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Research article

Smallholder farmers' livelihood vulnerability to climate change-induced hazards: agroecology-based comparative analysis in Northcentral Ethiopia (*Woleka* Sub-basin)

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ABSTRACT

Background: Due to its climate-sensitive agricultural system and low adaptive capacity of the subsistence farmers, Ethiopia is cited among the countries experiencing frequent drought and highly vulnerable to climate change associated impacts. Micro level vulnerability assessment, in the context of a changing climate, has a paramount significance in designing policies addressing climate change induced effects. Assessing vulnerability to climate change is important for defining the risks posed by the change and it provides a starting point for the determination of effective means of promoting remedial actions to minimize impacts by supporting coping strategies and facilitating adaptation options targeted at specific context.

Methods: We employed cross-sectional survey research design has to examine the extent of livelihood vulnerability of 384 randomly selected smallholder farmers from three agroecologies which was supplemented by interviews. Livelihood vulnerability index, using integrated indicator approaches and principal component analysis, has been used. Chi-square test, F-test and t-test were used to examine association and mean differences among three agroecologies and between cropping types in terms of different attributes.

Findings: Overall, smallholder farmers living in kolla agroecology were found to be the most vulnerable to climate change induced hazards followed by dega. In terms of type of cropping season, belg dominated areas were relatively more vulnerable than those residing in meher dominated areas. Different biophysical and socio-economic attributes contributed their own role both for exposure, sensitivity and adaptive capacity differences among smallholder farmers farming in different agroecologies and different types of cropping seasons.

Conclusion: We recommend that interventions undertaken to lessen the impact of climate change should be targeted to the factors which contribute to high extent of sensitivity and for those which could enhance the adaptive capacity of smallholder farmers. Specifically, we suggest that resilience-building adaptation interventions like expansion of small-scale irrigation, accessing of microfinance service, early warning and timely information, extension support, non-farm sources of income, training and skill development, expansion of infrastructure have to be promoted thereby increase the adaptive capacity of subsistence rainfed-dependent farmers to withstand the vagaries of the climate variability risk. Moreover, disparities in the same agroecology have to be addressed properly in livelihood vulnerability discourse.

1. Introduction

Evidences have ascertained that the climate of our planet is changing [1, 2] and the impacts which are already manifested in many places of the earth are more likely to become severe as changes in climate are expected to intensify in the near future [2, 29]. Studies Leary *et.al* and EPCC [3, 4] underlined that the livelihoods of smallholder farmers are highly vulnerable to several kinds of stressors, among which climate change is the major ones. In this regard, it is of paramount importance to understand threats emanating from climate change in order to design

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strategies that will lessen risks and help to take remedial action. Thus, assessing the impacts of climate change and extent of vulnerability, as underlined by UNFCCC [1], needs good quality information. As underscored by Simane [5] the importance of vulnerability assessment in designing proper adaptation strategies as "…*effective adaptation must be on a solid understanding of local vulnerability, including adaptive capacity alongside exposure and sensitivity*". Approaches to vulnerability assessment attempt to explore questions about 'who' and 'what' is vulnerable, 'to what' are they vulnerable, their degree of vulnerability, the causes of their vulnerability, and what responses can lessen their vulnerability [6].

Vulnerabilities of people's livelihood systems are determined by their exposures to the stressors, their sensitivity to the exposures, and their capacities to resist, recover from and adapt to the effects [3]. Vulnerability analysis has been for long related with the investigation of exposure of people and ecosystems to natural hazards (risk-hazard model) which has been propagated by advocates of environmental determinism and gives more weight for environmental constraints [7]. Such risk-hazard models are not adequate enough to explain the complex issue of vulnerability. In the recent discourse of vulnerability, besides natural calamities, socio-economic and political systems have been considered as major factors which make people vulnerable [8]. The Disaster, Pressure and Release Model and Access Model developed by Wisner *et.al* [8] are amongst the popular and widely employed approaches in the vulnerability analysis and emphasized that disaster is primarily the result of human actions rather than the natural factors which only have a triggering role. Very similar to access model, the entitlement concept, which was developed by Sen [9, 10], argued that individuals become poor if they do not have the freedom to achieve their goals of well-being (lack of entitlement and capabilities) and they become vulnerable when this lack of freedom persists over time, which Sen labeled 'vulnerability as lack of entitlements' [10]. According to the theory of entitlement, famine and food insecurity are not products of predominantly drought and crop failure, rather the results of entitlement failure [9].

Vulnerability and exposure are dynamic, varying across spatiotemporal scales and depend on different factors. As a result, the actual factors that determine vulnerability and reinforced adaptive capability are context specific and vary spatially [2, 5, 25]. Effects of climate change can only be understood if types of livelihoods, the extent of vulnerabilities and adaptive capacities of affected communities are well explored at the micro level [3]. Estimating vulnerability, in the context of a changing climate, is an important component of any intervention attempt to lessen the magnitude of the threat. Besides, it provides a starting point for the determination of effective means of promoting corrective actions to minimize impacts by enhancing coping strategies and facilitating adaptation options targeted at specific context [8]. Accordingly, vulnerability to climate change assessment at the grass root level has been becoming indispensable [11, 12]. IPCC [2] in its fifth assessment also stressed that "*impacts of climate change will vary across regions and populations, through space and time, dependent on myriad factors including non-climate stressors and the extent of mitigation and adaptation*". According to USAID [13], large numbers of adaptation programs had failed simply because they were not able to properly identify major aspects and magnitude of the vulnerabilities of communities. Vulnerability assessments conducted at the macro level will fail to capture location specificity of smaller areas which calls for the need of detailed explorations at finer spatial level. Based on this consensus and since the effects of observed and forthcoming changes in climate are spatially and socially differentiated [14], micro level vulnerability assessment has a paramount significance in order to design policies addressing climate change induced vulnerability.

Smallholder farmers in Ethiopia are more vulnerable to climatic change mainly due to their high dependence on rain-fed agriculture, low adaptive capacity and a higher dependency on natural resources base for livelihood [15]. In its latest growth and transformation plan [31], the intrinsic relationship between climate change and sustainable development as well as the impact of climate change on smallholders which are dependent on rainfed agriculture in Ethiopia has been stated as *climate and development are strongly interlinked: well-designed policies in these areas can make growth and climate objectives compatible and mutually reinforcing in both the short and medium terms. In the long term, if climate change is not tackled, growth itself will be at risk* (NPC, 2016:92–93). EPCC [4] particularly identified the highland areas in Ethiopia as among the most vulnerable agroecology due to the smaller per capita land availability, highly fragmented parcel of farmland, lower level of asset building, erratic nature of rainfall and lower level of experience to adapt to climate change impacts. Northcentral part of Ethiopia (where this was conducted) is among the drought-prone areas in Amhara National Regional State (ANRS) and it is among the food insecure areas of the country where farming is practiced in the context of unreliable rainfall [11]. This area has frequently suffered from recurrent drought often followed by devastating famine [16]. Since the study area is among the drought-prone areas of the country which has been affected and is expected to be affected severely by the changing climate, investigating the extent of vulnerability of smallholder farmers and accompanying factors would have a significant contribution to formulate policies which would enhance their adaptive capacity and resilience. According to NMA [15], quantitative climate change impact assessments made so far in various socio-economic sectors in Ethiopia are not adequate. There are few studies on livelihood vulnerability of subsistence farmers to climate change in Ethiopia [see, for example, 5, 17, 18, 19, 20]. The study by Temesgen *et.al* [17] was based on the integrated vulnerability assessment approach using indicators at the macro level. Such macro scale vulnerability assessment could not show variations in terms of the extent of vulnerability of smallholder farmers and on their adaptation strategies based on their locality-based assets. Moreover, the analysis carried out by Temesgen *et.al* [17] relied on analyzing vulnerability as a function of physical factors; which is based on risk-hazard approach [7]. But in addition to the physical factors, the political ecology [8] and entitlement failure [10] are also equally important in determining vulnerability of systems or people. We have used the integrated approach to analyze vulnerability of smallholder farmers by considering both the physical and socio-political factors. Besides, most studies in Ethiopia [5, 17, 20] employed agroecology-based assessment of vulnerability and came up with mixed results. For instance, Temesgen *et.al* [17] found that *kolla* zone was more vulnerable than other agroecologies. This was not true for Tesso *et.al* [19] which revealed that farmers living in the highland areas were found much vulnerable to climate-induced shocks than lowlands while lowlands were found even better than midlands. On the other hand, Teshome [20] found that *kolla* as more vulnerable than *woinadega* and *dega* agroecologies. A study by Negatu *et.al* [18] used livelihood-type based assessment of vulnerability and disclosed that agropastoral area with limited mobility were more vulnerable than nomadic pastoralists though both are found in the same agroecology. Such results indicated that, besides agroecological variation, different variables even in the same agroecology determine the extent of vulnerability and the type of adaptation strategies; therefore, needs further investigations. This study, therefore, was designed to contribute to the academic debate and considers the type of cropping season as a unit of analysis besides agroecology. Methodologically, vulnerability assessments conducted by [5, 20, 29, 30] have assigned equal weight for the indicators which might lead to overweighting of some less important indicators and underweighting of the important ones. On the other hand, Tesso *et.al*, Opiyo *et.al* and Mekonnen *et.al* [19, 21, 28] employed weighting methods. As a result, Principal Component Analysis (PCA) technique has been applied in this study so as to use indicators based on their contributing factor. Furthermore, most studies revealed only the overall sensitivity and exposure as well as adaptive capacity status of a system. Such approach does not show the explicit contribution of different attributes which creates differences in the extent of sensitivity, exposure, and adaptive capacity. Quantifying the contribution of each of the major indicators to their respective contributing factors enables to prioritize intervention actions. For such purpose, using PCA is highly recommended and we have followed this approach in this study.

