeconomic and biophysical indicators are used to reflect the three components of vulnerability: exposure, sensitivity, and adaptive capacity. A framework that combines exposure with sensitivity to give the potential impact, which was compared with adaptive capacity, was applied in order to yield an overall measure of vulnerability.

Chapter 6 addresses the last research question. It provides a detailed analysis of farmers' perceptions of change in climatic attributes and the factors that influence farmers' choice of adaptation measures to climate change and variability. In Ethiopia, climate change and associated risks are expected to have serious consequences for agriculture and food security. This in turn will have seriously impact on the welfare of the people, particularly the rural farmers whose main livelihood depends on rain-fed agriculture. The level of impacts will mainly depend on the awareness and the level of adaptation in response to the changing climate. Thus, the chapter provides insights into the role of the different factors that influence farmers' choice of adaptation strategies. In turn, this will aid the development of appropriate policy measures and the design of successful development programs.

Finally, chapter 7 presents the conclusions, discussions and recommendations for future research and policy and practice.

## **Chapter 2**

### **Coping with Food Insecurity on a Micro Scale**

Chapter is based on:

Gebrehiwot, T., van der Veen, A. (2012). Coping with Food Insecurity on a Micro Scale: Evidence from Ethiopian Rural Households. *Ecology of Food and Nutrition: An International Journal*, Accepted for publication.

## **Abstract**

Reducing poverty and improving household food security is still an important policy instrument for rural development in the Ethiopian highlands. While much has been achieved in reducing rural poverty in recent years, the problem of food insecurity is still high and it is uncertain why food insecurity is still pervasive. At household level, food security refers to the ability of a household to secure year round access to an adequate supply of nutritious and safe food. In consonance, this chapter examines the main household demographics and economic factors associated with food insecurity and coping behaviour of rural households during times of food shortages in northern Ethiopia. Using a Cost-of-Basic-Needs approach we estimated the food poverty line. This cut-off value was used to classify households as either food secure or insecure. Then empirical analyses were used, based on respectively a logit regression model and a coping strategy index, to determine the factors affecting household food security and coping behaviours of rural households. The estimated results revealed that household size, size of farm land owned, livestock ownership, own production per capita, frequency of extension services, and proximity to basic infrastructures influenced the food security status of farming households in the study area. The study further showed that households relied largely on consumption-based coping strategies when faced with food shortages.

## **2.1 Introduction**

Food is the most basic of all human needs for existence, health and productivity. It is thus the foundation for human and economic development. As is now well known, although enough food is produced to meet the needs of all people in the world today, hunger nevertheless remains a widespread problem in developing countries. Consequently, eradication of poverty and ensuring food security is a big challenge for development policy and practice in the new millennium. In 2012, less than five years are left to achieve the first goal of the MDGs of halving the proportion of people suffering from hunger and those living in extreme poverty. However, the number of undernourished people in the world remains unacceptably high close to the one billion mark despite a decline in 2010 for the first time since 1995. According to the recent report of FAO (2010), a total of 925 million people are still estimated to be undernourished in 2010, representing almost 16 per cent of the population of developing countries.

At continent level, food and nutrition security remain Africa's most fundamental challenges. Africa faces the world's gravest hunger problems and these problems are becoming worse. According to the FAO (2010), the number of Africans who are undernourished has been on the rise for decades and stood at about 279 million people lacking economic and physical access to the food required to lead a healthy and productive life in 2010. Even more disturbing, Sub-Saharan Africa (SSA) remains one of the most malnourished regions in the world. The greatest challenge to reduce hunger and undernourishment facing SSA is manifest in the number of undernourished people, which has escalated from 169 million in 1990–1992 to 239 million in 2010. Accordingly, at 30 per cent, the proportion of undernourished people in SSA remains highest in the developing countries (FAO, 2010). In many countries in the Sub-Saharan region, the number of people living below the poverty line is rising, and this trend is directly affecting the ability of the population to obtain sufficient food to live a healthy life.

Ethiopia, like many countries in the SSA, continues to experience high levels of food poverty despite decades of implementing poverty alleviation and prevention programs. Poverty and food insecurity are mutually reinforcing in Ethiopia, where over 30 per cent of the people live below the poverty line. About 80 per cent of the population reside in rural areas and subsist on agriculture, but Diao and Pritt (2006) indicated that 50 per cent of these rural households face a chronic food deficit. Though the poverty situation in the country has shown signs of improvement over time, Ethiopia still has a high level of food insecurity, and food shortages continue to be an on-going problem in the country. Adenew (2004) reported that many Ethiopians live in conditions of chronic hunger with a low average energy supply of 1880

kcal/capita/day and as well as a very high (44%) prevalence of undernourishment.

Like most of the developing countries' economies, especially those in SSA, the Ethiopian economy is agricultural-based. The overwhelming proportions of the Ethiopian population live in rural areas depend upon subsistence farming for survival. The agricultural sector is almost totally dependent on rainfall with only less than 5 per cent of the total arable land being irrigated. This heavy dependency on rain-fed agriculture renders the majority of Ethiopians powerless in the face of erratic and unpredictable rainfall. As a result, the majority of the poor in Ethiopia are severely affected by drought when it occurs. In the past 15 years, Ethiopia has been hit by different disasters, natural and human-induced, about 15 times (FAO, 2010). The recurrence of a drought makes the majority of these households who derive their livelihoods from farming vulnerable to poverty and food insecurity. The situation is worsened by the fact that the majority of these farmers are so poor that they have no assets at their disposal. Some of the few households who do hold assets (such as livestock) end up selling them to supplement their consumption in times of the drought (van der Veen and Tagel, 2011). The occurrence of persistent droughts thus continues to threaten the livelihoods of the rural people, who depend on agriculture for their livelihood. Because most people in the country live below the poverty line, they are perpetually in a state of food insecurity. As a result, the task of searching for food occupies a central place in the daily lives of the majority of people in the country.

Consequently, reducing poverty and ensuring food security have top priority and forms the cornerstone for sustainable economic growth and the poverty reduction strategy in Ethiopia. In light of this the current government has embarked on an aggressive economic reform program since November 2002 to revive the economy and eradicate rural poverty. Accordingly, different programs have been implemented to improve household food security. While much has been achieved in reducing rural poverty and unprecedented economic growth is registered in the country in recent years, the problem of poverty and food insecurity is still high in the rural areas. Roughly 30 per cent of the Ethiopian population live below the national poverty line (MoFED, 2012). Most rural households live on a per capita income of less than USD 0.50 per day (Chanyalew et al., 2010). The poorest sub-sector of rural households is unable to meet their basic needs and is chronically food insecure.

While many things are clear about the characteristics, causation and possible remedies of hunger in general, a thorough understanding of the causes of food insecurity at the household level is seriously lacking. One of the

problems is that local communities adopt different coping strategies in response to the effects of food shortages and entitlements. Nonetheless, this has attracted little scientific attention and to our knowledge no attempts have been made to systematically investigate the bundle of response actions employed by the rural households in response to declining food availability and the factors that influence their coping. A great deal of probing investigation - analytical as well as empirical - is thus needed to support public policy and action to eradicate poverty and eliminate endemic food insecurity. Additional evidence about the causes of food insecurity and the different coping strategies adopted is necessary, particularly at household level as the macro-level surveys may not be appropriate for finding possible solutions. Also, the process of identifying the food insecure as target groups and achieving a better understanding of the socioeconomic factors associated with household food security as policy instruments for development planners is crucial for designing effective food security programs.

The purpose in this chapter is to fill this gap and contribute to the efforts at reducing food insecurity in the study region. Accordingly, the objectives are: (1) to determine the food security indices for the sampled households; (2) to identify the socioeconomic factors associated with household food insecurity in the worst affected part of the northern Ethiopia; and (3) to investigate the coping mechanisms of rural households employed during times of food shortages. A combination of different approaches was employed in this study, which enabled us to measure the household demographics and economic factors associated with household food insecurity and the different coping strategies adopted in a valid way. A Cost-of-Basic-Needs approach was first applied to estimate the food poverty line. Based on this cut-off value, we identified food secure and insecure households. Then a logit regression model and a coping strategy index (CSI) were employed to quantify the main socioeconomic factors associated with household food security and elicit household coping strategies employed during times of food shortages.

### *2.1.1 Defining Food Security*

#### **The concept of food security**

The term food security originated in international development literature in the 1960s and 1970s and the definition of 'food security' has undergone significant transformations since then. Over time a large number of different definitions have been proposed. According to Hoddinott (1999), there are approximately 200 definitions and 450 indicators of food security. The concept has evolved and expanded over time to integrate a wide range of food-related issues and to more completely reflect the complexity of the role of food in human society. At one level early definitions concerned almost exclusively national food security, which is on the ability of a nation or region to assure an adequate food supply in all year to meet their requirement and

food security was conceived as the adequacy of these stocks, e.g. in the Food Availability Decline Theory. Such conceptualization of food security focused merely on food production variables (supply side) and overlooked the multiple forces that in many ways affect food access (demand side variables) (Devereux, 1993; Sen, 1981). It said nothing about people's income and purchasing power and generally overlooks household level food access.

However, in the early 1980s there was a shift in thinking about food security influenced by the concept of 'food entitlement' or the view of food as a basic right. Accordingly, analyses started to include the concept of stability or secured food access as a fundamental component. This evolution of thinking reflects an attitude that society's goals should reach beyond the ability of a country to produce and import enough food. Consequently the issue of household become more and more the centre of the food security concept.

The dimensions of food security on the other hand make it clear that the concept of the food problem is a complex one with many dimensions. Maxwell and Frankenberg (1992) identified many definitions for the concept food security. However, all definitions emphasis development from macro-level to micro-level concern; from adequate level of supply towards concern to meet the demand; and from short term to a concern of long term (permanent). Maxwell and Frankenger (1992) distilled a range of definitions of food security into the phrase 'secure access at all times to enough food'. Further discussions on defining food security have been summarized by Maxwell (1998) as identifying livelihood security as a necessary and often sufficient condition for food security and focuses on the long term viability of the household as a productive and reproductive unit, which favours the quality of the food entitlement.

The conceptualization of food security goals by Koc et al. (1999) however goes beyond the adequacy of food quantity and quality and extends to the four 'A's: availability, accessibility, acceptability, and adequacy. Availability connotes the physical presence (supply) of food in large amounts, accessibility addresses the demand for the food and suggests sufficient purchasing power or ability to acquire quality food at all times. Hence, food security requires that a sufficient supply of food be available and that it should be accessible to all equally. Acceptability addresses food's cultural and symbolic value that the food available and accessible should be affordable and socio-culturally acceptable with respect to individuals' cultural traditions. Adequacy is usually defined in terms of the long-term sustainability of food systems.

Apart from differentiating between macro-micro level conceptualizations, the understanding of food security also includes a time dimension, which

describes the intensity and characteristics of household's food insecurity. Consequently, food insecurity can be either 'chronic' or 'transitory.' In chronic food insecurity, there is continuous food shortage caused by the household's inability to acquire food. It therefore afflicts households that persistently lack the ability to either buy food or produce their own. On the other hand, transitory food insecurity refers to a temporary decline in household's access to food caused by instability in food production, drought or short-term variability in food prices or/and income shortfalls. The level of analysis is particularly important in understanding the use of the term food security. Hence, the term can be used with a focus on food-related issues on a number of levels, from global food security to regional, national, household and individual and a distinction should be made between these levels.

As noted earlier many definitions of food security can be found in the literature. Nevertheless, Household food and livelihood security should be seen as outcomes of processes taking place within the household for which resources and assets are used and managed. In this chapter, food security is defined as the ability of food-deficit countries or households within these countries, to meet target minimum levels of consumption on a yearly basis (Siamwalla and Valdes, 1980). In the Ethiopian context the essential aspect of food security is access to food. In general, poor people have least access to resources, entitlements, employment opportunities and income. In Ethiopia, it is the poorest part of the population that is most chronically food-insecure (Eneyew, 2010). Hence, the focus on food security is justified as it draws attention to the basic needs of the poorest and most vulnerable groups of the population (Maxwell, 1990). Household food security is a key determinant for the nutritional status of the individual household members. Consequently, having detailed insight in the determinants of food security at household level provides an understanding of the difficulties and specific necessities each household faces in regard to food security.

### *2.1.2 Food insecurity and its underlying causes*

The root cause of food insecurity in developing countries is the inability of people to gain access to food due to poverty. Various schools of thoughts have attributed food security problems in the region to different things, including unstable social and political environments that preclude sustainable economic growth, poor governance, frequent drought and famine, and agricultural dependency on the climate and environment.

Climate variability and extreme weather events such as droughts, excessive rains, and floods are among the main risks affecting agricultural productivity and hence rural household food security in Sub-Saharan Africa. While the impacts of natural hazards or stresses such as droughts may trigger a crisis, long term economic factors such as market failures, political instability,

institutional weakness, and conflicts also play a large role (Devereux and Maxwell, 2001).

The debate in Ethiopia about the causes of inconsistent food security between regions and communities has fuelled highly contested viewpoints between the academic disciplines and in development thinking over the past few decades, giving rise to a proliferation of demographic, economic, and political emphases across the food security literature (Devereux, 2000; Maxwell, 2001). The recent 2002–2003 food crisis has been evaluated to be the result of a suite of political, social and economic factors rather than only the result of environmental stressors leading to production shortfalls. The causes were complex: the country is prone to drought. Drought and environmental degradation are important natural factors that make households vulnerable to food shortage. The major challenge to food security in Ethiopia is its underdeveloped agricultural sector, which is characterized by over-reliance on subsistence agriculture. The agricultural sector is nearly totally dependent on rainfall and any weather fluctuation or rainfall failure is directly linked to agricultural failure, loss of major livelihood source that always accentuate food deficit. von Braun (1991) for example reported that a 10 per cent decline in rainfall below its long average results in a 4.4 per cent reduction in national food production.

Frequent droughts are not the only factors contributing to Ethiopia's food security problems. Like many African countries the country confronts several environmental issues that are particularly problematic for the agricultural sector. Poverty and food insecurity in the dry lands of Ethiopia are further caused by land degradation amplifying the negative impacts of droughts (Aune et al., 2001; Tewelde Berhan, 2006). Low agricultural productivity, poverty, food insecurity and land degradation are pervasive and interconnected problems in the Ethiopian highlands (Holden and Shiferaw, 2004; Pender and Gebremedhin, 2008). These factors often interact with one another resulting in a reinforcing cycle of the 'poverty, food insecurity and natural resources degradation trap'. The problem is further compounded by high population pressure, contributing to a decline in the size of per capita land holding.

In addition to natural and socio-economic factors, it is also strongly believed that government policy failures or inappropriate development strategies regarding food and agriculture, and governance are at the root of food security problems and underdevelopment in many African countries (Bird et al., 2003; Paarlberg, 2002). Ethiopia suffered from misdirected economic policies under the socialist Derge regime ruling between 1974 and 1991. With respect to the cause of the 1977-1988 Ethiopian famine, Downing (1995) notes the correlation between famine areas and specific government policies.

Gebremedhin (2000) similarly reported that in the 1970s and 1980s, the failures of agricultural policies in Somalia, Ethiopia, and the United Republic of Tanzania quickly became apparent in declining output and productivity, and a growing inability of these countries to feed their own people. The policy framework of the past Governments and decade's long civil war in the region has played a role in exacerbating food insecurity. To summarize, food security is a deep rooted problem in Ethiopia in general and in Tigray in particular. All these factors contribute to either insufficient national food availability or insufficient access to food for households and individuals, resulting in a vicious cycle of the poverty and food insecurity trap. These and other factors are supposed to be responsible for the country's struggle to ensure food security at household level. Thus, food security is a multifaceted issue and its attainment demands integrated policies and technologies that can contribute to increased production and improved food security.

In the following we will discuss the general theoretical frameworks used for this study. To identify the socioeconomic factors associated with household's food insecurity and consumption based coping strategies, we carried out multiple stages of analysis. First we will define the approaches used to construct the poverty line, below which people are classified as food insecure. Second, we will present the logit model used to determine the socioeconomic factors associated with household food insecurity. Finally, the methodological approach used for determining household's consumption based coping mechanisms will be discussed.

## **2.2 Methodology**

### *2.2.1 Construction of the food poverty line: Cost of Basic Needs Approach*

The analysis of poverty in a country is ultimately an attempt to compare living standards across households or individuals. It starts by choosing a welfare measure, which is frequently household income or expenditure. This is then adjusted for the size and/or composition of the household, to next set the poverty line at a level of welfare corresponding to some accepted minimum standard of living. Despite much literature existing on approaches to assess poverty, the question still remains as to where to draw the poverty line.

Economic theories suggest that per capita expenditure (or consumption or income) required to attain some minimum level of welfare is the best indicator of welfare, and the line is meant to reflect the cost of obtaining a given reference level of standard of living that defines the threshold to poverty. Although alternative approaches to define the poverty line are

possible, such as the Food Energy Intake, the Cost of Basic Needs approach, and the dollar-a-day criterion used for international comparison by the World Bank and others, we used the cost-of-basic-needs approach to estimate a poverty line. The most common methods for measuring poverty have used the nutritional norm and defined the poverty line in terms of minimum calorie requirements (Ahmed et al., 1991; Greer and Thorbecke, 1986; Osmani, 1982; Ravallion and Bidani, 1994). For developing countries like Ethiopia, the most significant component of basic needs poverty line is usually food expenditure necessary to attain some recommended food energy intake. This is then improved by a modest allowance for non-food goods so that both food and non-food items are accounted for in the costing exercise in order to estimate poverty levels (Ravallion, 1994). According to such criteria of poverty line, the poor are those who are unable to earn that income which is enough to cover their basic needs, i.e., cannot meet the minimum nutritional requirements which are defined as a basic food basket (Sen, 1976). Thus, in this study, we use the Cost-of-Basic-Needs approach to estimate a food poverty line.

The first step to defining the food poverty line was to identify the foodstuffs typically consumed by the rural community. Next we identified the foodstuffs commonly consumed by the reference household. In our study, 21 food items were chosen and their quantity determined to satisfy a predetermined level of minimum calorie requirement. However, estimates of such daily per capita requirements vary widely. For instance, for Indonesia the level is set at 2,100 kcal (Ravallion and Bidani, 1994), for Kenya 2,250 kcal (Greer and Thorbecke, 1986), while 2,350 kcal is recommended by the World Bank (Schubert, 1994). According to the Ethiopian Food Security Strategy Paper, food security, in Ethiopian context, is defined as an entitlement or access to balanced food basket of 225 kg of cereals per person per annum, or 2,200 kcal per day or cash equivalent of that (FDRE 2001, MoFED 2002). 2,200 Kcal is thus the minimum acceptable weighted average nutritional requirement for a person to lead a "normal" physical life under Ethiopian conditions as estimated by the Ethiopian Nutrition and Health Research Institute (EHNRI) and designated by the Ethiopian government. Accordingly, the food poverty line was set at 2,200 kcal per person per day for this study.

Having selected the foodstuffs and the minimum daily requirements, the resulting food bundle is then transferred into monetary value in order to identify the poverty line. The same pile of food items was valued according to the corresponding average price in January 2011 at each study site to determine the cost of consuming the reference pile of food items associated

with the poverty line. Furthermore, the non-food<sup>1</sup> share was estimated using the approach described by Ravallion and Bidani (1994), i.e. by examining the consumption behaviour of the reference household<sup>2</sup> who can just afford the reference pile of foodstuffs. The value of the non-food share for household  $i$  was thus estimated by:

$$s_i = \alpha + \beta \log\left(\frac{y_i}{z^f}\right) + \varepsilon_i \quad (2.1)$$

where  $s_i$  is the share of total expenditure,  $y_i$ , devoted to food;  $z^f$  is the cost of the basic food needs;  $\alpha$  and  $\beta$  are parameters to be estimated; and  $\varepsilon$  is the error term. The value of  $\alpha$  indicates estimates the average food share of those households that can just afford basic food needs, that is, those for whom  $y_i = z^f$ .

Finally after determining the value of the selected food items, this value was used as cut-off value for grouping households into food secure and food insecure.

### 2.2.2 Model Specification

Once we categorized the sample households, we selected a model to examine the socioeconomic factors associated with household's food security in the study sites. A range of statistical models can be used to establish this relationship. In this study, a binary logit model has been used to determine the key explanatory factors that influence household food insecurity. The logistic model is based on the logistic function  $f(z)$ , and is given as:

$$f(z) = 1/(1 + e^{-x}) \quad (2.2)$$

Where  $x$  varies from  $-\infty$  to  $+\infty$ . The range of  $f(z)$  is between 0 and 1, regardless of the values of  $x$ . Because of this peculiarity of the logistic function, the logit model can be used to find out the probability that will determine a household to be food insecure.

The logistic model can be developed from the logistic function by representing  $z$  as a linear sum of some constant and the products of independent variables and their corresponding coefficients, i.e.

$$z = \alpha + \sum \beta_i X_i, \text{ where } \alpha \text{ and } \beta_i \text{ are constants representing unknown}$$

<sup>1</sup> Non-food commodities consumed by households included goods and services periodically procured for household consumption but excluded durable capital assets. They constituted those goods and services on which households incurred recurrent expenditure.

<sup>2</sup> Poverty in Ethiopia and in northern Ethiopia, Tigray region, in particular is believed to be above 30%. Accordingly, we identified the poorest 30% as a reference household deemed to be typical of the poor.

parameters. In other words,  $z$  is an index that combines the independent variables ( $X_i$ ). Therefore

$$f(z) = 1/(1 + e^{-(\alpha + \sum \beta_i X_i)}) \quad (2.3)$$

Given that the dependent variable that a household may be classified as food insecure is dichotomous means it can take two values, a value of 1 if a household is classified as food insecure and 0 otherwise. In this case, the probability of being food insecure ( $Y$ ), given the presence of the independent variables can be represented as the conditional probability:

$$P(Y = 1 | X_1 - X_n) = 1/(1 + e^{-(\alpha + \sum \beta_i X_i)}) \quad (2.4)$$

where  $P$  is the conditional probability that household  $i$  is food insecure,  $\alpha =$  constant term,  $\beta_i =$  coefficient for  $i^{th}$  independent variable  $X$ , with  $i$  varies from 1 to  $n$ . The significance of the coefficients  $\beta_i$  is tested with the Wald test that is obtained by comparing the maximum likelihood estimate of every  $\beta_i$  with its estimated standard error (Hosmer and Lemeshew, 1989; van Den Eeckhaut et al., 2006). By inspecting the sign of a dependent variable's coefficient estimate, the influence of that variable on the probability of a household being food insecure can be determined.

The parameter estimates of the logit model provide only the direction of the effect of the independent variables on the dependent one. But these estimates represent neither the actual magnitude of change nor the probabilities. Differentiating equation (2.4) with respect to the covariates provides the marginal effects of the explanatory variables, which is given as:

$$\frac{\partial P_j}{\partial x_k} = P_j (\beta_{jk} - \sum_{j=1}^{J-1} P_j \beta_{jk}) \quad (2.5)$$

Green (2000) described marginal effects as functions of the probability itself and measure the expected change in probability with respect to a unit change in an independent variable from the mean.

The second part of the chapter covers coping strategies. We use the term coping strategies here to refer to the bundle of poor people's response actions to the effects of food shortages and entitlements in abnormal seasons or years (Davies, 1993). People adopt different coping strategies in response to different shocks. The range of coping strategies employed by people is numerous, and they differ according to prevailing conditions. The Coping Strategy Index (CSI) and Household Food Insecurity Access Scale (HFIAS) approaches can be applied to examine how households manage to cope with food shortages. Both approaches are relatively simple, quick to use, and use almost similar generic questions (Maxwell et al., 2003; Swindale and Bilinsky, 2006). Though there is no binding reason to prefer either approaches, we

applied the CSI to investigate households' coping strategies employed during times of food shortages, and their perceived severity. The CSI measures behaviour: the things that people do when they cannot access enough food. According to Maxwell et al. (2003), the CSI was originally developed as a rapid alternative to a 24-hour consumption recall.

According to Maxwell (1996a), the CSI is a relatively quick and simple indicator of household food security behaviour based on a single question: 'What do you do when you do not have enough food, and do not have enough money to buy food?' The answers to this simple question are a series of behaviours about how households cope with a shortfall in food consumption and comprise the basis for the CSI tool. These are formulated into a numeric frequency scores reflecting the frequency and perceived severity of these coping behaviours. Accordingly, a higher score reflects greater coping and hence the higher the level of food insecurity. The method for assigning numeric values to relative frequency was adapted from Maxwell et al. (2003). Before the baseline survey, focus group discussions were held in six *tabias* to establish a relevant set of consumption coping strategies as well as the perceived severity weightings of the different strategies. The CSI score for each household is then determined as follows.

A list of 11 coping strategies was included in the survey questionnaire with four relative frequency categories ranging between 'every day per week' to 'never'. Based on focus group discussion, we collected contextual information on the relevance of coping strategies and determined the relative severity of each coping strategy by assigning a severity score of 1 to 4 to each strategy. The different strategies are thus 'weighted' differently depending on how severe they are as considered by the people who rely on them. Following Maxwell et al. (2003), the frequency answer recorded during the household surveys is then multiplied by the weight factors that reflect the severity of individual behaviours based on ordinal ranking assigned by focus groups, as depicted in Appendix table 2.1. Finally, a discrete score for each strategy is obtained, which, added together, made up a cumulative food security score or index for a household. In order to rank the severity level, the individual coping behaviours were grouped according to similar levels of severity and a weight is assigned to each group, from lowest (least severe) to highest (most severe). A range of weights from one to four is commonly used. Furthermore, multivariate analysis was run to examine the predictive relationship between multiple household characteristics and the CSI measure of food insecurity using the CSI as dependent variable.

Figure 2.1: Assigning numeric values to relative frequency, Adapted from Maxwell et al. (2003)

<i>The relative frequency categories</i>				
All the time? Every day	Pretty often? 3-6 times/week	Once in a while? 1-2 times/week	Hardly at all? <1 times/week	Never 0 /week
7	4.5	1.5	0.5	0

Note: The relative frequency categories scored are according to the mid-point value of the range of each category.

### 2.2.3 Data

The data for this study are derived from a household survey conducted in the rural *woredas* of Hintalo Wajirat, Enderta, and Kilte Awelaelo from January to February 2011. Multi-stage sampling techniques were employed to draw the samples. The first stage was to select nine *tabias* randomly from these sample districts. In the second stage, random sampling techniques were employed to draw a total sample size of 400 farm households. For each study site the a sample size proportional to the entire population of the respective *tabia* was determined, and hence the samples were self-weighting (Dercon and Hoddinott, 2004). Accordingly, 160 households were drawn from Hintalo Wajirat, 130 from Enderta, and 110 from Kilte Awelaelo *woreda*. A numbered list of all households, acquired from the *tabia* administration, was used as a sampling frame to select households in each *tabia*.

To generate the required data a structured questionnaire was administered with the household being the unit of analysis. For the purpose of this study, a farm household has been defined as a group of people in a housing unit living together as a family and sharing the same kitchen. The survey captured information related to demographic characteristics, asset endowment, household food consumption, economic activities, wealth and income, household expenditure on food and non-food items, access to basic infrastructures and agricultural services, and household coping strategies. Data on the frequency of reliance on coping strategies were collected during a household survey using the standard questionnaire developed by Maxwell et al. (2003). Enumerators with knowledge of the local language and experience with socio-economic surveying were recruited locally and trained to work with the questionnaire. The questionnaire was tested prior to the actual fieldwork commencing.

#### **Model variables**

Based on review of literature and local knowledge, we identified the potential determinants of household food insecurity. Household head, age of the household head, family size, children under five years of age, educational level of household head, farmland size, livestock ownership, fertilizer usage, access to irrigation, per capita production, credit access, social capital, food-

for-work income, and proximity to an all-weather road and local markets were all analysed whether they influenced a household's level of food security or not. All the factors were a priori hypothesized to have a positive impact on the food security status of households.

Family size - refers to the number of family members living in a household. The size of a household definitely has an effect on food security though whether the effect is positive or negative cannot be identified beforehand. In many empirical works, the effect of household size on food security has been mixed. Some studies see household size as being negatively associated with food security since larger households need more resources to fulfil their food needs, whereas other studies see a positive association as larger households have a larger labour force and subsistence farmers almost entirely rely on family labour for field activities. In this study, family size is hypothesized to have a positive influence on food security.

Age - refers to the age of the head of the household in years. The head's age might affect food security of the household he/she manages through asset accumulation, technology adoption, diversifying his/her production activity, or risk aversion, but this cannot be determined ahead. Since household heads become more experienced with age and acquire more knowledge and physical assets it may affect food security in a positive way. Hofferth (2004) describe that the higher the age of the household head, the more stable the economy of the farm household. This is because older people have relatively more experience with their social and physical environment as well as with farming activities. Yet age could also be negatively correlated with food security as with the head ageing he/she might be less efficient in carrying out demanding farm operations resulting in lower farm production and productivity.

Male headship – refers to the sex of the household head, a dummy variable: 1 if the head is male or 0 for a female. Traditionally, male household heads are believed to have more access to information on improved technologies through extension agents, public gatherings, as well as more access to credits, etc. Therefore, male headship is hypothesized to influence household food insecurity negatively. Female-headed households are also expected to have lower food security status than their male-headed counterparts because male-headed households are assumed to be in a better position to arrange more labour force than their female-headed counterparts. Marital status is also a dummy variable: 1 means the household head is married and 0 means otherwise.

Education refers to the educational level of the head of the household. Mukudi (2003) claims education has a key role in accessing public

information especially concerning health, nutrition, and hygiene. Sen (1999) also reported that educated and informed people are more likely to select valuable objectives in life, such as having stable access to food for their household. Education is thus assumed to increase the farmer's knowledge, improving the use of information relevant to farm productivity. Educational status reflects the household's human capital and is thus assumed to play a role in determining the households' food security. It is a dummy variable: if the household head can read and write a 1; otherwise a 0.

Farmland size refers to a household's land holding. Najafi (2003) reported that food production can be increased extensively by expansion of the areas under cultivation. Consequently, in subsistence agriculture, land holding size is expected to play a significant role in influencing a farm household's food security. Farmland size is a continuous variable and is measured in *tsimad*<sup>3</sup>. We presumed farmland size to affect the food security status of households positively.

Livestock – a household's ownership of animals excluding plough oxen. Ownership of livestock is one of the basic assets in the Ethiopian rural economy. In the study areas, livestock serves as buffer in hard times. Households with the opportunity to save usually convert their money savings into livestock. They buy and sell livestock, particularly small ruminants to buy food grains, filling the gap in food requirements towards the end of the agricultural year when they encounter food shortages. Farmers with large numbers of livestock<sup>4</sup> will have a better source of income, higher consumption, as well as pack and draught power. As a result, livestock ownership is hypothesized to influence food security positively.

Oxen refer to the number of oxen farmers owned in the last cropping season. Like other developing nations small scale farmers rely on oxen as a main source of draught power, thereby significantly affecting households' crop production. Oxen are also usually seen as an indicator of relative wealth in the Ethiopian rural areas, including the study areas. The number of oxen owned by farmers is thus expected to influence a farmer's food security positively. The weighting index is set at 1.10.

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<sup>3</sup> *Tsimad* is an area of land that can be ploughed by a pair of oxen in a day approximately equal to a quarter of a hectare.

<sup>4</sup> The total number of livestock ownership is measured by Tropical Livestock Unit (TLU). TLU is an index number that aggregates the different types of livestock a household owned to a single number. It is calculated using the following weighing index factors from ILRI (1990): cow = 0.8, sheep and goats = 0.09, donkey = 0.36, horse & mule = 0.8

Fertilizer use is a dummy variable with a value of 1 if the household used fertilizer during the last cropping season and 0 otherwise. Food security is expected to be positively associated with modern technology use, such as fertilizer, as its application might augment both food and income. The use of chemical fertilizer during the sowing season is hence hypothesized to increase farmers' agricultural productivity, in turn increases food security.

Extension service refers to visits by agricultural extension service agent to household in the last cropping season. Access to an agricultural extension service is regarded as a major source of information concerning agricultural activities for the households in the study areas. Therefore, it is believed that the frequency of visits by agricultural development agents will increase the farmers' knowledge about new technology and thus the chance to improve food production, thereby reducing a household's chance of being food insecure. Frequency of visits by agricultural development agent to household farms is a continuous variable.

Per capita production – refers to the total quantity of food produced by the household from his/her own farm, divided by the household size. Higher agricultural production is expected to improve food security by decreasing food prices for consumers, increasing rural incomes and thereby contributing to economic development. Studies show that a 1 per cent rise in per capita agricultural output led to a 1.6 per cent rise in incomes of the poorest 20 per cent of people (Gallup et al., 1998). Thus it is assumed that per capita production positively influences household food security.

Irrigation – access to irrigation is a good strategy for promoting crop production in the region. Thus, it is hypothesized that household's access to irrigation positively influences household's food security. It is a dummy variable: a household with access to irrigation (any water harvesting scheme) was given a value of 1, and a 0 if not.

Credit – refers to accessibility of micro credit for the household. It is a dummy variable: 1 = yes, credit available, 0 = no, not available. Access to credit is anticipated to have a positive influence as it enables farmers to ease short term liquidity constraints, in turn influencing food production. Credit can also be used as a consumption smoothing mechanism in the event of food shortage in the household (Zeller and Sharma, 2000). It is therefore hypothesized that farmers with credit accessibility will have less chance of being food insecure.

Income determines a household's ability to secure food and remains an important variable, explaining the characteristics of food secure and insecure households. Income generated in the form of one's own production, or

income earned from other activities such as employment as daily wage labourers could enhance the capacity of a household's access to food. Therefore, a household's participation in Food-for-work (FFW) is expected to influence food security positively in this study. Data on income from FFW is distilled from the number of day's labour reported as part of the FFW program for all participating households. Since the FFW income is linearly proportional to the number of worked days, this number can serve as a proxy for the FFW income.

Social capital refers to resources (networks, social relations, associations) people can draw from (Scoones, 1998). We have included social capital because a growing number of articles (Grootaert and Narayan, 2001; Maluccio et al., 2000; Uchimura, 2005) confirms that it affects household food security through consumption. In our study we used membership of farmer's associations, *tabia* councils and other community operated associations as a proxy for social capital as members are considered to have better access to information on improved technologies. This is a dummy variable with a value of 1 when a household is a member and 0 otherwise.

Distance to market refers to the distance from a farmer's residence to the nearest market (walking distance in minutes). It is assumed that farmers who are closer to input and output market centres are expected to have easier access to fertilizer and/or exchange seeds. Similarly, distance to all-weather roads - is among the crucial factors that shape a household's activity choice. Access to roads opens new markets and opportunities for households to engage in off-farm activities, hence increasing the rural people's access to alternative sources of employment opportunities. Both variables are hypothesized to influence a household's food security positively.

## **2.3 Results and discussion**

Using the cost of basic needs approach, the food poverty line corresponding to the selected food items was found to be 2,532 Ethiopian Birr (ETB). Hence, those households falling below the minimum requirement of ETB 2,532, minimum food expenditure necessary to attain the recommended food energy intake, were deemed to be food insecure, while those above ETB 2,532 were classified as food secured households. Accordingly, the cut-off value for the food insecure household was used for the logit analysis in our study.

### **2.3.1 Descriptive: Productive resources**

Households in the studied *tabias* engaged in farm and/or non-farm activities. The rural nature of the study area made mixed farming (crops and livestock rearing) the most important livelihood sources. The farm sector comprises

crop cultivation, animal rearing and growing vegetable in gardens and irrigation plots. Only an average of 1.3 per cent of households relied on non-agricultural activities during the wet season. Unskilled wage labour and petty trading were the main non-farm income-earning activities in the study area.

Accordingly, farming and farm resources played significant role in the local economy, with important implications for the food security. Therefore, size of farmland, labour and livestock had important implications for households' food security, especially during normal agricultural years. During drought years, livestock formed a major asset that could easily be liquidated and was important in terms of implying better access to food.

Table 2.1: Average Ownership of Productive Resources in the Study Area

Variable	Obs	Min	Max	Mean	Std. Dev.
Farm size	400	0.25	2.00	0.96	0.43
Per capita land	400	0.03	1.50	0.20	0.14
Household size	400	1.00	11.00	5.29	1.76
Livestock owned (TLU)	400	0.00	7.96	2.80	1.71
Oxen ownership (No.)	400	0.00	4.00	1.52	1.07

**Note:** farm size is measured in 'tsimad'. One *tsimad* approximately equals a quarter of a hectare

Of the sampled households, 70.2 per cent owned one hectare or less, while the average farm size was 0.96 hectare (Table 2.1). On a per capita basis, the average farm size was as low as 0.20 ha. About 42 per cent of the farmers reported that they had no ox, with average ox ownership being only 1.32. The shortage of these productive resources was not only the problem, the technologies used to convert these inputs into farm outputs also contributed. In general, too little farm resources were available in the study area to provide adequate food and income for the average household. Based on this single indicator, data collected for this study indicated that about 61.2 per cent of the sampled households in the food insecure category had farms of less than 0.75 hectare, while 30 per cent of the households in the food secure category had farm of more than 1 hectare (Table 2.2).

Table 2.2: Size of Land Holding by Food Security Group

Size of land	Food insecure households	Food secured households	Total households
<=0.25 hectare	28	2	30
0.26-0.50 hectare	64	12	76
0.51-0.75 hectare	44	24	68
0.76-1.00 hectare	75	32	107
above 1 hectare	11	108	119
Total	222	178	400

### 2.3.2 Empirical results

The ability of households to ensure food security over time is a result of a complex nexus of factors such as household characteristics, household wealth, macro level economic processes and social networks. These are analysed below. In finding out the socioeconomic factors associated with household's food insecurity, we employed the logit model (Table 2.3). Thus, the model uses food security status of households as the dichotomous dependent variable: a household falling below the minimum requirement of ETB 2,532, minimum food expenditure necessary to attain the recommended food energy intake, was given a value of 1 and 0 otherwise.

The findings of our analysis revealed a positive association between household size and food insecurity, meaning that the more members a household has, the higher the odds of being food insecure. An increase in household's size by one member increases household's food insecurity by 8.6 per cent. This positive relationship between a household's food insecurity and the size of the household is a common finding in many empirical studies such as (Datt and Jolliffe, 2005; Lanjouw and Ravallion, 1995). This could be the result of most large households having many members of non-productive age, thereby increasing the dependency ratio in the household, as our findings revealed a strong positive relation between the numbers of children under 5 years of age and household food insecurity. Similar findings were reported by Haile et al. (2005) and Babatunde et al. (2007) in the Koredegaga peasant association in Ethiopia and in northern Central Nigeria, respectively. Hadley et al. (2011) also reported that higher dependency ratios, in the absence of significant differences in income between households, tend to aggravate food insecurity. However this finding is in contrasts with findings by Abdulai and CroleRees (2001), indicating that household size in rural farming areas was important, contributing more labour and thereby increasing the possibility of diversification into a complex portfolio of income earning activities.

Age and type of household head were found to be statistically insignificant when trying to explain variations in the probability of a household being food

insecure. Although the variable for gender of the household head came out negative, implying that male headed households were less food insecure than female headed households, statistically this was not significant at the 5 per cent level of significance. The coefficient for the household heads' education level (i.e., basically referring to the ability to read and write) was found to be insignificant at the 5 per cent level. Although difficult to interpret from a theoretical point of view, this is caused by the negative correlation between literacy level and ownership of productive resources, the latter carrying more weight when explaining existing variation in a household's food insecurity. Furthermore, since the education variable only captured formal education, it obscured the importance of skills, which are of a paramount importance to a households' access to food.

Land and livestock ownership are two of the basic assets in the Ethiopian rural economy. Accordingly, the coefficient for farmland size was positive and significant, indicating that the smaller a household's farmland, the higher the odds of being food insecure. An increase in cultivated land by one *tsimad* increases household food security by 9.6 per cent. Another important asset with a significant and positive effect was the number of oxen owned. Oxen form the main source of agricultural power. We found that an increase in the number of oxen owned by one increases a household's food security by 8.7 per cent. Similarly, the number of cows, sheep and goats owned were found to be significant. This indicates that the higher the number and diversity of livestock owned the lower the odds of being food insecure. In the study areas, livestock played a buffer role in times of drought and towards the end of every crop year when most households faced food shortage problems.

The logit regression result revealed that access to inputs such as fertilizer had no effect on the probability of a household being food insecure. The coefficient was statistically insignificant. While this is contrary to what was expected, it indicates that variation in the amount of fertilizer used during the survey year was too little to cause differences in food security among different households. On the other hand, per capita aggregate production had a significant and positive influence on household food security, indicating that the smaller the per capita crop production of a household, the higher the odds of a household being food insecure. A unit change in per capita aggregate production resulted in 11.8 per cent increase in the probability of food security, indicating own production as the main source of food entitlement for a household and positively influences household food security. Moreover, the result reveals that frequency of extension services and household food insecurity were inversely related, implying that less frequent visit by an agricultural service agent, meant higher odds of being food insecure. The use of irrigation in the study area was limited. All else being

equal, a household's food security status increased about 10.3 per cent if the household had access to irrigation.

Food security depends on income either income from one's own production of food or income earned from activities that allow access to food from the market. The finding shows that there is an inverse relationship between income earned from FFW and food insecurity, indicating that the lower the income a household earned from FFW, the higher the odds of being food insecure. These findings are similar to Nyariki et al. (2002) who found that involvement in off-farm activities positively and significantly affected food security in Kenya. The regression result further indicates that access to credit decreased the chance of a household to be food insecure. Providing the poor access to credit would encourage them to expand their production and would thus contribute to realizing sufficient food production and food security for individual household.

