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Agro-ecosystems' Vulnerability to Climate Change in Drought Prone Areas of Northeastern Ethiopia

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Abstract
Agro-ecosystem level evidence is crucial to design and formulate climate change adaptation policies so as to build climate resilient communities. However, agro-ecosystems' vulnerability to climate change studies are not available in drought prone areas of northeastern Ethiopia. On the other hand, these drought prone agro-ecosystems which depend mainly on rain fed agriculture and pastoral/agro-pastoral ways of life are intermittently vulnerable to climate variability and change. Hence, the objective of this study is to examine agro-ecosystems vulnerability to climate change in drought prone areas of northeastern Ethiopia focusing on *Kobo* and *Golina* districts in Amhara and Afar regions respectively. Accordingly, data was gathered from secondary sources (station data from National Meteorological Agency), observation, key informant interviews, focus group discussions, and household survey in highland mixed farming, lowland mixed farming, agro-pastoral, and pastoral agro-ecosystems. Consequently, quantitative data analyzed by SPSS and STATA software whereas qualitative information analyzed by content analysis. More specifically, principal component analysis (PCA) model used to perform quantitative analysis to calculate adaptive capacity, sensitivity, exposure and vulnerability indexes of highland mixed farming, lowland mixed farming, agro-pastoral, and pastoral agro-ecosystems. The findings have shown that while lowland mixed farming is less vulnerable since it is the most adaptive and the least exposed compared to others, agro-pastoral agro-ecosystem is most vulnerable because it is the least adaptive and the highly exposed when compared to others. Hence, it is recommended that the adaptive capacity of agro-ecosystems should be improved as it reduces the sensitivity and finally the overall vulnerability.
Keywords: agro-ecosystem, climate change, vulnerability, drought-prone, principal component analysis

INTRODUCTION

Climate change is one of the greatest challenges facing the international community in the 21st century (Mearns and Norton, 2010). This is because, multiple independent data sources confirm beyond any reasonable doubt that the Earth's surface warmed during the 20th century, and it is virtually certain that the Earth will continue to warm in the 21st century (Dessler and Parson, 2006). This climate change has different impacts such as droughts, floods, and forest fires, which causes lose of homes, crop failures, reduced agricultural productivity, increased hunger, malnutrition, and disease (WDR, 2010) on different countries showing that no country is immune from various impacts of climate variability and change. Africa is highly vulnerable to climate change and climate variability as the majority of the populations depend on subsistence rain-fed agriculture (Boko et al., 2007); for instance, 85 percent of the population in Ethiopia depends on rain-fed agriculture (MOFED 2008 cited in Deressa, 2010). Furthermore, climate change impacts are more serious in drylands as they are characterized by limited water resources, and seasonal, scarce and unreliable rainfall; poorly served by infrastructures; and affected by periodic droughts (Anderson et al., 2010).

Ethiopia, listed as one of the sub-Saharan country, which is most vulnerable to climate change impacts mainly frequent droughts and floods with the least capacity to respond (Di Falco et al., 2011). Hence, climate change is one of a major development challenge to Ethiopia. For instance, since the early 1980s, Ethiopia has suffered seven major droughts of which five led to famines (World Bank, 2010). More specifically, the major droughts occurred in late 1950s in northern parts of Ethiopia, in 1972/73 northeastern part of Ethiopia in Tigray and Wollo, in 1984/85 in major parts of the country, in 1994 in lowland pastoral areas of Ethiopia, in 2000 in southern lowland pastoral areas of Ethiopia, in 2002/3 in major parts of the country, and in 2007/8 in many highland and lowlands areas of Ethiopia (World Bank, 2010). Of these, the 1984/85 drought reduced Ethiopia's agricultural production by 21 percent, which led to a 9.7 percent fall in the GDP (World Bank, 2006). Crop and livestock losses over northeastern Ethiopia, associated with droughts during 1998-2000, estimated at US$266 per household, which is greater than the average annual income for 75 percent of households in this region (Stern, 2007). Thus, given the nature of Ethiopia's economy, which largely depends on weather-sensitive and small-scale agricultural practices and the low adaptive capacity of poor farm households, the potential adverse effects of climate change on crop agriculture and food security will be increasing through time (Balew et al., 2014), as Ethiopia has also suffered from drought due to El Nino in 2015. This shows that for developing countries like Ethiopia, climate change threatens to deepen vulnerabilities, erode hard-won gains, and seriously undermine prospects for development (WDR, 2010).

Accordingly, assessing vulnerability provides a starting point for the determination of effective means of promoting remedial action, limiting impacts, supporting coping strategies and facilitating adaptation (Kelly and

Adger, 2000); and can help answer where and how society best can invest to reduce vulnerability (Mearns and Norton, 2010). Moreover, effective planning for adaptation programming requires a fine-grained assessment of local vulnerabilities, practices and adaptation options and preferences (Kuriakose et al., 2009). To this end, some studies (Tadesse et al., 2008; Gebremichael and Kifle, 2009; Bewket, 2012; Tesso et al., 2012; Simane et al., 2013; Simane et al., 2014; Teshome, 2014) have been done in Ethiopia.

However, though most of the droughts occurred in the northeastern Ethiopia and the areas are more vulnerable to climate change impacts recently also suffering from drought due to El Nino; climate change vulnerability of agro-ecosystems is not well addressed as there are gaps in the study areas covered, unit of analysis employed and the methodologies applied. As to the study areas covered, Tesso et al. (2012) studied vulnerability and resilience to climate change induced shocks in North Shewa, Ethiopia, taking highland, midland and lowland agro-ecologies within the same livelihood system, but not agro-ecosystems of northeastern Ethiopia with different livelihood strategies. Bewket (2012) has assessed climate change perceptions and adaptive responses of smallholder farmers in central highlands of Ethiopia but not by comparing with lowland smallholder farmers, agro-pastoralists and pastoralists. Negatu et al. (2011) assessed the vulnerability of Borana agro-pastoralists and pastoralists in the southern part of Ethiopia but with a different cultural setting. Moreover, even in those few studies (Hadgu et al., 2015; Deressa, 2010) done in drought prone areas of northeastern Ethiopia, there are gaps in the unit of analysis employed not addressing agro-ecosystem. For instance, a study conducted by Tadesse (2010) has assessed vulnerability to climate change and adaptation responses using region as a unit of analysis in which, within the region there is a great variation from one agro-ecosystem to the other. Furthermore, there are gaps in the methodology applied in some of those studies. Tadesse (2010) has assessed vulnerability to climate change and adaptation responses only using quantitative approaches. However, both qualitative and quantitative approaches have their own strengths and weaknesses. In addition, though there are some studies conducted in Ethiopia using PCA; they are conducted in different areas not using agro-ecosystems as unit of analysis (Tesso et al., 2012; Tadesse, 2010).

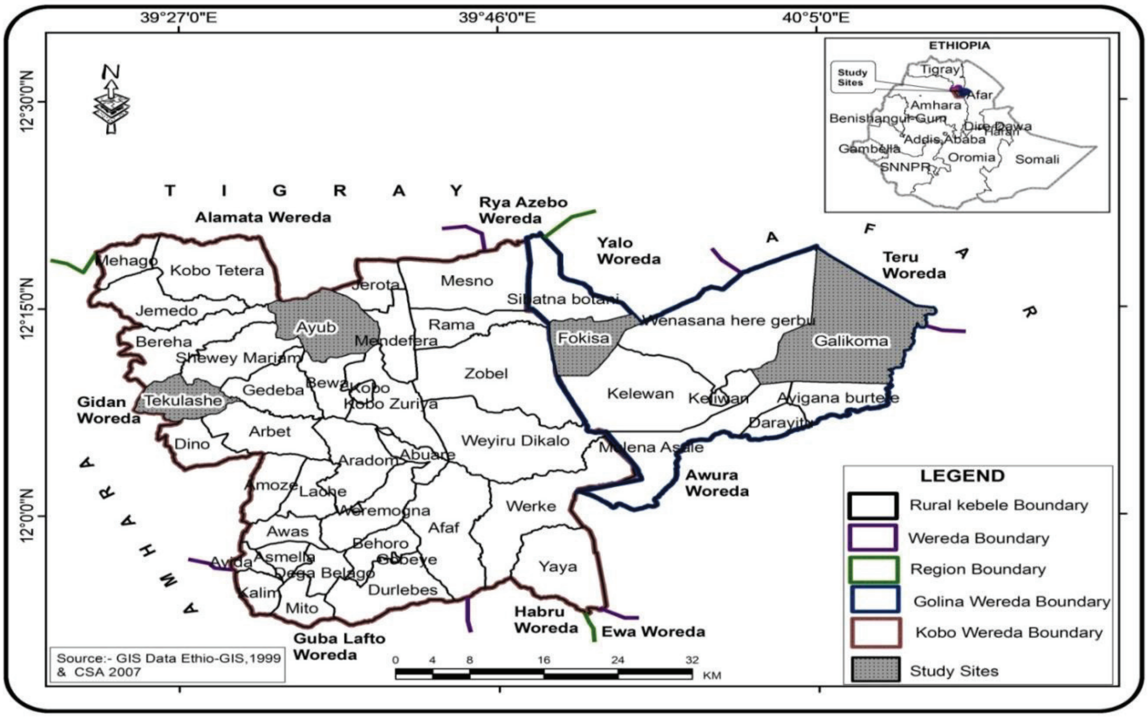
The purpose of this research, therefore, is to study climate change vulnerability in highland and lowland mixed farming, agro-pastoral and pastoral agro-ecosystems; employing agro-ecosystems as a unit of analysis and using mixed method in drought prone areas of northeastern Ethiopia to use as an input to develop/design appropriate adaptation strategies that increase the resilience of agro-ecosystems. In so doing, the study aims at describing the environmental contexts of highland mixed farming, lowland mixed farming, agro-pastoral, and pastoral agro-ecosystems; examining the vulnerability of those agro-ecosystems to climate variability and change; and analyzing various factors influencing the vulnerability of these agro-ecosystems to climate variability and change.

