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Climate Change Vulnerability Analysis Methods for Human and Natural Systems: A Review

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Abstract
Climate change is one of the most complex problems of our time presenting unique challenges for societies. Climate change impacts bring serious damages especially in developing countries and is making the resources of the countries more vulnerable. Vulnerability assessments can play a vital role in the designing of appropriate adaptation and mitigation policies targeted towards climate change and its impacts on human systems and natural systems. The review was based on secondary data obtained through various sources such as textbooks, journals, conference papers, published and unpublished materials with emphasizes on concepts and definitions of vulnerability, vulnerability analysis methods, conceptual approaches, and vulnerable human and natural systems to climate change. To this end climate change adaptation mechanisms in Ethiopia were reviewed. Moreover, different vulnerability and vulnerability analysis sector wise were also reviewed. Finally, as a case study, climate change vulnerability analysis in Agricultural and water Sectors in Ethiopia were also reviewed.
Keywords: Vulnerable, vulnerability analysis, climate change, impacts
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1. Introduction

Climate change is among the most challenging issues facing society severe environmental, economic, political and security impacts in the 21st century, and it is a process that both reinforces existing inequities, and creates new inequities (Brien and Leichenko, 2008). Climate change is increasingly recognized as a global challenge, especially regarding its impacts on the natural and human systems (IPCC, 2007).There is widespread recognition that the effects of climate change in natural and human systems are likely to be highly uneven, with some individuals, households, communities, or regions experiencing significant negative effects, such as the loss of life and property due to climate extremes, the loss of agricultural productivity, increased water stress, damage to infrastructure from the melting of permafrost (Brien and Leichenko, 2008).

It has become common knowledge that the poor are likely to be hit hardest by climate change, and that capacity to respond to climate change is lowest in developing countries and among the poorest people in those countries. It seems clear that vulnerability to climate change is closely related to poverty, as the poor are least able to respond to climatic stimuli. Furthermore, certain regions of the world are more severely affected by the effects of climate change than others. Generally speaking, vulnerability and adaptation to climate change are urgent issues among many developing countries (Downing *et al*., 2001) .Vulnerability to climate change defined as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes (IPCC, 2001).

Climate change vulnerability assessments help establish understanding of the extent to which changing climate will affect the system in question (e.g. basin, water use sector, country, city, etc.) and also it provides information for identifying measures to adapt to climate change impacts (Fussel and Klein, 2006).The objective of this review paper is to assess climate change vulnerability analysis methods on human systems and natural systems as well as reviewing climate vulnerability analysis methods in Agriculture and water sectors in Ethiopia as a case study.

2. Concepts and Definitions of Vulnerability

Climate change vulnerability is generally viewed as 'the degree to which a system is susceptible to, and unable to cope with, the adverse effects of climate change' (IPCC, 2007). As such, 'it is a function of the character, magnitude and rate of climate change to which the system is exposed, its sensitivity and its adaptive capacity' (IPCC, 2007).

2.1. Exposure

The degree of climate stress upon a species or ecosystem; it may be represented as either long-term change in climate conditions, or by changes in climate variability, including the magnitude and frequency of extreme

events: for example, degrees of annual temperature change per century (Comer *et al*., 2012).

2.2. Sensitivity

The degree to which a system (e. g. economic sector, population group and ecosystem system) is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct or indirect (Getnet Feyissa, 2010).

2.3. Adaptive Capacity

The ability or capacity of a system to modify or change its characteristics or behaviour so as to cope better with existing or anticipated external (IPCC, 2001).

3. Vulnerability analysis conceptual approaches

Given the different disciplines involved in vulnerability study, there are many conceptual and methodological approaches to vulnerability analysis. The major conceptual approaches include the socioeconomic, biophysical (impact assessment) and integrated approaches (Temesgen Deressa *et al,* 2008).

