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Measuring Ethiopian Farmers' Vulnerability to Climate Change Across Regional States

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ABSTRACT

This study analyzes the vulnerability of Ethiopian farmers to climate change based on the integrated vulnerability assessment approach using vulnerability indicators. The vulnerability indicators consist of the different socioeconomic and biophysical attributes of Ethiopia's seven agriculture-based regional states. The different socioeconomic and biophysical indicators of each region collected have been classified into three classes, based on the Intergovernmental Panel on Climate Change's (IPCC 2001) definition of vulnerability, which consists of adaptive capacity, sensitivity, and exposure. The results indicate that the relatively least-developed, semiarid, and arid regions—namely, Afar and Somali—are highly vulnerable to climate change. The Oromia region—a wide region characterized both by areas of good agricultural production in the highlands and midlands and by recurrent droughts, especially in the lowlands—is also vulnerable. The Tigray region, which is characterized by recurrent drought, is also vulnerable to the negative impacts of climate change in comparison with the other regions. Thus, investing in the development of the relatively underdeveloped regions of Somali and Afar, irrigation for regions with high potential, early warning systems to help farmers better cope in times of drought, and production of drought-tolerant varieties of crops and species of livestock can all reduce the vulnerability of Ethiopian farmers to climate change.

Keywords: climate change, vulnerability, adaptive capacity, regional states of Ethiopia

1. INTRODUCTION

Agriculture is the dominant sector in the Ethiopian economy. It contributes about 52 percent of gross domestic product (GDP), generates more than 85 percent of foreign exchange earnings, and employs about 80 percent of the population (Ministry of Economic Development and Cooperation [MEDaC] 1999). The contribution of the agricultural sector to the total economy, however, is challenged by its vulnerability to climate change.

The level of vulnerability of different social groups to climate change is determined by both socioeconomic and environmental factors. The socioeconomic factors most cited in the literature include the level of technological development, infrastructure, institutions, and political setups (Kelly and Adger 2000; McCarthy et al. 2001). The environmental attributes mainly include climatic conditions, quality of soil, and availability of water for irrigation (Canadian International Development Agency [CIDA] 2003; 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 to climate change.

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, and integrated approaches. The socioeconomic approach is mainly concerned with the social, economic, and political aspects of society (Adger 1999). The biophysical, or impact assessment, approach is mainly concerned with the physical impact of climate change on different attributes, such as yield and income (Füssel and Klein 2006). The integrated assessment approach combines both the socioeconomic and the biophysical attributes in vulnerability analysis (Füssel 2007).

The most commonly used methodological approaches in the climate change literature include the econometric and indicator methods. The econometric method, which has its roots in the poverty and development literature, makes use of household-level socioeconomic survey data to analyze the level of vulnerability of different social groups (Hoddinott and Quisumbing 2003). The indicator method of quantifying vulnerability is based selecting some indicators from the whole set of potential indicators and of then systematically combining the selected indicators to indicate the levels of vulnerability (Cutter, Boruff, and Shirley 2003; Easter 1999; Kaly and Pratt 2000).

Our study adopted the concept of integrated vulnerability assessment and the indicator method to analyze the vulnerability of seven of Ethiopia's agriculture-based regional states. Different socioeconomic and biophysical factors were collected and classified into three classes based on the Intergovernmental Panel on Climate Change's (IPCC 2001) definition of vulnerability, which consists of adaptive capacity, sensitivity, and exposure. We used principal component analysis to assign weights to the different indicators in creating an overall vulnerability indicator for each regional state. Knowledge of each regional state's vulnerability levels to climate change can assist in identifying the most vulnerable regions and in determining investments for adaptation to future impacts of climate change.

The remainder of this paper is organized as follows. Section 2 reviews the literature on conceptual frameworks and methodologies employed in vulnerability analysis that are relevant for this study. Section 3 presents the conceptual framework developed to analyze the vulnerability of Ethiopian farmers to climate change. Section 4 discusses model variables and data sources. Section 5 discusses construction of vulnerability indices. Section 6 presents the results and discussion, and Section 7 gives conclusions and policy recommendations.

2. REVIEW OF LITERATURE

Scholars from different fields of specialization have been conceptualizing vulnerability differently based on the objectives to be achieved and the methodologies employed. These differences limit the possibility of having a universally accepted definition and methodological approach to assessing vulnerability against which the appropriateness of a given concept or method can be judged. However, the knowledge of the existing conceptual and methodological approaches can guide the choice of one of the methods, or combinations of existing methods, in analyzing vulnerability for a specific area of interest. Literature on the conceptual and methodological approaches to vulnerability analysis is summarized in Adger (1999), Füssel and Klein (2006), and Füssel (2007). Our interest here is to review the current literature on the concepts and approaches to analyzing vulnerability to climate change in order to justify the conceptual framework and methodological approach adopted for this study.

Conceptual Approaches

There are three major conceptual approaches to analyzing vulnerability to climate change: the socioeconomic, the biophysical (impact assessment), and the integrated assessment approaches.

Socioeconomic Approach

The socioeconomic vulnerability assessment approach mainly focuses on the socioeconomic and political status of individuals or social groups (Adger 1999; Füssel 2007). Individuals in a community often vary in terms education, gender, wealth, health status, access to credit, access to information and technology, formal and informal (social) capital, political power, and so on. These variations are responsible for the variations in vulnerability levels. 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 hazard event (Allen 2003; Kelly and Adger 2000). Thus, vulnerability is considered to be constructed by society as a result of institutional and economic changes (Adger and Kelly 1999). In general, the socioeconomic approach focuses on identifying the adaptive capacity of individuals or communities based on their internal characteristics. A study by Adger and Kelly (1999) is an example of this approach. In that study, the environmental factor in a district to coastal lowlands of Vietnam was taken as given, and vulnerability was analyzed based only on variations in socioeconomic attributes of individuals and social groups.

The main limitation of the socioeconomic 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 socioeconomic characteristics but different environmental attributes can have different levels of vulnerability and vice versa. In general, this method overlooks—or takes as exogenous—the environment-based intensities, frequencies, and probabilities of environmental shocks, such as drought and flood. It also does not account for the availability of natural resource bases to potentially counteract the negative impacts of these environmental shocks—for example, areas with easily accessible underground water can better cope with drought by utilizing this resource.