The result of the logit regression further indicates that distance to all-weather roads and local markets positively influenced a household's food security. The greater the distance to an all-weather road and/or local markets, the higher the odds of being food insecure. Hence, the result confirms the vital role of infrastructure for household food security to ensure low food prices and efficient markets that can respond to changes in demand. Infrastructure reduces the cost of transporting produce and inputs (such as fertiliser), and of food storage; and markets provide an important platform for farmers to gather and share information. Better rural infrastructure also promotes economic diversification by linking rural and urban sectors of the economy or the farm and non-farm economic activities.

Table 2.3: Logit Estimates: Determinants of the odds of being food insecure and marginal effects from the logit model

Explanatory variables	Coefficients		Marginal effects	
Male Headship	-2.582	(0.158)	-0.164	(0.127)
Marital Status	-2.359	(0.181)	-0.133	(0.466)
Age of household head	0.045	(0.397)	0.003	(0.228)
HH head can read & write	1.191	(0.428)	0.038	(0.111)
Household size	6.039***	(0.001)	0.086**	(0.031)
Number of children under 5 years of age	3.102**	(0.017)	0.035***	(0.107)
Farmland size	-2.256*	(0.001)	-0.096**	(0.019)
Number of oxen owned	-2.441**	(0.046)	-0.087***	(0.002)
Number of cows owned	-1.397*	(0.037)	-0.028**	(0.001)
Number of sheep & goats owned	-0.440*	(0.026)	-0.012	(0.035)**
Number of pack animals owned	-0.811	(0.494)	-0.074	(0.251)
Per capita cereal production	-3.530***	(0.001)	-0.118***	(0.081)
Fertilizer use	0.724	(0.599)	(0.043)	(0.328)

Frequency of extension services	-1.395*	(0.020)	-0.047**	(0.025)
Credit access	-4.908**	(0.014)	-0.086***	(0.004)
Food-for-work income	-0.003***	(0.005)	-0.012	(0.002)***
Distance to all-weather road	0.226**	(0.027)	0.034**	(0.026)
Distance to market	0.181*	(0.004)	0.055**	(0.047)
Access to irrigation	-1.325*	(0.029)	-0.103**	(0.012)
Social networks	1.058	(0.603)	0.041	(0.525)
Constant	-10.04*	(0.04)		

Note: Dependent variable equals 1 if household is classified as food insecure and 0 otherwise. p-values are in parenthesis; \*, \*\*, and \*\*\* significant at probability levels of 10%, 5%, and 1% respectively.

### 2.3.3 Household coping strategies

The farmers' perception of their own conditions gives more insight into the realities of crop production in an environment subject to recurrent cycles of drought. Data collected for this study on the farmers' perception of factors influencing food shortages reveals that the major constraints experienced by most of the households originated from the crop production environment. Nearly 86 per cent of the sample households in the study area cited harvest failure caused by drought as the major cause of food shortage and lack of agricultural development. Other factors of concern included land degradation, lack of adequate farming implements and shortage of draft power. For generations, farmers have developed coping strategies as a buffer against the uncertainties induced by the yearly variation in rainfall coupled with the socioeconomic drivers impacting on their lives.

We first attempted to regroup individual coping behaviours according to the severity levels of the different coping strategies as locally perceived during the focus group discussions (Appendix Table 2.1). Investigations required identifying the proportion of farm households experiencing various severity levels. Accordingly, skipping meals for entire days, consuming seed stock, as well as sending household members to eat elsewhere were identified as most severe coping strategies by people in the study area.

Reviewing the coping strategy index indeed reveals different types of coping behaviours for different stress levels employed by households in times of food shortages. As Table 2.4 elucidates, the five most frequently mentioned individual coping strategies, in order of descending frequency, are: restrict consumption by adults, reduce the number of meals eaten per day, consume seed stocks meant for the next season, rely on less preferred but less expensive foods, and limit portion sizes at mealtimes. Note that these types of coping behaviours form part of three of the four main categories of coping behaviour, namely: dietary change, short term unsustainable measures to

increase household food availability and rationing strategies. The results of individual coping behaviour reveals that the majority of the sampled households had employed coping strategies as short-term measures during times of food shortages, which can be seen as reversible strategies that do not jeopardize household assets.

Table 2.4: Frequency of Coping Strategies by Households, n=400

Coping options	Times per week				Average severity index
	Every day	3-6 times/week	1-2 times/week	Never	
Rely on less preferred and less expensive foods	16	142	230	12	6.2
Borrow food, or rely on help from friends or relatives	4	8	87	301	1.7
Purchase food on credit	0	15	8	377	0.5
Reduce the number of meals eaten in a day (from 3 meals to 2 meals)	24	138	178	60	7.8
Limit portion sizes at mealtimes	12	111	217	60	4.5
Restrict consumption by adults so children can eat	4	47	245	104	8.9
Skip eating for entire days	0	12	71	317	1.8
Sell farm implements to purchase food	0	8	35	357	1.5
Consume seed stock held for next season	24	138	178	60	6.9
Send children to eat with neighbors	4	16	51	329	1.4

A multivariate analysis was also run to examine the relationship between individual coping strategy index scores and household demographic characteristics, economic variables and the two main asset variables in the Ethiopian rural economy: livestock and land (Table 2.5). The result shown in Table 2.5 demonstrates that the CSI scores were positively associated with household size and dependency ratio. This result reveals that the larger the household and the dependency ratio the higher the CSI scores, which in turn implies a more severe food insecurity situation. This indicates that household demographics may play a major role in the household's ability to cope with food shortages. The findings further reveal that there was no significant association between CSI scores and gender of the head of the household, implying that there were no significant differences in coping capacity status between male-headed and female-headed households.

Moreover, a negative association was found between CSI and a household's asset ownership, principally farmland holding size and livestock ownership, which stand to reason—more assets would imply both a higher level of wealth, as well as a greater capacity to cope with food shortages. Livestock serves as critical input in farm operations as it enhances production and thus is an important source of capital generating considerable income as well. Households in the area normally put any savings into livestock, which could then be liquidated whenever the household faced a food shortage. Similarly, a negative association (at varying levels of significance) was observed between household crop production, FFW income, participation in off-farm activity and proximity to market. This implies that these variables had an increasing effect on the level of a household's coping capacity, thereby decreasing food insecurity. Also intuitively, proximity to good markets would have a positive effect on a household's coping capacity, clearly giving those households an advantage regarding access to food.

Our result further confirms the importance of land, livestock ownership and household food production in rural Ethiopia. Lack of livestock ownership, smaller size land holdings and low household production all decreased a household's coping capacity when faced with food shortages, in turn leading to a decrease in household food security. Furthermore, better access to alternative economic activities and increased income-earning opportunities was found to strengthen household coping capacity. Interestingly, the findings from the CSI analysis matched our findings from the logit regression model. Thus, the study has measured the household demographics and economic factors associated with household food insecurity and the different consumption based coping strategies adopted particularly at household level in a valid way.

Table 2.5: Regression Analysis of CSI, n=400

Variable	Coefficients
Male headship	2.820 (1.72)
Age of household head	-13.123 (6.75)*
HH head can read & write	-0.087 (1.44)
Household size	3.052 (0.37)***
Dependency ratio	2.269 (0.78)**
Farmland size	-2.346 (1.91)*
Livestock ownership	-3.057 (0.46)***
HH cereal production	-9.225 (2.551)***
Proximity to market	-10.572 (4.50)**
Participation in off-farm activity	-3.773 (1.58)**
FFW income	-4.186 (0.44)***
Constant	109.80 (13.36)***
R-squared	0.62

Note: Standard errors of the coefficients are in parenthesis. \*, \*\*, and \*\*\* significant at probability levels of 10%, 5%, and 1% respectively.

## 2.4 Conclusions

The study indicated that household size, size of farm land owned, livestock ownership, per crop production, frequency of extension services, and proximity to basic infrastructures influence the food security status of farming households in the study area. Increasing household's crop production increases the odds of the household's food security, indicating that increasing agricultural production in a sustainable way is necessary to improve household food security as it is the first and main source of food entitlement for most of the Ethiopian farming community in terms of direct consumption of food. In addition, land and livestock ownership are two of the basic assets in the Ethiopian rural economy. Accordingly, the result showed that an increase in household's cultivated land and oxen ownership by one unit increases household food security by 9.6 per cent and 8.7 per cent respectively. The study also confirmed the vital role rural infrastructure for household food security. On the other hand, the result of the CSI revealed that households relied largely on consumption-based coping strategies when faced with food shortages. A negative association was found between CSI and a household's asset ownership, principally farmland holding size and livestock ownership, which stand to reason—more assets would imply both a higher level of wealth, as well as a greater capacity to cope with food shortages.

Appendix Table 2.1: Severity of coping strategies

Coping strategies	Severity of coping strategies as identified during focus group discussions (FGD) in six tabias						Average	Rank	Severity level
	FGD 1	FGD 2	FGD 3	FGD 4	FGD 5	FGD 6			
Eat less proffered foods	2	2	1	1	2	1	1.5	2	M
Borrow food	3	3	2	2	2	3	1.5	3	H
Buy food on credit	2	2	2	3	2	3	2.3	2	M
Gather wild food	1	1	2	1	2	1	1.3	1	L
Reduce the number of meals	2	3	2	2	2	3	2.3	3	H
Limit portion sizes at mealtimes	2	3	3	1	2	3	2.3	2	M
Restrict consumption of adults	3	2	3	3	2	2	2.5	3	H
Skip entire days without eating	4	4	4	4	4	4	4.0	4	VH
Sell farm implements to purchase food	3	4	3	4	3	3	3.3	3	H
Consume seed stock	4	4	4	4	3	4	3.8	4	VH
Send children to eat elsewhere	4	3	4	4	4	4	3.8	4	VH

Note: L = low severity; M = medium severity; H = high severity; and VH = very high severity

## Chapter 3

### Impacts of Program Interventions upon Food Security and Environmental Rehabilitation

Chapter is based on:

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Gebrehiwot, T., van der Veen, A. (2012). Estimating the impact of food security program by propensity-score matching. *Food Security Journal*, under review after revision.

Gebrehiwot, T., van der Veen, A. (2011). The effect of area enclosures in rehabilitating degraded lands: a case of Enderta district, northern Ethiopia. *Land Degradation & Development*, under review.

## **Abstract**

Reducing poverty and improving household food security is an important policy instrument for rural development in the semi-arid areas of many countries in Africa. Many pro-poor development programs have been introduced over the past decade to bring the cycle of poverty and food insecurity to an end, and concomitantly address the problem of environmental degradation. This chapter aims to investigate the impact of policy interventions targeted at improving food security and rehabilitating degraded lands. An empirical analysis based on Food Balance Sheet and a Propensity Score Matching method is employed to examine the effect of policies in improving food security at regional and household level respectively. We also used multi-temporal satellite images and a vegetation index differencing technique to investigate the effect of policy instruments, area enclosures in particular, implemented to regenerate the degraded vegetation. The findings of the food balance sheet indicate that the region has made some impressive development gains in improving regional food self-sufficiency. The estimated results further show that the food security program has a positive and statistically significant effect on household food calorie intake. According to our research, the program has raised food calorie intake by 41.8 per cent among beneficiary households. Moreover, the findings from the remote sensing analysis indicate that a consistent positive improvement in vegetation regeneration is observed in area enclosures as compared to the unprotected areas. The study demonstrates that only research aimed at the interplay of analysis at different levels is able to unravel the effectiveness of government policies in ensuring food security and improving the degraded lands for a certain region.

### **3.1 Introduction**

Food security is an important concern for many nations around the world. In fact, alleviating food insecurity and hunger is one of the eight Millennium Development Goals. Despite notable progress in economic growth and welfare improvement in developing countries over the last decades, food security has not been attained in most of the developing countries. Particularly food insecurity continues to form a deep seated problem in several Sub-Saharan African (SSA) countries. A recent report of the Food and Agriculture Organization of the United Nations (FAO) indicates that the number of undernourished in Africa still remain high at 279 million (FAO, 2010). Even now, countries in the horn of African are overwhelmed by heightened food security crises, making the problem of food security an issue of great concern to governments and the international community.

Like other SSA countries, Ethiopia is one of the least developed countries in the world according to all measures of poverty. Ethiopia is one of the most drought prone countries with a long history of famines and food shortages. In Ethiopia, problems of food security among the population are wide spread and there have been some instances of famine that cost the lives of about 200,000 people. Ethiopia is amongst the lowest income countries with an average per capita income of a merely USD 330 per year (World Bank, 2011a). Moreover, despite some changes, both rural and urban poverty have remained pervasive in Ethiopia for decades. The country has persistently suffered widespread food insecurity. Many rural people cannot meet their basic needs. The 2005-2009 World Bank assessment report estimated 41.6 per cent of the population of Ethiopia to be undernourished, which remains the highest prevalence of malnutrition (World Bank, 2011b). According to Adnew (2004), many Ethiopians live in conditions of chronic hunger with both a low average of daily energy supply (kcal/capita/day) of 1880 and a very high prevalence of under-nourishment (44%).

The country's food production is highly vulnerable to the influence of adverse weather conditions as the economy is totally dependent on rain-fed agriculture. Previous studies reported that a 10 per cent decline in the amount of rainfall below the long-term average leads to a 4.4 per cent reduction in the country's national food production (von Braun et al., 1992). Furthermore, drought has increasingly occurred over the past decades as has the proportion of the population adversely affected by it. Consequently, the country has been dependent on food aid to bridge its huge food gap. Devereux (2006) reported that even in a year where rainfall is favourable it is estimated that around 4 to 5 million Ethiopians depend on food aid reflecting how deep-rooted food insecurity is in the country.

The causes of food insecurity problems in Ethiopia are complex and interrelated. Lack of governance and misdirected economic policies during the military regime, over dependency on rain-fed agriculture and failure to bring about economic transformation have all contributed to the present poor state of the country's economy (Gebremedhin, 2006). Furthermore, unfavourable weather fluctuations can take a heavy toll on the lives of rural farmers and put them on the brink of starvation as a failure of the rainy season is directly linked to agricultural failure reducing food availability at household level. All these factors contribute to either insufficient national food availability or insufficient access to food by households. These and other factors are supposed to be responsible for the country's struggle to ensure food security at household level.

The dimensions, causes and consequences of food insecurity differ widely in the country. The study region, Tigray, is one of the regions most affected by recurrent cycle of drought and food security problems. Devereux, (2000) reported that majority of the rural people live in conditions of chronic hunger with a low average energy supply. A combination of factors has identified as the main causes of food insecurity in the region, which includes irregular rainfall, recurrent cycle of drought, environmental degradation, high population pressure, lack of diversification in economic activities and institutional factors.

In response, the government of Ethiopia formulated a long-term strategy to reverse the dismal situation of smallholder farmers and eventually alleviate its food deficiency. Accordingly, ensuring food security is one of the top national priorities and forms the cornerstone for the sustainable economic growth and poverty reduction strategy in Ethiopia. Accordingly, policies that tackle food insecurity both at regional and household level, which stretch from making food available to the rural poor to mitigate transitory economic shocks and diversify the income base of the rural poor, are seen as the most effective way to reduce poverty. The Food Security Package (FSP) program is among the programs introduced for this purpose. Concomitant to this the government has extensively carried out a number rehabilitation programs to contain and reverse the problems of land degradation. Accordingly, large amount of money and energy have been spent by the government and multi-lateral development bodies to reduce the problems of widespread rural poverty and improve people's access to food in order to achieve the greatest gain in food security improvements.

Given the large amount of money and energy spent to address the problems of food security, we still know surprisingly little about the actual impact of the FSP programs have had upon regional and household food security. In the literature, attention has been paid to analysing the causes of food insecurity

and poverty but studies that focus on the impact of government policy interventions on regional and household level food security are limited. There are few researches that assess the impact of food aid programs on household food security and welfare and to a more limited extent, nutrition (Barrett, 2002). Gilligan and Hoddinott (2007) studied the importance of food-for-work on household consumption, food security and assets in Ethiopia. However, to our knowledge no comprehensive attempts have ever been made to scientifically evaluate the impacts of the food security program have had on ensuring food security both at the regional and household levels. In addition, establishing area enclosures in various parts of the region have been priorities for the last decade to restore the degraded land to its natural vegetation. However, very little or virtually no systematic and scientific studies have been carried out to evaluate the effect of enclosures in the rehabilitation of degraded lands. Neither has potential remote sensing in monitoring vegetation regeneration after enclosures been evaluated. This apparent limitation provides us with the starting point of the present chapter. The main objective of this chapter is to fill this gap. Consequently, the objectives are: (1) to evaluate the impact of FSP programs have had on improving regional food security and rural household's food consumption, particularly food calorie intake; (2) to investigate the effect of area enclosure in restoring the degraded vegetation in a randomly chosen area in the Enderta *woreda*, Southern Tigray, a *woreda* that is adversely affected by heavy grazing and clearing of vegetation.

### 3.1.1 Policy evaluation

#### **The need for policy evaluation**

It is increasingly being recognised that improving food security is a foundation for reducing poverty and hunger, but also for economic development. Halve the proportion of people who suffer from hunger by 2015 is used as one of the key indicators for poverty reduction in the framework of the Millennium Development Goals (MDGs) (FAO, 2006). This reflects the insight that policies and programs had a role to play to improve food security outcomes, poverty reduction, and global development.

Accordingly, many developing countries have launched a series of development and poverty reduction packages to improve the wellbeing of the population. In Ethiopia, food security has been among governments' priority areas of development strategy. Consequently, different development programs have been implemented over the past years. Hence, the impacts of these program interventions need to be evaluated after a certain period of time. In order to track down the effect of these program interventions in a credible manner, applying scientific and reliable methods of evaluating policy interventions becomes indispensable. Impact evaluations generate valuable information and provide a sound scientific basis for policy making, by

providing reliable understanding on which program interventions work and are effective. This apparent rationale provides us the impetus for sound policy impact evaluation, which is increasingly recognized as a dominant field of economic expertise and an important tool in development research and policy making.

### **The concept of policy of evaluation**

The initial use of systematic tools of impact assessment dates back to 1950s when international development was dominated by multilateral and bilateral donors who were guided exclusively by modernization theory (Maredia, 2009). Different development agencies started to use ex-ante impact assessments and appraisal approaches to forecast a project's probable social, economic, and environmental significances as a condition to approve, adjust or reject the project funding. In contrast to the ex-ante impact assessment, retrospective impact assessments was a phenomenon that began in late 1950s–1960s and has evolved and expanded over the decades in both breadth and depth of analysis. Since then significant transformations has undergone on the different methods and approaches for assessing development effectiveness.

Definition of evaluation abound. Thomas Dye offers an excellent broad definition when he notes that policy evaluation is 'learning about the consequences of public policy' (Dye, 1987):

*Policy evaluation research is the objective, systematic, empirical examination of the effects on-going policies and public programmes have on their targets in terms of the goals they are meant to achieve.*

According to Baker (2000), a comprehensive evaluation is further defined as an evaluation that comprises monitoring, process evaluation, cost-benefit evaluation, and impact evaluation. However, each of these components is distinctly different. In this study we shall be concerned with impact evaluation, which is intended to determine whether the program had the desired effects on individuals and households, and whether those effects are attributable to the program intervention (Baker, 2000). Broadly speaking, impact assessment seeks 'to systematically investigate the effectiveness of social interventions' (Babbie, 2003; Rossi et al., 1999; Wond and Macaulay, 2010). It is the analysis that establishes the causal link between an intervention and outcome(s).

In measuring the causal relationship between program/policy and impact, micro and macro effectiveness is one of the important economic criteria for evaluating policy (Untiedt, 2009). According to Maredia (2009), macro-level impact assessments focus on examining the effect of development interventions to an impact goal aggregated at a sector or a system level.

These types of assessments provide evidence in relation to the long-term effectiveness of broad sector-level investments. On the other hand micro-level impact evaluations are concerned with estimating the average effect of an intervention on outcomes at the beneficiary level. The term 'effective' can be defined as 'successful in producing a desired or intended result'. Effectiveness relates to the extent to which the direct results of interventions (output) contribute to the sustainable achievement of policy objectives (outcome). An intervention is considered effective if its outputs have made a demonstrable contribution to achievement of the intervention's intended objectives. Evaluating effectiveness therefore aims to establish this causality.

In recent years, impact evaluation has blossomed as a powerful tool for enhancing development effectiveness. However, the goals of attaining food security and ending poverty and hunger did not receive explicit attention in impact assessments of development interventions in the early decades despite food security assessments have long been a topic of research. Studies that address questions of how agricultural development efforts are improving food security of targeted populations by tracking indicators that measure 'food security' were uncommon in the 1970s and 1980s (Maredia, 2009). Even today, it is rare for impact assessments to include an explicit indicator called 'food security' to measure the impact on this goal. Most studies estimate food security impacts through changes in outcome indicators related to consumption or infer this impact through changes in outcomes related to production and income.

Impact analysis therefore requires a rigorous research design in order to ensure that as far as possible any changes in the indicator variables are due to the instruments of the program/policy rather than to changes in the external environment. Typically this means a reliance on experimental or quasi-experimental methods rather than the more descriptive and circumstantial evidence used in performance monitoring studies. Policy evaluation based on rigorous experimental or quasi-experimental design has been rare in the study area.

### *3.1.2 Government policy instruments for food security*

Government policy failures or inappropriate development strategies and institutional weakness are claimed to be one of the main factors for the recurrence of food shortage, poverty and underdevelopment in many African countries (Bird et al., 2003). Paarlberg (2002) further notes that food insecurity persists largely because of governance and policy failure at the national level. The challenging of adopting enabling policies that lead to rapid economic growth is related the two challenges. For Africa in general, where 70 per cent of the population is engaged in agriculture, agricultural focused-strategy is the best way of reducing food insecurity and generating greater

employment both in farm and non-farm sectors. Sustainable economic development, food security, and social and political stability are intricately linked to the sustainable growth of the agricultural sector (Lal et al., 2003). Moreover, agriculture is the best strategy for conserving natural resources or reversing land degradation and deforestation, since poverty forces poor people to overuse natural resources and forests in order to meet their basic survival needs.

However, in the discussion of development economics of the 1950s, agriculture was not considered seriously as a potential for growth which could make a significant contribution to the overall economic development. According to Mellor and Johnston (1984), it only later that agriculture in developing countries started to be considered as a viable sector in which to commence development since it constitutes a dominant social and economic base. Investment on agriculture focused economic growth is increasingly recognized as crucial strategy for developing countries, where majority of the population makes its livelihood in agricultural related activities.

### *3.1.3 Government policies in Ethiopia*

A major development challenge for Ethiopia is to reduce absolute poverty and food insecurity at acceptable environmental and economic costs. As indicated earlier, many factors are contributing to trap Ethiopia, in the current state of food insecurity and poverty. Among these include production fluctuations, low level of non-farm employment opportunities, low income, fragmentation of markets, high rate of natural degradation, and low level of farm technology. These factors impede the achievement of food security and sustainable economic development. Ethiopia, along many African states, is caught up in vicious cycle of food insecurity, poverty, low agricultural productivity, and land degradation cycle.

In response, the government designed a long-term strategy to address the dire situation of smallholder farmers and eventually alleviate its food deficiency. Accordingly, agriculture is seen as point of departure and growth-engine within the long-term agricultural development-led industrialization strategy (ADLI), of the country (FDRE, 1994). Within the framework of ADLI, regional states have been able to draw economic strategies specific to their regional conditions. Conservation-based ADLI became the primary goal of economic development in Tigray, which gives priori focus to the rehabilitation and conservation of natural resources.

The long term development strategy of the government aims at promoting sustainable management of natural resources and increasing agricultural production, and ensuring food security of the population. Improving the production and productivity of smallholder agriculture through generation,

adoption and dissemination of suitable farm technologies in the form of improved inputs and farming methods, provision of credit, promoting off-farm employment through diversification of the rural economy, and rural asset building are at the centre of the strategy. In order to mobilise smallholder farmers and dissemination of better farming practices, the strategy has been operationalized via the Participatory Demonstration and Extension Training System (PADETS). Moreover, the natural resource conservation and development effort in the region has been aimed at improving environmental rehabilitation and protection through area enclosures, development of community woodlots and reforestation. Enhancing the management of soil and water resource and the development of irrigation through the construction of micro dams and river diversions are at the forefront of the development strategies.

By and large, for both microeconomic and macroeconomic reasons, no country has ever sustained rapid economic growth without first solving the food insecurity problem (Timmer, 1998). Thus, food security forms the major component of the ADLI strategy. In order to improve the food security situation of the country, successive national Food Security Strategies have been designed. The first version of the food security strategy was issued in 1996 and revised in 2002 highlighting the government's plan to address causality and effects of food insecurity in the country. The strategy envisages developing an agriculture-based economy by raising farm productivity and income. The food security measures also aim to promote and strengthen micro and small scale enterprise development, improving the food marketing system, promoting and strengthening supplementary employment and income generating schemes, and credit services to address the demand side problems. In conclusion, which is important for the design of our study, food security instruments are considered by the Ethiopian government as interplay between socio-economic and natural conservation issues. As an example, in our study the government interventions implemented to tackle the problems of food security are discussed below.

#### *3.1.3.1 Intervention to enhance food availability (Macro level)*

The macro policy perspective places the food system squarely in the context of economic growth and efforts to alleviate poverty and hunger. These efforts involve strategies for raising productivity in the agricultural sector; and thereby ensure food availability, one of the three conditions of food security as defined in the World Food Summit. Improving domestic production (supply side actions) is the first and main source of food entitlement for most of the Ethiopian farming community in terms of direct consumption of food. Increasing the production and productivity of agriculture in a sustainable manner could address the problem of food shortage by making more food available, as well as improves access by generating employment and income.

Improving agricultural production also stimulates non-farm employment since increased farm incomes provide effective demand for non-farm rural enterprises. Using macro policies to alleviate poverty and food insecurity is therefore recognized as only part of an effective food policy.

Accordingly, the government has given emphasis to bring substantial growth and expansion in the agricultural sector that would considerably reduce the spread of poverty and food insecurity in the region. Different packages were implemented to raise agricultural production by giving utmost attention to agricultural extension services. One of the major components of the extension package is the use of fertilizers and improved seeds. As indicated, the most plausible way to eradicate poverty is to increase food supply in the region and create the opportunity for people to attain food security. One of the means that has been followed to expedite the availability of enough food, which has been the obsession of the regional government, has been the increased use of fertilizers by smallholding farmers. Furthermore, several arrangements have also been worked out to facilitate farmers' access to rural credit to enable them to purchase fertilizer and other agricultural inputs. The regional government, Dedit Credit and Saving Institution (DECSI) and regional Cooperative Associations have made efforts to provide credit for such purpose.

The extension services also focused on introducing better and improved agricultural practices. These practices were accompanied by the development of infrastructures that enable farmers to sell their products and buy farm inputs more easily. Development agents were assigned in each *tabia* so that these agents train farmers by demonstrating practically the benefit of the program. In addition, the government introduced a variety of water harvesting schemes, which is considered as the single most important means to increase agricultural productivity and address the problems of water shortage. Accordingly, extensive pond construction and digging of water wells, traditional river diversion schemes and construction of small-scale irrigation schemes has been undertaken in different parts of the region since 2002.

### *3.1.3.2 Interventions at household level (Micro level)*

At the microeconomic level, inadequate or lack of access to food limits labour productivity and reduces investment in human capital thereby constraining sustained economic growth (Fogel, 1994; Strauss, 1986). Thus, focus for microeconomic level problems within the economic development policy is vital in addressing food insecurity.

In addition to programs oriented to boost agricultural production, the government launched a household oriented extension package program

known as the integrated household food security package program (FSP) in 2002 to address the problems of food security at the household level (Desta et al., 2006). This integrated program was developed within the framework of the federal government overall development policy and food security strategy, but addresses the specific and complex problems and causes of food insecurity that are plaguing the regional people. To this end, a twin-track strategy has been employed with selected target groups to redress short-term food deficits, whereas, in the long term, building up sufficient self-help capacity to allow the rural population to attain self-reliant food security.

Accordingly, the FSP program has been widely introduced in Tigray with the objective of furnishing the asset base of the poor to ensure food security through the provision of adequate and efficient financial services, training, and the provision of improved agricultural inputs. The intention of the program is to secure food at household level by diversifying the income base of the poor through provision of credit for a range of activities provided in a package. Identifying the basic interest of the poor and providing the necessary resources, technical assistance and training to engage in their choice of activities is the prime concern of the program. Other specific objectives of the program include expansion of small scale irrigation programs; rehabilitation and better management of natural resources and infrastructure in the program areas as a precondition for the target groups to regain their capacity for self-reliance; and diversification of employment and household income through off-farm activities to improve life for all rural people.

#### **Description of the program**

Selection of households for the program involved local consultation and a non-random placement. In the first place, *Tabias* were identified in each *woreda* based on the severity of the food insecurity problem. Next, individual households were selected in each *Tabia* to be beneficiaries of the program. The participating households were selected first by the *Tabia* administrative team leader and then approved in a general meeting. Households had to fulfil certain criteria in order to be considered for the FSP program. The main formal criteria for selection of beneficiary households were poverty status as expressed by the household's livestock holding (households without cows and oxen were given priority), land size and severity of food insecurity.

Upon selection, first an assessment was made of what the household already possessed and then only the components lacking were presented as a package. Households thus participated in one or more program activities, including irrigation, vegetable and fruit production, livestock production, poultry, beehives and crop production. Accordingly, a household could get financial support for a range of activities (package) and loans are disbursed

on an individual basis. Depending on the type of activity, loan periods vary from two to four years. They also could take part in communal work operations such as community road construction and environmental rehabilitation activities, receiving payment in kind or cash for their labour contribution. The FSP program components were designed to suit the different agro-ecological conditions of the region.

The FSP program was thus expected to address the rural household's risk of not having access to the required food through increasing food production, provision of improved technologies and promoting employment. These risks can be with respect to crop production, employment and income. Accordingly, increase in food production was expected to influence food security through increasing or stabilizing the real incomes of the rural people. Technological innovation in agriculture was also expected to induce economic gains by stimulating agricultural growth and improving employment opportunities. Provision of credit to the poor is expected to stabilize consumption and promote self-employment in off-farm activities. Gains in income are thus expected to improve household's food consumption and nutritional welfare. The program was also expected to increase household's livestock ownership and provide access to draft power that had been the long-time constraint of the agrarian society.

### *3.1.3.3 Interventions to rehabilitate degraded lands*

Poverty and environmental degradation are closely related, usually in a self-perpetuating negative spiral in which poverty accelerates environmental degradation and degradation results in or exacerbates poverty. As Pimentel et al. (1994) argued poverty does pose the most serious environmental threat in many low-income countries despite it is not the only cause of environmental degradation. In Ethiopia, there is a vicious cycle of natural resource degradation and food insecurity driven by poverty and population growth. The country is caught up in 'poverty – environmental degradation and food insecurity circle. Tewolde Berhan (2006) described land degradation as the main cause of poverty and food insecurity in the dry lands of Ethiopia. Over the past decades, for instance Tigray, has lost nearly all of its forests and a great part of its soil. The serious environmental degradation, among others caused by deforestation, vegetation clearance and subsequent soil erosion has led to periodic crop failure even under normal rainfall conditions. Consequently, low agricultural productivity, poverty, and land degradation are pervasive (Bekele and Holden, 1998; Holden and Shiferaw, 2004; Sonneveld and Keyzer, 2002).

In Ethiopia, as Tewolde Berhan (2006) noted, any attempt at poverty alleviation and ensuring food security has to start with forest rehabilitation if it is to have any long lasting effect. Consequently, halting environmental

degradation through rehabilitation and conservation of natural resources is at the forefront of government interventions. The Tigray government has extensively carried out a number of rehabilitation programs. Soil and water conservation works and the establishment of area enclosures have been two of the main strategies promoted to control land degradation and restore the natural vegetation.

Accordingly, to restore the degraded land to its natural vegetation, establishing area enclosures<sup>5</sup> in various parts of the region have been priorities for the last decade. The official data available on area enclosures indicated that up to the year 2000 a total of 262,704 hectares of degraded land have been enclosed for rehabilitation purposes in the region. Enclosed areas in several *woredas* of Tigray reached 920,000 hectares by 2009, covering about 17.2 per cent of the land.

Area enclosures in the region have been developed through a participatory process and due consideration was given to ways of gaining their confidence with local communities to increase their participation in natural resource management. Communities were given clear responsibilities to make decisions on issues pertaining ownership and protection, access, management and utilization of the resources, and future development directions. In addition, community members were involved in site selection and decision-making for the enclosure areas. Local community agreed before to strictly protect area enclosures from any form of grazing, harvesting grass, and tree cutting. This was supported by local rules and regulations developed by the *tabia* council. Moreover, the *tabia* council was involved in organizing and encouraging participation in woodlot development and also finance the guards who protect area enclosures who were nominated from the local people.

In the following we will discuss the general theoretical frameworks used for this study. First we will discuss the methodological approaches used to evaluate food security at the regional level. Second, we will present the Empirical approach used to determine the impact of food security program interventions upon household food security. Third we will discuss the methodological approach employed for detecting the effect of government strategy of area enclosures in rehabilitating degraded lands.

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<sup>5</sup> Area enclosures in the Ethiopian context can be defined as the degraded land that has been excluded from human and livestock interference for a certain period of time to encourage natural vegetation.

## **3.2 Methodology**

In this section, the impacts on food security are assessed both at the aggregate (macro level) and the household level (micro level) by tracking direct indicators that measure food security goals at both levels. At a macro level impacts are assessed by looking at changes in macro level indicators basically food availability and food self-sufficiency ratio. On the other hand, at a micro level the evaluation is carried out by looking at the ability of a household to meet his/her food requirements.

### *3.2.1 Methods*

#### *3.2.1.1 Determining regional level food security*

The concept of food security can be analysed for units at different conceptual levels and the exact dimensions that need to be measured should vary depending on the level of analysis selected. At a national or regional level, the conditions of food security can be analysed in terms of supply indicators by looking at the ability of the country or region to obtain sufficient food to meet the needs of all citizens (von Braun et al., 1992). The most widely used supply indicator is the quantity of food available as compared with requirements. Availability is a function of domestic production, food imports, food aids and security stock. Of these, domestic production is crucial in ensuring food availability at both regional and household levels.

First, the change in the regional level of food availability was analysed by computing a so-called Food balance Sheet (FBS). Frankenberger, (1992), described FBS as the principal tool used for determining national food security. FBS is used to determine the expected food deficit or surplus, the necessary food import and/or food aid requirements. The Ethiopian government has designated 2,200 Kcal as a minimum acceptable weighted average nutritional requirement for a person to lead a 'normal' physical life under Ethiopian conditions (FDRE, 2001; MoFED, 2002). We used this threshold level to determine the annual regional food requirements. Based on annual net cereal production, we determined a self-sufficiency ratio (SSR), which is measured as the ratio of the sum of net production of cereals to the food requirements. In addition, we derived a regional food availability ratio (FAR), which is the ratio of the total food supply to the food requirement. As food imports are only handled at the national level, total food supply (TFS) at the regional level is determined as the sum of net domestic produce and total food aid. However, one of the criticisms of FBS is that they are not usually drawn up on a disaggregated basis to detect differences across *woredas* (Davies et al., 1991). Thus, we determined the FBS for the 34 rural *woredas* to get insights on the trends, which ultimately could provide an important complement to entitlement information at a *woreda* level. By and large, the level of food security at the macro level is assessed based on gap between

domestic consumption (domestic production plus food aid) and consumption targets (regional food requirements).

### *3.2.1.2 Determining household food security*

National/regional level indicators like FBS, nonetheless, mask the impact of unequal food access at the household level. Evaluating impact of food security programs at the household level is therefore vital. However, as with other social programs, identifying and quantifying the causal effect of a program on household food security is not straightforward due to the multidimensional character of food security. Identifying an appropriate food security indicator is thus a difficult issue as not all aspects of food security can be captured by any single outcome indicator (Hendriks, 2005). Besides, collecting data for a comprehensive analysis of food security can be an almost impossible task in situations: (i) where household composition is variable, and the 'household' is in itself subject to varying interpretations; (ii) where there may be multiple income sources among adult members of one household who have strong incentives not to reveal to each other the full extent of their individual earning power or assets; (iii) where responsibility for the production and/or purchase of food may be shared among these adults; and (iv) where subsistence production is harvested piecemeal and is neither measured nor recorded (Maxwell, 1996b). To get around this difficulty, most analyses depend on measuring food consumption.

Maxwell and Frankenberger (1992) report 25 broadly defined indicators. Riely and Moock (1995) list 73 such indicators. In the work by Maxwell and Frankenberger, a distinction is further made between process indicators describing food supply and outcome indicators describing food consumption and food access. Nonetheless, process indicators are insufficient to characterize food security outcomes. Chung et al. (1997) found that there is little correlation between a very large set of process indicators and measures of food security outcomes. Instead, a household's level of food security can be determined better by obtaining information on a variety of specific conditions that serve as outcome indicators of the varying degrees of household conditions.

Von Braun et al. (1990) described outcome indicators as proxies for food consumption measured either directly as food expenditure and caloric consumption or indirectly through nutritional assessments, subsistence potential ratio or storage estimates. Maxwell et al. (2008) illustrated the frequently available and utilized indicators, which potentially measure food security as: a detailed analysis of household food consumption based on either directly measured or a 24-hour recall, indices of household coping strategies, household calorie acquisition, as well as proxy indicators such as household income, productive assets and under 5 nutritional statuses.

Similarly, different organisations and government agencies use different food security indicators depending on their primary objectives. Per capita food intake per day in kilocalories is used as the indicator for food security for regional and global assessments. For example, according to FAO (2003), at national level a per capita food intake of less than 2,200 kcal per day is considered as indicative of a very poor level of food security with a large proportion of the population being affected by malnutrition. Consumption-based measures are commonly used rather than income in measuring welfare at the household level. The most popular methods of poverty measurement have also used the nutritional norm and defined poverty line in terms of minimum calorie requirements (Ahmed et al., 1991; Greer and Thorbecke, 1986; Ravallion and Bidani, 1994).

Correspondingly, von Braun et al. (1992) recommended that food security at the household level is best measured by direct surveys of dietary intake in comparison with appropriate adequacy norms. For this study, we used food calorie intake as an outcome indicator to measure the impact of household food security package program, which is one of the most direct indicators related to food security and nutritional security (Gilligan and Hoddinott, 2007; Hoddinott and Skoufias, 2004). This indicator tends to be reasonably stable due to the availability of consumption-smoothing opportunities such as saving, borrowing and social networks. Therefore, current consumption is often used as an indicator of both the current and long-term standard of living (Deaton, 1997; Ravallion, 1994). Besides, this indicator is of direct interest to the government of Ethiopia as it is the prime indicator variable currently used to define food poverty in the country (MoFED, 2006). This infers that this indicator has direct relevance to local conditions and the food security context, which is identified as one of the criteria by Davies et al., (1991). As is also reported by Baker (2000), establishing measurable indicators that correspond directly to planned interventions is a key step in social program impact evaluation.

We used household survey data for constructing the food calorie intake variable at the household level. The food consumption data were collected using a structured household questionnaire designed for this purpose. The sample farm households were asked to report food items consumed in kind and amount, purchased or otherwise, by their families during the week preceding the survey. The physical food quantities consumed by a household were then converted into food calories adjusted for household age and sex composition following three steps. First, each of the food items consumed was converted into calories using the national food composition table compiled by the Ethiopian Health and Nutrition Research Institute (EHNRI, 2000). Secondly, all food calories consumed were then added up and

converted into daily amounts. Finally, the aggregate food calories were adjusted to an adult equivalent unit per household.

### Empirical approach

A valid measure of the impact of a household food security package would be to compare the outcomes in households receiving FSP benefits with the presumed outcomes had the same households not received any benefits. The construction of this unobserved counterfactual forms the basic dilemma in impact evaluation. Assessing the impact of any intervention requires making an inference about the outcome that would have been observed had the program participants not participated. Following Heckman et al. (1997) and Smith and Todd (2001), let  $Y_1$  be the means of the outcome conditional on participation, i.e. treatment group, and let  $Y_0$  be the outcome conditional on non-participation, i.e. control group. The impact of participation in the program is the change in the mean outcome caused by participating in the program, which is given by:

$$\Delta Y = Y_1 - Y_0, \quad (3.1)$$

where  $\Delta$  is the notation for the impact for a given household.

The fundamental problem of evaluating this individual treatment effect arises because for each household, only one of the potential outcomes either  $Y_1$  or  $Y_0$  can be observed, but  $Y_1$  and  $Y_0$  can never be observed for the same household simultaneously. This leads to a missing-data problem, which is the heart of the evaluation problem (Smith and Todd, 2005). The unobservable component in equation (3.1), be it  $Y_1$  or  $Y_0$ , is called the counterfactual outcome. Measuring impact as the difference in mean outcome between all households involved in the FSP and those not involved, even when controlling for program characteristics, may thus give a biased estimate of program impact. Since there will never be an opportunity to estimate individual treatment effects in (3.1) directly, one has to concentrate on population averages for the impacts of a treatment.

