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Climate Change Induced Vulnerability of Smallholder Farmers: Agroecology-Based Analysis in the Muger Sub-Basin of the Upper Blue-Nile Basin of Ethiopia

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Abstract

Ethiopia is also frequently identified as a country that is highly vulnerable to climate variability and change. The potential adverse effects of climate change on Ethiopia's agricultural sector are a major concern, particularly given the country's dependence on agricultural production, which is sensitive to climate change and variability. This problem calls the need to understand agroecology based vulnerability to climate change and variability to better adapt to climate risks and promote strategies for local communities so as to enhance food security. The objective of this study is to estimate and compare the level of vulnerability of smallholder farmers' to climate change and variability from three agroecology representing Muger River sub-Basin of the upper Blue Nile basin using Livelihood Vulnerability Index. The research used quantitative and qualitative data collected through Focussed Group Discussions, key informant interviews and a questionnaire survey of 442 sampled households across three different agro-ecologies in the sub-basin. The results reveal that along with the different agro-ecological zone, households and communities experienced different degrees of climate vulnerability. These differences are largely explained by differences in exposure, sensitivity and adaptive capacity of smallholder farmers. The livelihood vulnerability analysis reveals that *Kolla* agroecology exhibits relatively low adaptive capacity, higher sensitivity and higher exposure to climate change and variability that is deemed to be the most vulnerable agroecology. These contributing factors to a vulnerability in *Kolla* agroecology are largely influenced by assets, livelihood diversification, innovation, infrastructure, socio-demographic factors, social capital, agriculture, food security, and natural disasters and climate variability. The result furthermore shows that *Dega* agroecology has least vulnerable owing to its higher adaptive capacity.

These results suggest that designing agroecology based resilience-building adaptation strategies is crucial to reduce the vulnerability of smallholder farmers to climate change and variability.

Keywords

Vulnerability, Exposure, Sensitivity, Adaptive Capacity, Muger Sub-Basin

1. Introduction

Climate change impacts are widely observed in Africa where it has directly affected climate-dependent activities [1]. According to [2] Africa is one of the most vulnerable continents to climate change and variability because of multiple stresses and its low adaptation capacity. [3] reports that agricultural production and food security in many African countries are likely to be severely compromised by climate change and climate variability.

Like other African countries, Ethiopia is also frequently identified as a country that is highly vulnerable to climate variability and change [3] [4] [5]. Ethiopia's agriculture, which is the mainstay of the country's economy constituting 42.9% the nation's gross domestic product (GDP) and generates more than 85 percent of the foreign exchange earnings is mainly rain fed and heavily depends on rainfall [5]. Climate change is a major concern in Ethiopia because of its potential adverse effects on Ethiopia's agricultural sector, particularly given the country's dependence on agricultural production. In the last 50 years, the annual average minimum temperature in Ethiopia has shown an increasing trend of 0.2oC every decade [6]. Reports indicate that there have been major droughts in Ethiopia over the past centuries, 15 of which, in fact, occurred in the last 50 years leading to major losses or suffering in human as well as loss of livestock due to a shortage of water and grazing lands [7].

According to [8] report, long-term climate change in Ethiopia is associated with changes in rainfall patterns and variability, and temperature, which could increase the country's frequency of both droughts and floods. These climatic hazards, particularly drought, are becoming the major forces challenging the livelihoods of most farmers in Ethiopia. The rural population, for whom agriculture is the primary source of food, direct and/or indirect employment and income, will be most affected due agriculture's vulnerability to climate changes. There is an emerging consensus that vulnerability to climate change is a product of large inter-annual climate variability and an economy that is highly dependent on agriculture [9] as well as institutional factors that can create socio-economic crises even in the absence of a large meteorological anomaly [10] [11]. A major challenge is that this vulnerability varies across different agroecology based on differences in agro-ecological context, socio-economic factors, climatic impacts, and existing infrastructure and capacity.

It should be noted that vulnerability is defined differently in different disciplines [12] [13]. This study situates vulnerability by Intergovernmental Panel on Climate Change (IPCC) stated as "the degree to which a system is susceptible to and unable to cope with, adverse effects of climate change, including climate variability and extremes. The vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity" [2].

While it is increasingly accepted that climate change and variability will be Ethiopian farmers' greatest challenge, only a few studies have been undertaken in Ethiopia concerning livelihood vulnerability to climate change and variability. Most of this literature have looked into impacts of climatic variability on specific sectors such as agriculture, water resources, health, forestry, and to lesser extent socio-economic analysis [14] [15] [16] [17]. Nonetheless, studies developed expressly in the context of an integrated assessment of livelihood vulnerability to climate change and climate variability is limited. Important exceptions are [10] [18] [19] [20] [21] [22].

There is emerging a consensus that livelihood vulnerability to the changing climate varies with the scale of analysis. It is noted that vulnerability assessed at the national level can conceal variations in local vulnerability [23]. Notwithstanding of this understanding, many studies have been undertaken to assess climate change vulnerability at a national level and district level but failed to address local context. For instance, the study by [18] [24] is limited to an analysis of farmers vulnerability and does not take into account the spatial heterogeneity between agroecology regarding varying level of socio-economic and infrastructure development, households access to resources, level of food insecurity, and the ability to cope. This type of analysis is often overlooking local variations and inadequate to capture the full range of climate vulnerabilities among different agroecosystems. To the best of our knowledge, [10] is the only study attempted to assess livelihood vulnerability to climate change specific to agroecosystems. This problem calls the need to understand agroecology based vulnerability to climate change and variability to better adapt to climate risks and promote strategies for local communities so as to enhance food security. Therefore, this study aims to construct and compare vulnerability for smallholder farmers from four districts representing different agro-ecological zones in the Muger River Sub-Basin.

The findings of the research can assist in identifying specific factors contribute for farmers vulnerability to climate change and useful for targeting interventions and priority setting at the agroecology level in reducing vulnerability against adverse effects of climate change and variability. The overall objective of this study is to assess and compare the level of vulnerability of smallholder farmers to climate variability and change as a result of differences in agro-ecological settings, socio-economic factors, and existing institutional capacity. The specific objective is to examine exposure, sensitivity and adaptive capacity profiles of smallholder farmers in the sub-basin.

2. Research Methodology

2.1. The Muger River Sub-Basin: An Overview

1) Bio-Physical Setting

This study was conducted in the Muger sub-basin of the upper Blue-Nile basin. Muger sub-basin cover a total area of 8188 km^2. Muger River flows from the southeast of the basin into upper blue-nile river. The altitude in Muger sub-basin ranges between 953 masl and 3550 masl. The highlands in the eastern and southern part of the sub-basin are higher in altitude, greater than 2600 meters up to 3550 meters. The lowlands along the Muger River have lower altitude less than 1700 masl [25].

