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ANALYSIS AND MAPPING OF CLIMATE CHANGE RISK AND VULNERABILITY IN CENTRAL RIFT VALLEY OF ETHIOPIA

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ABSTRACT

There is growing demand for spatially explicit information among stakeholders across public and private institutions regarding vulnerability to climate change at the local scale. This study was conducted over 16 districts in Central Rift Valley (CRV) of Ethiopia, to determine the degree of climate risk and the relative vulnerability of the districts, to climate change and, thereby identify vulnerable hotspots. A biophysical and socio-economic indicator based integrated vulnerability assessment technique was used to map climate change vulnerability. Indicators were generated and analysed under three components of vulnerability, namely exposure, sensitivity and adaptive capacity; and finally aggregated into a single vulnerability index. The values of all indicators were normalised by considering their functional relationship with vulnerability, and expert judgment was then used to assign weights to all indicators. Aggregate vulnerability index (VI) was finally determined from the weighted sum of all indicators and mapped over the 16 districts. Selti, Dodotana-Sire and Tiyo districts had relatively high vulnerability to climate change; while Arsinegele, Adamitulu-Jido-Kombolcha and Dugda-Bora were the least vulnerable. The rest of the districts had medium vulnerability to changing climate. This study shows that vulnerability mapping is crucial in determining the varying degrees of vulnerability of different localities, and generating information that can help researchers, policy makers, private and public institutions in formulating site-specific adaptation strategies and prioritising adaptation investments to the most vulnerable hotspots.

Key Words: Socio-economic indicators, vulnerability index

RÉSUMÉ

Il ya une demande sans cesse croissante parmi les partenaires à travers les institutions publiques et privées, de l'information spatiale explicite concernant la vulnérabilité au changement climatique à l'échelle locale. Cette étude était conduite sur 16 districts de la Vallée du Rift Central (VRC) en Ethiopie, pour déterminer le degré de risque climatique et la vulnérabilité relative de ces districts au changement climatique et delà, identifier les sites les plus vulnérables. Une technique d'évaluation du degré de vulnerabilité basé sur un indicateur intégrant les aspects biophysiques et socio-économiques était utilisée pour établir la carte de vulnérabilité au changements climatique. Les indicateurs étaient générés et analysés sous trois composantes de vulnérabilité : exposition, sensitivité et capacité adaptive; et finalement agrégés en un seul indice de vulnérabilité. Les valeurs de tous les indicateurs étaient normalisées en considérant leur relation fonctionnelle avec la vulnérabilité, et ensuite, un jugement expert était utilisé pour leur assigner un poids. L'indice de vulnérabilité cumulative (VI) était finalement déterminé de la somme du poids de tous les indicateurs et cartographié sur l'étendue de seize districts. Les districts de Selti, Dodotana-Sire et Tiyo avaient relativement une vulnérabilité élevée au changements climatique, pendant que Arsinegele, Adamitulu-Jido-Kombolcha et Dugda-Bora étaient les districts les moins vulnérables. Le reste des districts présentaient une vulnérabilité moyenne au changement climatique. Cette étude montre que la cartographie de la vulnérabilité est cruciale dans la détermination des divers niveaux de vulnérabilité des différentes localités et la génération de l'information pouvant aider les chercheurs, les décideurs politiques, les institutions privées et publiques dans la formulation des stratégies spécifiques d'adaptation et à la formulation des priorités d'investissement pour renforcer l'adaptation des sites les plus vulnérables.

Mots Clés: Indicateur socio-économique, indice de vulnérabilité

INTRODUCTION

Climate change is one of the current issues that severely impact all climate sensitive sectors like agriculture. The manifestation of climate change such as rising temperatures, increasingly erratic rainfall, and more frequent and severe floods and droughts have grave consequences on the livelihood security of smallholder farming communities, making them more vulnerable. Agriculture plays a great role in the livelihood of rural communities in many African countries. Most such countries are, however, predicted to be among the globe's most vulnerable to climatic changes (Schlenker and Lobell, 2010; Samson *et al*., 2011; Morand *et al*., 2012). Muller *et al.* (2011) noted that the negative consequences of climate change are anticipated overall for Africa where over 95 % of the farmers subsist on rain-fed agriculture. In Ethiopia, agriculture is the dominant sector contributing around 50% of the Gross Domestic Product (GDP) and 85% of total employment and livelihoods. It is also the major source of food for the population and, hence, the prime contributor to food security (CEEPA, 2006).