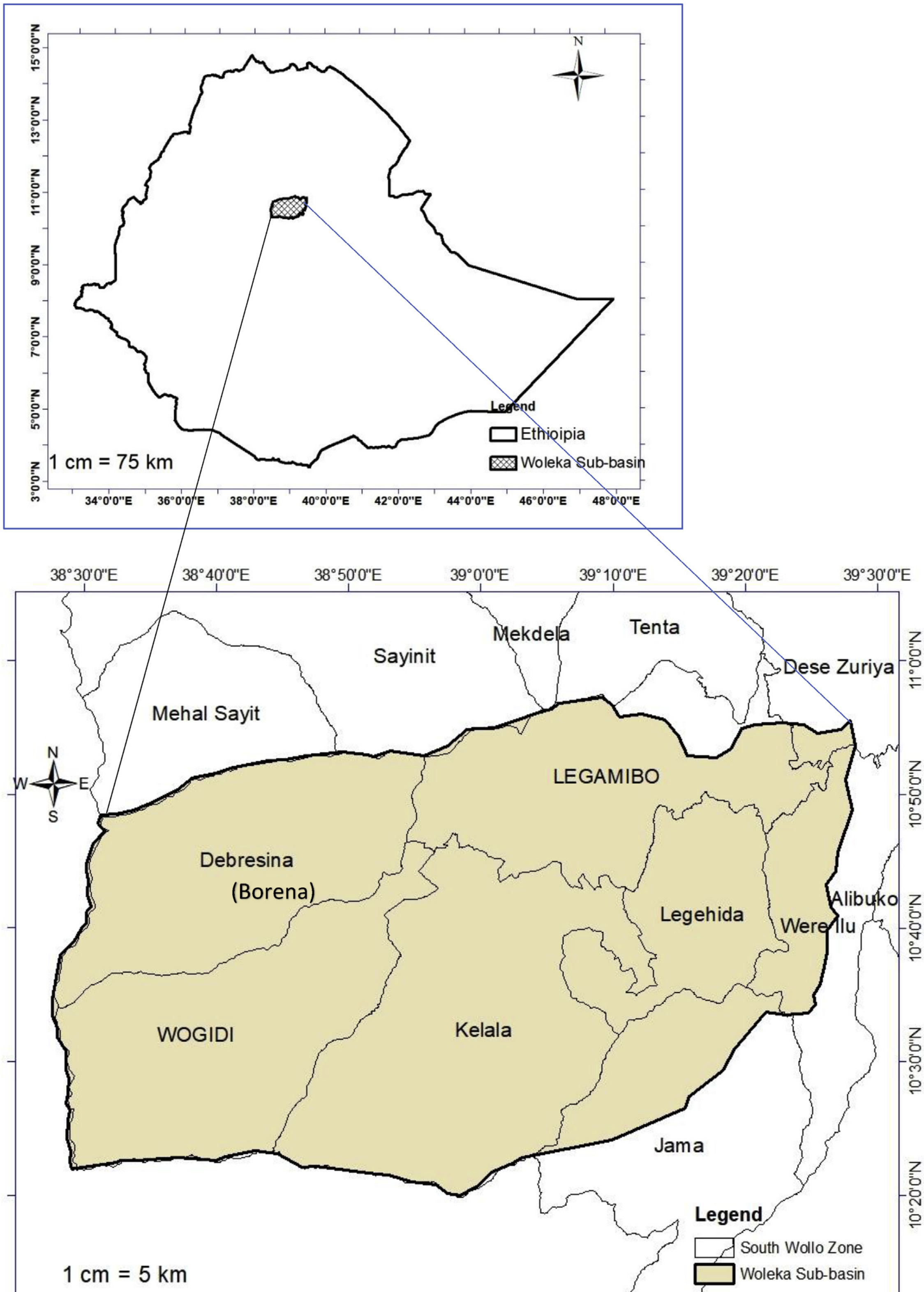

Figure 1. Relative Location of Woleka Sub basin.

Identifying the types of livelihoods and their degree of vulnerability to climate change plays a considerable contribution in designing climate change adaptation strategies. Vulnerability assessment in recent times is, therefore, recognized as a decisive step to identify feasible climate adaptation interventions and improve the adaptive capacity of the affected community. But, the fact is that very little empirical research has been carried out in the study area on the nexus of vulnerability; since the problem is severe; conducting research on such contemporary issues is relevant and timely so as to build the adaptive capacity of smallholder rainfed dependent farmers. This study intended to examine the extent of vulnerability of smallholder farmers to climate change based on agroecology. The study particularly focused on answering these questions: 1) To what extent do smallholder farmers are vulnerable to climate variability and change? 2) Is there any variation in the extent of livelihoods vulnerability based on agroecology? 3) Are *belg*[1] (small rainy months) dominated areas more vulnerable to climate variability and change than *meher* (main rainy season) dominated ones in dega agroecology? and 4) Which factors lead smallholder farmers to become vulnerable to impacts of climate change?

2. Methods and materials

2.1. Familiarizing the study area

Woleka sub-basin, which is found in the North central part of Ethiopia, covers an estimated area of 6,415 km^2 and situated approximately between $10^0 15'$-$10^0 55'$N and $38^0 25'$-39^0-30′E (Figure 1). The geographical altitude of the area ranges between 1070 and 4200 m above sea level (masl) which makes the area to have an agroecology types ranging from afroalpine to warm moist lowlands [22]. The long term mean annual rainfall of the area is 1150 mm with 15.85% coefficient of variation. There is high rainfall concentration, high intra- and inter-annual variability of rainfall while Palmer drought severity index proved the increasing trend of the number of drought years [32]. Mixed farming, which encompasses rainfed crop production and animal husbandry, is the major stay of smallholder farmers and the area is among the intensively cultivated parts of the country [23]. The major challenged in the farming sector are unreliable rainfall, poor soil fertility and small per capita landholding [16,23,32], [33]. As a result, as disclosed by SWDoFED [23], greater proportions of farmers did not produce enough food, the majority are severely food insecure and depended largely on food aid.

The area received a considerable amount of rainfall from June to mid-September (main rainy season), locally known as *kiremt*, and February to May is the small rain season, which is locally known as *belg* [22, 24] which makes the area to have bimodal rainfall regime leading to two harvesting periods [22] but the small rainy season is highly variable and experienced frequent failure which hampers *belg* harvesting [24]. Delayed onset and early cessation coupled with poor belg performance make the area as food insecure. The rugged and bare mountains of the sub-basin also enhance runoff, resulting in land degradation and hence low soil productivity. Thus, the area is one of drought-prone and food deficit areas of the country where food aid is a major source of livelihood for most of the population [16].

