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Socio-ecological vulnerability to climate change/variability in central rift valley, Ethiopia

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Abstract

Climate change/variability and environmental degradation have increased in the central rift valley of Ethiopia, which in turn making the people inhabiting in that ecosystem more vulnerable to the impacts. The purposes of this study were to assess the vulnerability of households and agro-ecosystems to climate change and environmental degradation and the factors determining vulnerabilities in the central rift valley, Ethiopia. Data were collected between November 2014 and May 2015 by interviewing 355 respondents. This has been supplemented with focus group discussions and key informant interviews. The indicator and matrix methods were used to describe socio-ecological vulnerabilities. The results showed that about 9% of the respondents were highly vulnerable to climate change/variability, and environmental degradation. Households in the lowland have the largest proportion of high vulnerable households (60%), while households in highland have the largest proportion of low vulnerable households (30%). In the lowland agro-ecology, the adaptive capacity component has contributed the largest share to household's vulnerability index to the impacts of climate change/variability and environmental degradation. The sensitivity component has higer contribution in highland agro-ecology and the exposure component in the midland agro-ecology. There were variations of income deviation between agro-ecologies that lead to variation in vulnerability of households. Household vulnerability index has shown a very light negative correlation with livelihood diversification index. The poorest households with little share of the total income distribution and with low livelihood diversity index, were the most vulnerable. The results showed that the highest exposure index on ecosystem functions and agricultural performance were in the lowland agro-ecology. This study highlighted the need to assess the social and ecological vulnerabilities in integrated approach as singling out one from the other is difficult. That is, social vulnerability impacts ecological vulnerability and vice versa.

Keywords: Adaptive capacity; Vulnerability; Exposure; Impacts; Ecosystem services; Sensitivity

1. Introduction

The impacts of climate change/variability had affected and will continue to affect human and ecological systems at multiple scales encompassing people, institutions and places (Downing and Patwardhan, 2004; Williamson et al., 2007). This in turn affects humans well-being and livelihoods (John, 2012; Swanston and Janowiak, 2012; Duguma et al., 2013; Chavez-Tafur and Zagt, 2014). Agro-ecosystems might be exposed to a range of natural, introduced, and anthropogenic stressors including climate change/variability which in turn affects their ecosystem services (Handler et al., 2014). In the context of climate change, many landscapes and households making their livelihoods within them are becoming vulnerable from time to time (El-Beltagy and Madkour, 2012).

In Ethiopia, impacts of climate change/variability are persistent as indicated by observed and projected trends of climate parameters (NMA, 2006/2016; McSweeney et al., 2008). Reports indicated that the frequency of drought in Ethiopia had shown increasing trend since the 19th century (WB, 2005; OFDA/CRED, 2009). The country will face

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significant climate change/vulnerability in 2050 for the scenario of continued vulnerability with a static representation of current adaptive capacity (Yohe et al., 2006). For the 2050 estimates (Springmann et al., 2016), the effect of climate change on food production will lead to an additional 3520 deaths. The Ethiopian central rift valley is under dynamic pressures of settlement expansion, population increase, agricultural development, overgrazing and deforestation which affect landscape functions and human livelihoods (Amdie, 2007; Gebeyehu et al., 2015). It is vulnerable to climate change/variability, as well as to environmental degradations (MOA, 2015). Mekonnen et al. (2017) indicated an increased trend in temperature and decreased trend in rainfall in the period 1983−2014. The increasing drought frequency combined with other environmental degradation (deforestation, land degradation, biodiversity loss) has affected the livelihoods of smallholders. Arsi Negele district is vulnerable to the impacts of climate change/variability, such as frequent drought (Belay et al., 2013; Biazen, 2014; MOA, 2015) and environmental degradation (Garedew et al., 2012; Gebreslassie, 2014; Molla, 2014; Yohannes et al., 2017). Even if it has been difficult to distinguish, interactions between climate change/variability, and environmental degradation are likely to affect a range of different ecosystem functions and the services they deliver, with consequent impacts on food production, livelihoods and human well-being (UNCCD, 2015).

Community vulnerability assessments (individual and community scale) to the impacts of climate change and variability, should be undertaken in participatory form to build robust knowledge on exposure, sensitivity and adaptive capacity (Williamson et al., 2007; Marshall et al., 2009; Seppälä et al., 2009; ADB, 2011). Participatory assessment helps to assimilate community know-how and engage vulnerable communities in the formulation of adaptation plans that are operable and suitable to their circumstances. In addition, it helps to develop practical tools to ensure that the communities will have the necessary capacity to analyze climate risk and decide on adaptation strategies (Marshall et al., 2009). Studies (Tesso et al., 2012; Akter and Mallick, 2013; Berman et al., 2014) showed that households who could not maintain their assets during shocks, such as drought, are more vulnerable than households who could maintain their assets in time of such extreme events. Households often vary in terms of their demographic, socioeconomic and socio-political characteristics (van Aalst et al., 2008; Satapathy et al., 2014). These variations are responsible for the variations in vulnerability levels (Paavola, 2008; Kuriakose et al., 2009; Eriksen and Silva, 2009; Hisali et al., 2011). In socio-economic perspective, vulnerability represents a present inability to cope with changing climate conditions (O'Brien et al., 2004), and in biophysical perspective it deals with the net impact of climate change/variability and can be characterized as loss-damage or as a change due to the impacts (Kelly and Adger, 2000; O'Brien et al., 2004; Smit and Wandel, 2006). It might be better to use the combination of both to determine overall vulnerability (Cutter et al., 2000; IPCC, 2001; Füssel and Klein, 2006; Füssel, 2007).

