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Research Article

Vulnerability of mountain communities to climate change and natural resources scarcity in Northwest Ethiopia: the case of Debark Woreda

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Abstract: In recent decades, climate change causes distressful shocks upon the poor people's natural resources and socio-economic processes from local up to global scales. The crisis is more severe in Ethiopia, where harsh ecological changes are frequent. Therefore, the objective of this study was to determine the vulnerability levels of rural communities to climate change and natural resources scarcity in Debark woreda, Northwest Ethiopia. Livelihood Vulnerability Index (LVI) and IPCC methods were used to analyze the data. The meteorological data reveal a declining precipitation trend by 61.13 mm in the past 31 years whilst maximum and minimum temperatures increased by 0.62 ^{0}C and 0.74 ^{0}C respectively. The LVI result indicates that the Debark community is highly vulnerable with land (0.59) and forest (0.57) scarcity. Water scarcity (0.50) and climate exposure (0.30) put them in a vulnerable class. Both the total LVI (0.48) and LVI-IPCC (-0.69) approaches placed the woreda community again in a vulnerable position. The findings imply that climate change should be placed within the broader context of development strategy and rural poverty reduction. Particularly, concerted efforts should be exerted to participatory integrated watershed management strategies supported with farmers training to ensure sustainable development of natural resources. Farmers' best natural resource conservation practices should be incorporated in the local plans.

Keywords: *climate change, Debark woreda, Ethiopia, livelihood vulnerability index, natural resource scarcity, vulnerability*

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Introduction

Communities of developing countries whose livelihoods depend on climate sensitive natural resources are drastically threatened by climate change-induced stresses (Adger et al., 2003; IPCC, 2007, 2013; Houghton, 2009). The effect of climate change is found to be more severe in low-latitude, developing countries due to their geographical location, the greater share of rain-fed agriculture in their economies, limited adaptive capacity, and changing environmental conditions (National Meteorology Service Agency of Ethiopia /NMSA, 2007). Africa is the most vulnerable region notably exposed to the impact of climate variability and climate change (Gebreegziabher et al., 2016). The continent is characterized by nature-dependent livelihoods, indicating that it is disproportionally hit by climate change-induced shocks. In this regard, IPCC (2007) assessment underlined that climate change is expected to expose 75 to 250 million people to water stress by 2020. In addition, by 2020 there will be a significant reduction in arable land and, yields from rain-fed agriculture will decline up to 50% (IPCC, 2007). Interaction of multiple stresses and limited adaptive capacity of most households in rural Africa also exacerbate the extent of vulnerability to climate change (Gebreegziabher et al., 2016).

Ethiopia is one of these fragile countries that experience an amplified effect on livelihoods of its population particularly, small-scale subsistence farmers and pastoralists are the most vulnerable social groups to the impact of climatic hazards like droughts, floods, desertification and hailstorms. A steady change in climate, broadcasted in case of extreme events, is currently undergoing increased stress with the threat of irreversible damage (NMSA, 2007; Deressa, 2010). Therefore, climate change is a case for concern in Ethiopia. As part of the fragile landscape of northern Ethiopia, communities in Debark woreda (district) have limited capacity to bounce back themselves from threats of climate change and extreme events. Consequently, a food self-sufficient woreda once a time has now become food insecure. Drought, flood, intensified storms and frost are more extreme hazards transpire in the woreda with severe effects on land, water and forest resources. In extreme cases, some administrative units in the woreda are forced to remain under food aid.

Most of the previous studies indicate the current reality of precipitation decline and temperature rises (Deressa, 2010; Gebreegziabher et al, 2016). Though these studies provide some useful insights in the area of vulnerability, perception and possible adaptation options, and reflect the current efforts to understand the relationship between climate change and vulnerability, most of them are at the aggregate level and hence have little policy relevance at the micro-level. In addition, to what extent the farming communities' are vulnerable to climate change and natural resource scarcity were not investigated in the context-specific nature of vulnerability and adaptation (Ford et al., 2010). The objectives of this study are: first, to construct individual sector's vulnerability indices for farming communities; and, second, to assess overall vulnerability and compare the extent across different sectors (land, water, forest and climatic exposure) in Debark woreda, Northwest Ethiopia.

Study Area

Debark woreda (district) is located in Amhara Regional State, Northwest of Ethiopia at a road distance of 282 kilometers north of Bahir Dar, the capital of Amhara Regional State, and 830 km northwest of Addis Ababa, the capital city of Ethiopia (Bekele and Melaku, 2016). The woreda is situated in 13^0 08 N - $13^0$30 N latitudes and $37^0$30 E - $38^0$15 E longitudes (see Figure 1). The total area of the woreda is 282,105 hectares (282.105 km^2) having 32 Kebele Administrations/KAs (39 rural and 3 urban KAs). Debark is bordered by Adi-Arkay woreda in the north, Dabat in the south, Jan-Amora in the east and Tegedie in the west (Mengistu and Herbert, 2010; Bekele and Melaku, 2016). This Wereda is crossed by the Limalimo Mountains, which form the western end of the Simien Mountains and the rivers include the Zarima.

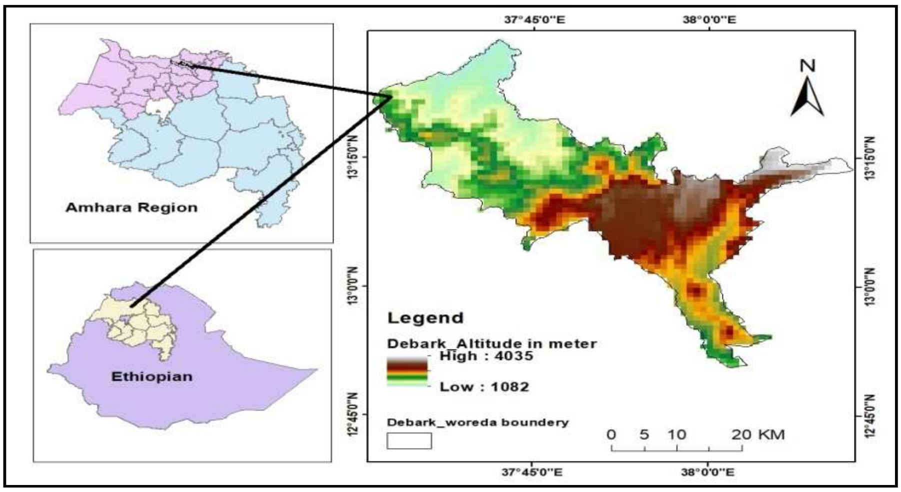

Figure 1. Location of Debark Woreda in the State and National Setting [Own Map]

The landscape of the woreda is the result of geomorphologic processes and volcanic eruptions over the geological history of the area. It was built up by the trap series lava flow of the tertiary period of the Cenozoic era. Broken topography is typical for the area with altitudes ranging from 1082-4035 m a. s. l (refer to Figure 1). Endemic animals, plants, birds and the beautiful land scenery of the area have contributed in attracting tourists (Hurni, 1986; Mengistu and Herbert, 2010). The topography, vegetation and rainfall pattern in the Wereda allows the existence of many perennial rivers. In Debark Wereda, there are many small and large rivers (Asere, Belegeze, Araro, Abera and Chlu, Lome, Meytmket, Mneguro, Serakeba) that have been providing water for traditional irrigation. According to the meteorological records, large portion of the area receives high annual rainfall ranging from1000 to 2000 mm in the main and short rainy seasons. The mean annual temperature ranges from 8.95 ^{0}C to 21.14 ^{0}C.