Two treatment effects are dominantly used in empirical studies. However, the most commonly used evaluation parameter is the so-called average impact of the treatment on the treated (ATT), which focuses explicitly on the effect on those for whom the program is actually introduced. In a random program assignment, the expected value of ATT is defined as the difference between expected outcome values with and without treatment for those who actually participated in treatment (Heckman et al., 1998b), which is given by:

$$\begin{aligned} \Delta Y_{ATT} &= ATT(\Delta Y | X; Z = 1) \\ &= E(Y_1 - Y_0 | Z = 1) \\ &= E(Y_1 | Z = 1) - E(Y_0 | Z = 1) \end{aligned} \quad (3.2)$$

where  $Z$  is an indicator variable indicating whether a household  $i$  actually received treatment or not:  $Z_i$  being equal to 1 if the household is a beneficiary of FSP, and 0 otherwise.  $X$  denotes a vector of control variables. Data on program beneficiaries identify the mean outcome in the treated state  $E(Y_1|X, Z=1)$ . The mean outcome in the untreated  $E(Y_0|X, Z=0)$  is not observed and a proper substitute for it has to be chosen in order to estimate ATT. The procedure in (3.2) could not be applied in our case as the household food security package program followed a non-random process in targeting its beneficiaries, giving rise to a biased estimate of program impact (Gilligan and Hoddinott, 2007). Under such conditions, Blundell and Costa Dias, (2000) noted that an impact evaluation is usually performed by applying a suitable non-experimental method.

Review of literature revealed that four different selection evaluation approaches are introduced to address this problem of selection bias in non-experimental evaluation methods. These are: Matching estimator, Linear regression approach, Heckman's Selection Model and Difference-in-Differences Estimator. These approaches apply different identifying assumptions to draw inference about the hypothetical population based on the observed population. Matching is based on the identifying assumption that conditional on some variables  $X$ , the outcome  $Y$  is independent of  $Z$ , i.e. being a participants or non-participants. Even though regression and matching both depend on the unconfoundedness assumption, there are some main differences between both approaches. One main difference is that matching avoids functional form assumptions which are implicit in linear regression models. Moreover, linear regression considers the additional assumption that simply conditioning linearly on  $Z$  suffices to eliminate selection bias. Heckman's Selection Model is based on the assumption that the participation in a program may be determined by some observed and unobservable factor(s). The difference-in-differences (DID) estimator requires access to panel data and it is based on the assumption of time-invariant linear selection effects, consequently differencing the differences between participants and non-participants eliminates the bias.

Our choice of evaluation method in this paper was limited by data availability. For instance, there was no baseline data collected on the outcome variable and other pre-intervention characteristics of FSP beneficiary and non-beneficiary households in the studied area. Hence, we have to rely on a propensity score matching (PSM) which can identify comparable treatment and comparison observations using cross-sectional data (Rosenbaum and Rubin, 1983). PSM is a non-parametric technique as opposed to an ordinary least squares (OLS) regression method which imposes a linear structure on the data. PSM also differs from an OLS regression in many other ways too; see Jalan and Ravallion (2003). For instance, an OLS regression employs all

observations in the treatment and control samples whereas PSM uses only matched sub-samples. However, Rubin and Thomas (2000) reported that impact estimates based on full samples yield less reliable and more biased estimates than those based on matched samples. Moreover, PSM allows computing heterogeneous treatment effects since it does not impose any assumption on the data.

Following Rosenbaum and Rubin (1983, 1985) and Heckman et al. (1997), we estimated the impact of the FSP program on household food consumption using PSM as a method of estimating the counterfactual outcome for program beneficiaries.

### Propensity score matching

The propensity score is defined by Rosenbaum and Rubin (1983) as the conditional probability of receiving a treatment given pre-treatment observable characteristics. Let  $P = \Pr(Z=1 | X)$  denote the probability of participating in the FSP program, i.e. the propensity score. PSM constructs a statistical comparison group by matching observations on the FSP participants to non-participants for similar values of  $P$ . PSM estimators are based on two assumptions:

- i) matching assumes that non-participants provide the same mean outcomes as participants would have provided had they not received the program. This is one major strand of evaluation literature that focuses on the estimation of treatment effects under the assumption that the treatment satisfies some form of exogeneity (Imbens, 2004). Different versions of this assumption are referred to as selection on observables, or unconfoundedness, or conditional independence assumption (Heckman and Robb, 1985; Lechner, 1999; Rosenbaum and Rubin, 1983). Thus, testing is important in order to check if a household's characteristics within its group are really similar.

$$E(Y_0 | P, Z = 1) = E(Y_0 | P, Z = 0) = E(Y_0 | P) \quad (3.3)$$

- ii) matching methods depend on the common support assumption. Heckman et al. (1999) described that this assumption ensures households with the same  $Z$  values have a positive probability of being both participants and non-participants:

$$0 < P < 1 \quad (3.4)$$

If assumptions (i) and (ii) are both satisfied, then, after conditioning on  $P$ , the  $Y_0$  distribution observed for the matched non-participant group can be substituted for the missing  $Y_0$  distribution for participants. Under these assumptions, the Average effect of Treatment on the Treated (ATT) of the program can be estimated as:

$$\begin{aligned} \text{ATT} &= E(Y_1 - Y_0 | Z = 1) \\ &= E(Y_1 | Z = 1) - E_{P|Z=1} \{E_Y(Y_0 | Z = 1, P)\} \\ &= E(Y_1 | Z = 1) - E_{P|Z=1} \{E_Y(Y_0 | Z = 0, P)\} \end{aligned} \tag{3.5}$$

where the first term on the right hand side of the last expression can be estimated from the treatment group and the second term from the mean outcomes of the matched (on P) comparison groups.

Imposing the common support restriction improves the quality of the matches as it excludes the tails of the distribution of P, but high quality matches may be lost at the boundaries of the common support and the sample size may be considerably reduced. The computations of causal effect are only performed for the treated and non-treated households that share a common support in their estimated propensity scores. Observations outside the common support are discarded as non-comparable in terms of observable attributes. According to Rosenbaum and Rubin (1983, 1984), PSM estimator is simply the mean difference in outcomes over the common support, properly weighted by the propensity score distribution of the participants.

Through comparisons with experimental estimators, Heckman et al. (1998a) and Heckman, Ichimura, and Todd (1997) showed that propensity score matching provides reliable and low-bias estimates of program impact as long as that (i) the same data source is used for participants and nonparticipants, (ii) participants and nonparticipants share a comparable socio-economic, demographic and economic environment (failure of this condition to hold is often referred to as the problem of "selection bias" in econometrics), and (iii) the data include sufficient variables capable of identifying program participation and outcomes. In the absence of these features, the difference between the mean calorie intake of the participants in a FSP program and the matched non-participants will be a biased estimate of the mean impact of the program. Our survey clearly met criterion (i) because a similar questionnaire was used to elicit data from beneficiaries and non-beneficiaries. Criterion (ii) was also met as our dataset came from farm households with similar socio-economic and demographic conditions as well as a similar economic environment. To meet precondition (iii), the propensity score was estimated by using the sample households' observable characteristics that were relevant for both participation in the program and for the outcome variable of interest.

For the FSP program, we estimated the propensity score for participation in the program with a logit model using observable variables that included both determinants of participation in the programs and factors that affect the

outcome. Once we estimated the propensity score that appeared to capture the similarities, we used these similarities to match each beneficiary with his/her closest non-beneficiary. A review of evaluation literatures (Becker and Ichino, 2002; Caliendo and Kopeinig, 2008; Dehejia and Wahba, 2002; Smith and Todd, 2005) show that there are four most commonly used methods to do this: Kernel Matching, Nearest Neighbour Matching, Stratification Matching, and Radius Matching. Algorithmic matching estimators differ according to the number of matched control units and how multiple matched control units are weighted if more than one control unit is matched to each treated unit (Abadie and Imbens, 2009; Morgan and Harding, 2006). The choice of a matching method is thus a difficult exercise and depends largely on the data at hand (Zhao, 2000). The quality of matching can also be compared using different statistical tests, see Caliendo and Kopeinig (2008) for details. In this paper, we performed several tests to select a preferred estimator and we chose the estimator that yielded statistically identical covariate means for both groups (Caliendo and Kopeinig, 2008), that provided a low pseudo-R<sup>2</sup> value (Sianesi, 2004) and statistically insignificant likelihood ratio test of all regressors after matching (Smith and Todd, 2005). Furthermore, Moreno-Serra (2009) indicated that a good matching estimator is expected to retain relatively larger observations for evaluating the impact of a program.

In this study, we implemented a kernel matching<sup>6</sup> estimator using the PSM algorithm developed by Leuven and Sianesi (2003) with STATA 12 to compute the average impact of the program among FSP households based on the above mentioned indicators. With kernel-based matching all beneficiaries are matched with a weighted average of all controls with weights that are inversely proportional to the distance between the propensity scores of beneficiaries and the controls. Following Heckman et al. (1997) and Smith and Todd (2005), the kernel matching estimator is given by:

$$ATT = \frac{1}{n} \sum_{i \in T} \left\{ Y_i - \frac{\sum_{j \in C} Y_{0j} K \left( \frac{p_j(X) - P_i(X)}{a_n} \right)}{\sum_{k \in C} \left( \frac{P_k(X) - P_i(X)}{a_n} \right)} \right\} \quad (3.6)$$

where T is the treatment group of household food security package beneficiaries, C is the comparison group of non-beneficiaries, K is a kernel function, and  $a_n$  is a parameter determining the kernel bandwidth. Lastly, for each specification model the associated standard errors of the mean impact estimator were also calculated. Abadie and Imbens (2008) showed that using

<sup>6</sup> A kernel matching estimator with a bandwidth of 0.25 was used for the analysis

the bootstrap after nearest neighbour matching, until recently a common approach to estimate standard errors in evaluation studies, does not yield valid estimates. However, bootstrapping standard errors for a kernel matching estimator has not been subject to this criticism because the number of observations used in the match increases with the sample size (Black and Smith, 2004; Gilligan and Hoddinott, 2006). Hence, we also calculated the bootstrapped standard errors for the impact estimators.

Finally we investigated whether the average treatment effect varied depending on household or individual characteristics. A convenient way to test whether ATT's differ across households is to recover the individual treatment effects from the matching exercise and regress them on the initial household characteristics (Wagstaff et al., 2009). Accordingly we computed these values for each household in the matched FSP group as the difference between the FSP household's observed food calorie intake and its counterfactual outcome.

As discussed, PSM can account for selection bias due to observable characteristics used in the matching process. However, as Smith and Todd (2005) described the bias due to selection on unobservables remains as its drawbacks. Selection on unobservables, or 'hidden bias' as Rosenbaum (2002) calls it, are driven by unobserved variables that influence treatment allocation as well as potential outcomes (Becker and Caliendo, 2007). Accordingly, following Rosenbaum (2002) we performed sensitivity analysis to examine the vulnerability of the estimated impact to unobservables.

### **Conditioning variables for program participation**

The construction of the unobservable counterfactual forms the basic dilemma of impact evaluation. The propensity score matching estimator used in this analysis is a way to 'correct' the estimation of treatment effects, controlling for the presence of confounding factors, which helps to control the sources of selection bias. It provides reliable estimates of program impact provided sufficient control variables relevant to modelling the program participation decisions are used. Accordingly, in propensity score matching it is desirable to condition the match on variables that are highly associated with the outcome variables (Heckman and Navarro-Lozano, 2004). Smith and Todd (2005) noted that there is little guidance available to researchers on how to select the set of conditioning variables used to construct the propensity score. Thus we focussed on finding a set of conditioning variables that were highly associated with the program eligibility and the outcome variable. Fortunately, our data set contained a rich set of conditioning variables to control program participation decisions in order to find the closest match possible.

As described earlier, the FSP program is intended to serve the very poor farm households. One way of judging the welfare level of rural households in the study region would be on the basis of assets owned. Hence, land and livestock ownership are included as these are the two basic assets in the Ethiopian rural economy. Lack of these assets was associated with program eligibility. Pre-intervention demographic variables such as type and age of household head, family size, number of children under five and dependency ratio associated with program eligibility and the outcome variables were also included.

Furthermore, we included a control variable for households' proximity to basic physical infrastructure. With this rich set of control variables (Table 3.1) and a relatively large and comparable sample size (in both the treatment and the comparison group) we could capture many of the determinants of participation typically unobservable to the researcher. This helps to reduce a potentially significant source of bias in propensity score matching estimators.

Table 3.1: Variable description and measurement

Variable	Type and definition	Measurement
Dependent variable, Treated	Dummy, beneficiaries of FSP	1 if yes, 0 otherwise
Explanatory variables		
SEX	Dummy, sex of household head	1 if head is male, 0 otherwise
AGE	Continuous, age of household head	Age of the household head in years
EDU	Dummy, whether the head can read and write	1 if he/she can, 0 otherwise
FSIZE	Continuous, family size	Size of the household in numbers
CHILD	Continuous, children under five years	Number of children under five
DEPR	Continuous, dependency ratio	Ratio of dependent members to the productive age group
LAND	Continuous, size of land holding	Hectare
TLU	Continuous, livestock holding	Tropical Livestock Unit
OXEN	Continuous, oxen holding	Tropical Livestock Unit
VAgEQP	Continuous, value of agricultural equipment owned	Ethiopian Birr
MKTDIST	Continuous, distance to the nearest market	Walking distance in minutes
AWRDIST	Continuous, distance to all weather road	Walking distance in minutes

### 3.2.1.3 NDVI analysis for vegetation change detection

Tian et al. (2007) used time series of remote sensing imagery to confirm whether government policy aimed to reduce expansion of the urban areas into agricultural lands were met in Haikou City, China. As an analogy, the role

of enclosures as a policy instrument was examined by investigating the change in vegetation cover for the period 2001 to 2009. Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). It involves the application of multi-temporal datasets to quantitatively analyse the temporal effects of the phenomenon (Lu et al., 2004). Accordingly, the temporal changes in vegetation that have occurred in the two study sites were examined by applying the Normalized Difference Vegetation Index (NDVI). According to Lawrence and Ripple (1998), NDVI is also the most common vegetation index applied in vegetation change studies and is well correlated to vegetation biomass.

From the 2001 to 2009 hyper-temporal SPOT-NDVI datasets, only nine decadal images from the last decade of February were considered for this analysis. Temporal analysis was performed on the datasets using ILWIS GEONETCast toolbox functionality. The original images were sub-mapped to the study sites and a ten-day composite NDVI map for the third decade of February was produced for both study sites for the period 2001 to 2009 to investigate the temporal change in vegetation cover. To examine the consistency of the change in vegetation, NDVI anomalies have been computed. For the two study sites, temporal changes in NDVI and precipitation for the period 2001-2009 were analysed to investigate the effect of rainfall on vegetation greenness by relating those data against time. Consequently, a trend line was fitted to evaluate the deviation from the mean as well as determine the magnitude of changes.

Change detection analysis was subsequently applied. Several methods are available for detecting change in satellite images based on multi-temporal digital data. Some of the methods employed for change detection studies as mentioned by Singh (1989) are: vegetation indices differencing; principal components analysis; change vector analysis; and image regression. As Hubert-Moy et al. (2001) described it the choice of method is dependent on the area characteristics. In this study a vegetation index differencing technique is applied for the change detection analysis, which has the advantage of emphasising differences in the spectral response of different features by reducing impacts of topographic effects (Lu et al., 2004). NDVI image differencing is a technique whereby changes in NDVI values between two images are derived by cell-by-cell subtraction of co-registered datasets based on spectral differences before and after the events. According to Dobson et al. (Dobson et al., 1995), the basic premise for image differencing is that subtraction results in an image dataset where values less than or greater than zero indicate areas of change. NDVI datasets can therefore be used for a variety of purposes, typically by determining the differences in NDVI with respect to the same period in previous years or with respect to the

long-term average, and by trend monitoring. Accordingly, we compared SPOT NDVI of 2009 with respect to the long-term average to monitor the long-term vegetation changes in both study sites. In order to perform the differencing, we first produced the average NDVI map for the year 2001-2008. Then the average NDVI map of 2001-2008 (8 years average) was subtracted from the 2009 SPOT NDVI map to obtain the difference image, which is a better way to see whether the NDVI map in 2009 is performing worse or better compared to the average of the previous years.

As Dobson et al. (1995) described, a critical element in image differencing change detection is defining threshold values that indicate where a significant change has occurred. Often, a standard deviation (SD) from the mean is established as the threshold value. In other cases, most researchers prefer to experiment empirically, placing the threshold at different locations in the tails of the distribution until a realistic amount of change is empirically selected after examining histograms of DN values (Dobson et al., 1995). However, the amount of change selected and eventually 'recoded' for display must be based on familiarity with the study area. A +1 SD was selected as the threshold value because the resulting classification appeared reasonable based on knowledge of the study area.

### 3.2.2 Data used

For examining the effect government policy intervention targeted at improving regional food self-sufficiency, data on indicators of regional food availability were collected. Data on annual agricultural crop production, population, fertilizer and improved seed supply, and irrigation coverage were acquired from the regional Bureau of Finance and Economic Development (BoFED). Data on the quantity of food aid was acquired from the Disaster Prevention and Preparedness Commission, Addis Ababa, Ethiopia. In addition, historical records of monthly precipitation data for the period 2000-2011 were collected from the Ethiopian National Meteorological Services Agency.

To empirically test the impact of program intervention upon household food security, a household survey is conducted in three rural *woredas* from January to February 2011, and includes 400 farm households randomly drawn from 9 *tabias*. A three-stage sampling techniques was employed to draw the samples. First, three *woredas* were purposively chosen for the study. Accordingly 2 *woredas*, Enderta and Kilde Awelaelo, for the FSP program participants and one, Hintalo Wajirat, for the non-FSP household were selected. Second, 4 *tabias* from the program *woreda* were purposively chosen. Concomitantly, 5 comparable non-program *tabias* from Hinatlo Wajirat *woreda* were purposively chosen based on their similarity in their social and economic characteristics, infrastructure, and agro-climatic characteristics with the program *tabias*. Finally, random sampling technique

was employed to draw a total sample size of 189 and 211 farm households from the program and non-program *tabias* respectively.

To generate the required data a structured questionnaire was administered with the household<sup>7</sup> being the unit of analysis. The survey captured information related to demographic characteristics, asset endowment, household food consumption, economic activities, wealth and income, household expenditure on food and non-food items, access to basic infrastructures and agricultural services. Enumerators with knowledge of the local language and experience with socio-economic surveying were recruited locally and trained based on the content of the questionnaire. Prior to the actual fieldwork the questionnaire was pre-tested. All forms were manually checked to ensure that they had been completed fully.

To empirically detect the change in vegetation induced due to the government policy intervention of area enclosures, a study is conducted in randomly chosen *woreda*, Enderta *woreda*, and includes two randomly drawn study sites: protected and unprotected sites. A time series of SPOT vegetation ten day composite Normalized Difference Vegetation (NDVI) images (S10 product) with spatial and temporal resolution of 1km×1km and 9 years respectively were used to detect the change in vegetation. The NDVI products were acquired from VGT4 Africa of the DevCoCast project website, <http://www.vgt4africa.org>, for the period 2001-2009. The product is used for monitoring of long-term vegetation changes and climate change models, seasonality studies; early warning of failing growing seasons; and as an indicator and alert function for drought events. The vegetation indices derived from the SPOT Vegetation enable improved estimates of biomass. The SPOT Vegetation NDVI data is useful to monitor photosynthetically active vegetation as the VEGETATION Instrument on board the satellite is equipped with better navigation, atmospheric correction, much reduced geometric distortions and improved radiometric sensitivity systems (Gobron et al., 2000; Tucker et al., 2005). In addition, the NDVI product used in this study is a 10-day NDVI maximum value composite (MVC). The MVC 10-day synthesis has an advantage of minimizing cloud and noise. That is to say: for a given pixel having been viewed several times, the selected reflectance corresponds to the viewing with the highest ground NDVI.

According to the seasonal calendar of the study area, all images were taken in the third decade of February. During this season (December to February) there is no effective rainfall and therefore only evergreen trees, bushes and shrubs can be captured with the remotely sensed images. Consequently, the

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<sup>7</sup> A household has been defined as a group of people in a housing unit living together as a family and sharing the same kitchen.

temporal variations in the NDVI reflect the presence of vegetation cover. Against this backdrop, February was selected as the ideal month for this study to examine the vegetation change thus preventing a dynamic change of vegetation cover that could occur due to seasonal variations.

### **3.3 Results and discussion**

#### *3.3.1 Estimating food availability at the regional level*

Domestic production of food grains or food availability was basically considered to evaluate government's effort made to boost production and ensure food security. Increase in agricultural productivity is an important factor for ensuring food security both through its impact on food availability as it contributes to output growth and to food access as it affects rural farm income.

Result of our FBS revealed that food requirement in the study region increased at 2.5 per cent while the food availability improved by 10.8 per cent (Table 3.2). As a result, the food deficit declined by 104 per cent over the period of 2000-2010. The self-sufficiency ratio (SSR) has increased by 11.5 per cent. The self-sufficiency ratio expresses the magnitude of production in relation to domestic utilization. Based on the government official food grain production figures the food grain SSR for Tigray region is gradually increasing. The lowest self-sufficiency rate is observed in 2002, which is attributed to the crop failure due to the severe drought occurred all over the country indicating the vulnerability of the agricultural sector to the natural vagaries. Moreover, the food availability ratio has increased by 10.8 per cent. After the major drought in 2002/03 that resulted in GDP contraction, crop production has increased dramatically (Table 3.2). The increase is mainly due to the expansion of cultivated land; increased and better use of improved technologies, including water conservation, fertilizer application, improved seeds, pest control and the expansion of irrigation schemes.

*Impacts of program interventions upon food security and environmental rehabilitation*

**Table 3.2: Food Balance Sheet for Tigray Region, 2000 – 2011**

No.	variable	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Growth Rate (%)
1	Production of cereals in ("000" MT)	748.4	843.3	414.0	608.1	657.9	715.0	1115.9	1275.9	1335.2	1597.5	2224.2	2479.5	14.2
2	Less 15% Post-harvest loss	112.2	126.5	62.1	91.2	98.7	107.2	167.4	191.4	200.3	200.3	239.6	333.6	
3	Less 6% seed	44.9	50.6	24.8	36.5	39.5	42.9	66.9	76.5	80.1	95.9	133.5	148.8	
4	Net production (1-2-3)	591.2	666.2	327.1	480.4	519.7	564.9	881.6	1007.9	1054.8	1262	1757.1	1958.8	14.2
5	Food Aid	9.8	1.3	26.5	18.1	6.6	-	-	-	-	-	-	-	
6	Total grain available (=total supply) (4+5)	601.0	667.6	353.6	498.6	526.4	564.9	881.6	1007.9	1054.8	1262	1757.1	1958.8	13.6
7	Total population <sup>8</sup> ("000")	3695	3797	3901	4006	4113	4223	4335	4454	4576	4699	4826	4956	
8	Food requirement at 2.25 Qt per person ("000" MT)	831.3	854.3	877.7	901.3	925.4	950.2	975.4	1,002.1	1,029.6	1057.3	1085.8	1115.1	2.5
9	Food Balance (6-8)	-230.3	-186.7	-524.1	-402.8	-399.0	-385.3	-93.8	5.8	25.2	204.7	671.3	843.7	
10	Self Sufficiency Ratio (4/8)	0.7112	0.7798	0.3726	0.5330	0.5616	0.5945	0.9038	1.01	1.024	1.1936	1.6183	1.7566	11.5
11	Food Availability Ratio (6/8)	0.7230	0.7814	0.4028	0.5531	0.5688	0.5945	0.9038	1.01	1.024	1.1936	1.6183	1.7566	10.8
12	Average annual precipitation (mm)	422	643	461	480	576	617	677	543	561	605	598	614	

Source: Computed by the authors, using data from Regional Bureau of Finance and Economic Development, and the Regional Disaster Prevention and Preparedness Commission, Tigray

The area under food grain increased dramatically since 2005 showing nearly a threefold increase as compared to the year 2000 (Table 3.3). Furthermore, fertilizer consumption has experienced a steady rise from 58.6 tons in 2000 to about 352.4 tons in 2011. The amount of improved seed supply also increased since 2005. A decline in Fertilizer and improved seed use was observed in the period 2002-2004. This reduction is to be attributed to an increase in input prices where more expensive transportation costs kept prices higher compounded by lack of a competitive improved seed market sector. Besides, substantial farmers were not able to get their investment back because of the 2002 drought and this situation generated a loss of confidence for some years to continue to buy-into the credit schemes. But the arrangements worked out to facilitate farmers' access to rural credit to enable them to purchase fertilizer and other agricultural inputs contributed for the increase in fertilizer consumption over the period. However, still the fertilizer market is not well developed and solely owned by the government.

The extension program was expanded extensively and is producing tangible results in terms of increasing productivity. The massive extension programs on soil and water conservation had significant impact on changing the environment. In a related study, Pender and Gebremedhin (2008) found that land investments and land management practices introduced in the region have a significant impact on the value of crop production and predictive crop productivity. The role of development agents was also pivotal in implementing the extension programs. The number of development agents

<sup>8</sup> Population is computed based on regional population growth rate taking 2000 as a base year

assigned to every *tabia* centres has increased from one in 2000 to three in 2006 with specialization in crop cultivation, natural resource protection and conservation, and animal husbandry. This new way of organization has helped in narrowing the gap in extension workers' to farmers' ratio; and these agents trained as many farmers as possible the benefits of packages by demonstrating practically.

Table 3.3: Distribution of agricultural inputs and area cultivated, 2000-2011

Year	Fertilizer consumption (Tone)	Improved seed consumption (Tone)	Area cultivated (Hectare)
2000	58.6	9.7	560,510
2001	135.7	7.3	635,100
2002	132.9	6.5	566,237
2003	117.0	0.34	446,372
2004	117.0	0.34	727,944
2005	141.8	10.9	701,905
2006	134.2	17.9	1,036,518
2007	147.8	27.7	1,064,595
2008	166.3	34.7	1,097,034
2009	185.1	35.1	1,224,598
2010	291.2	37.2	1,349,902
2011	352.4	38.7	1,447,866

Source: Bureau of finance and economic development, Tigray.

Furthermore, due to the variety of water harvesting schemes introduced since 2002, the amount of land under irrigation has increased from 4773 ha in 2000 to 125,558 ha in 2011. Thus, improvements in water use efficiency had helped the region to increase production over the period and these interventions had also given an opportunity for farmers' access to water resource and increased the likelihood of using improved inputs due to reduced risk of crop failure. However, the water harvesting scheme program implementation was not without problem. There were signs that these programs were tried to implement through measure of coercive persuasion while households were voicing problems on the technology in some areas of the region.

By and large, the result of the Food Balance Sheet analysis revealed that food availability and regional food self-sufficiency increased over the period 2000-2011, with dramatic increase over the period 2005-2011. Increase in the productivity was consistent and since 2007 the regional crop production has met the food requirements considering the necessary per capita dietary energy supply of 2,200 calories. The observed growth has raised the living standard of many poor households from a very low base as increase in productivity is one of the major indicators of economic development. On the other hand an attempt was made to check the influence of other exogenous

variables, rainfall in particular, on the observed increase in crop production. The temporal average annual precipitation exhibits variability over the period with a coefficient of variation of 13.6 per cent, which is high compared to the national figure of 8 per cent, while the production of cereals shows a consistent increase since 2003. This indicates that the policy instruments put in place are significant in improving food self-sufficiency at the regional level. However, a positive association ( $r=0.43$ ) between crop production and rainfall was also observed, indicating the dependence of crop agriculture on the blessing of nature.

Government official data also revealed that the region has made impressive development gains in the past years. Since 2003/04, the regional economy has grown by an unprecedented 14.3 per cent on average. This growth has emanated from the growth of smallholder agriculture and it can be inferred that the momentum of economic growth observed in the region is strong enough to sustain progress on reducing rural poverty and ensuring food security. According to reports from the World Bank (2012) and ECA (2011), similar development gains have been observed in the country over the same period. The sustained economic growth observed in the country over the past consecutive years had contributed to the decline in the proportion of food poor people (food poverty head count index) in the rural areas from 41.1 per cent in 2000 to 34.7 per cent in 2010/11 (MoFED, 2012). The Human Development Index (HDI) has also improved over the period as follows: in 2000, 0.274; in 2005, 0.313; in 2009, 0.352 and in 2011, 0.363 (UNDP, 2011).

However, food supply indicators at the regional level can provide some useful information regarding trends in food availability but they are often too aggregated to detect pockets of food deficit in a given woreda. Thus, the Food Balance Sheet analysis should also be looked at a disaggregated basis to detect differences across woredas. Thus, we also examined the spatial effect of government interventions across the 34 rural woredas. The findings of the FBS computed at woreda level revealed that improvements in food self-sufficiency ratio were observed in all woredas except in Naeder Adet woreda, where the food self-sufficiency ratio is decreased by 6.1 per cent (See Appendix Table 3.1). In general, the region had an impressive performance on improving its food self-sufficiency on a sustained basis since about 2004.

### *3.3.2 Estimating impacts on household food security*

#### **Propensity score estimate**

Prior to non-parametrically estimating the impact of the FSP program on food calorie intake, the propensity scores required specification justifying that a household had been included in the FSP. Thus we had to respect the

conditional independence assumption that the covariates are exogenous and unaffected by the program. Accordingly lagged variables were employed to ensure this condition (Caliendo and Kopeinig, 2008). We used a logit model to predict the probability to participate in the household food security program and we included different ranges of household characteristics as regressors.

Three different logit specifications of the propensity scores were used in order to check the robustness of the main result and the consistency of the estimated causal effect, which could have been affected by the set of exogenous variables used to estimate the p-score (Smith and Todd, 2005). The 'common support' restriction was imposed to improve the quality of the matches and the balancing property was set and satisfied in all regressions at the 95 per cent level of statistical significance. Hence we ensured that the mean propensity score was not different for the treatment sample and the sample of comparison observations at various levels of propensity scores. The estimated results of the three logit formulations of the propensity score are presented in Table 3.4. Significant coefficients in the estimated equation implied that FSP and non-FSP households were different with respect to the corresponding variable. We found that the estimates of the FSP programs were sensitive to the choice of variables used for conditioning participation, so we tried various alternative specifications, and chose the model that appeared most robust. The preferred specification should have a relatively high accuracy and expected sign of coefficients to key variables.

Specification 1 was estimated by including only the households' key physical resources in the model. This specification had a pseudo-R<sup>2</sup> of 0.70 and the coefficients of two of the key variables, oxen ownership and proximity to the market, influencing the targeting of food security package program were not significant. In the case of specification 2, we included different ranges of household demographic characteristics, preferring a larger set of variables making it less likely for unobservable characteristics to remain out of the matching process. Model 3 was estimated by including the linear and quadratic forms of all continuous variables present in specification 2. However, most of the original explanatory variables did not achieve the anticipated correlation with the dependent variable in model 3. For instance, oxen ownership, and proximity to an input and output market had no influence on participation in the program.

As indicated in Table 3.4 specification 2 did improve the accuracy of the model and a larger number of variables achieved statistical significance. In particular, size of the landholding, livestock ownership, proximity to an input and output markets significantly influenced household participation in FSP. As expected, participation in the program was negatively and significantly

influenced by the value of agricultural equipment owned. On the other hand proximity to all weather roads and to a market, and a household's participation in the program were also directly correlated. Moreover, specification 2 had a better accuracy than the other two specifications due to its relatively larger pseudo-R<sup>2</sup> value of 0.72. Ultimately, results reported here are based on a preferred specification for which we could not reject equality of the average propensity score, nor reject equality of the mean of each control variable, between treatment and comparison observations within the propensity score. Accordingly, we used specification 2 as our core specification to produce the main results in this chapter but the other specifications were also used to check the robustness of our main result. The estimated mean propensity score using the core specification for the whole sample was 0.472 (with a standard deviation of 0.453) implying that the average probability of participating in the FSP program for all individual households was 47.2 per cent.

Table 3.4: Logit estimates for participation in the FSP program (n=400)

Logit specification	Specification (1)	Specification (2)	Specification (3)
SEX		1.519* (2.08)	0.949 (1.50)
AGE		-0.461* (1.85)	0.738 (1.17)
EDU		-1.387*** (3.15)	-1.294** (2.63)
FSIZE		-0.189 (-0.13)	-0.709 (1.09)
PCHLD		1.185*** (3.85)	1.036 (1.16)
DEPR		0.387 (1.32)	-0.988 (0.77)
LAND	-2.970*** (4.78)	-3.198*** (4.88)	-4.369** (2.65)
TLU	-1.537*** (6.24)	-1.772*** (5.18)	-1.256** (2.21)
OXEN	0.043 (0.17)	-1.026*** (3.79)	-1.297 (1.57)
VAgEQP	-0.011*** (3.66)	-0.158*** (5.72)	0.008 (0.57)
AWRDIST	-0.085*** (3.95)	-0.102*** (5.21)	-0.063 (0.69)
MKTDIST	-0.026* (1.84)	-0.045*** (3.48)	0.001 (0.02)
AGE squared			0.053* (1.89)
FSIZE squared			0.067 (1.22)
CHLD square			0.087 (0.20)
DPR squared			0.522 (1.11)
LAND squared			0.572 (0.89)
TLU squared			0.533*** (3.36)
OXEN squared			0.089 (0.29)
VAgEQP squared			-0.006* (1.88)
AWRDIST squared			-0.004 (0.48)
MKTDIST squared			-0.0005 (0.70)
Constant	11.62*** (6.35)	12.19*** (8.17)	10.25*** (3.35)
Log likelihood	-76.61	-87.07	-82.57
Pseudo R2	0.7015	0.7231	0.6852
Chi2	389.15***	400.07***	378.17***
P	0.000	0.000	0.000

Note: Dependent variable equals 1 if household participated in the FSP program and 0 otherwise. Absolute value of z-statistics in parenthesis. \*, \*\* and \*\*\*= Significant at probability levels of 10%, 5% and 1% respectively.

### Average impact of participation in the FSP

Using estimated propensity scores for the program from the different model specifications in Table 3.4, the impact of the integrated food security package program on household calorie intake is estimated with kernel-based matching<sup>9</sup>. We also estimated the FSP impact using other matching estimators particularly the nearest neighbour matching (NN) estimator, to assess the robustness of the results. Matching with replacement was performed. The latter minimized the propensity-score distance between the matched comparison units and the treatment unit: each treatment unit being matched to the nearest comparison unit, even if a comparison unit was matched more than once. This is important in terms of reducing bias. By contrast, when matching without replacement, and with few comparison units similar to the treated units, one may be compelled to match treated units to comparison units that are quite different in terms of the estimated propensity score. This increases bias, but could increase the accuracy of the estimates. An additional problem of matching without replacement is that the results are potentially sensitive to the order in which the treatment units are matched (Dehejia and Wahba, 2002).

Table 3.5 presents estimates of the average impact of participation in the FSP. Overall, matching estimates show that the FSP program has a positive and robust effect on household food calorie intake. More specifically, the program has raised food calorie intake by 772.19 kilo calorie per day per adult equivalence unit. This suggests that the FSP program has a causal influence on total food consumption when individuals are matched according to relevant socio-demographics, assets and other covariates. If we allowed someone to be in the FSP (i.e. provided access to a food security loan for a package of activities and training) their food calorie intake would on average increase to 41.8 per cent above that of individuals not involved in the program. An explanation for this significant effect might be the close follow up, monitoring and implementation of the FSP by a technical staff, thus helping the program to improve food security for the beneficiary households. The number of development agents assigned to each *tabia* centre also increased from one to three over the past years. Thus, the role of development agents might have been pivotal in implementing the FSP package programs.

Furthermore, the integrated nature of the program provided ample opportunities for beneficiaries to choose a suitable component (or components) and participate depending on their needs and preferences. The household level FSP program is also a coordinated program involving key

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<sup>9</sup> We conducted the propensity score matching using the `psmatch2` procedure in Stata (Leuven and Sianesi 2003). Kernel was used with the bandwidth set at 0.25

players in the rural development of the region, in particular the regional Bureau of Agriculture and Rural Development, the regional Agricultural Marketing Promotion Agency, and the Dedebit Credit and Saving Institution - the leading locally operating micro finance institution in Ethiopia. We believe that the strong coordination among different key stakeholders contributed to the success of the program.

We also applied alternative specifications for estimation of the propensity scores and assessed whether differences in the propensity score equations affected our main result. As seen in Table 3.5, all the non-experimental methods show a positive program impact and the estimated impact of the program remains robust and statistically significant across all specifications of estimating the propensity scores. The results further clearly show that impact estimates vary with both matching algorithms. However, given the data available, the kernel algorithm seems to have performed best in the case of simple PSM, implying the validity of our impact estimate using the kernel matching estimator.

Table 3.5: FSP program impacts on households' food calorie intake, matching estimates (n=400)

	Specification 1		Specification 2		Specification 3	
	NN	Kernel	NN	Kernel	NN	Kernel
Household food calorie intake	599.28*** (4.62)	660.49*** (5.73)	691.01*** (4.14)	772.19*** (6.13)	634.86*** (5.33)	701.40*** (5.76)
Balancing property satisfied	Yes	Yes	Yes	Yes	Yes	Yes
Common support imposed	Yes	Yes	Yes	Yes	Yes	Yes
Observations						
FSP households	77	77	97	97	59	59
Non-FSP households	198	211	211	211	211	211

Note: Absolute values of t statistics on ATT are in parenthesis. These are based on bootstrapped standard errors using 50 replications of the sample. \* = Significant at 10% level; \*\* = Significant at 5% level; \*\*\* = Significant at 1% level.

### **Heterogeneous impacts of participation in the FSP**

The average impact of participation in the FSP may mask significant impacts of the program on some of the program households based on their characteristics. Taking the analysis a step further, we conducted a test for the presence of heterogeneity in the effect of the FSP across the program households.

The estimates show the impact of the program varied among beneficiaries (Table 3.6). The gain from the program was significantly larger for land-rich households. This implies that the impact estimate based on the full sample underestimated the true impact of the program for households with a larger holding size. The findings further indicated that the gain from the program was significant for household's closed to input and output markets.

Table 3.6: Regression analysis of variation in individual household treatment effects by initial household characteristics

Variables	Estimated coefficients
Male headship	154.58 (190.46)
Education household head	199.45 (166.75)
Family size	-70.02 (47.65)
Size of farm land holding	230.95 (115.93)**
Livestock ownership	67.07 (75.73)
Proximity to market	-20.03 (8.59)**
Constant	692.46 (333.75)**
Number of observations	97
F (6, 90)= 2.34** adjusted R <sup>2</sup> =0.14	

Note: Absolute values of standard error of the coefficients are in parenthesis. \* = Significant at 10% level; \*\* = Significant at 5% level

### Sensitivity analysis

As indicated, propensity-score matching approach cannot fully control for unobservable characteristics. In practice there may be unobserved variables that simultaneously affect the outcome, and the assignment into treatment. In such circumstance, a 'hidden bias' might arise to which influence the robustness of the matching estimators (Rosenbaum, 2002). As Ichino et al. (2006) suggested, the presentation of matching estimates should be accompanied by sensitivity analysis. Accordingly, we checked the sensitivity of the estimated treatment effects to selection on unobservables using the bounding approach developed by Rosenbaum (2002). We applied the mhbounds procedure by Becker and Caliendo (Becker and Caliendo, 2007) in STAT programs to aid in the construction of Rosenbaum bounds for the sensitivity testing.

This procedure uses the matching estimates to determine the confidence intervals of the outcome variable for different values of  $\Gamma$  (gamma)<sup>10</sup>.  $\Gamma$  captures the degree of association of an unobserved characteristic with the treatment and outcome required for it (the unobserved characteristic) to explain the observed impact (Duvendack and Palmer-Jones, 2011). DiPrete and Gangl (2004) indicated that if the lowest  $\Gamma$ , which encompasses zero, is

<sup>10</sup>  $\Gamma$  is the ratio of the odds that the treated have this unobserved characteristic to the odds that the controls have it

relatively small (say  $< 2$ ) then one may state that the probability of such an unobserved characteristic is relatively high and the estimated impact is therefore sensitive to the existence of unobservables.

Table 3.7 reports the mhbounds results, showing that under the assumption of no hidden bias, when  $\Gamma = 1$ , the  $Q_{MH}$  test statistic indicates a highly significant treatment effect for improved food security program intervention on household food calorie intake. The two bounds in the Mantel-Haenszel output table (Table 3.6) can be interpreted in the following way: The  $Q_{MH+}$  statistic adjusts the MH statistic downward for positive (unobserved) selection. In our case, positive selection bias occurs when those most likely to participate tend to have higher food calorie intake even without participation in the program, and given that they have the same  $\chi$  vector of covariates as the individuals in the control group. This effect leads to an upward bias in the estimated treatment effect<sup>11</sup>. The effect is significant under  $\Gamma = 1$  and becomes even more significant for increasing values of  $\Gamma > 1$  if we have underestimated the true treatment effect. The  $Q_{MH+}$  reveals the study is insensitive to hidden bias at the 5% significance level. The sensitivity analysis thus indicates that the observed results on the impact of food security program on household's food calorie intake are insensitive to selection on unobservable or hidden bias.

Table 3.7: Mantel-Haenszel bounds for outcome = food calorie intake

$\Gamma$	$Q_{MH+}$	$Q_{MH-}$	$P_{MH+}$	$P_{MH-}$
1	3.057	3.057	0.0012	0.0012
1.1	1.931	4.738	0.0586	0.0003
1.2	1.468	4.877	0.0336	0.0073
1.3	1.027	5.229	0.0132	0.0111
1.4	0.759	5.444	0.0289	0.0106
1.5	0.368	6.088	0.0324	0.0146

Source: MH Bounds using STATA 12

Note:  $\Gamma = 1 \approx$  No 'hidden' bias;  $Q_{mh+}$ : Mantel-Haenszel statistic (assumption: overestimation of treatment effect);  $Q_{mh-}$ : Mantel-Haenszel statistic (assumption: underestimation of treatment effect);  $p_{mh+}$ : significance level (assumption: overestimation of treatment effect); and  $p_{mh-}$ : significance level (assumption: underestimation of treatment effect)

<sup>11</sup> The  $Q_{MH-}$  statistic adjusts the MH statistic downward for negative (unobserved) selection.