Arsi Negele district in central Ethiopia has extensively modified landscapes at which food security, vulnerability to climate change/variability, adaptation to climate change and sustainable development are issues of concern (MOA, 2015). Studies regarding vulnerability to climate change/variability in Ethiopia were mainly focused on national and/or regional levels (Deressa et al., 2008; Tesso et al., 2012) but little focus was given at local levels and on landscapes and people's dependence on them for their livelihoods, and how this will be affected by climate change and combined environmental degradation. Curbing vulnerability at the national level does not necessarily curbs vulnerability at local levels (Downing and Patwardhan, 2004; Dunno, 2011). Doing vulnerability assessments at local level is important as vulnerability varies across space and time (Kelly and Adger, 2000). Most of the vulnerability studies in Ethiopia focused on social vulnerabilities with little focus on ecological vulnerabilities (Deressa et al., 2008; Tesso et al., 2012; Alemayehu and Bewket, 2016). Arsi Negele district victims an increasing trend in temperature and decreasing trend in precipitation (Mekonnen et al., 2017). Similarly, there was high decline in the forest and woodlands causing land degradation in this district (Mekonnen et al., 2018). Regardless of the fact that the changes in climate and environment which make people and agro-ecologies more vulnerable, there were research gaps in assessing vulnerabilities to these changes, especially across agro-ecologies. Therefore, this study was framed on the hypothesis that socio-ecological vulnerability varies between different social and ecological factors along the spatial and temporal scales. The objectives of the research were to assess the vulnerability of households to climate change/variability as well as environmental degradation across and within agro-ecologies. It was also aimed to assess the factors determining socio-ecological vulnerabilities across and within agro-ecologies.

2. Research methodologies

2.1. The study area

Arsi Negele district, Ethiopia, is located between 7.15° and 7.75°N and 38.35°−38.95°E. The average temperature varied from 10 °C for the minimum to 25 °C for the maximum. The annual rainfall varied between 500 and 1000 mm. The altitude ranges from 1500 to 3000 m above sea level (lowland <1600 m, midland 1600−2200 m, and highland >2200 m). The topography encompassed the central rift valley floor and extended to the eastern escarpment of the rift valley (Fig. 1). Andosols and nitosols are the dominant soils types. The district has four livelihood zones as showed in Table 1 (MOA, 2015). The population of the district has increased by more than double between 1994 and 2016 (CSA, 1994/2007, 2005/2016). This trend has imposed great impacts on natural resource degradation/deforestation and landscape fragmentation (Mekonnen et al., 2018).

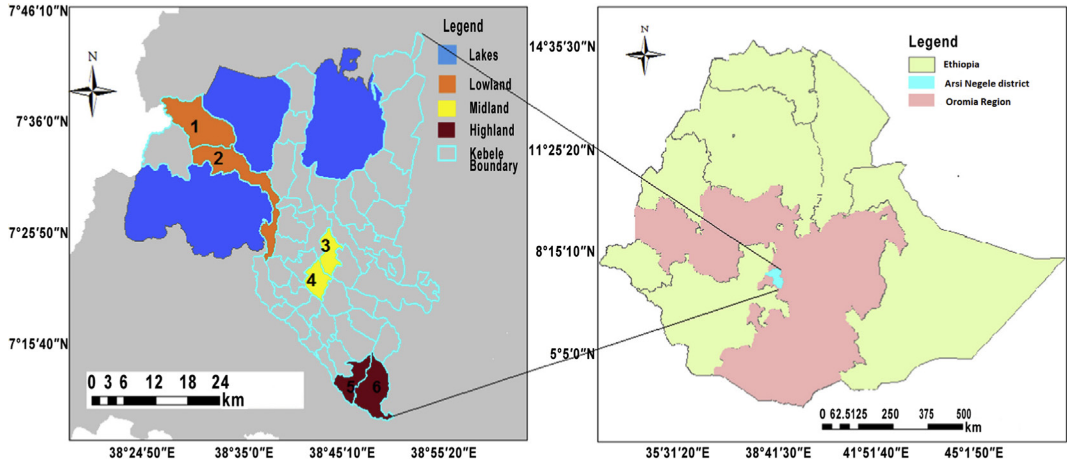

Fig. 1. Location of study kebeles in Arsi Negele district, 1 Mudi Arjo; 2 Shall Billa; 3 Meko Odda; 4 Sirba Lenda; 5 Meraro Hawilo; 6 Gode Duro.

2.2. Data collection and approaches

Data were collected from November 2014 to May 2015 in Arsi Negele district. From two representative kebeles (lowest administration division in Ethiopia) from each agro-ecology, 104, 103 and 148 households were selected randomly from the lowland, midland and highland agro-ecologies, respectively. This was done based on proportional samples of normal distribution with error of 5% (Israel, 1992; Bartlett et al., 2001). Respondent households were asked open and close ended questions on the five livelihood capitals (social, human, natural, financial, and physical), empowerment of a husband and a wife in a household for different responsibilities (share of each empowerment role of a wife from 100% compared to a husband), ranking of the impacts of major climatic and anthropogenic risk factors on agro-ecosystems.

The household survey was supplemented with focus group discussions (composed of 8–10 people encompassing elders, women and youth (Smith and Sharp, 2012)), key informant interviews (selected by snow ball method (Bernard, 2006)), and observations across the landscapes. Focus group discussions and key informant interviews were used to prioritize key indicators in the local contexts and give information on rate or frequency of climate change and/or environmental degradation in the study area.