Biophysical Approach

The biophysical approach assesses the level of damage that a given environmental stress causes on both social and biological systems. For instance, the monetary impact of climate change on agriculture can be measured by modeling the relationships between climatic variables and farm income (Mendelsohn, Nordhaus, and Shaw 1994; Polsky and Esterling, 2001; Sanghi, Mendelsohn, and Dinar 1998). Similarly, the yield impacts of climate change can be analyzed by modelling the relationships between crop yields and climatic variables (Adams 1989; Kaiser et al. 1993; Olsen, Bocher, and Jensen 2000). Other related impact assessment studies include the impact of climate change on human mortality and health terms (Martens et al. 1999), on food and water availability (Du Toit, Prinsloo, and Marthinus 2001; Food and Agriculture Organization [FAO] 2005; Xiao et al.

2002), and on ecosystem damage (Forner 2006; Villers-Ruiz and Trejo-Vázquez 1997). The damage is most often estimated by taking forecasts or estimates from climate prediction models (Kurukulasuriya and Mendelsohn 2006; Martens et al. 1999) or by creating indicators of sensitivity by identifying potential or actual hazards and their frequency (Cutter, Mitchell, and Scott 2000).

Füssel (2007) identified this approach as a *risk-hazard approach* and denoted the vulnerability relationship as a hazard-loss relationship in natural hazard research, a dose-response or exposure-effect relationship in epidemiology, and a damage function in macroeconomics. Kelly and Adger (2000) referred to the biophysical approach as an *end-point analysis* responding to research questions such as, "What is the extent of the climate change problem?" and "Do the costs of climate change exceed the costs of greenhouse gas mitigation?"

Although very informative, the biophysical approach has its limitations. The major limitation is that the approach focuses mainly on physical damages, such as yield, income, and so on. For example, a study on the impact of climate change on yield can show the reduction in yield due to simulated climatic variables, such as increased temperature or reduced precipitation. In other words, these simulations can provide the quantities of yield reduced due to climate change, but they do not show what that particular reduction means for different people. A 50 percent reduction in yield due to climate change does not mean the same for poor farmers that it does for rich farmers. Poor farmers very often cannot cope with marginal changes in their yields or income, whereas richer farmers can buffer their loss (smoothen consumption, in technical terms) by depending on savings or sale of some of their assets.

By the same token, research on climate change and malaria incidence analyzes how climate change favors or disfavors the reproduction (expansion) of main mosquito species of malaria in different geographical settings (Martens et al. 1999). But these types of research identify neither those people who have access to medication or preventive measures (such as vaccination) nor those people who do not have any access to preventive or treatment measures. In general, the biophysical approach focuses on sensitivity (change in yield, income, health) to climate change and misses much of the adaptive capacity of individuals or social groups, which is more explained by their inherent or internal characteristics or by the architecture of entitlements, as suggested by Adger (1999).

The Integrated Assessment Approach

The integrated assessment approach combines both socioeconomic and biophysical approaches to determine vulnerability. The hazard-of-place model (Cutter, Mitchell, and Scott 2000) is a good example of this approach, in which both biophysical and socioeconomic factors are systematically combined to determine vulnerability. The vulnerability mapping approach (O'Brien et al. 2004) is the other related example, in which both socioeconomic and biophysical factors are combined to indicate the level of vulnerability through mapping.

Füssel (2007) and Füssel and Klein (2006) argued that the IPCC (2001) definition—which conceptualizes vulnerability to climate as a function of adaptive capacity, sensitivity, and exposure—accommodates the integrated approach to vulnerability analysis. According to Füssel and Klein (2006), the risk-hazard framework (biophysical approach) corresponds most closely to sensitivity in the IPCC terminology. Adaptive capacity (broader social development) is largely consistent with the socioeconomic approach (Füssel 2007). In the IPCC framework, exposure has an external dimension, whereas both sensitivity and adaptive capacity have internal dimension, which is implicitly assumed in the integrated vulnerability assessment framework (Füssel 2007).

Even though the integrated assessment approach corrects the weaknesses of the other approaches, it has its limitations. The main limitation is that there is no standard method for combining the biophysical and socioeconomic indicators. This approach uses different data sets, ranging from socioeconomic data sets (e.g., race and age structures of households) to biophysical factors (e.g., frequencies of earthquakes); these data sets certainly have different and yet unknown weights. Cutter, Mitchell, and Scott (2000) explained that because this analysis provides no common metric for determining the relative importance of the social and biophysical vulnerability, nor for determining the relative importance of each individual variable, much care is required. The other weakness of this approach is that it does not account for the dynamism in vulnerability. Copying and adaptation are characterized by a continual change of strategies to take advantage of opportunities

(Campbell 1999; Eriksen and Kelly 2007); thus, this dynamism is missing under the integrated assessment approach. Despite its weaknesses, however, this approach has much to offer in terms of policy decisions. Thus, we adopted this method to analyze the vulnerability of Ethiopian farmers to climate change.

Methods for Measuring Vulnerability to Climate Change

Based on the previously discussed approaches, there are many methods for analyzing vulnerability to climate change, especially in the biophysical or impact assessment methods. Discussions of the weaknesses and strengths of all of the methods are beyond the scope of this study. Therefore, only the most common methods employed in vulnerability literature—namely, the econometric and indicator methods—are discussed below.

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. 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) (Hoddinott and Quisumbing 2003). All three share common characteristics in that they construct a measure of welfare loss attributed to shocks.

Vulnerability as Expected Poverty

In the expected poverty framework, vulnerability of a person is conceived as the prospect of that person becoming poor in the future if currently not poor or the prospect of that person continuing to be poor if currently poor (Christiaensen and Subbarao, 2004). Thus, vulnerability is seen as expected poverty, and consumption (income) is used as a proxy for well-being. 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, Jalan, and Suryahadi 2002).

Using cross-sectional survey data of 1998, Chaudhuri, Jalan, and Suryahadi showed that although only 22 percent of the population in Indonesia was poor, as much as 45 percent of that population was vulnerable to poverty. Tesliuc and Lindert (2002) used cross-sectional survey data of 2000 in Guatemala to show that three-quarters of the total poor have a vulnerability index of 0.67, which means that two out of three of the then poor households would still be poor in the coming period. 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).