The sub-basin has an annual rainfall varies between 833 mm and 1326 mm. Lower annual rainfall ranging from 833 mm up to 1000 mm is observed along the river and lowlands. Relatively high rainfall is found in the highlands of the sub-basin. The annual maximum and minimum temperature of the sub-basin varies between 16˚C - 31.5˚C and 3˚C -16.5˚C respectively. Temperature is higher along the river with a maximum of 28˚C - 31.5˚C and minimum of 13˚C - 16.5˚C. The sub-basin is characterized by tepid to cool moist highlands. The northwestern part of the lowlands is hot to warm moist lowlands [25]. The sub-basin is characterized by tepid to cool moist highlands. The northwestern part of the lowlands is hot to warm moist lowlands. The major soils of the sub-basin are Leptosols, Luvisols, Vertisols, Fluvisols, and Alisols. Leptosols represents the most widely occurring soils within the sub-basin. The second dominant soil is Luvisols. Small patches of Cambisols, Nitosols and Rigosols are also in some parts of the sub-basin.

2) Socio-Economic Setting

According to the current zonal structure, the sub-basin is shared between three zones: North shoa, West shoa, and Oromia regional state of Finfine special zone. Muger sub-basin covers 15 weredas; Ejersa (Addis Alem), Walmara, Juldu, Mulo, Sululta, Adda Berga, Meta Robi, Yaya Gulelena Debre Libanos, Wichalena Jido, Ginde Beret, Kuyu, Kutaya, Gerar Jarso, Degem, and Wara Jarso . The total population of the sub-basin is 2,442,247 people [25]. The sub-basin is predominantly rural in character and the farmers are engaged in small-scale and subsistence mixed agriculture. The dominant sources of livelihoods in the sub-basin are crop production and livestock rearing. Map of the study site is presented in **Figure 1**.

2.2. Research Design and Methods of Data Collection

The research design was based on multi-stage sampling procedure. In the first stage, the whole sub-basin constituting fifteen Woredas was grouped into three strata (Kolla, Woyina Dega, and Dega agro-ecological zones) based on their agro-ecological characteristics including the rainfall, soil, and topography. The intention of this grouping was to maintain the representativeness of the samples that have been selected. It helped to group Woredas' having the same features

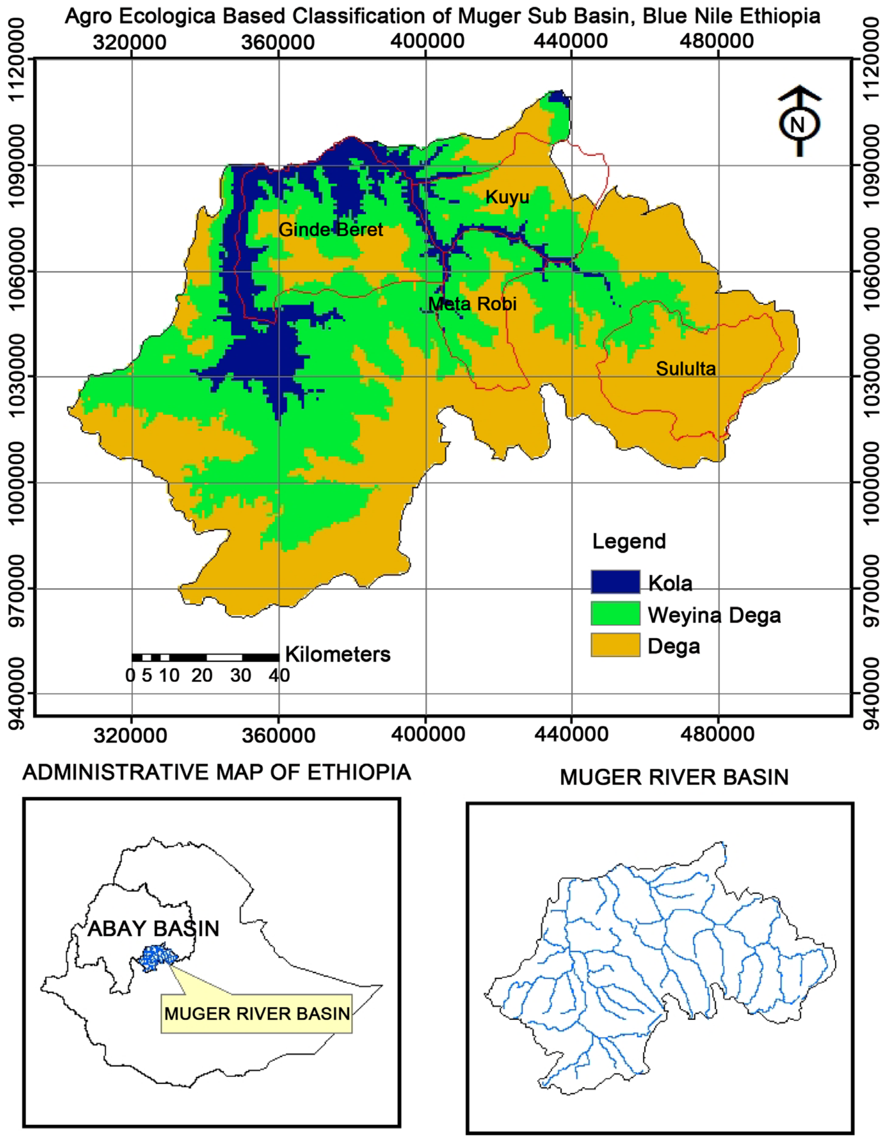

Figure 1. Agroecology-based classification of Muger sub-basin of the Blue-Nile basin in Ethiopia.

and characteristics into one group. Then, two woredas were randomly selected from Kolla and Dega agro-ecological zones. Similarly, two woredas were also selected from Woyina Dega agro-ecology using simple random sampling technique. In the second stage, only Peasant Associations (PAs) found in the sub-basin in each sampled Woreda were listed in consultation with agricultural experts in the area. This is mainly to exclude PAs which are not part of the sub-basin in that particular Woreda. Then, four PAs were randomly selected from each selected woredas. Finally, a total 442 sample respondents-143 from Kolla, 200 from Woyina Dega, and 99 from Dega agroecology were selected from 16 PAs using random sampling technique on the basis of probability proportional to size (PPS). The sampling frame was the list of households which was obtained from the PAs administration. Households for Focussed Group Discussions

(FGDs) were also drawn from each identified woreda, and a member of the group was identified with the help of development agents working in the area.

Both quantitative and qualitative methods of data collection were used to obtain information from the selected respondents. Quantitative data were gathered using semi-structured questionnaire. Qualitative data were obtained from FGDs and key informant interview to complement the information obtained through a semi-structured questionnaire in order to have a better understanding of major indicators that farmers use to determine the level of vulnerability to climate change and variability. Questions were posed to investigate factors that contribute to lower adaptive capacity, higher sensitivity, and higher exposure that could lead to higher vulnerability. Moreover, mean monthly temperature and precipitation from 1991 to 2016 were obtained from Ethiopian metrological station found in each sampled woredas.

