Analysis of smallholder farmers' vulnerability to climate change and variability in south Wollo, north east highlands of Ethiopia: An agro-ecological system-based approach

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Abstract

Background: Climate change and variability has been significantly affecting the Ethiopian agricultural production and thereby smallholder farmers livelihoods. The level of vulnerability varied across agro-ecological zones (AEZs). Identification of difference in the level of vulnerability of a system is important in selecting appropriate and effective adaption options to climate change. Therefore, the aim of this study was to analyze the level of vulnerability of agricultural communities to climate change and variability at micro-scale level in five agro-ecological zones (AEZs) of south Wollo, north east highlands of Ethiopia. Data was collected from a representative of 502 sample households from five AEZs through multi stage random sampling methods. Focus group discussion and key informant interviews were also carried out to supplement and substantiate the quantitative data. The indicator based approach was used to empirically calculate vulnerability. Principal Component Analysis (PCA) was applied to give weight for indicators and generate index of vulnerability contributing factors.

Results: The results showed that each of the vulnerability contributing factors (exposure, sensitivity and adaptive capacity) varied across the AEZs. M3, SM2 and SM3 are the most exposed AEZs but having a relatively better adaptive capacity whereas M1, M2 and M3 are the most sensitive AEZs with relatively low adaptive capacity to climate variability and change. Overall, SM2 is the most vulnerable AEZ which exhibited high sensitivity and low adaptive capacity followed by M1.

Conclusions: The study explored sources and levels of vulnerability to each agro-ecology. Since the study is conducted at micro-scale level, it helps decision makers and development partners to have context-specific understanding of the impact of climate change and variability and design appropriate adaptation measures to address the specific situations.

1 Background

Climate change is one of the current issues that have received increasing attention globally. In particular, Africa is viewed as the most vulnerable region to climate variability and change. Africa is characterized by nature-dependent livelihoods, indicating that the continent is disproportionally hit by adverse effects of climate change. Agriculture, which plays a vital role in the livelihood of rural communities in many African countries, is one of the sectors which is most vulnerable to climatic changes (Schlenker and Lobell, 2010; Morand *et al.,* 2012; Simane et al 2014). The dependence of African smallholder farmers on agriculture with lack of irrigation made them more vulnerable to rainfall changes (Fields, 2005).

The Intergovernmental Panel for Climate Change (IPCC) 2007 reported that climate change is expected to expose between 75 and 250 million people to water stress by 2020. In addition, by 2020 there will be a significant reduction in arable land and, in some African countries; yields from rain-fed agriculture will decline by as much as 50%, which worsens food insecurity. By the 2050s, 350 − 600 million Africans will be at risk for increased water stress, predominately in the northern and southern parts of the continent (Arnell, 2004; IPCC, 2007).

Ethiopia is heavily dependent on rain-fed agriculture which supports more than 85% of the population, and contributes about 50% of the country's gross domestic product (GDP) (GFDRR, 2011; Gizachew and Shimelis, 2014). Ethiopia is a country that is highly vulnerable to frequent climate variability and change (World Bank 2010; Conway and Schipper 2011) and it will be negatively affected by the changing climate patterns in the coming decades (McSweeney et al., 2010a).

Regional projections of climate models do not only predict a substantial rise in average temperatures over the twenty-first century but also an increase in rainfall variability with a rising frequency of both extreme flooding and droughts which significantly affect the Ethiopian agricultural production .

As a result, Ethiopia's agricultural productivity remains lower in the coming decades (Belay et al., 2014). A 10% decrease in seasonal rainfall from the long-term average brings a 4.4% reduction in the Ethiopian food production (Von Braun 2007). Unless steps to build resilience are effective, climate change will reduce Ethiopia's GDP growth up to 10% by 2045 between 0.5-2.35 per year (World Bank 2010, EPA 2011). The Climate Resilient Green Economy (CRGE, 2011) also indicated that climate change has the potential to hold back economic progress, or reverse the gains made in Ethiopia's development and could exacerbate social and economic problems.

Erratic and insufficient rainfall particularly during the short rainy season, lack of improved crop varieties, poor farming practices, land degradation and crop diseases were major challenges of crop production. Poor performance of local breeds, lack of animal fodder and prevalence of animal diseases also constrained livestock productivity. As a result of challenges related to biophysical and socio-economic issues, smallholder farmers are not able to produce enough to satisfy their annual food requirement. The national Productive Safety Net Program supported the majority of the community to complement their livelihoods (Mekonnen et al., 2013).

One of the key messages emerging out of the recent 5th IPCC reports is that the climate change is real, happening and will continue to happen for the foreseeable future. The reports also estimate with high confidence that the negative impacts on agriculture outweigh the positives which makes adaptation an urgent and pressing challenge. However, adaptation planning requires accurate information about where, when and how the impacts are going to be felt and who will be more vulnerable.

Vulnerability assessments can play a vital role in designing appropriate adaptation strategies targeted towards climate change and its impacts on ecosystems, and those who depend upon these resources for their livelihoods. Assessing which particular individual, group, community, region or nation is vulnerable, and in what ways, enables to formulate clear and effective policy and strategy that promotes adaptation. More specifically, vulnerability assessment helps set three policy measures. First, it is used to specify long-term targets for mitigation of climate change; second, to identify vulnerable places and people and to prioritize resource allocation for adaptation; and, finally, to put forward specific adaptation recommendations for specific places and groups (Füssel and Klein 2006).

Although Ethiopia is highly vulnerable to the impacts of climate variability and change, there are no detailed studies conducted at local level, except the works of Simane et al., (2014), Dechasa et al., (2016); G/Egziabher et al., (2016); Sisay (2016)   and Tesso et al., (2012). These reports showed the complex distribution of vulnerabilities across agro-ecologies since the Ethiopian highlands are highly dissected and fragmented. Therefore, prevailing climate conditions and the sensitivity of agricultural systems to climate variability can change over a distance of even a few kilometers (Simane 2014). As a result, an estimate of vulnerability at the national or regional scale is insufficient to have an overall understanding of climate vulnerabilities and adaptation interventions within the Ethiopian highlands.

This study was, therefore, aimed to assess the level of smallholder farmers' vulnerability to climate change and variability at micro-scale level in five AEZs of south Wollo. The study area is selected for this research because no similar study was conducted in the area before. Thus, it is important to understand the level of vulnerability of smallholder farmers to climate change and variability at the local level. Since the study is conducted at micro-scale level, it helps decision makers and development partners to have context-specific understanding of the impact of climate change and variability and take appropriate adaptation measures accordingly.

2 Methodology

2.1. Description of the study area

Biophysical setting

South Wollo zone is located in the north eastern part of Ethiopia with in 10°12'N, and 11°40'N and 38°30'E and 40°05'E (Fig. 1). Its zonal capital, Dessie, is found 400 kms North of Addis Ababa. It is one of the drought-prone and aid-dependent areas in Amhara Regional State (Bewket and Conway, 2007). The study area covers a total area of 17,053.45 km^2 with eighteen rural and two urban woredas with a projected total population of 2,980,912 (Male 1,475,525 & Female 1,505,387) for 2014 (CSA, 2015).

The digital elevation model (DEM) reveals that larger parts of south Wollo are characterized by rugged topography that consist of very high mountains, deeply incised canyons and gorges, valleys and plateaus (Fig.2). The elevation ranged from the dry plains at slightly less than 1000 m a.s.l. in the east to the high peaks above 4000 m a.s.l in the west. However high-land areas ranging between 1500 m and 3500 m a.s.l are the dominating feature of south Wollo (Rosell and Holmer, 2007; Rosell and Holmer, 2015). The areas covered by slopes < 2%, 2 to 15%, 15 to 30% and >30% cover 1.7%, 30.2%, 31.3% and 36.8 % of the total area, respectively (Fig. 2). Land with slopes less than 15% is most suitable for agriculture (Hurni 1988). However, this area accounts for only 32% of the total area.

Because of the diverse topography, the study area experiences different climatic zones that ranged from hot and arid lowlands in the eastern part to cold and humid highlands in the central   part. It is broadly classified into 5 agro-ecologies (M1,M2,M3,SM2 and SM3) (MoARD 2000).

Table 1: Agro-ecological zones of south Wollo

Symbol	Description	Length of growing period (days)	Average annual rainfall (mm)	Temperature (°C)	Elevation (m)
M1	Hot to warm moist lowlands	121-180	300-700	>21	<1600
M2	Tepid to cool moist mid highlands	121-180	300-700	11-21	1600-3200
M3	Cold to very cold moist sub afro-alpine to afro-alpine	121-180	300-700	<11	>3200
SM2	Tepid to cool sub moist mid highlands	61-120	300-700	11-21	1600-3200
SM3	Cold to very cold sub-moist sub afro-alpine to afro-alpine	61-120	300-700	<11	>3200

Source: MoARD (2000)

The average annual temperature varies from less than 10°C in the western highlands to 25°C in the eastern lowlands. The annual rainfall varies between less than 1000 mm in the eastern part to more than 1200 mm in the western part (Rosell and Holmer 2015). Eastern part has a relatively dry climate and western parts have moderate to large amount of water surplus in the main rainy season, which results in high run-off, soil erosion and water-logging depending on the soil type and topography. Bimodal rainfall pattern characterizes the study area which leads to two growing periods (with single maxima during summer). The main rainy season summer (locally called *kiremt*) is from June-August and the small rain season spring (locally called *belg*) is from March to May. The *spring* season is noticeable for mid to high latitude areas whereas the mid lands to lowland areas mainly depend on the *summer* rain. Crop production is rain-fed. The small rainy season is erratic and highly variable and experienced frequent failure which hampers *spring* harvesting (Rosell, 2011; Dereje et al., 2012). Delayed onset and early cessation as well as poor *spring* performance make the region food insecure and highly reliant on food aid (Lakew et al., 2000; Bewket, 2007; Amare et al., 2011; Daniel, 2011; Kahsay, 2013). The study area has various soil types, the major ones being Leptosols, Cambisols, Vertisols, Andosols and Luvisols (FAO, 1984).