Climate Resilient Green Economy (CRGE, 2011) noted 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. It is heavily dependent on rainfall, with irrigation accounting for less than 1% of the country's total cultivated land. Crop production is dominated by small scale subsistence farmers (about 8 million households) who practice more traditional farming, accounting for 95% of the total area under crop and more than 90% of the total agricultural output (CSA, 2011). Vulnerable agricultural systems are most prevalent in arid, semi-arid, and dry sub-humid regions of the developing world, home to half of the world's currently malnourished populations (Jon, 2009). The most vulnerable households are those with assets and livelihoods exposed and sensitive to climatic risks, and who have weak risk management capacity (Heltberg *et al*., 2009).

Assessment and mapping of the vulnerability to climate change is the base for the development of site specific adaptation options that reduce the risks associated with climate change. Several researchers have noted that vulnerability mapping including exposure, sensitivity, and adaptive capacity, has become a central tool for communicating with policy makers and local stakeholders as well as visualising climate change impacts on the landscape to more effectively support risk management and spatial planning (Eakin and Luers, 2006; Preston *et al*., 2011; López-Carr *et al*., 2014). Vulnerability assessment describes a diverse set of methods used to systematically integrate and examine interactions between humans and their physical and social surroundings. The level of vulnerability of different areas to climate change is determined by both socioeconomic and environmental factors. The socioeconomic factors include the level of technological development, infrastructure and institutional linkage (Kelly and Adger 2000; McCarthy *et al*., 2001); while the environmental attributes are climatic conditions, quality of soil, and availability of water for irrigation (O'Brien *et al*., 2004). The variations of these socioeconomic and environmental factors across different social groups are responsible for the differences in their levels of vulnerability and coping capacities to climate change.

Ethiopia is highly heterogeneous in elevation, climate, agricultural production, cultural practices and other socio-economic factors. The degrees therefore of vulnerabilities of different localities and farming systems vary accordingly. Capturing this variation in assessing vulnerability of the sector is essential for laying the bases for developing and prioritising different adaptation responses for different vulnerable groups.

The aim of this study was to determine the degree of climate risk and the relative vulnerability of the farming areas of Central Rift Valley of

Ethiopia to climate change by developing district level vulnerability maps that identify the most vulnerable hotspots.

MATERIALS AND METHODS

Description of the study sites. A study was conducted in sixteen selected districts in Central Rift Valley (CRV) of Ethiopia located between longitudes 38° 12'- 39° 60' E and latitudes 6° 58'- 8° 47' N. The districts are Dugda Bora, Adamitulu-Jido-Kombolcha, Arsinegele, Dodotana-Sire, Ziway Dugda, Hitosa, Degeluna Tijo, Tiyo, Munessa, Bekoji, Gedeb, Kofele, Sodo, Meskanena Mareko, Selti and Lanfero. The altitude of the study area ranges from 1396 to 4216 m above sea level. The area is predominantly characterised by semi-arid and sub-humid climate.

Data used

Selection of vulnerability indicators. This study was undertaken based on the definition of vulnerability of the Intergovernmental Panel on Climate Change (IPCC), where a region's vulnerability to climate change and variability is described by three components, namely exposure, sensitivity and adaptive capacity (IPCC, 2001). The indicator selection was also made based on the three components of vulnerability. In this study, vulnerability indicator approach is integrated, therefore, the selected indicators represent both the biophysical conditions of the farming regions and the socio-economic conditions of the farmers. The selection of indicators was done after extensive review of previous reports; in particular, we drew from TERI (2003), O'Brien *et al.* (2004), Temesgen *et al.* (2008) and Gbetibouo and Ringler (2009). After identifying the vulnerability indicators, 17 biophysical and socioeconomic vulnerability indicators that reflect the three vulnerability components (Exposure, Sensitivity and Adaptive capacity) were selected and used in this study (Table 1).

Data sources. Data on the selected indicators and parameters used to derive them were taken from various sources. Both primary and secondary data were used in this study. Indicators under the sensitivity and adaptive capacity component (Table 1) were extracted from a CD-ROM prepared by International Food Policy Research Institute (IFPRI); while statistically downscaled and gridded climate change projection data (rainfall and temperature) having 0.5 by 0.5 resolution used to derive indicators related to future change in climate were extracted from the Downscaled General Circulation Model (GCM) Data Portal of Climate Change Agriculture and Food Security (CCAFS) Research Programme (http://www.ccafs-climate.org/spatial_downscaling/).