2.2. Research design

2.2.1. Data: types, source, collection tools and analysis techniques

We employed cross-sectional survey design to investigate the extent of vulnerability of smallholder farmers in the context of climate change and factors contributing to their vulnerability. Using pilot tested structured survey questionnaires, data were collected from household heads mainly focusing on the demographic, socio-economic characteristics of respondents, and the biophysical characteristic of the study area. Livelihood Vulnerability Index (LVI), based on IPCC and Hahn *et.al* [2, 25], was used to estimate the degree of smallholder farmers' vulnerability to climate variability and change. Results were compared based on agroecology and type of cropping seasons. PCA was used to know the factor loading (See Annex 3) of each variable.

[1] *Belg* (short rain season) which extends from (February–May) while *Meher* or Kiremt (long rain season) which extends from June–September [15].

2.2.2. Sample frame and sampling technique

Due to its high likely extent of vulnerability to the negative impacts of climate change [32], [33] and its heterogeneity in agroecology [23], [33], *Woleka* sub-basin, was purposively chosen for this study. Multistage stratified random sampling procedure was applied to select representative samples for survey study. Legambo and Borena districts were purposively selected considering their heterogeneity in agroecology (*dega*, *woinadega* and *kolla*[2]) and type of cropping seasons (*belg* and *meher*). *Kebelles*[3] from each agroecology and household heads were selected randomly from a list obtained from corresponding *Kebelle* administrations. Out of 57,485 household heads lived in the study area during the survey period (of which 19461, 21557 and 16467 were in *dega*, *woinadega* and *kolla* agroecologies respectively), 384 household heads (130, 144 and 110 from *dega*, *woinadega* and *kolla* respectively) were selected using proportionate random sampling technique by applying the following formula.

$$n = \frac{Z^2 * N * p * q}{e^2(N-1) + Z^2 * p * q}$$

Where n is the desired sample size; N is the total target population; Z is the standardized normal deviation set at 1.96–95% confidence level; *p* is the estimated proportion of an attribute that is present in the population (0.5); q is the estimated proportion of an attribute that is not present in the population (1-p) (0.5); e is the degree of accuracy required normally set at 0.05 (5% of acceptable sampling error).

2.2.3. Livelihood vulnerability index model specification

Vulnerability assessment is a process for assessing, measuring, and characterizing exposure, sensitivity and adaptive capacity of a natural or human system to disturbance. It enables to properly identify vulnerable areas, specific capacities and potential responses of vulnerable people in the context of exposure in a particular location and it is identified as a vital tool for developing countries to evaluate and implement responses to climate change [1]. Vulnerability to climate change can be measured using the econometric and the integrated indicator approach [26]. Since composite indices capture the multi-dimensionality of vulnerability in a comprehensible form and combines both socioeconomic and biophysical attributes in vulnerability analysis [5, 6, 19, 25, 28], we have used a similar approach. LVI has been developed based on the concept of vulnerability as a function of the character, magnitude and rate of climate variability and change to which a system is exposed, people's sensitivity and their adaptive capacity. The indicators used to measure the extent of vulnerability to climate change for this study were grounded on sustainable livelihood framework and by adopting from [5, 25] tailoring to the context of rainfed dependent smallholder agrarian communities (see Annex 2). The process of construction of a vulnerability index progressed from a selection of indicators, assignment of weights and finally their aggregation to form an index.

The most conceivable way in calculating the contributing factor of each indicator is using PCA technique because in addition to its objectivity, it enables to estimate the contribution of each variable to the state of vulnerability [18]. As a result, the PCA was used to find out the contributing weight of each indicator. The magnitude of the weights describes the contribution of each indicator to the value of the index [27]. PCA was run separately for the indicators of exposure, sensitivity and subcomponents of adaptive capacity. The computation of indicator value for LVI followed the process of standardization adopted from the computation of the Human Development Index.Since the subcomponents are measured on a different scale; they have to be first standardized using the following indexes (see equation 1). Then after, the standardized value

[2] *Kolla* (agroecological zone equivalent with lowland between 500-1500 m above sea level); *woinadega*, (midland, between 1500 to 2300 m) and *dega*, highland, between 2300 and 3200 m).

[3] The smallest administrative division next to *woreda*(district).

of each indicator was multiplied by its respective absolute weight (first factor loading) which is derived from PCA result to calculate indices for each indicator.

$$IndexS_i = \frac{Actual - Minimum}{Maximum - Minimum} or \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (1)$$

But, where a sub-component has a negative relationship with vulnerability or when a higher value is good and has a positive contribution in minimizing vulnerability (like educational status, access to microfinance), the normalized value for each indicator can be computed by (1-index S_i) or the formula should be re-written as indicated in Eq. (2):

$$IndexS_i = \frac{Maximum - Actual}{Maximum - Minimum} or \frac{X_{max} - X_i}{X_{max} - X_{min}} \quad (2)$$

where S_i is the dimension value of each indicator; X_i the actual value for the specific indicator; and X_{min} and $X_{max:}$ the maximum and minimum sub-dimension values. After the weight of each variable is decided, they are aggregated into a composite index using Eq. (3). Therefore, the additive method of aggregation was used.

$$S_i = \sum_{i}^{i=n} W_i X_i \quad (3)$$

where S_i the normalized respective index value for each indicator (after weighting), W_i is the factor loading of each indicator obtained from the first PCA and X_i is the individual value of the indicator. After standardizing each indicator and weighted using the respective loading factors, the value of each dimension was calculated using Eq. (4):

$$M_v = \frac{\sum_{i=1}^{n} Index_{si}}{n} \quad (4)$$

where M_v: one of the major components; $\sum Index_{sv}$: summation of the sub-component and 'n' is the number of sub-components in each major component. Once values for each of the major components are calculated, they have to be averaged to obtain the total level of LVI using Eq. (5).

$$LVI_r = \frac{\sum_{i=1}^{7} Wm_i Mv_i}{\sum_{i=1}^{7} Wm_i} \quad (5)$$

where LVI_r: the livelihood vulnerability index for region 'r' (equals the average of the major components). The weights of each major component (Wm_i) are determined by the number of sub-components that make up each major component. LVI is scaled from 0 (least vulnerable) to 1 (most vulnerable). LVI-IPCC index is calculated by taking the three important parameters of vulnerability used by IPCC (namely: Exposure, Sensitivity and Adaptive Capacity). It uses the same indicators as LVI but rather than merging the major components, they are first combined according to their contributing factor. In the case of calculating IPCC-VI, the inverse of some components (to find adaptive capacity index) is not applied that is taken during the calculation of LVI. The reason is that, when such components (like education), which are assumed to increase adaptive capacity and resilience of community to the adverse impacts of climate variability are inversed, the final output becomes a paradox. Taking inverses of those components in adaptive capacity, contributing values would tend to zero which means educated households bear less adaptive capacity that is not theoretically true. The value for each contributing factor is calculated using Eq. (6).

$$CF_r = \frac{\sum_{i=1}^{n} Wm_i M_{ri}}{\sum_{i=1}^{n} Wm_i} \quad (6)$$

where CFr is an IPCC defined contributing factor (exposure, sensitivity or adaptive capacity), for region 'r'; M_{ri} is the major components for region 'r' indexed by i; W_{Mi} is the weight of each major component, and n is the number of major components in each contributing factor. Once exposure, sensitivity, and adaptive capacity are calculated, the three contributing factors will be combined using Eq. (7) [21].

$$LVI_{IPCCr} = [E_r - AC_r] * S_r \quad (7)$$

Table 1. LVI-IPCC Normalized Value calculation.

Factor	Capital	Profile (sub-component)	Total value				
			Agroecology			Cropping season	
			Dega	*w/dega*	*Kolla*	*Belg*	*Meher*
Exposure		Historical trends	.24	.26	.33	.34	.28
		Extreme Events	.72	.63	.75	.72	.73
		Contributing factor Value	**.551**	**.499**	**.602**	**.586**	**.571**
Sensitivity		Ecosystem (Biophysical environment)	.527	.449	.535	.511	.476
		Agricultural system	.548	.35	.555	.555	.539
		Water resource security	.430	.399	.588	.414	.447
		Contributing factor Value	**.510**	**.397**	**.557**	**.503**	**.493**
Adaptive Capacity	Human	Demographic	.695	.723	.722	.681	.713
		Knowledge and skill	.433	.443	.357	.437	.409
		Health and Food	.43	.633	.391	.419	.447
	Social	Networks and Relationships	.752	.635	.707	.763	.756
	Financial	Assets and Wealth	.39	.458	.347	.371	.414
	Physical	Technology	.417	.619	.361	.421	.504
		Infrastructure	.835	.844	.653	.859	.803
	Natural	Land Resource	.26	.21	.31	.27	.2
	Contributing factor Value		**.506**	**.572**	**.452**	**.505**	**.513**
LVI-IPCC value= [(Exposure - adaptive capacity) *sensitivity]			0.023	-0.029	0.084	0.041	0.029

−1(least vulnerable) to +1(extremely vulnerable); while 0 denotes moderately vulnerable
Source: Own survey (2015/16).