Similar to most parts of Ethiopia the woreda population practices mixed production system with both crop and livestock rearing. Crop production is mainly rainfed, except in a small number of localities where small-scale water harvesting processes have been recently introduced by the office of Agriculture. From the total land area of the woreda, 25.8% is under cultivation for growing both annual and perennial crops, while the remaining is grass and bare lands (35.4%), pastureland (30.8%) and forest cover (6.7%) (Mengistu and Herbert, 2010).

Materials and Methods

Research and sample design

The study employed cross-sectional research design and repeated time series meteorological records over the period 1980 -2010. Given that Debark woreda is vast having diverse features it is hard to conduct a full survey in all Kebele Administrations (KAs - the lower administrative unit next to district). Thus, this study used a multi-stage sampling technique to select the sample areas, KAs, and sample households. At the first stage, Debark woreda was selected purposely due to its highly undulated topography and frequent susceptibility to extreme events. In the second stage, three KAs were selected purposely based on the above-listed woreda selection criteria, namely Abergina, Abraham and Sera-midirgemes. In the third stage, sample households were drawn using simple random sampling technique from each sample area. Climate change affects the rural communities differently in different places and so levels of vulnerability and people's knowledge and skill vary from place to place.

The authors determined a total of 200 sample households from the three sample KAs. Then, these 200 households were proportionally allocated to each KA to make equal representation of households based on the formula of Yemane (1967) cited in Israel (1992). The formula allocated 83 sample households for Sera-midirgemes, 68 for Abraham and 49 for Abergina KAs. Based on Kothari and Garg (2014), in stratified sampling, the method of proportional allocation under which the sample size from different strata are kept relative to the sizes of the strata.

Data collection

This research used both secondary and primary data sources. The secondary and primary data sources were both quantitative and qualitative in nature. The sources of secondary data were published books, academic journals, and other research works, unpublished documents from Offices of Agriculture, Environment, and National Meteorological Service Agency of Ethiopia (NMSA). The 31 years daily and monthly precipitation and temperature records were gathered from NMSA Bahir Dar Branch for Debark town helped to analyze climatic trends, variability, and exposure indices in the study area over the period of 1980 to 2010. Besides, perception and observations of people on climate change were triangulated with existing scientific data on climate change. Primary data were collected using household questionnaire survey, interview and field observation.

Household survey: The household survey was used to collect quantitative data on natural assets and climate related hazards. The questions were prepared on the basis of the indicator method in terms of four major components: land, water, forest and climate elements. The actual household survey was conducted in the period between January and March 2013. Most of the household heads were contacted on the homesteads and a few of them were consulted on weekends, holidays and other community gathering places. Pre-testing was also done to evaluate in advance whether a questionnaire causes problems for interviewers or respondents. This study conducted pilot testing with 10% from 200 households drawn from the three study sites. Necessary modifications were made based on the comments obtained from the pilot responses.

Key informants interview (KII): The purpose of the key informant interview was to get data/information on the problems of natural resources in the woreda, climate change impacts on crop production, and frequency of climatic exposures such as drought, flood, water supply constraints, crop pests and diseases, soil erosion, and other attributes in the past ten years. Key informants included experts from agriculture offices and environmental protection office of the woreda.

Field observation: Field observation was conducted in all the KAs in order to gain better insights into the selected study sites using field notes and camera. Attentions were given to flood and erosion prone areas, settlement patterns, major land use and indigenous land management strategies, water schemes, protected areas, major livelihood activities, severity of damage on land, water and forests as well as location in hazard prone site, among others. The use of this qualitative data gathering method is recognized by Creswell (2012) stating that qualitative inquiries triangulate among different data sources to enhance the accuracy of a study. The researchers examine each information source and find to support a theme. This ensures the accuracy of the information collected from multiple sources of information.

Methods of analysis

The data gathered through different tools were analyzed using different analytical techniques. The descriptive statistics such as frequencies, percentage, mean, maximum, and minimum values were used to summarize and categorize the information gathered. Simple linear regression to see the tendency of long-term temperature and rainfall was used. Linear regression applies a best fit straight line to display simple linear datasets that contain data values that increase or decrease at a steady state. This type of trend line uses the following linear equations to calculate the least square fit for a line using MS Excel:

$$Y = B_X + c \quad [1]$$

Where: Y is physical factor (change in temperature and rainfall); B is slope of the regression equation; X is number of years from 1980-2010 (31 years), and C is regression constant.

The standardized precipitation index (SPI) was used to analyze rainfall anomalies and identify droughts (duration, magnitude and intensity) across the years during 1979 to 2010. The SPI is a statistical measure used to indicate unusual events and droughts strength. Rainfall anomaly is calculated by:

$$SPI = \frac{X - \bar{X}}{\sigma} \quad [2]$$

Where: SPI refers to rainfall anomaly (precipitation deficit) over the years; X is the observed rainfall in the year (1980-2010), $\bar{X}$ refers the mean annual rainfall over the years, and σ refers the standard deviation of rainfall over the years.

McKee et al.(1993) defined the criteria for a “drought event” for any of the time steps and classified the SPI to define various drought intensities. In their classification, a drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less.

Calculating the vulnerability indices

There are two broad approaches to empirically calculating vulnerability: econometric and indicator methods. The former expresses vulnerability as expected poverty, low expected utility and uninsured exposure to risk mostly using panel data sets (Hoddinott and Quisumbing, 2008), which is a handicap in the developing countries like Ethiopia. The latter tries to assess vulnerability by integrating indicators to form a composite index, which can be at a local level (Hahn et al. 2009; Gebreegziabher et al., 2016; Teshome, 2016a, 2016b), national level (Cutter et al., 2003; Gbetibouo and Ringler, 2009; Heltberg and Bonch-Osmolovskiy, 2011) or global level (Moss et al., 2001; Brooks et al. 2005). The basic challenge in constructing indices is the lack of standard ways of assigning weight to each indicator.

The two most common weighting methods used to combine indicators are equal and unequal weighting schemes. The former method assigns equal weight to each indicator. The latter method assigns different weights to various indicators using expert opinion, complex fuzzy logic, or a principal component analysis (Hahn et al., 2009; Gebreegziabher et al., 2016). In this study, we used an integrated approach to construct a composite vulnerability index based on weighting average schemes.