3.1. Socioeconomic Approach

The socio-economic vulnerability assessment approach mainly focuses on the socio-economic and political status of individuals or social groups (Fussel, 2007). Individuals in a community often vary in terms of education, gender, wealth, health status, access to credit, access to information and technology, formal and informal (social) capital and political power. These variations are responsible for the variations in vulnerability levels (Emebet Bekele, 2013). In this case, vulnerability is considered to be a starting point or a state (i.e. a variable describing the internal state of a system) that exists within a system before it encounters a hazardous event (Allen, 2003). Thus, vulnerability is considered to be constructed by society as a result of institutional and economic changes (Adger and Kelly, 1999). In general, the socio-economic approach focuses on identifying the adaptive capacity of individuals or communities based on their internal characteristics. The main limitation of the socio-economic approach is that it focuses only on variations within society (i.e. differences among individuals or social groups). In reality, societies vary not only due to sociopolitical factors but also to environmental factors. Two social groups having similar socio-economic characteristics, but different environmental attributes can have different levels of vulnerability and vice versa (Temesgen Deressa *et al*., 2008).

3.2. Biophysical (impact assessment)

The biophysical approach assesses the level of damage that a given environmental stress causes on both social and biological systems (Getnet Feyissa, 2010).For instance, the monetary impact of climate change on agriculture can be measured by modeling the relationships between climatic variables and farm income .According to Kelly and Adger (2000), biophysical approach as an ‘end-point analysis’ responding to research questions such as: ‘What is the extent of the climate change problem?

A major limitation is that the assessment of bio- physical factors is not a sufficient condition for understanding the complex dynamics of vulnerability. It also neglects structural factors and human agency both in producing vulnerability and in coping or adapting to it. The approach overemphasizes extreme events while neglecting root causes and everyday social processes that influence differential vulnerability (Gutu Tesso *et al*., 2012).

3.3. Integrated approaches

The integrated assessment approach combines both socioeconomic and biophysical approaches to determine vulnerability (Table 1). The hazard-of-place model is a good example of this approach, in which both biophysical and socioeconomic factors are systematically combined to determine vulnerability (Cutter *et al*., 2000).The vulnerability mapping approach is the other related example, in which both socioeconomic and biophysical factors are combined to indicate the level of vulnerability through mapping (O’Brien *et al*., 2004).Although the integrated assessment approach corrects the weaknesses of the other approaches, it also has some limitations. The main limitation is that there is no standard method for combining the biophysical and socio- economic indicators (Gutu Tesso *et al*., 2012).

Table 1.Conceptual differences between biophysical, socioeconomic and integrated perspectives of vulnerability

	Perspectives on vulnerability		
	Biophysical	**Social**	**Integrated**
Focal point of analysis	Biophysical conditions and the hazard	Social systems and social conditions	Both biophysical and social systems (Coupled human-environment system)
Type of analytical Questions	What are the hazards and impacts?	How are people affected? How are they capable to cope with climate change?	How and why do coupled systems change? What is their capacity to adapt?
System of analysis	Sectors, regions, activities, places	Social groups, e.g. communities, individuals	Coupled human-environment system, ecosystems
Time period of interest	Future climate Change	Current climate variability	Current and future climate Change

Source: (Bruno Soares, 2012)

4. Methods for Measuring Vulnerability to Climate Change

The most common methods for analyzing vulnerability to climate change employed in vulnerability literature are the econometric and indicator methods (Leichenko and O"Brien, 2001).

4.1. Econometric method

The econometric method has its roots in the poverty and development literature. This method use household-level socioeconomic survey data to analyze the level of vulnerability of different social groups. According to Hoddinott and Quisumbing (2003), the method is divided into three categories: vulnerability as expected poverty (VEP), vulnerability as low expected utility (VEU), and vulnerability as uninsured exposure to risk (VER).

4.1.1. Vulnerability as expected poverty (VEP)

This method is based on estimating the probability that a given shock, or set of shocks, moves consumption by households below a given minimum level (e.g., consumption poverty line) or forces the consumption level to stay below the given minimum requirement if it is already below that level (Chaudhuri *et al.,*2002).One of the disadvantages of this method is that if estimations are made using a single cross section, one must make a strong assumption that cross-sectional variability captures temporal variability (Hoddinott and Quisumbing, 2003).