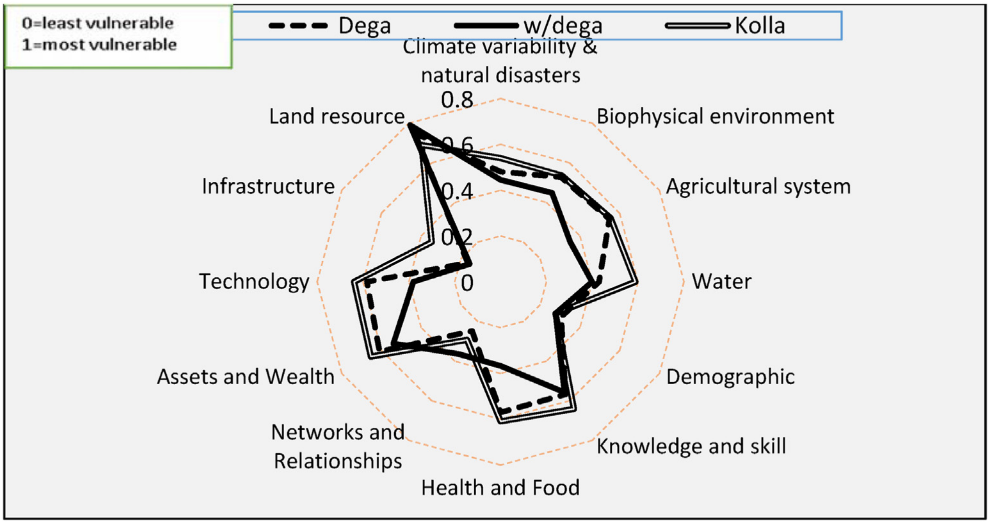

Figure 2. LVI-IPCC spider diagram based on Agroecology.

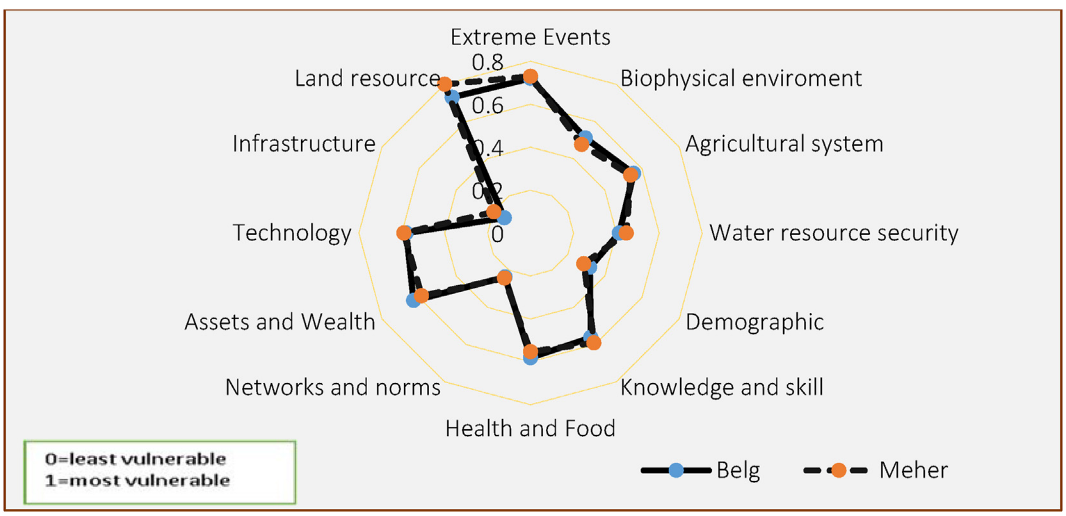

Figure 3. LVI-IPCC spider diagram based on type of cropping season.

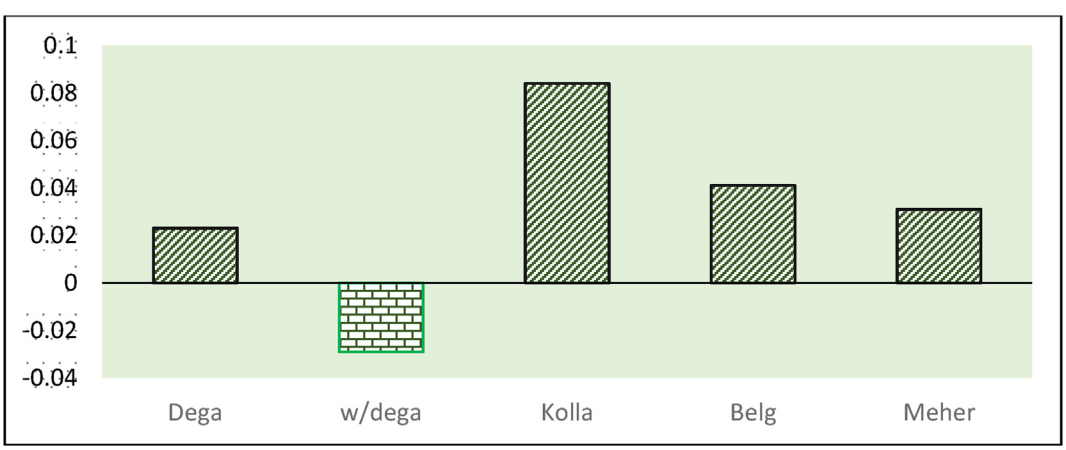

Figure 4. LVI-IPCC result based on agroecology and cropping season.

where: LVI_{IPCCr} is the LVI for region 'r' expressed using the IPCC vulnerability framework, 'E' is the calculated exposure score for region 'r' (equivalent to the natural disaster and climate variability major component), 'S' is the calculated sensitivity score for region 'r' (weighted average of biophysical environment, agricultural system and water) and 'AC' is the calculated adaptive capacity score for region 'r' (weighted average of the socio-demographic, assets and wealth, physical assets and social networks major components). The LVI_{IPCC} value scaled from -1 to +1, where -1 denotes least vulnerable (adaptive capacity is more than exposure and sensitivity), 0 denotes moderately vulnerable (exposure and adaptive capacity are equal) and 1 denotes extremely vulnerable: exposure and sensitivity are higher than the adaptive capacity [25].

2.3. Ethical consideration, ethical approval and consent to participate

This study was approved by the Addis Ababa University ethical committee (Approval number: Ref. No. CDR/CDS/AAU/048/2016) and South Wollo zonal Administrative office (approval number: SW/ADM/04/0419/2016). Written permission was obtained from South Wollo zonal administrative offices prior to conducting the study. During survey, official letters were written for each district; informed verbal consent was obtained from each respondent, and confidentiality was maintained by giving codes for each respondent rather than recording their name. Study participants were informed that they have full rights to discontinue or refuse to participate in the study. Hence, all participants throughout the research, including survey households, enumerators, the supervisors and key informants, were fully informed of the objectives of the study. Besides, the study complies all the necessary research regulations and ethical consideration.