Methods of Data Analysis

This study employed the livelihood vulnerability index (LVI) developed by [26] with replacements of some indicators to suit the local context in the study areas. It makes use of ten major components: soil and water, agriculture, food, asset, livelihood strategies, innovation, infrastructure, socio-demographic, social network, and natural disasters and variability. The indicators were developed based on a review of the literature and stakeholder (development and extension workers) consultation. Furthermore, the sub-components within the major components of the vulnerability were customized to the local context in consultation with field-level stakeholders. **Table 1** presents several sub-components of each major component [27]. These sub-components are selected on the basis of their relevance to contribution to each major component. Furthermore, to substantiate the LVI results, one way ANOVA analysis was employed.

To calculate the LVI, we used a balanced weighted average approach where each sub-component contributes equally to the overall index through each major component which comprised a different number of sub-components [28]. No prior assumption is made about the importance of each indicator or main components in the overall sum [29]. Many authors [10] [30] [31] [32] have used a similar approach in various contexts because this assessment tool is accessible to a diverse set of users in resource-poor settings. Minimum and maximum values were used to transform indicator into a standardized index.

As each sub-component was measured on a different scale, it is, therefore, necessary to standardize each as an index using the following equation;

$$index_{s_r} = \frac{s_r - s_{\min}}{s_{\max} - s_{\min}} \tag{1}$$

where s_r is the observed sub-component indicator for agroecology r and $s_{\min}$ and $s_{\max}$ are the minimum and maximum values, respectively. The equation for standardizing numerical values is the same as that used in constructing the Human Development Index—HDI [33]. After all the sub-components are indexed, the sub-components had been averaged to calculate the value of each major component as shown in Equation (2):

Table 1. Major components, sub-components and their hypothesized effect on vulnerability.

Major Components	Sub-Components	Hypothesized functional relationship between indicator and vulnerability
Soil and water	Inverse of average hectare of land under SWC	A Large hectare of land under SWC and irrigation reduce vulnerability, but here an inverse is considered.
	Inverse of average hectare of land under Irrigation	
	Percentage of households reporting land degradation by climate-related extremes during the past 20 years	A Higher percentage of households reporting land degradation increase vulnerability.
Agriculture	Inverse of Kilograms of total production harvested	Increased quantity of total production harvested reduces vulnerability but here an inverse is considered.
	Inverse of Percent of crop diversity	Higher crop diversity reduces vulnerability but here an inverse is considered.
	Percent of household who do not save seeds	Higher the proportion of Households who do not save seeds, higher is the vulnerability
Food	Percent of household who do not save crops	Higher proportion of households who do not save crops, higher is the vulnerability
	Average number of months households trouble getting enough food (range: 0 - 12)	Higher food insecurity results in a higher vulnerability.
Asset	Inverse of Number of livestock owned in TLU	Higher livestock ownership and landholding size reduce vulnerability, but here an inverse is considered
	Inverse of average Ha of land holding	
	Percent of households who do not have access to credit	A Higher proportion of households who do not have access to credit increased vulnerability.
Livelihood strategies	Inverse of Percent of households worked in non-farm activity	A Higher percentage of households who worked in non-farm and off-farm activity reduce vulnerability, but here an inverse is considered.
	Inverse of Percent of households worked in off-farm activities	
	Percentage of households solely dependent on agriculture as source of income	A Higher percentage of households solely dependent on agriculture as a source of income increase vulnerability.
Innovation	Inverse of Percent of HH used insecticide and pesticide	A Higher percentage of households used insecticide and pesticide, fertilizer, improved seeds, and practiced irrigation reduce vulnerability, but here an inverse is considered.
	Inverse of Percent of HH used fertilizer	
	Inverse of Percent of HH used improved seeds	
	Inverse of Percent of HH practiced irrigation	
Infrastructure	Walking distance in hours to main road	Longer the distance, the higher is the vulnerability.
	Walking distance to school	
	Walking distance to veterinary service	
	Walking distance to market	
	Walking distance to water sources	
	Walking distance to health center	
	Inverse of Percent of HH who owned mobile phone	A Higher percentage of households who used mobile phone reduce vulnerability but here an inverse is considered.

Continued

Socio-Demographic	Percent of female head households	A Higher proportion of female members increases vulnerability.
	Percentage of households where head of the household has not attended school	A Higher percentage of households has not attended school, and not owned Radio increase vulnerability.
	Percent of households do not own Radio	
	Age of the household head	Positive
	Dependency ratio	Higher dependency ratio increases vulnerability.
	Inverse of Percent of households attended agricultural training	A Higher proportion of households attended training reduce vulnerability, but here an inverse is considered.
Social Networks	Percent of households that have not gone to local government for assistance	A Higher proportion of households do not go to the government for assistance, borrowed money, do not help others, and receive help from others increase vulnerability.
	Percent of households borrowed money through social networks	
	Percent of households do not help others	
	Percent of households who received help from others.	
	Inverse of Membership in social group	More memberships in social groups reduce vulnerability but here an inverse is considered.
Natural Disaster and Climate Variability	Average number of floods and drought over the past 20 years	Higher the incidence of natural disasters, higher is the vulnerability
	Percent of households that didn't receive a warning about natural disasters	The higher proportion of households does not receive warning system the higher the vulnerability.
	Percent of households whose family members injured or died because of climate change	Higher prop oration of households affected by climate change the higher the vulnerability.
	Mean standard deviation of Monthly Avg. max. temperature (1991-2015)	Increasing temperature increase vulnerability.
	Mean std. deviation of monthly Avg. minimum temperature (1991-2015)	Increasing temperature increase vulnerability.
	Mean std. dev. of monthly Avg. Precipitation (1919-2015)	Decreasing precipitation increase vulnerability.

$$M_r = \frac{\sum_{i=1}^{n} index_{s_{ri}}}{n} \tag{2}$$

where M_r is one of the ten major components [Soil and Water, Agriculture, Food, Asset, Livelihood Strategies, Innovation, Infrastructure, Socio-Demographic, Social Networks, and Natural Disasters and Climate Variability] for agroecology r; $index_{s_{ri}}$, represents the sub-components indexed by i, that make up each major component, and n is the number of sub-components in each major component. Once values for each of the ten major components for agroecology were calculated, they were averaged using Equation (3) to obtain the agroecology-level LVI [34]:

$$LVI_r = \frac{\sum_{i=1}^{10} w_{miM_{ri}}}{\sum_{i=1}^{10} w_{Mi}} \tag{3}$$

where, LVI_r is the Livelihood Vulnerability Index for agroecology *r*, equals the weighted average of the ten major components. The weights of each major component, w_{Mi}, are determined by the number of sub-components that make up each major component and are included to ensure that all sub-components contribute equally to the overall LVI [27] [29]. In this paper, the LVI is scaled from 0 (least vulnerable) to 0.5 (most vulnerable) [27].