### 3.3.3 Effect of area enclosures in restoring degraded vegetation

Observed NDVI trend is an important input and appears reasonable from monitoring of long-term vegetation change perspective. In Senegal, for example, changes in Max NDVI have been related to changes in crop and rangeland use (Fuller, 1998), while in Tanzania positive trends in NDVI values in woodland and forest pixels have been related to changes in conservation policies (Pelkey et al., 2000). Numerous studies have also demonstrated that vegetation biomass and condition are often correlated with NDVI (Gamon et al., 1995; Hunt, 1994; Nilsson, 1995). Accordingly, we investigated the effect of area enclosure for purposes of environmental rehabilitation, vegetation regeneration in particular.

Our results indicated that the temporal SPOT NDVI images for area enclosure demonstrate a noticeable change during the period of 2001-2009, while no change was observed for the unprotected area (Figure 3.1 and 3.2). Figure 3.1 clearly shows a consistent increase in NDVI values between the period 2001 and 2009 in the area enclosure. The positive increase in NDVI values indicates high green leaf biomass, canopy closure, or leaf area (Myneni et al., 1997; Sader and Winne, 1992).

On the other hand, the temporal SPOT NDVI images for the unprotected area shows a better vegetation condition at the beginning of the study period compared to the enclosure area. However, the vegetation greenness starts to decline dramatically since the year 2003. This is mainly attributed to the increasing population and their persistent need for subsistent income and fuel wood that led to vegetation clearance in the area. The unprotected area is currently under a great pressure of wood collection as many people are collecting and transporting wood for sale to urban areas mainly to Mekelle city. On the contrary, Figure 3.1 clearly shows that vegetation condition in the enclosed area was very poor at the beginning of the study period and remarkable change was observed over time. This change is attributed to its closure from livestock interference and indiscriminate tree felling, which actually fostered regeneration of vegetation cover in the area.

Moreover, the dominant vegetation type of the enclosure area is described as dense mixed bush land dominated by *Euclea shimperi* locally known as 'Kilio'. The cover types are in the average range between 1m and 3m in height and with canopy cover of between 50 and 80 per cent. In the month of February, it also consists of dry grasses with some green *herbaceous* species such as *Rumex abyssinicus* locally known as 'Hohot', *Aloe barbadensis* locally known as 'ika' and *Ocimum lamiifolium*. On this basis, the increasing positive change in the SPOT NDVI images observed in the area enclosure is strong evidence that it is mostly related to improved vegetation as a result of the protection of the area from human and livestock interference.

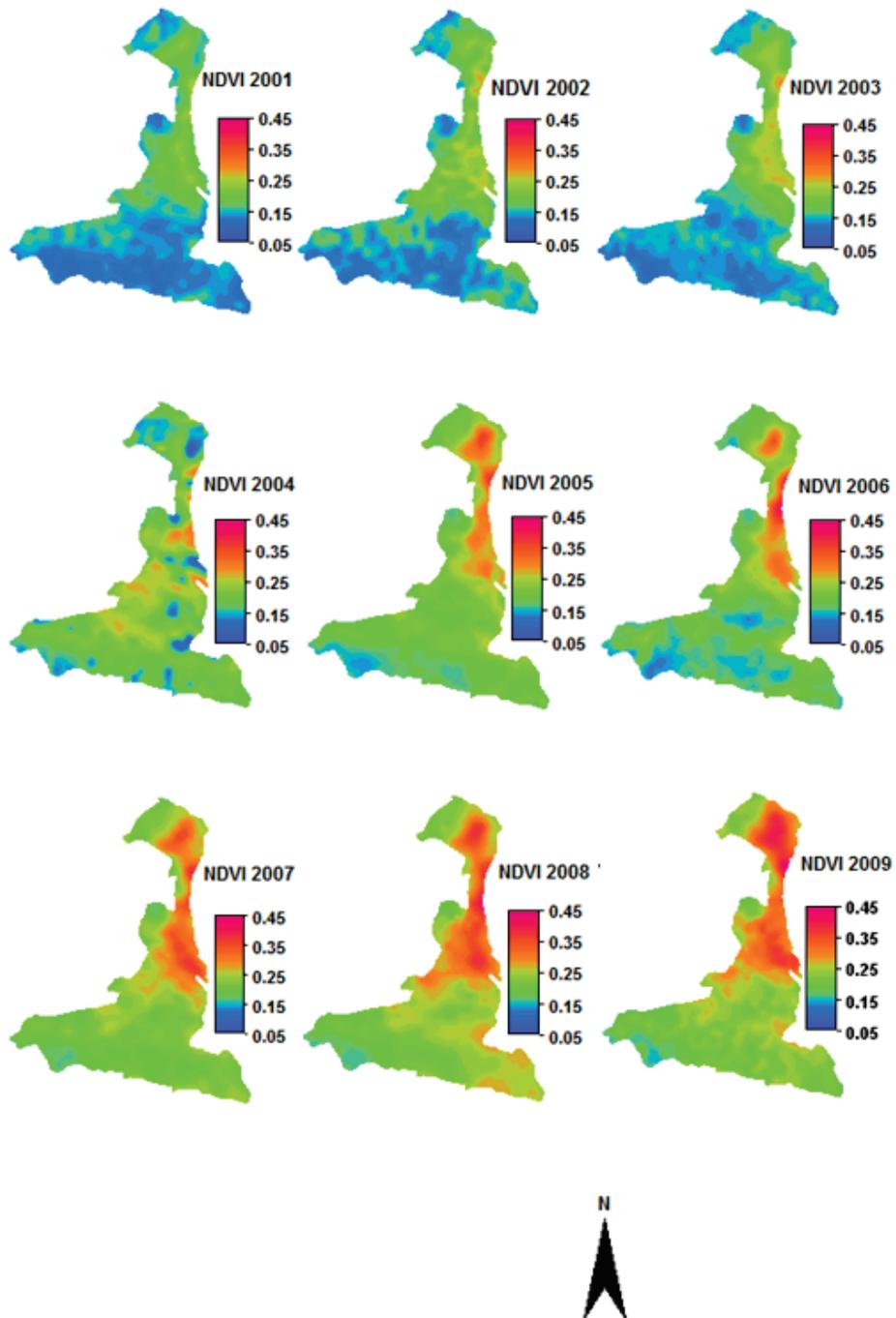


Figure 3.1: NDVI maps of the area enclosure for the period 2001-2009

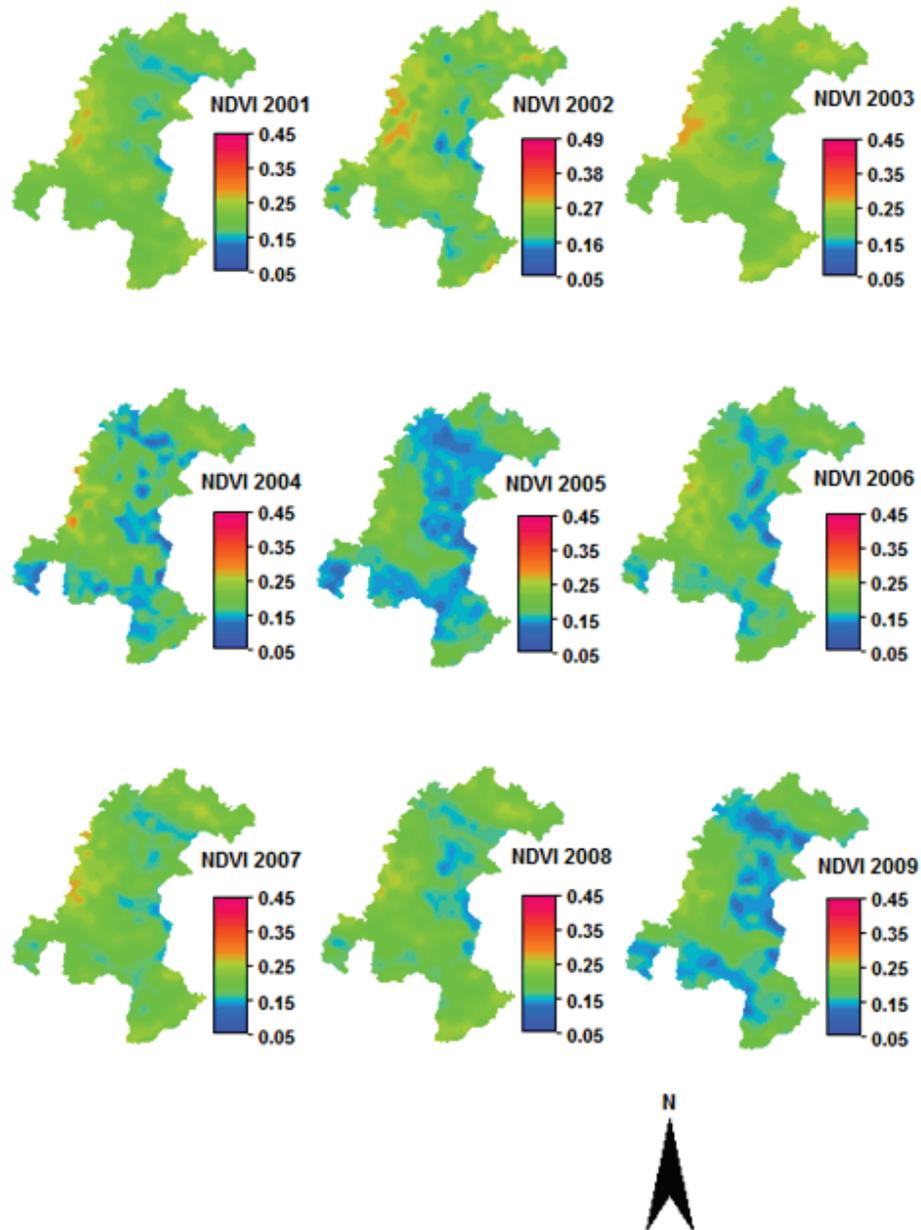


Figure 3.2: NDVI maps of unprotected area for the period 2001-2009

The temporal change in vegetation conditions was further analysed by computing NDVI anomalies for both the study sites (Figure 3.3). The result of the temporal analysis reveals that a consistent positive increase of the NDVI anomaly exists for the area enclosure while the NDVI anomaly for the unprotected area indicates a declining trend and exhibits variability over time

accentuated with positive and negative anomalies. In the period 2001 to 2009, with a linear trend line fit ( $R^2=73\%$ ) every year there is 8.03 wavy NDVI increase in the area enclosure while the NDVI anomaly in the unprotected area tends to decline by 3.62 ( $R^2=57\%$ ) annually indicating a declining trend in vegetation cover in the area. The aforementioned findings make it clear that there is strong evidence that enclosure areas appear to be successful in regenerating natural vegetation. Although the comparison is done for the dry season we also verified the results by examining the effect of other exogenous factors mainly rainfall.

One climatic station namely Mekelle airport, which is appropriate and nearby the selected study sites was considered to investigate the effect of rainfall. As Figure 3.3 makes it clear, rainfall at Mekelle airport station tended to decline annually by  $8.9 \text{ mm y}^{-1}$  for the period 2001 to 2009. During the nine years of rainfall recording, mean annual rainfall, amounts were below the mean in four years. The rainfall pattern over the study area exhibits variability's over time with a high coefficient of variation (25%) accentuated with positive and negative anomalies. Moreover, the study woreda has experienced both dry and wet years over the last 9 years. Years like 2002, 2004, and 2008 can be described as dry or meteorological drought years in statistical terms. From the foregoing analysis, we found that annual rainfall in the study woreda does not show an increasing trend over the time period 2001-2009, and the effect of rainfall was not significant. Consequently, it can be stated that the observed increasing trend in vegetation health in the enclosed area is attributed to the protection of the area from human and livestock interference, which is an outcome of the conservation policies.

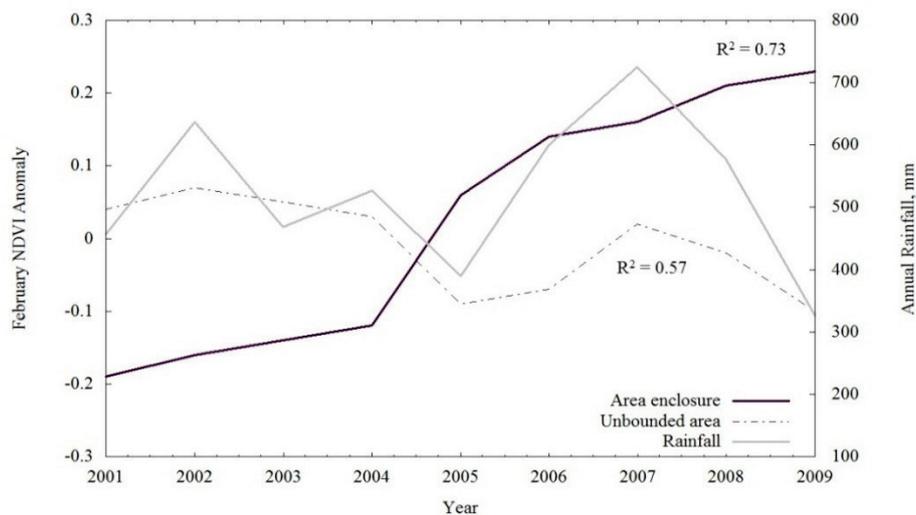


Figure 3.3: Average NDVI anomalies for area enclosure and unprotected areas vis-à-vis annual rainfall for Mekelle Airport station for the period 2001-2009.

Furthermore, a vegetation differencing technique was employed to investigate the direction of change and to examine whether vegetation conditions at 2009 are worse or better as compared to the average of the previous years. In our study, the average of 2001-2008 NDVI values were subtracted from 2009 SPOT NDVI values. In the resulting image dataset, values that are negative or close to zero indicate areas where NDVI decreases in 2009 or remains relatively unchanged, while positive values represent areas exhibiting an increase in NDVI in 2009.

Reviewing the vegetation index difference on both the area enclosure and unprotected area revealed that a positive change in the vegetation cover is observed in 2009 compared to the previous 8 years average for the enclosed area, while no change is observed for the unprotected area (Figure 3.4). This again indicates that areas which are protected from human and animal intrusion have a good chance of regeneration. The vegetation change detection further indicates that 11 per cent (5,030 hectare) of the protected area showed a substantial increase over the last 9 years when compared with the average NDVI of the previous 8 years. 57 per cent (26,924 hectare) of the protected area showed a moderate change and 32 per cent of the area does not show a change over the period. On the other hand, the results of the vegetation index indicated that no change was observed in the unprotected area in 2009 compared to the previous 8 years average (Figure 3.4).

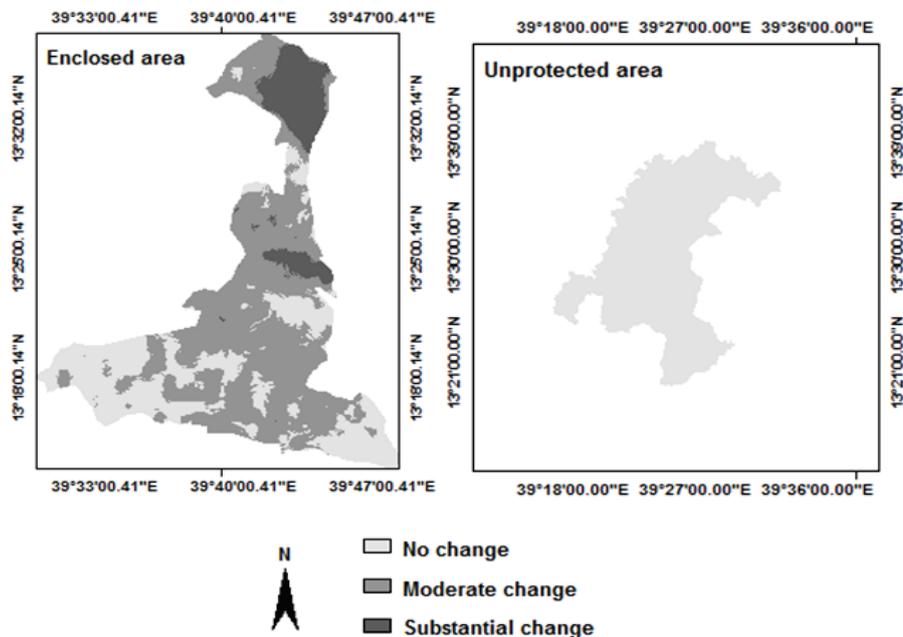


Figure 3.4: Classified NDVI difference map for area enclosure and unprotected area, Enderta Woreda

The vegetation change analysis thus reveals a vegetation restoration of degraded land that was gradually achieved in the area enclosure. Moreover, despite the study sites (the enclosure and unprotected) have uniformity in the amount rainfall, the enclosure area did not have the same NDVI reading. The difference hence is due to the 'with' and 'without' government intervention to protect the areas. Thus, the increase in the NDVI noticed during the dry season month, February 2009, is not attributed to rainfall. Our remote sensing analysis from the sample sites therefore provides evidence that a consistent positive improvement in vegetation regeneration is observed in the area enclosure. This indicates the role of area enclosures, exclusion of livestock grazing and human interference from selected areas, as an effective instrument to allow regeneration of degraded vegetation covers with concomitant benefits for reversing land degradation. Similar findings are reported in study of Palik et al. (2000) and Hobbs and Harris (2001). Aerts et al. (2004) also regarded area enclosure as a powerful tool for environmental rehabilitation.

This general finding echoes the findings of Kindeya (1997); Mengistu et al. (2005), Muluberhan et al. (2006) and Nyssen J. et al. (2007) where similar encouraging results on area enclosures have been reported. Descheemaeker et al. (2006) also reported area enclosures as an important measure to combat land degradation and to increase biomass production. The Nyssen et al. (2007) study on the impacts of environmental rehabilitation in Tigray also revealed that sheet and rill erosion rates have decreased, spring discharge, vegetation cover and crop production have improved.

Finally, the involvement of local communities in the rehabilitation program has contributed a lot to the success of the area enclosure program. Devolution of natural resource governance to the lowest level; to those who are close to the problems of natural resource is also one of the important instruments introduced in the environmental rehabilitation measures. Involving community members in site selection and decision-making for the enclosure areas has created a sense of ownership and the community's commitment for effective protection and sustainable management of the resources. Enforceable community laws are also crucial for the success of conservation efforts in the region. The involvement of the community members in designing conservation strategies is showing a great success in achieving the goals set for the projects.

By and large, the strategy of area enclosure is vital to halt and reverse land degradation; check the adverse effect of run-off and improve the micro-climate of respective places and thereby maintain environmental stability in the region in the long run. The establishment of area enclosures might indeed be one of the solutions to stop further land degradation and to promote

reclamation. Although we applied a restricted type of comparison, we can conclude that the combination of previous research and our new investigations show that the strategy of area enclosure is an effective policy measure.

### **3.4 Conclusions**

Results of the policy evaluation indicated that government interventions positively influenced household food consumption, regional food self-sufficiency and the recovery of degraded lands. Results indicate that food availability and food self-sufficiency both at the regional and woreda level has improved over the study period. The region has achieved tremendous increase in agricultural production and productivity in the last 10 years with domestic food-grain production reached 2,479,500 metric tonne by the end of 2011. Regional food self-sufficiency ratio (SSR) increased by 11.5 per cent. As a result, the regional food deficit declined by 104 per cent over the study period. Findings further indicated that the integrated household food security package program had a significant and robust effect in improving household food calorie intake. The level of food calorie intake of the program beneficiaries was 41.8 per cent higher than for the food calorie intake of households not involved in the program. In addition, the remote sensing analysis revealed government strategy of areas enclosures as an effective policy instrument to rehabilitate the degraded vegetation.

*Impacts of program interventions upon food security and environmental rehabilitation*

Appendix Table 3.1: Food Balance Sheet computed for 34 *woredas* of Tigray, 2000-2008

S/N	Woreda	Growth rate	
		Food Self Sufficiency Ratio (SSR)	Food Availability Ratio (FAR)
1	Adwa	154.6	25
2	Ahferom	77.8	3.2
3	Alaje	112.9	39
4	Alamata	13.4	1.9
5	Asegede Tsimbla	14.2	15.2
6	Atsbi Womberta	46.7	6.1
7	Degua Temben	13.5	2.5
8	Endamehoni	29.8	8.7
9	Enderta	46.3	21.1
10	Erob	29.2	16.3
11	Ganta Afeshum	45.6	3.5
12	Gulomekeda	68.3	17.9
13	Hawezen	54	18.9
14	Hintalo Wajerat	41.3	24.2
15	Kafta Humera *	-	-
16	Kilte Awelaelo	66.7	11.2
17	Kola Temben	16.6	3.2
18	Laelay Adiyabo	27.4	28
19	Laelay Maichew	0	-4.8
20	Medebay Zana	11.6	8.8
21	Merebleke	202.7	33.2
22	Naeder Adet	-6.1	-1.8
23	Ofa	12.5	8.7
24	Raya Azebo	143.2	160
25	Saesie Tsaeda Emba	61.6	17.5
26	Saharti Samere	9.6	1.3
27	Tahetay Adiyabo	169.1	117.8
28	Tahetay Koraro	11.5	16.1
29	Tahetay Maichew	19.7	7
30	Tanqua Abergele	70.6	20.8
31	Tsegede	36.2	36.2
32	Tselemti	31.1	12.8
33	Welkait	24.8	13.4
34	Werieleke	18.5	0.1

Note: \* The woreda was not included in the analysis as commercial farms owned by investors is highly practiced in the woreda

## Chapter 4

### Spatial and Temporal Assessment of Drought in the Northern Ethiopian Highlands

\*This chapter is based on:

Gebrehiwot, T., van der Veen, A., Maathuis, B.H.P. (2011): Spatial and temporal assessment of drought in the Northern highlands of Ethiopia. In: *International Journal of Applied Earth Observation and Geoinformation: JAG*, 13 pp. 309-321.

## **Abstract**

With the development of global changes, researchers from all over the world increasingly pay attention to drought detection, and severe droughts that may have resulted from climate change. In this chapter, the spatial and temporal variability of drought was evaluated based on precipitation data and remotely sensed images. The Standard precipitation index (SPI) and Vegetation Condition Index (VCI) are used to evaluate the spatial and temporal characteristics of meteorological and vegetative drought in Tigray, Northern Ethiopia. In addition, the study establishes a statistically significant relationship between NDVI/VCI and precipitation, and evaluates the time lag between the occurrence of precipitation and vegetation response using 28 meteorological stations. Based on the drought critical values of SPI and VCI defining drought, the spatial and temporal extent of droughts in the study area is established. We processed 396 decadal images in order to produce the multi-temporal VCI drought maps. The results of the SPI and VCI analysis reveal that the eastern and southern zones of the study region suffered a recurrent cycle of drought over the last decade. Results further show that there is a time lag between the period of the peak VCI and precipitation values obtained from the meteorological stations across the study area. A significant agreement was observed between VCI values with the current plus last two-months of precipitation. The study demonstrates the utility of the vegetation condition index in semi-arid and arid regions.

## **4.1 Introduction**

Although the name 'Water Tower of Africa' has been given to Ethiopia, the country is one of the Horn of African countries that is highly vulnerable to drought. The country's main economic activity, agriculture, is overwhelmingly dependent on the timely onset, amount, duration and distribution of rainfall. An incident of drought generally implies substantial and extended deviation from the normal rainfall pattern, which affects crop production and vegetation growth.

In Ethiopia, drought is a frequently recurring phenomenon. It is the most important climate related natural hazard impacting on the country from time to time. Historical drought events reveal that Ethiopia frequently faces drought and famine. In the past nine centuries there were about 30 major drought episodes. Of these drought episodes 13 of them are known to have covered the entire nation and they were reported as severe. From 1970 onwards, drought hit the country at least once in every ten years but during the last years the event is becoming even more frequent. It is now recurring every two or three years at different levels of intensity (Ferris-Morris, 2003). In recent years the spatial extent and frequency of droughts have both increased causing significant water shortages, economic losses and adverse social consequences.

Climatic conditions during drought years are characterized by either almost total failure of rainfall or a late or too early onset of inadequate rainfall during both the short and the main rainy seasons locally known as Belg and Kiremit respectively. A continuous dry spell or poor rainfall in successive years hinders ground-water recharge and imparts stress on ground-water resources leading to severe water deficit in many parts of the region during both the wet and the dry seasons.

The droughts of the last decades have produced a complex impact, which spans many sectors of the economy, especially the agriculture sector. Droughts of the year 1984-1985 took the lives of an estimated one million people, destroyed crops, contributed to the death of animals, and threatened the lives of millions of people with starvation. The drought caused the then biggest famine affecting an estimated 5.8 million people forcing them to be dependent on food hand-outs or food aid (Benson, 1998). As a result, a considerable part of the society proved vulnerable to drought that in turn caused a deep-seated destitution. The recent drought of 2002-2003 with affected 13.5 million people showed once more the magnitude and the proportion of the problem (Wagaw et al., 2005).

The chronology of Ethiopian drought history further indicates that most of the drought and food crisis events have been geographically concentrated in two broad zones of the country. The first consist of the central and northern highlands, stretching from northern Shewa through Wello and Tigray, and the second consists of low-lying agro-pastoral lands ranging from Wello in the north, through Hararghe and Bale to Sidamo and Gamo Gofa in the south (Ramakrishna and Assefa, 2002). They indicated the eastern and northern parts of the country as the most vulnerable.

Major parts of Northern Ethiopia experience year-round water deficit. Drought is frequent due to abnormally low and untimely rainfall. Even commencement of rainfall at the right time cannot guarantee a drought-free season since frequency, intensity; amount and duration of rainfall all play crucial roles in the occurrence of drought. Tigray region is dry for most of the year except during the rainy season, and exhibits a semi-arid climate. Recurrent droughts form the major threat to rural livelihoods and food security in the region. Almost every year, the study region experiences localized drought disasters causing crop failure and jeopardizing development activities. The region's agro-ecosystem is highly sensitive to rainfall fluctuations and even a slight change has a large impact on the socio-economic activities of the region. As a result, rural livelihoods and agricultural systems in the region are subject to continuous and widespread disequilibrium dynamics.

Despite the fact that drought forms the major uncertainty that farming households have to deal with, no attempts have been made to quantify the spatial and temporal characteristics of drought within the study region. A recent study by UNDP (UNDP, 2008) further indicated that climate change in Ethiopia may lead to extreme temperatures and rainfall events, and more severe and extended droughts and floods. Thus, expected changes in spatial and temporal patterns of precipitation can trigger new characteristics of drought in the affected regions. Consequently, the need for a drought assessment and monitoring mechanism is crucial to minimize socio-economic losses. This can be achieved by developing drought indices that are capable of characterizing and timely assessing drought at different spatial and temporal scales.

The objective in this chapter is to provide a detailed analysis of seasonal drought dynamics in order to identify the spatial and temporal characteristics of drought over the past decade. Standard drought index methods with meteorological and remote sensing data were employed for this purpose. Despite the fact that in literature several indices are used for monitoring and assessment of drought, in this study the Standardized Precipitation Index (SPI) and the Normalized Difference Vegetation Index (NDVI) are used to

analyse meteorological and vegetative drought respectively. In addition, the study aims to establish a statistically significant relationship between Normalized Difference Vegetation Index (NDVI)/Vegetation Condition Index (VCI) and precipitation, and to evaluate the time lag between the occurrence of precipitation and vegetation response. Since agricultural activities and ecological changes are controlled by rainfall, our analysis focuses on drought during the wet seasons. In this chapter, drought is considered to be a meteorological phenomenon characterized by prolonged periods of abnormal precipitation deficit. To our knowledge this study is the first research attempt to develop reliable drought information linking meteorological and remote sensing indices enabling us to identify and map spatial and temporal aspects of droughts for Tigray region. It is our view that development of a drought monitoring system, based largely on meteorological and remote sensing data, can be a great aid for early assessment of drought impacts.

In the following we will discuss and present the general theoretical framework for determining drought. First, we will discuss the methodological approach for quantifying drought using meteorological data, standard precipitation index in particular. Second we will present the vegetation condition index, satellite-derived drought index, which is developed to determine drought using satellite imagery. Finally, a comparison is made between the two indicators on their potential to identify and map the spatial and temporal aspects of drought over large areas.

#### *4.1.1 The Standard Precipitation Index (SPI)*

A variety of indices using meteorological data have been used to quantify droughts (Heim, 2002). However, the most widely used today is the SPI (McKee et al., 1993, 1995), which is now considered as the most reliable index for measuring the intensity, duration and spatial extent of drought (Guttman, 1998; Lloyd-Hughes and Saunders, 2002). This index enjoys several advantages over the others. Calculation of the SPI is easier than other complex indices such as the Palmer drought severity index (PDSI) (Palmer, 1965), because the SPI requires only precipitation data, whereas the PDSI uses several parameters (Soule', 1992). Moreover, the PDSI has some shortcomings in spatial and temporal comparability (Alley, 1984; Guttman, 1998; Karl, 1986). However, the SPI provides a comparison of the precipitation over a specified period with the precipitation totals of the same period for all the years available in the historical record. The SPI is comparable in both time and space, and it is not affected by geographical or topographical factors (Lana et al., 2002).

The SPI is a probability index that considers only precipitation. The probabilities are standardized so that an index of zero indicates the mean precipitation amount. The index is negative for drought, and positive for wet

conditions. As the dry or wet conditions become more severe, the index becomes more negative or positive. The duration of every drought appearance is determined by negative index values. Accumulated totals of negative values of SPI could also be used as a measure of drought severity. The relative simplicity of the SPI is one strong advantage of the index (Logan et al., 2010). Moreover, it is spatially consistent in its interpretation and the magnitude of the departure from zero is a probabilistic measure of the severity of a wet or dry event that can be used for risk assessment (Guttman, 1999). The SPI can track drought on multiple time-scales, i.e. 1-, 3-, 6-, 9-, 12-, and 48-months, but the index is flexible with respect to the period chosen. The SPI requires different interpretations according to its time scale. Among users there is a general consensus about the fact that the SPI on shorter time scales (say 3 and 6 months) describes drought events affecting agricultural practices, while on the longer ones (12 and 24 months) it is more suitable for water resources management purposes (Raziei et al., 2009). SPI for 3 and 6 months' time steps are used to study the characteristics of drought in short and medium range time scales.

Computation of the SPI involves fitting a gamma probability density function to a given frequency distribution of precipitation totals of a station. The alpha and beta parameters of the gamma probability density function are estimated for each station and each time scale of interest (3-, 6-, 12-, 24-, 48-months, etc.). The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station in question. The cumulative probability is transformed to the standard normal random variable  $Z$  with a mean of zero and variance of one, which is the value of the SPI. Gamma distribution functions are most often found to fit the precipitation data well because the distribution of rainfall totals are not normally distributed (US National Drought Mitigation Centre, 2010).

The gamma distribution is defined by its frequency or probability density function:

$$g(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \text{ for } x > 0 \quad (4.1)$$

Where,  $\alpha > 0$  is the shape parameter,  $\beta > 0$  is a scale parameter and  $x > 0$  is the amount of precipitation.  $\Gamma(\alpha)$  defines the gamma function.  $\alpha$  and  $\beta$  are parameters to be estimated for each station for each time step of interest. The maximum likelihood solutions are used to optimally estimate the gamma distribution parameters  $\alpha$  and  $\beta$ :

$$\hat{\alpha} = \frac{1}{4A} \left(1 + \sqrt{1 + \frac{4A}{3}}\right) \quad \text{and} \quad (4.2)$$

$$\hat{\beta} = \frac{\bar{\chi}}{\hat{\alpha}} \quad (4.3)$$

where:

$$A = \ln(\bar{\chi}) - \frac{\sum \ln(\bar{\chi})}{n}, \quad (4.4)$$

and,

n = number of precipitation observations.

This allows the rainfall distribution at the station to be effectively represented by a mathematical cumulative probability function given by:

$$G(x) = \int_0^x g(x) dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} dx \quad (4.5)$$

Since the gamma function is undefined for x=0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1 - q)G(x) \quad (4.6)$$

where, q is the probability of a zero. The cumulative probability H(x) is then transformed to the standard normal distribution to yield SPI (McKee et al., 1993). The complete procedure used for the calculation of the SPI is reported in Vicente-Serrano et al. (2006).

Although it is a quite a recent index, the SPI was already used in Turkey (Komuscu, 1999; Touchan et al., 2005), Argentina (Seiler et al., 2002), Spain (Lana et al., 2002), Korea (Min et al., 2003), China (Wu et al., 2001) Europe (Lloyd-Hughes and Saunders, 2002), Italy (Bordi et al., 2001) and South Africa (Mathieu and Richard, 2003) for real time monitoring or retrospective analysis of droughts. It is becoming an increasingly important tool for initiating drought response actions at state, regional and local level (Wilhite et al., 2000). Accordingly, we applied SPI to study the spatial and temporal characteristics of meteorological drought in the region of Tigray, which has a history of recurrent droughts.

#### 4.1.2 Vegetation based drought analysis

Drought indicators like the SPI assimilate information on rainfall, but do not express much spatial detail. Furthermore, drought indices calculated at one location are only valid for a single location. Thus, a major drawback of climate based drought indicators is their lack of spatial detail as they are

dependent on data collected at weather stations which sometimes are sparsely distributed affecting the reliability of the drought assessment indices (Brown et al., 2002). In contrast remote sensing or satellite imageries have proven to be effective tools that provide spatially continuous information regularly in timely manner with improved detail. The vegetation indices developed using band combination of satellite imagery has been used for monitoring drought over large areas since mid-1990s. A range of vegetation indexes based on remote sensing have been thus used to monitor greenness of vegetation (Bannari et al., 1995). Thus, as a second index we present an indicator based on remote sensing.

Satellite-derived drought indices typically use observations in multispectral bands, each of which provides different information about surface conditions. Because droughts are naturally associated with vegetation state and cover, vegetation indices are commonly used for this purpose (Tucker and Choudhury, 1987), utilizing data in the visible red (R), near infrared (NIR), and the shortwave infrared bands. The most commonly used vegetation index is the normalized difference vegetation index (NDVI) (Tucker, 1979) and is given by the equation:

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (4.7)$$

Where NIR is reflectance in the near-infrared wavelengths and RED is reflectance in the red wavelengths. The temporal variations in the NDVI reflect the vegetation's response to weather variability (Potters and Brooks, 1998). Consequently, this index has been widely used to monitor ecosystem dynamics, crop yield assessment/forecasting and to detect the spatial extent of drought episodes and their impact (Di et al., 1994; Groten and Octare, 2002; Kogan, 1995, 1997; Marsh et al., 1992; Tucker and Choudhury, 1987).

However, many studies report that the spatial and temporal variability of NDVI values is closely related to the contribution of geographical resources to the amount of vegetation. This contribution fluctuates considerably depending mainly on climate, soils, vegetation type and topography of an area (Di et al., 1994; Domenikiotis et al., 2004; Ichii et al., 2002; Li et al., 2002). Thus, in tropical rainforest areas, high NDVI values could result from the lush tropical forest vegetation, whereas, in deserts, low NDVI values are to be expected. Obviously, these differences are not due to the impact of the weather. For this reason the NDVI is not comparable in space, especially in non-homogeneous areas (Vicente-Serrano, 2007).

Furthermore, surface moisture and aerosol signals may limit the accuracy of the observed NDVI in arid or semi-arid regions (Funk and Brown, 2006). Soil formations in the most arid areas may also play an important role in

intensifying the effects of drought on vegetation. Land degradation and specific soil erosion may in part also prevent the development of a high amount of vegetation cover (Guerrero et al., 1999). These vegetation indices, NDVI, are also mainly linked to vegetation biophysical factors and problems exist because of external factor effects, such as soil background variations (Huete, 1989; Huete et al., 1985).

Therefore, Huete (1988) proposed a soil-adjustment factor to account for first-order soil background variations and obtained a soil-adjusted vegetation index (SAVI), which reduces the influence of the soil type below the vegetation. According to Huete (1988), SAVI is much better than NDVI for areas with low vegetation cover and can be used to characterize the arid zone vegetation. However, the SAVI is a method by which spectral indices requires local calibration so that soil substrate variations are effectively normalized and are not influencing the vegetation measure. Furthermore, it is difficult to predict how soil effects are manifested within large pixel areas, which aggregate soils and vegetation of many different types, each of which requires in principle, separate calibration making the method not easy to apply for large areas. We believe, therefore, that the most appealing approach to apply in our case is to rely on NDVI as is difficult to have access to such calibration values for our study region, which covers 53,000 square kilometres.

Moreover, though natural vegetation has developed a great capacity for physiological adaptation and resistance to long droughts and soil moisture below the theoretical wilting points, precipitation is considered as the primary limiting factor for plant growth in semi-humid and semi-arid areas (Reynolds et al., 2004; Wang et al., 2003). But when NDVI is used for analysis of weather impact on vegetation, the non-weather effect must be separated. Accordingly, we apply VCI for our study. This VCI is based on NDVI and applies maximum and minimum NDVI values in order to monitor weather impacts on vegetation.

The maximum amount of vegetation is developed in years with optimal weather conditions, because such conditions stimulate efficient use of ecosystem resources. Conversely, minimum vegetation amount develops in years with extremely unfavourable weather, which suppresses vegetation growth directly and through a reduction in the rate of ecosystem resources use (Domenikiotis et al., 2004). Therefore, the absolute maximum and minimum of NDVI, calculated over several years, contains the extreme weather events. The resulting maximum and minimum values can be used as criteria for quantifying the potential of geographical areas (Kogan, 1995, 1997). This is expressed by the VCI that is given by the equation:

$$VCI = \left( \frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} \right) * 100 \quad (4.8)$$

where NDVI,  $NDVI_{\min}$ , and  $NDVI_{\max}$  are the smoothed 10-day NDVI, its absolute multi-year minimum and its multi-year maximum NDVI respectively for each pixel. The VCI, given by Kogan (1995), has been used to estimate the weather impact on vegetation. The method is useful to separate the short-term weather signal in the NDVI data from the long-term ecological signal and in this sense it is a better indicator of water stress condition than NDVI (Kogan, 1997; Kogan and Sullivan, 1993; Maselli et al., 1993). The VCI provides accurate drought information not only for well defined, prolonged, widespread, and intensive droughts, but also for very localized and short-term droughts (Kogan, 1995). The VCI varies from 0 to 100 corresponding to changes in the vegetation condition from extremely unfavourable to optimal condition (Kogan, 1995; Kogan et al., 2003). Based on Kogan's (1995) VCI classification threshold, VCI values of 35% or less is considered to be as an indicator of drought condition. VCI values around 50% are considered as a fair vegetation condition, while VCI values between 50 and 100% are judged optimal or above normal conditions. The VCI algorithm was developed and tested in several areas of the world with different environmental and economic resources (Kogan, 1990, 1995).

## **4.2 Methodology**

Below, the empirical approaches for quantifying drought using standard precipitation index as well as vegetation condition index, which are adapted to this study, are discussed.

### *4.2.1 Drought evaluation using the SPI*

In this study, the SPI series were computed for 25 weather stations in the Tigray region from January 1979 to December 2009 at a temporal scale of 3- and 6-month to study the characteristics of drought at short and medium ranges. These scales are useful for monitoring various drought types (Edwards and McKee, 1997). The 3- and 6 months SPI is used to describe the drought events affecting agricultural practices and characterize seasonal droughts due to rainfall deficit during the main rainy season. The SPI program developed by the National Drought Mitigation Centre, University of Nebraska- Lincoln, was used to generate time series of drought indices (SPI) for each station. The 3-month SPI calculated for September uses the precipitation total for July, August and September while the 6-month SPI uses the precipitation total for April to September. Since drought is a regional phenomenon, the SPI values of the meteorological stations have been spatially interpolated using inverse-distance moving average interpolation technique in the software package ILWIS, to create drought severity maps

for the region at multiple time scales of the year. An inverse distance moving average technique was employed as it is better suited for interpolation of rainfall distribution over heterogeneous topographical terrain. SPI classification threshold values proposed by McKee et al., (1995) and explained by Edwards and McKee (1997) were used in order to map the spatial extent of meteorological drought intensities corresponding to the SPI value (Table 4.1).

Table 4.1: Drought classification by standardized precipitation index (SPI) value

SPI values	Drought category
-2.00 and less	Extreme drought
-1.50 to -1.99	Severe drought
-1.00 to -1.49	Moderate drought
0 to -0.99	Near normal or mild drought
Above 0	No drought

#### 4.2.2 Drought evaluation using the VCI

As an alternative, a ten-day composite NDVI for each month of the indicated period was produced for the study region. The decadal composite NDVI data set was divided into groups for analysis i.e. the main rain season or monsoon months (June, July, August and September) and the dry season (March, April and May). The monsoon months was only used for the analysis as this study was focused on drought due to water stress during the rainy season. All negative values have been reclassified to 0 in all data set so that scaled NDVI data contain only positive values, which are required for further analysis.

After the production of average monsoon NDVI (June – September), absolute NDVI minimum and maximum maps for each monsoon season were generated for the period 1998-2009. After the production of these images VCI composite images were produced for each year monsoon season using equation 4.8. Accordingly 396 decadal images were processed in order to produce multi-temporal drought maps and determine the relationships between average monthly precipitation and vegetation indices at station level. Kogan's (1995) VCI classification threshold values were then applied in order to prepare the annual vegetative drought maps. Pearson correlation analysis was performed to correlate VCI/NDVI values with precipitation data. To investigate the time lag between the occurrence of the precipitation and VCI response, correlation between VCI data and various precipitation schemes including the current month and the current month plus last two preceding months were examined.