Overall vulnerability is calculated as the net effect of adaptive capacity, sensitivity and exposure. Following (Moss et al., 2001; ICRISAT, 2006; Hahn et al., 2009; Teshome, 2006a; 2006b), we constructed the indices using functional relationships of indicators with vulnerability because their impact is assumed to be either positive or negative. In doing so, factors which are listed under adaptive capacity are assigned positive functional relationships, on the assumption that people with higher adaptive capacity are less sensitive to damages from climate extremes and variations, keeping the level of exposure constant. On the other hand, variables posing negative impact on the systems have positive functional relationships with vulnerability (see Tables 1 and 2). Calculating the vulnerability score is a three-step process where the indicators are first calculated followed by average scores for the major components and ultimately, the final composite index scores for the study area (Hahn et al., 2009; Teshome, 2016a, 2016b). This approach presents a framework for grouping and aggregating indicators in the woreda level. Primary household data helps to avoid pitfalls of using secondary data. Another noticed advantage is reduction of dependence on climate models, which still presented in a larger geographical scale to provide accurate projections and useful for community development and adaptation planning (Sullivan and Meigh, 2006; Hahn et al., 2009).

Table 1. Vulnerability indicators and sub-indicators

Components	Individual indicators	Functional relationship with vulnerability
	Landholding size in hectare	Small holding size indicate high vulnerability
	Percent of HHs reported high rate of soil erosion	High percentage indicate high vulnerability
Land	Percent of HHs having farmlands in sloppy area	High percentage indicate high vulnerability
	Average slope of Debark woreda in percent	The steeper the slope, the high the vulnerability
	Percent of HHs reported poor fertility of farmland	High percentage indicate high vulnerability
	Percent of HHs didn't get land managing training	High percentage indicate high vulnerability
	Percent of HHs who didn't practice SWC measures	High percentage indicate high vulnerability
	Productivity of farmlands per hectare in index	Low productivity indicates high vulnerability
	Percent of HHs who use only fire wood for cooking	High percentage indicate high vulnerability
	Percent of HHs who depend on firewood for lighting	High percentage indicate higher vulnerability
Forest	Average time to source of firewood in minute	Long distance indicates high vulnerability
	Percent of HHs who didn't practice of tree plantation	High percentage indicate high vulnerability
	Percent of HHs who didn't get forest managing training	High percentage indicate high vulnerability
	Trend of forest cover over the past 10 years in index	Lowest cover indicates high vulnerability
	Percent of HHs using water from unprotected sources	High percentage indicates high vulnerability
	Percent of HHs who haven't regular water supply	High percentage indicate high vulnerability
Water	Percent of HHs reporting water conflict	High percentage indicate high vulnerability
	Average time to reach water source in minute	Long distance indicates high vulnerability
	Percent of HHs having no access to irrigation water	High percentage indicate high vulnerability
	Percent of HHs didn't get water management training	High percentage indicate high vulnerability
	Average number of drought during last 10 years	Higher frequency indicates high vulnerability
	STDEV of maximum temperature by year (1980-2010) ^{0}C	High standard deviation imply high vulnerability
Climate	STDEV of maximum temperature by month (^{0}C)	High standard deviation imply high vulnerability
Exposure	STDEV of minimum temperature by year (^{0}C)	High standard deviation imply high vulnerability
	STDEV of minimum temperature by month (^{0}C)	High standard deviation imply high vulnerability
	Average annual precipitation (mm)	The lower the rainfall the higher the vulnerability
	STDEV of rainfall by month (mm)	High standard deviation imply high vulnerability
	STDEV of rainfall by year(1980-2010) mm	High standard deviation imply high vulnerability
	Magnitude of droughts based on Standardized Precipitation Index	The higher the drought magnitude, the higher the vulnerability

Based on Hahn et al., 2009, Teshome, 2016a, 2016b) * STDEV – standard deviation

Table 2. Hypothesized functional relationship of indicators to vulnerability

Factors of Vulnerability	Indicators	Hypothesized relationships to vulnerability
Adaptive Capacity	Farmland size of the household	Adaptive capacity ↑ as land size ↑ vulnerability ↓
	Crop yield trend stability index	Adaptive capacity ↑ as crop yield stability ↑ vulnerability ↓
	HHs who have access to water for irrigation	Adaptive capacity ↑ as accessed WI ↑ vulnerability ↓
	Land, water and forest management training	Adaptive capacity ↑ as land, water & forest magt. ↑ vulnerability ↓
	HHs who practice soil conservation methods	Adaptive capacity ↑ as soil conservation methods ↑ vulnerability ↓
	HHs who use battery for lighting	Adaptive capacity ↑ as HHs use battery for lighting ↑ vulnerability ↓
	HHs farmland located in sloppy areas	Sensitivity ↑ as population at risk ↑ vulnerability ↑
Sensitivity	Average slope of the woreda in percent	Sensitivity ↑ as slope of the area ↑ vulnerability ↑
	HHs who own infertile farmland	Sensitivity ↑ as own infertile land ↑ vulnerability ↑
	Decreasing trend of forest cover	Sensitivity ↑ as forest cover ↓ vulnerability ↑
	Time to needed reach source of firewood	Sensitivity ↑ as distance to firewood source ↑ vulnerability ↑
	HHs who use water from unprotected sources	Sensitivity ↑ as population utilize unprotected water ↑ vulnerability ↑
	HHs haven't access to regular water supply	Sensitivity ↑ as population without regular water supply ↑ vulnerability ↑
	Time needed to reach drinking water sources	Sensitivity ↑ as distance to water sources ↑ vulnerability ↑
	Decreasing trend of farmland productivity	Sensitivity ↑ as farmland productivity ↓ vulnerability ↑
Exposure	HHs reported very high farmland erosion	Exposure ↑ as population at risk from erosion ↑ vulnerability ↑
	STDV of mean maximum temp. by year and month	Exposure ↑ as deviation of mean maximum temperature ↑ vulnerability ↑
	STDV of mean minimum temp. by year and month	Exposure ↑ as deviation of mean minimum temperature ↓ vulnerability ↓
	Average annual precipitation (mm)	Exposure ↑ as precipitation ↓ vulnerability ↑
	Drought magnitude based on standardized ppt index	Exposure ↑ as drought magnitude ↑ vulnerability ↑
	STDV of rainfall by month and year	Exposure ↑ as deviation of monthly rainfall ↑ vulnerability ↑
	Hazard frequency over 10 years	Exposure ↑ as Hazard frequency ↑ vulnerability ↑
	HHs reported resource conflicts in their locality	Exposure ↑ as conflict in resources ↑ vulnerability ↑
	HHs who do not practice tree plantation	Exposure ↑ as the practice of afforestation & reforestation ↓ vulnerability ↑
	HHs who use fire wood for cooking	Exposure ↑ as HHs use firewood for cooking ↑ vulnerability ↑

Source: Hahn et al., 2009; Teshome, 2016a, 2016b HHs – Households; ppt – precipitation

Tables 1 and 2 outlined the vulnerability indicators and their functional relationships with vulnerability. These indicators were converted into index scores by the following equation [3] (Kaly et al., 1999; Hahn et al., 2009):

$$V_i = \frac{X_i - \text{Min } X_i}{\text{Max } X_1 - \text{Min } X_i} \quad [3]$$

Where: V_i = measure of vulnerability contributed by the i^{th} indicator in the study area, X_i = numerical value of the i^{th} indicator, Min and Max X_i = minimum and maximum value of the i^{th} indicator being compared with other variables.