Vulnerability as a Low Expected Utility

Ligon and Schechter (2002, 2003) defined vulnerability as the difference between the utility derived from some level of certainty-equivalent consumption at and above which the household would not be considered vulnerable and the expected utility of consumption. Ligon and Schechter (2003) applied this method to a panel data set from Bulgaria in 1994 and found that poverty and risk play roughly equal roles in reducing welfare. The disadvantage of this method is that it is difficult to account for an individual's risk preference, given that individuals are ill informed about their preferences, especially those related to uncertain events (Kanbur 1987).

Vulnerability as Uninsured Exposure to Risk

The VER method is based on ex post facto assessment of the extent to which a negative shock causes welfare loss (Hoddinott and Quisumbing 2003). In this method, the impact of shocks is assessed by using panel data to quantify the change in induced consumption. Skoufias (2003) employed this approach to analyze the impact of shocks on Russia. In the absence of risk-management tools, shocks impose a welfare loss that is materialized through reduction in consumption. The amount of loss incurred due to shocks equals the amount paid as insurance to keep a household as well off as before any shock occurs. The disadvantage of this method is that in the absence of panel data sets, estimates of impacts—especially from cross-sectional data—are often biased and thus inconclusive.

Indicator Method

The indicator method of 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. These levels of vulnerability may be analyzed at local (Adger 1999; Leon-Vasquez, West, and Finan 2003; Morrow 1999), national (O'Brien et al. 2004), regional (Leichenko and O'Brien 2001; Vincent 2004), and global (Brooks, Adger, and Kelly 2005; Moss, Brenkert, and Malone 2001) 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, Mitchell, and Scott 2000). The second method is assigning different weights to avoid the uncertainty of equal weighting given the diversity of indicators used. In line with the second method, many methodological approaches have been suggested to make up for the weight differences of indicators. Some of these approaches include use of expert judgment (Kaly and Pratt 2000; Kaly et al. 1999), principal component analysis (Easter 1999; Cutter, Boruff, and Shirley 2003), correlation with past disaster events (Brooks, Adger, and Kelly 2005), and use of fuzzy logic (Eakin and Tapia 2008). Even though there are attempts in giving weights, their appropriateness is still dubious; because there is no standard weighting method against which each method is tested for precision. Luers et al. (2003) explained the weakness of the indicator approach as follows:

> *While the 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, by the availability of data at various scales, and by the difficulty of testing or validating the different metrics. Perhaps most importantly, the indicator approach often leads to a lack of correspondence between the conceptual definition of vulnerability and the metrics: pp 257.*

Table 1 shows different indicators and the scales at which they could be used. Identification of the types of indicators and attachment of the scale of analysis was done by the International Food Policy Research Institute (IFPRI) and the Center for Environmental Economics and Policy in Africa (CEEPA) climate change research team. As shown in this table, level of education or literacy rate is a household characteristic (HHC) that can be analyzed at the household (HH) scale (by taking the education level of the head of a household), the district (D) scale (by taking the average of the education levels of the head of the household in the district), or the national (N) scale (by taking this average for the nation). Similarly, soil conditions are biophysical (BP) characteristics that can be seen at different scales, starting from the household level to the national level. The references listed in the fourth column of Table 1 are different studies that are based on different characteristics at different scales.

Table 1. Indicators or proxy variables used in vulnerability analysis

Type of Indicator*	Indicator	Scale of Analysis**	References
HHC	Level of education or literacy rate	HH, D, N	Kuhl 2004; Nyong et al. 2003; Paavola 2004; Brooks, Adger, and Kelly 2005; Haan, Farmer, and Wheeler 2001
HHC	Age	HH	Nyong et al. 2003; Kuhl 2004; Haan, Farmer, and Wheeler 2001; Næss et al. 2006
HHC	Labor unit/consumer unit	HH	Nyong et al. 2003
HHC	Assets, land value, house value (standard)	HH, D	Moser 1998; Nyong et al. 2003; Aandahi and O'Brien 2001
HHC	Household size, female-headed households	HH, D	Nyong et al. 2003; O'Brien et al. 2004; Paavola 2004; Kuhl 2004
HHC	Drinking water source	HH	Aandahi and O'Brien 2001; Paavola 2004
HHC	Household members	HH	Nyong et al. 2003
HHC	Non-farm income, diversity of income sources	HH, D	Nyong et al. 2003; Adger 1996, 1999; Eakin 2002; Ford, Barry, and Wandel 2005; Haan, Farmer, and Wheeler 2001
HHC	Food sufficiency	HH, D, N	Nyong et al. 2003
HHC	Adjustments measures	HH	Ford, Barry, and Wandel 2005
BP	Soil conditions	HH, D, N	O'Brien et al. 2004
BP	Current climate	HH, D, N	O'Brien et al. 2004
BP	Vegetation	D, N	Haan, Farmer, and Wheeler 2001
INST	Social networks (member of group or association)	HH	Ford, Barry and Wandel 2005; Nyong et al. 2003
INST	Institutional arrangements	D, N	Ford, Barry, and Wandel 2005; O'Brien et al. 2004
FC	Livestock ownership	HH	Paavola 2004
FC	Crop types, cropping systems (monocropping, multiple cropping), fertilizer consumption or input use	HH	Bantilan and Anupama 2002; Aandahi and O'Brien 2001
FC	Irrigation rate, irrigation source	HH, D	Aandahi and O'Brien 2001; O'Brien et al. 2004
BP	Drought and flood-prone areas	D, N	CIDA 2003; O'Brien et al. 2004
ECO	Income level	HH	Adger 1996; Haan, Farmer, and Wheeler 2001
ECO	Percentage of households below poverty line	D	Aandahi and O'Brien 2001; Adger 1996
ECO	Food expenditure	HH	Paavola 2004
ECO	Infrastructure	HH, D, N	O'Brien et al. 2004; Haan, Farmer, and Wheeler 2001

Source: Nhemachena, Benhin, and Glwadys (2006)
*Type of indicator: HHC = household characteristic, INST = institutional, FC = farm characteristic, BP = biophysical, ECO = economy
**Scale of analysis: HH = household, D = district, N = national