3. Results and discussion

3.1. Livelihood vulnerability of smallholder farmers to climate variability and change: agroecology-based comparative analysis

The vulnerability indices being relative values are compared across three agroecologies and between two cropping seasons. In terms of the overall LVI, *kolla* agroecology (lowland) was found to be the most vulnerable (0.534) followed by *dega* (highland) (0.483); while *woinadega* (midland) (0.417) was found to be relatively better (see Annex 1). Cognizant to our findings, a similar result in Ethiopia was found where lowlanders were found to be most vulnerable than other agroecologies [17, 20, 28, 31]. The vulnerability level of *belg* growing areas and *meher* growing areas was almost the same with *belg* (0.489) being slightly more vulnerable than *meher* dominated areas (0.477). In terms of LVI-IPCC (see Table 1 and Figures 2, 3, and 4), smallholders in *kolla* agroecology (0.084) were again found to be the most vulnerable followed by *dega* (0.023) while *woinadega* (-0.029) was the least vulnerable. In this regard, *belg* dominated areas (0.041) were found to be more vulnerable to climate variability and change than *meher* (0.029) dominated ones. Similar finding was reported by Negatu *et.al* [28], where farmers in the same agroecology but different way of life had differential status of vulnerability. Such results implied that vulnerability analysis should be disaggregated even in similar agroecology.

The extent of exposure to climate variability and change was assessed in terms of climate variability, the prevalence of extreme events and natural disasters. Based on this parameter, *kolla* (0.54) agroecology was found to be the most exposed to climate variability followed by *dega* (0.48) while *woinadega* was relatively better (0.45). When we compare the extent of exposure between *belg* and *meher* dominated areas in *dega* agroecology, households depending on *belg* (0.53) was found to be relatively more exposed to extreme events and climate variability than those living in *meher* (0.505) dominated areas. From the PCA output, erratic and short duration of rainfall, late onset of rainfall and seasonal variability of rainfall, frequent dry spell periods during rainy seasons, death and injuries of livestock due to climate-related hazards, and injury of family members due to climate-induced risks were found to be the major contributing factors.

3.2. Sensitivity of smallholder farmers to climate variability and change as assessed using selected indicators

The sensitivity component of vulnerability analysis was computed using the biophysical, agricultural system and water resource indicators. In this regard, *kolla* (0.559) was also found the most sensitive agroecology followed by *dega* (0.502) and *woinadega* (0.399). In the rift valley region of Ethiopia, it was reported that the extent of sensitivity in highland agroecology was fond to be more than other agroecologies [28]. The vulnerability index for the water resource component of the LVI showed that *kolla* (0.588) agroecology be the most and *woinadega* (0.399) the least vulnerable. The prominent water-related indicators those with higher load and brought a significant difference in the extent of sensitivity were: time spent to get water, the proportion of household having unprotected source of water and incidence of conflicts due to water scarcity. For instance, nearly 39% of the respondents from *kolla* had reported unprotected sources of water while the figure for *woinadega* and *dega* was only 13.2% and 7.7%. The average time taken to get water for home consumption in *kolla* agroecology (0.612 h) was higher than *dega* (0.34hours) and *woinadega* (0.31hours) agroecologies; and the difference was statistically significant (F (2, 381) = 30.3; $p < 0.05$).

The vulnerability index for the agricultural system evidenced that *kolla* (0.555) and *dega* (0.548) were found to be more vulnerable than *woinadega* (0.35) agroecology. The major factors having more weight and make a difference in the extent of sensitivity were land per capita, being highly dependent on rainfed agriculture (not supported by irrigation), reliance on food aid, incidence of failure of crop and sharing out of agricultural land. The majority (82.7%) of households in *kolla* agroecology had received food aid at least once for the last three years followed by *dega* (68.5%) and *woinadega* (42.2%). Smallholder farmers in *woinadega* (34.7%) do have better access to irrigation than *dega* (29.5%) and *kolla* (only 13.6%) and the difference in proportion was statistically significant (χ^2 (2) = 18.8; Phi = 0.22; $p < 0.05$). Sensitivity to climate variability and change is also assessed based on the degree of vulnerability of the biophysical environment. In this parameter, *kolla* (0.535) and *dega* (0.527) were found to be more sensitive than *woinadega* (0.449) agroecology. Similar finding was reported when the extent of resource depletion was found to be high in the highland areas which contributes for high extent of sensitivity [28]. In terms of their factor loading, being dependent on forest-based energy sources, the extent of using traditional stoves, access of information on climate-related problems and early warning, and time spent in collecting firewood was found to be the significant contributors. As far as sensitivity to climate variability and change is concerned, smallholder farmers from *belg* (0.493) cropping season have found to be relatively more sensitive than those living in *meher* (0.455) dominated areas. During interview, a respondent from *belg* growing areas in Legambo district also voiced that, "*most of our agricultural land is infertile and its moisture holding capacity is very low* [agricultural drought]. *The situation is aggravated by the shortage and erratic nature of rainfall* [meteorological drought]. *It is just 'mumps on goiter' and makes the farming system very challenging*" which in modern literature is termed as 'double exposure'.

3.3. Livelihood assets and adaptive capacity of smallholder farmers to climate change

The relationship between exposure and sensitivity with vulnerability is proportional; meaning highly exposed and sensitive areas are expected to be more vulnerable to climatic related impacts. The situation for adaptive capacity is different; individuals or systems that have better adaptive capacity are expected to be less vulnerable to climate variability and change. Based on this consensus, the adaptive capacity of smallholder farmers in the three agroecologies has been measured. Overall, *woinadega* (0.572) was found to be better in adaptive capacity (less vulnerable) followed by *dega* (0.506) and the least in adaptive capacity (most vulnerable) was *kolla* (0.452) agroecology. Consistent with this finding, Mekonnen *et al.* [28], had reported that low adaptive capacity in the lowland agroecology contributed smallholder farmers to be more vulnerable. Human capital, financial capital, and physical capital were found better in *woinadega* agroecology while social capital and natural capitals were found better in *dega* agroecology. Indicators with the highest PCA result and have contributed more to adaptive capacity among the human capitals were: total family size in productive age group, educational status of the household head, frequency of contact

Table 2. Financial capital (assets and wealth) comparisons based on agroecology.

Indicators (parameters)	*Dega*	*W/dega*	*kolla*	χ^2/*F*-test
Total land size (hectare per household)	0.77	0.626	0.797	12.53***
TLU per household	4.056	3.301	4.549	8.17***
Proportion of non-poor households (%)	62.3	73.6	60.9	5.79*
Having non-agricultural source of income (%)	36.2	36.1	34.5	0.086
Having no debt to pay back (%)	31.5	68.8	40	41.78***
Using money borrowed for productive activities (%)	31.1	72	28.8	29.5***
Having a saving account in microfinance or bank (%)	36.9	43.6	28.2	6.27**
Having access to formal financial institutions (%)	53.8	55.6	30.9	17.95***
Having income from remittance (%)	33.8	30.6	16.4	10.12***
Overall financial capital index	0.39	0.46	0.35	

Note: *, **, *** statistically significant at 0.1, 0.05 and 0.01 alpha level respectively.
Source: Own survey (2015/16).

Table 3. Proportion of households using modern agricultural inputs and technology.

Proportion (%) or mean	*Dega*	*W/dega*	*kolla*	χ^2/F-test	*Belg*	*Meher*
Using insecticide/pesticide/herbicide	16.2	46.1	31.8	27.99***	22.7	7.3
Using organic fertilizer	66.9	85.8	67.3		64	70.9
Improved seeds	48.5	80.1	50.9	34.98***	41.3	58.2
Having irrigation access of any type	29.5	34.7	13.6	18.78***	23	38.2
Having house of corrugated sheet	66.2	93.8	53.6	55.37***	74.7	54.5
Using modern fuel-efficient stove	38.5	53.5	10	51.74***	48	25.5
Average fertilizer used in one harvesting season (Kg/Ha)	112.1	218.4	123.4	40.24***	106.9	118.2
Overall Technology sub component index	0.417	0.619	0.361			

Note: *** statistically significant at 0.01 alpha level respectively.
Source: Own survey (2015/16).

with development agents (DAs), average number of food sufficient months, having capacity to cover medication costs, having financial capacity to fill out food deficit, proportion of households free from food aid, proportion of household producing enough and more food by themselves, proportion of households who completed all rural health packages and size of chronically ill members. In connection with this, Mekonnen *et al.* [28], confirmed that human capitals, like educational status and age of the household head, played a paramount contribution in enhancing the adaptive capacity of farmers to the adverse impacts of climate change.