### 4.2.3 Study area characteristics

Climatically, the region belongs to the sub-tropical region where monsoon weather prevails throughout the year. Three distinct seasons can be recognized from a climatic point of view: the dry winter season from October to February; the pre-monsoon hot season from March to May; and the rainy monsoon season which lasts from June to September (locally called kiremt), during which 80 per cent of the crops are cultivated. Rainfall is distributed very unevenly in the study region. The data from the Ethiopian National Meteorological Services Agency (ENMSA) reveals that the climate of the study region is characterized by large spatial variations which range from about 1000-1300 mm over some pockets areas in the Southwest to about less than 260 mm over the Northeast lowlands (Figure 4.1). The mean annual rainfall of the region is estimated to be 560 mm while the mean annual monsoon rainfall is 473 mm, 84 per cent of the annual rainfall. The coefficient of variation (CV) of annual rainfall is found to be 38 per cent, which is high compared to the national figure of 8 per cent.

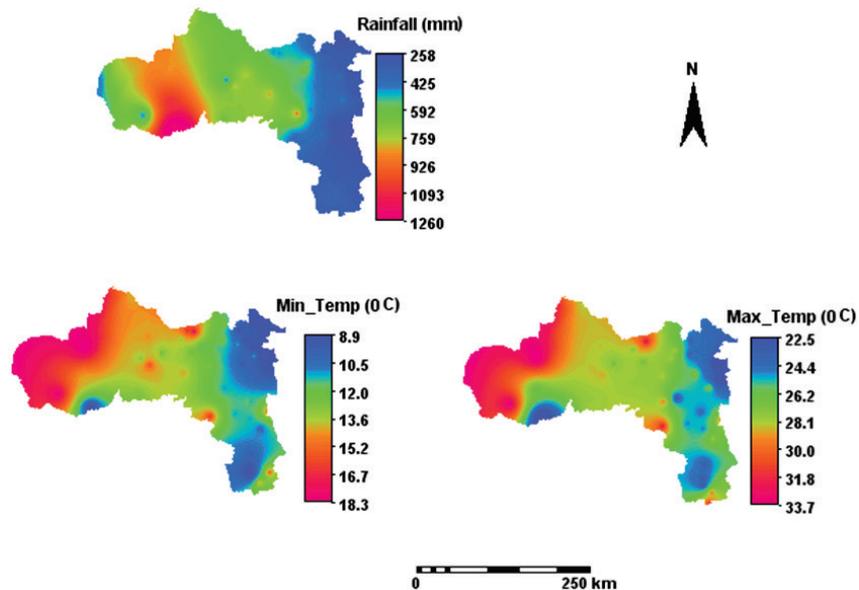


Figure 4.1: Climate distribution of monsoon rainfall, annual minimum and maximum temperature in the study region for the year 2008.

The southern and eastern zones of the region receive much lower rainfall than other parts of the region (Figure 4.1). The distribution of monsoon rainfall over the region is characterized by large spatial variation. The inter-annual variability of the monthly average minimum and maximum temperature based on the data from Ethiopian National Meteorological Services (ENMSA) for the period of 1979-2009 shows that the minimum

temperature is highest in May-June and reaches its lowest value in December-January, while the maximum temperature over the region is highest in May and reaches its lowest in August (Figure 4.2). Mean temperature distribution over the region varies from about 13.40C over the highlands of the Southwest and East to about 280C over Western lowlands in 2008.

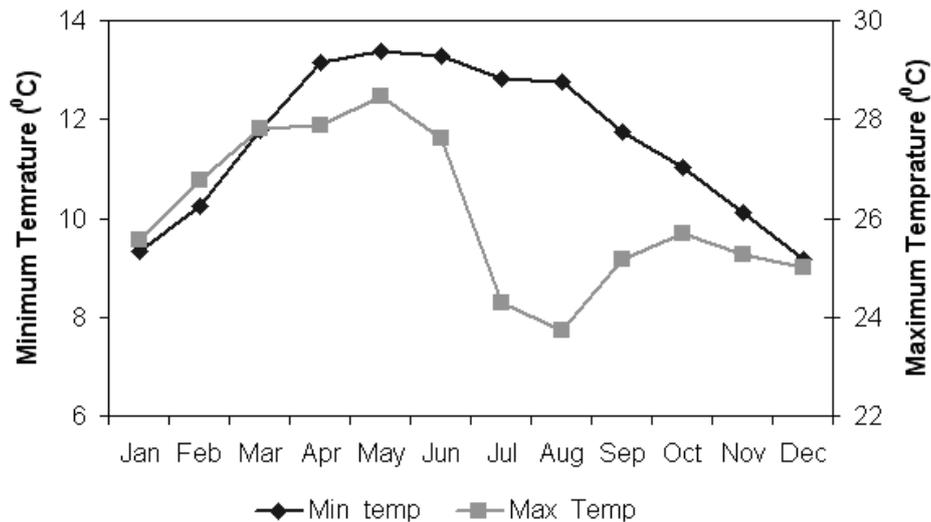


Figure 4.2: Inter-annual variability of the average monthly minimum and maximum temperature in Tigray for the period 1979-2009

#### 4.2.4 Data used

Historical records of monthly precipitation data for the time period 1954-2009 were acquired from the Ethiopian National Meteorological Services Agency for a total of 46 meteorological stations within Tigray (Figure 4.3). However, the period of records for these stations varies and some have missing records. Thus, the period of study has been chosen as long as possible depending on the availability of recorded data for 25 stations in the region, being 1979-2009.

Besides precipitation data, geo-referenced SPOT vegetation ten day composite Normalized Difference Vegetation (NDVI) images (S10 product) were acquired from vgt4africa of the DevCoCast project website, <http://www.vgt4africa.org>, for the period of April 1998-December 2009. In this paper drought is studied using 11 years SPOT NDVI data at 1km \* 1km resolution data, which covers the African continent. The NDVI product acquired is a 10-day synthesis. The satellite data on SPOT vegetation are applied for several procedures in order to ensure the quality of the NDVI product. The product can be used for crop and agricultural monitoring; early warning of failing growing seasons; and as an indicator and alert function for

drought events. The multi-temporal NDVI data was selected due to its provision of opportunities to recognize vegetation changes at a longer time span.

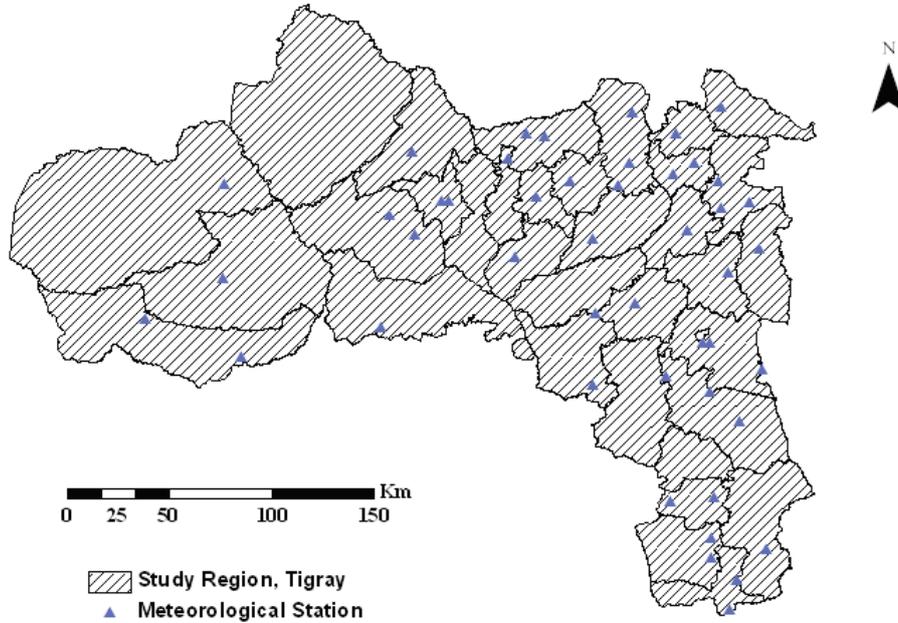


Figure 4.3: Location of rain-gauge stations in Tigray

## **4.4 Results and discussion**

### **4.4.1 SPI based drought identification**

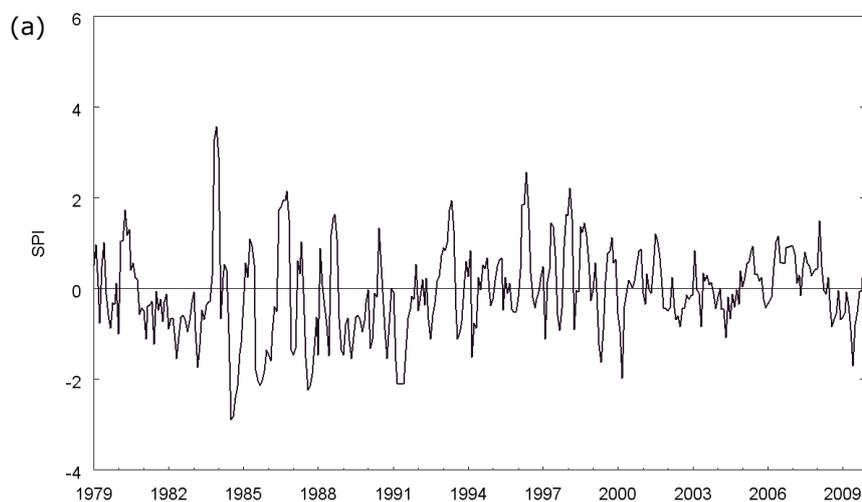
#### **Temporal drought pattern**

Meteorological drought indicates the deficiency of rainfall compared to normal rainfall in a given region. The temporal and spatial characteristics of drought in Tigray region was identified from the SPI time series with multiple-time steps. In our study, SPI for 3- and 6-months' time steps are computed to examine the characteristics of drought in short and medium time periods. The 3-month SPI provides a seasonal estimation of precipitation and the 6-month SPI indicates medium term trends in precipitation patterns (Lia et al., 2004). The 3-month SPI is thus used to describe the monsoon drought for the crop growing season, while the 6-month SPI is used to characterize seasonal droughts that occur due to rainfall deficit in monsoon months.

Appearance of drought is happening every time when SPI is negative and its intensity comes to -1.0 or lower. Drought stops when SPI is positive. The duration of every drought appearance is determined by negative index values. Accumulated totals of negative values of SPI could also be used as a

measure of drought severity. The regional SPI time series for all the stations selected were calculated at 3 and 6-months' time steps. A representative example of the evolution of the SPI for Mekelle station between 1979 and 2009 with a time scale of 3- and 6-months is shown in Figure 4.4. According to the criteria of McKee et al., (1995), severe and extreme droughts correspond to the categories of  $-1.99 < \text{SPI} \leq -1.5$  and  $\text{SPI} \leq -2.0$  respectively. Consequently, several drought episodes were detected from the temporal evolution of the SPI, the most severe or extreme droughts occurred in 1984, 1985, 1986, 1987 and 1991 (Figure 4.4).

The analysis shows that four extreme drought events occurred around the Mekelle station in the case of SPI-3 whereas in the case of SPI-6, five extreme drought events were evident during the recorded period. All these episodes were prolonged in time with critical and extreme situations. Two extreme drought events (1984 and 1985) lasted for 3-6 months with critical and extreme situation. Especially, the annual precipitation of the year 1984 is the smallest for the 30 years of analysis. The drought occurred in 1984 is the most severe drought ever experienced in Tigray region in general. The annual minimum 3-month SPI for this drought event occurred in July 1984 (SPI =  $-2.89$ ), whereas the annual minimum 6-month SPI observed in October 1984 (SPI =  $-2.84$ ). Successive moderate drought episodes were also recorded during the period 1992 to 2009 at the two short and medium term time scales.



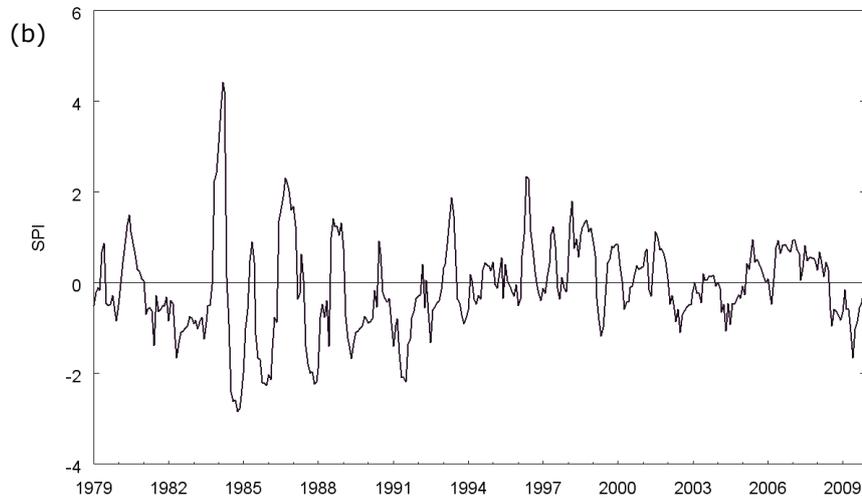


Figure 4.4: Values of SPI for Mekelle station (a) 3-month, (b) 6-month time steps

Severe drought events occurred in 1982, 1983, 1985, 1987, 1988, 1989, 1991, 1999, 2000 and 2009. Severe droughts are much more prolonged drought events than the drought event of 1984. The period 1985-1989 except for the year 1986 was characterized by rainfall shortages during the rainy season. The minimum 3-month SPI was observed in October 1987 (SPI = -1.88) and a minimum 6-month SPI was observed in September 1987 (SPI = -1.99). This prolonged drought event caused exploding water demands and subsequent impacts in Mekelle area and Tigray region in general. The annual minimum SPI values for the 3-month and 6-month time scale most frequently occur during July and October. The temporal analyses of 3-month and 6-month SPI values show that Tigray region was predominantly characterized by frequent moderate droughts.

#### **Spatial characteristics of drought**

Although the estimation of drought severity at a certain point gives useful information for water management, it is important to assess the drought over a specified region. The regional drought analysis is useful for determining the spatial distribution and characteristics of drought, and evaluating the most affected areas for a specific drought event. In this study, the spatial analysis was performed using the SPI values estimated for 3- and 6-month time scales. Using the developed SPI database and the abilities of ILWIS software package, one can visualize the distribution of SPI values across the area of interest for the various time scales. As an example, Figure 5 and 6 show the variation of SPI across Tigray for the period 2000-2009 for time scales of 3- and 6-month respectively.

The spatial analysis of moderate drought occurrences indicates that they tend to occur in the eastern and south zones of Tigray at a 3-month time step, while the northwest and western parts are characterized with the lowest frequencies at the same time step (Figure 4.5). In other words, the majority of the historical droughts that occurred in the eastern and southern zones of the study region were of moderate severity in short-time steps. At a 3-month time step, moderate droughts occurred more frequently and covered nearly two-thirds of the study region during the worst drought of 2002. As the time step increases to 6-month, severity of drought increased in some pocket areas.

Severe to extreme drought occurred during 2000-2009 in discrete pockets in two seasons. During 2002, 2004, and 2009 monsoon, most parts of the region suffered drought conditions. In the years 2000, 2001, 2003, 2006 and 2007 years, the monsoon period was mostly drought-free. Severe drought was observed in the year 2002, when the eastern and southern zones of the regions were affected by severe to extreme drought. During 2002, the monsoon was poor and as a result the whole region suffered drought conditions. During 1999–2009, just within a span of 10 years, monsoon-drought appeared throughout the Tigray region five times.

In 2002, 62 per cent of the study area was affected by drought, among which, 3 per cent was affected by severe droughts and 24 per cent was by moderate monsoon drought. In 2004, 2005, 2008 and 2009, the whole study area was affected by drought. About 67 per cent of the area in 2004 and 63 per cent of the area in 2009 was affected by mild drought.

The spatial extent of the 6-month SPI shows that in 2002, almost 64 per cent of the study area was affected by drought, with almost 29 per cent of the area affected by moderate drought for the 6-month time scale (Figure 4.6). In 2004, about 65 per cent of the area was affected by drought, with almost half of the region affected by mild drought. The spatial extent of both 3- and 6-month SPI's show that in most of the drought years the eastern and southern zones had an SPI less than -1.0. Drought is persistent for more than four seasons particularly in the southern and eastern zones of the region over the last five years (Figure 4.5 and 4.6). The spatial distributions of drought for a 3-month and 6-month time step are shown in figure 5 and 6 respectively.

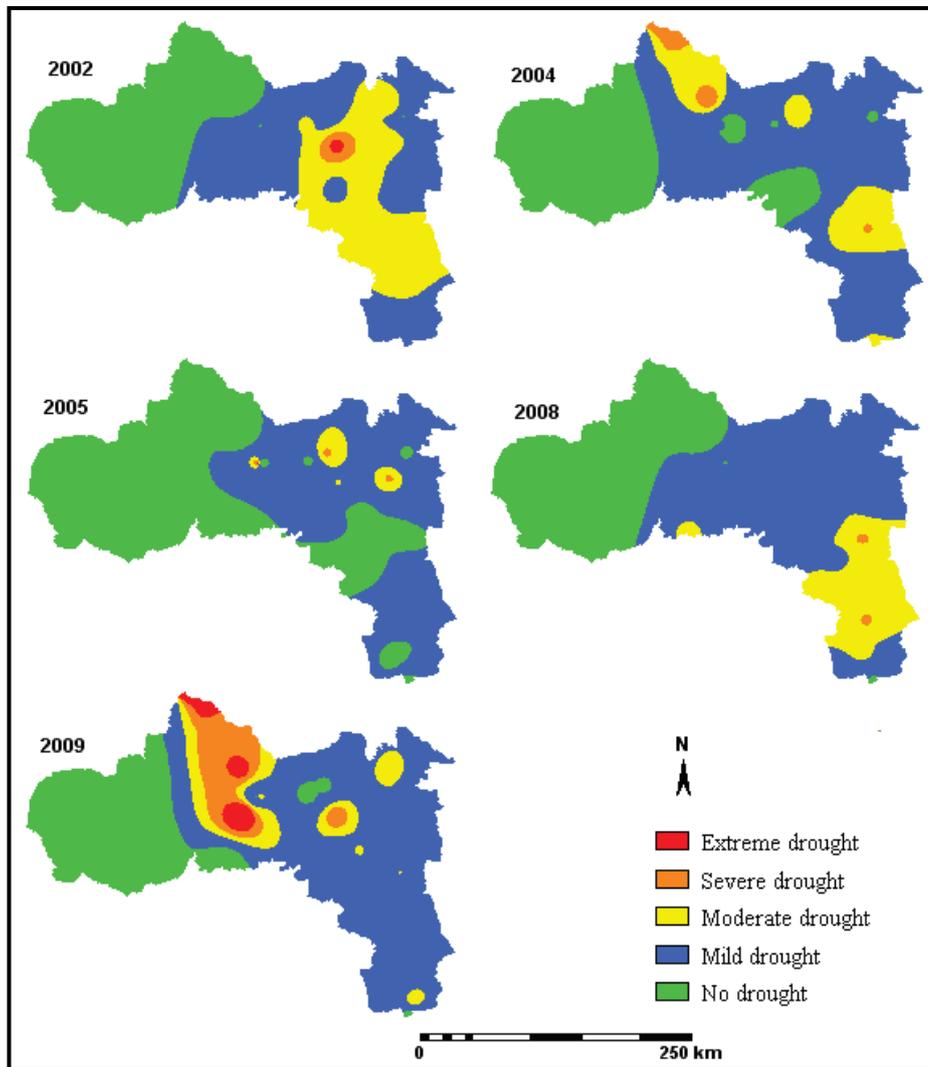


Figure 4.5: Spatial distribution of the 3-month Standard Precipitation Index for Tigray region computed for the month of September for five drought years

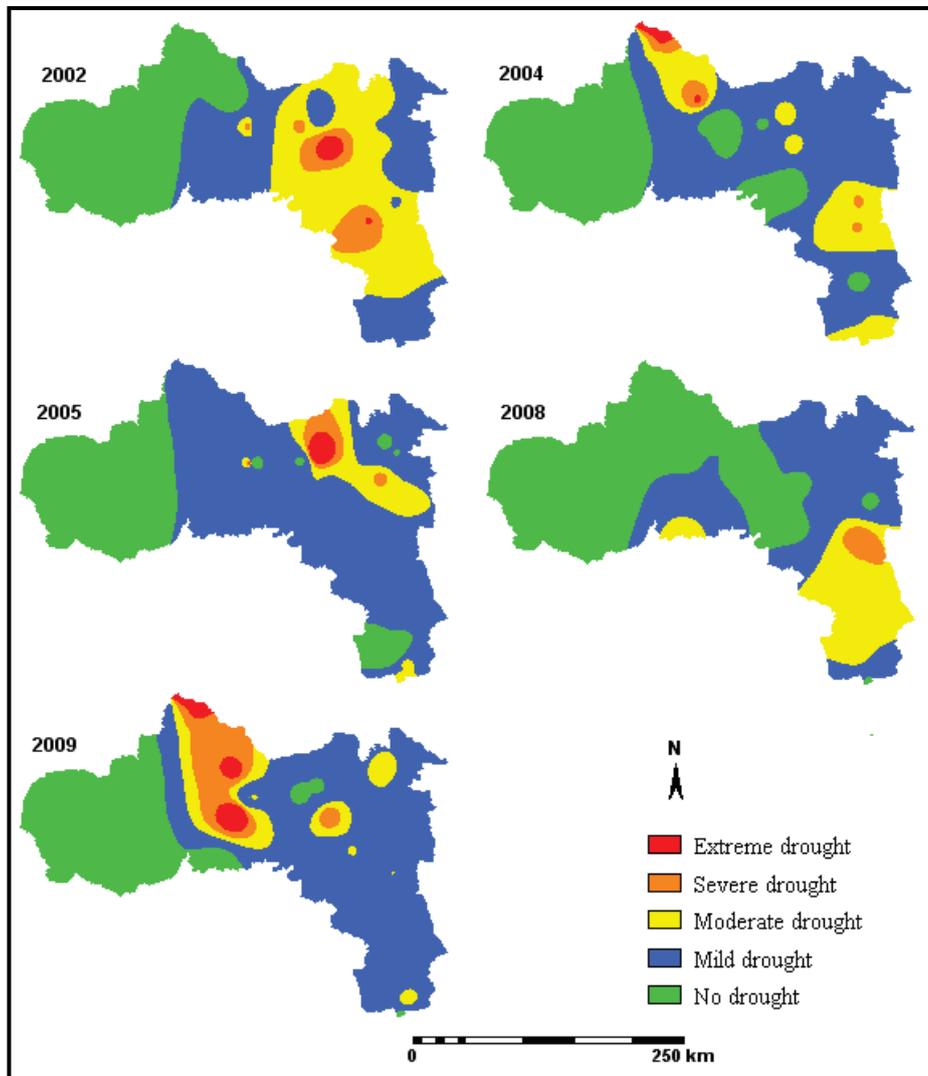


Figure 4.6: Spatial distribution of the 6-month Standard Precipitation Index for Tigray region computed for the month of September for five drought years

The SPI maps indicate that meteorological drought in the study region appears continuously in the monsoon seasons. The analysis of drought at the 3-month and 6-month time-steps further indicates that southern and eastern zones of Tigray are most vulnerable to droughts. Besides, certain pockets particularly in the northwest zone of the region have suffered from water stress. From the two time scales it can also be concluded that droughts in Tigray are of a more seasonal than a long-lasting character. Based on the

Standard Precipitation Index the southern and eastern zones of the region can be delineated as a drought prone zone.

However, Tigray is one of the Ethiopian regions where meteorological stations are generally inadequate and the networks are not well-developed. Weather stations are sparsely located from each other and hence the spatial resolution of rainfall data derived from these weather station has been approximately 100-150 square kilometre. Besides, continuous rainfall records are scarce or difficult to obtain in a timely fashion for all weather stations as infrastructural networks are very low. Consequently, SPI assimilated information on rainfall does not express much spatial detail and could have drawbacks in identifying localized drought at a regional level, which in turn hinders the possible prediction, monitoring and mitigation effects of drought disaster. Therefore, looking for other drought monitoring tools that provide spatially continuous information regularly in timely manner with improved spatial detail is pertinent. In light of this, the results from the VCI analysis are discussed below.

#### *4.4.2 Vegetation based drought identification*

##### **Mean vegetation and rainfall patterns**

The average rainfall for the monsoon season gives an overview of the general distribution of rainfall as the main crops are cultivated during June – September in the whole part of the region. Figure 4.7 provides a visual comparison of average monsoon rainfall and NDVI for the period 1998-2009. During the monsoon season, the southern and eastern zones of the study region receive low rainfall as compared to the other zones of the region. The figure shows an increasing rainfall pattern from southern zone to the western part of the region. The spatial pattern of NDVI for the growing season of the period 1998-2009 correspond well with the monsoon rainfall pattern with the most pronounced vegetation signal for the northwest and western zones of the Tigray region. The above normal greening of this region obviously is associated with high rainfall during the months of June–September in the area. We performed a correlation analysis on average monsoon rainfall and NDVI/VCI for the period (as described in section 4.4.3). The average monsoon precipitation and NDVI/VCI pattern for the whole study region for the period 1998-2009, reveal that there is a positive correlation between monsoon NDVI/VCI and rainfall (see Figure 4.11). The high similarity in spatial pattern of both NDVI and rainfall illustrates the impact of rainfall on vegetation condition.

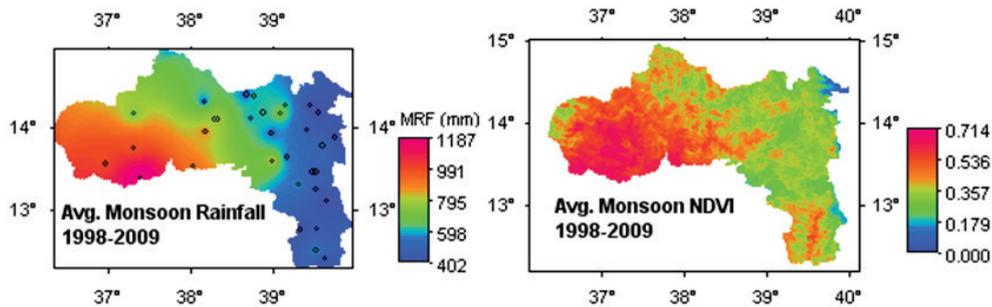


Figure 4.7: Multi-year average monsoon rainfall (MRF) and the multi-year average monsoon NDVI for the period 1998-2009

### Spatial extent of Vegetative drought

The annual cycle of vegetation in Tigray region is basically unimodal similar to the rainfall regime. As discussed before, we also analysed a monsoon drought based on time series VCI. Using Kogan's VCI threshold of 35 per cent or less as extreme drought condition, a VCI time series data was constructed to determine drought. At a VCI of around 50 per cent, fair or normal vegetation conditions exist. When VCI values are close to 100 per cent, the brightness vegetation for the monsoon/September is equal to the long-term Maximum for the pixel. Low VCI values indicate drought period in that year. A consistently low VCI value over several consecutive time intervals indicates drought development. Accordingly, our VCI indicates that the study area was affected by drought condition in the monsoon year 2002, 2004, 2005, 2008 and 2009 (Figure 4.8). During the monsoon of 2002, the vegetation experienced stress and loss of vegetation health. The region experienced an exceptionally continuous drought spell from the monsoon of 2002 until 2009 particularly in the southern and eastern zones of the region due to poor rainfall in the last consecutive monsoon seasons (Figure 4.8). The worst situation was encountered during the year 2004, 2008 and 2009 monsoon when 20.1 per cent, 18.1 per cent, and 17.4 per cent of the region suffered drought condition respectively; having VCI values less than 35 per cent. In the years 1999-2001, most of the study area except for some pocket areas had VCI values higher than 35 and thus experienced normal conditions. Agricultural practices, in particular in times of sowing and harvesting have significant bearing in shaping the NDVI patterns. Agriculture was severely affected during the year 2004, since crops could not be sown due to failure of rainfall commencement particularly in the southern part of the region.

Furthermore, a high intensity of drought condition occurred in 2004, 2005 and 2008 due to failure of rainfall during the last crop growing period, mostly around September as is illustrated in Figure 4.9. Figure 4.9 indicates the VCI

of September 2000-2009, the severity of drought in 2004, 2005 and 2008 appeared relatively higher.

Our result of vegetative drought analysis illustrates that the spatial and temporal analysis of drought using a vegetation condition index are useful in characterizing spatial patterns and temporal aspects, and in evaluating drought proneness across spatial units. Multi-temporal VCI maps are useful in assessing the severity of droughts at spatial details, implying the utility of the Vegetation condition index in semi-arid and arid regions.

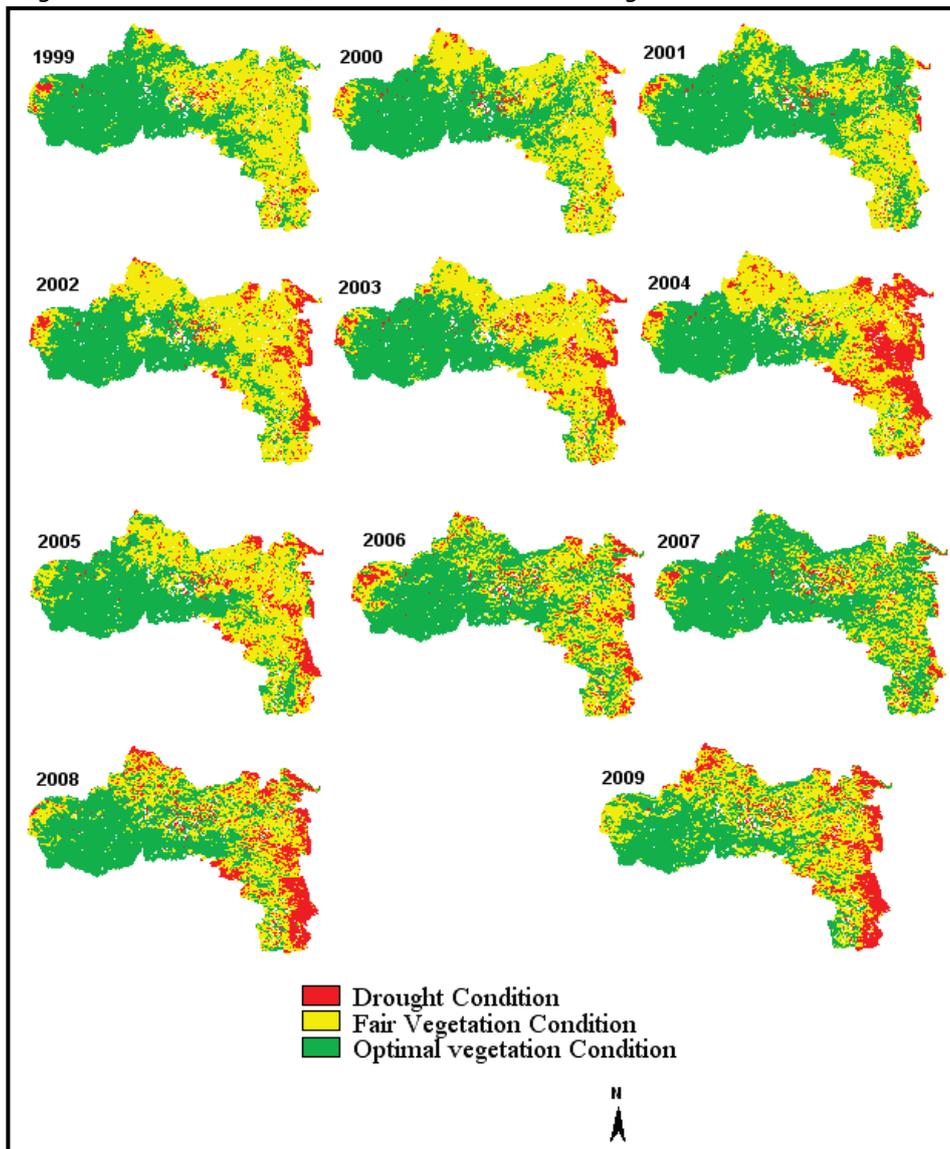


Figure 4.8: Drought frequent region using VCI for the monsoon season, 1999-2009

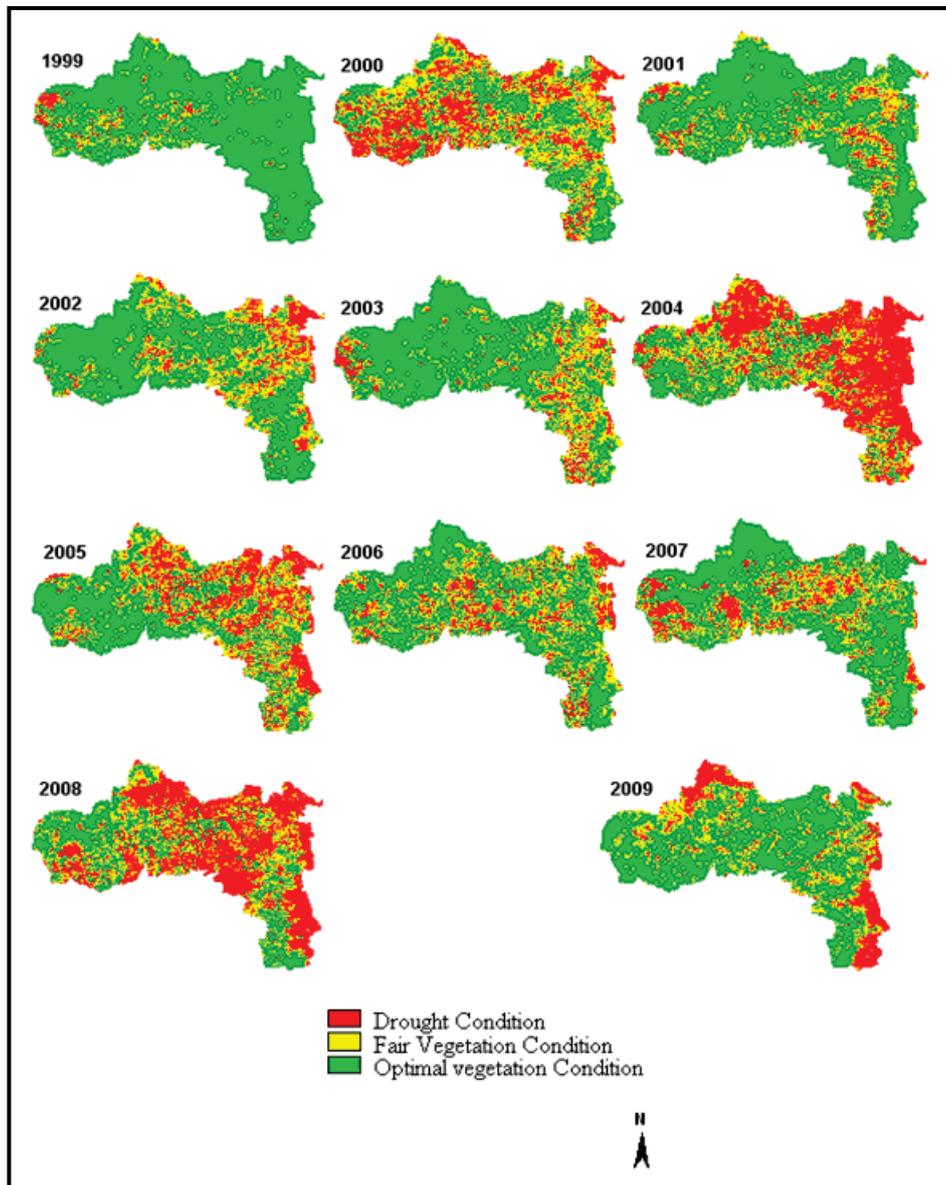


Figure 4.9: Drought frequent region using VCI for the month of September, 1999–2009

#### 4.4.3 Precipitation, NDVI and VCI variations

Although, the variations in vegetation indices can aid to recognize the effect of climatic factors on local vegetation, the variations will be of little practical value when planning for large-scale mitigation. Hence, determining the associations between precipitation and vegetation indices on a regional scale would provide better insight into drought onset and severity. Thus, this

section discusses the statistically relationship between NDVI/VCI and precipitation, and evaluates the time lag between the occurrence of precipitation and vegetation response at different meteorological stations. Different time lag schemes are used in order to investigate this relationship.

Inter-annual variability of the monthly average NDVI and precipitation are shown in Figure 4.10 for six sample stations reflecting monthly average values. The figure shows that the average monthly NDVI reaches its maximum value in September for the sample stations. The temporal pattern of the NDVI has high similarity with the temporal pattern of rainfall, which is relatively high in the rainy period from June to September. Figure 4.10 also shows that there is no agreement between the peak NDVI and current month precipitation values rather it shows that there is a time lag between the period of the peak NDVI and precipitation values.

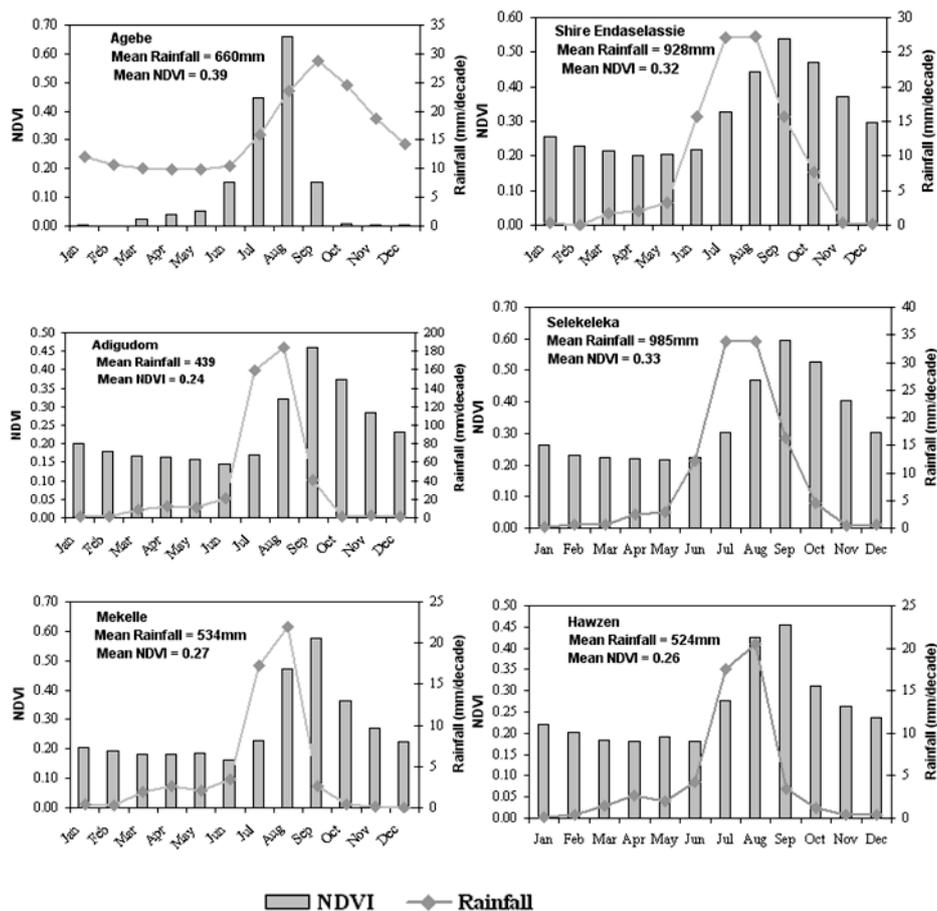


Figure 4.10: Inter-annual variability of monthly NDVI for sample stations, 1999-2009

### **Correlation analysis**

The statistical relationships between various time lag periods and NDVI/VCI were investigated by performing a Pearson correlation analysis between the values of vegetation indices and precipitation data for 28 meteorological stations (Table 4.2). For the Alamta and Maichew stations the VCI values are correlated with the current month precipitation. However, the VCI exhibited significant correlations with current plus last two-month precipitation in nearly all the stations (Table 4.2). This shows that vegetation is responsive to rainfall over a three-month period indicating a brief time-lag in the vegetation response to rainfall.

In the case of NDVI, NDVI values are correlated with the current month precipitation at Adigudom, Alamata, Hageresalam and Waja stations. Significant correlations are observed with the current plus two-month precipitation data for 21 stations. In general, nearly in more than half of the meteorological stations, highest correlation coefficients are obtained when NDVI or VCI values are correlated with the current plus last two-month precipitation data. Our result further reveals that VCI has a higher correlation than NDVI for the individual stations indicating that VCI can provide more accurate information on the impact of weather on vegetation, and can be used as good indicator of vegetation changes and in turn, as indicators of drought conditions for individual stations in the study area.