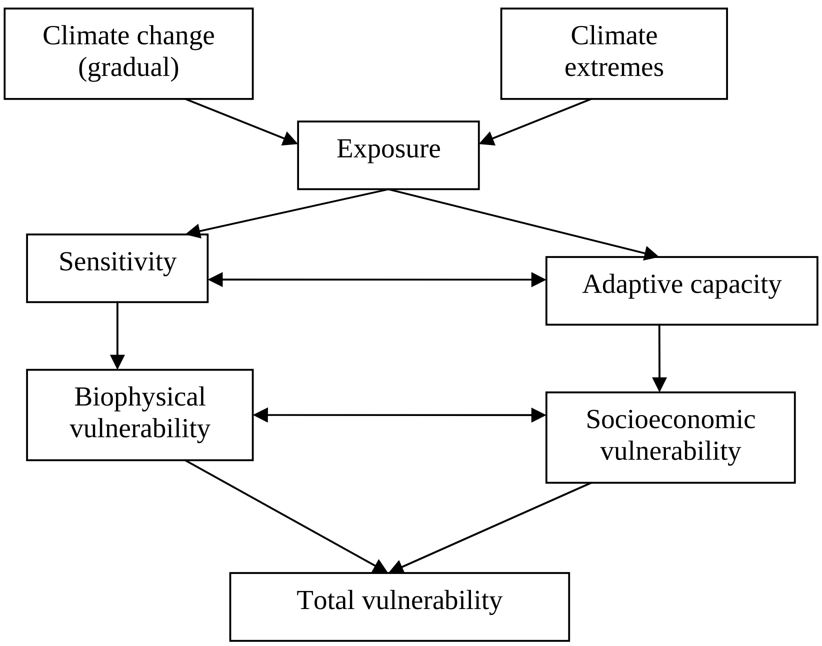
3. CONCEPTUAL FRAMEWORK OF THE STUDY

The IPCC's (2001) definition of vulnerability was adopted for this study by adapting it to the Ethiopian context. The IPCC defines vulnerability to climate change as follows:

> *The degree to which a system is susceptible, or unable to cope with adverse effects of climate change, including climate variability and extremes, and vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.*

As indicated earlier, because the IPCC definition accommodates the integrated vulnerability assessment approach, our study is based on that approach, which considers both the biophysical and the socioeconomic indicators in assessing vulnerability. Figure 1 shows the conceptual framework of vulnerability for this study.

Figure 1. Conceptual framework to vulnerability assessment



As Figure 1 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.

4. MODEL VARIABLES

The model variables for this study were categorized according to the study's conceptual framework (see Section 3). Adaptive capacity is the ability of a system to adjust to actual or expected climate stresses or to cope with the consequences of those stresses. According to IPCC (2001), the main features determining a community or region's adaptive capacity include economic wealth, technology, information and skills, infrastructure, institutions, and equity.

For this study, *adaptive capacity* is represented by wealth, technology, availability of infrastructure and institutions, potential for irrigation, and literacy rate. Wealth enables communities to absorb and recover from losses more quickly due to insurance, social safety nets, and entitlement programs (Cutter, Mitchell, and Scott 2000). Number of livestock owned, ownership of a radio, and quality of residential homes are commonly used as indicators of wealth in rural African communities (Langyintuo 2005; Vyas and Kumaranayake 2006). Proximity to supplies of agricultural inputs is identified as an indicator of technology. For instance, drought-tolerant or early maturing varieties of crops as technology packages usually require access to complementary inputs, such as fertilizers or pesticides. Thus, the supplies of such inputs positively contribute to successful adaptation.

The level of development and availability of institutions and infrastructure play an important role in adaptation to climate change by facilitating access to resources. For instance, all-weather roads allow for the distribution of necessary inputs to farmers, which helps them adapt to climate change. These roads also facilitate economic activity by increasing access to markets. Likewise, health services can assist in the provision of preventive treatments for diseases associated with climatic change, such as malaria. And the availability of microfinance often supports farmers by providing credits for technology packages. Smith and Lenhart (1996) indicated that countries with well-developed social institutions are considered to have greater adaptive capacity than those with less-effective institutional arrangements. According to O'Brien et al. (2004), areas with better infrastructure are expected to have a higher capacity to adapt to climate change. In their analysis of the vulnerability of Indian agriculture to climate charge, for example, O'Brien et al. included India's infrastructure development index—which includes the availability of transportation, irrigation, banking, communication, education, and health facilities—to measure adaptive capacity.

Irrigation potential and literacy rate are other important factors contributing to adaptation to climate change. Irrigation potential was selected because of the assumption that places with more potentially irrigable land are more adaptable to adverse climatic conditions (O'Brien et al. 2004). Literacy rate is often included to approximate the level of skills and education of a region. Smith and Lenhart (1996) argued that countries with higher levels of stores of human knowledge are considered to have greater adaptive capacity than are developing nations and those in transition.

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate change stimuli, whereas *exposure* is the nature and degree to which a system is exposed to climate variations (IPCC 2001). The agricultural sector's sensitivity to climate change is represented by the frequency of climate extremes. In our study, it is argued that in places with a greater frequency of droughts and floods, the agricultural sector responds negatively (i.e., yield is reduced). Thus, agriculture in drought- and flood-prone areas is more sensitive in terms of yield reduction.

Exposure is represented by the predicted change in temperature and rainfall by 2050. This figure provides the level of climate change to which regions are exposed. It is generally agreed that increasing temperature and decreasing precipitation are both damaging to the already hot and water-scarce African agriculture. Thus, regions with increasing temperature and decreasing rainfall were identified as regions more exposed to climate change. Table 2 gives the indicators and the hypothesized direction of relationship with vulnerability.