2.2.1. Households' vulnerability index

The indicator method of quantifying vulnerability, based on selected key indicators from the whole set of potential indicators, was used to systematically combine the selected indicators to indicate the levels of vulnerability (Adger, 1999; Gbetibouo et al., 2010; Tonmoy et al., 2014; Vincent and Cull, 2014). Key indicators were selected based on literatures that provide insight into the nature and causes of vulnerability (Piya et al., 2012) and have been verified with insights gained from focus group discussions conducted at the field level. Seven exposure, eight sensitivity and twenty-three adaptive capacity key indicators were selected on the bases of literature and prioritization by key informants and focus group discussants in the context of local situations (Table 2). Each household was asked on each indicator to give impact value based on continuous, nominal or ordinal scales and then each indicator values were normalized using Eq. (1) to come up with standard values between 0 and 1.

$$V_i = (\mathrm{Max}_i - x_i)/(\mathrm{Max}_i - \mathrm{Min}_i) \quad (1)$$

Where V_i is normalized value of indicator i; Max_i is maximum value of indicator i; Min_i is minimum value of indicator i and x_i is the ith value of an indicator for the ith household.

After normalized the indicators, we have used principal components analysis (PCA) to give different weights to the indicators so as to avoid the uncertainty of equal weighting given the diversity of indicators used (Cutter et al., 2003; Gbetibouo and Ringler, 2009; Nelson et al., 2010; Piya et al., 2012). The standardized values of exposure, sensitivity and adaptive capacity indicators were weighted by the absolute values of the first principal component of the multivariate analysis to calculate indices for each indicator. Then summation of each exposure indicator and divided by the total number of exposure indicators has given the exposure index (Eq. (2)). The sensitivity index (Eq. (3)) and the adaptive capacity index (Eq. (4)) have been done in the same way. Then, the vulnerability index for a household was calculated (Eq. (5)) and standardized between 0 and 1 inclusive. That is, 0 represents low vulnerable and 1 represents high vulnerable households. Correlation coefficients greater than 0.30 and all communality values greater than or equal to 0.50 within the exposure, sensitivity and adaptive capacity indicators were evaluated for data validation. Based on IPCC (2001) and local context, households were categorized into low ($0 \le V_i \le 0.45$), medium ($0.45 < V_i \le 0.70$), and high ($0.70 < V_i \le 1.00$) vulnerable by their vulnerability index.

$$E_i = \sum_{i=1}^{n} e_i We_i \Big/ n \quad (2)$$

Where E_i is exposure index for household i; e_i is normalized value of exposure indicator i; We_i is weight i of PCA1 for exposure indicator i; n is total number of exposure indicators.

Table 1
Livelihood zones of Arsi Negele district in 2008—2015 (MOA, 2015).

Livelihood zone	Agroecology	Main crops	Main livestock	Vegetation
Agro-pastoral	Lowland	Maize, haricot beans	Cattle, goats, donkeys, sheep	Acacia woodlands
Potato-vegetables	More of midland and some lowland	Maize, potato vegetables (onions), haricot beans, teff	Cattle, sheep, goats	Sparse acacias and parkland agroforestry
Maize-haricot bean	More of midland and few lowland	Maize, haricot beans, teff	Cattle, sheep, goats	Sparse acacias and parkland agroforestry
Barley-wheat	More of highland and some midland	Wheat, barley, pulses, rape seed, flax	Cattle, sheep, horse	Afromontane forest

$$S_i = \sum_{i=1}^{n} s_i Ws_i / n \quad (3)$$

Where S_i is sensitivity index for household i; s_i is normalized value of sensitivity indicator i; Ws_i is weight i of PCA1 for sensitivity indicator i; n is total number of sensitivity indicators.

$$A_i = \sum_{i=1}^{n} a_i Wa_i / n \quad (4)$$

Table 2
Prioritized key indicators used in the PCA to help calculate household's vulnerability index.

Indicator		Level/Degree/Measure
Exposure	Drought	Exposure level is measured by the relative effects of a risk on particular household (0 no impact; 1 low impact; 2 medium impact; and 3 high impact) as perceived by a household
	Erosion and flooding	
	Strong wind	
	Hailstorm	
	Extreme heat on human health and labor efficiency	
	Extreme heat on livestock health	
	Delay in rainfall onset	
	Erratic nature of rainfall	
Sensitivity	Dependence on rain-fed crop cultivation	Degree of sensitivity is measured by the relative susceptibility of a household's livelihood in relation to climate change and variability (0 not sensitive; 1 low; 2 medium; and 3 high) as perceived by a household
	Dependence on poor breed livestock	
	Dependence on forest products	
	Dependence on poor variety crops	
	Farming landscape quality (e.g. soil fertility)	
	Sustainability of coping activities as droughts becomes more frequent	
	Location	
Adaptive capacity	Age of household head (±)	years (continuous)
	Gender (±)	1 male; 0 otherwise
	Farm size (+)	hm^2 (continuous)
	Farmland soil fertility (+)	0 infertile; 1 low fertility; 2 medium fertility; 3 high fertility
	Total farm assets (+)	Eth Birr per year
	Total non-farm assets (+)	Eth Birr per year
	Livelihood diversity index (+)	scale 0—1
	Years of education (+)	years
	Farming experience (+)	years
	Place attachment ratio (−)	years lived in the area
	Land certification (±)	1 certified; 2 not certified; 3 on process
	Willingness and planning to adapt to climate change and variability impacts (+)	1 yes; 0 otherwise
	Integration of different approaches in climate change adaptation (+)	1 low; 2 medium; 3 high
	Access to irrigation water (+)	1 yes; 0 otherwise
	Access to forest resource (+)	1 yes; 0 otherwise
	Access to credit (+)	1 yes; 0 otherwise
	Savings (+)	1 yes; 0 otherwise
	Membership in insurance scheme (+)	1 yes; 0 otherwise
	Training on climate variation (+)	1 yes; 0 otherwise
	Membership in farm organization (+)	1 yes; 0 otherwise
	Access to market (+)	1 yes; 0 otherwise
	Access to health care (+)	1 yes; 0 otherwise
	Access to farm inputs (+)	1 yes; 0 otherwise