As far as knowledge and skill parameters are concerned, smallholder farmers living in *woinadega* agroecology do have better adaptive capacity followed by *dega* while the case for *kolla* is the least. Health situation and nutritional intake of individuals are among the worth mentioned determinants in building adaptive capacity. Based on this concept, the adaptive capacity of the three agroecologies in terms of health and food parameters (as a sub-component of human capital) was compared. The average index value for health subcomponent proved that households in *woinadega* agroecology had better adaptive capacity (0.633) followed by *dega* (0.43) and those living in *kolla* had the least (0.391). When individual parameters are evaluated separately, the difference among the three agroecologies is noticeable. For instance, 48.2 percent of households from *kolla* agroecology had reported of having a chronically ill family member(s) or/and having a family member(s) demanding support while the proportion for *dega* and *woinadega* was only 28.3 and 6.9 percent respectively. *Kolla* agroecology is more prone to water and climate-induced diseases than *dega* and *woinadega* agroecologies.

Nearly a quarter of the surveyed households, of which the majority were from *kolla* agroecology and *belg* dominated areas, struggle more than four food deficit months yearly to get life sustenance bread for their family. The average number of food deficient months was found to be highest in *kolla* (2.52) followed by *dega* (2.42) while the case in *woinadega* was better (1.69). Sampled respondents in *woinadega* agroecology were found to be better in their capacity to take medical treatment whenever needed, in completing basic rural health packages, can produce enough food for their family, average food insufficient months were less, and have better financial capacity to fill out food deficit. The finding implies that development interventions to be undertaken by government and/or NGOs should take into consideration of such disparities.

The adaptive capacity of smallholder farmers farming in *belg* and *meher* dominated areas was compared separately particularly in their human capital. Overall, the adaptive capacity as far as human capital is concerned for these two areas was almost the same (0.47 for *belg* and 0.48 for *meher*). A pronounced difference was observed in terms of educational attainment of heads: the mean educational level of the household was

Table 4. Infrastructure (Average time taken to the nearest physical infrastructure).

Average walking distance in hours to the nearest:	*Dega*	*W/dega*	*kolla*	Mean	F-test
All weather road	.78	.37	2.76	1.2	182.4***
Health centre	.75	.61	1.75	0.98	136.2***
First cycle School	.36	.30	.45	0.37	19.7***
Veterinary service	1.03	0.69	1.67	1.09	69.22***
Input/output major market	1.09	1.6	3.32	1.9	216.8***
Telecommunication centre	1.18	1.59	1.93	1.6	18.5***
FTC	.72	.64	1.53	0.92	79.8***
Overall Index of the sub component	**.835**	**.844**	**.653**		

Note: *** statistically significant at 0.01 alpha level respectively.
Source: Own survey (2015/16).

Table 5. Major indicators of natural capitals based on agroecology and cropping season.

Indicators	*Dega*	*W/dega*	*kolla*	F-test	*Belg*	*Meher*	t-test
Agricultural land size of the HH in Ha	.71	.569	.769	17.99***	0.60	0.86	6.65***
Wood land size of the HH in gemed	0.86	1.37	0.2	2.46	.86	.72	0.86
Grazing land of the HH in gemed	1.59	1.48	1.81	1.046	1.66	1.48	0.66
Irrigation land of the HH in gemed	1.217	1.224	1.3	0.029	1.57	0.67	3.99***
Overall Index of Natural capital	0.26	0.21	0.31		0.27	0.20	

Note: *** statistically significant at 0.01 alpha level respectively.
Source: Own survey (2015/16).

1.96 and 3.47 years of schooling for *belg* and *meher* respectively. Relatively more households from *belg* dominated areas have had training on the operation and management of small-scale businesses and have made more contacts with health extension workers. The incidence of more training opportunities and contacts with DAs in *belg* dominated areas was due to the involvement of NGOs in the drought-prone areas where *belg* harvest had failed for consecutive years. Households from *belg* cropping season had faced shortage of food relatively for a longer period (for about 3.76 months per year) while it was less (2.92 months) in *meher* dominated areas. The proportion of households having the financial capacity to fill out food deficit was 40 and 36 percent for *meher* and *belg* areas respectively; while the proportion of households taking meal type and quality reduction whenever there is a shortage of food for the whole family was the same for both areas (around 70%).

Financial capacity would play a vital role in building the adaptive capacity of smallholder farmers to the adverse impacts of climate change. As a result, the extent of the adaptive capacity of smallholder farmers in terms of financial capital was compared. As presented in Table 2, in terms of financial capital parameters, though *woinadega* seems better, the difference was not as such remarkable. Among the indicators used to measure financial capital, those with the highest PCA result and make a difference among individuals were having financial service and saving account in formal financial institutions, having income from non-agricultural sources, wealth status and relatively TLU. More households from *dega* and *woinadega* had a non-agricultural source of income than *kolla* areas. A study by Mekonnen *et al.* [28], reported a similar result where the extent of vulnerability of household with diversified source of income were found to be less as compared with their counter parts.

The proportion of non-poor households was higher in *woinadega* than others. In terms of livestock asset (in TLU), households in *kolla* (4.55) and *dega* (4.06) were found to be better than *woinadega* (3.30); and the difference was statistically significant (F (2, 381) = 8.17; p < 0.05). Such differences might be due to a difference in availability of grazing land where it is relatively better in *kolla* and *dega* agroecologies. As far as financial capital is concerned, *meher* dominated areas (0.414) were found to be better than *belg* growing areas (0.371). The livestock asset (in TLU) was relatively high for *meher* (4.79) than *belg* (3.52) areas (t (128) = 3.16; p < 0.005). Around 58.2% of households residing in *meher* dominated areas do have a source of income from non-agricultural sources while the figure for *belg* was 44.4%. More households in *belg* dominated areas have used the money received from financial institutions for consumption smoothening and faced a problem of paying the debt back. Such disparities between different cropping zones but in the same agroecology indicate the importance of conducting vulnerability assessment based on locality contexts. A similar difference in vulnerability based on the type of livelihood (but similar in agroecology) was also reported by Negatu *et.al* [18].

Having easy access to physical capitals is a vital resource in building the adaptive capacity of smallholder farmers so as to overcome the adverse effects of climate change. As part of the physical capital, the major indicators having better factor loading and make a difference in adaptive capacity of households were access to irrigation, the extent of applying selected seeds, average fertilizer used, having a house with a corrugated iron sheet and proportion of households using fuel-efficient stove. Having irrigation access was reported among the factors which determine the adaptive capacity of subsistence farmers [28]. A poor female-headed household from Borena woreda (Betaso *Kebelle*) beneficiary of small-scale irrigation affirmed that '*it is the money earned from the selling of cabbage and potato which enabled me to cover the educational logistic of school-age children and to cover all my expenses*'. This evidenced the importance of small-scale irrigation particularly to the marginalized segment of the population in withstanding the adverse impacts of climate change. Entitlement failure of basic assets, as argued by Sen [9], has implication in worsening the extent of vulnerability to adverse impacts of climate change. As portrayed in Table 3, farmers in *woinadega* agroecology were found better (0.619) in applying technological outputs in the agricultural system followed by *dega* (0.417) and the case in *kolla* was the least (0.361).

When we observe the contribution of each indicator, a great proportion of households in *woinadega* have used insecticide and pesticide, organic fertilizer, improved seeds, have better access to irrigation, the roof of their house is corrugated iron sheet and use modernfuel-efficient stove. The mean amount of fertilizer used per hectare (Kg/ha) during 2015/2016 harvesting season was 112.1, 218.4 and 123.4kg for *dega*, *woinadega* and *kolla* agroecologies respectively and the mean difference was statistically significant (F (2, 288) = 40.24; p < 0.05). Regarding the technology sub-component of physic capital (as part of adaptive capacity to climate variability and change), *meher* cropping seasons (0.504) are better than *belg* dominated ones (0.421). Access to basic infrastructures in rural communities would play a significant role in building the adaptive capacity of smallholder farmers. As far as infrastructure sub-component of physical capital is concerned, *dega* and *woinadega* were found to be better than the situation in *kolla*. The average time taken to reach the nearest basic infrastructures was lower in *woinadega* agroecology; while *dega* agroecologies do have better access to market and telecommunication centers (see Table 4). As far as access to basic infrastructures is concerned, *belg* dominated areas were found to be better in their adaptive capacity (0.859) than those living in *meher* growing areas (0.803). Most of the *belg* growing areas in the study area are crossed by the main highway of Dessie-Mekaneselam and Dessie-Tenta which makes them to have better access to physical infrastructure.