Table 2. Vulnerability indicators, units of measurement, and expected direction with respect to vulnerability

Determinants of Vulnerability	Vulnerability Indicators	Description of Each Indicator Selected for Analysis	Unit of Measurement	Hypothesized Functional Relationship Between Indicator and Vulnerability
Adaptive capacity	Wealth	Livestock ownership Ownership of radio Quality of residential home Nonagricultural income Gift and remittance	Percentage of total population who own or have access to	The higher the percentage of total population with asset ownership, and access to these income sources the lesser the vulnerability.
	Technology	Insecticide and pesticide supply Fertilizer supply Improved seeds supply	Percentage of total population within 1–4 kilometers of supply sources	The higher the percentage of total population of the region within 1–4 kilometers, the lesser the vulnerability.
	Infrastructures and institutions	All-weather roads Health services Telephone services Primary and secondary schools Veterinary services Food market Microfinance	Percentage of total population within 1–4 kilometers of these infrastructures and institutions	The higher the percentage of total population of the region within 1–4 kilometers, the lesser the vulnerability.
	Irrigation potential	Irrigation potential	Percentage of potential irrigable land (irrigable land divided by total area)	The higher the irrigation potential, the lesser the vulnerability.
	Literacy rate	Literacy rate age 10 years and older	Percentage of total population	The higher the literacy rate, the lesser the vulnerability.
Sensitivity	Extreme climate	Frequency of droughts and floods	Number of occurrences (counts of the occurrences of drought and flood in different parts of the region)	The higher the frequency, the more the vulnerability.
Exposure	Change in climate	Change in temperature Change in precipitation	Change (delta T) in degrees from base value (2000) Percentage change from base value (2000)	Increasing temperature and decreasing precipitation increase vulnerability.

Data Sources

Ethiopia has 11 administrative regions (Figure 2). Data on socioeconomic and environmental factors affecting vulnerability were collected for seven of these regions.[1] Socioeconomic data include wealth, income, technology, literacy rate, infrastructure, and institutions. These data were collected from Ethiopia's Central Statistical Agency (CSA 2006). Environmental factors, including irrigation potential, frequency of drought, and flood frequency, were collected from various sources. Data on irrigation potential was taken from the International Water Management Institute (Awulachew et al. 2005). Data on drought and flood frequencies were taken from the International Disaster Data Base for 1906 to 2006 (Emergency Events Database [EM-DAT] 2006). Predicted changes in climatic variables2 (i.e., temperature and rainfall) for 2050 were taken from the hydrology component for the GEF Project: Climate Change Impacts on Agriculture in Africa (Strzepek and McCluskey, 2006).

Figure 2. Ethiopia's regional states

1 No data were available for the Gambella region, and Addis Ababa, Dire Dawa, and Harari were excluded, because (1) they are very small in comparison with the other regions, and (2) they are not rural.

2 Data from different metrological stations in different districts were aggregated over each region.

5. CONSTRUCTION OF VULNERABILITY INDEX

This study attempts to analyze vulnerability based on the integrated approach by making use of vulnerability index. As indicated earlier, the use of indices is challenged by many ambiguities, some of which are the choices of the right indicators, directions of relationships with vulnerability, weights attached, and the optimal scale. The choice of indices was undertaken based on a review of the literature and adjusting to the context of Ethiopian agriculture. The direction of relationship in vulnerability indicators (i.e., their sign) was adopted from the procedure followed by Moss, Brenkert, and Malone (2001), who assigned a negative value to sensitivity and a positive value to adaptive capacity and then calculated the vulnerability resilience indicator. In our study, we attached a negative value to both exposure and sensitivity. The main argument for this is that areas that are highly exposed to damaging climate are more sensitive to damages, assuming constant adaptive capacity.

Sensitivity could best be measured by a change in income or livelihood attributed only to climatic factors. However, it was not possible to find this type of data. Instead, we were obliged to make the simple assumption that those areas with higher frequencies of climate extremes (e.g., drought and flood) were subjected to higher sensitivity due to loss in yield and thus loss of livelihood, given that the main source of livelihood in rural Ethiopia is agriculture. In addition, exposure could best be represented by both future gradual changes in climate and the forecasted values of the probabilities of extreme events (e.g., drought and flood). Data on the forecasted probabilities of future climate extremes were not found; thus, we were forced to make the very simple assumption that areas with higher changes in temperature and precipitation are more exposed. Variables listed under adaptive capacity are given a positive value. In this study, it is assumed that people with higher adaptive capacity are less sensitive to damages from climate change, keeping the level of exposure constant. Therefore, vulnerability is calculated as the net effect of adaptive capacity, sensitivity, and exposure.

$$\textit{Vulnerability} = (\textit{adaptive capacity}) - (\textit{sensitivity} + \textit{exposure}) \quad (1)$$

In this relationship, higher net value indicates lesser vulnerability and vice versa.

The next step is the attachment of weights to the vulnerability indices. For this step, the method of principal components analysis (PCA) was employed. PCA is frequently used in research that is based on constructing indices for which there are no well-defined weights. The use of asset-based indices for measurements of wealth across different social groups is a good example (Filmer and Pritchett 2001; Langyintuo 2005; Sumarto, Suryadarma, and Suryahadi 2006; Vyas and Kumaranayake 2006). Our argument is that as with the asset-based indices for wealth comparison, there are no well-defined weights assigned to the vulnerability indices we chose for this study. Therefore, we let a statistical method (PCA) generate the weights.

Principal components analysis is a technique for extracting from a set of variables those few orthogonal linear combinations of variables that most successfully capture the common information. Intuitively, the first principal component of a set of variables is the linear index of all the variables that captures the largest amount of information common to all the variables. For example, suppose we have a set of *Z*-variables (a^*_{1j} to a^*_{Zj}) that represents the *Z*-variables (attributes) of each region *j*. PCA starts by specifying each variable normalized by its mean and standard deviation. For instance, $a_{1j} = (a^*_{1j} - a^*_1)/s^*_1$, where a^*_1 is the mean of a^*_{1j} across regions and s^*_1 is its standard deviation. The selected variables are expressed as linear combinations of a set of underlying components for each region *j:*

$$\begin{aligned} a_{1j} &= y_{11} W_{1j} + y_{12}W_{2j} + \ldots + y_{1z}W_{zj} \\ &\ldots \qquad\qquad\qquad\qquad j = 1 \ldots J \\ a_{z1j} &= y_{z1}W_{1j} + y_{z2}W_{2j} + \ldots + y_{zz}W_{zj}\,, \end{aligned} \quad (2)$$

where the *W*'s are the components and the *y*'s are the coefficients on each component for each variable (and do not vary across regions). Because only the left side of each line is observed, the solution to the problem is indeterminate. PCA overcomes this indeterminacy by finding the linear combination of the variables with maximum variance (usually the first principal component W_1j), then finding a second linear combination of the variables orthogonal to the first and with maximal remaining variance, and so on. Technically, the procedure solves the equations $(\mathbf{R} - \lambda \mathbf{I})\mathbf{v}_n = 0$ for λ_n and $\mathbf{v}_n$, where **R** is the matrix of correlations between the scaled variables (the *a*'s) and $\mathbf{v}_n$ is the vector of coefficients on the *n*th component for each variable. Solving the equation yields the characteristic roots of **R**, λ_n (also known as eigenvalues), and their associated eigenvectors, **v***n*. The final set of estimates is produced by scaling the $\mathbf{v}_n$s so that the sum of their squares sums to the total variance—another restriction imposed to achieve determinacy of the problem.