4.1.2. Vulnerability as low expected utility (VEU)

This method is based on a definition of vulnerability as "as the utility lost due to risk, as the difference between the expected household consumption and the certainty-equivalent consumption," or consumption that would have occurred in a situation of certainty (Moret, 2014).

4.1.3. Vulnerability as uninsured exposure to risk (VER)

This method is not a predictive tool, but instead measures actual changes in welfare due to a given risk. It is easy to calculate and can attribute welfare loss to either idiosyncratic or covariate risks (Moret, 2014).

4.2. Indicator method

The indicator method quantifying vulnerability is based on selecting some indicators from the whole set of potential indicators and then systematically combining the selected indicators to indicate the levels of vulnerability (Emebet Bekele, 2013).According to Leon-Vasquez *et al*. (2003), these levels of vulnerability may be analyzed at local, regional and global scales. Two options are available for calculating the level of vulnerability using this method at any scale. The first is assuming that all indicators of vulnerability have equal importance and thus giving them equal weights (*Cutter et al*, 2000). The second method is assigning different weights to avoid the uncertainty of equal weighting given the diversity of indicators used .Luers *et al*. (2003) explained the weakness of the indicator approach as follows:

1. *indicator approach is valuable for monitoring trends and exploring conceptual frameworks, indices are limited in their application by considerable subjectivity in the selection of variables and their relative weights,*
2. *by the availability of data at various scales, and by the difficulty of testing or validating the different metrics.*

3. *The Indicator approach often leads to a lack of correspondence between the conceptual definition of vulnerability and the metrics*

5. General classification of vulnerability assessment

Vulnerability assessment approach can be divided into top down frameworks and bottom up framework (Fig.1).

5.1. Top-down approach

Primarily based on larger scale (e.g. global, regional) simulation models and approaches. Such approaches most commonly use future climate scenarios, combined with models for e.g. water resources or energy, and other socioeconomic variables and criteria.

5.2. Bottom-up approach

Using participatory methods, tools and local climate datasets. Bottom-up approaches have a higher degree of focus on the local aspects that increase vulnerability of one social group (area, ecosystem, etc.) over other and how changes in their sensitivity can help increase climate resilience. Such assessments may focus more on present day vulnerabilities, though methods for bottom-up future vulnerability assessments are also available.