This method of normalization considers the functional relationship between vulnerability and the predictor variables (refer Table 1 and 2). Two types of relationship are identified: vulnerability increases with the increase (decrease) in the value of the indicator (ICRISAT, 2006). In this case the formalization was done using Equation [3]. For these types of variables, the average values are taken to represent the observed values. For variables that measure frequencies of events, the minimum value is set at 0 and the maximum at 100. For indicators, which assumed to have negative relationship with vulnerability, the inverse scoring technique was used to formalize each indicator's value using Equation [4] based on Kaly et al. (1999), ICRISAT (2006) and NMSA (2007).

$$V_i = \frac{\text{Max } X_i - X_i}{\text{Max } X_i - \text{Min } X_i} \quad [4]$$

After normalizing each predictor variable, they were averaged by the following equation [5] to determine the value of each major contributing factor to vulnerability.

$$MV_i = \frac{\sum_{i=}^{n} 1\, V_i}{n} \quad [5]$$

Where: MV_i is mean vulnerability index for a given component (land, water forest and climatic exposure indicators) in the LVI approach and exposure, sensitivity and adaptive capacity in case of IPPC approach; V_i index of individual vulnerability indicator represented by i, and n is the number of sub-indicators. Once the values for each major component calculated, they were aggregated using the following equation to obtain woreda level livelihood vulnerability index.

$$LVI = \frac{\sum_{i=}^{4} NI\, MI}{\sum_{i=}^{4} NI} \quad [6]$$

Where: LVI is livelihood vulnerability index for the woreda; NI is weights of each major component (Number of indicators in each sector) and MI is index value of the major component.

The second approach aggregates the four major components into IPCC's three contributing factors to vulnerability − exposure, sensitivity, and adaptive capacity. Table 2 grouped proxies based on the IPCC framework to calculate indices for exposure, sensitivity and adaptive capacity and then the overall vulnerability status of the study area. Once simple average index-scores for exposure, sensitivity and adaptive capacity components were calculated by equation [3], woreda level composite vulnerability index score was constructed using Equation [7]:

$$\text{Vulnerability} = (\text{Adaptive Capacity}) - (\text{Sensitivity} + \text{Exposure}) \quad [7]$$

Note that in Equation (7) a higher net value indicates lesser vulnerability and vice-versa.

In this study, LVI scaled from 0 (least or no vulnerability) to1 (most vulnerable) (Hahn et al., 2009); whereas LVI-IPCC scaled from -1 (most vulnerable) to 1 (least vulnerable) (Gebreegziabher et al. (2016). This LVI in turn, is classified into four vulnerability classes based on Getnet (2010). Vulnerability classes are depicted in Table 3 below:

Table 3. Classes of vulnerability

No.	Classes of vulnerability	Classes of indices
1	Less vulnerable	0.097 – 0.2347
2	Moderately vulnerable	0.2348 – 0.3715
3	Vulnerable	0.3716 – 0.5083
4	Highly vulnerable	0.5084 – 0.6452

Statistical package for social sciences (SPSS) instat (3.36) climate processing software and Microsoft excel were the main tools to analyze the collected quantitative data.

Results and Discussion

Temperature

The results of the meteorological data show that the mean annual, maximum and minimum temperatures by 0.62 ^{0}C and 0.74 ^{0}C in the study area had been in a warming trend for the last three decades (1980 to 2010). This finding is consistent with the result of the household survey in that 90.5% of the respondents reported a warming temperature trend in the past 20 years. In addition to increasing temperature trend, greater temporal variability was observed in the study area over the same period (1980-2010). The deviation was calculated using the SPI formula based on Mongi et al. (2010).

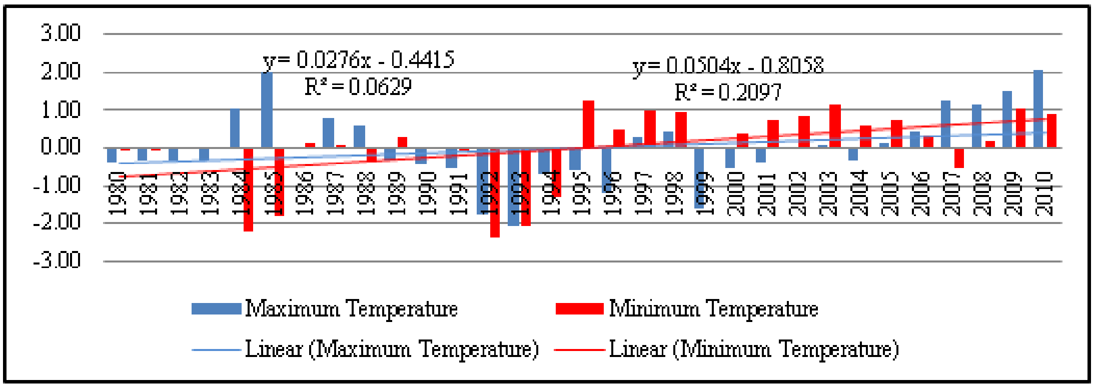

Figure 2. Long-term maximum (Tmax) & minimum temperature (Tmin) deviations in Debark Woreda

Figure 2 demonstrates the maximum and minimum temperature deviation from the long-term average temperature in Debark woreda from the period 1980 to 2010. It is clear from the figure that from 1980 to 1983 there was no important deviation both in maximum and minimum temperatures from the long-term average temperature. In 1984 and 1985 the maximum temperature deviations went up while the minimum temperature deviations went down. From 1986 to 1991 both maximum and minimum temperatures oscillate around the long-term mean while from 1992 to 1994 both of the deviations went down ward. In 1995 the maximum temperature deviation went up whilst the minimum one went down. From 1996 until 2001 temperature deviations continued with fluctuation. In 2002 and 2003 the maximum temperature deviations was found to be similar with the long term average whereas, the minimum temperature deviation slightly went up wards from the long-term average temperature. In most of the years since 2004 both maximum and minimum temperature deviations showed increasing trend with greater fluctuations over time.