Notes: + positive contribution to adaptive capacity; − negative contribution to adaptive capacity; ± conditional to contribute positively (e.g. early carrier and matured ages) or negatively (e.g. very young and very old ages) to adaptive capacity. Total farm assets in this case represents all farm assets in terms of monetary value (livestock + crop produced) and total non-farm assets include off-farm income and the monetary values of home furniture including the house.

Where A_i is adaptive capacity index for household i; a_i is normalized value of adaptive capacity indicator i; Wa_i is weight i of PCA1 for adaptive capacity indicator i; n is total number of adaptive capacity indicators.

Household vulnerability index (HVI) for the ith household (H_i) was calculated as follows:

$$H_i = (E_i + S_i) - A_i \quad (5)$$

2.2.2. Livelihood diversity and income inequality

A higher amount of total income from a single activity alone might not guarantee a household from being vulnerable. Total household's income that have been derived from more than one source is more important (Kurosaki, 2003; Kimenju and Tschirley, 2009; Piya et al., 2012). To verify this, the livelihood diversity index (LDI) (Eq. (6)) was calculated for each household and relate it with climate change vulnerability index for each household.

$$D_k = 1 - \sum_{i=1}^{n} (Si, k)^2 \quad (6)$$

Where D_k is LDI within the scale of 0−1; i is the ith income source; n is the total number of income sources; k is the particular household; and $S_{i,k}$ is the share of the ith income source to the total household income for kth household.

Income inequality is important to indicate variation among households' vulnerabilities than the total income used in the PCA. The extent to which the distribution of income among households within an economy deviated from a perfectly equal distribution is important to consider. In this study, Lorenz curve (FAO, 2005) and Gini index (WB, 2016) were used to measure the income inequality and income distribution among respondents.

2.2.3. Impact matrix

The impact matrices for major ecosystem profiles and agricultural performance with respect to the perceived impacts by major risk factors were developed from the data obtained during household survey. Resource depletion (in this context) was defined with respect to decline in forest resources, soil fertility, loss of biodiversity and water quantity and quality. The major risk factors (C1−C8, representing heat wave, drought, flood, hialstorm, wind damage, erosion, frost, and resource depletion, respectively) were arranged across the columns, while the variables describing ecosystem profiles and agricultural performance arranged along the rows (Table 3). The impacts of the major risk factors were ranked from 1 (low) to 3 (high) based on the perceived impacts on agricultural performance. The sensitivity of ecosystem's profile to major risk factors was ranked from 1 (least sensitive) to 4 (highly sensitive). The probabilities (frequencies) of the major risk factors for Arsi Negele district were set with participation of district level experts and key informants combined with the existing documents and literatures on the climatic and environmental situations of the district. Then, the average frequency was taken for each risk factor. The sum of the columns of each row divided by the total possible score gives the

Table 3
Matrix on the effects of major risk factors on agroecosystem in Arsi Negele district.

Factor		Major risk factors								Exposure index
		C1	C2	C3	C4	C5	C6	C7	C8	
		F1	F2	F3	F4	F5	F6	F7	F8	
Effects on ecosystem	Composition	R1	R2	R3	R4	R5	R6	R7	R8	E1
(4 point scale)	Structure	R1	R2	R3	R4	R5	R6	R7	R8	E2
	Function	R1	R2	R3	R4	R5	R6	R7	R8	E3
	Provisioning	R1	R2	R3	R4	R5	R6	R7	R8	E4
	Regulating	R1	R2	R3	R4	R5	R6	R7	R8	E5
	Supporting	R1	R2	R3	R4	R5	R6	R7	R8	E6
	Culture	R1	R2	R3	R4	R5	R6	R7	R8	E7
	Impacts index	I1	I2	I3	I4	I5	I6	I7	I8	PIE
Effect on agriculture	Length of growing period	R1	R2	R3	R4	R5	R6	R7	R8	E1
(3 point scale)	Soil moisture	R1	R2	R3	R4	R5	R6	R7	R8	E2
	Crop insect and disease	R1	R2	R3	R4	R5	R6	R7	R8	E3
	Crop production and productivity	R1	R2	R3	R4	R5	R6	R7	R8	E4
	Livestock disease	R1	R2	R3	R4	R5	R6	R7	R8	E5
	Weed infestation	R1	R2	R3	R4	R5	R6	R7	R8	E6
	Grain storage	R1	R2	R3	R4	R5	R6	R7	R8	E7
	Planted seedlings	R1	R2	R3	R4	R5	R6	R7	R8	E8
	Impacts index	I1	I2	I3	I4	I5	I6	I7	I8	PIA

Note: R1 is average rank by 355 respondents for the impact on ecosystem and agriculture profiles by risk factor 1 (C1); R2 is average rank by risk factor 2 (C2), and so on. The R's with the same script for the different profiles of ecosystem and agriculture are not equal (i.e. for ecosystem, for example, R1 for composition is not equal with R1 for structure, and so on). F1 frequency of C1, F2 frequency of C2, and so on. Exposure total possible score equals the products of the numbers of major risk factors (in this case 8) and maximum point scale (4); impacts total possible score equals to the products of the number of variables in each category and maximum point scale (ecosystem 7 × 4 and agriculture 8 × 3). Exposure score (E1, E2, …, E8) is the percentage of the sum of the rows to the total exposure possible score; impact score (I1, I2, …, I8) is the percentage of the sum of the columns to the total impact possible score. PIE and PIA are mean potential impacts on ecosystem and agriculture respectively.

exposure index, and those of the rows for each column give the impacts index.