Socio-economic setting

Although agriculture is the major economic sector, it is still underdeveloped. The agriculture is largely based on cereal-livestock farming systems (ANRS-BFED, 2008) where they have complimentary and competitive effects to each other (Haileslassie et al., 2005). Farmlands used to supply crop residue as animal feed without putting manure back to farmlands while fallowing practices have been greatly

reduced. These increased soil nutrient depletion, worsens the degradation processes and gradually contributed to crop production failure (Haileslassie et al., 2005). Due to the increasing demand for agricultural land, marginal lands have been converted to cultivation and grazing (Tekle 1999). As a consequence, land degradation has alarmingly increased (Tekle 1999; Descheemaeker et al., 2010). Land holdings are also reduced from time to time. As a result, agriculture in the zone has been unable to provide sufficient food for its population.

The study area is highly degraded and deforested in terms of indigenous trees but does have substantial eucalyptus plantations. Alpine species unique to extreme highland areas are found in central parts of the study area. Local people in the area are engaged in subsistence agriculture for their livelihood. Unlike other areas of Ethiopia where highlands generally are the most food secure, the opposite is often the case in the study area. In fact, the crowded, steep-sloped highlands above 2000 meters a.s.l, including large parts of south Wollo, are among the Ethiopia's most famine-prone areas (Little et al., 2006).

2.2 Method

Sampling techniques and procedures

The primary data sources for this study were smallholder farmers and multistage sampling techniques were used to select sample respondents. The first stage involves selection of south Wollo purposively as it was vulnerable to climate variability and change. The area is highly prone to frequent drought (Bewket and Conway 2007; Spielman et al., 2011;Yimer et al., 2017). Total sample size was determined using the following formula.

$$n= \frac{z^2.N.p.q}{e^2(N-1)+Z^2.p.q} \qquad \text{(Kothari 2004)}$$

Where, n = Total sample size,

N= represent the total rural household heads,

Z= Standard variation at a given confidence level (95%=1.96)

P= Estimated characteristics or proportion of the target population that is 0.5

q = 1-p which is equal to 0.5

e = Margin of error (5%)

Secondly, representative woredas from each agro-ecology zone were selected using the probability proportional to size (each agro-ecology) method. Third, the kebeles (the smallest administrative units) in each woreda were selected using simple random sampling procedure. Fourthly, the number of sample respondents in each kebele was determined using the probability proportional to size method.

$$n = \left(\frac{Ni}{N} * ni \right) \qquad \text{(Kothari 2004)}$$

where n= total number of samples to be taken from each kebele,

Ni= the total number of HH in each kebele,

N= total number of HHs in all selected kebeles

 ni= sample size determined by the researcher

and; lastly household heads in each kebele were selected on simple random sampling basis. Household heads with more than 45 years of age were subjects of this study. This helps   see any visible change in microclimate of a particular place with in almost 30 years of time span. Therefore they are assumed to provide more accurate data in local climate study. The scale of analysis was agro-ecological zone.

Data sources and collection methods

The study used a mixture of data collection methods (questionnaires, key informant interviews and focus group discussions) A cross-sectional survey was conducted from October to December 2015 involving 502 sample households in 13 kebeles spread across all 5 agro-ecological zones (Fig 1, Table 2). The survey questions were designed to address each indicator of exposure, sensitivity and adaptive capacity.

To substantiate the quantitative information gathered through household survey, key informant interviews with elderly who have in-depth knowledge about their environment and focus group discussions with the household heads were held. One focus group discussion and two key informant interviews were held in each sample kebele.

Table 2: Number of sample smallholder farmers in each kebele

AEZ	Woreda	Kebele	No of HHs		Samples			
			Male	Female	Male	Female	Total	
M1	Kalu	Arabo	756	49	24	2	26	67
	Debresina	Dokis	1000	266	32	9	41	
	Wereilu	Meni	1206	550	39	18	57	
M2	Kalu	Choresa	571	90	21	2	23	193
	Kutaber	Doshign	1517	460	49	15	64	
	Tehuledere	Tebisa	1334	185	43	6	49	
M3	Tenta	Keregimba	698	191	23	6	29	29
	Mekdela	Haroge	857	236	29	7	36	
	Tenta	Kulbitamba	808	130	26	4	30	173
SM2	Sayint	Meles Sanka 03	1218	413	28	12	40	
	Debresina	Worke meskel	486	357	25	13	38	
	Wogde	Abey	479	406	16	13	29	
SM3	Legambo	Welelet	1131	120	36	4	40	40
Total			12061	3453	391	111	502	

2.3 Approaches for measuring vulnerability

As a methodology, this study adopted the livelihood vulnerability index (LVI) developed and demonstrated by Hahn et al. (2009) in Mozambique. They developed and demonstrated the LVI-IPCC in studying the risks of climate change on two villages in Mozambique. They applied seven major vulnerability indicators in their study that map into the three IPCC vulnerability determining factors (exposure, sensitivity and adaptive capacity). This study adopted the works of Hahn et al., (2009). However, this study made some modifications in selecting vulnerability indicators with as applied in the works of Shah et al., (2013), Simane et al., (2014), Dechasa et al., (2016) and Tessema and Simane (2019) and assigning weight for each indicator. Eight major vulnerability indicators were identified for this study; wealth, community, technology, infrastructure, institutions, ecosystem, changes in climate, and extreme climatic events (Table 3).

Table 3: Vulnerability determinant factors, livelihood capitals and vulnerability indicators used for computing vulnerability index

Vulnerability factors	Major components	Sub-component (Indicator)	Units	Hypothesized functional relationships
	Human	Marital status, Education level of HH head, Household size	Counts	The more married, educated and large family size farmers, the more adaptive capacity
Adaptive capacity	Wealth	Number of livestock, Food availability, Dependency ratio	% of change Months Ratio	The more financial sources and income, the more adaptive capacity
	Off-farm income	Remittance, Food/cash aids, Safety Net	% of HHs received off-farm income	
	Technology	Use of fertilizer, improved seeds, soil and water conservations techniques, weather forecast information	% of HHs using technologies	The more access to technology, the more adaptive capacity and less vulnerability
	Infrastructures	Average time to access all weather road, health services, schools, credit, clean water sources	Minutes	Better access to infrastructures means greater adaptive capacity
	Institution/ Social networks	Land ownership, Connections with extension workers, Membership in CBO, Mutual support	% engagement of HHs in social networks	The more social networks, the more adaptive capacity
Sensitivity	Ecosystem	Irrigation potential, land degradation, land productivity Landholding size	% HH's perception ha/HH % of HH's experience	The more access to irrigated land, fertile soil, suitable agricultural land, land management practices, diversity of crop species, vegetation cover, the less sensitivity; the more occurrences of pests and disease, the greater sensitivity

		Diversity of crop species , Vegetation cover, Occurrences of pests and diseases, yield		
Exposure	Climate	Change of rainfall and temperature as well as extreme events (flood and drought)	% HH's experience	The higher the change the higher exposure

Source: Deressa et al., (2010), Simane et al., (2014), Dechasa et al., (2016) and Tessema and Simane (2019)

2.4 Constructing vulnerability index

There are two broad approaches to empirically calculating vulnerability: i) econometric and ii) indicator methods. The former expresses vulnerability as expected poverty, low expected utility and uninsured exposure to risk (Hoddinott and Quisumbing 2003). The latter tries to assess vulnerability by integrating indicators to form a composite index, which can be at a local level (Adger 1999; Hahn et al. 2009). This study adopted the indicator approach in measuring the vulnerability of smallholder farmers to climate change and variability. The basic challenge in constructing indices is the lack of standard ways of assigning weight to each indicator. The two most common weighting methods used to combine indicators are equal and unequal weighting schemes. The former method assigns equal weight to each indicator. The latter method, we adopted, assigns different weights to various indicators using (i) expert judgment (Brooks et al. 2005; Moss et al., 2001) or statistical methods such as principal component analysis (PCA) (Cutter et al. 2003; Thornton et al. 2006).

Each indicator of exposure, sensitivity, adaptive capacity doesn't have equal impact on computation of vulnerability indices of different agro-ecological zone. As a result, different weights were assigned for these indicators. Therefore, Principal component Analysis (PCA) was selected to generate the weights for each indicator component in this study (G/Egziabher et al., 2016; Thornton et al., 2006; Cutter et al., 2003; Filmer and Pritchett 2001). PCA was run for the selected indicators of exposure, sensitivity, and adaptive capacity separately using STATA Software.

Once one or more indicators are selected, the selected indicators were integrated into sub-indices and composite index was produced. The data sets measured using different scales or measurement units were made comparable by transforming them into a common scale by normalization (Nelson, et al., 2010b; Gbetibouo & Ringler, 2009; Hahn 2009; Vincent, 2004).

$$Normalized\ value = \frac{(observed\ value - Min)}{Maximum - minimum}$$

The loadings from the first component of PCA are used as the weights for the indicators. The magnitude of the weights describes the contribution of each indicator to the value of the index. A stepwise (nested) PCA was run separately for the indicators of exposure, sensitivity and adaptive capacity to get the index of these three vulnerability determining factors.

For example, the adaptive capacity index has been generated by using four nested PCAs. The inner most PCA was performed to produce an index for fertilizer consumption, improved seed, soil and water conservation and access to weather forecast. These four categories have been used in the second PCA to generate index for technology. At the third PCA, we have generated index for financial capital, physical capital, human capital and social capital. The results of the third PCA were used to generate the fourth index for adaptive capacity (PCA 4). The index of the adaptive capacity is computed by using loadings of financial capital, physical capital, human capital and social capital. The indices of sensitivity and exposure are also calculated in similar way. Finally the outer most PCA was performed to generate index for overall vulnerability.

Finally the overall vulnerability was calculated as the difference of exposure and adaptive capacity with a multiplying effect of sensitivity as employed by Hahn et al., 2009; Etwire et al., 2013; Simane et al., 2014; Etwire et al., 2013; Shah et al., 2013; Dechasa et al., 2016; Tessema and Simane (2019).

Vulnerability index was calculated as:

$$LVI\text{-}IPCC = (E_r - AC_r) * S_r$$

where, LVI-IPCC is the vulnerability index of the region,

E_r is the calculated exposure score for AEZ r

AC_r is the calculated adaptive capacity score for AEZ r

S_r is the calculated sensitivity score for AEZ r.

The Livelihood Vulnerability index ranges from -1 (least vulnerable) to +1 (most vulnerable).