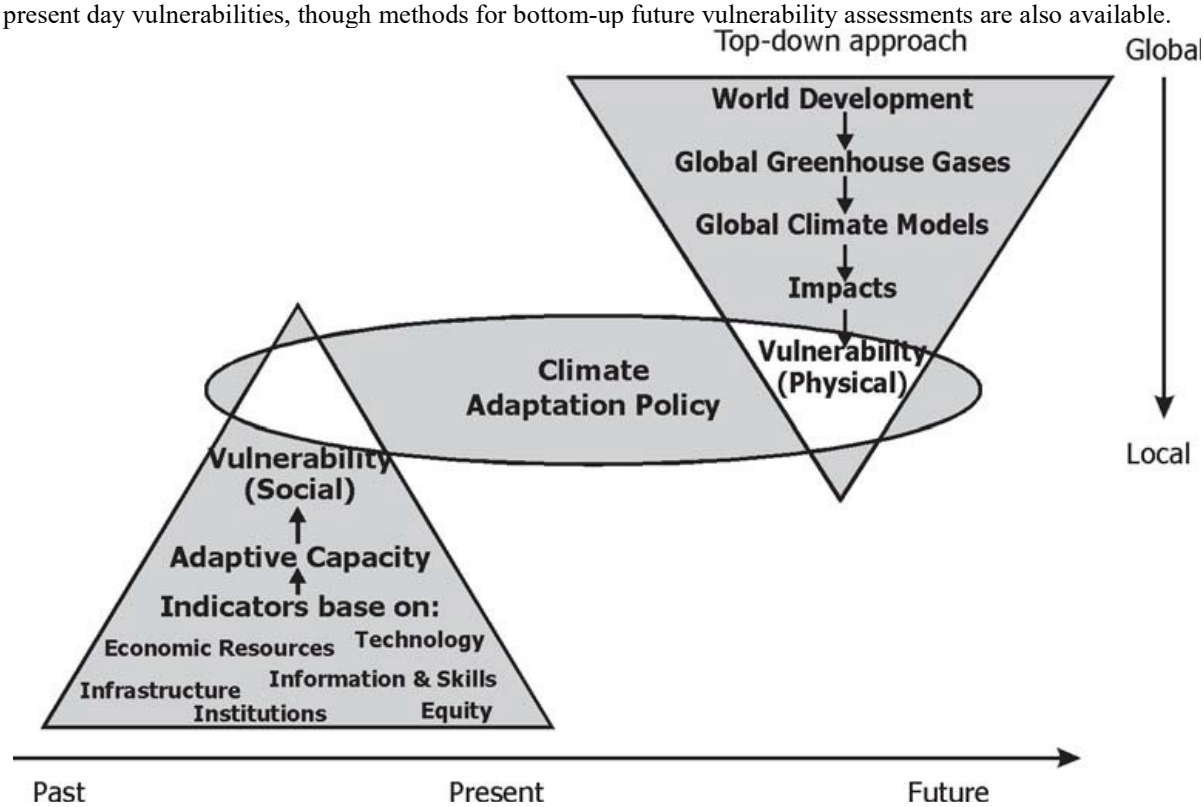

Figure 1.Relation between Top Down, Bottom up Approach and Climate Adaptation Policy
Source: (Nair and Bharat, 2011)

6. Vulnerable human and natural systems to climate change

People who live on arid or semi-arid lands, in low-lying coastal areas, in water limited or flood-prone areas, or on small islands are particularly vulnerable to climate change (Pearson and Langridge, 2008). It is clear that climate change will, in most parts of the world, adversely affect socio-economic sectors, including water resources, agriculture, forestry, fisheries and human settlements, ecological systems (natural systems), and human health, with developing countries being the most vulnerable (IPCC, 2001).In Ethiopia the most vulnerable sector and the risks of which are summarized in Table 2.

Table 2.Key Vulnerable Sectors

Sector	Likely impacts of climate change
Agriculture	• Increased incidence of fires, droughts, and floods • Decreased water availability for crops and livestock • Increased soil erosion • Changes in the agricultural calendar • Increased incidence of pests and diseases for crops and livestock • Degradation in rangelands due to soil erosion, droughts, and floods • Loss of crop and livestock production
Water	• Decrease in water flow • Increased incidence of flooding and drought
Roads	• Washing-out of roads • Higher maintenance and recovery costs • Disruption of transportation services
Energy	• Interruption and reduction in hydropower generation infrastructure • Damages to energy • Loss in biomass due to increased soil erosion and extreme weather events
Health	• Increased incidence of water-, air-, and vector-borne diseases • Increased healthcare expenditures • Damage to healthcare infrastructure • Interruption in health services

Source :(Echeverría and Terton, 2016)

7. Vulnerability analysis method in the Agriculture and water sectors in Ethiopia – Case Study

7.1. Background

Ethiopia is one of the countries in Africa, with current intensity and pattern of climate variability or change, and the resultant adverse effects currently the country is facing, there is no a single social or economic sector in the area which is expected to be free from climate change-induced impacts and shocks (Emebet Bekele, 2013).Almost all sectors are vulnerable to impacts of climate change but the most vulnerable sectors to climate variability and change in the context of Ethiopia include: Agriculture (crop cultivations and livestock rearing), water ,health, forests, pastures, biodiversity, education and energy; although, the magnitude of vulnerability and degree of sensitivity to climate change-induced shocks and hazards vary from sector to sector (Abate Feyissa, 2009). According to Keffyalew Gebremedihin (2011), in terms of livelihood means, smallholder rain-fed farmers and pastoralists in Ethiopia are found to be the most vulnerable to climate change shocks.

7.2. Performance of the agricultural sector

Agriculture is the backbone of the Ethiopian economy and therefore this particular sector determines the growth of all the other sectors and, consequently, the whole national economy.