METHODOLOGY

Description of the Study Sites

The study is conducted in Kobo and Golina, two bordering districts, in the Amhara and Afar regions respectively in the northeastern part of Ethiopia representing different agro-ecosystems. Agro-ecosystems mainly consist of agro-ecology and farming systems. Ethiopia has five traditional agro-ecological zones: bereha (desert, below 500 m.a.s.l.), kola (lowland, 500 to 1500 m.a.s.l.), weynadega (middle land, 1500 to 2500 m.a.s.l.), dega (highland, 2500 to 3500 m.a.s.l.), and Wurch (above 3500 m.a.s.l.) (MOA, 2000). The study districts fall in three of them (kola, weynadega and dega). Kobo is classified as highland/midland and lowland with an altitude ranging from 1000 to 3000 m.a.s.l. (Woreda Agricultural Development Office, 2013); and received an average annual rainfall of 750 mm and mean annual maximum and minimum temperature of 25 and 12^{0}C, respectively (NMA, 2012). On the other hand, Golina district comprised of two major agro-ecological zones. A smaller portion lies in the desert with an elevation of less than 500 m while a greater portion lay in the lowland with elevation between 500 and 650 m (Woreda Pastoral Development Office, 2013). This study considers mainly the lowland part and characterized with mean annual maximum and minimum temperature of 37 and 22^{0}C, respectively and average annual rainfall of 200 mm (NMA, 2012).

Figure 1: Map of the Study Sites



On the other hand, there are four major farming systems in Ethiopia: seed-farming, *enset*-planting, shifting cultivation, and pastoral complexes. The seed-farming complex focuses on grain production in the central, northern, and eastern highlands involving the majority of Ethiopian small farmers. Shifting cultivation and pastoral complexes are most common in the western and eastern lowlands, respectively (Westphal, 1975 cited in Chamberlin and Schmidt, 2011). Kobo district in the Amhara region is found in seed farming system (i.e., crop-livestock mixed farming), characterized by various constraints mainly moisture scarcity due to rainfall variability, reduction of soil fertility, occurrence of crop pests and diseases, and shortage of farmland (Amhara Bureau of Agriculture, 2014). Golina district is found in pastoral farming system in Afar region. The Afar pastoralists pursue their livelihoods in subsistence based, mixed livestock management of camels, cattle, goats and sheep (PCDP, 2005). However, crop production is a newly emerging livelihood system in Golina district in Afar pastoral system. As a result, agro-pastoral farming system (crop production and livestock raising) is included in this study to get a complete picture of agro-ecosystem level analysis of climate change vulnerabilities in the study areas.

Data Collection

A combination of qualitative and quantitative research methods applied to overcome various weaknesses inherent in different methods (Dawson, 2009). Mixed research approach, therefore, employed to collect quantitative and qualitative data. Accordingly, household survey, observations, key informant interviews, focus group discussions, and secondary data analysis used iteratively to collect both primary and secondary data for this study. Temperature and rainfall station recorded data of the study areas and nearby stations from 1980 to 2010 obtained from National Meteorological Agency. Direct observation of the study sites conducted to look at the environmental, socio-economic and institutional contexts. Key informant interviews conducted with representatives of Ministry of Environmental Protection and Forestry, Ministry of Agriculture, Ministry of Federal Affairs, Pastoralist Forum Ethiopia, and Climate Change Forum Ethiopia at the federal level. Moreover, representatives of different regional sectoral offices of Amhara and Afar regional states, local government officials and experts of the study districts, development agents of the study *kebeles* (the lowest administrative unit in Ethiopia), and households of both sexes at each agro-ecosystem interviewed. Fourteen focus group discussions (7 at each district) are conducted. The first FGD conducted with local government officials from different sectors (such as agriculture, environmental protection, water, health, education and women's affair) at district level to gather relevant information for both highland and lowland, and agro-pastoral and pastoral agro-ecosystems. Then, three FGDs conducted with local community workers (development agents, teachers and health extension workers), male households and female households for each agro-ecosystem.

The study districts were selected purposively to compare climate change vulnerability and adaptation of agro-ecosystems/households being found in drought prone areas and bordering each other. As it can be recalled from the description of the study sites section, the study areas are stratified by agro-ecosystem: highland mixed farming, lowland mixed farming, agro-pastoral, and pastoral areas. Then, since both districts have more or less proportional number of rural kebeles by agro-ecosystem, one rural *kebele,* representing each agro-ecosystem selected randomly. Finally, households selected using systematic sampling technique proportionately.

The study has employed the following formula to determine the sample size (Lohr, 2010). Accordingly, to obtain absolute precision e, find the value of n that satisfies:

$$e = z\alpha_{/2}\sqrt{\left(1-\frac{n}{N}\right)\frac{S}{\sqrt{n}}}$$

To solve this equation for n, first find the sample size n_0

$$n_0 = \left(\frac{z\alpha_{/2}S}{e}\right)^2, \text{ then}$$

$$n = \frac{n_0}{1+\frac{n_0}{N}}$$

$$n = \frac{z^2_{\alpha/2}S^2}{e^2 + \frac{z^2_{\alpha/2}S^2}{N}}$$

Where n = required sample size
$z^2_{\alpha/2} = 1.96^2$
N = the population size = 4530
$S^2 \approx P\ (1-p)$, which attains its maximum value when $p = 1/2$
e= marginal error, usually for many surveys using a proportion, e=0.03
α= level of significance, usually for many surveys using a proportion, α=0.05

Finally, $n_0 = \frac{(1.96)^2\left(\frac{1}{2}\right)\left(1-\frac{1}{2}\right)}{(0.03)^2} \approx 1067$

$$n = \frac{n_0}{1+\frac{n_0}{N}} = \frac{1067}{1+\frac{1067}{4530}} = 864$$

Lohr (2010) has also pointed out that the final decision to set the sample size is up to the researcher based on the existing situation. More specifically, the same source has indicated that though the larger the sample the smaller is the sampling error, some adjustments can be done to reduce non-sampling error, based on the availability of the budget, and to control selection and measurement bias (Lohr, 2010). Accordingly, the sample size for this study adjusted to 432 due to the aforementioned factors.

Accordingly, as presented in Table 1, a total sample size of 432 households (169 from highland mixed farming, 181 from lowland mixed farming, 49 from agro-pastoral, and 33 from pastoral agro-ecosystems) are included in the survey using stratified proportionate sampling formula.

$$Total\ sample\ n = n_1 + n_2 + \cdots + n_k$$

$$n = \left(\frac{1769}{4530}(432) + \frac{1899}{4530}(432) + \frac{513}{4530}(432) + \frac{349}{4530}(432)\right)$$

$$\mathbf{n = 169 + 181 + 49 + 33 = 432}$$

Table 2: Sampling Distribution

Region	*Zone*	*District*	*Agro-ecosystem*	*Rural kebele*	*No of HHs**	*No of selected HHs*
Amhara	North Wollo	Kobo	Highland Mixed Farming	Tekulashe	1769	169
			Lowland Mixed Farming	Ayub	1899	181
Afar	Zone 4	Golina	Lowland Agro-pastoral	Fokisa	513	49
			Lowland Pastoral	Galikoma	349	33
Total		**2**	**4**	**4**	**4530**	**432**

* Source: Respective Agricultural/Pastoral Development Offices, 2013

However, from 432 questionnaires, 6 of them were not included in the analysis due to various problems. Accordingly, a total sample size of 426 households (165 from highland mixed farming, 180 from lowland mixed farming, 48 from agro-pastoral, and 33 from pastoral agro-ecosystems) are included in the analysis.

Modeling and Data Analysis

Analytical Model

There are biophysical, socioeconomic, and integrated approaches for vulnerability analysis of climate change; the integrated assessment approach combining both the biophysical and socioeconomic attributes (Füssel, 2007).

Accordingly, this study attempts to analyze households and agro-ecosystems vulnerability based on the integrated approach using vulnerability indexes. In so doing, indicators chosen based on a review of the literature and adjusting to the context of drought prone areas of Ethiopia. However, in calculating the direction of relationship in vulnerability indicators (that is, their sign), a negative value was assigned to both exposure and sensitivity. The justification is that households that are highly exposed to climate shocks are more sensitive to damage, assuming constant adaptive capacity. Consequently, vulnerability to climate change calculated as the net effect of adaptive capacity, sensitivity, and exposure (IPCC, 2001).

$$\text{Vulnerability} = (\text{Adaptive Capacity}) - (\text{Sensitivity}) - (\text{Exposure}) \ldots\ldots (1)$$

In such relationship, higher net value indicates that the household or the agro-ecosystem is less vulnerable to climate change and vice versa.

Indicators of sensitivity, exposure and adaptive capacity encompass a wide range of biophysical and socio-economic aspects of vulnerability that are not necessarily directly comparable (Adger, 2006). While each individual indicator may be of interest to researchers/policymakers, in isolation they might not provide a clear understanding of composite (or aggregate) vulnerability (Abson et al., 2012). Moreover, weights should be assigned to those indicators through different techniques. Livelihood Vulnerability Index (LVI) or Livelihood Vulnerability Index combined with IPCC's three contributing factors to vulnerability, i.e., exposure, sensitivity, and adaptive capacity (LVI-IPCC) follows equal weighting (Hahn et al., 2009). However, it is too arbitrary and leads to overweighting of some less important indicators while underweighting the important ones. The other weighting can be based on expert judgment (Vincent, 2007; Adger and Vincent, 2005; Vincent, 2004); however, this approach criticized for being too subjective and often constrained by the availability of subject matter specialists or lack of consensus among the experts themselves (Gbetibouo, 2009). Assigning weight by Principal Component Analysis (PCA) following Filmer and Pritchett (2001) is thus preferred compared to the former two methods (Cutter et al., 2003).