Determining the scale of analysis is very important in measuring vulnerability. Analysis of vulnerability to climate change ranges from household to global level (Adger 1999; Brooks *et al.,* 2005). The decision of scale selection is determined by many factors such as the objective of the study, the methodologies set, and the available data for the analysis. Although the most appropriate scale of analysis for vulnerability study is at the lowest administrative units, the scale of analysis, for this study was AEZs.

This index does not give the absolute measurement of vulnerability; rather it gives a comparative ranking of study agro-ecologies. Test of a one way analysis of variance (ANOVA or F-test) was conducted to

compare the averages of major indicators of vulnerability among the five AEZs. ANOVA tells whether there was an overall difference between the groups, but it does not tell which specific group was differed. In order to confirm where the differences occurred between groups, post hoc tests were used. It should only be run when an overall statistically significant difference in group averages occurred (i.e., a statistically significant one-way ANOVA result).

3 Results And Discussion

In this chapter, the contribution of each major component to vulnerability was analyzed. In this study, eight major components of vulnerability were used to generate the vulnerability index.

3.1 Adaptive Capacity Profiles

Adaptive capacity profile is composed of many socio-economic profiles which include human capital, wealth, technology, infrastructure, institutions/social capital. The detail explanation of each profile together with their indicators was presented in Table 5. The relationship between most of the profiles and vulnerability is believed to have negative relationship.

Human/demographic characteristics: The demographic and socioeconomic characteristics of the study population constituted the human capital which was indexed under adaptive capacity. From a total of 502 sample smallholder farmers, 77.9% were male and 22.1% were female; 76.7% were married; 10.6%divorced and 11% widowed. In terms of age category, majority of respondents (83.5%) were within the active working age group (45–64), while 16.5% respondents were above 64 years of age. The education level of the respondents was low where 30.9% of them were illiterate and the remaining 70.1% were literate. Household heads with higher levels of education believed to have a better level of planning, access and effectiveness of early warning information from different sources, better reactions and rehabilitation skills during and after natural shocks, alter agricultural operation and adopt extension strategies (Legese et al., 2016; Muttarak and Lutz 2014). Education tends to improve the ability of smallholder farmers to better comprehend issues affecting them and therefore look for possible solutions (Etwire et al., 2013). The One-way ANOVA analysis reveals that there was a significant difference of educational status among the sample households in the study AEZs (Table 4). The level of education was the least in SM3 (Table 5).

The survey also indicated that household size ranged from two to fourteen household members, with an average of 5.8 with slight difference across agro-ecologies. From the total 502 interviewed farmers, 46 had small family size (1-3), 300 had medium family size (4-6) and 156 had large family size (>6). The average family size of the study area is higher than the regional average (4.6) (CSA 2014). Household size is related with poverty and consequently, with climate change vulnerability. A study conducted by Cutter et al., (2009) suggested that a large family size increases social vulnerability to climate hazards. Saldajeno et al., (2012) further explained that larger households may have limited capacity to adapt and manage their resources. On the other hand Deressa et al., (2009) reported that, although they could not

find significant result in the model, the larger the size of the household, the better the chance of adapting to climate change.

Wealth: Number of livestock, food availability and dependency ratio were considered as major indicators of wealth in the study area. Livestock production was one of the most important livelihood systems in the study area. However, climate change brought a negative impact on livestock production. More than 70% of the farmers in the study area reported that the number of their livestock was decreasing through time. Shortage of animal feed attributed to the reduction of their number. They also added that availability of water for livestock is diminished in recent times. Respondents (88%) in M1 stated that their livestock number is significantly decreased (Table 5). The analysis indicates that M1 and SM3 had significant difference in the number of livestock than others AEZs. SM3 is the most vulnerable in terms of livestock number with average value of 0.000 (Table 5). Different reasons were provided for this. First, it was due to the extremely cold nature of the area and unavailability of pasture and water; second, since the area is accessible to all weather roads, farmers could sell their products to towns and gave attention to quality than quantity. The other reason was that their nearby grazing lands were delineated for area closure under watershed management program. However, the livestock market was showing a remarkable improvement in its price in recent times compared to the past years. This helps them minimize their vulnerability to climate change.

It is worth to cite the statement of the following key informants' response from the M3 agro-ecological zone (*Keregimba*) as follows:

> *"We used to practice livestock rearing and crop production equally. Before two or three decades, most of us had large number of livestock because of unlimited access to abundant grazing lands and excess crop residues available on our farms. But, today, neither the grazing lands nor crop residues are available. Grazing lands were either changed into area closure or converted to crop lands and we do not leave plant residues during harvesting. This has created an increased shortage of feed for livestock and this became a challenge for us and we supplement the gap by purchasing livestock feed from other remote areas. Hence, the number and variety of livestock population gradually decline as the result of lack of grazing lands and water resources".*

Although varied in its magnitude, food insecurity was common in the study zone. 62% (313) of the respondents confirmed that their household did not have adequate food in some months of the year. They were assisted by food aid. The finding showed that households remained with food shortage in a year for long periods ranging from 1-6 months. Households significantly differ (P<0.001) in their food security status across AEZs (Table 4). M3 and SM3 were vulnerable in terms of food availability (Table 5).

The average dependency ratio in the study area was 0.33 (33%). However, it was very high in M3 and M1 compared to the remaining regions. It has a strong implication in vulnerability reduction efforts. A higher dependency ratio could lead to labor shortages. A higher dependency ratio is likely to reduce productivity. As the number of dependent family members (children and elders) becomes large, the active population would not support the family instead the degree of vulnerability worsen. They spent their time to cover

livelihood costs of their unproductive family member. Siagian et al., (2014), reported that high number of dependency ratio increases sensitivity and may limit their ability to bounce back or recover from the impacts of natural hazards, like climate extremes.

Technology: The households widely used fertilizers to improve the productivity of their small plots of land. Considerable number 82% of smallholder farmers in the study area indicated that their fertilizer consumption is being increased for the last 20 and 30 years (Table 5). However, 82% smallholder farmers in SM3 reported a significant reduction in using fertilizers compared to the others. They did not afford the price of fertilizers. SM3 is found in high altitude and it is susceptible for degradation due to water erosion.

Smallholder farmers were aware of new technologies through agricultural extension workers. As food insecurity prevails in the study area, smallholder farmers were showing strong willingness to accept what extension workers told to them. They tried to increase productivity by using improved seeds. About 90% of interviewed farmers revealed that the use of improved seeds was increasing in recent years when compared to the past 20 and 30 years.

Soil and Water Conservation*:* In order to reduce soil erosion, a number of soil and water conservation structures have been constructed in the study area including physical measures (terracing, check dams, eye brow basin, and area closure). Farmers' land use/ownership right helps farmers invest more on their land. The study shows that 74.7% and 16.3% of the respondents possessed land as owner and both as owner and share cropping respectively.   Large number of the respondents (92%) exercised the physical soil and water conservation (SWC) measures. However, the practice is significantly noticeable in relatively lower altitude AEZs (M1, M2 and SM2) than high altitude AEZs (M3, SM3) due to the fact that the problem is serious in lower altitude areas. There exists a significant difference in the use of fertilizer, improved seed, soil and water conservation across AEZs (Table 4).

Infrastructure: Infrastructure is very essential for providing any social services to the rural community. When roads are easily accessible, the provision of any services will be facilitated. There were considerable efforts in different AEZs to make various infrastructures accessible. Almost 78% of interviewed farmers explained that they had road access. Smallholder farmers have significant difference ($P<0.001$) in accessing all weather roads. Relatively, SM3 had better road access than others and SM2 had less road access than others (Table 4)

Access to credit was showing progressive trend in recent years. In terms of access to credit there was a significant difference ($P<0.001$) between agro ecological zones. However farmers in M1, M2, and SM2 had a better access to credit than SM3 and M3. It has strong implication to household vulnerability. Farmers who received credit will have high probability to reduce vulnerability as compared to those who do not have access within that category.

Accessibility of primary schools was more or less similar in all AEZs (Table 5). Majority (75%) of the respondents indicated that children have to travel on average less than 30 minutes to reach nearby primary school. However, the post hoc test analysis confirmed that children in SM3 were significantly

taking more time than others. More than 90% of farmers in SM3 reported that their children took long time to reach primary schools ranging from half an hour to one hour to reach nearby primary school.

Table 4: Explanatory variables considered for ANOVA for the five agro-ecological zones

Variable	F-Test	Significance level
Educational status of households	12.926***	0.000
Average number of livestock	8.550***	0.000
Food aid	2.00*	0.096
Use of fertilizers	59.087***	0.000
Use of improved seed	4.312**	0.002
Time spent to access primary schools	16.043***	0.000
Time spent to access health posts	4.967***	0.000
Time spent to access all weather road	4.874***	0.000
Access to credit institutions	16.761***	0.000
Land ownership	11.194***	0.000
Use of SWC	56.226***	0.000
Access to water resource	28.52***	0.000
Size of irrigable land	7.395***	0.000
Land degradation	16.462***	0.000
Land productivity	12.181***	0.000
Diversity of crop varieties	38.640***	0.000
Frequency of occurrences of crop pests and diseases	19.657***	0.000
Number of flood incidences	5.788***	0.000
Late onset of rain	11.116***	0.000
Occurrences of rain during harvesting period	15.92***	0.000
Decline of rainfall amount	6.351***	0.000
Temperature increment	5.958***	0.000
Frequency of occurrences of drought	7.920***	0.000

*, **, *** significant at 0.1, 0.05, 0.001 respectively

The government of Ethiopia gave emphasis to the development of health sectors across the country. Similarly, all agro-ecologies in the study area have access to primary health services especially health posts with slight difference. In addition, there are health extension workers who helped the community around their settlement/residential area. However, there was significant difference in distance (P<0.001) to reach nearby health posts between AEZs (Table 4) where farmers in M3 travel the longest distance (Table 5).

3.2 Sensitivity profiles

Landholding size: Almost 34.46% and 48.2% of the respondents own less than 0.5 hectare and 0.5-1 hectare respectively. It is in line with the findings of CSA (2013) and Little D. et al., (2006) which reported landholding size of south Wollo to be 0.51-0.75 ha and 1.72 ha respectively. This shows that the land holding size of the study region is less than the national average (1.2 ha). There was no significant change in landholding size across all AEZs. Households who owned a better size of land were less vulnerable/ less sensitive and thereby increase their adaptive capacity. The larger the size of land, the higher the diversity of crops that are grown, the better their access to improved technology, and the better their access to financial services and extension services (Dechasa et al., 2016; Gutu et al., 2012).