Table 4.2: Pearson correlation coefficient between NDVI/VCI and precipitation

No.	Station name	NDVI		VCI	
		Current month	Current + preceding two months	Current month	Current + preceding two months
1	Abi-adi	0.516	0.364	0.220	0.529*
2	Adigudom	0.495**	0.586*	0.356	0.670*
3	Adiremese	0.270	0.406	0.133	0.375
4	Adidaero	0.056	0.105	0.366	0.531**
5	Adigrat	0.242	0.689*	0.007	0.580*
6	Adwa	0.362	0.026	0.209	0.264
7	Agebe	0.119	0.408**	0.142	0.517*
8	Alamata	0.650*	0.827*	0.579*	0.759*
9	Axum	0.216	0.092	0.034	0.346
10	Aynalem	0.083	0.563*	0.157	0.622*
11	Dengolat	0.026	0.490**	0.113	0.717*
12	Edagahamus	0.070	0.439**	0.212	0.443**
13	Endabaguna	0.232	0.167	0.146	0.428*
14	Enticho	0.141	0.832*	0.147	0.867*
15	Feresemay	0.159	0.592*	0.208	0.768*
16	Hagereselam	0.484**	0.650*	0.364	0.630*
17	Hawezen	0.254	0.533*	0.202	0.603*
18	Korem	0.194	0.687*	0.093	0.663*
19	Maichew	0.187	0.384	0.433**	0.677*
20	Maykenetal	0.070	0.656*	0.052	0.710*
21	Mekelle	0.155	0.525*	0.208	0.620*
22	Ramma	0.225	0.308	0.282	0.587**
23	Selekeleka	0.292	0.523*	0.217	0.615*
24	Sheraro	0.275	0.575**	0.307	0.650*
25	Shire	0.135	0.157	0.100	0.515*
	Endasselassie				
26	Waja	0.407**	0.614*	0.326	0.556*
27	Wedisemero	0.217	0.277	0.263	0.247
28	Wukero	0.189	0.562*	0.337	0.726*

Note: \*\* and \* significant at probability levels of 5% and 1% respectively (2-tailed)

Moreover, the relationships between precipitation and vegetation indices on a regional scale would also provide better insight into drought onset and severity. Therefore, average NDVI and VCI values of all 28 meteorological stations in the study area were determined as 'average NDVI' and 'average VCI' and their correlation with average precipitation data were observed. Because the results of individual stations showed better correlations between NDVI/VCI values and multi-month precipitation, only the average of three-month precipitation of all stations in the entire study area for the period 1999-2009 was used (Figure 4.11). It can be clearly seen from the scatter plots that VCI values responded well to precipitation. The correlation coefficient ( $r$ ) for this relationship was found to be 0.70 and significant at

0.01 levels, which indicates a strong positive linear relationship between three-month precipitation and VCI.

A similar trend is observed when the average NDVI of the study area is plotted versus three-month precipitation. An agreement is easily observed which is confirmed by a significant  $r$  value of 0.62. The correlation was found to be significant at 0.01 levels.

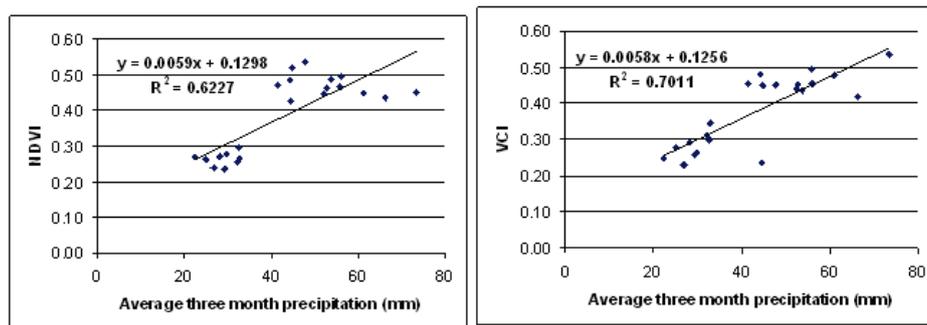


Figure 4.11: Average NDVI and VCI versus average three month precipitation for the whole study area

Generally, a significant agreement is observed between NDVI/VCI values and average three-month precipitation. Thus, the general agreement between VCI values and precipitation data clearly shows that the maximum and minimum NDVI values used to determine the VCI at a station level have been influenced by the weather condition. Drought area dynamics studied by VCI images represent the negative impact of adverse meteorological conditions on vegetation and show a more useful way to monitor regional drought evolution in time and space.

## 4.5 Conclusions

This study investigates the spatial and temporal characteristics drought over the past decade in Tigray region, northern Ethiopia. Standard drought index methods with meteorological and remote sensing data were employed for this purpose. Accordingly, the objective is approached by examining the potentials of Standard Precipitation Index (SPI) and Vegetation Condition Index (VCI) in detecting drought over a large area. The study indicated that SPI assimilated information on rainfall does not express much spatial detail and could have drawbacks in identifying drought proneness across the spatial units, and thereby affects the reliability of the drought indices. However, the result from the satellite derived vegetation condition indices indicates that VCI provides better real time and spatially continuous data that can be used for rigorous analysis of drought proneness over large areas, offering the

possibility for early prediction of droughts as is necessary for drought risk management. Thus, promoting satellite derived drought monitoring tools in guiding the operational responses in drought risk reduction is vital for developing countries like Ethiopia where meteorological stations are generally inadequate and continuous rainfall records are scarce or difficult to obtain in a timely fashion.

### **Acknowledgements**

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## **Chapter 5**

### **Variability in Vulnerability: scale matters to Ethiopian farmers**

\*Chapter is based on:

Gebrehiwot, T., van der Veen, A. (2012). Variability in vulnerability: scale matters to Ethiopian farmers. *Journal of Eastern African Studies*, under review.

## **Abstract**

Climate change and variability severely affect rural livelihoods and agricultural productivity, yet they are causes of stress vulnerable rural households have to cope with. In this study we investigated farming community's vulnerability to climate change and climate variability across 34 agricultural-based *woredas* in Tigray, northern Ethiopia. We considered 24 biophysical and socioeconomic indicators to reflect the three components of climate change vulnerability: exposure, sensitivity, and adaptive capacity. We used a framework that combines exposure and sensitivity to produce potential impact, which is then compared with adaptive capacity in order to yield an overall measure of vulnerability. The classic statistical technique of factor analysis was applied to generate weights for the different indicators and an overall vulnerability index was constructed for the 34 rural *woredas*. The analysis revealed that the *woredas* deemed to be most vulnerable to climate change and variability overlapped with the most vulnerable populations. The most exposed farming communities showed a relatively low capacity for adaptation. The study further showed that vulnerability to climate change and variability is basically linked to social and economic developments.

## **5.1 Introduction**

Most African countries rely on rain-fed agriculture. As a result, agriculture is highly susceptible to changes in climate variability and seasonal shifts. This is attributed to the fact that climate change affects the two most important direct inputs to agricultural production: precipitation and temperature (Deschênes and Greenstone, 2007). According to Bolin et al. (1998), climate change also indirectly affects agriculture by influencing the emergence and distribution of crop pests, exacerbating the frequency and distribution of adverse weather conditions and reducing water supplies.

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) revealed that developing countries are expected to suffer most from the negative impacts of climate change and variability. The fourth assessment report of the IPCC on regional climate projections also predicted that throughout the African continent the increase in temperature is very likely to be above the global annual mean warming (IPCC, 2007). Consequently, the negative impact of climate is believed to be higher on the African continent. This is also due to the continent's low adaptive capacity, the economic importance of climate-sensitive sectors to these countries, and their limited human, institutional and financial capability to anticipate and respond to direct and indirect effects of climate change and variability (Collier et al., 2008; McCarthy et al., 2001).

As well as to other African countries, climate change and variability pose an enormous threat to Ethiopia. In Ethiopia, drought is the most important climate related natural hazard impacting on the country from time to time. Recurrent droughts form the major threat to rural livelihoods and food security in the country. Almost every year, the country experiences localized drought disasters causing crop failure and jeopardizing development activities. As a result, rural livelihoods and agricultural systems in the country are subject to continuous and widespread disequilibrium dynamics.

A recent study revealed that climate change in Ethiopia could lead to extreme temperatures and rainfall events, as well as more heavy and extended droughts and floods (UNDP, 2008). Considering the fact that more than 80 per cent of Ethiopians are engaged in subsistence rain-fed agriculture and farms are already under significant climate stress, climate change could greatly exacerbate this already difficult situation and will have numerous knock-on effects on economic growth and welfare. Climate change will therefore form at great risk for the agricultural sector, in turn creating a major threat to food security in the country.

While it is increasingly accepted that climate change and climate variability will be Ethiopian farmers' greatest challenge, to our knowledge only one study has been undertaken in Ethiopia concerning vulnerability. This study by Deressa et al. (2008) is a macro-scale assessment of farmers' vulnerability to climate change and variability at a national level. This could mask enormous variability in livelihoods vulnerability within regions. Moreover, the spatial impact of climate variability varies across a region, woreda, or even a tabia. There is also considerable heterogeneity between districts regarding households' access to resources, poverty and food insecurity levels, and the ability to cope. In such circumstances local variation is often overlooked in a macro scale vulnerability study. Consequently, it is challenging to accurately capture the spatial dimension of farmer's vulnerability from macro-scale vulnerability assessments. This indicates the importance of scale in vulnerability studies and makes further study at a smaller scale, identifying the vulnerability of the farming community, pertinent.

This chapter aims to examine climate change vulnerability of the farming community and identify hot spot areas across 34 rural woredas of Tigray region. We investigated farmers' vulnerability by first considering the different components of vulnerability separately. We considered 24 biophysical and socio-economic indicators reflecting the three components of climate change vulnerability: exposure, sensitivity, and adaptive capacity. We then performed a factor analysis to generate weights for the different indicators and construct an overall vulnerability index for 34 rural woredas. Finally, we performed a cluster analysis aimed at identifying the most vulnerable woredas based on the different combinations of indicators. A GIS (geographic information systems) was employed to produce vulnerability maps taking woredas as a spatial unit of analysis.

### *5.1.1 Vulnerability, conceptual context and analytical tools*

The linguistic roots of the word vulnerability can be traced back to the Latin word *vulnus*, meaning 'a wound' and *vulnerare*, 'to wound'. In Late Latin the word *vulnerabilis* referred to a wounded soldier (Ford, 2002). The scientific use of the word 'vulnerability' has its roots in geography, natural hazards research, and in the analysis of food insecurity. In recent years the concept vulnerability has gained importance within the global change research community.

Vulnerability is multi-dimensional and its conceptualization has developed over time (Cutter, 1996; Dow, 1992; Hewitt, 1997). Different disciplines conceptualize the term vulnerability in different ways based on their areas of concern, objectives to be achieved and the methodologies employed (Cutter et al., 2000; Finan et al., 2002; Liverman, 1999; P. Mike Kelly and Adger, 2000). These differences limit the possibility of having a universally accepted

definition for and methodological approach to assessing vulnerability. In general, the idea of vulnerability has been conceptually addressed by researchers Adger et al. (2004), Dolan and Walker (2004), Paton and Johnston (2001), and Wei et al. (2004).

In this study we used the definition by the IPCC (2001), where vulnerability is defined as the degree to which a system is susceptible or unable to cope with adverse effects of climate change including climate variability and extremes. According to the IPCC (2001) definition, vulnerability is characterised as a function of three defining components: exposure, sensitivity, and adaptive capacity. Nkem et al. (2007) suggested that these three components should be integrated in a vulnerability assessment irrespective of the differences that may exist in the levels or intensities of these three components.

Generally there is no established consensus in the literature regarding the most appropriate approach to assessment of vulnerability. Given the different disciplines involved in vulnerability studies, three main approaches to conceptualizing and assessing vulnerability can be distinguished. Deressa et al. (2008) cites the socioeconomic, the biophysical, and integrated assessment as the three approaches to vulnerability assessment.

The socioeconomic vulnerability assessment approach regards vulnerability as a priori condition of a household or a community determined by socio-economic and political factors (Adger and Kelly, 1999). Vulnerability according to this view is considered the interaction between hazard and social vulnerability that produces an outcome, usually measured in terms of physical or economic damage or human mortality and morbidity (Brooks and Adger, 2003). Adger and Kelly (1999) also viewed socioeconomic vulnerability as an inherent property of a system arising from within. Based on this formulation, vulnerability is something that exists within systems independently from external hazards. For instance, individuals in a community often vary in terms of wealth, education, gender, access to insurance, housing quality, health, access to resources, access to technology, social capital, and so on. These variations are responsible for the variations in vulnerability level. The socioeconomic approach in general focuses on identifying the ability of a system, individuals, or communities to cope with and respond to the stimulus based on their internal characteristics.

Biophysical vulnerability, on the other hand is concerned with the ultimate impacts of a hazard event. Adger et al. (2004) viewed biophysical vulnerability in terms of the amount of damage experienced by a system as a result of a hazard event. Accordingly, the biophysical approach assesses the level of damage that a given environmental stress causes on both social and

biological systems, i.e. in terms of monetary cost, human mortality, etc (Jones and Boer, 2004). Fussel (2007) identified this approach as a risk-hazard approach and denoted the vulnerability relationship as a hazard-loss relationship in natural hazard research.

An integrated assessment approach combines both socioeconomic and biophysical approaches to determine vulnerability. The IPCC (2001) definition that conceptualizes vulnerability to climate as a function of sensitivity, exposure, and adaptive capacity accommodates this integrated vulnerability assessment approach. Vulnerability according to this definition includes: an external dimension characterized by the exposure of a system to climate variations; an internal dimension that comprises its sensitivity; and its adaptive capacity to these stressors (Fussel and Klein, 2006).

In general, the most appropriate vulnerability assessment approach for a specific climate-sensitive sector and/or region depends on the research questions addressed, the geographical and temporal scope of the analysis, the level of previous knowledge, availability of data, expertise, and other resources. The purpose of the analysis should therefore guide the selection of the most effective conceptual approach to the vulnerability assessment.

Different methodological approaches have been found in the literature for measuring vulnerability, despite the difficulties in its quantification. These are the econometric and the indicator approach. The econometric approach is used to analyse the level of vulnerability across different social groups employing household level data. Hoddinott and Quisumbing (2003, 2008) provide a comprehensive review on the three approaches used in the micro-econometric literature to measure vulnerability: vulnerability as expected poverty, vulnerability as expected utility and vulnerability as uninsured exposure to risk. In this study we used the indicator approach for an integrated assessment of the vulnerable farming communities.

### *5.1.2 Indicator method for measuring vulnerability*

According to Vogel and O'Brien (2004), capturing the differential dimensions of vulnerability is a necessary condition for the formulation and implementation of policies that promote equitable and sustainable development. However, since vulnerability is often not a directly observable phenomenon, defining the criteria for quantifying vulnerability has proven to be difficult (Downing, 2001). In climate change impacts research and vulnerability assessment specifically, as well as in hazard research, indicators are most commonly used to develop a better understanding of the socio-economic and biophysical factors contributing to vulnerability (Hebb and Mortsch, 2007). Birkmann (2006) defined the vulnerability indicator as an operational representation of a characteristic of a system able to provide information regarding the susceptibility and resilience of an element at risk to

an impact of an albeit ill-defined event. Similarly, Clerici et al. (2004) described the importance of vulnerability indicators as being central to the decision-making process, providing policy makers with appropriate information about the location of the most vulnerable communities.

The indicator approach is the method most commonly adopted for quantifying vulnerability in the global change community and it can be applied at any scale, i.e., global, national, region, and district (Brooks et al., 2005; Gbetibouo and Ringler, 2009; O'Brien et al., 2004). The approach uses a specific set or combination of proxy indicators and measures vulnerability by computing indices for those selected indicators (Gbetibouo and Ringler, 2009). Accordingly, the indicator approach is widely used in the field of sustainable development: the environmental sustainability index of the World Economic Forum (World Economic Forum, 2002), the Human Development Index of the United Nations Development Program (UNDP, 1990), the Food Security Index by Downing (1992), the Water Poverty Index (WPI) developed by the Centre for Ecology and Hydrology in Wallingford (Sullivan, 2002), the Index of Human Insecurity by Lonergan et al. (2000), and the Mapping of vulnerability to multiple stressors of by The Energy Research Institute (TERI, 2003). However, this approach has its own limitations. Luers et al. (2003) identified existence of subjectivity in the selection of variables and their weights, as well as availability of data at various scales as the main limitations of the approach.

## 5.2 Methodology

The concept of vulnerability is analysed as the net effect of potential impacts and the potential to effectively cope with the impacts; where potential impacts combine the exposure and sensitivity of a system. This relationship is adopted to develop an implicit model, which can serve as a basis for indicator development and measurement of the overall vulnerability:

$$\text{Vulnerability} = (\text{Potential impacts}) - (\text{Adaptive Capacity}) \quad (5.1)$$

Having considered the theoretical determinants of farming community's vulnerability and selected appropriate indicators for its denotation, the most important task when constructing composite indicators is choosing a method to assign weights to the indicators in order to develop an overall index. A review of the literature showed three methods for assigning weights to indicators: (i) using expert judgment (Brooks et al., 2005; Moss et al., 2001); (ii) applying the arbitrary choice of equal weights (Lucas and Hilderink, 2004; O'Brien et al., 2004; Patnaik and Narayanan, 2005); and (iii) using statistical methods such as factor analysis or principal component analysis to assign the weights (Cutter et al., 2003; Deressa et al., 2008;

Filmer and Pritchett, 2001; Gbetibouo and Ringler, 2009; Nardo et al., 2005; Rygel et al., 2006; Thornton et al., 2006; Vyas and Kumaranayake, 2006). Assigning equal weights to each indicator was considered, but not all indicators equally affect vulnerability and assigning equal weights as a strategy is judged as being too subjective (Hebb and Mortsch, 2007). The next option was to weight indicators based on the opinion of experts who know the policy priority and theoretical backgrounds, thus incorporating extra knowledge in the indicator aggregation step. However, Lowry et al. (1995) argues that the development of weights via expert judgment is often constrained by lack of expert knowledge in smaller communities and the difficulties in reaching a consensus.

The third method uses a classic statistical technique such as factor analysis. This method avoids the uncertainty of assigning equal weights when a diversity of indicators is used. The method presented in this paper belongs to this third group. In contrast to the first two methods the main feature for the use of factor analysis is that it assists in statistically (not subjectively) identifying and weighing the most important indicators in order to determine an overall composite vulnerability index for a specific woredas.

Following Filmer and Pritchett (2001) the factor scores were used as weights to construct an overall vulnerability index for each woreda ( $W_j$ ) based on the formula:

$$W_j = b_1(a_{j1} - x_1)/s_1 + \dots + b_k(a_{jk} - x_k)/s_k$$
$$W_j = \sum_{i=1}^k [b_i(a_{ji} - x_i)]/s_i \quad (5.2)$$

where  $W_j$  is a standardized vulnerability index for each *woreda*,  $b_i$  represents the weights assigned to the  $i^{th}$  indicator in the factor analysis,  $a_{ji}$  is the  $j^{th}$  district's value for the  $i^{th}$  indicator,  $x_i$  and  $s_i$  are the mean and the standard deviation of the  $i^{th}$  indicators for all *woredas*. Once the vulnerability scores for each *woreda* were determined, we used a cluster analysis to map and facilitate the relevant comparison across *woredas*. Cluster analysis groups the *woredas* into clusters so that the degree of association is strong among the members of the same cluster and weak between the members of different clusters. We used a hierarchical clustering technique, which allows observations to be assigned to one cluster in successive iterations in the clustering procedure.

### 5.2.1 Model indicators

The choice of indicators certainly matters for vulnerability studies. Studies have shown that different indicators can lead to different vulnerability rankings at the sub-national level. The selection of indicators thus has practical implications for the results in terms of identifying vulnerable locations. Accordingly, one should always consider whether the retained measures are appropriate. For our study, the choice of indicators was undertaken based on an extensive review of the literature and adjusted to fit the context of the study region, and secondly, on their significance to agriculture sector. Reports from Cutter et al. (2003), Flax et al. (2002), Wu et al. (2002), TERI (2003), O'Brien et al. (2004), Brooks et al. (2005), Brenkert and Malone (2005), Thornton et al. (2006), Phillips et al. (2005), Vyas and Kumaranayake (2006), Deressa et al. (2008), and Gbetibouo and Ringler (2009) were used.

For mapping agrarian communities' vulnerability to climate change and variability at *woreda* level, we employed the IPCC's definition whereby a country's or region's vulnerability is understood to be a function of three components: exposure, sensitivity and adaptive capacity (IPCC 2001). Each vulnerability components and the selected indicators representing these components are discussed below.

**Exposure:** relates to the degree of climate stress upon a particular unit of analysis. It refers to the exposure of a system to stimuli that affect that system. This can be readily conceptualised as climate variability and/or the various changes in the climate system that are often of concern to stakeholders: increase in temperature, changes in rainfall, or changes in drought frequency.

In this study exposure is represented by the frequency of climate extremes and predicted change in temperature and rainfall. Frequency of climate extremes reflects the level of climate change that *woredas* are exposed to. It is generally agreed that in *woredas* with a high frequency of climate extremes, increasing temperature and decreasing precipitation are expected to have negative impacts on farm production.

**Sensitivity:** refers to the degree to which a system is affected by climate related stimuli, either positively or negatively. A study by the Stockholm Environment Institute (2004) as cited in Gbetibouo (2009), described that the responsiveness of a system to climatic influences is shaped by both socio-economic and ecological conditions. This in turn determines the degree to which a group will be affected by an environmental stressor. In our study, four indicators were considered that may have an influence on the sensitivity of the farming community in a *woreda*. These are share of subsistence

farmers, rural population density, landless population and share of dependent population.

Agricultural dependency is measured by the percentage of the *woreda* workforce employed in agriculture. It is assumed that high levels of agricultural dependency will increase farming communities' vulnerability to climate change and fluctuations in agricultural income. Vulnerability of the agricultural labour force, with the percentage of landless labourers used as measurement, provides an indication of inequality in landholding. A *woreda* with a larger share of landless labourers in the agricultural workforce is thus more vulnerable to social and economic disruption as the result of drought or other climate stress. Here, it is argued that places with a high frequency of droughts, a higher share of subsistence farmers, and agricultural dependency are more sensitive to climate change and climate variability.

Adaptive capacity: describes the ability of a system to adjust to climate stresses, to moderate potential damages, or to cope with the consequences. Wealth, education, technology, information and skills, infrastructure, access to resources, and institutions are identified as the main factors that determine adaptive capacity of communities or regions (IPCC 2001; McCarthy et al. 2001). Socioeconomic factors also play an important role in determining the extent of vulnerability. The most vulnerable *woredas* and communities are those which are highly exposed to expected changes in climate and have limited adaptive capacity.

Analysing vulnerability further involves identifying not only the threat to, but also the resilience in the system, and its ability to exploit opportunities and recover from the negative effects of the changing environment. Moser (1998) identified assets and entitlements that households or communities can mobilize and manage in the face of hardship as a means of resistance or capacity to cope. This indicates the close link between vulnerability and asset ownership.

For this study, adaptive capacity is represented by levels of wealth, technology, human and social capital, the presence of alternative economic activities, physical environment, and availability of infrastructure and institutions. Wealth assists communities to absorb and recover from losses more quickly (Cutter et al., 2000). The number of livestock owned, ownership of radio, and quality of the residential home are commonly used as indicators of wealth in rural African communities (Vyas and Kumaranayake 2006).

The level of development of institutions and infrastructure also play an important role in adaptation to climate change by facilitating access to resources. Areas with better infrastructural facilities are expected to have a

higher capacity to adapt to a changing climate (O'Brien et al. 2004). Similarly Smith and Lenhart (1996) indicated that countries with well-developed social institutions are considered to have greater adaptive capacity than those with less effective institutional arrangements. Access to all-weather roads, technology, health services, and microfinance are used to represent the level of institutions and infrastructure in this study.

Literacy rate is another factor contributing to adaptation to climate change. Lack of education is associated with poverty and marginalisation - the least educated and lower skilled members of a society are likely to be the most vulnerable to climate hazards in terms of livelihoods and geographical location. Smith and Lenhart (1996) argued that countries with higher levels of human knowledge are considered to have greater adaptive capacity than developing nations and those in transition. Populations with low overall levels of literacy are more likely to depend on climate-sensitive economic activities such as agriculture. Increasing the overall literacy level will thus reduce vulnerability by increasing people's capabilities and access to information and this in turn increases their ability to cope with adversity. In our study human and social capital is represented by adult literacy rates and female literacy. The presence of alternative economic activities is also represented by the proportion of non-agricultural income.

Irrigation potential was selected based on the assumption that places with more potentially irrigable land are more adaptable to adverse climatic conditions (O'Brien et al. 2004). The irrigation rate is measured by looking at the net irrigated area as a percentage of the net sown area. Improved irrigation systems are therefore said to reduce farmers' vulnerability to erratic rainfall as agriculture in the study region is nearly totally rain-fed. Concerning the physical characteristics of the environment, land cover or a green environment are desirable for most rural households and should form an important consideration in farming community's vulnerability assessment. Ecosystem stress and destruction can increase the physical vulnerability of settlements. Deforestation and ecosystem fragmentation can increase a region's ecological vulnerability to climate change. Greenness (in the form of vegetation cover) is thus believed to be a good surrogate for socioeconomic conditions, and is measured in the form of a vegetation index. Thus, in this study the long-term (decade) average Normalized Difference Vegetation Index (NDVI), which is commonly used to monitor greenness of vegetation, is used as an indicator of available natural resource.

In total our study employs 24 indicators to capture the vulnerability of farming communities to climate-change and variability. The selected indicators represent both the biophysical and socio-economic conditions of the farming community at *woreda* level (Table 5.1). Furthermore, we

attempted to validate the selected indicators with stakeholders during the fieldwork and then we assessed practicality in relation to the availability of data. We acknowledge that there are many relevant indicators to describe vulnerability of farming communities to climate change and variability, such as rate of degradation and ground water availability. However, due to a lack of available data at *woreda* level we were not able to include them in the study. Furthermore, some of the proxies are not independent. This is an issue for all proxy sets that seek to provide a complete picture of a system, and it is probably impossible to have proxies that are totally independent. Dependencies must therefore be acknowledged as part of the analysis of results and properly taken into account. Independent components are not a requirement for an effective vulnerability index, however (Brenkert and Malone 2005). Despite such constraints, we believe that the retained indicators are sufficient for assessing farming communities' vulnerability at a *woreda* level.

### *5.2.2 Data used*

A *woreda* is the second administrative unit above the *tabia*. Although vulnerability may vary at smaller geographic scales and at household level, our scale of analysis is useful and practical for policy makers. Data on socioeconomic and biophysical factors were collected for 34 rural *woredas*. Socioeconomic data on wealth, technology adoption, human capital, infrastructure and institutions were acquired from the census data of the Central Statistics Agency of Ethiopia. Data on irrigation were collected from Tigray Bureau of Agriculture and Rural Development. Data on drought events for the period 1978 to 2010 were acquired from the Disaster Prevention and Preparedness Commission, Addis Ababa- Ethiopia. Data on temperature and precipitation were acquired from the Ethiopian National Meteorological Services Agency.

Besides the above mentioned data, SPOT vegetation ten-day composite Normalized Difference Vegetation (NDVI) images (S10 product) were acquired from *vgt4africa* of the DevCoCast project website <http://www.vgt4africa.org> for the period January 2000 to December 2009. Accordingly, 360 decadal NDVI images were processed in order to produce the 10 year average NDVI for each *woreda*.

Table 5.1: Selected variables used in vulnerability assessments

Indicators of vulnerability	Unit of measurement
Frequency of drought	Number of occurrence of droughts from 1978-2009
Change in temperature	Change in degrees from base value (2000)
Change in precipitation	Percentage change from base value (2000)
Rural population density	Population per Sq.km
Agricultural dependency	Percentage
Landless population	Percentage
Dependent population	Percentage
Livestock ownership	Per cent of total population who own
Ownership of radio	Per cent of total population who own
Quality of residential home	Per cent of total population who own
Non-agricultural income	Per cent of total population who own
Farm holding size	Hectares
Insecticide and pesticide supply	Per cent of population within 1-4 kilometres to supply sources
Fertilizer supply	Per cent of population within 1-4 kilometres to supply sources
Improved seeds supply	Per cent of population within 1-4 kilometres to supply sources
Access to all-weather roads	Per cent of population within 1-4 kilometres to
Health Services	Per cent of population within 1-4 kilometres to
Veterinary services	Per cent of population within 1-4 kilometres to
Food market	Per cent of population within 1-4 kilometres to
Micro finance	Per cent of population within 1-4 kilometres to
Percentage of irrigated land	Percentage
Average NDVI*	Long-term average NDVI for the past decade
Adult literacy rate	Percentage
Adult female literacy rate	Percentage

\*NDVI = Normalized Differential Vegetation Index

### 5.3 Results and discussion

There are several socioeconomic and biophysical indicators that may affect agriculture's vulnerability to climate change and climate variability. The main challenge is how to develop appropriate indices from the indicators that can be used to estimate the vulnerability. In this study factor analysis is applied to develop the indices and quantitatively assess the overall vulnerability index. Twenty four indicators reflecting the main components of vulnerability were studied.

Prior to applying factor analysis, the appropriateness of the data was examined based on the Kaiser-Meyer-Olkin (KMO) and Bartlett's tests. Li and Weng (2007) argued that the KMO value must be greater than 0.5 and the Bartlett's test value must be less than 0.1 in order to apply factor analysis. The orthogonal varimax rotation method was applied to ensure that the attributes were maximally correlated with only one factor and for ease of interpreting the factors. To ensure factor scores were uncorrelated, the Anderson-Rubine method was carried out to identify the factor score

coefficients. The attributes that had the highest loading in the respective components were selected to construct the vulnerability index.

The analysis indicated that the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy is 0.68 (Table 5.2), labelling the model fairly acceptable (Henry et al., 2003), and that the Bartlett's significance test for these data is highly significant ( $p < 0.001$ ), implying that factor analysis is appropriate for integrating the socioeconomic and biophysical indicators at woreda level.

Table 5.2: KMO and Bartlett's Test

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Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.678
Bartlett's Test of Sphericity	Approx. Chi-Square	602.767
	df	190
	Sig.	0.000

---

The approach generated five components with an Eigenvalue greater than 1.0. Attributes with factor loadings of greater than 0.5 were considered for identifying vulnerabilities. Accordingly, four components accounting for 74.21 per cent of the total variation in the dataset were retained (Table 5.3). The first principal component explained 30 per cent of the total variation in the data, the second factor explained 18 per cent, the third 15.5 per cent, and the fourth factor 10.5 per cent. The component loadings, which are most important output for determining the relative importance of each variable to each principal component (Zeller et al., 2006) are presented in Table 5.3.

Table 5.3: Factor loading matrix

<b>Vulnerability indicators</b>	<b>Principal components</b>			
	<b>First</b>	<b>Second</b>	<b>Third</b>	<b>Fourth</b>
Fertilizer supply	0.924			
Improved seeds supply	0.891			
All weather roads	0.875			
Pesticide supply	0.875			
Micro finance	0.846			
Veterinary services	0.805			
Food markets	0.719			
Frequency of droughts	0.533			
Female literacy		0.868		
Radio ownership		0.841		
Literacy		0.813		
Dependent population		0.728		
Average NDVI (Vegetation cover)		-0.636		
Landless population			0.870	
Non-agricultural income			0.869	
Agricultural dependency			-0.850	
Livestock ownership			0.537	
Decrease in rainfall				0.849
Increase in temperature				0.788
<i>Eigenvalue</i>	6.091	3.551	3.106	2.095
<i>Proportion of variance</i>	0.3045	0.1775	0.1553	0.1047
<i>Cumulative proportion</i>	0.3045	0.4821	0.6374	0.7421

Extraction Method: Principal Component Analysis.

To construct the overall vulnerability index, 19 of the 24 indicators were selected, based on the value of their factor score having an absolute value greater than or equal to 0.5. The components of vulnerability and the overall vulnerability index for each *woreda* were then constructed by applying equation 5.1 and 5.2 respectively.

### 5.3.1 Estimates for the components of vulnerability

#### The potential impact index

As a follow up the overall exposure and sensitivity of the farming community was analysed across the 34 *woredas* of the study region. The findings revealed that the majority of the farming communities living in the southern and eastern zones of Tigray form the group most exposed to changes in climate including variability. These *woredas* are prone to recurrent cycles of drought. The least exposed *woredas* are found in the central and western zones of the region (Figure 5.1).

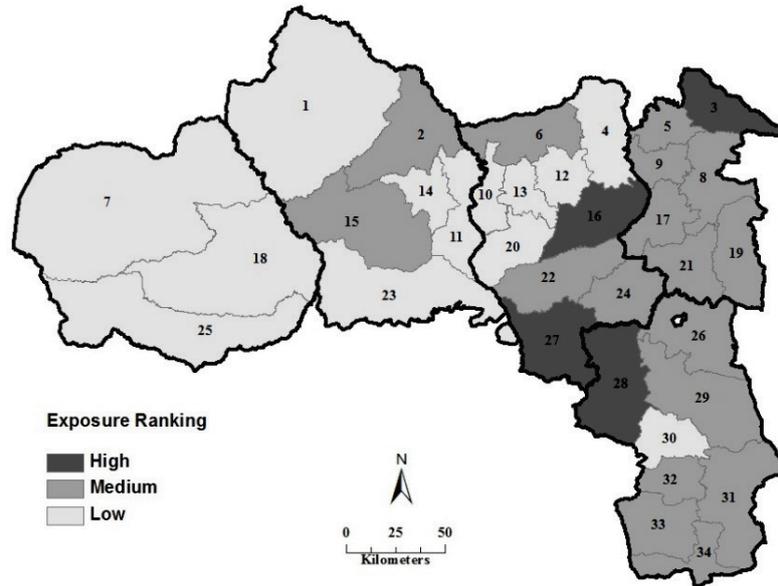


Figure 5.1: The exposure indices across the rural districts of Tigray region

The result of the overall sensitivity analysis also revealed that Tselemti, Asegede Timbla, Gulomekeda, Hawuzen, Tanqua Abergele, Seharti Samere, Enderta, Werieleke, Alaje, Saesie Tsaeda Emba, and Tahetay Adiyabo *woredas* are the most sensitive *woredas* (see Figure 1.1 for the location of the *woredas*). This is mainly due to the relatively large landless population, the very large proportion of small-scale farmers that produce primarily for subsistence purposes, the use of very low technology, low irrigation potential, and high dependence on rain-fed agriculture. A rapidly growing population in conjunction with deforestation and soil erosion have been partly responsible for the increasing sensitivity of the *woredas*. On the other hand, in the Western Zone of the region, the small land less and rural population and the low population pressure make it less sensitive to social and economic disruption as the result of climate change and variability. The least sensitive *woredas* are Kafta Humera, Tsegede, and Alamata. A common feature of these *woredas* is that they only have a low percentage of subsistence farmers and landless labourers, and that, apart from Alamata *woreda*, they are the least populated rural areas in the region.

The combined effect of the sensitivity and exposure indicator produce the potential impact of climate change and variability on the various *woredas*.

According to Figure 5.2 the *woredas* with the largest potential impact are Erob, Werei Leke, Hawezen, Saesie Tsaeda Emba, Enderta, Tselemti, Kola Temben and Tanqua Aberegel. These *woredas* will suffer most. The majority of these *woredas* have both the highest exposure and the highest sensitivity. A mid-range potential impact is seen for Welkayte, Tselemeti, Laelay Adeyabo, Tahetay Koraro, Tahetay Maichew, Adwa, Aheferom and Alaje *woredas*. The Kafta Humera, Tsegede, Medebay Zana, and Alamata *woredas* show the lowest potential impact.

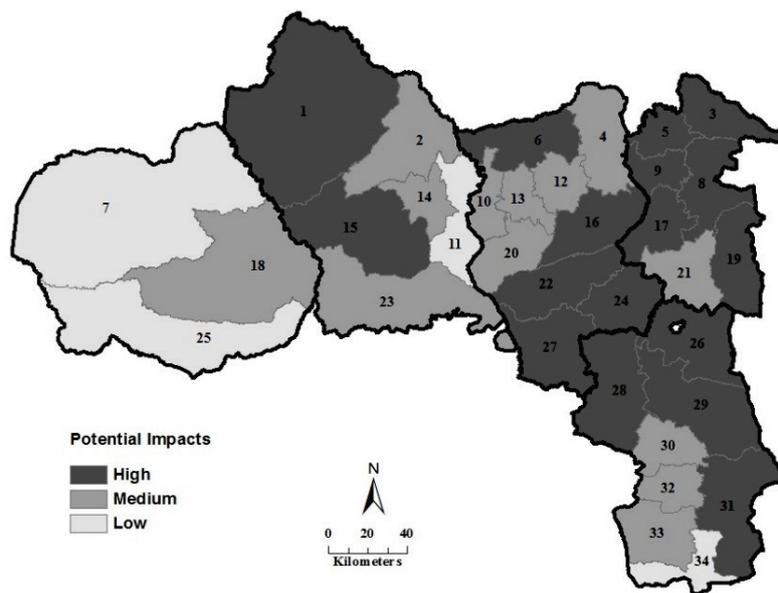


Figure 5.2: Exposure-sensitivity indices across the rural district of Tigray Region

### The adaptive capacity index

The analysis of the adaptive capacity indicated large variation across the 34 rural *woredas*. Adwa, Alamata and Enderta *woredas* have the highest adaptive capacity because of the combined effects of a relatively well-developed infrastructure network and institutions and high levels of literacy (Figure 5.3). Ganta Afeshum, Kilde Awelaelo, Saesie Tsaeda Emba, Alaje, Endamekoni and Ofla exhibit a mid-range coping capacity. These *woredas* are close to urban cities and the farming population in these *woredas* are in closer proximity to sources of agricultural inputs, and have better access to infrastructure and institutions. Moreover, these *woredas* have relatively high literacy rate.

Woredas with a low adaptive capacity include Tsegede, Tselemti, Asgede Tsimbla, Tanqua Abergelle, and Naeder Adet. These woredas are unlikely to cope effectively with the potential impact of climate change and variability. These woredas have comparatively little access to the most important socio-economic factors including asset ownership, access to agricultural technologies and institutions, infrastructural support (such as irrigation and road networks) or to services (micro-finance, veterinary) and human capital.

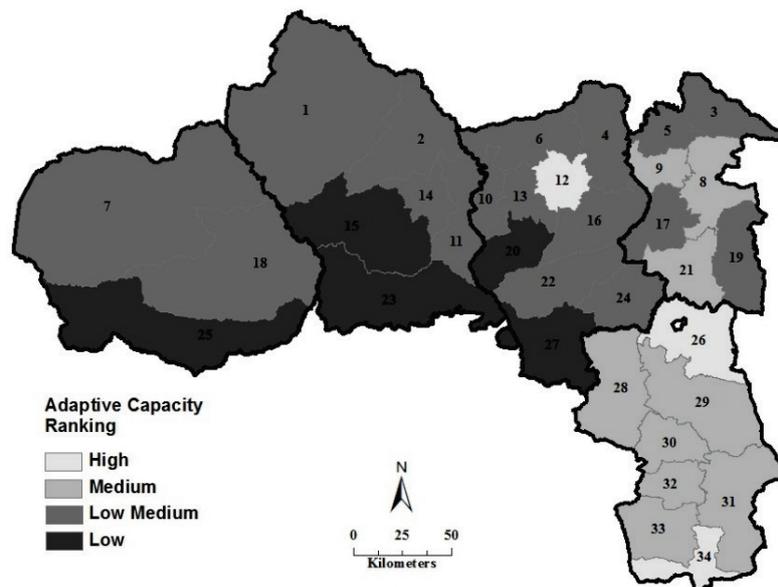


Figure 5.3: Adaptive capacity indices across the rural districts of Tigray region

### Overall vulnerability estimate

Although maps of individual component scores can be useful, it is vital to assess the overall vulnerability throughout the region by combining the multidimensional components into a single measure. Accordingly, we measured the overall vulnerability based on the implicit model adopted for our study (equation 5.1). Our analysis revealed that the overall vulnerability index ranges from -14.64 (low vulnerability) to 10.38 (high vulnerability), with a mean vulnerability score of 0.13 and standard deviation of 5.58 for all *woredas*. The finding showed that Alamata *woreda* has low vulnerability indices (Figure 5.4). The low vulnerability of the *woreda* is basically associated with high levels of infrastructure development, high levels of wealth, and low numbers of landless labourers.



## **5.4 Conclusions**

Vulnerability analysis provides a scientific base for the policy making of disaster mitigation. In this chapter, we examined farming sector's vulnerability to climate change and variability at *woreda* level. The results on the vulnerability analysis indicated that the *woredas* deemed to be most vulnerable to extreme events and climate variability overlap with the most vulnerable populations. *Woredas* most exposed to climate variability also have a relatively low capacity to adapt to climate change. Thus, it will take only a moderate climate change to disrupt the livelihoods and wellbeing of the rural inhabitants in those *woredas*. This finding is similar with the findings of Deressa et al. (2008) at national level. Farmers in these *woredas* are therefore likely to bear the burden of the negative impacts of climate change, which will include increased food insecurity. The results further show that vulnerability to climate change and variability is intrinsically linked to social and economic development. By and large, to the best of my knowledge this study is the first research attempt at this spatial scale of analysis in the country.

## **Chapter 6**

### **Farm level Adaptation to Climate Change and Climate Variability**

\*This chapter is based on:

Gebrehiwot, T., van der Veen, A. (2012). Farm level adaptation to climate change: the case of farmer's in the Ethiopian highlands. *Environmental Management*, under review after revision.

Gebrehiwot, T., van der Veen, A. (2012). Assessing the evidence of climate variability in the northern highlands of Ethiopia. *Journal of Development and Agricultural Economics*, under review.

## **Abstract**

In Ethiopia, climate change and associated risks are expected to have serious consequences for agriculture and food security. This in turn will seriously impact on the welfare of the people, particularly the rural farmers whose main livelihood depends on rain-fed agriculture. The level of impacts will mainly depend on the awareness and the level of adaptation in response to the changing climate. It is thus important to understand the role of the different factors that influence farmers' adaptation measures to ensure the development of appropriate policy measures and the design of successful development projects. This study examines farmers' perception of change in climatic attributes and the factors that influence farmers' choice of adaptation measures to climate change and variability. The estimated results from the climate change adaptation models indicate that level of education, age, and wealth of the head of the household; access to credit and agricultural services; information on climate, and temperature all influence farmers' choices of adaptation. Moreover, lack of information on adaptation measures and lack of finance are seen as the main factors inhibiting adaptation to climate change. These conclusions were obtained with a Multinomial logit model, employing the results from a survey of 400 smallholder farmers in three *woredas* in Tigray, northern Ethiopian.