Principal components analysis is a multivariate technique in which a number of related variables transformed to a smaller set of uncorrelated variables called principal components (Jackson, 2003). To this end, suppose there are a set of *Z*-variables ($a_{1j}^* \ to \ a_{zj}^*$) that represents the attributes of each household *j*. PCA starts by specifying each variable normalized by its mean and standard deviation since different units measure different indicators. For instance, $a_{1j} = (a_{1j}^* - a_1^*)/s_1^*$ where a_1^* is the mean of a_{1j}^* across households/agro-ecosystems and s_1^* is its standard deviation. The selected/relevant variables for adaptive capacity, sensitivity and exposure expressed as linear combinations of a set of underlying components for each agro-ecosystem/household *j:*

$$a_{1j} = C_{11}V_{1j} + C_{12}V_{2j} + \cdots + C_{1z}V_{zj}$$

$$\ldots \qquad j=1 \ldots J$$

$$a_{zj} = C_{z1}V_{1j} + C_{z2}V_{2j} + \cdots + C_{zz}V_{zj} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Where the *V*'s are the components and the *C*'s are the coefficients on each component for each variable. Since only the left side of each line observed, the solution to the problem is indeterminate. PCA overcomes this indeterminacy by finding the linear combination of the variables with maximum variance (usually the first principal component V_{1j}), then finding a second linear combination of the variables orthogonal to the first and with maximal remaining variance, and so on. Accordingly, the procedure solves the equations $(R - \lambda \mathbf{I})v_n = 0$ for λ_n and v_n, where **R** is the matrix of correlations between the scaled variables (the *a*'s) and v_n is the vector of coefficients on the n^{th} component for each variable. Solving the equation yields the eigenvalues of **R**, λ_n and their associated eigenvectors, v_n. The final set of estimates produced by scaling the v_ns so that the sum of their squares sums to the total variance, another restriction imposed to achieve determinacy of the problem.

Another interesting property of PCA is the fact that the preceding equation (equation 2 in this case) inverted so that the principal components stated as a function of original variables and factor scores (Jackson, 2003). This yields a set of estimates for each of *Z* principal components:

$$V_{1j} = f_{11}a_{1j} + f_{12}a_{2j} + \cdots + f_{1z}a_{zj}$$

$$\ldots \qquad j=1 \ldots J$$

$$V_{zj} = f_{z1}a_{1j} + f_{z2}a_{2j} + \ldots + f_{zz}a_{zj} \ , \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

Where the *f*'s are the factor scores. Following Filmer and Pritchett (2001), the first principal component, expressed in terms of the original (un-normalized) variables is an index for each agro-ecosystem/household of the study areas based on the following expression:

$$V_{1j} = f_{11}\,(a_{1j}^* - a_1^*)/(s_1^*) + \cdots + f_{1z}(a_{Zj}^* - a_Z^*)/(s_Z^*) \ldots\ldots\ldots\ (4)$$

To this end, PCA run for the indicators of exposure, sensitivity, and adaptive capacity. The loadings from the first principal component used as the weights for the indicators. Finally, vulnerability index for each agro-ecosystem/household is calculated using equation 1.

Empirical Model for the Study

PCA run separately for each vulnerability component (adaptive capacity, sensitivity, and exposure) at each agro-ecosystem. The loadings of first principal component that explained the majority of the variation in the data set are taken as factor scores. Accordingly, factor scores from the first principal component and the normalized values of the corresponding variables employed to construct indices for each vulnerability component at each agro-ecosystem. Then, vulnerability index for each agro-ecosystem is calculated using equation 1.

$$\mathbf{ACI} = (\mathrm{DV} * \boldsymbol{ZDV}) + (\mathrm{LC} * \boldsymbol{ZLC}) + (\mathrm{T} * \boldsymbol{ZT}) + (\mathrm{I} * \boldsymbol{ZI})$$

Where, ACI – Adaptive capacity index
DV – Positively loaded demographic variables factor scores
ZDV– Normalized value of positively loaded demographic variables
LC – Positively loaded livelihood capitals factor scores
ZLC– Normalized value of positively loaded livelihood capitals
T – Positively loaded access and use of technologies factor scores
ZT – Normalized value of positively loaded access and use of technologies
I – Positively loaded institutions factor scores
ZI – Normalized value of positively loaded institutional factors

$$\mathbf{SI} = (\mathrm{CPRL} * \boldsymbol{ZCPRL}) + (\mathrm{LPRD} * \boldsymbol{ZLPRD}) + (\mathrm{FS} * \boldsymbol{ZFS}) + (\mathrm{WS} * \boldsymbol{ZWS}) + (\mathrm{C} * \boldsymbol{ZC})$$

Where, SI – Sensitivity index
CPRL – Crop production reduction or loss factor scores
ZCPRL – Normalized value of crop production reduction or loss
LPRD – Livestock production reduction or death factor scores
ZLPRD – Normalized value of livestock production reduction or death
FS – Food shortage factor scores
ZFS – Normalized value of food shortage
WS – Water scarcity factor scores
ZWS – Normalized value of water scarcity
C – Conflict factor scores
ZC – Normalized value of conflict

$$\mathbf{EI} = (\mathrm{TIP} * \boldsymbol{ZTIP}) + (\mathrm{RFDP} * \boldsymbol{ZRFDP}) + (\mathrm{FDO} * \boldsymbol{ZFDO})$$

Where, EI – Exposure index
TIP – Temperature increase perception factor scores
ZTIP – Normalized value of temperature increase perception
RFDP – Rainfall decrease perception factor scores
ZRFDP – Normalized value of rainfall decrease perception
FDO – Frequency of drought occurrence factor scores
ZFDO – Normalized value of Frequency of drought occurrence

Then,

$$\mathrm{VI} = (\mathrm{ACI}) - (\mathrm{SI}) - (\mathrm{EI})$$

Where, VI – Vulnerability index
ACI – Adaptive capacity index
SI – Sensitivity index
EI – Exposure index

Data Analysis

The survey data edited, coded and entered into a computer, and then analyzed using SPSS and STATA soft-wares as they do have differentiated qualities in data management and regression analysis respectively. Primarily, descriptive analysis [mainly percentage] done to present data/information in a manageable and understandable form. Subsequently, inferential analysis performed through principal component analysis model to examine climate change vulnerability of agro-ecosystems. On the other hand, the qualitative data gathered through observations, key informant interviews, and focus group discussions are analyzed using content analysis by moving deeper and deeper into understanding the data (Creswell, 2009). Finally, the obtained indexes of different agro-ecosystems explained using relevant indicators and qualitative findings from key informants, focus group discussion participants, and observations.

Description of Model Variables

The model variables for this study are categorized by exposure, sensitivity, and adaptive capacity (Table 2). The household's adaptive capacity constitutes demographic characteristics, livelihood strategy, livelihood capitals (human, social, natural, physical and financial), access and use of modern technology, and institutions hypothesized to influence agro-ecosystems/households' vulnerability in drought prone areas of northeastern Ethiopia. The sensitivity and exposure constitutes environmental and related factors.

Table 3: Vulnerability indicators, description, and anticipated direction in relation to vulnerability of households

Vulnerability sub-component	*Vulnerability indicators category*	*Vulnerability indicators*	*Description*	*Relationship with Vulnerability*
Exposure	Environmental factors	Perception of temperature increase	1 if households perceive increased temperature and 0 otherwise	+ or -
		Perception of rainfall decrease	1 if households perceive decreased rainfall and 0 otherwise	+ or -
		Drought occurrence frequency	1 if drought occurred yearly and 0 otherwise	+ or -
Sensitivity	Environmental and related factors	Crop productivity reduction/loss	1 if households face crop failure and 0 otherwise	+ or -
		Livestock productivity reduction/death	1 if households encountered livestock death and 0 otherwise	+ or -
		Water scarcity	1 if households face water scarcity and 0 otherwise	+ or -
		Food shortage	1 if households face food shortage and 0 otherwise	+ or -
		Conflict	1 if households face conflict and 0 otherwise	+ or -
Adaptive capacity	Demographic variables	Gender	1 if a household is male and 0 otherwise	+ or -
		Age	Number of years	Positive
		Marital status	1 if a household is married and 0 otherwise	+ or -
		Family planning methods	1 if a household use family planning methods and 0 otherwise	+ or -
		Household size	Number of household size	Positive
		Number of dependents	Number of dependents	Positive
		Migration/mobility	1 if a household practice migration/mobility and 0 otherwise	+ or -
	Livelihood strategy	Livelihood strategy	1 if a household practice mixed farming and 0 otherwise	+ or -
	Livelihood capitals	Formal education	1 if a household has formal education and 0 otherwise	Positive
		Adult education	1 if a household participated in adult education and 0 otherwise	+ or -
		Framing experience	Number of years	Positive
		Access to information	1 if a household has access to information and 0 otherwise	+ or -
		Health status	1 if any household members are not sick and 0 otherwise	+ or -
		Social networks	1 if a household has social networks and 0 otherwise	+ or -
		Institutional membership	1 if a household has institutional membership and 0 otherwise	+ or -
		Land ownership	Land owned in *timads**	Positive
		Access to water for irrigation	1 if a household has water access for irrigation and 0 otherwise	+ or -
		Walking distance to vicinity all weather road	Number of hours travelled	Positive
		Walking distance to the nearest market	Number of hours travelled	Positive
		Access to clean water supply	1 if a household has clean water access and 0 otherwise	+ or -

Vulnerability sub-component	*Vulnerability indicators category*	*Vulnerability indicators*	*Description*	*Relationship with Vulnerability*
		Mobile phone possession	1 if a household has mobile phone and 0 otherwise	+ or -
		Saving	1 if a household has saving and 0 otherwise	+ or -
		Credit taking	1 if a household has taken credit and 0 otherwise	+ or -
		Livestock ownership	Livestock owned in TLUs**	Positive
		Non-agricultural income	1 if a household has non-agricultural income source and 0 otherwise	+ or -
	Technological variables	Improved cooking stoves	1 if a household use improved cooking stove and 0 otherwise	+ or -
		Improved crop varieties	1 if a household use improved crop varieties and 0 otherwise	+ or -
		Improved livestock breeds	1 if a household use improved livestock breeds and 0 otherwise	+ or -
		Use of chemical fertilizer	1 if a household use chemical fertilizer and 0 otherwise	+ or -
		Water harvesting	1 if a household use water harvesting and 0 otherwise	+ or -
		Irrigation	1 if a household practice irrigation and 0 otherwise	+ or -
	Institutional indicators	Agricultural extension services	1 if a household has agricultural extension service and 0 otherwise	+ or -
		Access to credit institution	1 if a household has access to credit institution and 0 otherwise	+ or -
		Market access	1 if a household has market access and 0 otherwise	+ or -
		Education access	Number of hours travelled to get the nearest primary school	Positive
		Health access	Number of hours travelled to get the nearest health post	Positive