Ethiopian economy more depend on agricultural sector for the following reasons: (i) it directly supports about 85% of the population in terms of employment and livelihood; (ii) it contributes about 50% to the country's gross domestic product (GDP); (iii) it generates about 90% of export earnings; and (iv) it supplies around 70% of the raw material requirements of agro-based domestic industries (CSA, 2011).It is also the major source of food for the population and hence the prime contributing sector to food security. According to MoFED (2008), agriculture plays a key role in generating surplus capital to speed up the country's overall socio-economic development.

7.3. Vulnerability of Ethiopian agriculture to climate change

The vulnerability of Ethiopian farmers to climate change is attributed to their dependence on rain-fed agriculture and high poverty. Rain-fed agriculture, which supports the livelihoods of the majority of the population, is highly sensitive to climatic conditions. It is characterized by: highly erratic rainfall; frequent droughts that often cause famines; and intensive rainfall that often cause floods (Woldeamlak Bewket, 2009).Given the dependence of the economy on agriculture and the dependence of the agricultural sector on climatic conditions, especially rainfall, the macroeconomic performance of the country follows rainfall patterns. In years where there is good rainfall,

the economy performs well and in years of bad rainfall the economy performs very badly.

Low levels of economic development or poverty is the other source of vulnerability of Ethiopian farmers. The majority of Ethiopian farmers have limited capacities to mitigate, adapt or cope with effects of climate extreme events such as droughts, which significantly reduce the already low consumption. In addition to creating severe food shortages, experiencing a drought at least once in five years lowers per capita consumption by about 20 percent (Dercon and Hoddinott, 2005).

7.4. Vulnerability of Ethiopian farmers to climate change

Climate change is real and its first effects are already being felt. Climate change is expected to have serious environmental, economic, and social impacts of Ethiopia particularly rural farmers, whose livelihood depend on the use of natural resources (Anbesu Bikila, 2013).As figure 2 shows Ethiopian farmers are exposed to both gradual climate change (mainly temperature and precipitation) and extreme climate change (mainly drought and flood). Exposure affects sensitivity, which means that exposure to higher frequencies and intensities of climate risk highly affects outcome (e.g. yield, income, health). Exposure is also linked to adaptive capacity. For instance, higher adaptive capacity reduces the potential damage from higher exposure. Sensitivity and adaptive capacity are also linked: Given a fixed level of exposure, the adaptive capacity influences the level of sensitivity. In other words, higher adaptive capacity (socioeconomic vulnerability) results in lower sensitivity (biophysical vulnerability) and vice versa. Therefore, sensitivity and adaptive capacity add up to total vulnerability.

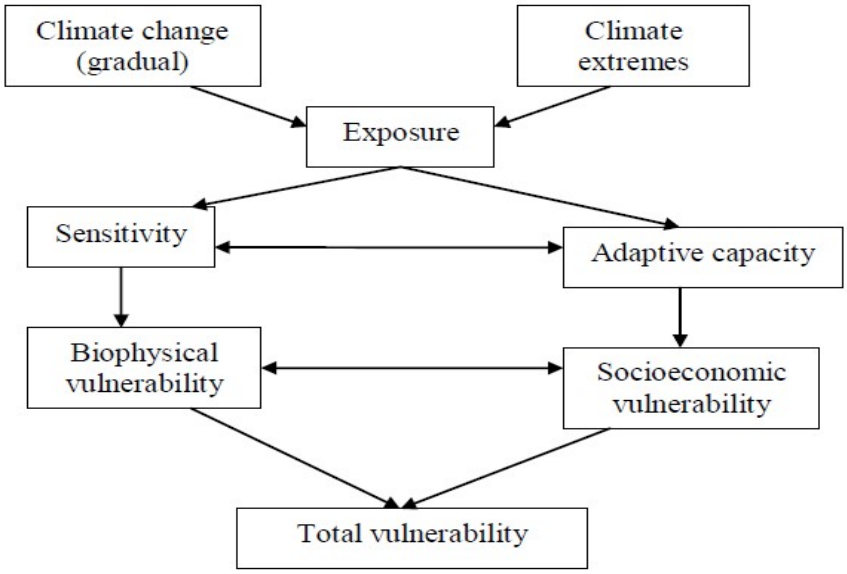

Figure 2.Conceptual framework to vulnerability assessment
Source: (Temesgen Deressa *et al*., 2008)

7.5. Vulnerability assessment of climate change on agricultural sector of Ethiopia

Vulnerability assessment uses an assumption that vulnerability is directly proportional with exposure and sensitivity, while inversely proportional to adaptive capacity (Ruminta and Handoko, 2016). Decline in precipitation and increases in temperature both are damaging Ethiopian agriculture and increase its vulnerability (Emebet Bekele, 2013).Case studies indicate that Ethiopian agriculture is highly vulnerable (with large spatial and temporal variation) to the impacts of climate change because of high exposure and sensitivity of the sector to climate variability and change.