The scoring factors from the model are recovered by inverting the system implied by equation (2). This yields a set of estimates for each of the *Z*-principal components:

$$\begin{aligned} W_{1j} &= b_{11}\, a_{1j} + b_{12}\, a_{2j} + \ldots + b_{1z}\, a_{zj} \\ &\ldots \qquad\qquad j = 1 \ldots \mathrm{J} \\ Wz_j &= b_{z1}\, a_{1j} + b_{z2}\, a_{2j} + \ldots + b_{zz}\, a_{zj}\,, \end{aligned} \tag{3}$$

where the *b*'s are the factor scores. Following Filmer and Pritchett (2001), the first principal component, expressed in terms of the original (unnormalized) variables is an index for each region in Ethiopia based on the following expression:

$$W_{1j} = b_{11}\,(a^*_{1j} - a^*_1)/(s^*_1) + \ldots + {}_{b1z}\,(a^*_{Zj} - a^*_Z)/(s^*_Z) \tag{4}$$

The final point we considered in creating the indices was the scale of analysis. Vulnerability analysis ranges from the local or household (Adger 1999) level to the global level (Brooks, Adger, and Kelly 2005). The choice of scale is dictated by the objectives, methodologies, and data availabilities. For this study, the scale of analysis was the regional level, even though the regional level is too aggregated, and local variations are often overlooked. In fact, some pockets of the country where drought is so frequent are often masked in regional-scale studies. The most appropriate scale for this type of study is actually the lowest administrative unit, such as a district or even a village within a district. Because we were limited by the availability of data at these scales, however, we were obliged to do our research at the regional level.

6. RESULTS AND DISCUSSION

Descriptive Statistics

Preliminary analyses indicate that regions in Ethiopia vary in their socioeconomic and environmental characteristics. Tables A1 through Table A4 depict the indicators of adaptive capacity, whereas Tables A5 and A6 depict indicators of sensitivity and exposure across the seven agricultural regions. Farmers living in Amhara and Oromia are wealthier than those in the other regions in terms of the quality of the houses they own. The percentage of people owning radios is highest in Afar and lowest in Amhara. Livestock ownership is highest in Somali, due to the fact that most farmers in Somali are nomads and make their livelihoods mostly from livestock. Overall, a very small proportion of farmers in Ethiopia has access to nonagricultural income, gifts, and remittance, clearly indicating that agriculture is the main source of livelihood in the rural community. Table A1 shows the wealth distribution across the seven regional states.

SNNP has the highest access to technology, as the percentage of farmers in this region are the highest in terms of proximity to insecticides, pesticides, fertilizer, and supplies of improved seeds. Farmers in Somali and Afar have the lowest access to supplies of inputs (Table A2).

Afar has the highest proportion of all-weather roads and health services; whereas Somali has the lowest proportion of health services and Amhara has the lowest proportion of all-weather roads. Food market is highest in SNNP and lowest in Somali and Amhara. Primary and secondary schools are relatively equally distributed across the regions, except for Somali, in which they are very low. Telephone services are highest in rural Afar and lowest in Benishangul Gumuz. Tigray has the highest proportion of microfinance and veterinary services, whereas Somali has the lowest proportion of both microfinance and veterinary services (Table A3). Irrigation potential and literacy rates are highest in SNNP and Tigray, respectively. Irrigation potential and literacy rates are lowest in Afar and Somali, respectively (Table A4). In terms of the frequency of drought and flood, Amhara stands first (even though the figures for Oromia and Somali are closer), whereas Benishangul Gumuz and Afar experienced a lesser frequency of drought and flood over the past century (Table A5). By 2050, the predicted change in temperature (increment) is highest for Afar and Tigray and lowest for SNPP, whereas the change in precipitation3 is the highest for Somali and lowest for SNPP (Table A6).

Results from the Principal Component Analysis

For this analysis, PCA was run on the indicators listed in Table 3 using data analysis and statistical software (STATA). The PCA of the data set on vulnerability indicators revealed three components with eigenvalues greater than 1. These three components explain 95 percent of the total variation in the data set. The first principal component explained most of the variation (56 percent), and the second principal component explained 25 percent, and the third explained the least (14 percent). Based on earlier arguments for the use of PCA in constructing indices, we take the first principal component, which explained the majority of the variation in the data set. As can be observed from the factor scores, the first PCA (our vulnerability index, in this case) was positively associated with the majority of the indicators identified under adaptive capacity and negatively associated with all the indicators categorized under exposure and sensitivity (Table 3).

Thus, for the construction of our vulnerability indices, we selected indicators of adaptive capacity, which are positively associated with the first PCA, and all the indicators of sensitivity and exposure, as they are negatively associated with our PCA (remaining with a total of 15 indices). Higher values of the vulnerability index show less vulnerability and vise versa, as we are dealing with the fact that adaptive capacity is positively loading. The exposure and sensitivity indices are negatively loading to our PCA.

3 Climate prediction studies on precipitation for Ethiopia are inconclusive, with some indicating increases and others decreases in rainfall.