Following from Equations (1)-(3), [26] calculated a new variable, LVI-IPCC by taking IPCC definition of vulnerability into consideration. The LVI-IPCC diverges from the LVI when the major components are combined [27]. Rather than merge the major components into the LVI in Equation (3), the major components are first combined according to three categories namely exposure, adaptation capacity and sensitivity using the following equation:

$$CF_r = \frac{\sum_{i=1}^{n} w_{mi} M_{ri}}{\sum_{i=1}^{n} w_{Mi}} \tag{4}$$

where CF_r is an IPCC-defined contributing factor (exposure, sensitivity, or adaptation capacity) for agroecology *r*, M_{ri} is the major components for agroecology *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 adaptation capacity were calculated, the three contributing factors were combined using Equation (5):

$$LVI\text{-}IPCC_r = \left(e_r - a_r\right)^{*} s_r \tag{5}$$

where $LVI\text{-}IPCC_r$ is the LVI for agroecology *r* expressed using the IPCC vulnerability framework, e_r is the calculated exposure score for agroecology *r* (equivalent to the natural disaster and climate variability major component), a_r is the calculated adaptation capacity score for agroecology *r* (weighted average of the Assets, livelihood strategies, Innovations, Infrastructures, socio-demographic, and social networks), and s_r is the calculated sensitivity score for agroecology *r* (weighted average of the Soil and Water, Agriculture, and food). The LVI-IPCC was scaled from −1 least vulnerable) to 1-most vulnerable [28].

Finally, this research was framed in the lens of vulnerability framework developed by Turner and his colleague's [35] based on the IPCC definition to understand farmer vulnerability. Turner and his friends divided a system's vulnerability into three major components: exposure, sensitivity, and adaptive capacity. Exposure considers the frequency, magnitude, and duration to which a system is subject to hazards. We used the term "climate-related hazards" to cover both climate-related shocks, such as floods and droughts, and longer-term climate stresses, such as increasing rainfall variability and increasing temperature. The sensitivity of a system is determined by both the environmental and human characteristics that contribute to how a system responds to exposures. Finally, the adaptive capacity of a system refers to actions that can improve a system's ability to cope with outside hazards.

2.3. Indicators of Vulnerability

Adaptive capacity, exposure, and sensitivity are the key factors that determine the vulnerability of households and communities to the impacts of climate variability and change [36]. Indicators for each of these factors are therefore essential elements of a comprehensive vulnerability assessment.

For this study, *adaptive capacity* is represented by asset, livelihood strategies, innovation, availability of infrastructure, socio-demographic, and social networks. Wealth enables communities to absorb and recover from losses more quickly due to insurance, social safety nets, and entitlement programs [37]. Livestock is an important component of the agriculture system. It is an asset for a family as it provides the significant energy input to the croplands required for plowing, threshing and essential nutrients required for soil fertility and crop yields in the form of organic manure. In the case of disasters or any impact on agriculture, livestock can serve as means of coping mechanism. It can be a source of alternative or additional income for the farmers. Thus, higher livestock density would indicate higher adaptive capacity. A number of livestock owned, a hectare of land owned, and available finance is commonly used as indicators of wealth in rural African communities [38]. Thus, we assumed that households and communities with more of these are better able to cope with and adapt to the impacts of climate variability and change.

Access to agricultural inputs is identified as an indicator of innovation. For instance, [18] noted that drought-tolerant or early maturing varieties of crops as technology packages usually require access to complementary inputs, such as fertilizers or pesticides. Thus, the supplies of such inputs positively contribute to successful adaptation.

[18] pointed out that the level of development and availability of institutions and infrastructure play an important role in adaptation to climate change by facilitating access to resources. For instance, all-weather roads allow for the distribution of necessary inputs to farmers, which helps them adapt to climate change. These roads also facilitate economic activity by increasing access to markets. Likewise, health facilities are an important indication of health adaptive capacity in case of disasters and other related health impacts. Similarly, educational facilities indicate the infrastructure available to adapt to climate change in terms of knowledge. Microfinance plays a vital role by providing credits for technology packages that would help increase the adaptive capacity [18]. [39] indicated that countries with well-developed social institutions are considered to have greater adaptive capacity than those with less effective institutional arrangements. According to [40], areas with better infrastructure are expected to have a higher capacity to adapt to climate change.

The literacy rate is another important factor contributing to adaptation to climate change. It shows the degree to which the community can have access to the right kind of knowledge in understanding changes in the environment and the management practices required to deal with them. [40] argued that countries with higher levels of stores of human knowledge are considered to have greater adaptive capacity than are developing nations and those in transition.

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate change stimuli. In this study, three indicators were considered that may have an influence on the sensitivity of the farming community in the study area. These includes: soil and water, agriculture and food. Thus, it is hypothesised that smaller SWC, irrigation, and higher perception of land degradation increases sensitivity of smallholder farmers' to climate change and variability. In addition, smaller amount of total production harvested, less crop diversity, and larger households who do not save seed increases sensitivity. On the same vein, high prevalence of food insecurity has a negative impact on sensitivity to climate change and variability.

E*xposure* is the nature and degree to which a system is exposed to climate variations [36]. Temperature and precipitation are critical parameters of climate which strongly influence people, biodiversity, and ecosystems. It governs the distribution and abundance patterns of both plant and animal species. It is generally agreed that increasing temperature and decreasing precipitation are both damaging to the already hot and water scarce agriculture [18]. Exposure indicators selected for this study characterize the frequency of extreme events, a warning system for natural disasters, number of people injured due to climate change impact, and variations in temperature and rainfall. Thus, reduced precipitation and increased temperature in a region show a higher level of exposure to climate change.

3. Result and Discussions

The result of Vulnerability analysis for all the three agro-ecologies is reported in two parts. First, the results obtained from the assessment of individual major components and subcomponents contributions to each of the major components for each agroecology are presented. Second, the estimated values for the different dimensions (sensitivity, exposure, and adaptive capacity) of the climate vulnerability index are presented. The LVI provides information of which components determine vulnerability. The LVI-IPCC indicates which of the three factors (exposure, adaptive capacity and sensitivity) influences the most when determining the vulnerability.