Gridded data on Standardised Precipitation Index (SPI) (Mckee et al., 1993), which is the most widely used index for quantifying drought, was extracted from IRI/LDEO Climate Data Library (http://iridl.ldeo.columbia.edu/) and used to derive drought frequency indicator. An administrative map showing the boundary of the study districts was obtained from the Central Statistical Agency (CSA) of Ethiopia.

Data analysis. Selected indicators were computed from primary data as follows:

(a) Drought frequency indicator. Climate risk was quantified in terms of drought events. Mckee *et al.* (1993) noted that SPI is the most widely used index for quantifying the frequency of drought events. Indicators in exposure components of vulnerability were quantified using gridded SPI data obtained from IRI/LDEO Climate Data Library (http://iridl.ldeo.columbia.edu/). Thirty three (1970-2002) years' gridded seasonal SPI data having 0.5 by 0.5 degree resolution were extracted in the form of XY table from TS2 dataset, and based on SPI value less than -1.5 (Mckee *et al.*,1993), drought frequency analysis was done for each grid and the value was interpolated using Kriging interpolation techniques (Spherical semivariogram/Covariance model) in ArcGIS 9.3 version environment, and classified to represent the spatial trends of drought frequency. The drought frequency value of each district was also extracted using majority rule method for vulnerability analysis.

TABLE 1. List of identified indicators and their relationship with vulnerability by vulnerability components in Ethiopia

Vulnerability components	Component indicators (weight)	Indicators (weight)	Description of indicators	Relationship with vulnerability
Exposure	Exposure indicators (1)	Frequency of drought (0.4)	Number of drought events from 1970-2000	Increasing
		Change in rainfall (0.4)	% change (base period compared to 2050s)	Increasing
		Change in mean temperature (0.2)	change in ^{0}C (base period compared to 2050s)	Increasing
Sensitivity	Human sensitivity (0.3)	Rural population density (0.2)	Rural population/km^2	Increasing
		Dependency ratio (0.1)	Percentage of unemployment	Increasing
	Livelihood sensitivity (0.7)	Proportion of Household fully engaged in Agriculture (0.3)	Agricultural household heads	Increasing
		Crop diversification index (0.2)	Percentage of area under a major crops	Increasing
		Access to water sources (0.1)	Percentage of population to proximity to water source	Decreasing
		Topography (0.1)	Percentage of sloppy area	Increasing
Adaptive capacity	Socio-economic assets (0.7)	Literacy rate (0.2)	Proportion of agricultural population aged 15 years and older who can read and write	Decreasing
		Farm organization (0.1)	Percentage of farmers utilizing advisory services	Decreasing
		Access to credit (0.1)	Percentage of farmers utilizing credit service	Decreasing
		Crop productivity (0.15)	Amount of Yield per hectares for major crops	Decreasing
		Farm asset (0.15)	Total value of farm asset	Decreasing
	Infrastructural assets (0.3)	Access to market (0.2)	All weather road density	Decreasing
		Land area under smallholder farmers (0.1)	Percentage of total land area	Increasing

(b) Change in rainfall and temperature. Projected change in rainfall (% change) and temperature (absolute change) were analysed using historical empirical data (1980-2012) from worldclim (http://www.worldclim.org/) as base period and ensemble of four downscaled GCMs (CGCM3, HADGEM, MK3 and ECHAM5) data of 2050s (2040-2069) under A1B emission scenario from CCAFS (www.ccafs-climate.org/spatial_ downscaling/), using the Delta method as future projection. A Delta value of each grid was generated that quantify the possible changes of rainfall and temperature.

Vulnerability index. Vulnerability to climate change was analysed using an integrated vulnerability assessment approach using diverse set of biophysical and the socioeconomic indicators listed in Table 1 that reflect the three vulnerability components; exposure, sensitivity and adaptive capacity.

The identified indicators have different units and scales, and to use them for assessment they were normalised using the methodology used in United Nations Development Programme (UNDP)'s Human Development Index (HDI) (UNDP, 2006). The first step was to determine the functional relationship of all the indicators with vulnerability, i.e. vulnerability increases with increase (decrease) in the value of the indicators (Table 1). Then, standardised indicator values, which are free from the units and that lie between 0 and 1 were determined using the Equations 1 and 2. Equation 1 was used when the increase in the indicator was hypothesized to increase vulnerability; and Equation 2 when the increase in the indicator was hypothesized to decrease vulnerability (Table 1).

$$Ini,j = (Iaci,j - Ijmin)/(Ijmax - Ijmin) \quad \text{Equation 1}$$

$$In = (Ijmax - Iaci,j)/(Ijmax - Ijmin) \quad \text{Equation 2}$$

Where:

i and j are indicators and districts respectively, Ini,j= normalised ith indicator for the jth district, Iac=actual value of the ith indicator of the jth district before normalisation; Ijmin and Ijmax=minimum and maximum value of the ith indicator when compared among all the districts, respectively.