In research conducted in North Shewa Zone of Oromia national regional state (Fiche town) by social, economic and environmental vulnerability, show that most of the farmers vulnerability level for climate change effect is high, Table 3, 4 and 5 .Net effect of adaptation, exposure, and sensitivity computed from principal component analysis for the three Agro –Ecology (High land, Mid high land and Lowland) only positive for community living in the lowland areas; while it is negative for those living in midland and highland agro ecologies (Fig.3).

Table 3.Social vulnerability indicators for North Shewa

Social vulnerability	Percentage
Sex: Female headed	15.9
Education: illiterate and less than grade 2	86.1
Marital status: Single (including divorce and widow)	14.2
No. of relatives: relative to less than 5 households	38.3
No. institutions: Participation in less than 2.35 institutions	57.1
Dependency: High dependency of 4 person and more	86.3
Farm to farm ext: No access to farmer to farmer extension	31.6
Year Ag. Experience: Lack of farm experience if <3 years	7.3
Access to indigenous early warning information: Having no access	43.8

Source: (Gutu Tesso *et al*., 2012)

Table 4.Economic vulnerability indicators for North Shewa

Economic vulnerability	Percentage
Livestock ownership: Own less than 2 tropical livestock unit	35.6
Access to information: Having no access to	73.9
Ownership of perennial crops: no area under perennial crops	87.2
Land size: own less than 0.5 ha of land	36.1
Land fragmentation: own only one plots	74.6
Non-farm income: Have no non-farm income	82.7
Soil and water conservation structures: More than 50% is not conserved	32.3
Income level: Having less than minimum requirement	74.2
Consumption expenditure: Spending less than minimum requirement	62.4
Crop diversity: less than 50% of the 8 major crops grown in the area	70.7
Land under irrigation: no access to irrigation at all	64.2
Land under improved seed: area not covered with improved seed (average of high yielding, drought tolerant, early maturing)	64
Land under commercial fertilizer: Having no access to fertilizer at all	38.5
Cash reserve: Having no cash saving at all	92
Food reserve: Having no food reserve for next year	71
Credit: Having no access to credit at all	44.5

Source: (Gutu Tesso *et al*., 2012)

Table 5.Environmental vulnerability indicators for North Shewa

Environmental Vulnerability Variables (Measures of Sensitivity and Exposure)	Amount (%)
Land topography: Slope greater than 15% and 0% slope	49.1
Fertility: Poor fertility and cannot produce without heavy fertilizer use	31.6
Vegetation cover: Bare land	96.3
Frequency of hazards: People facing more than two natural hazards in a year	84.3
Rainfall: Receiving below average	46.2
Temperature: Experiencing above average	95.4
Change in wind direction: Encountering change in wind direction than usual	91.4

Source: (Gutu Tesso *et al*., 2012)