Irrigable land: Access to irrigation is negligible in the study area. Only 12.5% of the total respondents had an irrigable land. There was a significant difference across AEZs in having irrigable land (Table 4) where SM3 had the least access to irrigable land (Table 5). It is believed that the availability of rivers for irrigation was not common in areas where located in very high altitude. SM3 is found on the highest altitude of the zone in which Amba Ferit (4246 m.a.s.l) is found. Households having more irrigable land will be less sensitive to climate change impacts by maximizing the cropping intensity. Farmers reported that they harvested twice in a year from their irrigable land and be less vulnerable.

Land productivity: There was low agricultural productivity in the study area. More than half (55 %) of the respondents explained the reduction of their land productivity. The crop yield was dwindling from time to time. They tried to avoid the decline in crop yield by applying fertilizers and improved seeds. However, there was a significant (P<0.001) variation in land productivity between AEZs (Table 4). Poverty and fast-growing population, coupled with land degradation poses a serious threat to household food security (Simane et al., 2013). In the study area, 63.7% of the respondents also perceived progressive land degradation. They claimed that loss of soil fertility, soil erosion, and steepness of the slope attributes to less productivity. More than 75% of the respondents perceived that the status of soil fertility was deteriorating from time to time. This problem was worse in central and western highland woredas of south Wollo where it is dominated by worst terrain with very stony, steep and bare lands (Little et al., 2006; Castro et al., 1999). This fully characterizes M3 and SM2 agro-ecological
zones.

Variety of crops: Smallholders were diversifying crop varieties they grow to avoid the effect of climate change and variability. There was significant difference (P<0.001) in diversifying crop varieties between

AEZs where M3 is the lowest in crop diversity. This is due to the fact that this AEZ experiences very cold climate which is conducive to grow only barley. The focus group discussion held with farmers living in SM2 agro-ecology zone (Haroge kebele) revealed that they were able to diversify the type of crops grown. In the abnormal rainfall seasons, all of the crops may not be affected equally. Some may be efficient in absorbing the shock and the others not. This increases the adaptive capacity of farmers and lessens their vulnerability to climate change impacts. Crop diversity has an implication to climate change adaptation. Different crops have different capacity to respond to the changing climate. They need water for their growth in a varying degree. A few may grow with less water and other need excess water for their optimum growth. Some may provide yield under harsh environment than others.

Pests and diseases: These problems became common threats to all AEZs because of the changing climate. The findings from the focus group discussions held with farmers living in M1, M2 and SM2 agro ecological zones revealed that leguminous crops like Beans (*Vicia faba*) and Peas (Pisum sativum), which were widely grown in the study area are no longer cultivated today. The discussants told that they have noticed this challenge in recent years and related it with climate change. These leguminous crop starts to be damaged by pests and diseases at its flowering stage. As a result, the production of such crop has been worsened from time to time to the extent of disappearing and their market value is growing alarmingly when compared to other crops. Most farmers mentioned that the loss of such crops have brought a negative effect on their livelihoods.

The increment of CO_2 and temperature concentrations associated with climate change has a substantial impact on plant-disease interaction (Yanez-Lopez et al., 2012; Rosenzweig and Tubiello, 2007). The rising levels of CO_2 and temperatures are having direct effect on pests and diseases in crops. Exposure to high CO_2 generally increases the carbon-to-nitrogen ratio (C: N) of plant tissues (Rogers et al., 2004; Hamilton et al., 2005), reducing the nutritional quality for protein-limited insects. Some insects and pests may increase consumption rates to compensate reduced leaf nitrogen content. Concentration of CO_2 can increase levels of simple sugars in leaves and lower their nitrogen content (Dermody et al., 2008). These can increase the damage caused by many insects, who will consume more leaves to meet their metabolic requirements of nitrogen. Thus, any attack will be more severe. Higher temperatures from global warming, mainly due to elevated CO_2, will mean that more numbers of pests will survive. Besides, warmer temperature lowers the effectiveness of some pesticides.

3.3 Exposure Profile

This was mainly composed of rainfall and temperature variability and change. This includes six indicators (Table 5). All indicators were significantly (P<0.001) showing variation between AEZs. Farmers living in different AEZs had different biophysical and socio-economic characteristics. It is believed that farmers perceive climate change differently due to disparities in local climate impacts, as well as difference in socio-economic perspectives on these impacts (Simane et al., 2013). Sampled households were asked to point out the manifestations of temperature and rainfall changes for the last 30 years. 73

% of the respondents pointed out that temperature was showing increasing trend for the last 30 years. This perception is consistent with scientific temperature analysis done for the study area, which showed a warming trend of average monthly maximum temperature between 0.07-0.49 °C/decade (Yimer et al., 2018). With regard to rainfall change for the last 30 years, 78.39 % of respondents perceived declining of annual rainfall, however, differed significantly across AEZs. This was consistent with the analysis of meteorological data which showed a declining tendency of spring rainfall, ranging from 8.55mm/decade to 50.52 mm/decade in all study stations of south Wollo (Yimer et al., 2018). In addition to the reduction of its amount, the late onset and early cessation of rainfall affected their livelihood.

The analysis of the profiles revealed that M3 and SM3 AEZs were significantly vulnerable in terms of reduction of rainfall amount, increment of temperature, late onset of rainy season and highest frequency of drought than other AEZs. These AEZs were also more vulnerable than others in the frequency of drought. These two AEZs are typically very cold highlands which were known for using spring rain (become erratic and variable in recent years) for their main growing season.

A 48 years old man residing in SM3 stated the following about the changing climate.

"*When we were teenagers, the highland area that you see in front of us (by showing his hand to the mountain peak) was covered by snow during winter. But it was decreasing from time to time and currently we do not observe any snow cover in the area. The rain used to come regularly and consistently, and we were able to plant and harvest on time. But currently, it deviates from the normal. It is unpredictable, kiremit rain starts late (mid of July) and stops early around* **buhe** *(Christian festival celebrated on August 19). We were also highly dependent on spring rainfall for our agricultural practices. Availability of water and pasture becomes scarce after the long dry season (which extends from December–February). It is the spring rainfall (March-May) which saves our livestock. Besides, we plant crops like barley (Hordeum vulgare) which need longer gestation period for harvesting. But today, we lost all these chances due to failure or/and inadequate spring rain.*

Table 5: Indexed sub-components and major components in each agro-ecology zone

Major Component	Sub-Component	M1	M2	M3	SM2	SM3
Wealth	Number of livestock	0.090	0.212	0.621	0.197	0.000
	Food availability	0.149	0.492	0.000	0.318	0.000
	Dependency ratio	0.419	0.304	0.518	0.320	0.090
	Major component index value	**0.868**	**0.662**	**0.671**	**0.749**	**0.991**
Off-farm income	Remittance	0.433	0.140	0.276	0.335	0.000
	Food Aid	0.716	0.187	0.517	0.173	0.025
	Safety- Net	0.507	0.228	0.241	0.601	1.000
	Major component index value	**0.512**	**0.832**	**0.702**	**0.617**	**0.740**
Human	Marital status	0.791	0.824	0.724	0.723	0.675
	Education level of HH head	0.373	0.368	0.172	0.173	0.000
	Average household size	6.269	6.026	4.862	5.214	6.575
	Major component index value	**0.521**	**0.466**	**0.917**	**0.656**	**0.862**
Technology	Fertilizer consumption	0.776	0.886	0.862	0.919	0.175
	Supply of improved seeds	0.716	0.58	0.138	0.769	0.85
	Use of soil and water conservations	0.821	0.679	0.034	0.659	0.350
	Access to weather forecast information	0.000	0.005	0.000	0.000	0.000
	Major component index value	**0.371**	**0.303**	**0.334**	**0.298**	**0.199**
Infrastructure	Access to all weather road	0.94	0.772	0.862	0.682	1.000
	Nearby health services	0.94	0.601	0.103	0.786	1.000
	Access to telephone	0.985	1.000	1.000	0.983	1.000
	Access to schools	0.955	0.912	1.000	0.821	0.975
	Access to market	0.134	0.383	0.793	0.618	0.975
	Access to credit	0.91	0.611	0.379	0.815	0.600
	Access to fuel (energy)	0.418	0.207	0.655	0.399	0.250
	Access to clean water sources	0.463	0.591	0.517	0.312	0.000

	Major component index value	**0.83**	**0.835**	**0.917**	**0.829**	**0.912**
Institutions	Land ownership	0.642	0.699	0.517	0.827	0.975
	Connections with extension workers	0.642	0.684	0.724	0.694	0.925
	Membership in CBO	0.015	0.124	0.069	0.017	0.025
	Mutual support	0.313	0.456	0.31	0.243	0.700
	Major component index value	**0.379**	**0.412**	**0.316**	**0.43**	**0.401**
	Irrigation potential	0.269	0.316	0.552	0.254	0.000
	Level of soil Fertility	0.209	0.275	0.000	0.272	0.000
	land productivity	0.254	0.71	0.862	0.462	1.000
Ecosystem	Land size	0.627	0.775	0.681	0.669	0.713
	Diversity of crop species	0.254	0.451	0.034	0.561	1.000
	Vegetation cover	0.03	0.249	0.207	0.405	0.025
	Wildlife	0.000	0.078	0.069	0.191	0.000
	Frequency of pests and diseases	0.493	0.694	0.276	0.526	0.400
	Invasive species	0.687	0.741	0.621	0.809	0.400
	Major component index value	**0.657**	**0.666**	**0.754**	**0.57**	**0.632**
Climate Change and extreme events	Change in annual rainfall	0.030	0.119	0.000	0.185	0.000
	Change in temperature	0.493	0.710	0.793	0.642	1.000
	Occurrence of rain at harvesting period	0.493	0.570	0.552	0.815	1.000
	Late start of rainy season	0.627	0.813	0.862	0.855	1.000
	Frequency of flood incidence	0.552	0.513	0.138	0.329	0.000
	Frequency of drought	0.687	0.694	1.000	0.861	1.000
	Major component index value	**0.637**	**0.673**	**0.743**	**0.764**	**0.844**

3.4 LVI -IPCC contributing factors

The overall vulnerability index based on the function of exposure, adaptive capacity and sensitivity was presented in Table 6 below. Generally the exposure of the AEZs to climate change and variability in the study area ranges from 0.637 in M1 to 0.844 in SM3. Sensitivity of AEZs to climate change and variability ranges from 0.57 in SM2 to 0.75 in M3. Land degradation has been the greatest challenge in highlands of the study area. Farmers reported that loss of soil fertility, high soil erosion, small size of landholding and steep slope of their farm land were factors for the deterioration and aggravation of land degradation which eventually leads to the declining of productivity. This challenge was especially worst in M3 and SM3 AEZs. More than 75% of the respondents perceived that the status of soil fertility was dwindling with time. Adaptive capacity of AEZs also varied from 0.46 (M1) to 0.77 (SM3). Areas with high altitude have relatively better adaptation capacity in various indicators. Highland areas (M3, SM2, and SM3) have better adaptive capacity in terms of access to technology, infrastructure, off-farm income, institutions than M1 and M2. However SM3 and M3 had high proportion of illiterate people which has an implication on their adaptation practices. M3 and M1 had high dependency ratio and less social network which reduces adaptive capacity of the farmers. Human and financial capitals were found to determine the level of adaptive capacity of households in all agro-ecologies.