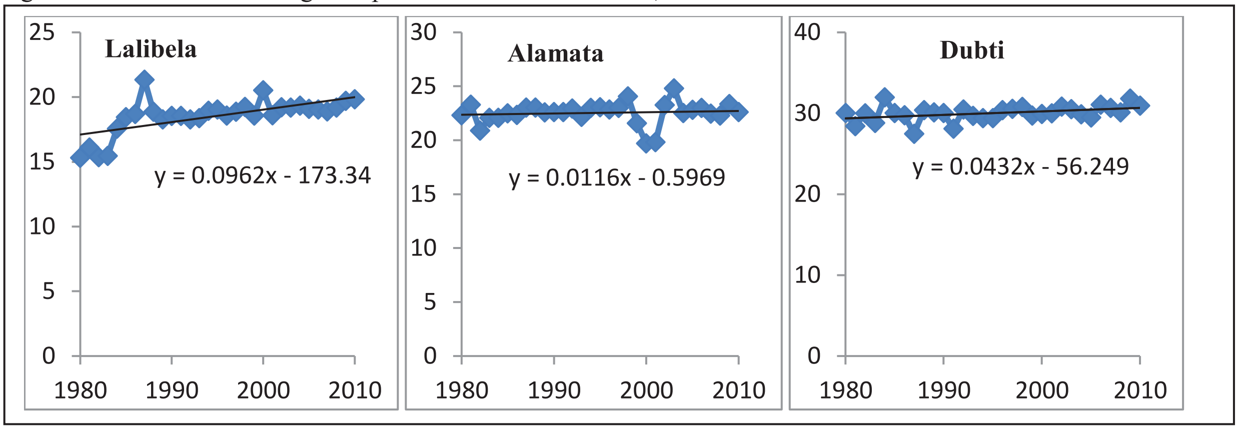
* 4 *timads* are equal to 1 hectare
** Tropical Livestock Unit (TLU) conversion factors: camel = 1, cattle = 0.7, horse = 0.8, mule = 0.7, donkey = 0.5, sheep/goat = 0.1, chicken = 0.01 (Source: FAO, 1987).

RESULTS AND DISCUSSIONS

Environmental Contexts

Total annual average temperature has increased by 2.9^{0}C in Lalibela station, by 0.35^{0}C in Alamata station, and by 1.3^{0}C in Dubti station within 30 years (Figure 2). This shows that temperature is increasing in all of the three stations though the magnitude is different. A study conducted by Assefa (2009) asserted that warming has occurred across Ethiopia, particularly since the 1970s at a variable rate but broadly consistent with wider African and global trends with increasing trend in time (0.37^{0}C/decade). On the other hand, IPCC (2014) has indicated that warming in excess of 1^{0}C has negative impacts without adaptation. Above 1^{0}C temperature increase, is found in the two stations except Alamata station during the last 20-30 years showing that such temperature increase has caused different negative impacts in the study areas. Likewise, key informants and focus group discussion participants from the respective agro-ecosystems have asserted that temperature has increased in their locality during the last 20-30 years.

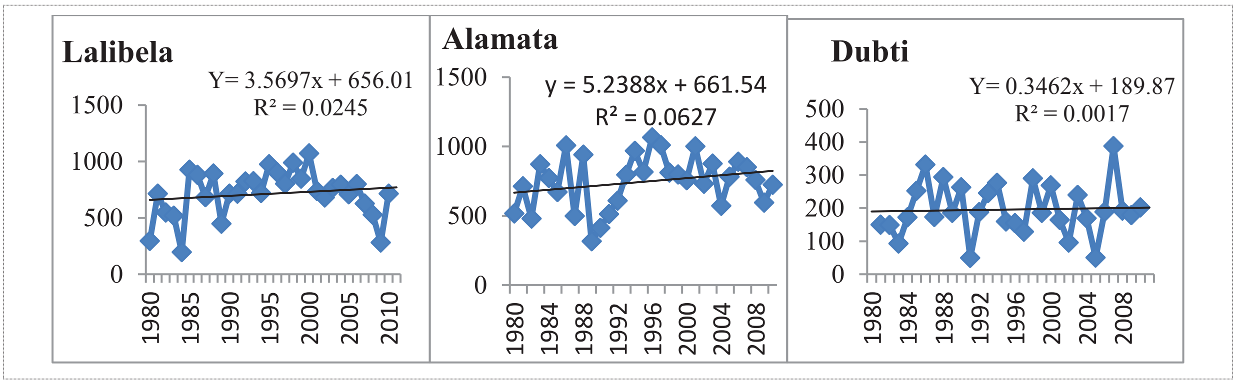
Figure 2: Total annual average temperature trends of Lalibela, Alamata and Dubti stations from 1980-2010



Source: NMA, 2012

On the other hand, annual rainfall has increased by 107, 157 and 10 mm in Lalibela, Alamata and Dubti stations respectively in 30 years (Figure 3). However, a study conducted by World Bank (2010) has shown that there was drought in most of these periods that have led to livelihood insecurity; and another study by Riche et al. (2009) has indicated that the frequency of drought has increased from every 5-10 years to 1-2 years. The probable reason might be that the amount of rainfall may not be decreased or even it may be increased as indicated in figure 3, however, what matters is the distribution of the rainfall. In relation to this, a key informant from lowland mixed farming agro-ecosystem has argued that, there is a huge amount of rainfall for some days or sometimes for months; however, it will stop raining at a critical time when the planted crops require rain/water.

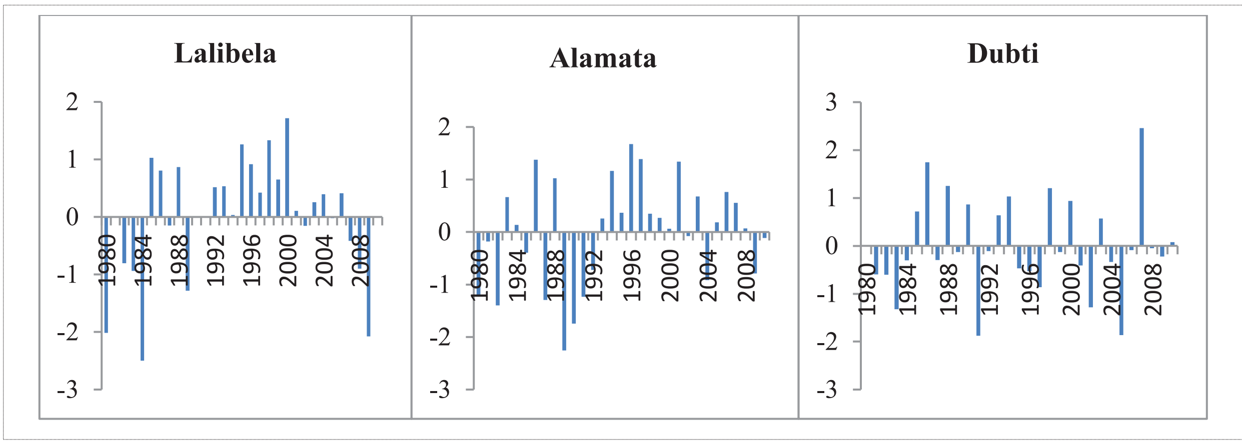
Figure 3: Annual rainfall trends of Lalibela, Alamata and Dubti stations from 1980-2010



Source: NMA, 2012

Similarly, rainfall anomalies graph of Lalibela, Alamata and Dubti stations from 1980-2010 show that while some years have been characterized by dry conditions resulting in drought and famine like the great famine in 1984, others are characterized by wet conditions (Figure 4). The graphs show that the normalized deviation value of rainfall is below zero in almost half of the last 30 years indicating that there was drought in most of these years. In line with this, a key informant from the highland mixed farming agro-ecosystem has pointed out that *in the past when there was cloud, we were sure that there would be rain. However, these days when we are expecting that there will be rain, there is no rain; and any farm preparations made become worthless. Moreover, he added, the livestock are highly affected by shortage of pasture and water due to lack of rain. Accordingly, most households are suffering from drought and then food insecurity.* In relation to this, a previous study conducted by Gebremichael and Kifle (2009) asserted that as there is decrease in rainfall there is decrease in crop and livestock productivity.

Figure 4: Rainfall Anomalies of Lalibela, Alamata and Dubti stations from 1980-2010



Source: NMA, 2012

Principal Component Analysis Model Results

Adaptive Capacity

Highland Mixed Farming Agro-ecosystem

The results of PCA for indicators of highland mixed farming agro-ecosystem revealed 12 components with eigenvalue greater than 1, explaining 78.84 percent of the total variation in the data set. The majority of indicators identified under adaptive capacity [demographic, livelihood capitals, technological and institutional indicators] are positively loaded.

To this end, age of a household head, household size, number of dependents, household head experience, land ownership, access to clean water supply, livestock ownership, credit taking, water harvesting, agricultural extension services and market access are the most important indicators in explaining 78.84 per cent variation of the data set (Table 3). Similarly, key informants and focus group discussion participants have pointed out that land ownership, livestock ownership, water access for irrigation and access to credit are the most determining factors of adaptive capacity in their locality. Opiyo et al. (2014) also confirmed that sex of household head, age of household head, number of dependents, marital status, social linkages, access to extension services and early warning information, complementary source of income, herd size and diversity, herd structure, herd mobility, distance to markets, employment status, and access to credit determine the resilience of households.