LVI results

Overall, *Kolla* agroecology has a higher LVI than *Woyina Dega* and *Dega* (0.5991; 0.5118; 0.4801, respectively), indicating relatively greater vulnerability to climate change and variability impacts. The spider diagram in **Figure 2** presents the ten major components. The scale goes increasing from the center (less vulnerable) to 0.9 (more vulnerable). **Figure 2** shows that *Kolla* agroecology is more vulnerable in terms of asset, livelihood strategies, innovation, infrastructure, socio-demographic, social network, agriculture, food, and natural disasters and climate variability, whereas *Woyina Dega* is more vulnerable in terms of soil

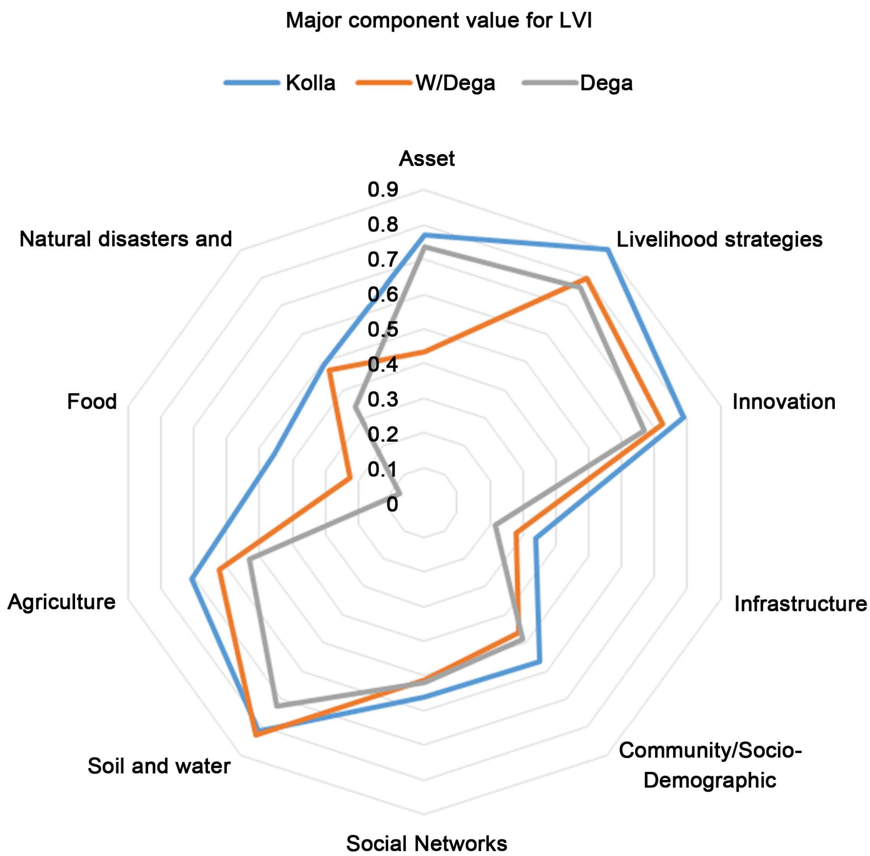

Figure 2. Spider diagram for major components of LVI.

and water component. The next sections present the details of sub-components and major components that could contribute to exposure, sensitivity and adaptive capacity for each agroecology.

Exposure*: *Natural disaster and climate variability

The natural disasters and climate variability component are made up of six sub-components. In terms of natural disasters and climate variability, the analysis reveals that *Kolla* agroecology is found to be more vulnerable (0.4916) whereas *Dega* agroecology is found to be least vulnerable (0.3386) (Table 2). The results further reveal that higher vulnerability of Kolla agroecology in terms of natural disasters and climate variability is as a result of three contributing factors. Firstly, the highest percent of households to report death or injury and number of severe drought and flood was reported in *Kolla* (31.47 percent, 4.68 respectively). Monthly maximum average temperature and monthly average precipitation were also considered major contributing factors for higher vulnerability to natural disasters and climate variability for *Kolla*. Although *Woyina Dega* households reported a higher percent of households that did not receive a warning about impending natural disasters over the past 20 years, the variability in the average maximum monthly temperature and precipitation has been greater in *Kolla* agroecology. The meteorological data further shows that *Kolla* agroecology recorded more precipitations and also witnessed more variations in

Table 2. Sub-component index across agroecology.

		Agro-Ecology	*Kolla*	*Woyina Dega*	*Dega*
Major components	Sub-component	Explanation of Sub-Components	Index	Index	Index
Soil and Water	Average hectare of land under SWC	Inverse of Average hectare of land under SWC	0.8422	0.8699	0.8419
	Average Ha of land under Irrigation	Inverse of Average Ha of land under Irrigation	0.9888	0.9476	0.8809
	Percent of households reporting land degradation by climate-related extremes during the past 20 year	Percentage of households reporting land degradation by climate-related extremes during the past 20 years.	0.6084	0.675	0.4545
Agriculture	Total production harvested in Kilogram	Inverse of Kilograms of total production harvested	0.9339	0.8168	0.8018
	Crop diversity	Inverse of Percent of sown area under all crops divided by number of total crops	0.6721	0.6546	0.7069
	Percent of household who do not save seeds	Percent of household who do not save seeds	0.5175	0.395	0.091
Food	Percent of household who do not save crops	Percent of household who do not save crops	0.6573	0.345	0.0708
	Number of months households trouble to get enough food	Average number of months households trouble getting enough food (range: 0 - 12)	0.2532	0.1041	0.0816
Asset	Number of livestock in TLU	Inverse of average Number of livestock	0.8876	0.2357	0.7565
	Average Ha of land holding	Inverse of average Ha of land holding	0.8577	0.266	0.7468
	Percent of households who do not have access to credit	Percent of households who do not have access to credit	0.5664	0.795	0.707
Livelihood Strategy	Percent of households who work in non-farm activity	Inverse of Percent of households who work in non-farm activity	0.9226	0.8772	0.7920
	Percent of households who worked in off-farm activities	Inverse of Percent of households who worked in off-farm activities	0.9167	0.8163	0.8535
	Percentage of households who solely dependent on agriculture as source of income	Percentage of households who solely dependent on agriculture as source of income	0.8602	0.70	0.6465
Innovation	Percent of HH used insecticide and pesticide	Inverse of Percent of HH used insecticide and pesticide	0.8773	0.8197	0.8684
	Percent of HH used fertilizer	Inverse of Percent of HH used fertilizer	0.5793	0.5348	0.5103
	Percent of HH used improved seeds	Inverse of Percent of HH used improved seeds	0.7688	0.8230	0.7279
	Percent of HH practiced irrigation	Inverse of Percent of HH practiced irrigation	0.9286	0.7246	0.5723
Infrastructure	Distance to the main road	Walking distance in hours to main road	0.3763	0.2140	0.0953
	Distance to school	Walking distance to school	0.2176	0.1579	0.1433
	Distance to veterinary service	Walking distance to veterinary service	0.2439	0.2053	0.2154