The adaptive capacity of communities is partly determined by their ability to act collectively. Social capital theory offers a description of how individuals use their relationships for their own wellbeing and for the benefits of the groups [14]. Agroecologically, smallholder farmers in *dega* and *kolla* areas do have relatively better social capital as compared with those residing in *woinadega* areas. Probably this might be due to more exposure of the community in *dega* and *kolla* to climate-related problems which demanded the collective action of the people. The prominent factors with the highest PCA loading making a difference in the extent of social capital were the proportion of giving and receiving help, having frequent contact with local government officials and being a member of cooperatives.

Natural capital plays a noticeable role in societies where their livelihood is highly dependent on exploiting natural resources. In terms of this capital, *kolla* and *dega* agroecologies do have better asset. The first three indicators having better loading in PCA result were the size of agricultural land, the size of grazing land and ownership of land for irrigation. Among the major capitals, the contributing factor of natural capital for building adaptive capacity of smallholder farmers (based on the weight of PCA) was found to be the highest (0.764).

Agricultural land, which is very crucial in farming societies, was found to be proportionally less in *woinadega* than the remaining two agroecologies with a statistically significant difference. Surprisingly, households in *woinadega* do have better plots of woodlots and this might be due to easy access of firewood from natural forests in *dega* and *kolla* where it is hard to get such resources in *woinadega;* and forced households to have their own plots of land reserved for woodlots. As it was observed during the field, most of the woodlots privately owned were planted with eucalyptus trees which served both for construction and source of firewood. In some accessible areas, eucalyptus tree is planted even at the expense of agricultural land due to its increasing price which has been ignited by high demand for construction purpose. Basing type of cropping season as a unit of analysis, a statistically significant mean difference was found between *belg* and *meher* dominated areas in terms of agricultural and irrigation land size where the former favoring*meher* dominated areas and the latter for *belg* ones (see Table 5).

4. Conclusions and implication

Investigating livelihood vulnerability to climate change and extreme events is necessary for policymakers and practitioners to formulate feasible adaptation interventions so as to enhance resilience. Micro-level vulnerability study using LVI has been employed to measure the extent of smallholder farmers' vulnerability to adverse impacts of climate change based on agroecology and type of cropping season. Based on the overall index, *kolla* agroecology was found to be the most vulnerable area followed by *dega* while *woinadega* area was found to be relatively least vulnerable. Based on exposure parameter, *kolla* areas are more exposed for extended dry spell dates during rainy seasons, erratic and short duration of rainfall, late onset of rainfall and seasonal variability of rainfall. Though late onset and early cessation of *kiremt* rainfall are mentioned as a critical problem for both agroecologies, the situation in *kolla* areas is severe where the time span of main rain season becomes less than two months (very high concentration).

Sensitivity, which is measured based on the biophysical environment, agricultural system and water resources, has been severe again for *kolla* agroecology. When the overall adaptive capacity is compared based on the cumulative index of human, financial, physical, social and natural capitals; smallholder farmers in *woinadega* agroecology were found to be better followed by *dega* and the least in adaptive capacity was *kolla* agroecology. Varied socio-economic, demographic, physical and institutional factors are responsible for the variation in their adaptive capacity among the three agroecologies. Particularly, households headed by educated heads, having more family size in productive age group, having fewer dependents, access of information, having financial and extension services, having easy access of physical capitals, having better infrastructure and built up assets were found to be the contributing factors which make difference in adaptive capacity.

LVI, besides the overall extent of vulnerability of a system or an economy, should identify the prominent factors which would contribute to the sensitivity of smallholder farmers. Though targeting to reduce the likelihood of exposure of smallholder farmers to climate change is very difficult at micro level, addressing the sensitivity and adaptive capacity of rainfed dependent smallholders would enable them to build their resilience capacity to the current and expected impacts of climate variability and change. The study area is among the vulnerable regions of the country and particularly smallholder farmers in *kolla* agroecology and in *belg* dominated areas are found to be the most vulnerable areas which policymakers should give due attention. Furthermore, strategies which enhance the adaptive capacity of smallholder farmers and minimize their extent of sensitivity like expansion of small-scale irrigation, accessing of microfinance service, early warning and timely information, extension support, non-farm sources of income, training and skill development, expansion of infrastructure have to be promoted thereby increase their adaptive capacity to withstand the vagaries of the climate variability risk. Unless such strategies put into practice, climate change can compromise the well-being of smallholder farmers, whose livelihoods depend largely on rain-fed agriculture. Moreover, LVI study has to be disaggregated so as to capture difference even in the same agroecology because households living in the same geographic setting and exposed to similar type of risks might differ in their level of vulnerability due to a difference in adaptive capacity. Though the results of this study are specific to drought-prone areas in Northcentral Ethiopia, the approaches and findings might be pertinent to similar geographical and livelihood conditions. Besides the LVI analysis could be applied as a viable approach to pinpoint vulnerable sections of the society, to identify factors contributing to vulnerability at micro-level and also to prioritize the plausible adaptation interventions appropriate to the local context. Methodologically, the application of PCA in vulnerability analysis is vital so as to point out the most important contributing factors for sensitivity and adaptive capacity. In doing so, proper designing of adaption intervention and informed decision can be possible. Additionally, depending on either risk-hazard model or social vulnerability model alone while mapping vulnerability studies might lead to draw wrong conclusions. As a result, the application of the integrated model and the integration of socio-economic and biophysical determinants of vulnerability enable to capture the holistic nature of vulnerability and driving factors behind the vulnerability of smallholder farmers. Though scientific method of estimating vulnerability was applied using representative and adequate sample size, the analysis was undertaken at agroecology level and disaggregating at household level was not considered. For future research, disaggregating vulnerability at household level besides agroecology would enables to identify context specific factors and provides more viable result.

Declarations

Author contribution statement

Amogne Asfaw; Amare Bantider: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Belay Simane; Ali Hassen: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

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Annexes.

Annex 1. LVI-Normalized Value (Summary)

Factor	Capital	Profile (sub-component)	No of indicators	PCA average loading	Total value					Index				
					Agroecology			Cropping season		Agroecology			Cropping season	
					Dega	*w/dega*	*Kolla*	*Belg*	*Meher*	*Dega*	*w/dega*	*kolla*	*Belg*	*Meher*
Exposure	Climate variability & natural disaster	Historical trends	6	1.000	.24	.26	.33	.34	.28	.48	.445	.54	.53	.505
		Extreme Events	11	0.364	.72	.63	.75	.72	.73					
Sensitivity	Natural environment	Biophysical environment	8	0.381	.527	.449	.535	.511	.476	0.502	0.399	0.559	0.493	0.455
		Agricultural system	9	0.304	.548	.35	.555	.555	.539					
		Water resource security	6	0.507	.430	.399	.588	.414	.447					
Adaptive Capacity	Human	Demographic	5	0.549	.305	.277	.277	.319	.287	0.481	0.400	0.509	0.487	0.477
		Knowledge and skill	11	0.358	.567	.557	.641	.562	.591					
		Health and Food	12	0.601	.57	.367	.609	.581	.553					
	Social	Networks & norms	5	0.473	.248	.365	.293	.237	.243	.248	.365	.293	.237	.243
	Financial	Assets and Wealth	10	0.427	.61	.54	.653	.629	.586	.61	.54	.653	.629	.586
	Physical	Technology	7	0.464	.583	.381	.639	.579	.59	0.374	0.269	0.493	0.360	0.394
		Infrastructure	7	0.580	.165	.156	.347	.141	.197					
	Natural	Land resource	4	0.764	.75	.79	.69	.73	.8	.75	.79	.69	.73	.80
LVI										**0.483**	**0.417**	**0.534**	**0.489**	**0.477**
LVI is scaled from 0 (least vulnerable) to 1 (most vulnerable)										**2nd**	**least**	**1st**	**1st**	**2nd**
LVI-Example: [*Dega* = [(.48*17) +(.502*23) +(.481*28) +(.248*5) +(.61*10) +(.374*14) +(.75*4)/(17 + 23+28 + 5+10 + 14+4)] = 0.483														

In terms of agroecology, *Kolla* agroecology was most vulnerable followed by *dega* while *Woinadega* was found to be least vulnerable; while the type of cropping season was taken into account (only for *dega* agroecology), *belg* areas were found to be relatively vulnerable than *meher* ones.