## **6.1 Introduction**

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) revealed that developing countries are expected to suffer the most from negative impacts of climate change and variability. Moreover, there is increasing evidence that climate change will strongly affect the African continent, which depends mainly on agriculture, and will thus be one of the challenging issues concerning future development particularly for the drier regions (Adger et al., 2007; Haile, 2005; Huq et al., 2004). According to Sivakumar et al. (2005), climate change will have an impact on numerous sectors as well as the productive environment, including agriculture and forestry.

Climate change is expected to affect the two most important direct agricultural production inputs: precipitation and temperature. These inputs are crucial for livelihoods in Africa, where the majority of the population relies on local supply systems sensitive to climate variation (Deschênes and Greenstone, 2007). The prevailing limited human and financial capacity to anticipate and respond to the direct and indirect effects of climate change will further undermine attempts to reduce the adverse effects of climate change (Collier et al., 2008; Easterling et al., 2007; McCarthy et al., 2001).

Despite the emerging threat of climate change and variability, agriculture remains the crucial mainstay of local livelihoods for most rural communities in developing countries in general and for Ethiopia in particular. Agriculture, an important sector in the economy of Ethiopia, accounts for approximately 42 per cent of the gross domestic product (GDP), supports about 80 per cent of the population in terms of employment, and serves as the main base for food security. Sustainable economic development and food security are, therefore, intricately linked to sustainable growth in the agricultural sector. Notwithstanding its high economic significance to the overall economy, this sector has been facing serious challenges through climate change induced natural and man-made disasters.

Drought remains the country's major hazard, with floods following in second place. A marked increase in both size and frequency has recently become apparent (Margaret, 2003). In the past 15 years, the country has been hit by climate change induced disasters about 15 times (FAO, 2010). A recent study by UNDP (2008) further indicated that climate change in Ethiopia may lead to extreme temperatures and rainfall events, and more severe and extended droughts and floods. The prevailing low adaptive capacity of the poorest populations will also contribute to the vulnerability of the country to climate change and variability.

Consequently, climate change and associated risks are expected to have serious consequences for the country's economy, and agriculture and food security in particular. Dercon (2004) reported that in Ethiopia a season with starkly reduced rainfall depressed consumption even after four to five years. Left unmanaged, climate change and variability will reverse development progress made and compromise the well-being of the people, particularly the rural farmers', whose livelihoods depend largely on rain-fed agriculture. Against this backdrop, literature on climate change and agriculture has increasingly directed attention to the issue of adaptation, while its significance is also being recognized in national and international policy debates on climate change and variability (Smit et al., 2000; Smit and Pilifosova, 2001). Farm level adaptation can greatly reduce vulnerability to climate change by making rural communities better able to adjust to the changing climate, helping them to cope with adverse consequences, and moderating potential damages (IPCC, 2001). Furthermore, understanding the perspectives of the local farmers, the way they think and behave in response to the changing climate, as well as their values and aspirations, has a significant role in addressing climate change. Therefore, there is an urgent need to find out farmers' perceptions regarding long-term climatic change, the measures they are using to cope with the situation, and the main factors affecting a farmer's choice of adaptation. A study of this nature can help in providing a framework for policy formulation and better research orientation.

Despite the importance of adaptation in response to the changing climate, it has attracted little scientific attention and to our knowledge no attempts have been made to examine the factors influencing farmers' perception and adaptation measures to climate change and variability in the study region. Therefore, empirical studies that examine factors affecting the choice of adaptation measures within the context of the study region are crucial.

The specific objective of this chapter is to examine farmers' perceptions regarding changes in climate, factors affecting farmers' choice of adaptation, and barriers to adaptation in response to the changing climate in Tigray. A discrete choice model of Multinomial logit was employed to examine the factors influencing farmers' choice of adaptation measures.

### *6.1.1 Adaptation to climate change*

As noted earlier, Africa's agriculture is negatively affected by climate change (McCarthy et al., 2001; Onyeneke and Madukwe, 2010; Pearce et al., 1996). Without appropriate responses climate change is likely to constrain economic development and poverty reduction efforts and exacerbate already pressing difficulties. As a result adaptation is recognized as one of the policy options to reduce the negative impact of climate change (Adger et al., 2003; Kurukulasuriya and Mendelsohn, 2006). Currently, adoption of technological

innovations in agricultural has become a key focus of the scientific and policy-making communities and is a major area of discussion among development economists in the multilateral climate change process. Adaptation is increasingly recognized as an appropriate and necessary response option to climate change. Especially developing countries need to pay attention to the management of natural resources and agricultural activities as climate change is projected to hit the poorest hardest.

The IPCC (2001) definition of adaptation is adopted here, which defines adaptation as the ability of a system to adjust in response to actual or expected climatic stimuli to moderate harm or to cope with the consequences. Adger et al. (2007) allow adaptation to comprise actions adjusting practices, and capital in response to the threat of changing climate, as well as responses in the decision environment. Adaptation to climate change then refers to the adjustment in natural or human systems in response to actual or expected climatic stimuli. Hence, the purpose of undertaking agricultural adaptation is to effectively manage potential damage resulting from effects of climate change.

## **6.2 Methodology**

### *6.2.1 Analytical framework and empirical model*

We modelled the adaptation measures farm households<sup>12</sup> chose, based on their perceived utility of the different adaptation options. According to Norris and Batie (1987), and Pryanishnikov and Katarina (2003), the decisions of a farmer (or economic agent) in a given period are generally assumed to be derived from the maximization of expected profit or utility theories.

Accordingly, the adoption of a new technology (in our case an adaptation method) is modelled as a choice between two alternatives: 'use adaptation method' and 'no adaptation'. It is thus assumed that smallholder farmers will make their decisions by choosing the alternative that maximizes their perceived utility (Fernandez-Cornejo et al., 1994; Pryanishnikov and Katarina, 2003). However, only the actions of economic agents are observed through the choices they make as utility is not directly observed. Assume that  $Y_j$  and  $Y_k$  represent a farm household's utility for two choices, which

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<sup>12</sup> In this chapter, we used the definition of a household usually employed by economist. A household is understood as a domestic unit with autonomous decision-making regarding production and consumption (Ellis, 1988; Roberts, 1991). The assumption underlying this definition is that a household has an unequivocal hierarchy of authority. Additionally, the head of household have the power and exercising decision-making over the household's resources.

could be denoted by  $U_j$  and  $U_k$ , respectively. Following Green (2000) and Pryanishnikov and Katarina (2003) the linear random utility model can be represented as:

$$U_{jt} = V_{jt} + \varepsilon_{jt} \quad \text{and} \quad U_{kt} = V_{kt} + \varepsilon_{kt} \quad (6.1)$$

where  $U_j$  and  $U_k$  are the perceived utility from choosing an alternative  $j$  and  $k$  at time period  $t$  respectively,  $V_{jt} = \beta_j' x_{it}$  and  $V_{kt} = \beta_k' x_{it}$  are the deterministic component, and  $\varepsilon_{jt}$  and  $\varepsilon_{kt}$  are random components (or error terms) of the utility function, which are assumed to be independently and identically distributed. Choice experiments are thus based on the assumption that an individual  $n$  chooses an alternative  $j$  at time period  $t$ , if and only if this alternative choice generates at least as much utility as any other alternative (say  $k$ ), represented as

$$U_{njt}(V_{njt} + \varepsilon_{jt}) > U_{nkt}(V_{nkt} + \varepsilon_{kt}), \quad k \neq j \quad (6.2)$$

The probability of individual  $n$  choosing alternative  $j$  among the set of adaptation options at time  $t$  can then be specified as:

$$\begin{aligned} P_{njt}(Y = 1 | X) &= P(U_{njt} > U_{nkt}) \\ &= P(V_{njt} + \varepsilon_{njt} > V_{nkt} + \varepsilon_{nkt}) \\ &= P(V_{njt} + \varepsilon_{njt} - V_{nkt} - \varepsilon_{nkt} > 0 | X) \\ &= P(V_{njt} - V_{nkt} + \varepsilon_{njt} - \varepsilon_{nkt} > 0 | X) \\ &= P(V^* + \varepsilon^* > 0 | X) \end{aligned} \quad (6.3)$$

where  $P$  is a probability function,  $\varepsilon^* = \varepsilon_{njt} - \varepsilon_{nkt}$  is the stochastic component,  $V^*$  is the deterministic components with a vector of unknown parameters which can be interpreted as the net influence of the vector of independent variables influencing adoption. Depending on the assumed distribution that the random disturbance terms follows, several qualitative choice models such as a linear probability model, a logit or probit models could be estimated (Green, 2000). However, the probit and logit models are the two most common functional forms used in adoption models. These models have got desirable statistical properties as the probabilities are bound between 0 and 1 (Green, 2000).

Apparently, adoption models could be grouped into two categories based on the number of options available to the economic agents (Pindyck and Rubinfeld, 1997; Green, 2000). A setting where there are only two adaptation options would give rise to binomial adoption models whereas

choice sets with more than two alternatives would give rise to multinomial adoption models.

For this study, we employed six adaptation options or response probabilities: crop diversification, soil conservation, differing planting dates, tree planting, irrigation and no adaptation. These choice sets with more than two alternatives give rise to multinomial adoption models. Under this circumstance, the appropriate econometric model would, therefore, be either a multinomial logit (MNL) or multinomial probit (MNP) regression models. Both MNL and MNP models indeed, estimate the effect of explanatory variables on a dependent variable involving multiple choices with unordered response categories (Green, 2000; Long, 1997). However, MNP model is rarely used in empirical studies due to the estimation difficulties imposed by the need to solve multiple integrations related to multivariate normal distributions (Pryanishnikov and Katarina, 2003). In addition, the MNP model makes maximum likelihood infeasible for more than five alternatives (Wooldridge, 2002). In this study, therefore, we chose the multinomial logit (MNL) model over the multinomial probit model (MNP). The MNL model thus permits the analysis of decisions across more than two options, allowing the determination of the likelihood of the different options to be chosen.

It is thus assumed that the random disturbance terms (or the error terms) in equation (6.3) are independently and identically distributed with a Gumbel<sup>13</sup> distribution over  $n$  and  $t$ . The cumulative and density functions are respectively  $G(\varepsilon_{njt}) = \exp(-e^{-\varepsilon_{njt}})$  and  $g(\varepsilon_{njt}) = \exp(-\varepsilon_{njt} - e^{-\varepsilon_{njt}})$ . As shown by McFadden (1973) and Train (2003), this specification leads to the multinomial logit model with:

$$P_{njt} = \frac{e^{V_{njt}}}{\sum_{k=1}^K e^{V_{nkt}}} \quad (6.4)$$

Similar to the expression under equation (6.1) above,  $V_{njt}$  is specified to be linear in parameters

$$V_{njt} = \beta' x_{njt} + \varepsilon_{njt} \quad (6.5)$$

where,  $x_{njt}$  is a vector of observables relating to alternative  $j$ . With this specification, the choice probabilities in equation (6.4) become

<sup>13</sup> Two common assumptions about the error term are either the Normal or the Gumbel distribution. Normal random variables have the property that any linear combination of normal varieties is normal. The difference between two Gumbel random variables has a logistic distribution, which is similar to the normal but with larger tails. Thus the choice is somewhat arbitrary with large samples (Greene 2000).

$$P_{jt} = \text{Prob}(n_j = 1) = \frac{e^{\beta_j x_t}}{1 + \sum_{j=1}^J e^{\beta_j x_t}}, j = 1 \dots J \quad (6.6)$$

which gives the probability that a farm household  $n$  with characteristics  $X$  taking up adaptation  $j$  at time  $t$  among  $J$  alternatives (Green, 2000).

Unbiased and consistent parameter estimates of the MNL model in equation (6.6) require the assumption of Independence of Irrelevant Alternatives (IIA)<sup>14</sup> to hold. The IIA assumption necessitates that the probability of a given household using a certain adaptation method needs to be independent from the probability that another adaptation method is chosen. The premises of the IIA assumption are the independent and homoscedastic disturbance terms of the basic model in equation (6.1). The validity of the IIA assumption could be tested using Hausman's specification. The Hausman's test is based on the fact that if a choice set is irrelevant, eliminating a choice or choice sets from the model altogether will not change parameter estimates, systematically. Following Green (2000), the statistic of Hausman's specification is given as:

$$\chi^2 = (\hat{\beta}_s - \hat{\beta}_f)' [V_s - V_f]^{-1} (\hat{\beta}_s - \hat{\beta}_f) \quad (6.7)$$

where,  $s$  indicates the estimator based on restricted subsets,  $f$  indicates the estimator based on the full set of choices, and  $\hat{V}_s$  and  $\hat{V}_f$  are the respective estimates of the asymptotic covariance matrices.

Provided that the IIA assumption is met, the maximum likelihood estimators are asymptotically normally distributed with a mean zero and a variance of one for large samples (Long, 1997). Significance of the estimator is tested with z-statistic and goodness of fit of the model is assessed by the likelihood-ratio (LR) tests comparing the log-likelihood from the full model (the model with all the explanatory variables) with a restricted model where only the constant is included.

The parameter estimates of the MNL model provide only the direction of the effect of the independent variables on the dependent or response variable. But these estimates represent neither the actual magnitude of change nor the probabilities. Differentiating equation (6.6) with respect to the explanatory variables provides marginal effects of the explanatory variables, which is given as:

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<sup>14</sup> Hausman's test of IIA is invoked in STATA using *mlogtest*, *hausman base*

$$\frac{\partial P_j}{\partial x_k} = P_j(\beta_{jk} - \sum_{j=1}^{J-1} P_j \beta_{jk}) \quad (6.7)$$

Green (2000) and Long (1997) described marginal effects as functions of the probability itself and measure the expected change in probability of a particular choice being made with respect to a unit change in an independent variable.

### 6.2.2 Data and model variables

#### Data used

The same sample of 400 farm households drawn from three rural *woredas* is used to empirically test the factors influencing farm level adaptation measures in response to changes in climate. The study was based on interviews with rural households using a structured questionnaire to elicit whether the farm household's had noticed long-term changes in temperature and precipitation, and which adaptations they had made as a response to whatever changes they had noticed. Those farmers who felt they had experienced climate change were further questioned on the main barriers they encountered, preventing them from fully adapting to climate change. The survey captured information related to demographic characteristics, economic activities, asset endowment, wealth and income.

#### Model variables

A literature review was used to identify the potential determinants of farmers' choice of adaptation to climate change. Accordingly, a range of household and farm characteristics, household access to resources, agro-ecological settings, and climate attributes are hypothesized to influence farmers' adaptation choice to climate change (Deressa et al., 2009; Hassan and Nhemachena, 2008; Nhemachena, 2009). Therefore, different variables were included:

**Age** - refers to the age of the head of the household, which is assumed to represent a farmers experience in farming. The effect is believed to stem from accumulated knowledge and experience with his/her farming system obtained over the years and may favour reacting to climate change. Maddison (2006) as well as Ishaya and Abaje (2008) reported that experienced farmers have a higher probability of perceiving climate change as they have been exposed to climatic conditions over a longer period of time. Accordingly, it is hypothesize that older and more experienced farmers have a higher likelihood of perceiving and adapting to climate change.

**Education** - refers to the numbers of years of schooling of the head of the household. Education increases the ability of farmers to obtain and apply relevant information concerning the changing climate, which thereby

increases farm level adaptation options. Literature indicates that improving education and disseminating knowledge is an important policy measure for stimulating local participation in various development and natural resource management initiatives (Anley et al., 2007; Deressa et al., 2009; Dolisca et al., 2006; Glendinning et al., 2001). Thus, it is hypothesized to positively affect awareness of changes in climate.

Household size - refers to the number of family members living in a household. Review of the literature on technology adoption showed that household size has a mixed impact on farmers' adoption of agricultural technologies. On one hand larger family size is expected to enable farmers to take up labour intensive adaptation measures (Anley et al., 2007; Croppenstedt et al., 2003; Nyangena, 2007). On the other hand, Deressa et al., (2009) found that increasing household size did not significantly increase the probability of adaptation. In this study we presumed that farm households with a large family size are better able to adapt to changes in climate.

Farmland size - refers to a household's land holding. Farmland holding size is expected to play a significant role in influencing farm households' choices in subsistence agriculture. Empirical adoption studies have found that farmers with larger farm land size allocated more land for constructing soil bunds and improved cut-off drains in Nigeria (Okoye, 1998). On the other hand, Nyangena (2007) found that farmers with a small area of land were more likely to invest in soil conservation. In this study we hypothesized that farmers with large farm size would be more likely to adapt.

Extension service - refers to a household's access to agricultural services. Extension services are a crucial source of information on agronomic practices as well as on climate. Access to information on climate change through extension agents is believed to create awareness and favourable conditions for adoption of farming practices suited to climate change (Maddison, 2006). The influence extension services have on adoption is mixed. Empirical studies on adoption of soil conservation measures found that extension services were not a significant factor (Pender et al., 2004). In this study, we assumed that the availability of better climatic and agricultural information helps farmers make comparative decisions about alternative adaptation options enabling them to cope better with changes in climate. Hence availability and frequency of extension services is expected to influence adoption positively.

Income - refers to farm and non-farm income of the head of the household. Semenza et al. (2008) indicated that higher income positively affects perception of climate change. Moreover, external off-farm income sources are of relevance as well, as they help farmers overcome a working capital

constraint and enable them to apply agricultural practices, which may otherwise jeopardize their subsistence income. On this basis we hypothesized that higher farm and non-farm incomes positively influence a farmer's perception of climate change.

Access to credit - is an important determinant enhancing the adoption of various technologies (Kandlinkar and Risbey, 2000). Having access to financial sources enables farmers to make use of available information and improve their management practices in response to changes in the climate. Access to credit is necessary to finance the adoption of agricultural technologies and is often cited as a factor affecting differential rates of adoption.

Distance to input and output markets - refers to the average time it takes a farmer to travel from his/her farm to the market where he/she buys inputs and sells products. Market access is another important factor affecting adoption of agricultural technologies (Feder et al., 1985). Proximity to market is identified as an important determinant of adaptation as markets also serve as a platform for farmers to exchange information. Hence, we assumed the relationship between adoption and distance to input and output markets to be negative.

Livestock - ownership of livestock is one of the basic assets in the Ethiopian rural economy. Deressa et al. (2009) found ownership of livestock to be positively related to most of the adaptation options even though the marginal impacts were not significant. Various studies on adoption of soil and water conservation technologies have shown that farm assets significantly affect adoption decisions (Lapar and Pandely, 1999; Pender and Kerr, 1998).

Agro-ecology - refers to the agro-ecological setting of farmers. Diggs (1991) identified that farmers living in drier areas with more frequent droughts were more likely to describe the climatic change as warmer and drier than farmers living in a relatively wetter climate with less frequent droughts. This is associated with the cognitive heuristics used by farmers in the formation of climate change perceptions, which are biased by the frequency of drought in drier areas (Diggs, 1991). In Ethiopia, lowland areas are drier and have a higher drought frequency than other areas (Belay et al., 2005). Thus, it is assumed that farmers living in lowland areas are more likely to perceive climate change than those in midland and highland areas.

The prevailing local climatic condition in an area - defines the number of outstanding adaptation measures that might be undertaken in response to a change in the climate. The prevailing actual climate also dictates whether such adaptation measures are necessary. Accordingly annually averaged

temperature and precipitation for each study *woreda* are included in the model.

Table 6.1: Description of Independent variables

<b>Explanatory variables</b>	<b>Mean</b>	<b>Std. Dev.</b>	<b>Description</b>
Gender of household head	0.77	0.42	Dummy, takes a value of 1 if male and 0 otherwise
Age of the household head	39.04	12.22	Continuous
Years of Schooling	2.67	3.02	Continuous
Size of household	5.29	1.76	Continuous
Non-Farm income	542.21	788.92	Continuous
Farm income	6259.85	5003.42	Continuous
Frequency extension services	2.07	0.84	Continuous
Farm size in hectare	0.98	0.50	continuous
Livestock ownership	1.79	1.21	Continuous, In Tropical Livestock Unit
Information on climate change	0.39	0.48	Dummy, takes a value of 1 if there is and 0 otherwise
Access to credit	0.56	0.49	Dummy, takes a value of 1 if there is access and 0 otherwise
Distance to market	71.44	42.62	Continuous
Temperature	21.86	1.17	Continuous, annual average over the period 2008-2011
Precipitation	37.72	6.98	Continuous, annual average over the period 2008-2011
Local Agro-ecology Weyna-degua	0.73	0.45	Dummy, takes a value of 1 if Weyna-degua and 0 otherwise
Local Agro-ecology Degua	0.27	0.46	Dummy, takes a value of 1 if Dega and 0 otherwise

## **6.3 Results and discussion**

### *6.3.1 Farmers' perception and barriers to adaptation*

This section briefly summarizes farmers' perceptions of climate change and the adaptation strategies they consider appropriate, based on the cross-sectional data collected from 400 rural households. During the survey, the sampled farm households were asked questions about their observations regarding the patterns of temperature and rainfall over the past 20 years.

The results of our survey showed that almost 78 per cent of the surveyed farmers have perceived an increase in temperature whereas 69 per cent of them perceived a decrease in rainfall over the past 20 years, while on average 17 per cent did not perceive any change<sup>15</sup> (Figure 6.1).

<sup>15</sup> We further attempted to substantiate the spatial similarities of respondents' assessment in climate change perception with the responses of neighbouring farmers using Moran's I test for spatial autocorrelation. The spatial autocorrelation statistic measures the correlation among neighbouring observations in a pattern and the levels of spatial clustering among neighbouring districts (Boots and Getis, 1998). Moran's I test with an inverse distance weighted matrix on the farmers who perceived particular types of climate change within a given area is used. Moran's I Index,  $I_M$ , statistic was determined as:

$$I_M = \left( \frac{n}{\sum_i \sum_j W_{ij}} \right) \frac{\sum_i \sum_j W_{ij} (Y_{(R)i} - \bar{Y}_{(R)}) (Y_{(R)j} - \bar{Y}_{(R)})}{\sum_i (Y_{(R)i} - \bar{Y}_{(R)})^2}$$

where  $W_{ij}$  is the element in the spatial weights matrix corresponding to the *tabias* pairs  $i, j$ ; and  $Y_{(R)i}$  and  $Y_{(R)j}$  are the perception responses for *tabias*  $i$  and  $j$  with mean perception of  $\bar{Y}_{(R)}$ .

The results of the Moran's I test indicated significant and positive values for perception of increasing temperature and decreasing rainfall showing the presence of significant spatial autocorrelation confirming temperature is increasing and rainfall is decreasing respectively at 1% and 5% probability levels (refer to Appendix 6.1). Thus, neighbouring farmers reported a consistent story. These results provide evidence that farmers are capable of perceiving changes in climate.

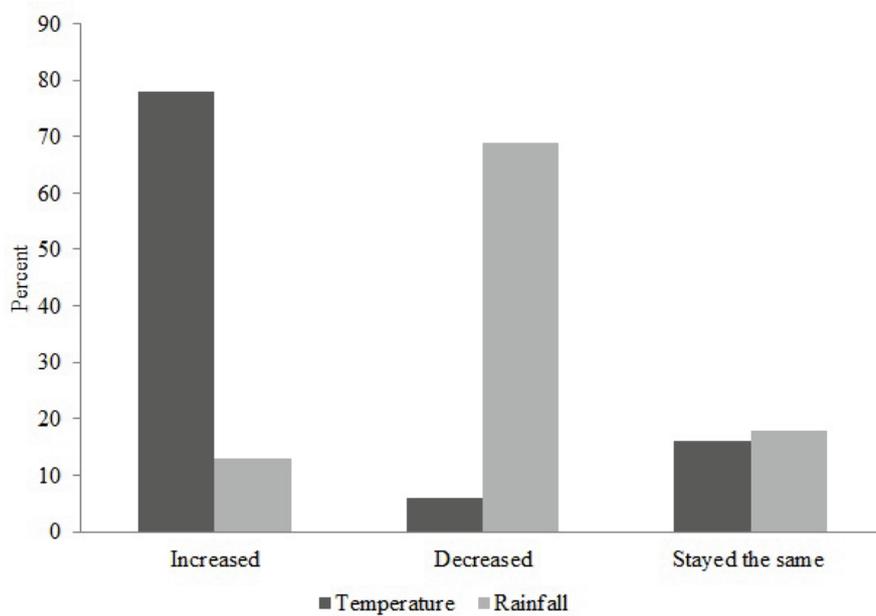


Figure 6.1: Farmers' perception of long-term temperature and precipitation changes

To verify the farmers' perception of long-term change in temperature and precipitation, the historical regional annual rainfall and temperature data for the period 1954 to 2008 were analysed. The temporal data showed a deficiency in rainfall compared to their long-term mean for most years, indicating high rainfall variability, quite often accentuated by positive and negative anomalies (Figure 6.2). Similarly, the observed temperature data indicated a clear trend of rising temperatures during the past three decades (Figure 6.3). The historical record further revealed that the average annual minimum temperature across the region increased by about  $0.72^{\circ}\text{C}$  every ten years while the average annual maximum temperature increased about  $0.37^{\circ}\text{C}$  per decade. This shows that the region is warming faster than the national average of  $0.25^{\circ}\text{C}$  per decade. Thus it can be inferred that the farmers' perceptions of climatic variability corresponded with the climatic data records. It is also interesting to note from the analysis of the historical temperature data that the average annual minimum temperature is increasing faster than the average annual maximum temperature, which is clearly an indication that the nights are warming over time.

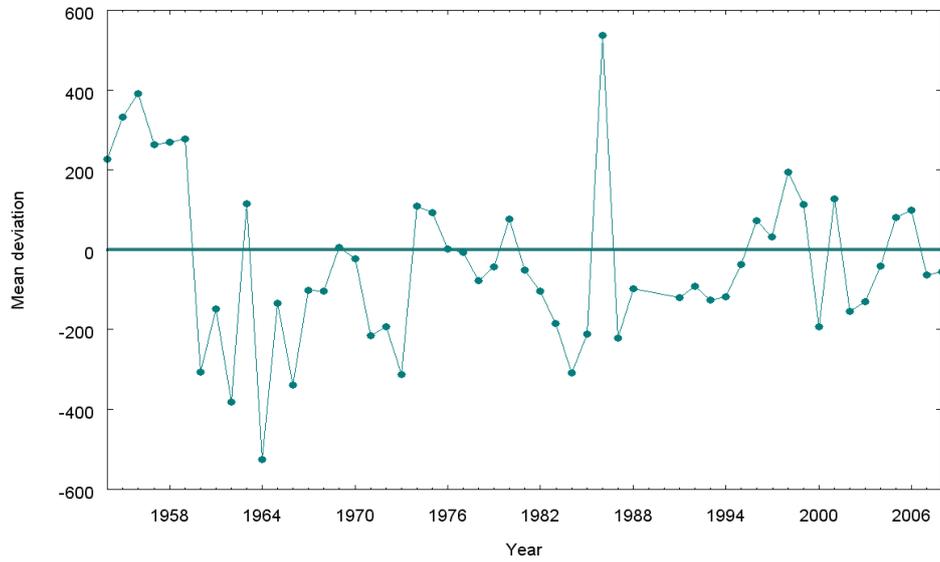
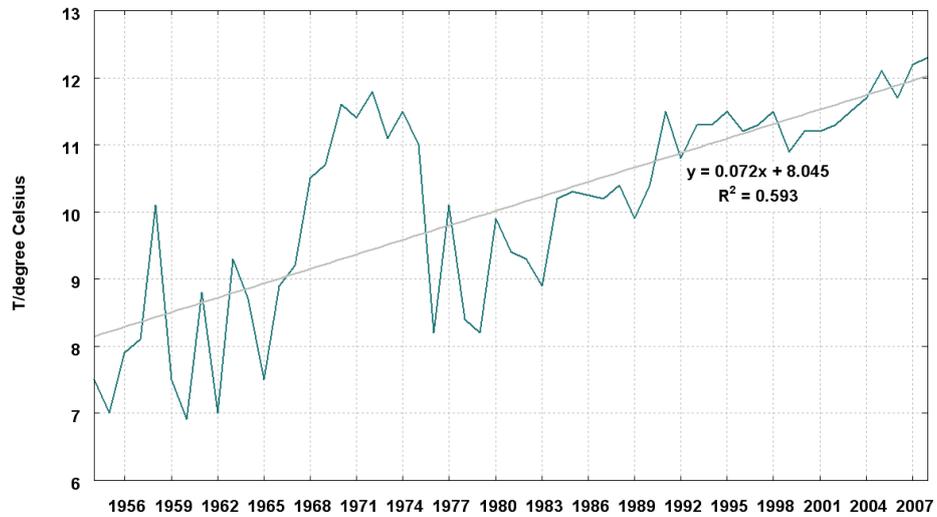


Figure 6.2: Mean deviation of annual rainfall in the Tigray region between 1954 and 2008.

a)



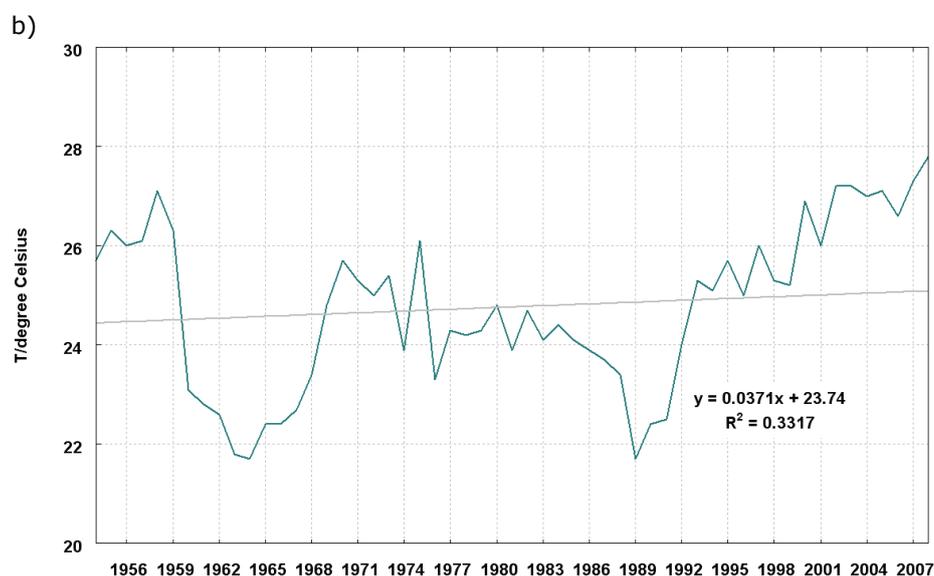


Figure 6.3: Year to year variability in annual minimum (a), and maximum (b) temperature in the Tigray region between 1954 and 2008

However, despite the majority of the farmers perceiving changes in climate over the past decades only 53 per cent indicated adopting different strategies to counteract the impact of the climate change. These adaptation strategies included crop diversification, soil conservation, irrigation, planting trees, changing planting dates, and irrigation (Table 6.2). The study further revealed that crop diversification was the major adaptation strategy in the studied *tabias*. The strategy of crop diversification as an adaptation method could be associated with low expense and ease of access for farmers. Similar findings were reported by Kurukulasuriya and Mendelsohn (2008), Maddison (2006), Nhemachena and Hassan (2007), Deressa et al. (2009), and Hassan and Nhemachena (2008). On the other hand, farmers who did not adapt gave many reasons, with lack of information forming the main barrier for farmers to adapt to the changing climate (Figure 6.4).

Table 6.2: Farmers' adaptation strategies in response to change in precipitation and temperature, n=400

Variables	Percentage of respondent
Crop diversification	24
Soil conservation	10
Application of irrigation	8
Planting trees	6
Change in planting date	5
No adaptation	47

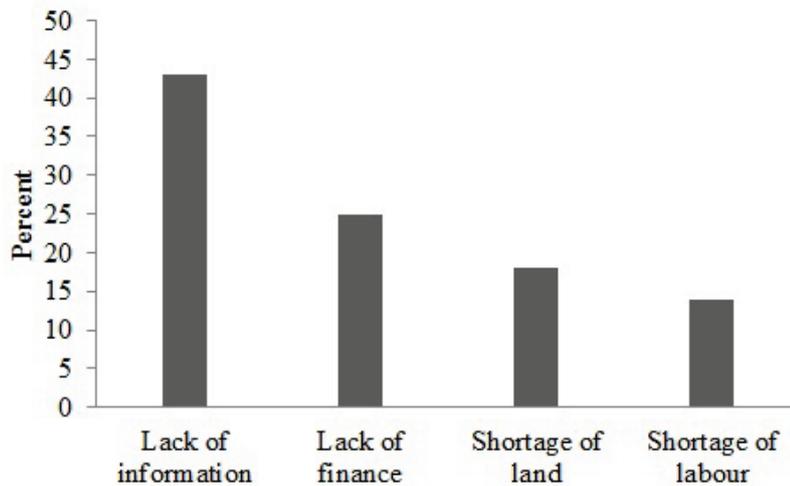


Figure 6.4: Barriers to adaptation to the changing climate

### 6.3.2 Estimation results

By applying a multinomial logit (MNL) model it is necessary to choose a base category for normalization. In this study, 'no adaptation' is used as the base category.

The MNL adaptation model was run and showed some significant levels for the parameter estimates. The likelihood ratio statistic as indicated by  $\chi^2 = 243.05$  was found to be highly significant,  $P < 0.001$ , implying the model has a strong explanatory power. Moreover, we tested the Independence of Irrelevant Alternatives (IIA) assumption of the multinomial logit using the Hausman test, where differences in coefficients are tested on systematic differences. The corresponding test statistic is found to be  $\chi^2 = 0.583$  with P value of 0.928. None of the test results rejected the null hypothesis ( $H_0$ ); therefore, the IIA assumption was not violated, suggesting that the multinomial logit specification is appropriate for modelling climate change adaptation behaviour by smallholder farmers (Hausman and McFadden, 1984). The results of the MNL model along with the levels of significance are presented in Table 6.3.

As indicated earlier, the parameter estimates of the MNL model provide only the direction of the influence of the independent variables on the dependent variable, which is the farmers' choice of adaptation measures in the study area. However, these estimates do not represent the actual magnitude of change. Therefore, the marginal effects from the MNL model, which measure

the expected change in probability of a particular choice being made with respect to a unit change in the explanatory variable, are also reported and discussed. Table 6.4 presents results of the marginal effects along with the levels of statistical significance.

Table 6.3: Parameter estimates of the multinomial logit adaptation model, n=400

Explanatory variables	Crop diversification		Soil conservation		Planting trees		Changing planting date		Irrigation	
	Coefficients	P level	Coefficients	P level	Coefficients	P level	Coefficients	P level	Coefficients	P level
Gender of household head	2.345**	0.011	2.113**	0.022	1.365	0.564	1.519	0.652	3.213**	0.012
Age of household head	0.167*	0.016	-0.003	0.892	0.009	0.671	0.064*	0.054	0.291**	0.032
Size of household	0.026	0.791	0.042	0.754	0.375**	0.033	0.115	0.486	0.144	0.373
Education	0.562***	0.006	0.269*	0.094	0.115	0.204	0.117*	0.058	0.109***	0.004
Livestock ownership	0.204*	0.101	0.167	0.325	0.040	0.842	-0.054	0.818	0.119	0.537
Farm size	0.325*	0.071	0.667*	0.014	0.958**	0.023	0.023	0.963	1.211	0.099
Farm income	0.007*	0.015	-8.3e-5	0.227	2.3e-5*	0.014	4.8e-5	0.589	2.2e-5**	0.012
Non-farm income	0.004	0.425	8.7e-5	0.731	4.3e-4	0.173	5.8e-4	0.120	3.3e-4	0.231
Frequency of extension services	0.179**	0.029	0.593*	0.042	0.016	0.964	0.316**	0.018	0.057	0.271
Credit availability	0.971*	0.047	0.097	0.807	0.451	0.756	0.205	0.427	0.301	0.487
Distance to market	0.002	0.820	0.009	0.278	0.018*	0.066	-0.001	0.347	0.014*	0.088
Information on climate change	1.729***	0.000	1.987***	0.000	1.647***	0.000	2.751***	0.000	1.754***	0.000
Temperature	0.972*	0.057	0.504*	0.006	-0.027	0.942	0.789	0.134	0.892*	0.090
Precipitation	-1.265*	0.085	0.059	0.362	-1.211*	0.099	-0.224**	0.013	-0.017	0.314
Agro-ecology Weyn-degu'a	0.802*	0.028	0.201	0.830	0.178**	0.044	0.081	0.931	-0.105	0.419
Agro-ecology Degu'a	0.572	0.471	0.318	0.777	0.017	0.990	0.139**	0.006	0.034	0.978
Constant	-10.06*	0.040	-17.40*	0.057	-5.95***	0.011	-29.75**	0.042	-4.85***	0.029
Diagnostic Base category	No									
	Adaptation									
LR chi-square	503.46									
Log likelihood	-158.25									
Pseudo-R <sup>2</sup>	0.14									

Note: \*\*\*, \*\*, and \* = are significant at 1%, 5% and 10% probability level, respectively

### Gender of the head of the household

Gender significantly increases adaptations using crop diversification, changing planting dates and planting trees in the studied *tabias*. The findings of the marginal effects from the multinomial logit model show that male-headed households were 18.2 per cent more likely to use crop varieties, 12.2 per cent more likely to conserve soil, 5 per cent more likely to plant trees and 14 per cent more likely to apply irrigation to adapt to climate change. The findings are in line with the claim of Asfaw and Admassie (2004) that male-headed households are often considered more likely to gain information about new technologies and take on risk than female-headed households. However, this finding is contrary to the findings by Nhemachena and Hassan (2007) in the Southern Africa region.

### Age of the head of the household

Age, which is assumed here to represent the farming experience of the head of household, has a significant, positive effect on adaptation to climate change in the studied *tabias*. The result indicates that a unit increase in the age of the household head increases the probability of using crop diversification by 8.3 per cent, of changing planting date by 5.3 per cent, using irrigation to adapt to the changing climate by 4.4 per cent. This means

that the likelihood of taking up climate adoption measures was higher among older farmers. This might be attributed to the experience of older farmers perceiving changes in climatic attributes. These results are in line with the findings of Nhemachena and Hassan (2007) in a similar study of adaptation in the Southern Africa region. Maddison (2006), and Ishaya and Abaje (2008) also reported that farm experience plays a significant role in the perception of and adaptation to changing climate.

### **Education**

Education increases the probability of the head of the household adapting to climate change, particularly through an increase in crop diversification, soil conservation, the changing of planting dates, and irrigation measures. A unit increase in the number of years of schooling results in a 5.8 per cent increase in the probability of using crop diversification, a 3.4 per cent increase in the probability of conserving soil, a 1.1 per cent increase in the probability of changing planting dates, and a 2.3 per cent increase in the probability of using irrigation to adapt to climate change.

### **Household size**

Increase in the household size results in a 6.7 per cent increase in the probability of planting trees to adapt to the changing climate. Though the probability of employment of other adaptation options, such as crop diversification, soil conservation, changing the planting date and applying irrigation measures, did increase with an increase in household size, this increase was not significant.

### **Farm size**

A larger farm size increases the likelihood of adapting to climate change. A unit increase in farm size results in a 3.6 per cent increase in the probability of using crop diversification, a 4.4 per cent increase in the probability of conserving soil, and a 7.4 per cent increase in the probability of planting trees to adapt to climate change. Amsalu and Graaff (2007) also found that farmers with large farm holdings were more likely to invest in soil conservation measures in the Ethiopian highlands. The finding agrees with the argument that larger farms offer farmers more flexibility in their decision-making process, more opportunity to take up new practices on a trial basis, and more ability to deal with risk (Nowak, 1987).

### **Farm and non-farm income**

The result of the analysis reveals that farm income of a household had a positive and significant impact on using different crop varieties, conserving soil, and irrigation, though for one unit increase in farm income these probabilities increased by less than 0.01 per cent. Increasing non-farm income does not significantly increase the probability of adaptation to the

changing climate, despite mainly positive coefficients. The study echoes the findings of McNamara et al. (1991) that off-farm employment might constrain adaptation as it competes for on-farm managerial time. Contrary to our findings, Gbetibouo (2009) reported that expanding smallholder farmers' access to non-farming sources of income increased the likelihood they would invest more in farming activities.

### **Livestock ownership**

Ownership of livestock is one of the basic assets and an important component of the farming system in the Ethiopian rural economy. In rural Ethiopia, more than 90 per cent of total asset values are held in the form of livestock (Dercon, 2004). In the study areas, livestock is a source of cash and serves as a buffer against climatic uncertainties. The MNL results indicate that ownership of livestock increases the probability of adapting to climate change, particularly through an increase in crop diversification measures. A unit increase in number of livestock results in a 4.5 per cent increase in the probability of using different crop varieties to adapt to climate change. Moreover, livestock ownership is positively related to adaptation methods such as soil conservation, planting trees, and irrigation, indicating a positive relationship between livestock ownership and adaptation to climate change. Households with livestock are in a better position to invest in climate adaptation measures as they have the financial resources to pay for the extra labour required for initial investments.

### **Frequency of extension services**

As expected, frequency of extension services has a positive and significant impact on crop diversification and changes in planting dates. Increasing the frequency of extension services increases the likelihood of adopting crop diversification and changes to planting dates by 5.4 per cent and 6.9 per cent, respectively. In the study region, access to an agricultural extension service is regarded as a major source of information concerning agricultural activities and natural resource conservation for the farming households. The results therefore confirm the hypothesised positive role extension services play regarding climate change adaptation measures. Similar findings were reported by Yirga (2007), Maddison (2006), and Nhemachena and Hassan (2007). Thus, the positive effect of extension contacts implies that farmers who had contact with extension agents tended to take up adaptation measures in response to the changing climate.