Table 6: Calculated indices for LVI-IPCC contributing factors and Vulnerability

Agro-ecology	Exposure	Adaptive Capacity	Sensitivity	Vulnerability Index	Vulnerability Rank
M1	0.6372	0.4609	0.6566	0.116	2
M2	0.6726	0.5703	0.6659	0.068	3
M3	0.7427	0.6766	0.754	0.05	4
SM2	0.7642	0.5335	0.5701	0.131	1
SM3	0.844	0.7708	0.6319	0.046	5

Overall, SM2 (mid highland) and M1 (lowland) AEZs are more vulnerable to climate change and variability than other AEZs in the study area (figure 5). As Table 6 indicates SM2 was the most vulnerable AEZ due to its greater exposure to climate change and variability as well as least adaptive capacity whereas M1 is more vulnerable due to its high exposure and sensitivity scores. SM3 and M3 were less vulnerable AEZs due to a relatively better adaptive capacity and lower sensitivity scores than others.

4 Conclusions And Policy Implications

This study adopted the indicator approach in measuring the vulnerability. It employed the livelihood Vulnerability Index (LVI) for measuring vulnerability of farmers in different AEZs to climate variability and change. It provides a detailed description of factors driving households to vulnerability. Vulnerability was

calculated as the net effect of sensitivity and exposure on adaptive capacity. The analysis provides useful insights and captures specific variations across agro-ecologies. The results indicated that the lowland and mid highland AEZs were found to be most vulnerable to climate change due to high level of exposure and sensitivity and relatively low level of adaptive capacity compared to highland areas. Although highland AEZs have less vulnerability index due to their better adaptive capacity, their exposure to climate variability and change was very high. The   frequency of climatic variability/change has been increasing both in terms of frequency of extreme climate events and gradual changes, and consequently worsening the vulnerability of agriculture to these events. Smallholder farmers perceived declining trends of rainfall (especially *belg* rain) and increasing trends of temperature in the study area over the last 30 years. These perceptions agreed with the analysis made using the metrological data in the previous chapters. The results indicated that level of exposure to the long term changes and the degree of adaptive capacity was the most important components to determine the overall vulnerability of the AEZS. However, biophysical elements in the ecosystem have a multiplier effect to the deviation of the two.

The finding of the study will have important policy relevance that could enable vulnerable smallholder farmers in lowland and mid highland AEZs to better adapt to the impacts of climate change and variability. Improving the adaptive capacity of farmers has implications on improving the sensitivity of the community. For example, improving the irrigation facilities (infrastructures) decrease the sensitivity of crops to droughts which in turn increases crop diversity and farmers' resilience to climate change vulnerability.   Improving credit access would also strengthen the capacity of farmers to be engaged in alternative economic activities. Creating more access to technologies (fertilizers, improved seed and soil fertility management) with affordable price would lead to improve adaptive capacity and lessen sensitivity of biophysical factors to climate change. Promoting insurance schemes as a strategy would also help farmers avoid risks during drought or flood incidences. Replication of this study in the same location over time might provide information about how the exposure, adaptive capacity, and sensitivity of the study AEZs change as adaptation practices are initiated and promoted.

Abbreviations

AEZs-Agro-Ecological Zones

ANRS-Amhara National regional State

BFED-Bureau of Finance and Economic Development

CBO-Community Based Organizations

CSA-Central Statistics Authority

DEM-Digital Elevation Model

EPA-Environment Protection Authority

GDP-Gross Domestic Product

IPCC-Intergovernmental Panel for Climate Change

LVI-Livelihood Vulnerability Index

M1-Hot to warm moist lowlands

M2-Tepid to cool moist mid highlands

M3-Cold to very cold moist sub-afro-alpine to afro-alpine

SM2-Tepid to cool sub moist mid highlands

SM3-Cold to very cold sub-moist sub-afroalpine to afro-alpine

MoARD- Ministry of Agriculture and Rural Development

PCA-Principal Component Analysis

SWC-Soil and Water Conservation

Declarations

Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

Availability of data and materials: Datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests

Authors' contributions: YM was responsible for all activities of the research process such as the design, data compilation and entry, data analysis, and interpretation of results as well as writing up of the manuscript. The other three authors were involved in improving the quality of manuscript by providing constructive guidance, critical comments and suggestions on the study design, data analysis and interpretation. All authors read and approved the final manuscript.

References

Adger, WN, (2006) Vulnerability. Global Environmental Change. *16*(3), 268-281.

Adger, WN, Brooks N, Kelly M, Bentham S, and Eriksen S. (2004) New Indicators of Vulnerability and Adaptive Capacity. Technical Report 7, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, UK.122

Adger, WN, (1999) Social Vulnerability to Climate Change and Extremes in Coastal Vietnam. World Development . 27(2): 249-269.

Amare B, Hurni H, Gete, Z (2011) Responses of rural households to the impacts of population and land-use changes along the Eastern Escarpment of Wello, Ethiopia. Nor. J. Geogr. doi.org/10.1080/00291951.2010.549954.

ANRS-BFED. Amhara National Regional State Bureau of Finance and Economics Development (ANRS-BFED) (2008) Annual statistical bulletin, Bahir-Dar, Ethiopia. 29-50

Arnell, NW (2004) Climate change and global water resources: SRES emissions and socio-economic scenarios. Global Environmental Change. 14, 31–52.

Bewket W, Conway D (2007) A Note on the temporal and spatial variability of rainfall in the drought-prone Amhara Region of Ethiopia. .Int. J. Climatol. **27**: 1467–1477.

Brooks N, Adger WN, and Kelly PM (2005) The Determinants of Vulnerability and Adaptive Capacity at the National Level and the Implications for Adaptation. Global Environmental Change. 15(2005): 151-162.

Chambers R, Conway G (1992) Sustainable rural livelihoods: practical concepts for the 21st century. Institude of Development Studies (IDS), UK.

Coltorti M, Dramis F, Ollier CD (2007) Plantation surfaces in northern Ethiopia. Geomorphology. 89(3-4):287-296

Conway D, & Schipper E (2011) Adaptation to climate change in Africa: challenges and opportunities identified from Ethiopia. Global Environmental Change. 21, 227– 237

Central Statistical Agency (CSA) (2015) Ethiopian Population projection report.

Central Statistical Agency (CSA) (2014) "Agricultural Sample Survey (2013/2014): Report on Land Utilization (Private Peasant Holdings, Meher Season)." Volume IV. Statistical Bulletin no573. The Federal Democratic Republic of Ethiopia, Central Statistical Agency (CSA).

Central Statistical Agency (CSA) (2008) Central Statistical Agency Population and Housing Census of Ethiopia, Addis Ababa.

Central Statistical Agency (CSA) (2007) Summary and statistical report of the 2007 Population and Housing Census

Cutter SL, Emrich CT, Webb JJ & Morath D (2009) Social Vulnerability to Climate Variability Hazards: A Review of the Literature: Oxfam America.

Cutter SL, Boruff BJ, and Shirley WL (2003) Social Vulnerability to Environmental Hazards. Social Science Quarterly. 84(2): 242-261.

Daniel GY (2011) Climate Variability in the Drought Prone Regions of Afar and Amhara, Northern Ethiopia (MSc thesis submitted to Goteborg University, Sweden).

Dechassa C, Simane B, Alamirew B, Azadi H. (2016) Agro-ecological based small-holder farmer's livelihoods vulnerability to climate variability and change in Didesa sub Basin of Blue Nile River, Ethiopia. Acad. J. Agric. Res.   4(5): 230-240.

Dereje, A, Tesfaye, K, Mamo, G, Yitaferu, B, Bayu, W. (2012) Variability of rainfall and its current trend in Amhara region, Ethiopia. Afr. J. Agric. Res.   doi.org/10.5897/AJAR11.698.

Deressa T (2010) Assessment of the vulnerability of Ethiopian agriculture and farmers' adaptation strategies. PhD dissertation, University of Pretoria, South Africa.

Deressa, TT, and Hassan RM (2009) Economic Impact of Climate Change on Crop Production in Ethiopia: Evidence from Cross-section Measures. Journal of African Economies. 18(4): 529-554.

Deressa TT, Hassan RM, Ringler C, Alemu T, Yesuf M (2009) Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Glob. Environ. Change. 19: 248–255.

Dermody O., Neill F., Zangerl R., Berenbaum R., DeLucia H (2008) Effects of elevated CO_2 and O_3 on leaf damage and insect abundance in a soybean agro ecosystem. Arthropod-Plant Interactions   DOI 10.1007/s11829-008-9045-4

Descheemaeker K, Mapedza E, Amede T, Ayalneh W (2010) Effects of integrated watershed management on livestock water productivity in water scarce areas in Ethiopia. Physics and Chemistry of the Earth. 35(13-14):723-729.

DFID (1999) Sustainable Livelihoods Guidance Sheets. London, UK: Department for International Development.

Ellis F (2000) Rural Livelihoods and Diversity in Developing Countries. New York: Oxford University Press.

Etwire PM, Al-Hassan RM, Kuwornu JKM, Osei-Owusu Y (2013) Application of livelihood vulnerability index in assessing vulnerability to climate change and variability in Northern Ghana. J. Environ. Earth Sci. 3: 157–170.