Table 3: Factor scores of the first principal component of adaptive capacity indicators by agro-ecosystem

Adaptive capacity indicators	Factor scores of households in agro-ecosystems			
	Highland mixed farming	Lowland mixed farming	Lowland Agro-pastoral	Lowland Pastoral
Household head Gender: male headed	0.1950	0.0758	0.0934	-0.0015
Household head Age in years	0.2214	0.2555	-0.0281	-0.3551
Marital status: married	0.1926	0.1194	0.0905	0.1751
Household size	0.3477	0.2372	-0.0106	-0.1725
Number of dependents	0.2162	0.0432	0.1137	0.2132
Migration/mobility: practicing migration/mobility	-0.1228	-0.0762	na	na
Educational status: attending formal education	-0.0946	-0.2051	0.1941	0.3042
Adult education: participating in adult education	0.1892	-0.0462	0.1017	-0.0416
Household head farming experience in years	0.2344	0.2395	-0.0256	-0.3764
Access to information: have access to information	0.0557	-0.2204	0.2896	0.1541
Health status: no household members sickness in survey year	0.0463	-0.2448	0.3348	0.2133
Family planning: using family planning methods	0.1051	-0.1434	-0.1522	0.0879
Social networks: have social networks	0.0417	0.1023	-0.1139	-0.0410
Institutional membership: have institutional membership	-0.0263	0.0544	-0.0462	0.0728
Land ownership in timads*	0.2265	0.2988	0.3562	na
Access to water for irrigation: have access to water	0.0557	0.0912	0.1579	-0.1331
Main livelihood strategy: mixed farming	0.2059	0.1136	na	na
Walking distance to vicinity all weather road in hours	-0.1762	0.0488	-0.1198	-0.2324
Distance to the vicinity market place in hours	-0.1562	0.1405	-0.2116	-0.0006

Access to clean water supply: have access to clean water	0.2246	-0.0269	-0.0416	-0.1052
Mobile phone possession: have mobile phone	0.1626	0.0078	0.0795	0.2879
Saving: have saving	0.0505	-0.0212	0.0527	0.2582
Credit taking: has taken credit	0.1085	0.2016	na	na
Livestock ownership in TLUs **	0.2997	0.2578	0.1220	-0.1741
Non-agricultural income: have non-agricultural income	-0.1183	0.0738	-0.0058	0.3007
Improved cooking stoves: adopting improved stove	0.1261	0.1946	na	na
Improved crop varieties: using improved varieties	0.0420	0.1892	0.3390	na
Improved livestock breeds: using improved breeds	0.0900	-0.2267	0.1336	-0.1439
Use of chemical fertilizer: using chemical fertilizer	0.1563	0.1100	na	na
Water harvesting: harvesting water	0.2041	0.1723	0.3030	-0.1814
Irrigation: practicing irrigation	0.0580	0.1736	0.3133	na
Agricultural extension services: have got services	0.2338	0.1914	0.2275	0.0007
Credit access: have access to credit institution	0.0899	0.2540	na	na
Market access: have market access	0.1635	-0.0125	-0.1278	-0.1857
Education access : Distance to the nearest primary school in hours	-0.1597	0.1761	-0.1389	0.0830
Health access: distance to the nearest health post in hours	-0.1316	0.1761	-0.1990	-0.0066

Source: Field Survey, 2014
* 4 *timads* are equal to 1 hectare
na= not applicable/available
** Tropical Livestock Unit (TLU) conversion factors: camel = 1, cattle = 0.7, horse = 0.8, mule = 0.7, donkey = 0.5, sheep/goat = 0.1, chicken = 0.01 (Source: FAO, 1987).

Adaptive capacity index of the highland mixed farming agro-ecosystem ($ACI_{HLMFAES}$) calculated using all positively loaded indicators of adaptive capacity (Table 3) as follows:

$$ACI_{HLMFAES} = \begin{bmatrix} (0.1950 * 0.54) + (0.2214 * -1.14) + (0.1926 * -0.53) + \\ (0.3477 * -0.92) + (0.2162 * -0.76) + (0.1892 * 1.13) + \\ (0.2344 * -1) + (0.0557 * 1.08) + (0.0463 * 1) + \\ (0.1051 * 0.98) + (0.0417 * 0.76) + (0.2265 * -0.27) + \\ (0.0557 * 0.66) + (0.2059 * 0.68) + (0.2246 * 0.05) + \\ (0.1626 * -1.32) + (0.0505 * -0.64) + (0.2997 * -0.86) + \\ (0.1085 * 0.83) + (0.1261 * 1.39) + (0.0420 * 0.24) + \\ (0.0900 * 0.81) + (0.1563 * 1.34) + (0.2041 * 0.11) + \\ (0.0580 * -0.46) + (0.2338 * 1.34) + (0.0899 * 0.82) + \\ (0.1635 * 0.83) \end{bmatrix} = 0.19$$

Highland mixed farming agro-ecosystem with adaptive capacity index of 0.19 is less adaptive when compared to lowland mixed farming agro-ecosystems though it is more adaptive as compared to agro-pastoral and pastoral agro-ecosystems (Figure 5). Key informants and focus group discussion participants from highland mixed farming agro-ecosystem argue that households of these areas have less adaptive capacity. This is due to the fact that most of the households in their locality own a farmland size of less than 0.5 hectare, and the owned lands are not suitable for irrigation. As a result, households are highly vulnerable to climate change impacts particularly with frequent droughts. This finding is in line with a previously conducted study by Deressa (2010) indicating that households who do not have livestock and farmland, and households with no credit and extension services are more vulnerable.

Lowland Mixed Farming Agro-ecosystem

The results obtained from PCA analysis for indicators of lowland mixed farming agro-ecosystem revealed 12 components with eigenvalue greater than 1, explaining 75.76 percent of the total variation in the data set. The majority of indicators identified under adaptive capacity are positively loaded. Consequently, adaptive capacity index of the lowland mixed farming agro-ecosystem ($ACI_{LLMFAES}$) calculated using all positively loaded indicators of adaptive capacity (Table 3) as follows:

$$ACI_{LLMFAES} = \begin{bmatrix} (0.0758 * 1) + (0.2555 * 0.4) + (0.1194 * 0.2) + \\ (0.2372 * -0.73) + (0.0432 * -0.96) + (0.2395 * -0.07) + \\ (0.1023 * 0.96) + (0.0544 * 0.81) + (0.2988 * 1.21) + \\ (0.0912 * 1.02) + (0.1136 * 1.04) + (0.0488 * -0.68) + \\ (0.1405 * -0.75) + (0.0078 * 1.06) + (0.2578 * -0.56) + \\ (0.2016 * 0.9) + (0.0738 * 1.21) + (0.1946 * 0.06) + \\ (0.1892 * 0.95) + (0.1100 * 0.18) + (0.1723 * -1.45) + \\ (0.1736 * 1.33) + (0.1914 * 0.15) + (0.2540 * 0.91) + \\ (0.1761 * -1.02) + (0.1761 * -1.13) \end{bmatrix} = 0.75$$

Age of a household head, household size, land ownership, livestock ownership, credit taking, water harvesting, practicing irrigation, and agricultural extension services are the most important indicators in explaining 75.76 per cent variation of the data set (Table 3). On the other hand, key informants and focus group discussion participants have pointed out that land ownership, livestock ownership, water access for irrigation and access to credit are the most determining factors of adaptive capacity in their locality.

Lowland mixed farming agro-ecosystem with adaptive capacity index of 0.75 is more adaptive as compared to highland mixed farming, agro-pastoral and pastoral agro-ecosystems (Figure 5). Similarly, key informants and focus group discussion participants have pointed out that households in their locality are more adaptive as they have better land size ownership, livestock ownership, water access for irrigation and access to credit as compared to their vicinity highlanders. A study conducted by Tesso et al. (2012) computed the net effect of adaptation, exposure, and sensitivity from principal component analysis results and the net value is only positive for community living in the lowland areas; while it is negative for those living in midland and highland agro-ecologies. This shows that the lowland agro-ecologies are better adaptive than the midland and highland agro-ecologies.

Lowland Agro-pastoral Agro-ecosystem

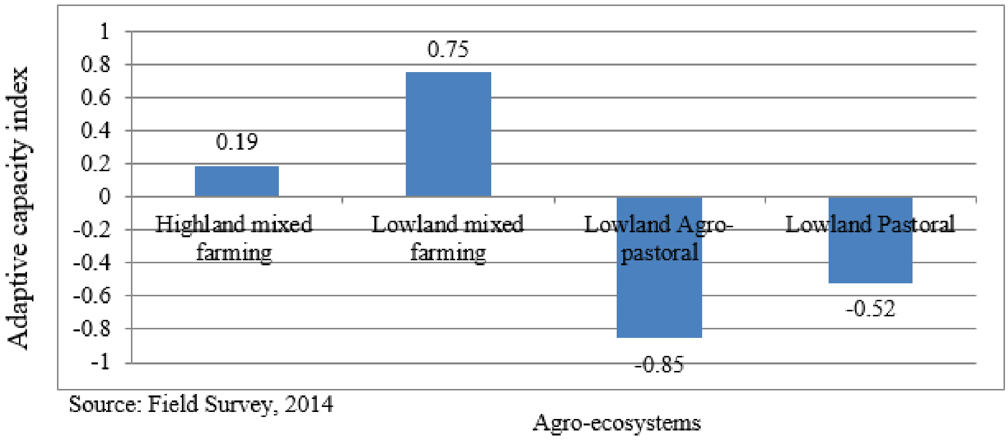
PCA results for indicators of agro-pastoral agro-ecosystem revealed 9 components with eigenvalue greater than 1, explaining 82.16 percent of the total variation in the data set. The majority of indicators identified under adaptive capacity are positively loaded. Consequently, adaptive capacity index of agro-pastoral agro-ecosystem (ACI_{APAES}) calculated using all positively loaded indicators of adaptive capacity (Table 3) as follows:

$$ACI_{APAES} = \begin{bmatrix} (0.0934 * -0.25) + (0.0905 * -0.98) + (0.1137 * 0.86) + \\ (0.1941 * -0.79) + (0.1017 * -0.48) + (0.2896 * -0.9) + \\ (0.3348 * -1.05) + (0.3562 * 0.24) + (0.1579 * -0.63) + \\ (0.0795 * 0.35) + (0.0527 * -0.37) + (0.122 * 0.03) + \\ (0.339 * 0.23) + (0.1336 * -0.82) + (0.303 * 0.61) + \\ (0.3133 * 0.13) + (0.2275 * -0.95) \end{bmatrix} = -0.85$$

Number of dependents, educational status, adult education participation, access to information, health status, land ownership, water access for irrigation, livestock ownership, use of improved crop varieties, use of improved livestock breeds, water harvesting, and practicing irrigation are the most important indicators in explaining 82.16 per cent variation of the data set (Table 3). On the other hand, key informants and focus group discussion participants have pointed out that land ownership, livestock ownership, and water access for irrigation are the most determining factors of adaptive capacity in their locality.