After normalising, expert judgment (Moss *et al*., 2001; Brooks *et al*., 2005) was used to assign weights to all the normalised indicators. Then, sub-indices of vulnerability were calculated for each district using weighted sum of indicator values under each of the exposure, sensitivity and adaptive capacity components of vulnerability. The aggregate vulnerability index was also determined by summing weighted indicator values to produce a single number, which can be used to compare the 16 districts. The sub- and aggregate index values of vulnerability were then categorised into high, low and medium classes, whereby the medium level of vulnerability was defined as an index within one standard deviation unit of the whole districts index, meanwhile high and low level were greater than and less than 1 standard deviation unit above or below the whole districts index mean, respectively. Finally, a GIS tool was used to map both the sub- and aggregate indices of vulnerability.

RESULTS

Frequency of drought. Climate risk quantified in terms of drought frequency revealed that all the districts experienced drought ranging from 2 to 5 times within 33 years (Fig. 1). Among the worst hit districts, which experienced the highest frequency of drought (5 times in 33 years), were Adamitulu-Jido-Kombolcha, Dugda Bora, Ziway Dugda, Dodotana-Sire and Tiyo districts. Gizachew (2012) also confirmed that Adamitulu-Jido-kombolcha and Ziway dugda districts had the highest probability of severe drought occurrence with 46 to 76% severe severity level in East Shoa zone of Ethiopia. Bekoji, Gedeb, Kofele and Lanfaro districts experienced the lowest drought frequencies of 2 to 3 times in 33 years. The remaining districts experienced drought 4 times in 33 years. This result was used as a proxy indicator for exposure to future climate change in vulnerability analysis.

Change in rainfall and temperatures. A change in rainfall and mean temperature in CRV by 2050