Annex 2. Vulnerability Index (LVI): Components, profiles, indicators and expected hypothesis

Component	Capital	Subcomponent	Indicators	Expected hypothesis/realtionship with vulnerabiltiy
Exposure	Climate	Climate variability and extrem events	Long term temperature and rainfall variability which is expressed in terms of coefienceint of variation and concentration index; incidences of extreme events	Variabiltiy in temperature and precipitaion as well as freqnt occurrences of exterm events will exabrates vulenrabiltiy to climate change
Sensitivity	Natural	Ecosystem (Biophysical environment)	Percentage of people using forest-based energy for cooking; people living in malaria, frost, flooding, water logging prone areas; people living in water scare areas;	People living in such areas are expecte to be more sensitive and can easily be vulerable to adverse impacts of climate change
		Agricultural system	Landless farmers; land fertility; crop diversity index; dependent on food aid and only on rainfed agriculture; those who rented out or sharecropped their land; found in *belg* dominated areas; experienced crop failure	Smallholder farmers with such scinaros are excepted to be more sensetive for slight changes in climate
		Water resource	Dependent on unprotected source of water; experienced water-related conflicts; expericeining shortage of water for home consumption; domestic animals and irrigation	Changes in climatic situation will exabrates these situations and households will be easily vulnerable to climate change induced impacts
Adaptive capacity	Human	Demographic	Proportion of male headed households; proportion of family size with productive age group;	Headed by male and having more family size in the productive age = better adaptive capacity
		Knowledge and skill	Educational level of HHH; having radio/mobile phone; family member having vocational training/training on small scale business/climate change/crop production; having better contact with DAs/health extension workers	Having better educational level and those having means of informaton as well as training are supposed to have better knowledge and skill of adaptation stategies
		Health and food	HHs free of chronically ill members; financial capacity to take medical care; HHHs completed health packages; capacity to produce enough food for their family; no meal reduction due to shortage; financial capacity to fill out food deficit	HHs who are free from chronically ill member, having financial capacity for midication and to buy food items; producing enough food and those who did not force to reduce meal due to scarity do have better adaptive capacity
	Social	Networks and relationships	Providing/receiving helps; being membership of community-based organizations; being a member of producers/cooperative organizations; being leaders in such organizations	Being a member of such organizations; being leaders in such organizations would give room to develop adaptive capacity
	Financial	Assets and wealth	Land per capita; livestock assets; wealth status; access to financial institutions; no debt to pay back; beyond agriculture source of income; remittance	The better having such assets, the better in building adaptive capacity
	Physcial	Technology	Extent of using land augmenting modern inputs; irrigation access; house with corrugated sheet; using modern stoves	Having better access to such technological inputs would enable farmers to have better adaptive acpacity
		Infrastructure	Access to all weather road/health facilities/school/ veterinary services/input and output markets/ telecommunication centers	Households with better access to such facilities would have better adaptive capacity to climate change
	Natural	Land resourse	Total land size (cultivable/woodlot/grazing/irrigated)	Having better land resource increase the adaptive capacity

Indicators were developed (tailored with local context) based on Hahn *et al.* [25] and Simane *et al.* [5].

Annex 3. PCA result (based on the first factor loading of principal component analysis)

Factor	Capital	Sub-component	Specific indicators	PCA value	Mean Index
Exposure	Climate variability and natural disasters	Historical trend	Not run using SPSS (Considered as having a value of 1)		1.0
		Extreme events	Seasonal variation of rainfall	0.287	0.364
			Trend of rainfall through time (decreased)	0.039	
			Late onset of rainfall	-0.303	
			Early cessation of rainfall	-0.134	
			Dry spell of rainfall during rainy seasons	-0.554	
			Trend of temperature through time (increased)	-0.149	
			Erratic and short duration of rainfall	-0.387	
			Extent of extreme events (increased)	-0.291	
Sensitivity		Biophysical environment	Dependent on forest based energy for cooking	0.619	0.381
			Time take to collect fire wood per week	0.147	
			Firewood become scarce through time	0.145	
			Dependent on traditional stove for cooking	-0.407	
			Frost and dew become a problem	0.040	
			Flooding and water logging become a problem	-0.265	
			No information on climate change and variability	0.708	
			No early warning information on weather related issues	-0.720	
		Agricultural System	Fertility of land (infertile)	0.091	0.304
			Did not get enough food from own production	0.435	
			Productivity of land through time (decreased)	0.017	
			Supported by food aid for the last five years	-0.476	
			Rainfed agriculture dependent (no irrigation at all)	-0.668	
			Having agricultural land less than 0.2Ha per capita	0.802	
			Rented out or share cropping land	0.19	
			Experienced partial or total crop failure	0.058	
		Water	Conflict due to water resource	-0.472	0.507
			Water access from unprotected sources	-0.379	
			Time taken to get water for home consumption	0.848	
			Time taken to get water for domestic animals	0.903	
			Volume of water for domestic purpose (decreased)	0.168	
			Volume of water for domestic animals (decreased)	0.272	
			Mean Index for Sensitivity		**0.397**
Adaptive Capacity	Human	Demographic	Being male headed households	0.245	0.549
			Age of the HHH	0.994	
			Total size in productive age group	-0.240	
			Below 15 years old	0.975	
			Above 64 years of old	0.182	
			Total size of the family	0.656	
		K/dge and skill	Educational level of HHH	0.95	0.358
			Educational level of the husband	0.918	
			Educational level of the wife	0.63	
			Having radio	0.532	
			Having mobile	0.484	
			Having educated children	-0.019	
			Vocational training	0.118	
			Training on small-scale business	-0.049	
			Training on climate change and variability	0.041	
			Training on crop production and management	0.189	
			Contact with DAs	0.208	
			Contact with health extension workers	0.159	
		Health and food	Having chronically ill family member	0.331	0.601
			Missing school or work due to illness	0.145	
			Having a family member needing daily care	0.139	
			Having the capacity to take medication	0.761	
			Completed all rural health packages	0.581	
			Able to produce enough food	0.772	
			Average food sufficient months	0.803	

(continued on next page)

Annex 3 (*continued*)

Factor	Capital	Sub-component	Specific indicators	PCA value	Mean Index
			Taking meal type/quality reduction	0.680	
			Dependent on food aid	0.669	
			Having meal three and more times a day	-0.569	
			Having financial capacity to fill out food deficit	-0.764	
			Mean Index for Human Capital		**0.538**
	Social	Norms, Networks and associations	Proportion of households received support	0.765	0.473
			Proportion of households giving support	0.830	
			Proportion of households visited local government	0.552	
			Being members of community based organization	0.002	
			Having family member with cooperative membership	0.218	
	Natural	Land	Agricultural land in hectare per household	0.873	0.764
			Woodlot in gemed Per household	0.683	
			Grazing land in gemed per household	0.762	
			Irrigation land in gemed per household	0.738	
	Financial	Wealth Assets	Own agricultural land in hectares per HH	0.067	0.427
			Own agricultural land in hectares per capita	-0.085	
			TLU	0.193	
			Proportion of poor households	0.300	
			Having income source form non-agricultural sources	0.493	
			HHHs who do not have debt to pay back	0.090	
			Having a saving account in formal financial institutions	0.853	
			Having access to financial service	0.895	
			HHHs having remittance	0.291	
	Physical	Technology	HHHs using insecticide, pesticide and herbicide (%)	0.118	0.464
			HHHs using organic/inorganic fertilizer (%)	-0.088	
			Average fertilizer used in one harvesting season(in Kg)	0.630	
			HHHs using improved/selected seeds (%)	0.668	
			HHHs having irrigation access toany type (%)	-0.731	
			Having a house with corrugated iron sheet roofing (%)	0.495	
			HHHs using fuel efficient cooking stove (%)	0.521	
		Infrastructure	Time taken to the nearest all weather road	0.433	0.58
			Time taken to the nearest health center	0.773	
			Time taken to the nearest primary school	-0.077	
			Time taken to the nearest veterinary service	0.849	
			Time taken to the nearest major market center	0.326	
			Time taken to the nearest telecommunication	0.771	
			Time taken to the nearest FTC	0.831	
			Mean Index for Physical capital		**0.522**
			Mean Index for Adaptive Capacity		**0.545**

Source: (SPSS/Stata result, 2016).

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