Agro-pastoral agro-ecosystem with adaptive capacity index of -0.85 is less adaptive when compared to highland and lowland mixed farming, and pastoral agro-ecosystems (Figure 5). Key informants and focus group discussion participants substantiated this indicating that households have less adaptive capacity, as most of them not own a farmland; most of the owned lands by few households are not suitable for irrigation as there is no water in the vicinity, and there is no credit access. In relation to this, Riché et al. (2009) asserted that Ethiopian pastoral communities are highly vulnerable as they are solely dependent on livestock, have undiversified herd composition, have poor livestock quality and productivity, have poor human health and nutrition, have weak social structures and interactions, and lack of markets.

Figure 1: Adaptive capacity index by agro-ecosystem



Source: Field Survey, 2014

Lowland Pastoral Agro-ecosystem

The results of PCA for indicators of pastoral agro-ecosystem revealed 8 components with eigenvalue greater than 1, explaining 80.51 percent of the total variation in the data set. The majority of indicators identified under adaptive capacity are positively loaded. Consequently, adaptive capacity index of pastoral agro-ecosystem (ACI_{PAES}) calculated using all positively loaded indicators of adaptive capacity (Table 3) as follows:

$$ACI_{PAES} = \begin{bmatrix} (0.1751 * 1.31) + (0.2132 * 0.86) + (0.3042 * -0.94) + \\ (0.1541 * -0.8) + (0.2133 * -0.65) + (0.0879 * -0.92) + \\ (0.0728 * -1.19) + (0.2879 * -0.1) + (0.2582 * -0.49) + \\ (0.3007 * -0.51) + (0.0007 * -0.53) + (0.083 * 1.12) \end{bmatrix} = -0.52$$

Table 3 shows that marital status, number of dependents, educational status, access to information, health status, mobile phone possession, saving, and availability of non-agricultural income source are the most important indicators in explaining 85.19 per cent variation of the data set. On the other hand, key informants and focus group discussion participants have pointed out that livestock ownership and mobility are the most determining factors of adaptive capacity in their locality.

Pastoral agro-ecosystem with adaptive capacity index of -0.52 is less adaptive when compared to lowland and highland mixed farming agro-ecosystems though it is more adaptive as compared to agro-pastoral agro-ecosystem (Figure 5). Key informants and participants in focused group discussion substantiate this indicating that households of these areas have less adaptive capacity as no households own a farmland and have no credit and market access to diversify their livelihood strategies. In connection to this, Kassa et al. (2005) has indicated that pastoralists have little market outlet to sell their animals or are forced to sell them at lower prices particularly during drought. This makes them unable to restock their livestock after the drought or to use the money for other livelihood improving purposes.

Sensitivity

Highland Mixed Farming Agro-ecosystem

PCA results for indicators of highland mixed farming agro-ecosystem revealed 2 components with eigenvalue greater than 1, explaining 63.48 percent of the total variation in the data set. Sensitivity index of the highland mixed farming agro-ecosystem ($SI_{HLMFAES}$) calculated using all sensitivity indicators (Table 4) as follows:

$$SI_{HLMFAES} = \begin{bmatrix} (0.5354 * 1.05) + (0.4982 * -1.13) + (-0.4785 * -1.24) + \\ (-0.0514 * 0.83) + (0.4834 * -1) \end{bmatrix} = 0.07$$

Crop failure, livestock death, water scarcity, and conflict occurrence are the most important indicators in explaining 63.48 per cent variation of the data set (Table 4). On the other hand, key informants and focus group discussion participants have pointed out that food shortage is the most determining factor of sensitivity in their locality.

Highland mixed farming agro-ecosystem with a sensitivity index of 0.07 is less sensitive when compared to lowland mixed farming, agro-pastoral and pastoral agro-ecosystems (Figure 6). The possible reason might be highlanders are not usually encountering conflict like pastoralists and agro-pastoralists do with lowlanders for water and pasture. However, key informants and focus group discussion participants from highland mixed farming agro-ecosystem argued that households are highly sensitive to climate change impacts particularly during drought, as most of the households in their locality are suffering from crop failure and then food insecurity. A study, which was conducted by Bewket (2012), has indicated that climate change is making households sensitive in highland areas of Ethiopia by affecting crop production in many ways through changing the length of growing period, creating moisture stress and occurrence of pests and diseases, which in turn results in crop failure.

Table 4: Factor scores of the first principal component of sensitivity indicators by agro-ecosystem

Sensitivity indicators	Factor scores of households in agro-ecosystems			
	Highland mixed farming	Lowland mixed farming	Lowland Agro-pastoral	Lowland Pastoral
Crop productivity reduction/loss: facing crop failure	0.5354	0.4367	0.6380	na
Livestock productivity reduction/death: facing livestock death	0.4982	0.6127	0.0725	0.4561
Water scarcity: facing water scarcity	-0.4785	-0.3420	-0.0691	-0.2808
Food shortage: facing food shortage for 3 months and above	-0.0514	-0.0888	-0.3488	0.6076
Conflict occurrence: facing conflict	0.4834	0.5559	0.6792	0.5865

Source: Field Survey, 2014
na= not applicable/available

Lowland Mixed Farming Agro-ecosystem

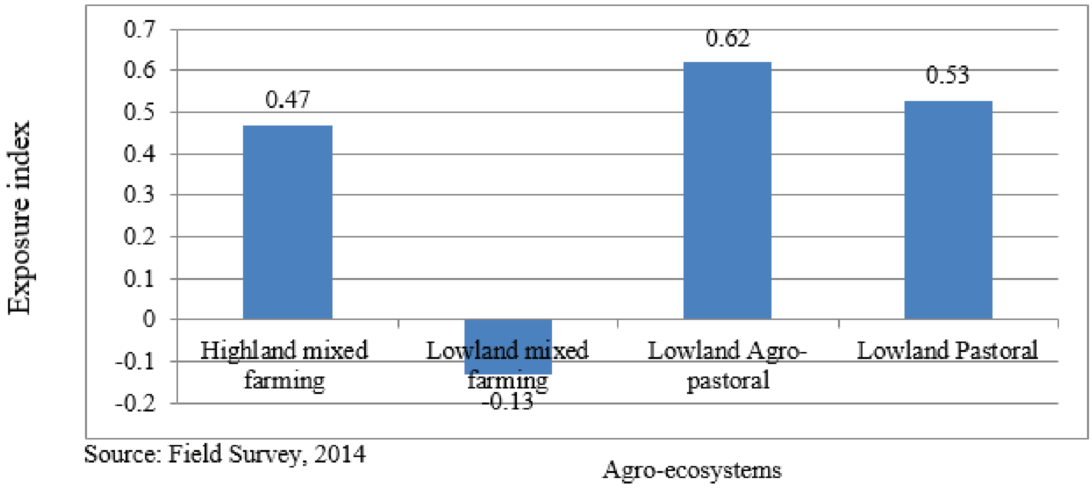
The results obtained from PCA analysis for indicators of lowland mixed farming agro-ecosystem, 2 components revealed with eigenvalue greater than 1, and explaining 57.69 percent of the total variation in the data set. Sensitivity index of the lowland mixed farming agro-ecosystem ($SI_{LLMFAES}$) calculated using all sensitivity indicators (Table 4) as follows:

$$SI_{LLMFAES} = \begin{bmatrix} (0.4367 * -0.11) + (0.6127 * -0.25) + (-0.342 * -0.39) + \\ (-0.0888 * -1.43) + (0.5559 * 0.14) \end{bmatrix} = 0.14$$

Table 4 shows that crop failure, livestock death, water scarcity, and occurrence of conflict are the most important indicators in explaining 57.69 percent variation of the data set. On the other hand, key informants and focus group discussion participants have pointed out drought is making almost all households sensitive by causing crop failure and death of their livestock intermittently. This is corresponding to what is observed currently in the study areas in which drought has caused crop failure and livestock death and consequently food insecurity due to El Nino.

Lowland mixed farming agro-ecosystem with a sensitivity index of 0.14 is less sensitive when compared to agro-pastoral and pastoral agro-ecosystems though it is more sensitive as compared to highland mixed farming agro-ecosystem (Figure 6). However, key informants from lowland mixed farming agro-ecosystem have pointed out that the majority of households in their locality are food secure and less affected by water scarcity as compared to their vicinity lowlanders making them less sensitive to climate change impacts. A study by Tesso et al. (2012) asserted that lowland mixed farming agro-ecologies are less sensitive to shocks as they do have access to irrigation, better soil fertility, and diversifying income sources.