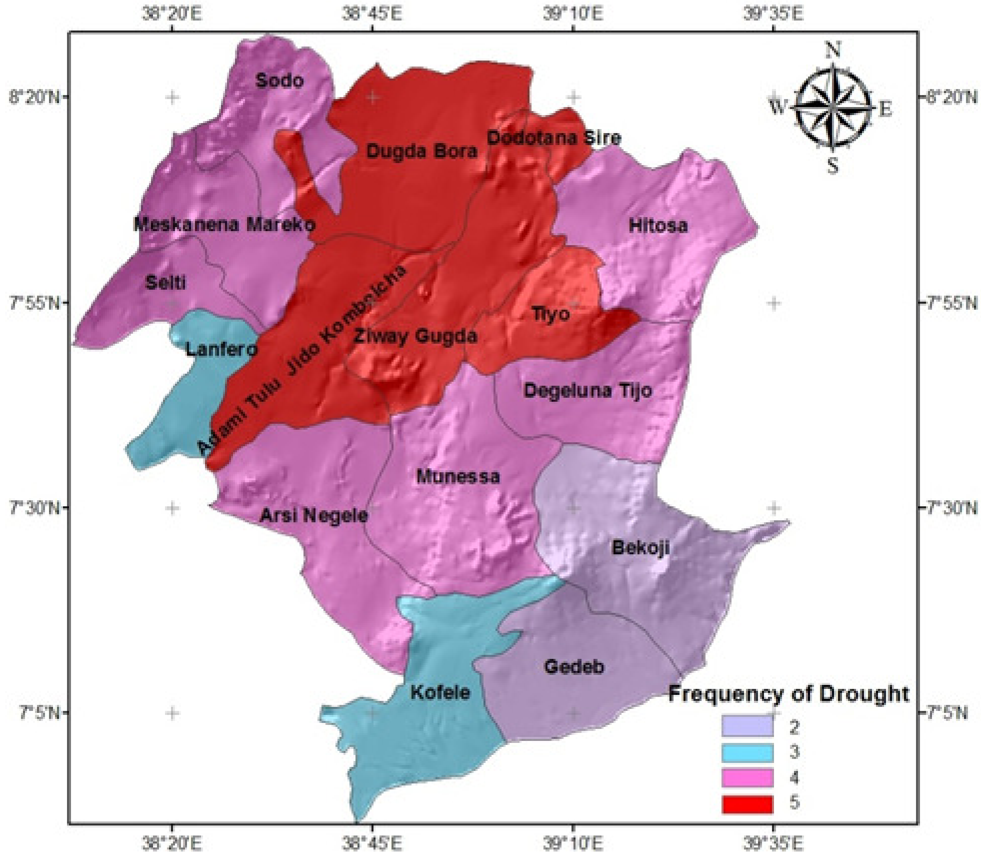

Figure 1. Drought frequency map of Central Rift Valley of Ethiopia.

was predicted from the future climate projection. The delta values overlaid over the study area vary substantially from district to district. For rainfall, a relatively high positive percentage change of around 8.6 was determined for districts of Hitosa, Munesa and Tiyo; while the highest reduction of rainfall around -11.3% was predicted for districts of Arsinegele, Gedeb and Kofele when compared with the base period (Fig. 2). In the case of temperature, the change varied between 3.5 ^{0}C at parts of Dodotana-Sire and Arsinegele districts and -1.1 ^{0}C at parts of Hitosa, Munesa, and Tiyo districts. This result was also used as a proxy indicator for exposure to future climate change in vulnerability analysis.

Analysis of vulnerability using vulnerability components

Exposure index. The exposure index related to the frequency of climate hazards results indicated that Dugda Bora and Dodotana-Sire districts are highly prone to drought given their projected future change in temperature and rainfall, while Kofele, Bekoji and Gedeb districts were relatively less prone (Fig. 3). The remaining districts had moderate risk of exposure to climate hazards.

Sensitivity index. Sensitivity index measures the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli (IPCC, 2001). Results from the sensitivity analyses revealed that Hitosa and Tiyo districts were highly sensitive to the adverse impacts of climate change due to high human environmental interactions (Fig. 4) caused by combined effects of high population density and small ratio of land holdings, and high dependency on rain-fed cropping system. The least sensitive districts were Dugda Bora, Adamitulu-Jido Kombolcha and Arsinegele districts.