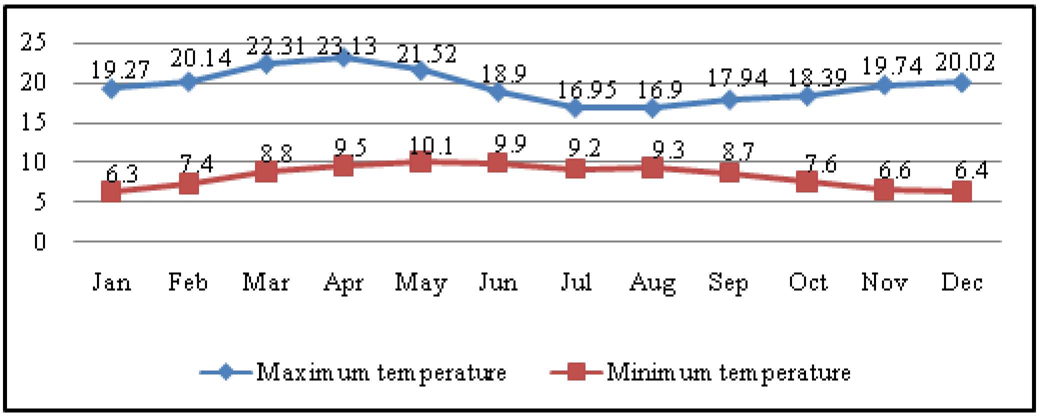

Figure 3. Monthly mean minimum and maximum temperatures (1979 -2010)
[Own work from NMSA, 2012].

The highest mean maximum temperatures were recorded in *Belg* (small rainy) season, namely in March (22.31^{0}C), April (22.13^{0}C) and May (21.52^{0}C). And the highest mean minimum temperatures of 9.5 ^{0}C, 10.1^{0}C and 9.9^{0}C were also recorded in the months of April, May and June respectively [refer to Figure 3]. So, the result is consistent with the report of NMSA (2007), which states that almost the highest mean maximum and minimum temperatures were recorded in the *Belg* season of Ethiopia. The direction of the temperature in the study area was found in line with a study in Tabora by Mongi *et al*. (2010) and study in Ethiopia by Teshome (2016a, 2016b, 2017) which found out that both minimum and maximum temperature show increasing trends. Also, the results differ from that of Shinyanga rural District study by Lyimo and Kangalawe (2010) who reported that both minimum and maximum temperature showed an increasing trend but the minimum temperature increased sharply while the maximum temperature increased gradually. This implies that different areas experiencing similar climatic conditions can experience changes in climate differently.

The finding indicates the seriousness of climate change manifested in temperature rise seeks serious attention in recent decades. Consistently, IPCC (2007) and NMSA (2007) indicate that there has been a very high warming and variable temperature trend over time. IPCC (2013) added that globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85 [0.65 to 1.06] °C, over the period 1880–2012, when multiple independently produced datasets exist. The total increase between the average of the 1850–1900 period and the 2003–2012 period is 0.78 [0.72°C to 0.85” °C] based on the single longest dataset.

Rainfall anomaly

Based on the rainfall data obtained from NMSA of Ethiopia, which was analyzed using simple linear regression model, the total annual rainfall shows a declining trend in the past 31 years [1980-2010] with 61.13 mm and 19.10 mm per decade in Debark woreda. The results showed temporal variability in amount and distribution of rainfall. Besides a significant decrease in rainfall, there is also problem in timing (late onset and early cessation) and falling in intense episodes in very short duration. This result is in line with the perception of the respondents and interview participants which agree with the decreasing tendency of the rainfall. About 50.5% of the respondents reported that rainfall showed a decreasing trend in the past years while 46.5% of them reported late onset and early offset of rainfall. In addition, the woreda natural resource expert expressed that early offset of rainfall is the main problem for some years exposing the area to shortage of precipitation that leads low land productivity. In addition to the rainfall trend, drought analysis was done using standardized precipitation index (SPI). The SPI results illustrated in Figures 4 show the long-term drought patterns for the study area.

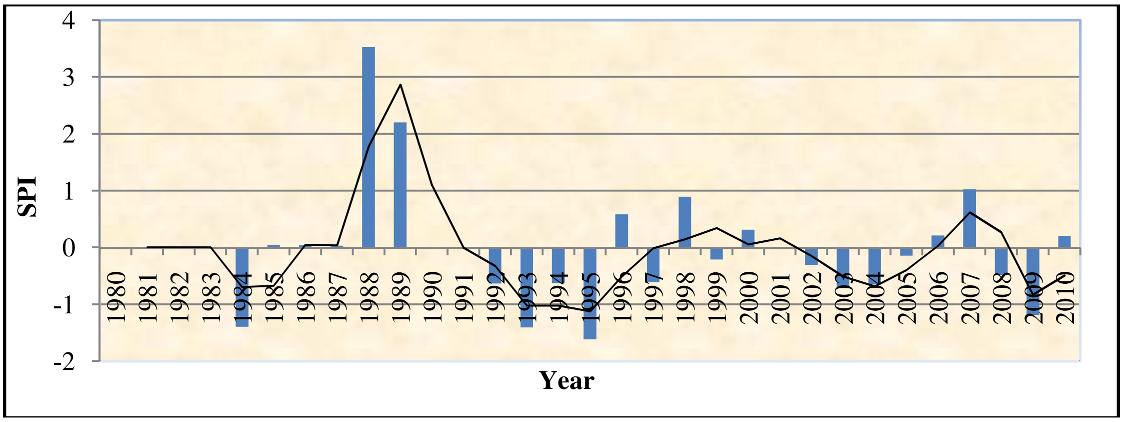

Figure 4. Standardized precipitation index for Debark woreda (1980–2010) [Authors ‘own work from NMSA, 2012].

Figure 4 shows the standardized precipitation index for Debark woreda. It is clear from the figure that the rainfall shows fluctuation of wet and dry years in a periodic pattern. From 31 years of observation, 14 years (45.16%) received below the long-term average rainfall whilst 12 years obtained above average. The years 1980 to 1983, 1985 to 1987, 1990 to 1991 received normal rainfall. Consecutive negative SPI values were observed from 1992 to 1995 followed by a recovery in 1996. The rainfall went down in 1997 and went up in 1998 followed by slight decline in 1999 and again small increase in 2000. Rainfall had reduced in amount from the years 2002 to 2006 and become positive in 2006 and 2007 while fall down in 2008 and 2009 with a small improvement in 2010. The 1984, 1993, 1995 and 2009 rainfall amounts emerged as the lowest records in the observation period, marking the moderate and severe drought years in the study area. The high SPI values indicate surplus rainfall and may be associated with flood years though there is no standard to classify the years in relation to flood occurrence. We can deduce that the year 1988 stands first by the probability of flood occurrence followed by 1989, 2007 and 1998 in order of importance (refer to Figure 4).

Table 4 presents the statistical analysis of daily precipitation data (1980 - 2010) with 11,322 daily records. It is clear from the Table that month to month rainfall variability is considerable across the years in Debark Woreda. July (11.4266) and August (10.8454) had the highest standard deviation in the study area. The highest amount of average monthly rainfall was also recorded in July (511.65 mm with 30.94 average rainy days/PCPD) followed by August (465.62 mm with 30.9 PCPD), while the lowest was recorded in December (2.38 mm with 3.58 PCPD) closely followed by January (4.28 mm with 3.94 PCPD) and February (6.35 mm with 5.29 PCPD). From the analysis, it was observed that rainfall is usually at its peak between June and September which receive over 87 % of the rainfall amount in these months (see Table 4). This report is consistent with the report of NMSA (2007), which states that most parts of Ethiopia receive rainfall during summer season and the peak in July and the lowest from November to February.