2.3. Data analysis

Both qualitative and quantitative techniques were used for analysis of data. Data obtained from the household survey was coded and encoded into SPSS-20 and/or Mintab-17 software, as required, for analyzing PCA so as to obtain weightings for each indicator and standardize the indicator values as well as to produce descriptive statistics including correlations. Gini index calculator software was used to calculate the Gini coefficients. Qualitative data from focus group discussion, key informant interviews and field observations were presented in the form of interpretation and narrations.

3. Results

3.1. Socio-ecological vulnerability patterns and determinants

Respondent households were characterized by mean age 36.9 years, family size 7.7, farm size 1.62 hm^2, education 5.6 years, farming experience 18.5 years and Eth. Birr 54,317.4 estimated annual subsistence income for the year 2015. These were among the key adaptive capacity sub-components amalgamated with the sensitivity sub-components to determine social vulnerabilities of households. Together with the exposure sub-components, which mostly related to ecological vulnerabilities, social vulnerabilities have determined the levels of the overall household's vulnerability.

In aggregate, 59% of the respondent households have a vulnerability index between 0 and 0.45 inclusive and were low vulnerable to the impacts of climate change/variability (Fig. 2). Whereas 32% and 9% of the respondents, respectively, have vulnerability index values between 0.45−0.70 and 0.70−1.0 with medium and high levels of vulnerability. Households in the lowland have the largest proportion of high vulnerable households (60%), while households in highland have the largest proportion of low vulnerable households (30%). This was in line to the views of the focus group discussants and key informants by which they claimed that lowland agro-ecology has low rainfall and poor soil fertility that yield lower production, as compared to the highland agro-ecology.

In the lowland agro-ecology of the study area, the adaptive capacity component (score 0.62) of vulnerability contributed the largest share to households' vulnerability index to the impacts of climate change/variability, and environmental degradation. The sensitivity component (score 0.45) has significant contribution to households' vulnerability index in the highland agro-ecology, while the exposure component (scores 0.45 & 0.44) contributed the largest share in the midland and highland agro-ecologies (Fig. 3). In total, for the sensitivity component, dependence on rain fed crop cultivation and non-resilient livestock rearing have contributed the largest share to households' sensitivity to climate change/variability. For the exposure component, the largest contribution to households' exposure index has steamed from the impacts of drought on crops and livestock productivity and delay in rainfall onset.

Regarding the adaptive capacity component, the human and natural capitals indicators have played a significant role in a household's adaptive capacity to climate change/variability, and environmental degradation. The human capitals included in this study were age of household head, farming experience, education, place attachment ratio, gender, and willingness and planning to adapt. These were found to affect households' vulnerability to climate change/variability, and environmental degradation. For instance, gender is one of the human capital sub-indicators in the vulnerability analysis and female were found to be more vulnerable to climate change/variability, and environmental degradation. The analysis of gender parity index based on access to productive resources, decision making over production, control over use of income, community leadership and time allocation showed that almost 50% of the wives in a male headed household have gender parity index less than or equal to 0.5 which indicated lower parity. This was also agreed during focus group discussions that disempowerment of women in a household had not only made them vulnerable to climate change and variability and environmental degradation but also reduced the whole household's

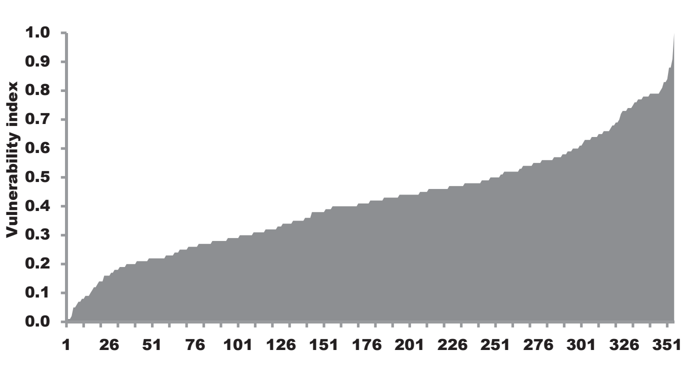

Fig. 2. Households' vulnerability patterns in Arsi Negele district, Ethioipa in 2015−2016.

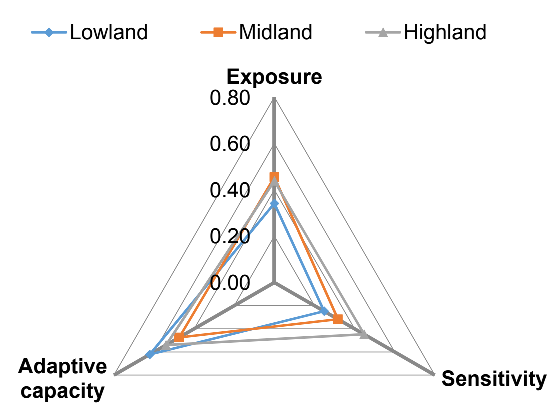

Fig. 3. Diagram showing the contributing factors of the households' vulnerability across different agro-ecologies in Arsi Negele district, Ethiopia in 2015−2016 (0 is low contribution and 0.7 is high contribution).

resilience. This is due to women's great role in building the adaptive capacity of a household by doing different activities.