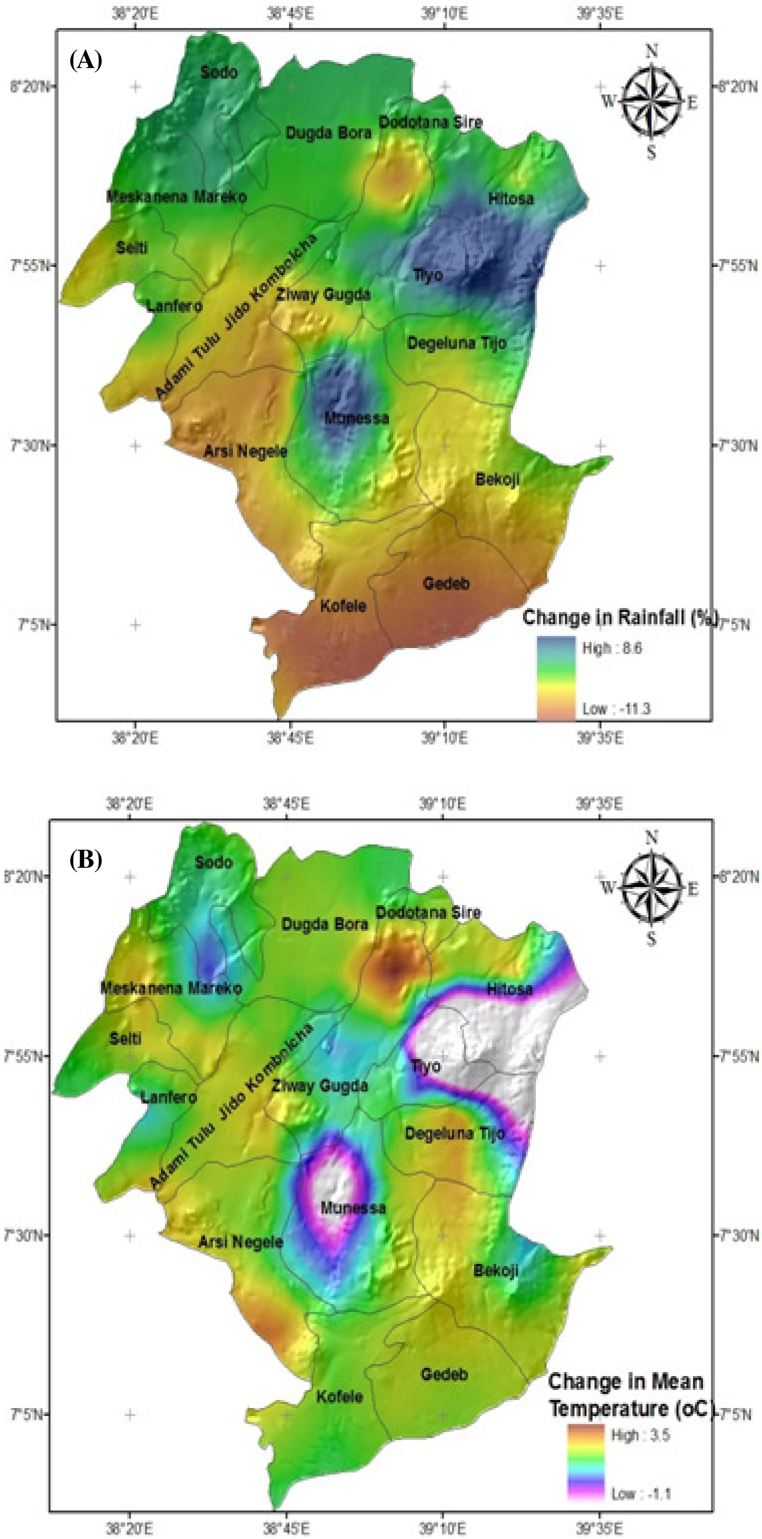

Figure 2. Projected change in rainfall and mean temperature in the Central Rift Valley of Ethiopia a period of 2050s (2040-2069).

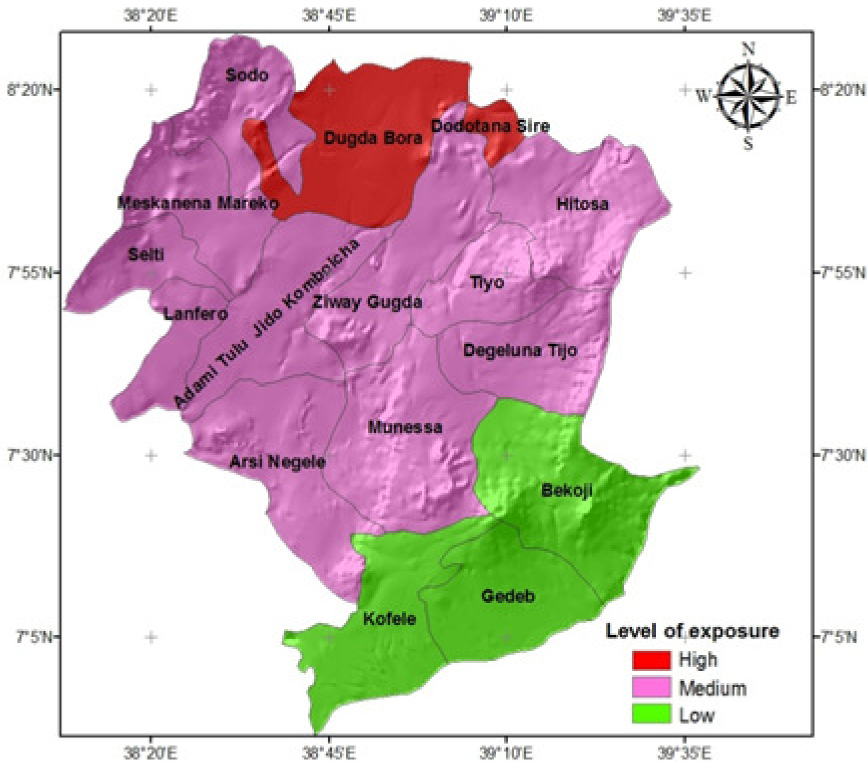

Figure 3. Vulnerability sub-indices map for the Central Rift Valley of Ethiopia: Exposure index.

Adaptive capacity index. Adaptive capacity index measures the ability of a given system to adjust to climate change, including climate variability and extremes, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2001). The majority of the districts had medium level of adaptive capacity that could avert the negative consequence of climate change. Munessa and Lanfaro districts had relatively high adaptive capacity compared to the rest (Fig. 5). This was mainly due to the combined effect of high level of literacy, crop productivity, farm assets and use of credit and advisory services. Arsinegele, Meskanena Mareko and Hitosa districts had relatively low adaptive capacity, while the rest of the districts had medium level adaptive capacity.