Table 4: Statistical Analysis of Daily Precipitation Data (1980 - 2010)

Number of Years = 31
Number of Leap Years = 8
Number of Records = 11,322

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
January	4.28	1.3858	17.2568	0.0667	0.5082	3.94
February	6.35	1.0243	6.588	0.0871	0.5732	5.29
March	33.88	3.7714	7.9247	0.1574	0.698	11.32
April	49.48	4.2761	6.1008	0.2252	0.7675	15.68
May	44.47	3.8059	5.9409	0.2267	0.7302	15.06
June	150.81	7.7125	2.575	0.4586	0.8875	24.94
July	511.65	11.4266	1.1008	1	0.9656	30.94
August	465.62	10.8454	1.3712	1	0.9645	30.9
September	91.07	4.9513	2.4527	0.2799	0.8056	19.74
October	30.02	4.611	9.0577	0.0794	0.6634	6.61
November	8.8	1.5579	8.7615	0.0513	0.6718	4.23
December	2.38	0.4887	11.0695	0.0541	0.5676	3.58

PCP_MM = average monthly precipitation [mm]
PCPSTD = standard deviation
PCPSKW = skew coefficient
PR_W1 = probability of a wet day following a dry day
PR_W2 = probability of a wet day following a wet day
PCPD = average number of days of precipitation in month

Vulnerability to natural resources scarcity: LVI approach

Land: the indicators have been identified to analyze the vulnerability levels of the rural households' farmland to climate change. Accordingly, an assessment of farming households' levels of farmland vulnerability was carried out based on farmland size, terrain characteristics of the areas (slope of the land) where farmlands located, soil erosion severity, land fertility level, farmland productivity and crop yield trend based on households response. Land management training and soil conservation measures were also included to measure the adaptive capacity of the studied communities based on Hahn et al. (2009) and Teshome (2016a, 2016b) (see Table 5). Table 5 presents the LVI scores for land major component including observed (mean), maximum and minimum values for each specific indicator. It is clear from the Table that even though all indicators have their own contribution to the vulnerability of communities to land resource scarcity, the indicators such as reported high rate of farmland erosion (92 %), low productivity of farmland (84 %), lack of land management training (75 %), limited soil conservation practice (74 %), and farmlands' location in sloppy areas (68 %) are the highest contributors to its total vulnerability.

Table 5. Vulnerability index scores for major component of land with its indicators

Sub-indicators	Unit	Observed	Max	Min	Index
Land size of the households [L1]	hectare	1.25	5	0.25	0.21
Average slope of the woreda	Percent	9.65	38.69	0.7	0.24
HHs farmland located in sloppy area [L2]	Percent	68	100	0	0.68
High rate of farmland erosion [L3]	Percent	92	100	0	0.92
Proportion of HHs who reported infertile farmland [L4]	Percent	33.5	100	0	0.34
Percent of HHs who didn't take LMT[L5]	Percent	74.5	100	0	0.75
HHs who didn't practice SCM [L6]	Percent	73.9	100	0	0.74
Low farmland productivity [L7]	Percent	83.5	100	0	0.84
Total vulnerability to land resource scarcity [VI]					0.59
HHs who utilize water from unprotected sources	percent	64	100	0	0.64
HHs who haven't regular water supply	percent	41.5	100	0	0.42
Percent of HHs reporting water conflict\	percent	28.5	100	0	0.29
Average time to reach water sources	minute	32.92	180	3	0.17
HHs who have no access to water for irrigation	percent	71.5	100	0	0.72
HHs who do not get water management training/WMT	percent	78	100	0	0.78
Total vulnerability to water scarcity /WVI/					0.503
HHs who use fire wood for cooking	Percent	72.5	100	0	0.73
HHs who utilize firewood for lighting	Percent	19.5	100	0	0.20
Trend of forest cover over the past 10 years	Percent	94	100	0	0.94
Average time to reach source of firewood	Minute	72.72	240	2	0.30
HHs who do not practice tree planting	Percent	51	100	0	0.51
HHs who didn't get forest management training	Percent	76	100	0	0.76
Total vulnerability to forest scarcity					0.573
Drought frequency over 10 years	Freq	3.7	9	1	0.34
STDV of maximum temperature by year (1980-2010)	0C.	2.43	6.71	1.29	0.21
STDV of maximum temperature by month	0C	1.58	3.87	0.6	0.30
STDV of minimum temperature by year (1980-2010)	0C	1.53	3	1.11	0.22
Average annual precipitation (mm)	Mm	1113.69	2011.21	702.4	0.31
STDV of mean minimum temperature by month	0C	0.79	1.57	0.49	0.28
STDV of rainfall by month	Mm	41.03	130.21	4.39	0.29
STDV of rainfall by year	Mm	120.28	245.54	71.13	0.28
Drought magnitude based on standardized precipitation index	Index	4.60	5.13	4.13	0.47
Total Climate variability Index					0.30

*STDEV= standard Deviation

Index scores should be interpreted as relative values to be compared within the study sample only. LVI is on a scale from 0 (lease vulnerable) to 1 (most vulnerable) and LVI-IPCC is on a scale from -1 (most vulnerable) to 1 (least vulnerable).

From the result we can infer that due to sloppy nature of the area (see Figure 5), the communities' farmlands are susceptible to very high rate of soil erosion. The prevalence of high rate of erosion, in turn, leads to the emergence of bare soils and then to low agricultural productivity. The total livelihood vulnerability score of land resource scarcity is found to be 0.59. This implies that the Debark rural communities are found to be highly vulnerable to climate change and land resource scarcity based on Getnet (2010) LVI classification method. Figure 5 demonstrates that the slope angle of the woreda ranges from 0.07 % (least sensitive) to nearly 39 % (more sensitive) to severe soil erosion by water and landslide in the rainy season and wind erosion and mass movement in the dry seasons.

Water: The LVI score for water resource component with the mean, minimum and maximum values of each indicator are presented in Table 5. It is clear from the Table that even though all indicators have important contributions to vulnerability of communities to climate change and water resources scarcity, limited access to water management training (0.78), lack of water for irrigation (0.72) and proportion of households who use water from unprotected sources (0.64) are the highest contributors to vulnerability to water scarcity. The LVI measurement results indicate that the water resource was found to be vulnerable at average 0.50 LVI score based on Getenet (2010) LVI classes.