Table 3. Factor scores of the first principal component

Vulnerability indicators	Factor scores
Ownership of livestock	–0.2951
Ownership of radio	**0.0375**
Quality of house	**0.1096**
Nonagricultural income	–0.1264
Gifts and remittances	–0.2863
Insecticide and pesticide supply	**0.29**
Fertilizer supply	**0.2873**
Improved seeds supply	**0.2789**
All-weather roads	–0.0637
Health services	**0.2597**
Telephone services	–0.0140
Primary and secondary schools	**0.2958**
Veterinary services	**0.2586**
Food market	**0.1737**
Microfinance	**0.2107**
Irrigation potential	**0.2595**
Literacy rate	**0.2799**
Frequency of climate extremes	**–0.1852**
Change in temperature	**–0.0508**
Change in precipitation	**–0.2720**
Eigenvalue	11.23
Proportion of variance	56.16
Cumulative proportion	56.16

As indicated in Section 5 (equation 4), factor scores from the first principal component were employed to construct indices for each region. For instance, the vulnerability index for Afar is calculated as follows:

$$\begin{bmatrix} (0.1096*\text{-}0.76856494)+(0.0375*1.094139)+(0.29*\text{-}1.08114)+ \\ (0.2873*\text{-}1.40065)+0.2789*\text{-}1.08821)+(0.2597*1.956076)+ \\ (0.1737*\text{-}0.05282)+(0.2958*0.215667)+(0.2107*\text{-}1.09422)+ \\ (0.2586*\text{-}0.02715)+(0.2595*\text{-}1.04492)+(0.2799*\text{-}1.1312) \end{bmatrix} - \begin{bmatrix} (0.1852*\text{-}1.12272)+ \\ (0.0508*1.141059)+ \\ (0.272*\text{-}0.06116) \end{bmatrix} = -1.16 \qquad (5)$$

The calculations for the rest of the regions followed the same procedure. Table A7 presents the normalized values for each variable by their means and standard deviations for all regions. Figure 3 shows the vulnerability index for each region.

Figure 3. Vulnerability indices of the seven regional states of Ethiopia

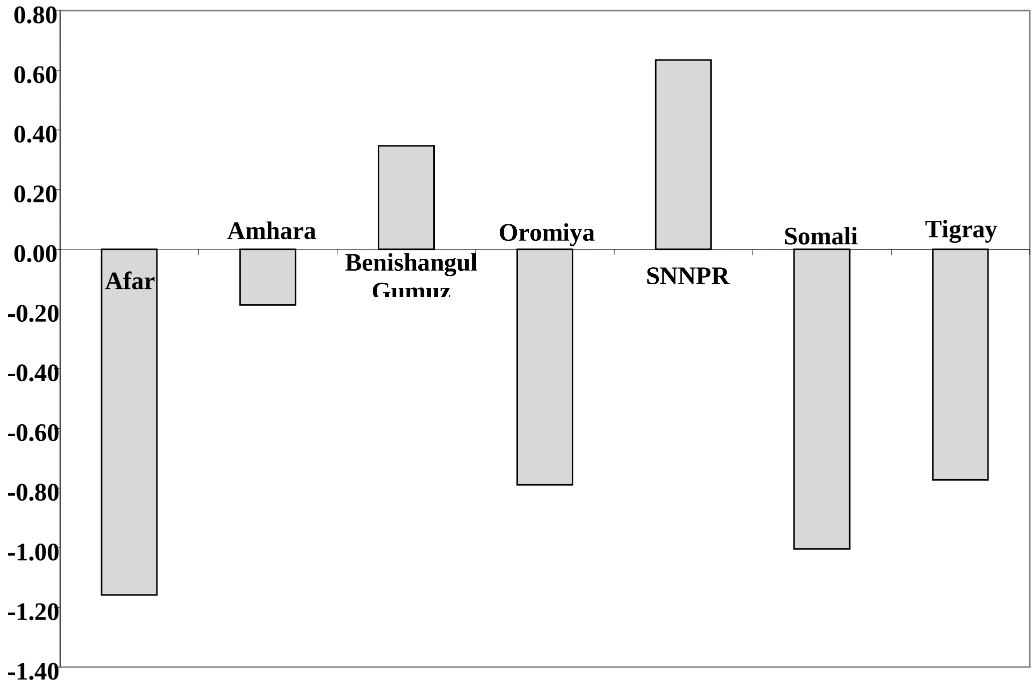


Figure 3 shows that the net effect of adaptation, exposure, and sensitivity is positive for SNNP and Benishangul Gumuz and negative for Afar, Amhara, Oromia, Somali, and Tigray. This indicates that SNNP and Benishangul Gumuz are relatively not vulnerable, whereas Afar, Amhara, Oromia, and Somali are vulnerable. The lesser vulnerability of SNNP is associated with its relatively higher access to technology and food market, its highest irrigation potential, and its literacy rate. Afar, Somali, Oromia, and Tigray are among the highly vulnerable regions. Vulnerability of Afar and Somali is mainly associated with lower levels of regional development. Despite the fact that these regions are less populated than the other regions, the percentage of people with access to institutions and infrastructure remains very low due to the lowest level of regional development.

The vulnerability of Oromia is associated with a high frequency of drought and flood and lower access to technology, institutions, and infrastructure. Similarly, the vulnerability of Tigray is attributed to lower access to technology, health services, food markets, and telephone services and the high frequency of drought and flood. Unlike Afar and Somali, the lower access to technology, institutions, and infrastructure in Tigray and Oromia is due to their high population in proportion to what is available.

7. CONCLUSIONS

This study analyzed the vulnerability of Ethiopian farmers to climate change by creating vulnerability indices and comparing these indices across regions. Seven of Ethiopia's 11 regional states were considered for this study. The vulnerability analysis followed the IPCC (2001) definition of vulnerability, which explains it as a function of adaptive capacity, sensitivity, and exposure.

The socioeconomic and environmental factors of each region were included in developing the vulnerability indices. Thus, the integrated vulnerability assessment approaches were adopted to combine these biophysical and socioeconomic indicators. The socioeconomic factors include wealth, literacy rate, technology, institutions, and infrastructure. The biophysical factors include irrigation potential, frequency of climate extremes, and future changes in temperature and rainfall. These factors were again divided into three categories to reflect adaptive capacity, sensitivity, and exposure. Positive values were attached to adaptive capacity and negative values to sensitivity and exposure. The method of principal component analysis was employed to give weights to the different factors affecting vulnerability.

Vulnerability was calculated as the net effect of sensitivity and exposure on adaptive capacity. Results indicate that Afar, Somali, Oromia, and Tigray are relatively more vulnerable to climate change. The vulnerability of Afar and Somali is attributed to their low level of regional development. The vulnerability of Tigray and Oromia is attributed to higher frequencies of drought and flood and lower access to technology, institutions, and infrastructure. Unlike Afar and Somali, the lower access to technology, institutions, and infrastructure in Tigray and Oromia is due to their high population in proportion to what is available.