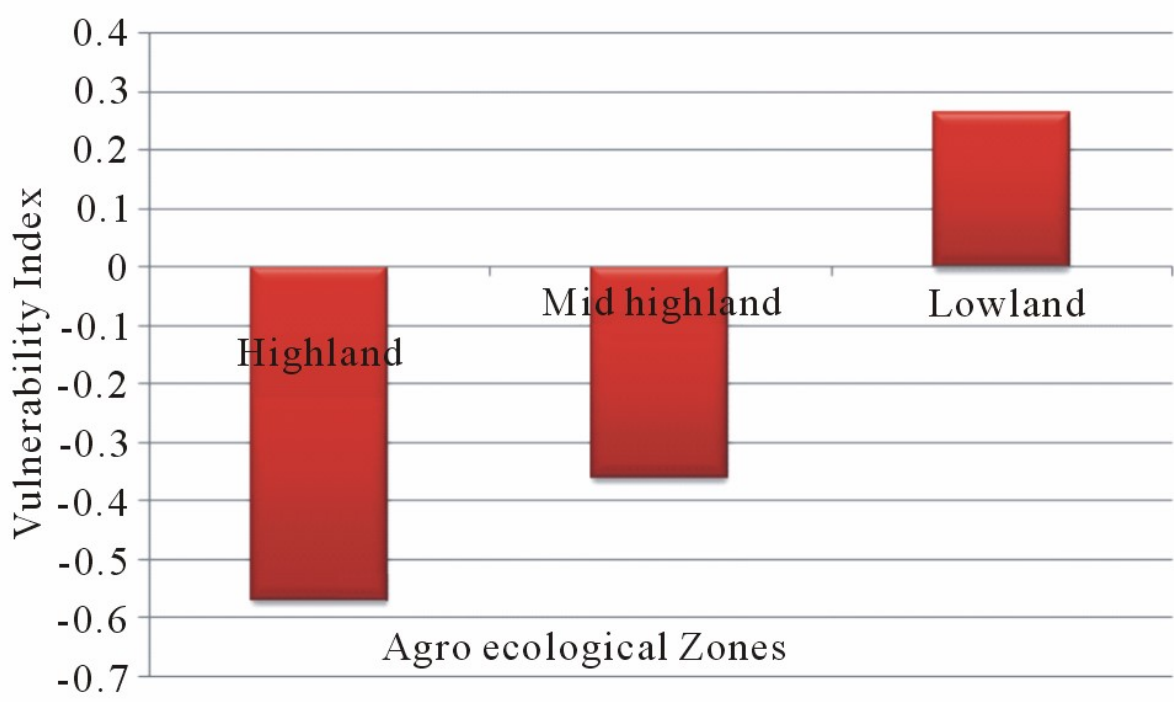

Figure 3.Household's vulnerability to climate change impacts in North Shewa
Source: (Gutu Tesso *et al*., 2012)

7.6.The three Vulnerability dimensions on Agricultural sector

The vulnerability is define as having three components such as Exposure, Sensitivity and Adaptive capacity. The indicators for the three components are (1).Agricultural land area and number of farmers as exposure's indicators, (2).Agricultural land types (Non -irrigated) topography elevation and farmer's income as sensitivity indicators and (3).irrigation infrastructure and level of education as adaptive capacity indicators (Fig.4).