Forest: The forest resource major component includes indicators of forest trend, average time taken to source of firewood, the practice of tree plantations, fuel wood supply for cooking and lighting and forest management training. The LVI values for forest resource major component with the mean, minimum and maximum values of each indicator are also presented in Table 5. All indicators have contributed to the vulnerability of forest resource though the indicators such as low forest cover (0.94), lack of forest management training (0.76), use of fuel wood for cooking (0.73) and limited tree plantation practices (0.51) have the highest proportion for communities' vulnerability to forest scarcity (see Table 5).

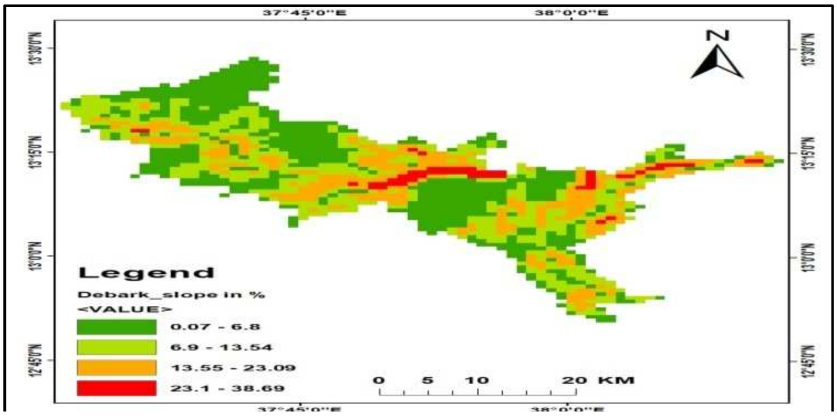

Figure 5. Debark woreda by slope classification

From the result we can understand that due to these reasons coupled with lack of appropriate intervention, the forest resource of the woreda is being exhausted and showing diminishing trend from time to time. The LVI result indicates that the forest resource is being highly vulnerable at 0.57 index value with high probability to be affected by climate change based on Getnet (2010) LVI classes.

Climate variability: It is the major indicator used in this study and is constructed with the indicators of average number of droughts during last 10 years, drought magnitude based on SPI, standard deviation of temperature and rainfall by year (1980-2010) and by month. In addition, the exposure index score for the major component of climate variability and mean, minimum and maximum values for each indicator are also depicted in Table 5. As shown from the Table 5 drought frequency and magnitude together with other indicators contributed 30% to the vulnerability situation of the rural communities' to climate change and climate variability. This means, climate variability contributed for the vulnerability of the three natural resources with 0.30 exposure index score. Drought magnitude (0.47), drought frequency (0.34), average annual precipitation (0.31) and standard deviation of maximum temperature by month (0.30) were found to be the major contributors to communities' vulnerability to natural resources scarcity and climatic exposures.

The calculated results for land, forest and water are presented collectively in a radar diagram (Figure 6). The scale of the diagram ranges from 0 (less vulnerable) at the center of the web, increasing to 0.6 (more vulnerable) at the outside edge in 0.1 unit increments. Figure 6 presents the vulnerability radar of the three natural resources and climate variability components.

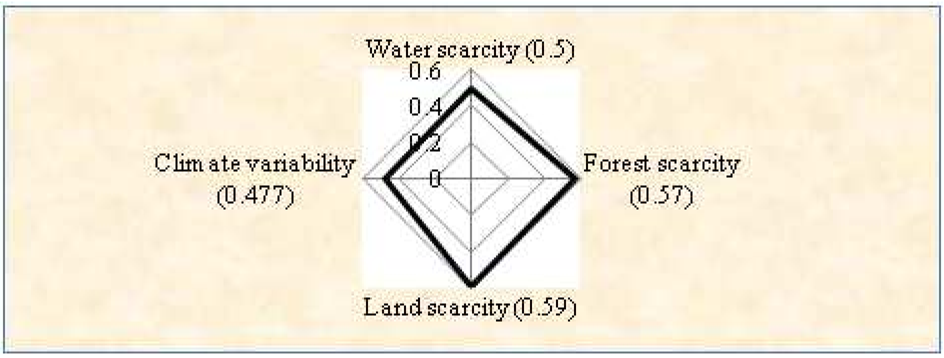

Figure 6. Vulnerability radar of the three natural resources

From the figure we can understand that Debark households had vulnerability scores for land (0.59), forest (0.57) water (0.5) and climate exposure (0.30) components putting the studied woreda in highly vulnerable position in terms of land and forest scarcity while in a vulnerable scale in terms of water scarcity and climate change exposures. Table 6 shows the four major components and twenty nine specific indicators of vulnerability. The overall livelihood vulnerability index for all major components of Debark woreda is found to be 0.477 (48%) indicating the communities' vulnerability to the impact of climate change and natural resources scarcity, livelihoods insecurity and environmental poverty.

Table 6. Total LVI Value of the four major indicators (Based on Getnet, 2010)

Major components	**Number of indicators**	**VI of major components**	**Class of vulnerability**
Land resource	8	0.59	Highly vulnerable
Forest resource	6	0.57	Highly vulnerable
Water resource	6	0.50	Vulnerable
Climate variability	9	0.30	Vulnerable
Composite LVI	29	0.477	Vulnerable

Source: Household survey and meteorology data, 2012

Vulnerability to natural resource scarcity: LVI-IPCC approach

The indicators under exposure, sensitivity and adaptive capacity component, presented in Table 2 were analyzed to show vulnerability status of communities to climate change and natural resource scarcity. The calculation of index and the scores for contributing factors are the same as that of LVI composite index approach as can be seen from Table 6 and 7.

For adaptive capacity, households who used battery for lighting accounts for the highest score (0.85) while households who have access to water for irrigation (0.19) and farmland size of the households (0.21) account the least vulnerability scores. This indicates that when forest resources became scarce, the farmers use batteries for light instead of fuel wood as an alternative mechanism. As discussed above, however, water shortage is the problem of the woreda, except some kebeles which have water potential to practice irrigation agriculture accounting for 19% of the surveyed households. The farmers' farmland size is too small to be productive and thus exacerbated by high rate of erosion that hinders the adaptive capacity of the farming community. In addition, taking trainings on management of land, forest, water as well as the practice of soil conservation measures contributed less to the adaptive capacity of the community. Therefore, the woreda has adaptive capacity of 0.32 score, indicating only a 32 % ability to undertake potential adaptation measures. Within sensitivity, infertile farmland, low forest cover, low farmland productivity, households farmland located in sloppy areas, time taken to reach sources of drinking water and firewood sources, households who utilize water from unprotected sources and households haven't access to regular water supply have made the area more sensitive (58 %) to the impact of climate change.Based on these indicators of exposure, the LVI- IPCC value of exposure is at 0.43 implying that the woreda has a 43% probability to be exposed to natural resources scarcity and climate change and associated risks. With this probability of exposure the Debark woreda is sensitive to climate change by 0.57 sensitivity score. Indeed, from the LVI score and vulnerability radar (Figure 7), we can understand that the woreda is found to be 57% sensitive to climate change impacts having a very low adaptive capacity of 32%.