EPA (2011) Ethiopia's Climate-Resilient Green Economy (CRGE). In: (ed). 2011: Vol. pp. 188, Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia.

Filmer D, & Pritchett LH (2001)Estimating Wealth Effects Without Expenditure Data - or Tears: An Application to Educational Enrollments in States of India. Demography *38*(1), 115 - 132.

Ethiopian CRGE Ethiopia's Climate-Resilient Green Economy (CRGE) (2011) Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia.

FAO. Ethiopian geomorphology and soils (1:1,000,000 scales) (1984) Assistance to Land Use Planning, Addis Ababa, Ethiopia.

Fields S (2005) Why Africa's climate change burden is greater. Environmental Health Perspectives. 113, A534–A537.

Füssel HM (2007) Vulnerability: a generally applicable conceptual framework for climate change research. Glob Environ Chang. 17:155–167

Füssel and Klein (2006) Climate Change Vulnerability Assessments: An Evolution of Conceptual Thinking. Climatic Change. (75): 301-329.

Gallopín GC (2006) Linkages between vulnerability, resilience, and adaptive capacity. Glob Environ Chang. 16:293-303

Gbetibouo GA and Ringler C (2009) Mapping South African Farming Sector Vulnerability to Climate Change and Variability: A Subnational Level Assessment. IFPRI Discussion Paper 00885. International Food Policy Research Institute, Washington, D.C.

Gebreegziabher Z, Mekonnen A, Deribe R, Boka J, and Abera S (2016) Mapping Vulnerability to Climate Change of the Farming Sector in the Nile Basin of Ethiopia:A Micro-level Perspective. Environment for Development Discussion Paper Series 16-19.

Gizachew L, and Shimelis A (2014) Analysis and mapping of climate change risk and vulnerability in central rift valley of Ethiopia. African Crop Science Journal. Vol. 22, Issue Supplements 4, 807 – 818.

Gonfa L (1996) Climatic classification of Ethiopia. Addis Ababa, Ethiopia. 15-58

Gutu T, Bezabih E, Mengistu K. (2012) Analysis of vulnerability and resilience to climate change induced shocks in North Shewa, Ethiopia. J. Agric. Sci. 3(6): 871-888.

Hadgu G, Tesfaye K, Mamo G, and Kassa B (2015) Farmers' climate change adaptation options and their determinants in Tigray region, Northern Ethiopa. African Journal of Agricultural Research. DOI: 10.5897/AJAR2014.9146

Hahn, Riederer, Foster (2009) The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique. Elsevier, Global Environmental Change. 19 74–88.

Haileslassie A, Priess J, Veldkamp E, Teketay D, Lensschen J (2005) Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances. Agriculture, Ecosystems and Environment. 108(1):1-16

Hamilton JG, Dermody OC, Aldea M, Zangerl AR, Rogers A, Berenbaum MR (2005) Anthropogenic changes in tropospheric composition increase susceptibility of soybean to insect herbivory. Environ Entomol. 34:479–485

Hoddinott, J, and Quisumbing A (2003) Methods for Microeconometric Risk and Vulnerability Assessments. Social Protection Discussion Paper Series No. 0324. Social Protection Unit, Human Development Network. Washington, DC: World Bank.

Hurni H (1998) Principles of soil conservation for cultivated land. Soil Technology. 1(2):1001-116.

IPCC. Climate Change (2013) The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds F Stocker et al) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 1535pp

IPCC. Climate Change. Impacts, Adaptation and Vulnerability (2007) Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK. 976pp.

Kahsay B (2013) Diagnosis and Intervention Plans for South Wollo Zone, Amhara Region: Livestock and Irrigation Value Chains for Ethiopian Smallholders (LIVES) (Unpublished).

Lakew D, Menale K, Benin S, Pender J (2000) Land Degradation and Strategies for Sustainable Development in the Ethiopian Highlands: Amhara Region. Socioeconomic and Policy Research Working Paper 32. ILRI (International Livestock Research Institute), Nairobi, Kenya. p. 122.

Legese A, Olutayo A, Sulaiman H, and Rao P (2016) Assessing climate change impacts in the Lake Tana Sub-Basin, Ethiopia using Livelihood Vulnerability Approach. J Earth Sci Clim Change. doi: 10.4172/2157-7617.1000368

Little PM, Priscilla S, Tewodaj MA, Peter C, & Workneh N (2006) 'Moving in Place': Drought and Poverty Dynamics in South Wello, Ethiopia. Journal of Development Studies. Vol. 42, No. 2, 200–225.

Lopez Y, Torres-Pacheco R, Guevara-González G, Hernández-Zul MI, Quijano- Carranza JA, and Rico-García E (2012) The effect of climate change on plant diseases. African Journal of Biotechnology. Vol. 11(10), pp. 2417-2428 DOI: 10.5897/AJB10.2442 ISSN 1684–5315.

Lucas PL, and Hilderink HB (2004) The Vulnerability Concept and its Application to Food Security. Report 550015004/2004. Netherlands: National Institute for Public Health and the Environment (RIVM).

McSweeney C, New M, and Lizcano G (2010a) UNDP climate change profile for Ethiopia.

Mekonnen K, Duncan A, Kefyalew D, Amede T, Teklemariam B, and Wubet A (2013) Enhancing communities' adaptive capacity to climate change in drought-prone hotspots of the Blue Nile Basin in Ethiopia. Project report in Kabe.

Ministry of Agriculture and Rural Development (MoARD) (2000) Agro-ecological zonations of Ethiopia. Addis Ababa, Ethiopia.

Morand P, Kodio A, Andrew N, Sinaba F, Lemoalle J, and Bene C (2012) Vulnerability and adaptation of African rural populations to hydro-climate change: Experience from fishing communities in the Inner Niger Delta (Mali). Climatic Change. 115(3-4): 463-483.

Moss RH, Brenkert AL, and Malone EL (2001) Vulnerability to Climate Change: A Quantitative Approach. Research Report Prepared for the U.S. Department of Energy.

Nelson R, Kokic P, Crimp S, Martin P, Meinke H, Howden Sl. (2010b) he Vulnerability of Australian Rural Communities to Climate Variability and Change: Part II - Integrating Impacts with Adaptive Capacity. *Envrionmental Science and Policy. 13*, 18 – 27

O'Brien K, Leichenko R, Kelkar U, Venema H, Aandahl G, Tompkins H, Javed A, Bhadwal S, Barg S, Nygaard L, and West J (2004) Mapping Vulnerability to Multiple Stressors: Climate Change and Globalization in India. Global Environmental Change. 14: 303-313.

 Patnaik U, and Narayanan K (2005) Vulnerability and Climate Change: An Analysis of the Eastern Coastal Kebeles of India. Paper presented at the "Human Security and Climate Change International Workshop," Asker, Norway. June 21-23.

Reed M, Podesta G, Fazey I, Geeson N, Hessel R, Hubacek K, Letson D, Nainggolan D,

Prell C, Rickenbach M, Ritsema C, Schwilch G, Stringer L, Thomas A (2013). Combining analytical frameworks to assess livelihood vulnerability to climate change and analyse adaptation options. Elsevier, Ecological Economics. 94 66–77.

Rogers A, Allen D, Davey P, Morgan P, Ainsworth E, Bernacchi C (2004) Leaf photosynthesis and carbohydrate dynamics of soybeans grown throughout their life-cycle under Free-Air Carbon dioxide Enrichment. Plant Cell Environ. 27:449–458. doi:10.1111/j.1365-3040.2004.01163.x

Rosell S, and Holmer B (2015) Erratic rainfall and its consequences for the cultivation of teff in two adjacent areas in South Wollo, Ethiopia, Norsk Geografisk Tidsskrift - Norwegian Journal of Geography. DOI: 10.1080/00291951.2014.992805

Rosell S (2011) Regional perspective on rainfall change and variability in the central highlands of Ethiopia, 1978–2007. Appl. Geogr. 31 (1), 329–338.

Rosell S, and Holmer B (2007) Rainfall change and its implications for spring harvest in South Wollo, Ethiopia. Geogr Ann. 89(4):287–299

Rosenzweig C, Tubiello F (2007) Adaptation and mitigation strategies in agriculture: an analysis of potential synergies. Mitig. Adapt. Strat. Glob. Change. 12: 855-873

Rygel L, O'Sullivan D, and Yarnal B (2006) A method for constructing a social vulnerability index: an application to hurricane storm surges in a developed country. Mitigation and Adaptation Strategies for Global Change. 11(3), 741- 764.

Saldajeno P, Florece L, Lasco R, & Velasco M 92012) Vulnerability Assessment of Upland Communities in Sibalom Natural Park, Antique, Using Capital-based Approach. Journal of Environmental Science and Management. 15(2).

Schlenke W, and Lobell D (2010) Robust negative impacts of climate change on African

agriculture. Environmental Research Letters. 5(1):1-8.

Shah U, Dulal B, Johnson C, Baptiste A (2013) Understanding livelihood vulnerability to climate change: Applying the livelihood vulnerability index in Trinidad and Tobago. Elsivier, Geoforum. 47 (2013) 125–137

Siagian T, Purhadi P, Suhartono S, & Ritonga H (2.014) Social vulnerability to natural hazards in Indonesia: Driving factors and policy implications. Natural Hazards. 70(2), pp. 1603-1617.

Simane B, Zaitchik B, & Folt J (2014) Agroecosystem specific climate vulnerability analysis: application of the livelihood vulnerability index to a tropical highland region. Mitig Adapt Strateg Glob Change. DOI 10.1007/s11027-014-9568-1

Sisay T (2016) Vulnerability of Smallholder Farmers to Climate Change at Dabat and West Belesa Kebeles, North Gondar, Ethiopia. J Earth Sci Clim Change. doi: 10.4172/2157-7617.1000365

Spielman D, Kelemwork D, Alemu D (2011) Seed, fertilizer, and agricultural extension in Ethiopia. Ethiopian strategy support program (ESSP II), Working Paper No. 20, pp 4-8.