Aggregate vulnerability index. The overall vulnerability index map, which is a composite of the three sub-indices map (Exposure, Sensitivity and Adaptive capacity) revealed that Selti, Dodotana-Sire and Tiyo districts were relatively highly vulnerable to the impact of climate change (Fig. 6); while Arsinegele, Adamitulu-Jido-Kombolcha and Dugda Bora districts were the least vulnerable. The rest of districts were under medium level of vulnerability to the impact of climate change.

DISCUSSION

Even though vulnerability assessments is the major task for studying climate change impact and developing site specific adaptation options, so far limited studies (only at large scale such as regional level) have been conducted in Ethiopia (NMA, 2007; Temesgen *et al*., 2008). The result obtained from this study is based on district levels, which is relatively at small scale level. This is one of the limitations to compare the result obtained from this study with those of other research works.

Vulnerability to climate change was analysed by generating vulnerability indices from 17 biophysical and socioeconomic vulnerability

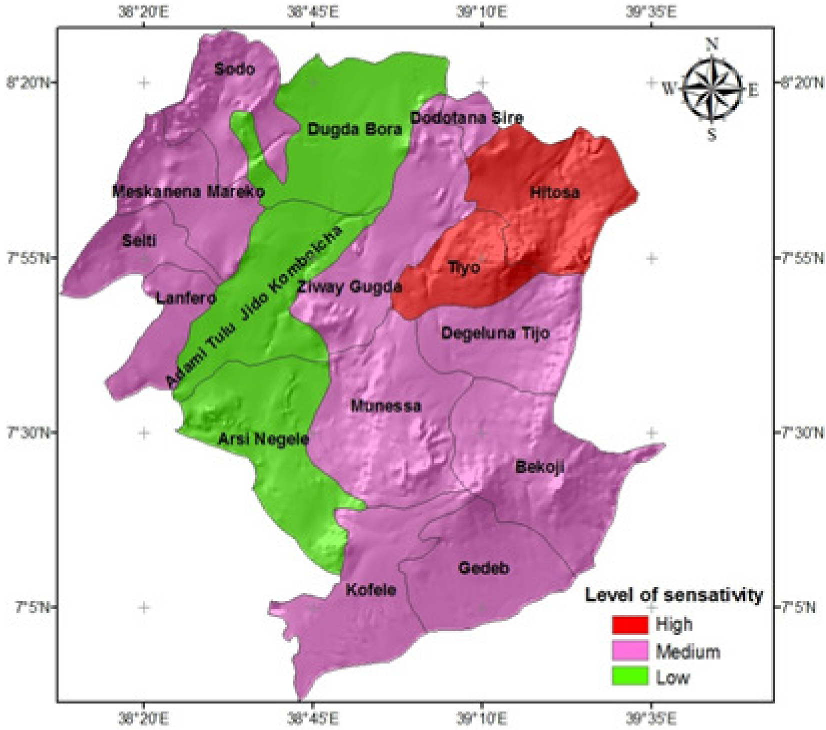

Figure 4. Vulnerability sub-indices map of the Central Rift Valley of Ethiopia: Sensitivity index.