Following the formula pertaining to the IPCC's definition of vulnerability, the LVI was calculated by subtracting and multiplying the parameter scores. As such, the vulnerability due to exposure, sensitivity and adaptive capacity are counted, by using the following equation (Gebreegziabher et al., 2016):

Vulnerability = (Adaptive Capacity) – (Sensitivity + Exposure) = $(0.32) - (0.43 + 0.58)$ = **[- 0.69**]

Under the consideration of similar indicators calculated based on their respective methods, LVI and IPCC-LVI yielded consistent results in this study. LVI is calculated to be **0.48** score indicating the existence of vulnerable situation in the studied woreda. The LVI-IPCC provided (**-0.69**) index score showing the occurrence of highly vulnerable conditions of communities to climate change and natural resources scarcity, such as land, forest and water and, in turn, the livelihood sources of the communities. Note that there is no category of 'not vulnerable' with the value of zero (0).

Table 7. The vulnerability index value of the three IPCC contributing factors (Exposure, sensitivity and adaptive capacity)

Factors	Indicators	Unit	Observed value	Max.	Min.	Index value
Adaptive Capacity	Farmland size of the household	Hectare	1.25	5	0.25	0.21
	Households/HHs who practice soil conservation measures	Percent	26.1	100	0	0.26
	HHs who took land management training	Percent	25.5	100	0	0.26
	HHs who took forest management training	Percent	24	100	0	0.24
	HHs who took water management training	Percent	22	100	0	0.22
	HHs who have access to water for irrigation	Percent	18.5	100	0	0.19
	HHs who use battery for lighting	Percent	84.5	100	0	0.85
	Adaptive capacity Index					**0.32**
Sensitivity	HHs farmland located in sloppy area	Percent	68	100	0	0.68
	Average slope of the woreda	Percent	9.65	38.69	0.7	0.24
	HHs who own infertile farmland	Percent	95	100	0	0.95
	Time takes to reach to source of firewood	Minute	72.72	240	2	0.30
	HHs who utilize water from unprotected sources	Percent	64	100	0	0.64
	HHs haven't access to regular water supply	Percent	41.5	100	0	0.42
	Distance to drinking water sources	Minute	32.92	180	3	0.17
	Decreasing trend of farmland productivity	Percent	83.5	100	0	0.84
	Decreasing trend of forest cover	Percent	94	100	0	0.94
	Sensitivity Index					**0.58**
Exposure	HHs reported very high farmland erosion	Percent	92	100	0	0.92
	Hazard frequency over 10 years	freq.	4.02	9	2	0.29
	HHs reported resource conflicts in their locality	Percent	72.5	100	0	0.73
	HHs who do not practice tree planting	Percent	51	100	0	0.51
	HHs who use fire wood for cooking	Percent	72.5	100	0	0.73
	STDEV of maximum temperature by year (1980-2010)	^{0}C	2.43	6.71	1.29	0.21
	STDEV of maximum temperature by month (1980-2010)	^{0}C	1.58	3.87	0.6	0.30
	STDEV of minimum temperature by year (1980-2010)	^{0}C	1.53	3	1.11	0.22
	STDEV of minimum temperature by month (1980-2010)	^{0}C	0.79	1.57	0.49	0.28
	Average annual precipitation (mm) (1980-2010)	MM	1113.69	2011.21	702.40	0.31
	STDEV of rainfall by month (1980-2010)	MM	41.03	130.21	4.39	0.29
	STDEV of rainfall by year(1980-2010)	MM	120.28	245.54	71.13	0.28
	Drought magnitude based on standardized precipitation index (1980-2010)	index	4.60	5.13	4.23	0.47
	Exposure Index					**0.43**
	Composite LVI value					**(-0.69)**

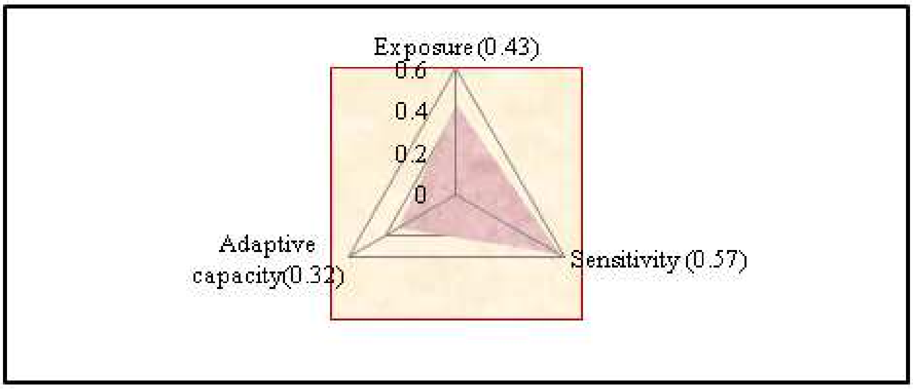

Figure 7.Vulnerability radar of the three IPCC contributing factors

The analysis thus assumes that the population of Debark woreda is vulnerable to climate change and natural resource scarcity to some degree consistent with Ethiopia's vulnerability to food insecurity assessment using Chronic Vulnerability Index (Burg, 2008).

Conclusions

We applied the LVI and LVI-IPCC as alternative methods of examining the relative vulnerability of mountain communities to climate change and natural resource (land, water and forest) scarcity. Each approach yields detailed evidence of factors deriving communities' livelihood vulnerability to climate change in Debark woreda, Northwest Ethiopia. Although all indicators have their own contribution to the vulnerability of land resource, high rate of farmland erosion (92%), low farmland productivity (84%), lack of land management training (75%) and low practice of soil conservation measures (74%) contribute the highest for communities' vulnerability to land scarcity having 0.59 index score in the woreda. From indicators of forest resources, low forest cover (94%), lack of forest management training (76%) and use of fuel wood for cooking (73%) contributed the highest for communities' vulnerability to forest scarcity and climate change. Therefore, the forest resource is found to be relatively more vulnerable to climate change at 0.57 index score.

All components have their own contribution to the vulnerability of communities to water resource scarcity and climate change though the three indicators, such as water management training (78%), lack of access to water for irrigation (72%) and use of unprotected water sources (64%) contribute the highest. Communities are vulnerable to water resource scarcity and climate change at 0.50 index score while land and forest resources are highly vulnerable to climate change impact at 58 % and 57 % respectively. Both the total LIV (0.48 index score) obtained from four major components and 29 indicators and LVI-IPCC (-0.69 index score) obtained from three major components (exposure, sensitivity and adaptive capacity) have put the Debark woreda farming community into vulnerable position to climate change and natural resource scarcity. The findings imply that climate change should be placed within the broader context of development strategy and rural poverty reduction. Particularly, concerted efforts should be exerted to participatory integrated watershed management strategies to ensure sustainable development of such land, water and forest resources. This study also recommends the need for further study using different data sources, indicators and analytical techniques to further validate results of LVI and LVI-IPCC approaches.

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