Continued

	Distance to market	Walking distance to market	0.3130	0.2174	0.1617
	Distance to water sources	Walking distance to water sources	0.1812	0.1644	0.1040
	Distance to health center	Walking distance to health center	0.2704	0.2500	0.2296
	HH owned mobile phone	Inverse of Percent of HH owned mobile phone	0.7647	0.7435	0.5657
Socio-Demographic	Percent of female head households	Percent of female head households	0.1049	0.0850	0.2222
	Household had not attended school	Percentage of households where head of the household had not attended school	0.5804	0.5600	0.4646
	Households do not own Radio	Percent of households do not own Radio	0.6923	0.2750	0.0809
	Age of the household head	Number of years of age of the household head	0.4059	0.3482	0.4423
	Dependency ratio	Dependency ratio	0.9763	0.8934	0.9649
	Households attended agricultural training	Inverse of Percent of households attended agricultural training	0.6413	0.6098	0.7443
Social Network	Households that have not gone to local government for assistance	Percent of households that have not gone to local government for assistance	0.8811	0.8900	0.9595
	Households borrowed money through social networks	Percent of households borrowed money through social networks	0.1259	0.025	0.1818
	Households who do not help others	Percent of households who do not help others	0.6434	0.9050	0.6566
	Households who received help from others	Percent of households who received help from others	0.3566	0.0600	0.1717
	Membership in social groups	Inverse of Membership in social groups	0.7974	0.6753	0.6189
Natural Disaster and Climate Variability	Number of floods and drought over the past 20 years	Average number of floods and drought over the past 20 years	0.468	0.412	0.288
	Households that didn't receive a warning about natural disasters	Percent of households that didn't receive a warning about natural disasters	0.4476	0.595	0.5656
	Households whose family members injured or died because of climate change	Percent of households whose family members injured or died because of climate change	0.4663	0.035	0.0101
		Mean standard deviation of monthly Avg. max temperature (1991-2015)	0.5608	0.4596	0.3967
		Mean std. deviation of monthly Avg. minimum temperature (1991-2015)	0.2953	0.7092	0.2597
		Mean std. dev. of monthly Avg. Precipitation (1919-2015)	0.7113	0.6059	0.5115

maximum monthly temperature and precipitation. This implies that high temperature and high rainfall will cause failure to crops grown.

The two main contributing factors for a higher vulnerability to natural disasters and climate variability for *woyina Dega* are a higher percentage of the household did not receive a warning about impending natural disaster such as drought and floods (*Woyina Dega* 59.5 percent, *Dega* 56.56 percent, *and Kolla* 44.76 percent) and mean std. deviation of monthly average minimum temperature (2.485545). A significant number of farmers in all three agroecology did not receive any warning about impending natural disaster such as floods or droughts, however, the problem is most prevalent in the *woyina Dega* agroecology where about 59.5 percent of the sample reported a lack of information about impending disasters and are therefore unable to adequately prepare for them. This result indicates that broadcasting early warning is more limited to Kolla and Dega agroecology and not available to a remote area of Woyina Dega agroecology. This may imply that early warning systems and community preparedness plans may help communities to prepare for extreme weather events. It is also noted that seasonal weather forecasts distributed through local farming associations may help farmers adjust the time for their plantings and prevent diversion of scarce water resources for irrigation during severe drought.

Sensitivity*: *Soil and water, agriculture, and food

Land degradation has become one of the most important environmental problems in the Muger river sub-basin, mainly due to soil erosion and nutrient depletion. Although the study does not show much difference in the soil and water vulnerability of the three agro-ecologies, the vulnerability of soil and water component was lowest in *Dega* (0.7258) and highest in *Woyina Dega* (0.8308). The majority of the households in *Woyina Dega* (67.5%) and *Kolla* (60.83%) reported that their land has been degraded due to climatic events, such as flash floods, landslides, and erosions. Lack of efficient agricultural practice to preserve topsoil, lack of proper terrace system for farming and practice of occasional slash and burn has made topsoil prone to degradation which potentially would make households in Woyina Dega more vulnerable. These facts provide enough reasons to make a claim that the households in *Woyina Dega* are highly vulnerable in terms of soil and water component. One way ANOVA analysis reveals that hectare of land under soil and water conservation measure is significantly different across the three agro-ecologies (Table 3). Households' in *Woyina Dega* constructed soil and water conservation measures such as stone bunds, soil bunds, hillside terracing, and check dams relatively on small land size than households in the rest of two agro-ecologies (Table 2).

On the same vein, the inferential analysis shows that hectare of land under irrigation is significantly different among the three agro-ecologies (Table 3). The *Kolla* households have practiced irrigation on the small size of land (0.0227 ha) next to *woyina Dega* (0.1105 ha) that contributed for higher sensitivity. *Dega* household has practiced irrigation relatively on the larger size of land (0.27 ha) that helped reduce sensitivity. The lower percentage of irrigated area out of the

Table 3. Continuous variables considered in the ANOVA analysis.

Variable	F-test	Significance level
Hectare of land under irrigation	63.209*	0.000
Crop Diversity index	2.710***	0.068
Hectare of land with soil and water conservation measure	2.532***	0.081

*, ***: Significant at 10% and 1%, respectively.

net sown area in Kolla agroecology gives an indication of the higher dependence on rainfall.

As seen in Table 5, the agriculture component has the largest contribution to the vulnerability of the community in *Kolla* with a value of 0.7078. In *Kolla*, a larger proportion of households (about 52 percent) reported that they do not save seeds to grow for the next season. This is probably due to the fact that households in *Kolla* harvested smaller than *Woyina Dega* and *Dega* households that could only be used for their subsistence. On the other hand, the index analysis of farmers reporting not saved seeds to grow for the next season shows that Dega agroecology is the least with an index value of 0.454545. The result further reveals that there exists a statistically significant difference of crop diversity among the three agro-ecologies (Table 3). Least crop diversity was observed in *Dega* agroecology. Relatively speaking, *Woyina Dega* has larger crop diversity than *Kolla* agroecology (Table 2). This result suggests that research development and promotion of new seed varieties is an important concern in Kolla agroecology that would help to reduce sensitivity to climate change and variability.

Food is another component that has a high effect on a vulnerability in *Kolla*, with a value of 0.4553. The results reveal this high value is presumably due to the fact that *Kolla* households struggled about 2.53 months per year to find adequate food for their families as compared to 1.04 months in *woyina Dega* and 0.8163 month in *Dega*. The result further shows that a higher percentage of *Kolla* households (65.73%) reported that they do not store crops compared to *woyina Dega* (34.5) and *Dega* (7.08). The main lesson drawn from this point is that farmers in Kolla agroecology are more likely food insecure that could aggravate their vulnerability to the changing climate. This suggests that adaptation options designed to reduce the adverse effect of climate change and variability in Kolla agroecology should give priority to food security.

Adaptive capacity*: *Asset, Livelihood strategies, innovation, infrastructure, Scio-demographic, and social networks

The fifth component that mainly affects the vulnerability of *Kolla* agroecology is an asset with a value of 0.7706. This high value is presumably due to the fact that *Kolla* agroecology has lower livestock ownership and smaller landholding as compared to *Dega* and *Woyina Dega* agroecology. One way ANOVA analysis reveals that there exists a significant difference of livestock ownership and size of landholding among the three agro-ecologies (Table 3). The result indicates that *Kolla* households owned small average landholding size (1.6592 hectares) than 2.66 hectares of landholding in *Woyina Dega* and 3.39 hectare of landholding in *Dega*. Similarly, *Kolla* households reported a smaller size of livestock ownership (3.76 TLU) as compared to 7.00 TLU in *Woyina Dega* and 9.56 TLU of livestock in *Dega* (Table 2). This lesson might lead the policy makers to mainstream asset building strategy in the existing development that could help to offset the negative impact of climate change and variability.