Figure 2: Sensitivity index by agro-ecosystem



Source: Field Survey, 2014

Lowland Agro-pastoral Agro-ecosystem

The results of PCA for indicators of agro-pastoral agro-ecosystem revealed 2 components with eigenvalue greater than 1, explaining 61.44 percent of the total variation in the data set. Sensitivity index of agro-pastoral agro-ecosystem (SI_{APAES}) calculated using all sensitivity indicators (Table 4) as follows:

$$SI_{APAES} = \begin{bmatrix} (0.638 * -0.94) + (0.0725 * 0.09) + (-0.0691 * 0.85) + \\ (-0.3488 * 0.11) + (0.6792 * 1.33) \end{bmatrix} = 0.21$$

Crop failure, food shortage, and occurrence of conflict are the most important indicators in explaining 61.44 per cent variation of the data set (Table 4). On the other hand, key informants and focus group discussion participants have pointed out that livestock death due to drought is the most determining factor of sensitivity. In relation to this, Riché et al. (2009) asserted that drought is causing decreased pasture availability, decreased water availability, decreased livestock disease resistance, decreased livestock prices, crop failure in agro-pastoral areas, food insecurity and malnutrition, increased human diseases and death, and increased conflicts over scarce resources making agro-pastoralists and pastoralists more sensitive to climate change.

Agro-pastoral agro-ecosystem with a sensitivity index of 0.21 is less sensitive when compared to pastoral agro-ecosystem though it is more sensitive as compared to highland and lowland mixed farming agro-ecosystems (Figure 6). Key informants and focus group discussion participants argued that households who are producing crops are less sensitive to climate change impacts since they are diversifying their livelihood strategies. However, others argue that households that are practicing in crop production in this agro-ecosystem are highly sensitive to climate change impacts due to rainfall variability and lack of appropriate irrigation schemes.

Lowland Pastoral Agro-ecosystem

The results from PCA analysis for indicators of pastoral agro-ecosystem show one component revealed with eigenvalue greater than 1, explaining 54.24 percent of the total variation in the data set. Sensitivity index of pastoral agro-ecosystem (SI_{PAES}) calculated using all sensitivity indicators (Table 4) as follows:

$$SI_{PAES} = \begin{bmatrix} (0.4561 * 1.29) + (-0.2808 * 0.78) + (0.6076 * 0.5) + \\ (0.5865 * -0.47) \end{bmatrix} = 0.4$$

Livestock death, water scarcity, food shortage, and conflict occurrence are the most important indicators in explaining 85.19 per cent variation of the data set (Table 4). On the other hand, key informants and focus group discussion participants have pointed out that food shortage and conflict with the neighboring Amharas are the major factors of households' sensitivity especially aggravated during drought.

Pastoral agro-ecosystem with a sensitivity index of 0.4 is highly sensitive as compared to lowland and highland mixed farming and agro-pastoral agro-ecosystems (Figure 6). Key informants and focus group discussion participants argue that households of these areas are highly sensitive to climate change impacts as they are facing livestock death due to lack of pasture and water and then food insecurity. Kassa et al. (2005) has found that the major causes of death of livestock during drought are shortage of water, feed, animal diseases, and livestock feeding on toxic plants due to feed shortage, which they do not usually take.

Exposure

Highland Mixed Farming Agro-ecosystem

The results obtained from PCA analysis for indicators of highland mixed farming agro-ecosystem show 1 component with eigenvalue greater than 1, explaining 70.63 percent of the total variation in the data set. Exposure index of highland mixed farming agro-ecosystem ($EI_{HLMFAES}$) calculated using all indicators of exposure (Table 5) as follows:

$$EI_{HLMFAES} = [(0.5247 * 0.86) + (0.6067 * -1.43) + (-0.5971 * -1.49)] = 0.47$$

Households perception to temperature increase, households perception to rainfall decrease, and drought occurrence frequency are the most important indicators in explaining 70.63 per cent variation of the data set (Table 5). Similarly, key informants and focus group discussion participants have pointed out that drought is the main factor for their exposure causing crop failure and livestock death.

Highland mixed farming agro-ecosystem with an exposure index of 0.47 is less exposed when compared to agro-pastoral and pastoral agro-ecosystems though it is more exposed as compared to lowland mixed farming agro-ecosystems (Figure 7). This is in line with findings in the previous discussions of environmental contexts of this study in which high temperature increase (2.9^0C) from 1980 to 2010 was found in Lalibela station representing the highland mixed farming agro-ecosystem. Key informants and focus group discussion participants argue that temperature is increasing and rainfall is variable for the last 20-30 years as a result most of the households are highly exposed to climate change impacts particularly drought. A study conducted by Bewket (2012) asserted that in highland areas, there is an increase in temperature and a decrease in annual total rainfall, and drought had become more frequent compared to the situation before two decades.

Table 4: Factor scores of the first principal component of exposure indicators by agro-ecosystem

Exposure indicators	Factor scores of households in agro-ecosystems			
	Highland mixed farming	Lowland mixed farming	Lowland Agro-pastoral	Lowland Pastoral
Perception to temperature: perceiving temperature increase	0.5247	0.6504	0.5774	0.6752
Perception to rainfall: perceiving rainfall decrease	0.6067	0.6428	0.5860	0.6657
Drought occurrence frequency: occurring every year	-0.5971	0.4048	0.5685	0.3177

Source: Field Survey, 2014

Lowland Mixed Farming Agro-ecosystem

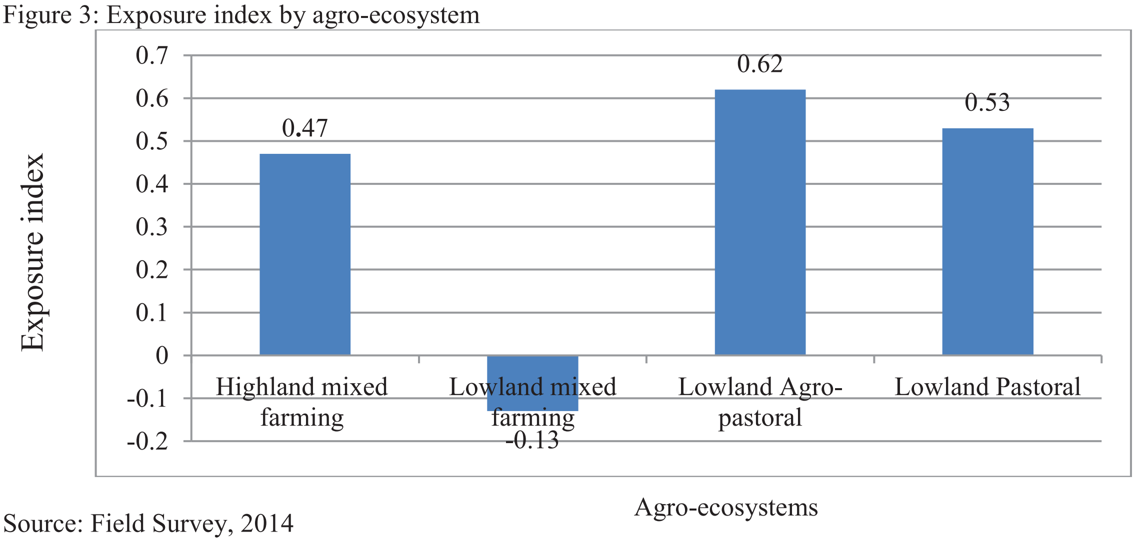
The results obtained from PCA analysis for indicators of lowland mixed farming agro-ecosystem show 1 component with eigenvalue greater than 1, explaining 47.97 percent of the total variation in the data set. Exposure index of lowland mixed farming agro-ecosystem ($EI_{LLMFAES}$) calculated using all indicators of exposure (Table 5) as follows:

$$EI_{LLMFAES} = [(0.6504 * -1.44) + (0.6428 * 0.9) + (0.4048 * 0.56)] = -0.13$$

Table 5 shows that households perception to temperature increase, households perception to rainfall decrease, and drought occurrence frequency are the most important indicator in explaining 73.49 per cent variation of the data set. On the other hand, key informants and focus group discussion participants have pointed out that frequently occurrence of drought is the most noticeable indicator of exposure causing crop failure and death of their livestock intermittently.

Lowland mixed farming agro-ecosystem with an exposure index of -0.13 is less exposed as compared to highland mixed farming, agro-pastoral and pastoral agro-ecosystems (Figure 7). This might be because of that the temperature change over 30 years in the station representing this agro-ecosystem was less than the threshold value (1^0C). Similarly, key informants and focus group discussion participants have pointed out that households in their locality are less exposed to rainfall variability or decrease as they do have better access to irrigation. However, a study by Tesso et al. (2012) asserted that families and communities are highly exposed to ever-changing and inconsistent weather affecting their livelihoods, and many have been forced to sell livestock or remove children from school as coping mechanisms that only increase the cycle of vulnerability.

Figure 3: Exposure index by agro-ecosystem



Source: Field Survey, 2014

Lowland Agro-pastoral Agro-ecosystem

The results obtained from PCA analysis for indicators of agro-pastoral agro-ecosystem revealed one component with eigenvalue greater than 1, explaining 94.16 percent of the total variation in the data set. Exposure index of agro-pastoral agro-ecosystem (EI_{APAES}) calculated using all indicators of exposure (Table 5) as follows:

$$EI_{APAES} = [(0.5774 * 0.2) + (0.586 * 0.27) + (0.5685 * 0.61)] = 0.62$$

Households perception to temperature increase and rainfall decrease, and drought occurrence frequency are the most important indicators in explaining 94.16 per cent variation of the data set (Table 5). On the other hand, key informants and focus group discussion participants have pointed out that drought is causing crop failure and death of their livestock.

Agro-pastoral agro-ecosystem with an exposure index of 0.62 is highly exposed when compared to highland

and lowland mixed farming and pastoral agro-ecosystems (Figure 7). Key informants and focus group discussion participants argue that agro-pastoralists are highly exposed to climate impacts especially during drought, as they are producing crops with highly uncertain and variable rainfall or lack of irrigation schemes, and rearing livestock with lack or shortage of pasture and water.