Tefera M, Chernet T, Harro W (1996) Explanation on geological map of Ethiopia a 1:2,000,000 scale. Bulletin No 3, Addis Ababa, Ethiopia, pp 2-64

Tekle K (1999) Land degradation problems and their implications for food shortage in south Wollo, Ethiopia. Environmental Management. 23(4):419-427

Tessema I, and Simane B (2019) Vulnerability analysis of smallholder farmers to climate variability and change: an agroecological system-based approach in the Fincha'a sub-basin of the upper Blue Nile Basin

of Ethiopia. Ecological process, springer. doi.org/10.1186/s13717-019-0159-7

Tesso G, Emana B, and Ketema M (2012) Analysis of vulnerability and resilience to climate change induced shocks in North Shewa, Ethiopia. Agricultural Sciences. doi:10.4236/as.2012.36106

Thornton PK, Jones PG, Owiyo T, Kruska RL, Herrero M, Kristjanson P, Notenbaert A, Bekele N, Omolo A, with contributions from Orindi V, Otiende B, Ochieng A, Bhadwal S, Anantram K, Nair S, Kumar V, and Kulkar U (2006) Mapping Climate Vulnerability and Poverty in Africa. Report to the Department for International Development (ILRI). Nairobi, Kenya.

Vincent K, (2004) Creating an Index of Social Vulnerability to Climate Change for Africa. Technical Report 56. Norwich, U.K.: Tyndall Centre for Climate Change Research, University of East Anglia.

Von Braun J (2007) The World Food Situation: New Driving Forces and Required Actions. International Food Policy Research Institute. Washington, D.C. pp.18.

World Bank (2010) In: Economics of adaptation to climate change, Ethiopia.
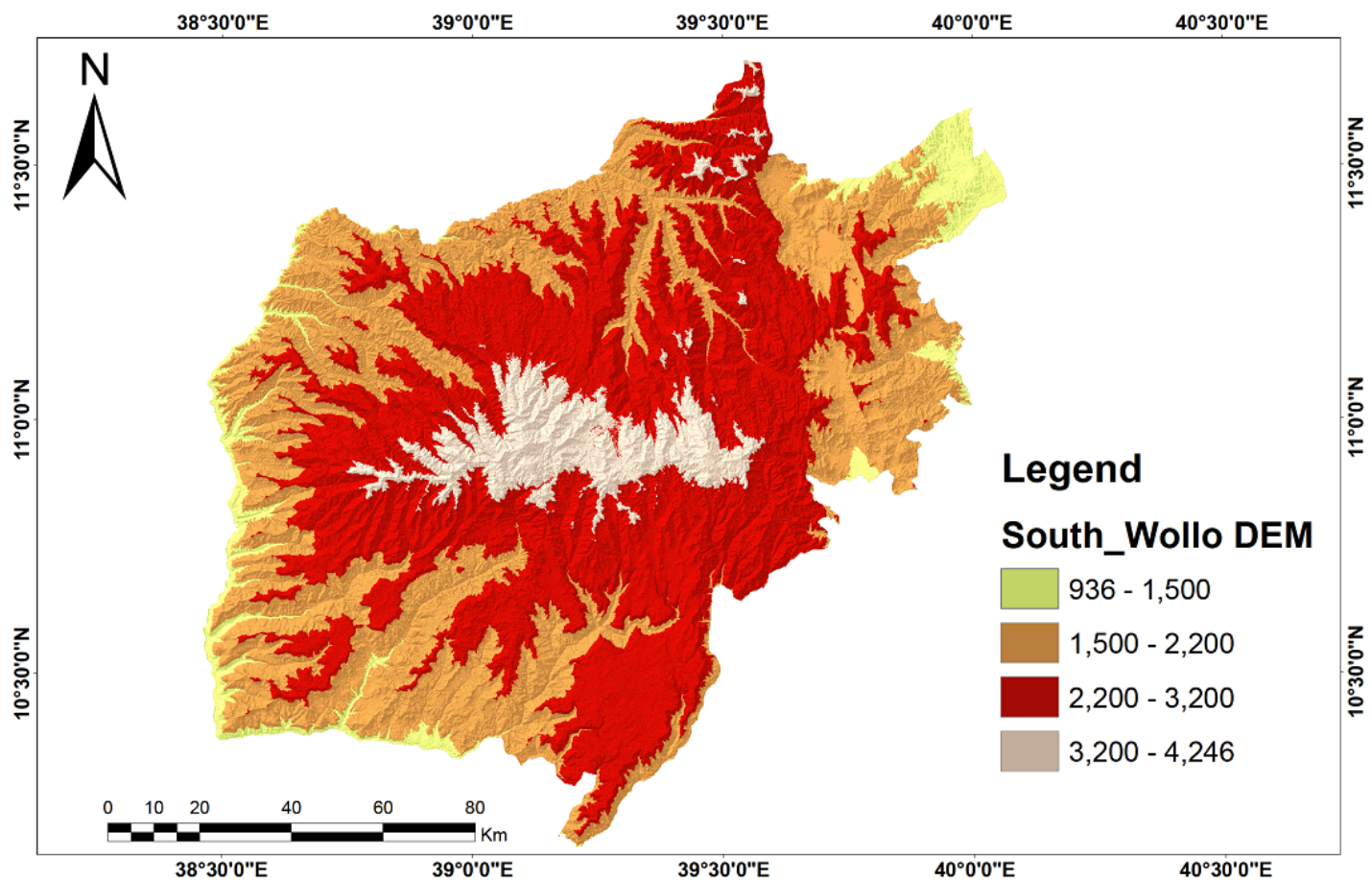
Yimer M, Fantaw Y, Menfese T, and Kindie T (2018) "Meteorological drought assessment in north east highlands of Ethiopia", International Journal of Climate Change Strategies and Management, doi.org/10.1108/IJCCSM-12-2016-0179
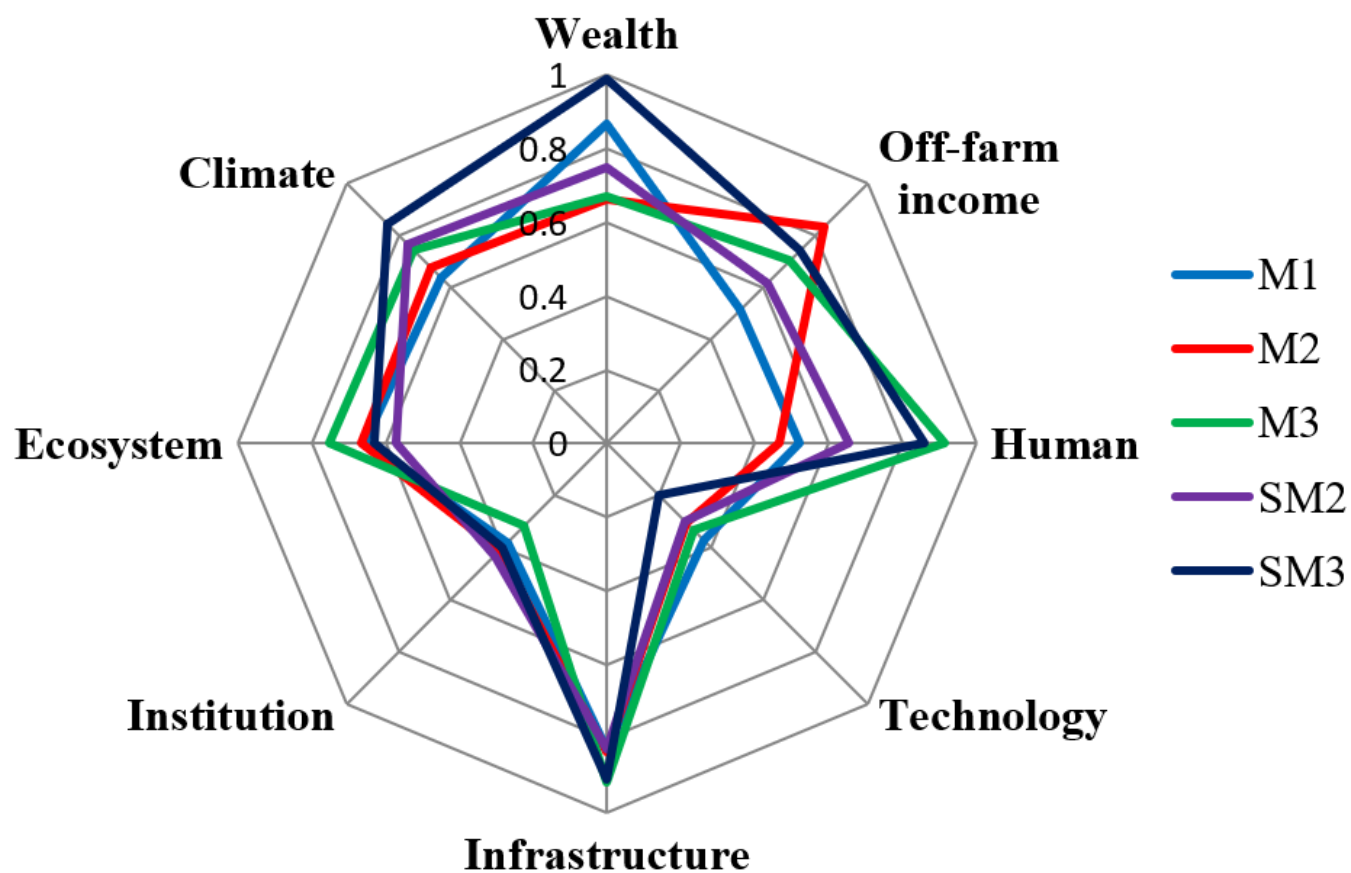
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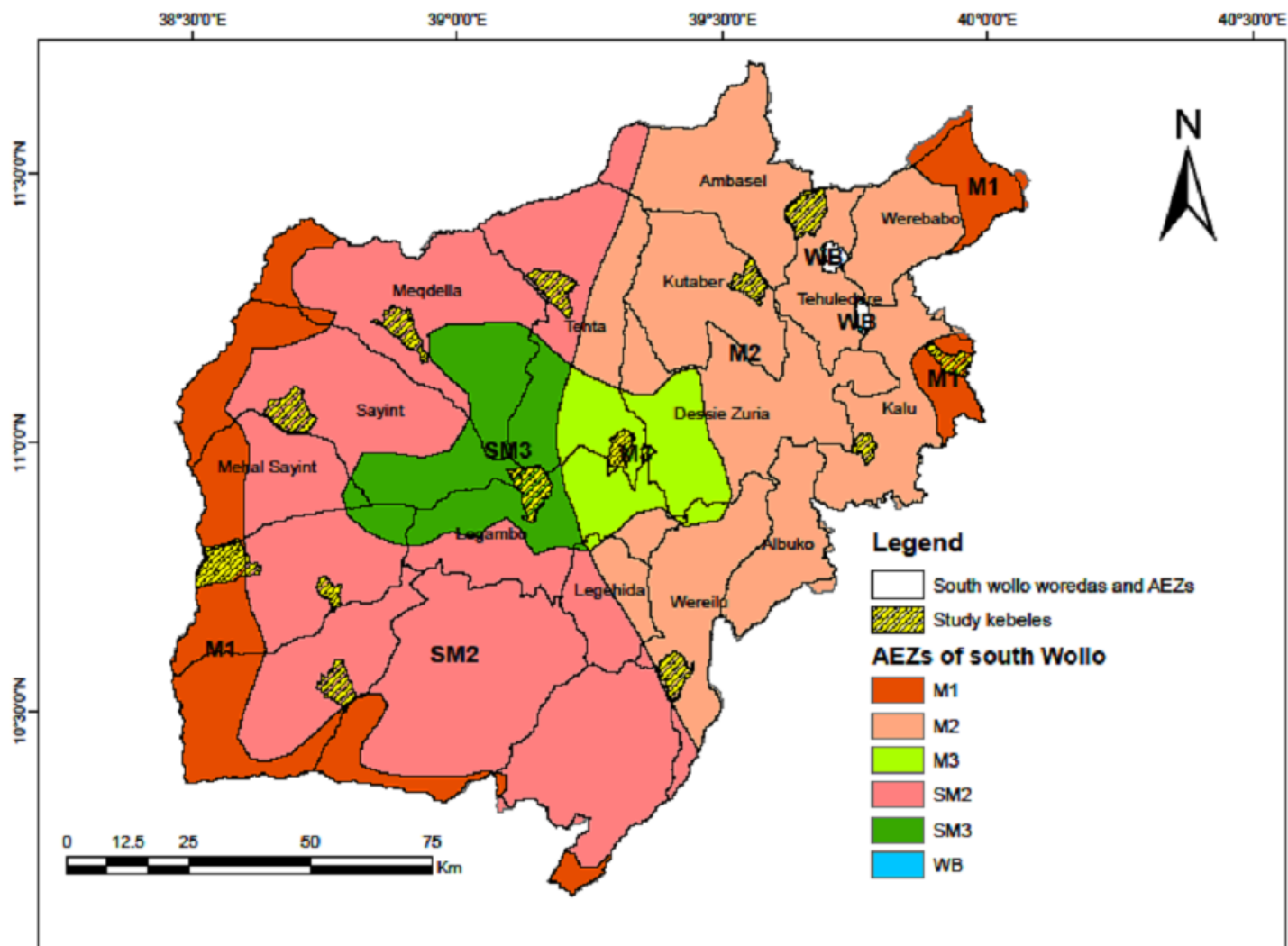
Figure 1