Kolla agroecology, with an index value of 0.8998 on livelihood strategies have a higher effect on vulnerability, than in *Dega* and *Woyina Dega*. This value came as a result of three main factors. The first is that a higher percentage of *Kolla* households reported relying solely on agriculture for income as compared to *Woyina Dega* and *Dega* households (Table 2). This result supports the notion that large dependence on agriculture greatly increases household vulnerability since crop problems can cause remarkable reductions of income. The second factor is that *Kolla* households have less diversified livelihood strategies which is explained by fewer households with members working on non-fam activities and smaller percentage of households with members working on off-farm activities. This tells that a more diversified livelihoods had the potential to reduce the vulnerability of the household. For instance, quantitative analysis of this study shows a larger proportion of households (including 35.36% and 30% in *Dega* and *Woyina Dega* agroecology respectively) that tend to engage in a number of livelihood activities outside of agriculture are less vulnerable to climate change and variability. Households belonging to *Dega* have more diversified livelihoods options including other non-farm jobs such as teaching, petty trading, and fishing. This could be described as a household with principal livelihood activity coupled with complementary livelihood strategies are less vulnerable to climate change and variability.

With an index value of 0.7885, innovation is the high influencing component on a vulnerability in Kolla than the rest two agro-ecologies (Table 4). Differences in innovation component between agroecology were attributed primarily to differences in the use of chemical fertilizer, insecticide, and improved seed as well as irrigation practice. The Application of insecticides and fertilizers is low in *Kolla* probably due to low infrastructure and lack of understanding of the cultivation mechanism. The possible explanation is that lack of access to proper roads and transport services might constrain the use of inputs such as fertilizer and planting materials and this may result in a decrease in agricultural yield, and

Table 4. Major component value of Vulnerability across agro-ecologies.

Contributing factors	Major component	*Kolla*	*Woyina Dega*	*Dega*
Adaptive capacity	Asset	0.7706	0.4322	0.7368
	Livelihood strategies	0.8998	0.7978	0.7640
	Innovation	0.7885	0.7255	0.6697
	Infrastructure	0.3382	0.2789	0.2164
	Socio-Demographic	0.5669	0.4619	0.4865
	Social Networks	0.5609	0.5111	0.5177
Sensitivity	Soil and water	0.8131	0.8308	0.7258
	Agriculture	0.7078	0.6221	0.5332
	Food	0.4553	0.2246	0.0762
Exposure	Natural disasters and climate variability	0.4916	0.4695	0.3386
LVI		0.5991	0.5118	0.4801

it is even more difficult and expensive to transport produce to the market. Similarly, the percentage of farmers with some irrigation on their land varies between agro-ecologies. Table 4 presents nearly 75% of farmers in *Dega* practiced small scale irrigation, while small proportion (5%) of farmers in *Kolla* have access to small scale irrigation. The result shows that higher percentage of households in *Kolla* has not practiced irrigation in their farm. It is apparent that a lesser percentage of irrigated land will increase dependence on rain-fed agriculture which is becoming more unpredictable with the advent of environmental climate change.

Although *Kolla* households have higher vulnerability score for the use of insecticide and pesticide, chemical fertilizer, and irrigation practice of the innovation indicators, percent of households used improved seeds has been found to be higher in *Dega*. In *Woyina Dega* agroecology, only 21.5 percent of households used improved seeds to enhance crop production as compared to 37.37 percent and 30 percent in *Dega* and *Kolla* households respectively (Table 2).

Infrastructure development is another important component that determines the level of vulnerability of smallholder farmers in the study area. The result indicates that access to major indicators of infrastructure significantly varies across agro-ecologies at less than 1% significance level except for distance to the health center (Table 5). The present study indicates *Kolla* households take more time to reach the main road, school, veterinary service, market, and water point as compared to *Woyina Dega* and *Dega* households. The results in Table 5 confirm

Table 5. Explanatory variables considered in the ANOVA analysis for the three agroecology.

Variable	F-test	Significance level
Number of total livestock in TLU	49.071***	0.000
Educational status of the household head in year	2.974*	0.052
Age of the household heads in year	7.821***	0.000
Total crops harvested in kilogram	58.179***	0.000
Estimated annual income from non-farm activity in birr	8.093***	0.000
Estimated annual income earned from off-farm activity	1.334	0.265
Sex of the household head	6.189***	0.002
The distance to all-weather roads from your home in walking hours	65.955***	0.000
The distance of your home to the nearest school	9.383***	0.000
The distance to veterinary service from your home	3.473**	0.032
The distance to health services from your home	2.215	0.110
The distance to water source from your home	6.840***	0.001
The distance to saving and credit institution	44.573***	0.000
The distance to market from your home	36.996***	0.000

*, **, ***: Significant at 10%, 5% and 1%, respectively.

that *Kolla* households have higher vulnerability score (0.3382) than *Woyina Dega* and *Dega* households on the infrastructure component (0.2789, 0.2164 respectively) (Table 5). Moreover, a small proportion of households (30 percent) in *Kolla* has access to telephone service as compared to 34 percent and 76 percent in *Woyina Dega* and *Dega* households.

The socio-demographic component has higher vulnerability effect in *Kolla* (0.5669) than *Dega* (0.4865) and *Woyina Dega* (0.4619). The ANOVA analysis reveals that sex of the household head and age of the household head are statistically significant ($P < 1\%$) among the three agro-ecologies (Table 5). When the socio-demographic component is reviewed by its sub-components (*i.e.* indicators), *Dega* households is found to be most vulnerable in terms of female-headed households, the age of the household heads, and percent of households who do not attend agricultural training. *Dega* households reported a higher proportion of female-headed households, old household heads and a larger proportion of household heads that not received any training to cope climate extremes than the rest of two agro-ecologies. On the other hand, *Kolla* households have been found to be more vulnerable in terms of education, ownership of Radio, and dependency ratio. The result further shows that *Kolla* agroecology has a larger proportion of household heads that do not attend school than Woyina Dega and Dega households. The dependency ratio index is also higher for Kolla (0.9763) than Dega (0.9649) and Woyina Dega (0.8934).

The social network is an important component that determines vulnerability of farmers in the study site. The results reveal that households that have not gone to local government for assistance, households borrowed money through social networks, households who do not help others, households who received help from others, and household heads membership in social groups are found to be an important indicators that explain the social network component [41]. The study found that *Kolla* households have greater vulnerability on the social network component (0.5609) than *Dega* (0.5177) and *Woyina Dega* (0.5111) (Table 4). This is possibly because a higher proportion of household heads in *Kolla* agroecology borrowed money through social networks has not helped others, and has received help from others. On the other hand, households in *Dega* has a lower index for the inverse of a number of memberships (0.6189) of different social groups found in the area as compared to *Woyina Dega* (0.6753) and *Kolla* (0.7974) (Table 2). This shows that social capital creates incentives for farmers to reduce their vulnerability to climate change through mutual help mechanism. This suggests that although the existing social capital has helped farmers by enhancing their adaptive capacity, the benefit of social capital is still not fully realized.