Regarding natural capitals, households who have large farm size with fertile soils, have access to irrigation water and forest products were found to be less vulnerable than those who haven't. This shows that having access to and the use of natural capitals properly is one of the key factors to determine adaptive capacity of households to the impacts of climate change. On the other hand, social capitals such as land certification, integration of different approaches in adaptation to climate change and training on climate variation have played a role in building household's adaptive capacity and reducing vulnerability. Access to farm inputs, markets and health care were also important physical capitals that have contributed to households' vulnerability to climate change/variability, and environmental degradation in the study area.

3.2. Income inequality vs. vulnerability

Income inequality between households, especially across agro-ecologies, was one of the key indicators to determine households' adaptive capacity and then their vulnerability. The analysis of income distribution by cumulative proportion of households (CPHH) against the cumulative proportion of income (CPI) has shown that there was inequality of income between households in all the three agro-ecologies. The income deviation in lowland agro-ecology was 1.8% and 0.7% higher than the income deviation in highland and midland agro-ecologies, respectively. And that in the highland agro-ecology was 1% higher than in the midland agro-ecology. These variations of income deviation between agro-ecologies (which are significant in economic terms) also lead to variation in vulnerability of households across agro-ecologies.

The poorest 20% of the households in the lowland, midland and highland agro-ecologies have the shares of 5.2%, 5.8% and 5.1% of the total income, respectively. However, the richest 20% of the households in lowland, midland and highland agro-ecologies have the shares of 50.2%, 47.1% and 48.9% of the total income, respectively (Fig. 4). This shows that about 50% of the income was in the hands of the 20% better off households. Income distribution between households in lowland, midland and highland agro-ecologies, respectively, were deviated by 45.5%, 43.7% and 44.7% from perfect equality (Fig. 4a–c). In addition, from focus group discussants and key informant interviews it has also understood that drought has caused asset loss due to crop failure and death of livestock. Climate change/variability as well as environmental degradation could make the deviation wider by income loss, especially for the poor. In this perspective, the poorest households, in all agro-ecologies of the study area, which have the lowest share of the total income, were highly vulnerable to the impacts of climate change/variability as well as environmental degradation.

3.3. Vulnerability vs. livelihood diversity

Households with income sources from diversified livelihood activities (five or more) had higher livelihood diversity index and those households with income source from one or two livelihood activities had lower livelihood diversification index. In general, household vulnerability index has shown a very light negative correlation with livelihood diversity index (Fig. 5). That is, in relative terms, when the livelihood diversity index of a household has increased, the vulnerability of a household to the impacts of climate change/variability as well as environmental degradation has decreased.

3.4. Climate and environmental changes impact matrix on agro-ecosystems

In the lowland agro-ecology of the study area, the most pressing risk factors on ecosystem profiles were resource depletion, soil erosion, drought and heat wave (Table 4). The function and structure of ecosystem profiles were the most

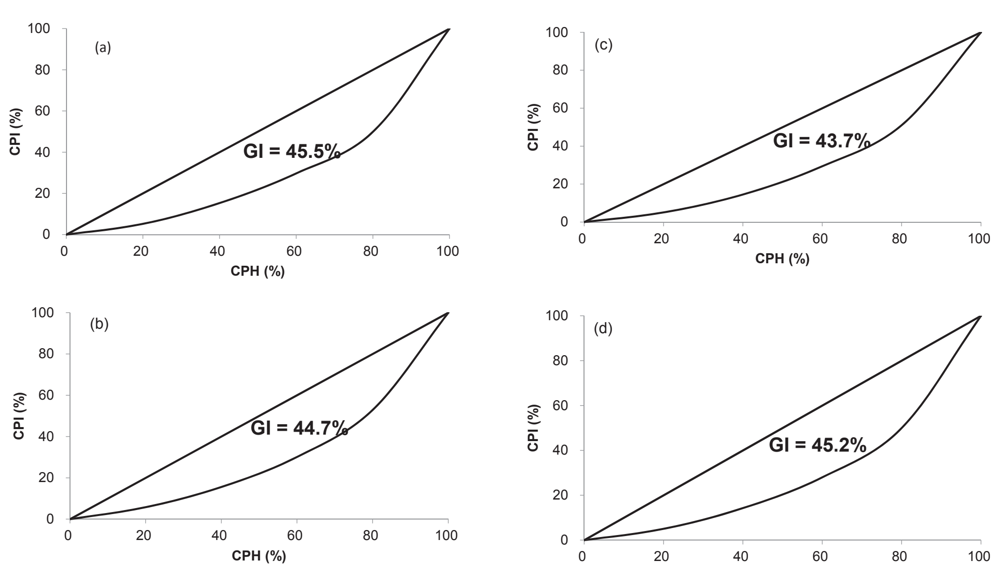

Fig. 4. Income distribution of sampled households in lowland (a), highland (b), midland (c) and overall (d) in 2015–2016.

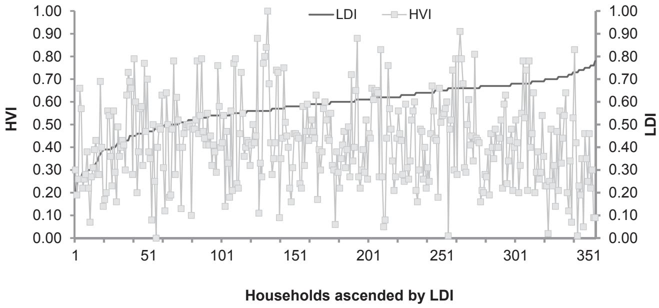

Fig. 5. Households' vulnerability index (HVI) versus livelihood diversity index (LDI).

impacted. Drought and heat wave have the most likely impact on agriculture at which crop production and productivity, planting seedlings, length of growing period and soil moisture were highly impacted.