Lowland Pastoral Agro-ecosystem

The results obtained from PCA analysis for indicators of pastoral agro-ecosystem revealed one component with eigenvalue greater than 1, explaining 68.34 percent of the total variation in the data set. Exposure index of pastoral agro-ecosystem (EI_{PAES}) calculated using all indicators of exposure (Table 5) as follows:

$$EI_{PAES} = [(0.6752 * 0.38) + (0.6657 * 0.27) + (0.3177 * 0.31)] = 0.53$$

Households' perception to temperature increase, households' perception to rainfall decrease and drought occurrence frequency are the most important indicators in explaining 68.19 percent variation of the data set (Table 5). On the other hand, key informants and focus group discussion participants have pointed out that lack/shortage of rainfall and the resulting drought are the most important factors in exposing households to death of their livestock.

Pastoral agro-ecosystem with an exposure index of 0.53 is more exposed when compared to lowland and highland mixed farming agro-ecosystems though it is less exposed as compared to agro-pastoral agro-ecosystem (Figure 7). Key informants and focus group discussion participants argue that households of these areas are more exposed to climate change due to mainly drought. Likewise, Opiyo et al. (2014) has found that drought events are the most frequent hazards in pastoral area and had devastating impacts on household livelihoods, pasture and water, which escalates the area's chronic conflicts, insecurity and food insecurity, and undermine human and livestock population mobility, as well as development efforts.

Vulnerability

After computing and discussing the three components of vulnerability in each agro-ecosystem, the vulnerability index of highland mixed faming, lowland mixed farming, lowland agro-pastoral, and lowland pastoral agro-ecosystems is calculated. Accordingly, the vulnerability index of highland mixed farming agro-ecosystem ($VI_{HLMFAES}$) is calculated as:

$$VI_{HLMFAES} = ACI_{HLMFAES} - SI_{HLMFAES} - EI_{HLMFAES}$$
$$VI_{HLMFAES} = (0.19) - (0.07) - (0.47)$$
$$= -0.35$$

The net effect of adaptive capacity, exposure, and sensitivity is -0.35, which indicates that highland mixed farming agro-ecosystem is relatively less vulnerable from agro-pastoral and pastoral agro-ecosystems though it is more vulnerable than lowland mixed farming agro-ecosystem (Figure 8). As it was observed and discussed with key informants and focus group discussion participants, most households of highland mixed farming agro-ecosystem are highly vulnerable and food insecure. A study done by Tesso et al. (2012) asserted that the most vulnerable agro-ecology is the highland compared to midland and lowland agro-ecologies. This is due to small land size, highly fragmented farm, low productivity of land due to fertility lose, high degradation of farmlands due to steep sloping, lower level of asset building like livestock and perennial crops, and generally lower level of experience to adapt to climate change impacts (Tesso et al., 2012).

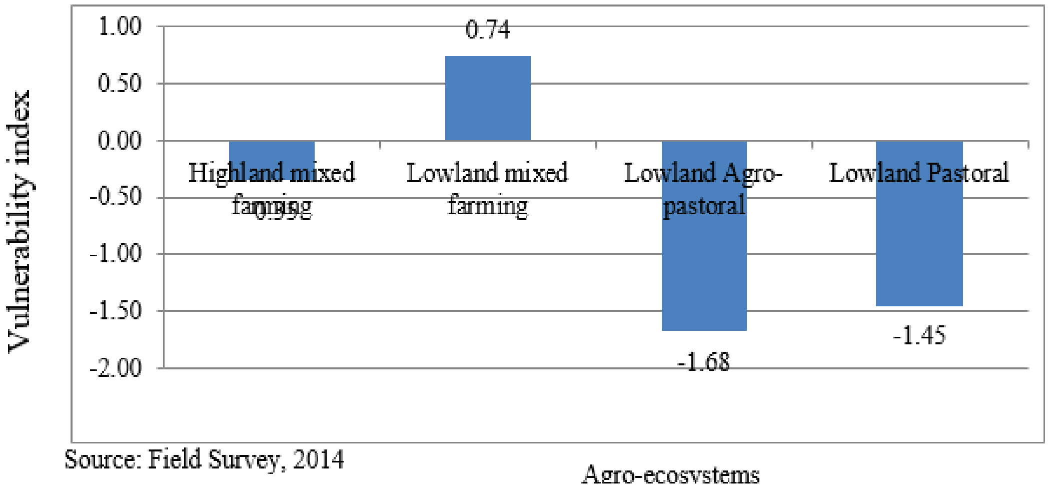
Moreover, the vulnerability index of lowland mixed farming agro-ecosystem ($VI_{LLMFAES}$) is calculated as:

$$VI_{LLMFAES} = ACI_{LLMFAES} - SI_{LLMFAES} - EI_{LLMFAES}$$

$$VI_{LLMFAES} = (0.75) - (0.14) — 0.13$$
$$= 0.74$$

The net result of adaptive capacity, exposure, and sensitivity is 0.74 that indicates lowland mixed farming agro-ecosystem is relatively less vulnerable as compared to highland mixed farming, agro-pastoral and pastoral agro-ecosystems (Figure 8). Similarly, key informants have confirmed that lowland mixed farmers are relatively less vulnerable than their adjacent highlanders, agro-pastoralists and pastoralists. A study conducted by Tesso et al. (2012) also asserted that contrary to the expectations, the lowland area was less vulnerable when compared with the midland and highland because of better experience of operating agricultural activities under stressful conditions, relatively larger farm size with optimal number of farm plots, moderate slope of farm lands, better fertility level of farmlands, better size of land under irrigation, and better adaptation to changing climatic conditions.

Figure 4: Vulnerability index by agro-ecosystem



Source: Field Survey, 2014

Furthermore, the vulnerability index of lowland agro-pastoral agro-ecosystem (VI_{APAES}) is calculated as:

$$VI_{APAES} = ACI_{APAES} - SI_{APAES} - EI_{APAES}$$
$$VI_{APAES} = (-0.85) - (0.21) - (0.62)$$
$$= -1.68$$

The net outcome of adaptive capacity, exposure, and sensitivity is -1.68 which indicates that lowland agro-pastoral agro-ecosystem is highly vulnerable from highland mixed farming, lowland mixed farming and pastoral agro-ecosystems (Figure 8). As it is recalled from the previous discussions, livestock ownership is most determining factor of households adaptive capacity and the recurring drought usually affected livestock holdings making them more sensitive. In relation to this, Kassa et al. (2005) has found that the average livestock holding of the pastoral households was 85 TLU and 21 TLU before and after drought respectively while the respective figures for the agro-pastoral households were 74 TLU and 27 TLU, which means in normal years, the pastoral households have relatively large livestock than the agro-pastoralists. This in turn makes agro-pastoralists more vulnerable than pastoralists do, which is in line with this finding. Moreover, Negatu et al. (2011) has also asserted that agro-pastoralists are more vulnerable to climate change and variability than pastoralists.

Finally, the vulnerability index of lowland pastoral agro-ecosystem (VI_{PAES}) is calculated as:

$$VI_{PAES} = ACI_{PAES} - SI_{PAES} - EI_{PAES}$$
$$VI_{PAES} = (-0.52) - (0.4) - (0.53)$$
$$= -1.45$$

The net value of adaptive capacity, exposure, and sensitivity is -1.45 which indicates that lowland pastoral agro-ecosystem is highly vulnerable from highland mixed farming and lowland mixed framing agro-ecosystems though it is less vulnerable than agro-pastoral agro-ecosystem. A study done by UN OCHA-PCI (2007) has indicated that violent conflict is often cited as having a fundamental effect on human and economic development; and pastoralists' reliance on mobility makes them particularly vulnerable to conflict and fear of conflict, which can cut off their access to key resources and block them from important markets.

In conclusion, while lowland mixed farming agro-ecosystem is more adaptive, agro-pastoral agro-ecosystem is the least adaptive. Moreover, while highland mixed farming agro-ecosystem is less sensitive, pastoral agro-ecosystem is the most sensitive. Furthermore, while lowland mixed farming agro-ecosystem is the least exposed, agro-pastoral agro-ecosystem is highly exposed. As a result, while lowland mixed farming agro-ecosystem is less vulnerable, agro-pastoral agro-ecosystem is the most vulnerable.

However, it is assumed that not all households in lowland mixed farming agro-ecosystems are less vulnerable and not all households in agro-pastoral agro-ecosystems are more vulnerable. Moreover, it is assumed that there might be up and down movement of households from one vulnerability group to the other over time. This enquires to study households in each agro-ecosystem to know the adaptive capacity, sensitivity, exposure, and vulnerability of households and the major determining factors for the movement of households from one vulnerability category to the other.

CONCLUSIONS AND POLICY IMPLICATIONS

Conclusions

Environmental contexts have influenced agro-ecosystems vulnerability to climate change. For instance, above 1^0C temperature increase which is a threshold level (IPCC, 2014) is found in Lalibela and Dubti stations during the last 20-30 years showing that such temperature increase has caused different negative impacts in the study areas.

Lowland mixed farming agro-ecosystem is less vulnerable since it is the most adaptive and the least exposed compared to others. By contrast, agro-pastoral agro-ecosystem is most vulnerable because it is the least adaptive and the highly exposed when compared to others. A study conducted by Tesso et al. (2012) also confirmed that lowland agro-ecology is less vulnerable compared to midland and highland agro-ecologies because of better experience under stressful conditions, larger farm size ownership, better fertility level of farmlands, and better size of land under irrigation.

Policy Implications

The results imply that exposure of a locality to long term changes in climate variables and occurrences of drought is the most important component to determine the overall vulnerability of the locality. However, biophysical elements determining the exposure like temperature, rainfall and drought are beyond the immediate influence of the policy makers. Of the three components of vulnerability, adaptive capacity has direct policy implications though improving the adaptive capacity also has indirect implications on improving the sensitivity of the community. For example, improving the irrigation schemes in a certain locality/agro-ecosystem decreases the crop failure due to droughts. Similarly, creating opportunities for non-farm income in different agro-ecosystems reduces the extensive dependence of households on natural resource based livelihoods, thereby reducing their sensitivity towards climate change and its extremes like drought. Thus, improving the adaptive capacity of these vulnerable households reduces their sensitivity and finally decreases their overall vulnerability. Hence, the concerned organs should work jointly to improve the adaptive capacity of households/agro-ecosystems in the study sites.

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