Livelihood Vulnerability Index-IPCC Results

Table 6 presents the three contributing factors to climate change vulnerability-exposure, sensitivity, and adaptive capacity that differ across the three agro-ecologies. As is evident from the equation for IPCC_LVI, high values of exposure relative to adaptive capacity assume positive vulnerability scores while

Table 6. LVI-IPCC contributing factors across agroecology.

Agro-ecology	IPCC contributing factors to vulnerability			
	Exposure	Sensitivity	Adaptive capacity (*inverse*)	LVI-IPCC
Kolla	0.4916	0.6842	0.36326	0.0878
Woyina Dega	0.4694	0.6009	0.40011	0.04164
Dega	0.3386	0.4912	0.43412	−0.04692

low values of exposure relative to adaptive capacity yield negative vulnerability scores. Sensitivity acts as a multiplier, such that high sensitivity in an agroecology for which exposure exceeds adaptive capacity will result in a larger positive LVI-IPCC vulnerability scores [26].

It is apparent from **Table 6** that the index value is only negative for *Dega* agroecology; while it is positive for *Kolla* and *Woyina Dega* agroecology. This result reveals a variation in the level of exposure, sensitivity and adaptive capacity of the smallholder farmers across agroecology. The analysis illustrates that *Kolla* household's unveils higher exposure and sensitivity and lower adaptive capacity which results in higher positive LVI-IPCC vulnerability score (0.0878) as compared to *Woyina Dega* and *Dega* households. The highest exposure and sensitivity coupled with lowest adaptive capacity in *Kolla* made it the most vulnerable. The possible explanations are that household located in *Kolla* agroecology experience more socio-economic and biophysical vulnerability. This high socio-economic vulnerability is attributed to households operating on less diversified livelihoods, low off-farm engagement, low access to infrastructure, small landholding, and small or no area under irrigation among others. Similar studies by [41] found that households which diversify their livelihood activities in the form of non-farm business activities such as trade, transport, shop keeping and brick making among others are better off economically and hence less vulnerable. A large body of literature reported less diversified livelihood options are the main means for high levels of social economic vulnerability in Ethiopia, Kenya, and India [21] [26] [42].

On the other hand, biophysical vulnerability is exacerbated by relatively low soil fertility due to land degradation by soil erosion, diminishing water resources and increasing trends of environmental hazards like drought and floods. All these factors lead to deterioration of agroecology thereby compromising their ability to provide ecosystem services leading to farmers' vulnerability as also reported by [43] in other studies. Similar results of the pronounced biophysical vulnerability of communities inhabiting remote areas characterized by low developments were reported by [18] [43].

The result further reveals that *Dega* agroecology is least vulnerable study site owing to its lowest sensitivity and exposure and highest adaptive capacity. The higher adaptive capacity of the households in *Dega* can be explained by the fact that there exists improved infrastructure and institutional services (*i.e.*, access to credit, extension service, and market facilities), higher asset possession, diversified livelihood strategies, and high access to innovations. It is also noted that *Dega* agroecology has successful and endured local institutions that create relationships with a common purpose and promote shared interest. From the above indicators considered in the sensitivity analysis, the *Dega* agroecology is less vulnerable because of the better size of land under small-scale irrigation and large size of land under soil and water conservation measures.

Overall, the key observation here is even if the existing development interventions have helped farmers to reduce the adverse effect of climate change and variability, the benefit of agroecology specific interventions to reduce farmers' vulnerability are still not fully realized. It is this problem that makes Kolla agroecology the most neglected area by development interventions for unjustified reasons. This suggests that development interventions should target their efforts to reduce farmers' sensitivity and enhance adaptive capacity so as to reduce vulnerability to climate change and variability specific to the agro-ecologic context.

4. Conclusions and Policy Implications

This paper has aimed to address a gap in differences of smallholder farmers' vulnerability to climate change among different agroecology by using empirical data to assess the exposure, adaptive capacity, and sensitivity. Though significant attention has been given to assessing vulnerability at the national level, fewer papers have looked vulnerability across varying agro-ecology. Through LVI developed by Hahn and his colleagues, the research demonstrates empirically the differences in exposure, sensitivity, and adaptive capacity of farmers across three Argo-ecologies.

The results reveal that *Kolla* agroecology is found to be the highest exposure and sensitive to climate stress and have the most limited adaptive capacity. Its higher sensitivity to extreme climate events is probably because of small land under irrigation, low level of crop diversity, and high level of food insecurity in the area. The result further points out that *Kolla* agroecology has the limited adaptive capacity to adapt to the changing climate is due to the combined effect of limited livelihood options, underdeveloped infrastructure, low access to the most important socio-economic factors including asset ownership, and weak social cohesion. This will lead to the conclusion that a moderate climate change will disrupt the livelihoods of smallholder farmers in this agroecology. In contrary, *Dega* agroecology has lower exposure and sensitivity, and greater adaptive capacity as compared to the other two agroecology and this could be attributable to higher asset ownership, developed infrastructure, more diversified livelihood options, access to innovation, and relatively well-developed social networks. Although the aggregate sensitivity is higher in Kolla agroecology, land degradation problem is found to be more pronounced in woyina Dega.

Several important policy implications can be drawn from this analysis. Feasible interventions to reduce vulnerability and ameliorate the impact of climate change revolve around promoting small-scale irrigation and crop diversification that would later or sooner help to increase food security. In line with this, it is, therefore, imperative to ensure access to alternative sources of income through non-farm and off-farm activities, improving infrastructure, and increase vulnerable farmers' asset base thereby increase their adaptive capacity to withstand the vagaries of the climate variability risk. This result also suggests that more emphasis needs to be given to investing in social capital formation by involving and building good relationships with smallholder farmers who can then take care of and obtain benefits from it to reduce their vulnerability to climate change and variability. Reducing land degradation problem using soil and water conservation measures will also help to reduce the sensitivity of farmers in *Woyina Dega* agroecology. Overall, it is imperative to give a closer attention in planning adaptation options to reduce current and future vulnerability based on agroecology and socio-economic context.

As often stated in climate change theory, vulnerability is a function of three contributing factors via adaptive capacity, sensitivity, and exposure [36]. Higher adaptive capacity, lower exposure, and lower sensitivity reduce farmers' vulnerability to climate change impacts. In practice, although current adaptation options used by farmers helped reduce vulnerability through reducing sensitivity and enhancing adaptive capacity, determinants of adaptation options to climate change and variability remains an important concern. Future research needs to investigate factors constrains or facilitate the adoption of adaptation options to fully realize the benefit of adaptation options.

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Authors' Contributions

Abayineh Amare and Belay Simane generated the idea and designed the study. Abayineh carried out the data collection, data analysis, and write-up. Belay provided statistical assistance and read and revised the manuscript. .Both authors read and approved the final manuscript.

Competing Interests

The authors declare that they have no competing interests.

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