Resource depletion, drought and heat wave were the most imperative risks factors on ecosystem profile in the midland agro-ecology. The structure, composition and supporting profiles were the most impacted by these risk factors. Again, drought and heat wave were the most pressing climatic risk factors on agriculture by which crop production and productivity, planting seedlings, length of growing period and soil moisture were impacted most.

In the highland agro-ecology of the study area, resource depletion has the highest impact score (0.74) on ecosystem profiles followed by drought (0.65) and heat wave (0.64). The highest exposure score was 0.56 for the function profile of ecosystem followed by 0.54 for the supporting ecosystem profile. This shows that these ecosystem profiles were the most sensitive. All the prioritized risk factors have balanced impact index on agriculture with a little bit higher impact by drought and heat wave. Crop production and productivity as well as soil moisture were the most impacted.

For all agro-ecologies in aggregate, resource depletion, drought and heat wave have the most pressing impacts on ecosystem's profile. However, their levels of impact were the highest in lowland and the lowest in highland. The highest ecosystem exposure index (0.63) for lowland indicates the higher vulnerability of the ecosystem to climatic and environmental risk factors. Similarly, drought and heat wave were the most pressing impacts on agriculture and farmers in lowland, midland and highland, with the highest impact score in lowland and the least in highland. The highest agricultural exposure index (0.67) for lowland means, agriculture was more vulnerable to climate change and environmental degradation in lowland than in midland and highlands. This in turn indicates that farmers in the lowland are more vulnerable than farmers in midland and highland. Indeed, the most sensitive and vulnerable groups were the poor farmers in all agro-ecologies.

4. Discussion

The results showed that six, four and twelve principal component factors explained 89%, 75% and 74% of the variation among sensitivity, exposure and adaptive capacity indicators respectively. The social and ecological vulnerability of households to the impacts of climate change/variability and environmental degradation was generally determined by their adaptive capacity and the potential impact imposed on them by exposure and sensitivity (Fig. 6).

Even though there might be several indicators in each category, we have prioritized the key ones which mostly determine the vulnerability of households in the local context of the study area. The thirty-eight indicators consisted of key adaptive capacity 23 sub-components, 7 sensitivity sub-components, and 8 exposure sub-components have enabled us to calculate the vulnerability index of respondents. In this case, nearly 59% of the respondents were fall in the lower vulnerability level with an index between 0 and 0.45. The adaptive capacity component plays greater role in affecting households' vulnerability in the lowland agro-ecology as they have less options to adapt to the changes than those in the midland and highland agro-ecologies. Previous studies (WB, 2005; Deressa et al., 2008; Gebrehiwot and van der Veen, 2013; Alemayehu and Bewket, 2016) on vulnerability were mainly focused on community vulnerability at coarse scale but with limited focus on individual households at finer scale which this study tried to fill this gap. Coarse scale

Table 4
Sensitivity of ecosystem and agriculture across and within agro-ecologies.

Factor		Mean EI	Most pressing risks (impact index)	Most impacted (exposure index)
Ecosystem	Lowland	0.63	Resource depletion (0.79), drought (0.77) and heat wave (0.77)	Function (0.67), structure (0.66), composition (0.66)
	Midland	0.54	Resource depletion (0.74), drought (0.74) and heat wave (0.72)	Function (0.59), structure (0.56), composition (0.54)
	Highland	0.52	Resource depletion (0.74), drought (0.65) and heat wave (0.64)	Function (0.56), supporting (0.54), provisioning (0.53), structure (0.52)
Agriculture	Lowland	0.67	Drought (0.83), heat wave (0.82)	Crop production and productivity (0.73), planted seedlings (0.72), length of growing period (0.70)
	Midland	0.66	Drought (0.77), heat wave (0.73)	Crop production and productivity (0.74), planted seedlings (0.70), soil moisture (0.69)
	Highland	0.65	Heat wave (0.67), drought (0.67), soil erosion (0.66)	Crop production and productivity (0.68), soil moisture (0.68)

Note: Indices are scaled in 0–1 (near to 0 low and near to 1 high impacts/exposures).

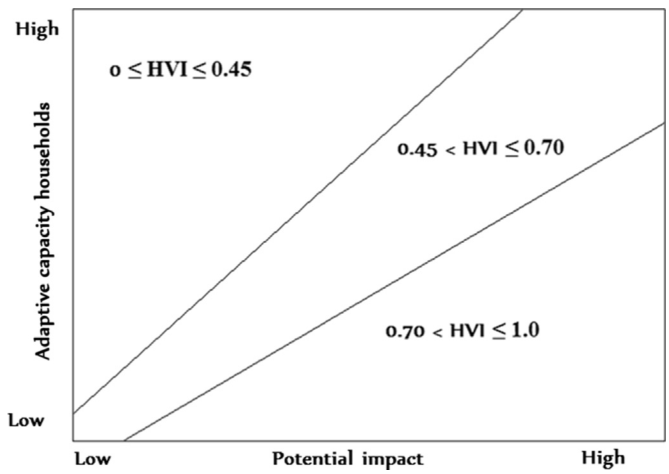

Fig. 6. Representation of households' vulnerability to climate and environmental changes.

vulnerability assessment might overestimate or underestimate the vulnerability of households; Gizachew and Shimelis (2014) has come up with that Arsi Negele district was least vulnerable, which contradicts with this study. In addition, this research result has also tried to show the gaps in women disempowerment assessment which increases their vulnerability to climate change and environmental degradation due to lack of access to productive resources and decision making.