Map of the study area showing sample kebeles in five agro-ecological zones (AEZ)
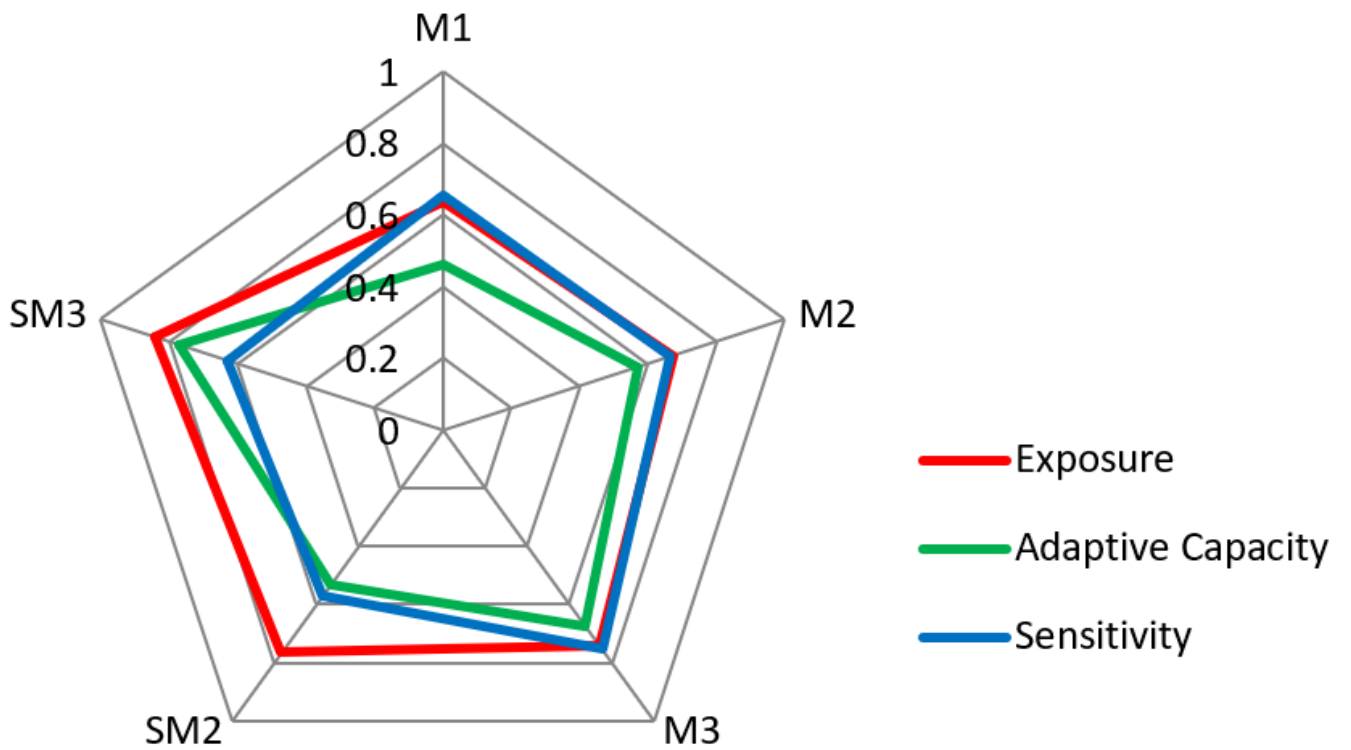
Figure 2

Digital Elevation Model of South Wollo.

Figure 3

Spider diagram of major components of livelihood vulnerability

Figure 4

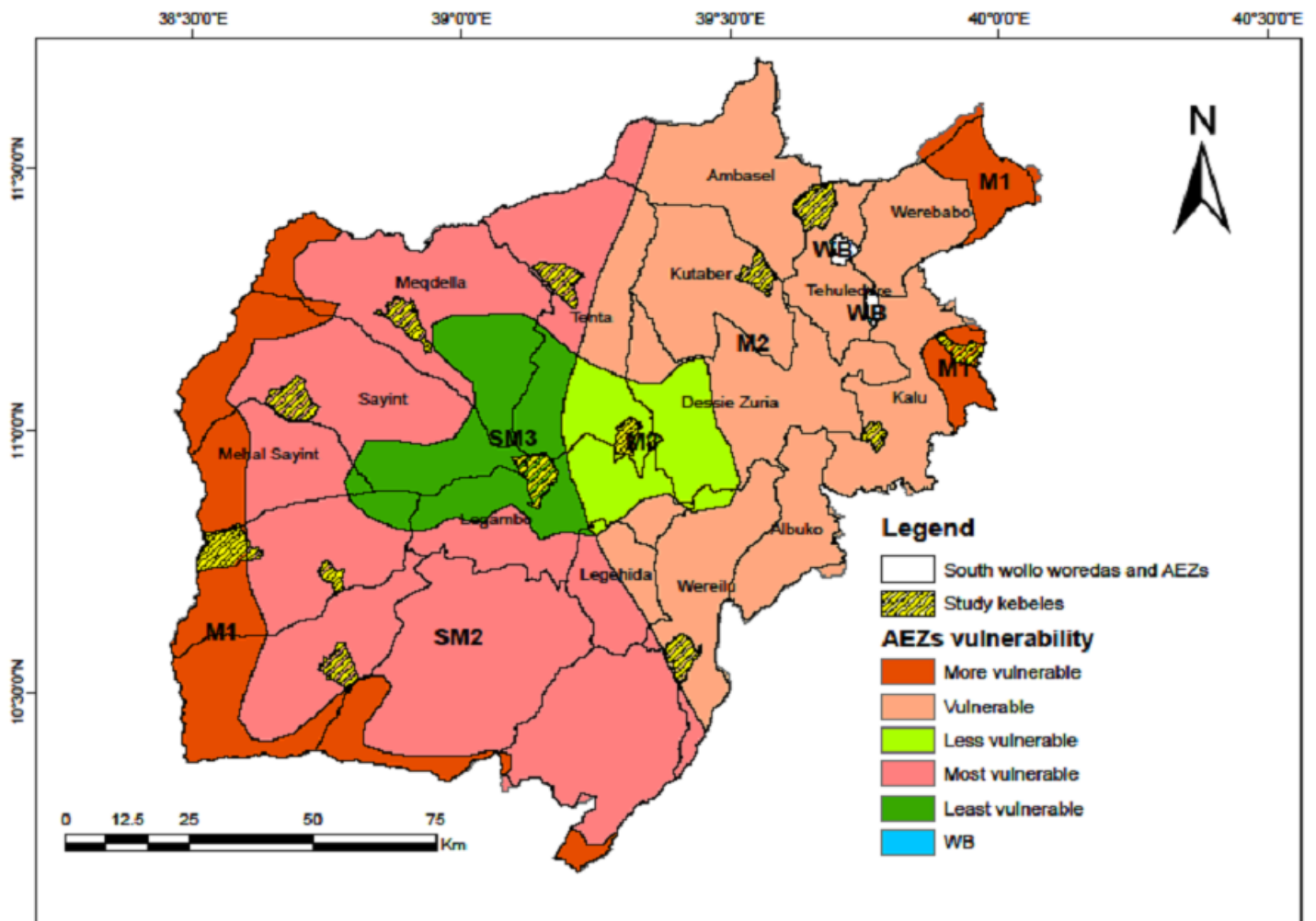Vulnerability Spider diagram of the three dimensions of the Livelihood Vulnerability Index-IPCC (LVI–IPCC)

Figure 5

Map of vulnerability across Agro-ecological Zones of south Wollo