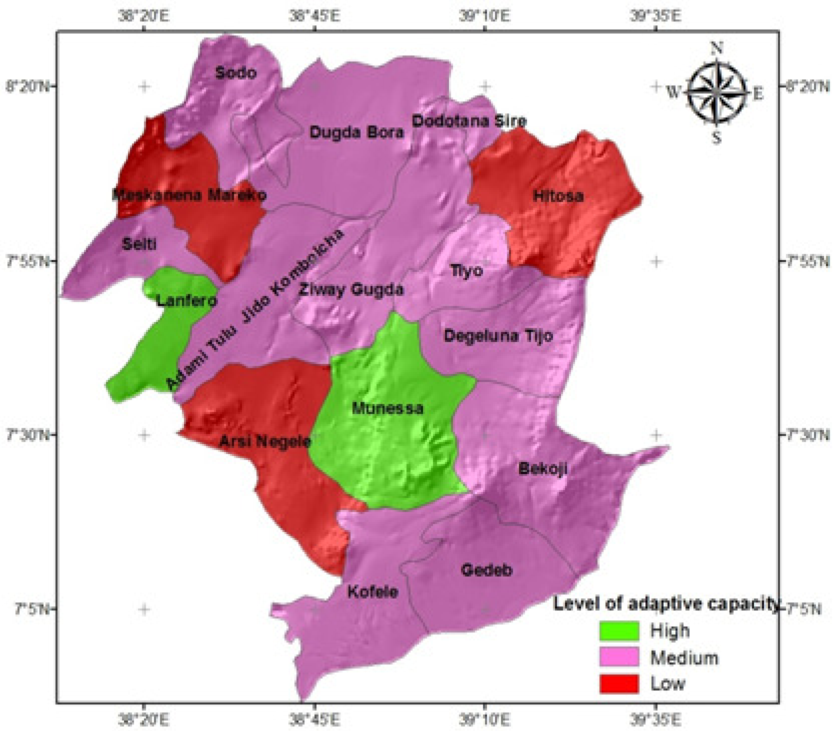

Figure 5. Vulnerability sub-indices map of the Central Rift Valley of Ethiopia: Adaptive capacity index.

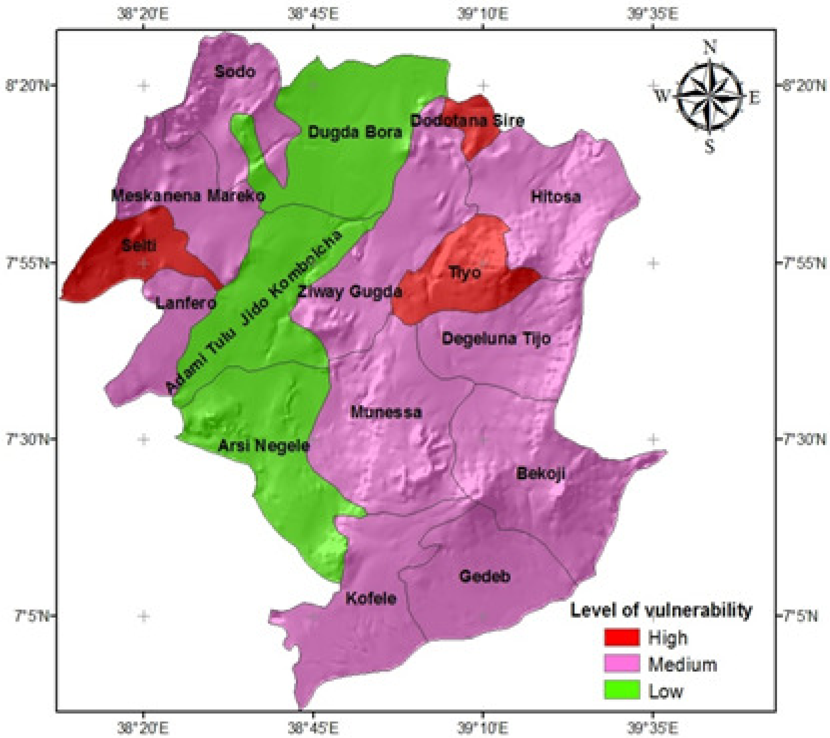

Figure 6. Aggregate vulnerability index map of the Central Rift Valley of Ethiopia.

indicators that reflect the three vulnerability components: Exposure, Sensitivity and Adaptive capacity; and comparing these indices across 16 districts, to produce vulnerability maps. Based on the result, relative vulnerability of districts within CRV to climate change varies spatially and vulnerable hotspot districts were identified as the result of their differences on exposure, sensitivity and adaptive capacity to climate change. Therefore, districts require site specific adaptation options based on their level of vulnerability to climate change.

Vulnerability mapping helps to target vulnerable hotspots and recommend appropriate interventions. This also helps to generate baseline information that helps researchers to conduct further site specific impact and adaptation studies, based on such identification of risk levels within relatively large geographical area. The knowledge of vulnerability to climate change can also assist decision makers in recommending the existing adaptation measures and prioritising resource allocation for specific areas, as well as determining investments for adaptation measures to future impacts of climate change.

Detailed biophysical impacts of climate change on the different sub-sectors of agriculture (crop, livestock, forestry, etc) should further be studied using ex-ante approach through system simulation models like APSIM and DSSAT for development of site specific adaptation options. The results of district scale level vulnerability analysis are believed to be important for decision makers and a good starting point for different impact and adaptation study. However, it is recommended that detailed assessment of vulnerability analysis at the smallest geographical unit, "Kebele", or household level and then at national level can be done using more diverse indicators for further refinement of the result of this study.

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