Although the method has limitation to describe the dynamics of impacts of climate change/variability as well as environmental degradation over time, it showed that there were differential vulnerabilities across and within agro-ecologies by which the poor households within the community are the most vulnerable to the impacts. The human, natural, social, financial and physical factors (23 factors in total) were found to constrain the adaptive capacity of the most vulnerable households at which these groups have limited options and influence over these factors. The result also showed that households in the lowland agro-ecology are more vulnerable to the impacts of climate change/variability, and environmental degradation. This was also reflected by other studies in North Shewa (Alemayehu and Bewket, 2016) and in Blue Nile Basin (Deressa et al., 2008). This in turn helps to set coping and adaptation strategies accordingly. The income inequality in the study area communities was another concern that brought differential vulnerability between households by which almost 50% of the income was in the hands of 20% of the better off households. Mideksa (2010) has come up with parallel discourse to this study. The Calculation of income deviation based on Gini index at the household level was little practiced in Ethiopia like it was done at national level. This was also determined by the livelihood diversity index of a household. The study indicated that there were inequalities of income between households in all the three agro-ecologies leading to variation in vulnerability of households to climate change shocks. Income distribution between households showed deviation by more than 40% from perfect equality across agro-ecologies. In all agro-ecologies, the poorest households that have the lowest share of the total income were highly vulnerable to the impacts of climate change and variability as well as environmental degradation. Over and above, households with higher LDI are less vulnerable to the impacts of climate change and environmental degradation as compared to those with less LDI, Ceteris paribus. In this case, strategies that minimize income inequalities between households could lessen households' vulnerability to the impacts of climate and environmental changes. Communities are composed of different socio-economic groups with varying degrees of vulnerability (Lasco et al., 2010). For instance, vulnerability may vary by age (Mitchell and Borchard, 2014) and gender (WEF, 2013; USAID, 2015; GHI, 2016; Jost et al., 2016). This study highlighted that there is a need to make policy strategies that can accommodate the vulnerability differences accordingly (i.e. a strategy set for lowland agro-ecology may not be suitable for a highland agro-ecology, because the two are different in their vulnerability).

The impact matrix showed that socio-ecological systems were impacted by different climatic and non-climatic factors. The degree of impact by a risk factor on ecosystem and agriculture is determined by the frequency of that particular risk factor, say drought. The aggregate impact by all risk factors would determine the performance of an agro-ecosystem and which in turn determines the performance of farmers' livelihoods and helps to suggest what adaptation measures should be taken to enhance such performances. Drought, heat wave, resource depletion were the most pressing impacts on ecosystem, agriculture and farmers in the study area. Human well-being is directly depends on ecosystem services (MEA, 2005; Louman et al., 2009). However, the results of this study showed that climate change/variability, and environmental degradation have affected these services negatively. This was also indicated by other studies that climate change has impacted the composition (USC, 2009), structure (Myster, 2001; Bellard et al., 2012; Grimm et al., 2013) and functions (Staudinger et al., 2012; Grimm et al., 2013; Beier et al., 2015; Reid, 2016) of an ecosystem and hence exacerbated socio-ecological vulnerabilities. The implication of the results is that, at given point in time, social vulnerability and biophysical vulnerability in a particular system are dependent, i.e. one could affect the other. The research also implicates the need to make agriculture climate smart that can enhance agricultural performance in time of climate change and adopt ecosystem based adaptations which can enhance and sustain the ecosystem services.

5. Conclusion

The results showed that there were differential vulnerabilities of households to climate change and/or environmental degradation across agro-ecologies of the study area with high proportion of vulnerable households in the lowland agro-ecology. Income inequality, women disempowerment, livelihood diversity index and age were some of the factors to magnify differential vulnerabilities between households. This differential vulnerability was a proxy that indicated the weak resilience capacity of the community during climatic shocks. Ecosystem and agricultural performances were found to be affected by different climatic and environmental factors. When such impacts are exceeded (high impacts and exposure scores) the ability of the ecosystem to cope with impacts, ecosystems may alter attributes that will disrupt important ecosystem functions and key environmental benefits. As well, when the impacts surpassed a threshold (e.g. when system's ability fails to respond to a drought), agricultural performance will decline and farmers' livelihood will be critically affected and become more vulnerable.

In general, understanding the differential vulnerabilities among age groups, gender, locations and so forth, making an integrated tailor-made approaches which accommodate all the differences are the cornerstones to build households' resilience to impacts of climate change/variability. In more or less in all agro-ecologies, resource depletion, drought and heat wave have the highest impact on ecosystem profiles by which the functional and supporting profiles were most affected. With respect to agricultural performances, drought and high temperature have the greatest impact by which crop production and productivity and soil moisture were the most impacted. The study gives insights that households' vulnerabilities are better proxies to indicate individual and community vulnerabilities. The study also provides directions to adaptation and land management policies and strategies in study area that can be scaled up to similar geographical locations. It further highlights the necessity that development initiatives should particularly focus on poor households so as to avoid the likely systematic differences in vulnerability. Further research on synergies and trade-offs should be considered in social and ecological systems integration to bring about a general system's resilience to the impacts of climate and environmental changes.

Conflict of interest

The authors declare no conflict of interest.

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