The scale of analysis for this study is at the regional level, which is highly aggregated. Each region included in this study covers a very wide area of land characterized by different biophysical and socioeconomic attributes. These variations within each region should be considered in order to target areas that are highly vulnerable and to recommend appropriate interventions. Although the results of this study indicate the general features of each included region, future research should focus on local levels, especially district or village levels, where actual dynamics of vulnerability to climate change take place.

Based on the analysis, a few general policy options for decreasing the vulnerability of Ethiopian farmers to climate change can be presented. In general, vulnerability to climate change in Ethiopia is highly related to poverty (loss of copying or adaptive capacity) in most of the regions that were indicated as vulnerable. Integrated rural development schemes aimed at alleviating poverty can play the double role of reducing poverty and increasing adaptive capacity to climate change. Special emphasis on the relatively less-developed regions of the country (i.e., Afar and Somali), as well as the relatively more populated regions (e.g., Oromia and Tigray), in terms of investment in technology, institutions, and infrastructure can also play a significant role.

Moreover, early warning of extreme climatic events, such as drought, can alert farmers to sell their livestock and buy food and other items. Without this warning, such events could shrink or kill livestock that would have been used to insure farmers. In addition, investment in irrigation in places with high potential for irrigation (e.g., SNNP) can increase the country's food supply. This supply could then be stored and soled out during drought events instead of depending on food aid from other nations. Strengthening the ongoing micro-level adaptation methods of governmental and nongovernmental organizations, such as water harvesting and other natural resource conservation programs, can also boost the adaptive capacities of farmers.

APPENDIX. SUPPLEMENTARY TABLES

Table A.1. Indicator of wealth

Region	Quality of house	Radio	Livestock	Nonagricultural income	Gifts and remittance
Afar	9.25	25.48	42.4400	1.82	
Amhara	27.88	11.18	46.4500	2.60	0.08
Benishangul Gumuz	8.96	23.32	30.6425	4.44	
Oromia	23.21	23.20	46.7475	3.89	0.02
SNNP	11.44	18.28	41.8425	6.20	0.01
Somali	7.30	18.66	55.6875	7.45	0.17
Tigray	21.25	21.73	45.1775	2.71	0.02

Table A.2. Technology

Region	Insecticides and pesticides	Fertilizer supply	Improved seeds
Afar	4.61	1.50	4.47
Amhara	11.31	14.11	13.46
Benishangul Gumuz	15.97	18.47	19.48
Oromia	14.65	16.99	15.82
SNNP	18.91	21.41	21.00
Somali	1.94	2.18	1.94
Tigray	11.05	12.34	10.22

Table A.3. Infrastructure and institutions

Region	Health services	All-weather roads	Food market	Primary and secondary school	Telephone services	Microfinance	Veterinary services
Afar	28.11	33.86	23.68	25.595	13.16	0.22	15.98
Amhara	10.18	14.84	19.11	25.305	3.89	6.83	15.26
Benishangul Gumuz	11.21	19.97	24.13	22.885	3.52	2.38	21.42
Oromia	15.72	19.66	26.27	25.430	6.04	3.47	13.86
SNNP	18.55	26.53	42.06	31.935	7.08	5.91	20.11
Somali	8.66	30.59	19.11	13.880	6.87	0.04	2.01
Tigray	13.13	32.04	14.66	25.970	5.72	9.26	24.61

Table A.4. Irrigation potential and literacy rate

Region	Irrigation potential	Literacy rate
Afar	1.62	16.85
Amhara	3.14	26.61
Benishangul Gumuz	2.46	31.42
Oromia	3.82	31.07
SNNP	6.23	34.92
Somali	1.84	12.74
Tigray	5.99	37.04

Table A.5. Frequency of drought and flood

Region	Drought and flood
Afar	9
Amhara	15
Benishangul Gumuz	9
Oromia	14
SNNP	10
Somali	14
Tigray	12

Table A.6. Change in climatic conditions

Region	Increasing temperature	Percentage change in precipitation
Afar	2.74	1.03
Amhara	2.64	1.01
Benishangul Gumuz	2.53	0.99
Oromia	2.51	0.97
SNNP	2.41	0.88
Somali	2.55	1.29
Tigray	2.76	1.12

Table A.7. Normalized values of the original data by their respective means and standard deviations

Region	Quality of house	Ownership of livestock	Ownership of radio	Nonagricultural income	Gift and remittance	Insecticide supply	Fertilizer supply	Improved seeds supply	Health services	All-weather roads	Food market	Primary and secondary schools	Telephone services	Veterinary services	Irrigation potential	Literacy rate	Drought and flood	Increasing temp
Afar	–0.769	–0.227	1.094	–1.142	–0.890	–1.081	–1.401	–1.088	1.956	1.169	–0.053	0.216	2.050	–0.027	–1.045	–1.131	–1.123	1.141
Amhara	1.482	0.308	–1.906	–0.761	0.297	0.017	0.215	0.155	–0.736	–1.445	–0.571	0.162	–0.852	–0.126	–0.237	–0.068	1.235	0.413
Benishangul Gumuz	–0.804	–1.801	0.641	0.137	–0.890	0.781	0.774	0.987	–0.581	–0.740	–0.002	–0.285	–0.968	0.717	–0.600	0.456	–1.123	–0.485
Oromia	0.918	0.348	0.616	–0.131	–0.593	0.565	0.585	0.481	0.096	–0.783	0.241	0.185	–0.179	–0.317	0.126	0.418	0.842	–0.634
SNNP	–0.504	–0.307	–0.416	0.997	–0.741	1.263	1.151	1.197	0.521	0.161	2.032	1.388	0.147	0.537	1.406	0.837	–0.730	–1.414
Somali	–1.004	1.541	–0.337	1.608	1.631	–1.519	–1.314	–1.438	–0.964	0.719	–0.571	–1.950	0.081	–1.937	–0.930	–1.579	0.842	–0.351
Tigray	0.681	0.138	0.307	–0.708	–0.593	–0.026	–0.011	–0.293	–0.293	0.918	–1.076	0.285	–0.279	1.153	1.278	1.068	0.056	1.330

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