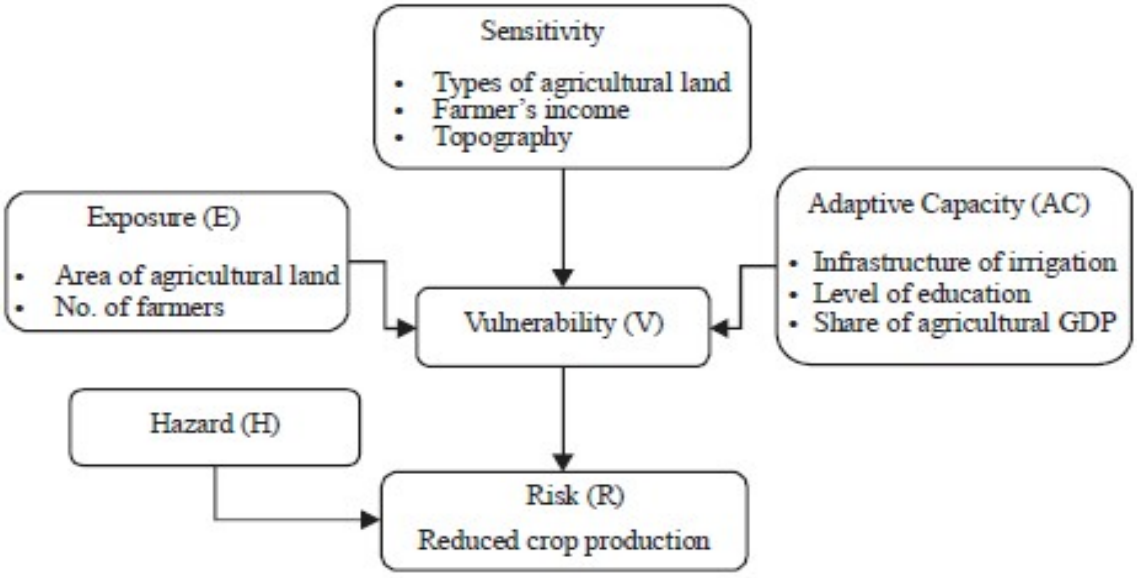

Figure 4.Flow chart of the analysis of hazard potential vulnerability and risk of climate change on agricultural sector
Source: (Rumnta and Handoko, 2016)

7.7. Vulnerability of water sector to climate change

Water is central to the sustainable functioning of the ecosystems on which our socioeconomic activities depend. For example, it is essential for agricultural production and energy generation, as well as for industrial production and domestic use (UNEP, 2017).But water is the primary medium through which climate change influences the

Earth's ecosystems, people's livelihoods and wellbeing (Animesh,2012).Climate change affects the hydrological cycle, through changes in precipitation, maximum and minimum temperature and evapotranspiration.

7.8. Vulnerability assessment of climate change on water sector of Ethiopia

Water resources vulnerability (WRV) can be defined as the ease with which a water resources system can be damaged by both natural factors and human activity (Wang *et al*., 2012). The higher the degree of vulnerability, the harder it is to encourage the sustainable development of a system. As a foundation for water safety measurement, the WRV assessment helps to further understand the characteristics of a water resources system and provides a scientific decision-making basis for water resources management and planning. Water Vulnerability Assessment research was conducted in Eastern Nile Basin by using an indicator-based approach, including a representative range of social and physical factors. Mostly used water vulnerability indicators shown in Table 6.According to Moursy (2009), the finding are listed as follow**:**

1. Vulnerability of water resources is highest in Sudan, followed by Ethiopia and then Egypt
2. While vulnerability in Egypt stems mainly from hydro-physical factors; in Sudan and Ethiopia it is directly related to poverty and underdevelopment
3.Higher stresses on available water resources in Egypt are due to increases in total withdrawals; while in Sudan and Ethiopia it is mainly due to water mal-distribution and quality deterioration;
4. Governance factors in the three countries hinder the proper management of the available water resources.

Table 6.Vulnerability component for water vulnerability analysis

Component	Indicator
Exposure (E)	• People's water needs • Land use
Sensitivity (S)	• Water resources • People density
Adaptive Capacity (AC)	• Population welfare

Source: (Hamdani, 2018)

7.9. Climate Change Adaptation in Ethiopia

Climate change adaptation represents a process through which people reduce the adverse effects of climate variability on their health and wellbeing, and take advantage of the opportunities that their climatic environment provides (UNFCCC, 2007). It can thus be enhanced by i) altering exposure ii) reducing sensitivity of the system to climate change impacts and iii) increasing the adaptive capacity of the system (Anbesu Bikila, 2013). According to Bekele Tona *et al*.(2017),traditional and contemporary coping mechanisms to climate variability and extreme in Ethiopia include changes in cropping and planting practices, reduction of consumption levels, collection of wild foods, use of inter-household transfers and loans, increased petty commodity production, temporary and permanent migration in search of employment, grain storage, sale of assets such as livestock and agricultural tools, mortgaging of land, credit from merchants and money lenders, use of early warning system, food aid.

8. Conclusion

Climate change is the burning issue of the current world because it is considered to be one of the most serious threats to sustainable development, with adverse impacts expected on the environment, human health, food security, economic activity, natural resources and physical infrastructure. Vulnerability to climate change is closely related to poverty, as the poor are least able to respond to climatic stimuli. It is important to analyze the human and natural systems vulnerability in order to mitigate the challenges of climate change at the local/community level, Vulnerability analysis can have a lead role in adaptation policies designed to reduce climate change impacts and extreme events on services that are the foundation of human wellbeing.

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