### **Information on climate change**

Information on temperature and rainfall has a significant and positive impact on the likelihood of using different crop varieties, soil conservation, planting trees, changing planting dates and irrigation measures. Thus the finding confirmed that having access to information on climate change increases the

likelihood of using different crop varieties, adopting soil conservation measures, changing planting dates, and adopting irrigation measures by 18.5 per cent, 9.5 per cent, 5.1 per cent and 5.4 per cent, respectively. This is in line with the findings of Kebede et al. (1990), Ghadim and Pannell (1999), and Herath and Takeya (2003) that there is a strong positive relation between access to information and the adoption behaviour of farmers.

#### **Access to credit**

Lack of financial resources is one of the main constraints to adjusting to a changing climate. In a study in Tanzania, O'Brien et al. (2000) reported that although there were numerous adaptation options farmers were aware of and willing to implement, lack of sufficient financial resources to purchase the necessary inputs and other associated equipment formed one of the significant constraints to adaptation. In our study, 47 per cent of the respondents who did not adapt cite lack of financial resources as the main constraint. The results of our analysis show that access to credit has a positive impact on the likelihood of using different types of crops in the course of changes in climatic conditions. Increasing a farmer's access to credit indeed increases the likelihood of choosing crop diversification measures by 10.6 per cent, indicating that access to credit improved poor farmers' opportunities to make productive investments.

#### **Temperature**

Areas with high annual mean temperature over the period 2009 to 2011 were more likely to adapt to climate change through the adoption of different practices. An increase in temperature by one degree Celsius higher above the mean increases the probability of using crop diversification (13.5%), soil conservation (4.3%), and irrigation (5.6%). The findings indicate that, to cope with increased temperatures, farmers will tend to use drought-tolerant crop varieties, as well as conserve soil to preserve moisture content. Moreover, farmers employ irrigation measures to supplement rainfall deficits due to increased temperature. Kurukulasuriya and Mendelsohn (2008) and Deressa et al. (2009) similarly reported that farmers living in regions with relatively high temperatures had an increased likelihood of adapting. Similarly, we found that farmers in the Weyena-Degua zone significantly increase the probability of planting trees by 2 per cent, compared with farmers in Degu'a.

#### **Precipitation**

Like rising temperatures, a decrease in rainfall was likely to increase the probability of adapting to climate change. The finding indicates that decreasing precipitation significantly increased the likelihood of using different crop varieties and changing planting dates.

Table 6.4: Results of the marginal effects from the multinomial logit adaptation model

Explanatory variables	Crop diversification		Soil conservation		Planting trees		Changing planting date		Irrigation		No Adaptation	
	Coefficients	P level	Coefficients	P level	Coefficients	P level	Coefficients	P level	Coefficients	P level	Coefficients	P level
Gender of household head	0.182*	0.077	0.122	0.609	0.049**	0.042	0.009	0.578	0.137*	0.086	-0.092	0.224
Age of household head	0.083*	0.041	-0.002	0.888	0.001	0.626	0.053*	0.068	0.044**	0.013	-0.002**	0.061
Size of household	0.008	0.635	0.003	0.748	0.067**	0.017	0.009	0.785	0.010	0.330	0.003	0.895
Education	0.058*	0.084	0.034**	0.001	0.005	0.219	0.011**	0.035	0.023**	0.019	-0.121*	0.090
Livestock ownership	0.045**	0.034	0.018	0.170	0.004	0.710	-0.001	0.902	0.0.11	0.382	0.013	0.607
Farm size	0.036*	0.007	0.044**	0.028	0.074**	0.033	-0.004	0.707	-0.051	0.191	-0.094*	0.101
Farm income	1.42e-5**	0.050	9.06e-06*	0.093	4.91e-07	0.890	8.01e-07	0.683	5.6e-07**	0.047	-7.02e-06	0.450
Non-farm income	9.13e-06	0.772	1.97e-06	0.922	8.2e-5	0.250	1.1e-5	0.183	1.6e-5	0.357	-5.4e-5*	0.015
Frequency of extension services	0.054**	0.029	0.004	0.158	0.006	0.731	0.069*	0.036	0.011	0.626	-0.046***	0.021
Credit availability	0.106*	0.058	0.001	0.980	0.014	0.887	0.007	0.596	0.016	0.580	-0.044	0.470
Distance to market	-0.00033	0.670	0.0002	0.544	-0.0003	0.402	-0.0001	0.619	9.2e-05	0.821	0.0004	0.660
Information on climate change	0.185***	0.000	0.095***	0.006	0.037*	0.081	0.051**	0.015	0.054*	0.062	-0.423***	0.000
Temperature	0.135**	0.004	0.043*	0.080	-0.004	0.832	0.017	0.140	0.056*	0.006	-0.195***	0.000
Precipitation	-0.016*	0.042	0.005	0.324	0.001	0.851	0.005**	0.020	-0.002	0.719	0.144*	0.078
Agro-ecology	0.115*	0.055	0.039	0.547	0.020**	0.012	0.007	0.283	0.011	0.467	0.119**	0.035
Weyna-Degu'a												
Agro-ecology Degu'a	0.095	0.443	-0.013	0.874	0.011	0.878	0.004*	0.035	0.015	0.857	0.086*	0.024

Note: \*\*\*, \*\*, and \* = are significant at 1%, 5%, and 10% probability level, respectively

## 6.4 Conclusions

The study used multinomial logit (MNL) to investigate the factors influencing farmers' choices of climate change adaptation measures and their perceptions of changes in the climate respectively. The findings of the marginal effects from the MNL indicated that most of the household variables, as well as wealth attributes, availability of information, agro-ecological features, and temperature influenced adaptation to climate change in the study region. Moreover, the analysis of the farmers' perceptions of climate change indicated that most of the farmers in the study area were aware of the fact that temperature was increasing and the level of precipitation declining.

Our empirical findings provide important messages for policy makers. First of all, the findings in this study provide evidence that access to agricultural services and information on climate change are key factors in influencing the likelihood of farmers taking up adaptation measures. Thus, ensuring access to information on climate change through extension agents is believed to create awareness and favourable conditions for the adoption of farming practices suited to climate change. Thus, improving the knowledge and skills of extension service personnel about climate change and adaptation strategies, and making the extension services more accessible to farmers is strongly recommended. Furthermore, our analysis confirms that access to credit has a positive impact on the likelihood of taking up adaptation

measures in the course of changes in climatic conditions. Hence, ensuring farmers have access to credit is vital to improve their ability and flexibility to change production strategies in response to a changing climate.

Although current government efforts will gradually increase the coping capacity of farmers, more needs to be done in terms of effective adaptation to climate change to protect the already weak agricultural sector. Generally, advancing robust and resilient development policies that promote adaptation is needed today, as changes in the climate will increase even in the short term. Accordingly, the issue of adaptation needs to be integrated into the development strategy of government policy, ultimately increasing resilience, reducing the threats of further warming and improving development outcomes.

Appendix table 6.1: Moran's I Test for spatial correlation of climate change perception

Perception of climate attributes	Moran I statistics	P value
Temperature		
• Increased temperature	0.317*	0.004
• Decreased temperature	-0.104	0.169
• Stayed the same	0.308	0.294
Rainfall		
• Increased rainfall	-0.024	0.170
• Decreased rainfall	0.286**	0.053
• Stayed the same	-0.226	0.138

Note: \*\* and \* = are significant at a 1% and 5% probability level, respectively

## Chapter 7

### Synthesis

#### Introduction

This final chapter presents the conclusions and discussion of the main findings of this study. The first part of this chapter deals with the research questions formulated in Chapter 1. The second part of the chapter discusses the results of the research with regard to the main themes of the study and the final part addresses the recommendations for future research and policy and practices.

#### **7.1 Conclusions from chapters**

This research investigated three interrelated issues. First, it investigated the socio-economic factors associated with household food security and the effect of policy interventions in reducing food insecurity and natural resource degradation. Second, it examined the spatial and temporal characteristics of drought. Third, it thoroughly investigated farmer's vulnerability to the changing climate and the factors influencing farm level adaptation in one of the poverty and drought stricken regions of Ethiopia – the Tigray regional state. Generally, the study has addressed three issues of relevance in food security analysis and the efforts to achieve food security.

In chapter 2, an analysis of the main socio-economic factors associated with household food insecurity and coping behaviour of rural households were done. This enables us to better understand the main factors influencing household food insecurity and recommend policy actions best adapted to tackle chronic food insecurity. The study confirms the critical role that productive farm assets – principally farm holding size, livestock, and household food production - play in household food security and coping capability. Per capita crop production significantly influences household food security. The lower the per capita crop production of a household was, the higher the odds of the household belonging to the food insecurity category. Ownership of livestock is one of the basic assets and an important component of the farming system and significantly influences household food security. In the study area, livestock is a source of cash and serves as a buffer against climatic uncertainties and towards the end of every crop year when most households faced food shortage problems. The empirical analysis further provides evidence that household size plays a key role in influencing household's food security and capacity to cope during times of food shortages. In addition, a positive and significant association is observed between participation in off-farm activities and household food security and

coping behaviour highlighting the importance of programs that create employment opportunities for farmers to diversify their income sources. The analysis further reveals that the households relied largely on consumption-based coping strategies when faced with food shortages.

Chapter 3 focuses on government policy impact evaluation. The impact of program interventions targeted at reducing food insecurity was empirically tested, both at macro and micro level, and natural resource degradation. The findings show that food security program interventions positively affect both regional food self-sufficiency and household food consumption. Efforts made to increase agricultural production and productivity in the region has produced remarkable results. Results indicate that food availability and food self-sufficiency both at regional and *woreda* level has improved over the period 2000-2011. The regional food self-sufficiency ratio (SSR) increased by 11.5 per cent. As a result, the regional food deficit declined by 104 per cent over the period. The region has achieved its goal of food self-sufficiency in the past years, with domestic food-grain production reaching 2,479,500 metric tonne by the end of 2011. Indeed, by FAO's estimate, the regional average per capita calorie availability was a comfortable 2,200 calories since 2007. Deliberate government policies have led to increases in cereal production. The adoption of high-yielding varieties in conjunction with increased use of fertilizer has more than doubled cereal production. The supply of agricultural credit, particularly for fertilizers has been increased and consumption increased at annual rates of 20.5 per cent. At regional level, the existing data revealed that the region has made impressive development gains in the past years. Since 2003/04, the regional economy has grown annually by an unprecedented 14.3 per cent on average. This growth has emanated from the growth of smallholder agriculture, resulting in significant reductions of poverty.

The policy impact analysis further indicated that the Integrated Household Food Security Package program had a significant and robust effect in improving household food consumption, food calorie intake in particular, in the study areas. More specifically, the program has raised food calorie intake by 772.19 kilo calorie per day per adult equivalent unit. By employing propensity score matching approach we investigated that the FSP program has a causal influence on total food consumption. If we allow someone to be in the FSP program (that is provided access to a food security loan for a package of activities and training) his/her food calorie intake would on average increase to 41.8 per cent above that of individuals not involved in the program. On the other hand, the heterogeneous impact analysis showed that the average impact of the program masks important differences in its impact across targeted beneficiaries. The program impact is, for instance, strongly related to policy variables such as landholding. The gain from the

program was significantly larger for land-rich households. Access to input and output markets and proximity to all weather roads are observed to have an important role in improving household food security.

The analysis on the role of area enclosures based on satellite imagery indicated that a positive and consistent improvement in the recovery of natural vegetation is observed in the area enclosure as compared to the unprotected site. Based on the results of the remote sensing analysis, 11 per cent (5,030 hectare) and 57 per cent (26,924 hectare) of the protected area showed a substantial and moderate increase over the period 2001 to 2009 respectively, while no change was observed in the unprotected area. The findings indicated the strategy of area closure as an effective policy instrument to rehabilitate the degraded vegetation. Furthermore, devolution of natural resource governance to the lowest level and increasing local communities' participation in the natural resource management are also observed to be an important factor for the success of the program of environmental rehabilitation. By and large, the impact evaluation showed that government policy interventions indeed improve food security both at the regional and household levels, and have had a positive impact on restoring the degraded natural vegetation. The study generally provides evidence that integrated interventions prove to be vital to improve the situation of food security in the region. It is thus hoped that this study will contribute to a growing impact evaluation literature in such a way that we are now in a better position to identify causal effect of food security program interventions on regional food self-sufficiency and household's food calorie intake in low income settings such as Ethiopia.

In Chapter 4 an analysis of the characteristics of seasonal drought dynamics in the region were done. The chapter focused on identifying the spatial and temporal characteristics of drought over the past decade and identifies the utilities of using meteorological and remote sensing drought monitoring tools in providing better real time and spatially continuous data. This enabled us to analyse drought over large areas and suggest the most effective tool, which aids in monitoring drought, early warning, and mitigating the effects of drought disaster.

The analysis of the spatial and temporal characteristics of droughts revealed that drought appears in the southern and eastern zones in most of the monsoon seasons over the past decade. Strong association between rainfall distribution and drought potential zones is observed in the region. Drought conditions change continuously over seasons depending upon rainfall amount and its spatial distribution. The analysis on the SPI and VCI drought dynamics generally indicate that the identification, classification, and analysis of drought dynamics are highly influenced by the monitoring parameters. SPI

monitors precipitation deficit, the primary cause for drought development, but takes no account of the impacts. A region can be free from water-stress and may maintain normal vegetation despite of negative SPI. As Bhuiyan et al. (2006) describe negative SPI anomalies do not always correspond to drought. SPI classification schemes rely on the assumption that droughts follow the scale of probability and normal statistics. This is debatable. Drought area dynamics studied by VCI, however, characterize the negative impact of unfavourable meteorological conditions on vegetation and show a more useful way to monitor regional drought evolution in time and space, and therefore represent a better picture of drought than the SPI.

Furthermore, in developing countries like Ethiopia meteorological stations are generally inadequate and the networks are not well-developed. Weather stations are also sparsely located far from each other and hence the spatial resolution of rainfall data derived from these weather stations has been approximately more than 100 square kilometres. Besides, continuous rainfall records are scarce or difficult to obtain in a timely fashion as infrastructural networks are low in these countries. Consequently, SPI assimilated information on rainfall does not express much spatial detail and could have drawbacks in identifying drought proneness across the spatial units, and thereby affects the reliability of the drought assessment indices. Brown et al. (2002) reported similar findings.

The result from the satellite derived vegetation condition indices, however, indicates that VCI provides accurate information on the spatial diversity of drought over large areas including localized droughts, offering the possibility for early prediction of droughts as is necessary for drought risk management. Similar studies in Africa, South America, and Asia by Kogan and others (Kogan, 1995, 1997; Liu and Kogan, 1996; Unganai and Kogan, 1998) also reveal that drought area dynamics studied by VCI images demonstrated more clearly the intensity of droughts at a regional scale and showed to be an effective tool to detect regional drought evolution in time and space than those by other types of drought delineation. The study further indicated that VCI values have strong correlation with precipitation as compared to the Normalized Difference Vegetation Index (NDVI). This indicates that rainfall characteristics may not be the only factor to influence NDVI values. Other local factors, such as soil characteristics, stress in previous years, and land cover characteristics of the area could also have an influence on vegetation. However, Bajgirana et al. (2008) found VCI values to be unreliable in Northwest Iran. This is mainly explained due to the short time span, 5 years, of the satellite data used for their study, which is difficult to make a firm comment on the applicability of the VCI index.

In light of this, developing countries like Ethiopia can therefore benefit from remote sensing tools that provide better real time and spatially continuous data that can be used for rigorous analysis of drought proneness over large areas. Cognizant with this, the study detected the spatial diversity of drought in Tigray by employing a rich database. Our result further indicates that detailed studies at a regional level will support appropriate spatial identification and regionalization of the drought phenomena. This in turn provides evidence for policy makers to tailor appropriate policies to local conditions in order to manage the risks of drought. By and large, the study has demonstrated the importance of vegetation condition index in assessing the severity of droughts in semi-arid and arid region, indicating the utility of the tool in assisting policy makers in guiding the operational responses in drought risk reduction. To my knowledge this analysis is the first research which has attempted to develop reliable drought information linking meteorological and remote sensing indices enabling the identification and mapping of spatial and temporal aspects of droughts for Tigray region.

Chapter 5 focuses on investigating farmers' vulnerabilities to the expected changes in climate and climate variability. Vulnerability analysis provides a scientific base for the policy making of disaster mitigation. This study enabled the quantification of farming sectors' vulnerability to climate change and climate variability at *woreda* level, which makes the study the first in the country at this spatial scale of analysis. The results of the vulnerability analysis indicate that the *woredas* deemed to be most vulnerable to extreme events and climate variability overlap with the most vulnerable populations. *Woredas* most exposed to climate variability also have a relatively low capacity to adapt to climate change. Thus, it will take only a moderate climate change to disrupt the livelihoods and wellbeing of the rural inhabitants in those *woredas*. This echoes the findings by Deressa et al. (2008) at the national level. Farmers in these *woredas* are therefore likely to bear the burden of the negative impacts of climate change, which will include increased water scarcity and food insecurity. The results further showed that vulnerability to climate change and variability is intrinsically linked to social and economic development.

Chapter 6 investigates farmers' perceptions regarding changes in climate, factors influencing farmers' choice of adaptation methods, and main barriers to adaptation in response to the changing climate. This enabled us to identify the main factors that influence farmer's decision making regarding the choice of adaptation measures and recommend policy actions best adapted to enhance farm-level adaptation. The study indicated that most of the household variables, as well as wealth attribute, availability of information, agro-ecological features, and temperature significantly influence the likelihood of taking up measures to adapt to climate change and variability.

The analysis further indicates that age and education of the head of the household, as well as information on climate change, positively influences farmers' perception of change in climatic attributes. The study provides evidence that access to agricultural services, information on climate change and access to credit are key factors in influencing the likelihood of farmers taking up adaptation measures in the course of changes in climatic conditions.

## **7.2 Recommendations**

The research findings lead to the following recommendations. These can best be viewed against the background of on-going programs geared towards reducing poverty and ensuring food security.

1. Food security is the basis for economic, social and cultural development of a country. The outcome of the study confirms the critical role of productive farm assets - principally land, livestock, and household food production - play in household food security and coping capability. This calls for policies that enhance the asset base of households thus strengthening their food production capability on the one hand and their coping capacity in the event of shocks on the other hand. Increasing agricultural production in a sustainable way is indispensable to improve household food security as it is the first and main source of food entitlement for most of the Ethiopian farming community in terms of direct consumption of food. Concomitantly, the increase in production enhances households' coping capability when faced with food shortages. Furthermore, the findings reveal that large family size is strongly associated with household food insecurity and low coping capacity. Thus along the package of improving productivity, strong family planning to limit family size works significantly to reduce chronic food insecurity.
2. Improving the use of fertilizer and improved seed are the major component of the extension package implemented in the efforts to boost crop production. Notwithstanding the increased consumption of fertilizers, the application has not yet developed from a general recommendation to a specific area nutrient requirement. The amount of fertilizer and improved seeds is inadequate when compared with the total crop area. The quantity used by farmers is still much lower than the national average of fertilizer and improved seed use. Therefore, enhancing the capacity of the farmers to utilize them need to receive more and better attention. The government should further stimulate fertilizer and improved seed use by keeping retail fertilizer and improved seed prices affordable and liberalizing the fertilizer market. However, farmers should use these technologies through encouragement and based on their free will. There have been reports of coercion in pushing farmers to accept the

package and such actions are counterproductive in economic sense, as farmers have to choose what is suitable for them. In addition, efforts have to be made not only to introduce and expand the usage of improved inputs but also to bolster the market system. Creating an enabling environment for the private sector roles in the rural sector is also crucial for sustained agricultural growth and poverty reduction.

3. An approach, whereby attention is given to improving rural households' asset ownership, access to agricultural services (marketing, credit and training), improving alternative sources of income streams as well as improved production capacity to acquire food at a household level should guide food security program interventions. The rural poor should be assisted to acquire productive farm resources, principally land and oxen through the credit scheme as the initial asset base of a household in terms of ownership of land and livestock is an important factor that sets the ground for take-off for food security. The observed positive and significant association of food security and coping behaviour with participation in off-farm activities highlights the importance of programs that create employment opportunities for farmers to diversify their income sources. Enhancing the creation of employment opportunities in rural non-farm activities and access to credit would effectively benefit the poor. Non-farm self-employment activities are important not only to overcome temporary shocks but also to reduce chronic food insecurity and poverty. It increases the liquidity of rural households and plays an important role in alleviating the asset constraints. Measures, such as provision of training to develop their marketing and entrepreneurial capabilities, and access to credit, need to be taken to expand these activities and minimize technical and liquidity constraints that limit households to join these activities. Food security program interventions should also support livelihoods in ways that protect and buffer the natural resilience of households for them to be able to cope with the fragile and variable situations in which they exist. Social safety net programs should also be strengthened in order to protect households from using damaging coping strategies in times of prolonged food shortage.
4. Another important outcome of the study is the crucial role of satellite derived drought monitoring indices (such as VCI) in identifying the spatial diversity of drought conditions over large areas, offering the possibility for early prediction of droughts as is necessary for drought risk management. Thus, promoting satellite derived drought monitoring tools in guiding the operational responses in drought risk reduction is vital.
5. The study showed that efforts made to increase agricultural production have produced commendable results but the region is still short of achieving household food security. Rain-fed agriculture as always remains susceptible to environmental changes and the increase in the frequency of droughts has greatly affected the outcome. As a result, a significance

portion of the population remains vulnerable to slight changes in rainfall patterns or amounts. The study outcome indicated that farmer's vulnerability to climate change is highly associated to low adaptive capacity or local development in most of the *woredas* that are indicated as vulnerable. Thus, given the large spatial differences in the level of vulnerability across *woreda*, policy makers should tailor policies to local conditions.

An effective way to address the impacts of climate change would be to integrate adaptation measures into sustainable development strategies, thereby improving the most important socio-economic factors such as building rural households' asset ownership and access to services, and increasing the social wellbeing of the poor by developing alternative means of income from off-farm activities. Improving human and social capital, improving investment in productivity-enhancing agricultural research, enhancing rural infrastructure, increasing irrigation infrastructures, reducing the pressure on natural resources and improving environmental rehabilitation programs will all help to fortify the adaptive capacity of the farming community.

Moreover, access to agricultural services and information on climate change are found as the key factors influencing the likelihood of farmers taking up adaptation measures. Thus, ensuring access to information on climate change through extension agents is believed to create awareness and favourable conditions for the adoption of farming practices suited to climate change. Improving the knowledge and skills of extension service personnel about climate change and adaptation strategies, and making the extension services more accessible to farmers is therefore strongly recommended. Furthermore, ensuring farmers access to credit is vital to improve their ability and flexibility to change production strategies in response to a changing climate. As discussed, the rural poor are highly vulnerable to drought related risks, and their ability to cope with a crisis can be severely reduced by their lack of resources. On the other hand, the level of investment in agriculture depends on the extent to which a farmer can reduce downside risk and thus uncertainty on their investment. Hence, we strongly recommend effective mechanisms to deal with agricultural risks such as introducing actuarially fair agricultural insurance products or schemes, which is one financial tool that the rural poor can utilize to mitigate the impacts of unpreventable risks or uncertainties.

Although current government efforts will gradually increase the coping capacity of farmers, more needs to be done in terms of effective adaptation to climate change to protect the already weak agricultural

sector. Advancing robust and resilient development policies that promote adaptation is needed today, as changes in the climate will increase even in the short term. Accordingly, the issue of climate change and adaptation should be integrated within the broader development strategy of government policy to ultimately improve farmer's resilience to the changing climate.

6. By and large, the rural centred strategy was formulated to assist the fight against poverty and ensure food security for the mass of the population which happens to reside in the rural areas. Therefore, investment in human capital should also be the government's priority in the fight against poverty and food insecurity.

To sum up, the research on the impact of pro-poor focussed programs, spatiotemporal drought analysis, farming sector's vulnerability and farm level adaptation provides a complete picture of macro and micro level analysis, and a valuable lesson on how to better tackle and reduce poverty and food insecurity, which has been an affront to human dignity in Ethiopia in general and in the study region in particular.

### **7.3 Suggestions for future research**

A wide range of issues ranging from determinants of household food insecurity, macro-micro level policy impact evaluation, spatiotemporal characteristics of drought, vulnerability, to farm level adaptation were raised and discussed in the different chapters in this research. A lot remains, however, to be done in this area. The following recommendations for future research are suggested:

- The study indicated that the widely applied food security program interventions in the Tigray region have a much wider economic and environmental impact. Nevertheless, as the study is limited to only one observational data, further research is needed on the effect of these policy interventions towards its contribution to food security and poverty reduction in a sustainable manner.
- Food calorie intake is one of the outcome indicators used as a proxy for food security to identify impacts on household food security in this study. However, food calorie intake should not be the only determinant to show the impact of government interventions on household food security adequately. Consequently, we emphasize the need for additional research to identify the impacts of household food security package program intervention on other dimensions of food security in addition to the one investigated here.
- Impact evaluations can generate valuable information and provide a sound scientific basis for policy making, by providing reliable understanding on which interventions work and are effective.

Accordingly, impact evaluation has become an important tool in development research and policy making. In this research we attempted to demonstrate and quantify the outcomes generated by a policy by looking at the impact of program interventions on the different dimensions of food security both at the regional and household levels. However, whether the costs of the interventions have been outweighed by the benefits should also be investigated. Thus, an initiative for a cost-benefit analysis is needed to answer whether the observed outcome of government interventions are the best outcomes that could have been achieved for the money spent. Consequently, a cost-benefit analysis is recommended to provide a more complete picture of impact evaluations and further insight on the implementation of the interventions.

- In this research farming sectors vulnerability at *woreda* level was investigated. However, there is still enormous heterogeneity within *woredas* with regard to household-level access to resource, poverty level, and ability to cope with climate change and variability domain. Additional research is needed to investigate climate change vulnerability at a micro level, the household level.

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## Summary

Ethiopia is one of the least developed countries in SSA that faces an almost overwhelming challenge in achieving food security. Poverty is widespread and deep-rooted and constitutes the priority development challenge in the country. Understanding the factors influencing food insecurity, the spatiotemporal characteristics of drought and the opportunities for its reduction is of high policy relevance to Ethiopia.

The present research investigated three interrelated issues. The first is related to understanding of food security and the correlates thereof. It starts with the socioeconomic factors associated with household food security, and goes on to analyse the impact of policy interventions, FSP, upon reducing food insecurity and natural resource degradation. The second issue is on drought. We examined the spatial and temporal characteristics of drought over the period 1999-2009. The third issue related to understanding of farmers vulnerability to the changing climate and farm level adaptations. We thoroughly investigated farmer's vulnerability to the changing climate and the factors influencing farm level adaptation.

The following research questions are addressed in the thesis:

1. Who is food insecure? What influences rural household's food insecurity? What are the main household coping mechanisms employed during times of food shortage?
2. How effective are program interventions in the Tigray region in reducing food insecurity both at regional and household levels, and at enhancing the recovery degraded lands?
3. How does the spatial and temporal characteristic of drought vary across the region? Which drought monitoring tool offers the possibility to effectively detect regional drought evolution in time and space?
4. Where do the vulnerable farming communities locate?
5. What determines farmer's choice of possible adaptation measures?

We unravel these questions in successive chapters that address the three interrelated issues of food security discussed above. The study is based on the results of a cross-sectional dataset of 400 farm households, precipitation and temperature data for the period 1954-2010, and datasets from satellite imagery for the period 1999 to 2009.

For the first question, we take a closer look at the socioeconomic factors associated with household food insecurity and coping behaviour. The household nature of the data enabled us to estimate the poverty line and determine factors influencing household food insecurity. Our results confirms the critical role that productive farm assets – principally farm holding size,

livestock, and household food production - play in household food security and coping capability. Per capita crop production, ownership of livestock, and size of farm holding significantly influences household food security. Ownership of livestock is one of the basic assets and an important component of the farming system. In the study area, livestock is a source of cash and serves as a buffer against climatic uncertainties and towards the end of every crop year when most households faced food shortage problems. The empirical analysis further provides evidence that household size plays a key role in influencing household's food security and capacity to cope during times of food shortages. In addition, a positive and significant association is observed between participation in off-farm activities and household food security and coping behaviour highlighting the importance of programs that create employment opportunities for farmers to diversify their income sources.

With respect to the second research questions, we empirically tested the impact of the widely applied food security program interventions upon reducing food insecurity, both at macro and micro level, and natural resource degradation. FBS and propensity-score matching approach was applied to determine the impact of program intervention on macro and micro level food security respectively. Moreover, multi-temporal image analysis and image differencing technique was applied to evaluate the role of area enclosure on rehabilitating the degraded lands. The findings show that food security program interventions positively affect both regional food self-sufficiency and household food consumption. Efforts made to increase agricultural production and productivity in the region has produced remarkable results. Results indicate that regional food self-sufficiency ratio (SSR) increased by 11.5 per cent over the period 2000-2011. As a result, the regional food deficit declined by 104 per cent. Deliberate government policies have led to increases in cereal production. This growth has emanated from the growth of smallholder agriculture, resulting in significant reductions of poverty.

The matching approach indicates that the Integrated Household Food Security Package program had a significant and robust effect in improving household food consumption, food calorie intake in particular. More specifically, the program has raised food calorie intake by 772.19 kilo calorie per day per adult equivalent unit. If we allow someone to be in the FSP program (that is provided access to a food security loan for a package of activities and training) his/her food calorie intake would on average increase to 41.8 per cent above that of individuals not involved in the program. The analysis on the role of area enclosures based on satellite imagery indicates that a positive and consistent improvement in the recovery of natural vegetation is observed in the area enclosure as compared to the unprotected site over the period 2001 to 2009. The findings indicated the government

strategy of area enclosure as an effective policy instrument to rehabilitate the degraded vegetation. By and large, the impact evaluation showed that government policy interventions indeed improve food security both at the regional and household levels, and have had a positive impact on restoring the degraded natural vegetation.

Concerning the third question, we analyse seasonal drought dynamics in Tigray region. We identified the spatial and temporal characteristics of drought over the past decade using meteorological and remote sensing drought monitoring tools. The analysis of the spatial and temporal characteristics of droughts revealed that drought appears in the southern and eastern zones in most of the monsoon seasons over the past decade. Strong association between rainfall distribution and drought potential zones is observed in the region. The analysis on the SPI and VCI drought dynamics generally indicate that the identification, classification, and analysis of drought dynamics are highly influenced by the monitoring parameters.

In developing countries like Ethiopia meteorological stations are generally inadequate and the networks are not well-developed. In addition, weather stations are sparsely located far from each other and continuous rainfall records are scarce or difficult to obtain in a timely fashion. Consequently, SPI assimilated information on rainfall does not express much spatial detail and could have drawbacks in identifying drought proneness across the spatial units, and thereby affects the reliability of the drought assessment indices. The result from the satellite derived vegetation condition indices, however, indicates that VCI provides accurate information on the spatial diversity of drought over large areas including localized droughts, offering the possibility for early prediction of droughts as is necessary for drought risk management. In light of this, developing countries like Ethiopia can benefit from remote sensing tools that provide better real time and spatially continuous data that can be used for rigorous analysis of drought proneness over large areas. By and large, the study has demonstrated the importance of vegetation condition index in assessing the severity of droughts in semi-arid and arid region, indicating the utility of the tool in assisting policy makers in guiding the operational responses in drought risk reduction.

To answer the fourth questions, we investigated farmers' vulnerabilities to the expected changes in climate and climate variability. The results of the vulnerability analysis indicate that the *woredas* deemed to be most vulnerable to extreme events and climate variability overlap with the most vulnerable populations. *Woredas* most exposed to climate variability also have a relatively low capacity to adapt to climate change. Thus, it will take only a moderate climate change to disrupt the livelihoods and wellbeing of the rural inhabitants in those *woredas*. The results further showed that

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vulnerability to climate change and variability is intrinsically linked to social and economic development. This is the first study at this scale of analysis which has been conducted in Ethiopia.

Concerning the fifth question, we investigate farmers' perceptions regarding changes in climate, and factors influencing farmers' choice of adaptation methods. This enabled us to identify the main factors that influence farmer's decision making regarding the choice of adaptation measures and recommend policy actions best adapted to enhance farm-level adaptation. The study indicates that most of the household variables, as well as wealth attribute, availability of information, agro-ecological features, and temperature significantly influence the likelihood of taking up measures to adapt to climate change and variability. The analysis further indicates that age and education of the head of the household, as well as information on climate change, positively influences farmers' perception of change in climatic attributes. Access to agricultural services, information on climate change and access to credit are found to be the key factors in influencing the likelihood of farmers taking up adaptation measures in the course of changes in climatic conditions.

To sum up, the research on the impact of pro-poor focussed programs, spatiotemporal drought analysis, farming sector's vulnerability and farm level adaptation provides a complete picture of macro and micro level analysis, and a valuable lesson on how to better tackle and reduce poverty and food insecurity, which has been an affront to human dignity in Ethiopia in general and in the study region in particular.

## Samenvatting

Ethiopië is een van de minst ontwikkelde landen in Sub-Saharisch Afrika die de uitdaging moet aangaan om voedselzekerheid te bieden voor haar inwoners. Armoedebestrijding heeft in het land de hoogste prioriteit gekregen. Om te begrijpen wat de factoren zijn die voedselzekerheid bepalen is een spatio-temporele analyse van droogte van belang om de mogelijkheden te onderzoeken voor beleidsevaluatie.

Deze studie onderzocht drie met elkaar gerelateerde onderwerpen: Allereerst het begrijpen van wat voedselzekerheid betekent op huishoudniveau, maar ook op beleidsniveau als de overheid instrumenten ontwikkelt om de impact te onderzoeken van bijvoorbeeld milieudegradatie op voedselzekerheid. Ten tweede aandacht voor droogte: We onderzochten de ruimtelijke en temporele aspecten van droogte over de periode van 1999-2009 in Ethiopië. In de derde plaats onderzochten we de kwetsbaarheid van boeren en hun mogelijkheden om zich aan te passen aan een veranderend klimaat.

In de studie werden de volgende onderzoeksvragen aan de orde gesteld:

1. Wie hebben te maken met voedselonzekerheid? Welke factoren spelen daarbij een rol? En welke mogelijkheden hebben huishoudens om in tijden van voedselschaarste alternatieven te vinden?
2. Hoe effectief is het overheidsinstrumentarium geweest in het bestrijden van voedselschaarste in de regio Tigray, zowel op macro beleidsniveau als op het individuele huishoudniveau? Was er ook een effect te meten op uitputting van natuurlijke hulpbronnen?
3. Hoe varieert droogte in ruimte en tijd in de regio Tigray? En hoe kunnen we een monitoring instrument ontwikkelen dat droogte detecteert?
4. In welke regio's kunnen we de meest kwetsbare huishoudens vinden?
5. Welke factoren zijn van invloed op de beslissingen van boeren om zich aan te passen aan droogteverschijnselen?

De antwoorden op de onderzoeksvragen zijn gebaseerd op regionale data van neerslag en temperatuur voor de periode 1954-2010, op data van satellietbeelden voor de periode 1999-2009, en op data van 400 huishoudens.

Voor wat betreft de eerste vraag namen we de sociaal-economische factoren in ogenschouw die van invloed zijn op voedselonzekerheid en het daarmee samenhangende gedrag. Gebruik makend van data op huishoudensniveau waren we in staat om de armoedegrens te bepalen en om gedrag te onderzoeken om om te gaan met voedselonzekerheid. Onze resultaten bevestigen de kritische rol die economische activa spelen, zoals grootte van

de boerderij, en van de veestapel. Voedselproductie per capita, eigendom van vee en omvang van de boerderij beïnvloeden voedselzekerheid significant. Eigendom van veestapel blijkt een van de belangrijkste aspecten te zijn van het boerenbedrijf: het is een bron van inkomen en fungeert als een buffer in onzekere tijden. Verder speelt omvang van het huishouden natuurlijk een sleutelrol in de mogelijkheid om voedseltekorten het hoofd te bieden. Daarnaast is er een positieve relatie tussen voedselzekerheid en off-farm activiteiten. Deze activiteiten creëren mogelijkheden om te variëren in inkomens.

Met betrekking tot de tweede onderzoeksvraag hebben we onderzocht wat het effect is van overheidsbeleid op voedselzekerheid en op degradatie van natuurlijke rijkdommen. Dit onderzoek werd gedaan op macro- en op microniveau voor de regio Tigray. Daarnaast werd een multi-temporele analyse toegepast om met geo-beelden de rol van specifiek overheidsbeleid voor het afsluiten van bepaalde gebieden en landschappen te evalueren. De resultaten laten in de eerste plaats zien dat overheidsinterventies de zogenaamde zelfvoorzienendheid positief beïnvloeden, als ook voedselconsumptie door huishoudens. In de tweede plaats hebben pogingen om de landbouwproductie en productiviteit te laten toenemen tot opmerkelijke resultaten geleid. Over de periode 2000-2011 nam de regionale zelfvoorzieningsgraad met 11.5% toe. Als gevolg daarvan nam het regionale voedseltekort met 104% af. Specifiek overheidsbeleid heeft tot een toename van graanproductie geleid, resulterend in een daling van armoede.

Met een techniek die corrigeert voor zelf-selectie van data (de matching benadering) kon worden aangetoond dat het Voedsel Zekerheidspakket Programma een significant positief effect had op de voedselconsumptie van huishoudens in het algemeen en op de calorie inname in het bijzonder.

In de evaluatie van het overheidsbeleid voor het totaal afsluiten van bepaalde gebieden kon met behulp van satellietbeelden worden aangetoond dat er een herstel plaatsvindt in natuurlijke vegetatie in vergelijking met gebieden die niet waren afgesloten. Deze analyse werd gedaan voor de periode van 2001-2009. Overheidsbeleid ten aanzien van gebiedsafsluitingen blijkt dus effectief te zijn.

Voor wat betreft de derde onderzoeksvraag zijn seizoensdata voor droogte voor de regio Tigray geanalyseerd. De ruimtelijke en temporele karakteristieken van droogte laten zien dat droogte zich vooral manifesteert in het zuiden en oosten van de regio. Er is een sterke associatie tussen de ruimtelijke verdeling van regenval en droogtezones.

Probleem in een land als Ethiopië is de beperkte beschikbaarheid van data afkomstig van weerstations. Het gebruik van satellietbeelden in combinatie met de zogenaamde Vegetatie Conditie Index (VCI) geeft de mogelijkheid om accuraat ruimtelijke informatie te vergaren en om voorspellingen te doen over droogte.

In de vierde onderzoeksvraag kon worden aangetoond dat de regio's die het meest bloot gesteld zijn aan klimaatverandering relatief weinig mogelijkheden hebben om zich aan te passen. Klimaatverandering heeft dus een direct effect op sociaal-economische ontwikkeling. Behalve dit meer macro getinte onderzoek werd in de vijfde onderzoeksvraag aandacht gegeven aan percepties van huishoudens over risico's van droogte en aan besluitvorming voor adaptatie om het hoofd te bieden aan dergelijke risico's.

Percepties over mogelijke veranderingen in het klimaat worden bepaald door leeftijd, opleiding en beschikbaarheid van informatie. De kans dat een huishouden maatregelen neemt om zich aan te passen aan klimaatveranderingen worden ook bepaald door de beschikbaarheid van informatie. Daarnaast spelen specifieke omgevingsvariabelen een rol. Toegang tot krediet en informatie over klimaatverandering blijken de sleutelvariabelen te zijn om boeren er toe te bewegen aanpassingen te plegen in de uitoefening van hun bedrijf.

De vraag achter dit onderzoek was hoe de situatie van arme boeren kan worden verbeterd in de overgang naar een klimaatverandering met meer droogte. Macro-analyses die gebruik maken van satellietbeelden en micro-analyses die ingaan op de kwetsbaarheid van individuele huishoudens leverden data die de voedselzekerheid van Ethiopische boeren kan verbeteren.

En het was ons juist te doen om het probleem van voedselonzekerheid aan te pakken; een probleem dat een belediging is van de menselijke waardigheid in het algemeen en Ethiopische boeren in het bijzonder.



## Publications of the author

### ISI journal articles

**Gebrehiwot, T.**, van der Veen, A., Maathuis, B.H.P. (2011): Spatial and temporal assessment of drought in the Northern highlands of Ethiopia. In: *International Journal of Applied Earth Observation and Geoinformation: JAG*, 13 pp. 309-321

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**Gebrehiwot, T.**, van der Veen, A. (2012). Farm level adaptation to climate change: the case of farmer's in the Ethiopian highlands. *Environmental Management*, **under review after revision.**

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**Gebrehiwot, T.**, van der Veen, A. (2012). Assessing the evidence of climate variability in the northern highlands of Ethiopia. *Journal of Development and Agricultural Economics*, **under review.**

### Conference Proceedings Papers

**T. Gebrehiwot**; E.J.M. Dopheide; A. van der Veen (2011) Variability of vulnerability : the scale matters : a case of a developing country : ENSURE final Workshop with the participation of MOVE, 10-11 May 2011, BRGM Orléans.

Morsink, K., **Gebrehiwot, T.**, Geurts, P., van de Veen, A.(2012): Changes in credit uptake and on-farm risk management preferences due to agriculture input insurance. Research Conference on Microinsurance, 11-13 April, Univeristy of Twente, Enschede, Netherlands.

## **ITC dissertation list**

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