Assessing climate change vulnerability of smallholder farmers in northwest Ethiopia: application of a household intrinsic vulnerability index

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Abstract

Purpose – The purpose of this study is to identify the most vulnerable households and districts in Northwest Ethiopia and help decision-makers in developing and prioritising effective adaptive strategies and actions.

Design/methodology/approach – A multi-scale analytical tool and hazard-generic socio-economic indicators were developed to identify and prioritise the most vulnerable households and districts in Northwest Ethiopia. Categorical principal component analysis with 36 indicators was used to develop weights for different indicators and construct a household intrinsic vulnerability index. Data were collected through key information interviews, focus group discussions and a household survey with 1,602 randomly selected households in three districts of Northwest Ethiopia.

Findings – Drawing on intrinsic vulnerability index computation, this study highlights that low levels of education, low access to climate information and credit services, long distance travelled to fetch water and frequent food shortages are the dominant factors contributing to high levels of intrinsic vulnerability at district level, while lack of livelihood support and income diversification are the key drivers of vulnerability at household level. The findings of this study further show that the majority of households (78.01%) falls within

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the very high to moderately high vulnerable category. Disaggregating the data according to agro-climatic zones highlights that the prevalence of high intrinsic vulnerability is most widespread in the lowland agro-climatic zone (82.64%), followed by the highland (81.97%) and midland zones (69.40%).

Practical implications – From a policy intervention vantage point, addressing the drivers of vulnerability provides a reliable approach to reduce the current vulnerability level and manage potential climate change-induced risks of a system. Specifically, reliable information on inherent vulnerability will assist policymakers in developing policies and prioritising actions aimed at reducing vulnerability and assisting in the rational distribution of resources among households at a local level.

Originality/value – This study contributes to the existing vulnerability literature by showing how hazard-generic socio-economic indicators in the vulnerability assessment adopted by the IPCC (2014) are important to identify drives of vulnerability which ultimately may feed into a more fundamental treatment of vulnerability.

Keywords Intergovernmental Panel on Climate Change (IPCC) 2014 framework, Intrinsic vulnerability index, Categorical principal component analysis (CATPCA), Northwest Ethiopia

Paper type Research paper

1. Introduction

Over time, studies on vulnerability to climate change have increasingly acknowledged the use of vulnerability assessments to inform policy-making (Füssel, 2007; O'Brien *et al.*, 2004; Patt *et al.*, 2005). However, there is an ongoing debate on how to characterise vulnerability in theory and practice (Esteves *et al.*, 2016). For a long time, vulnerability analysis has been associated with external influences that may negatively affect a valued attribute of a system, with greater weight given to natural calamities (Asfaw *et al.*, 2021; Dwyer *et al.*, 2004). However, it has been argued that such vulnerability framing is not adequate enough to explain the dynamic nature of vulnerability (Asfaw *et al.*, 2021). Vulnerability does not depend on the likelihood that a system will encounter a particular hazard; rather, it results from the interaction of various socio-economic processes (Rajesh *et al.*, 2014; Rajesh *et al.*, 2018). The recent paradigm shift in vulnerability assessment views vulnerability as an intrinsic characteristic of a system, as framed by the Intergovernmental Panel on Climate Change (IPCC) (2014).

Under the changed paradigm of the IPCC-2014 report, vulnerability is reconceptualised as "a propensity of the internal property of the system to be adversely affected which comprises sensitivity and adaptive capacity" (Sharma and Ravindranath, 2019, p. 2). While sensitivity and adaptive capacity are recognised as intrinsic [1] attributes of a system, which predispose a community to be adversely affected by any damage (Esteves *et al.*, 2016; Farooq *et al.*, 2021), exposure is understood as some external influence that may adversely affect a valued attribute of a system (Das *et al.*, 2020; Sharma and Ravindranath, 2019). Based on the new discourse of IPCC-AR5, intrinsic vulnerability assessment has a paramount significance to design adaptation policies addressing climate induced vulnerability of smallholder farmers (Esteves *et al.*, 2016; Rajesh *et al.*, 2018; Wisner *et al.*, 2014). However, an analysis of vulnerability which takes into account inherent socio-economic and livelihood characteristics and helps to understand "who is vulnerable and why" remains scanty. Intrinsic vulnerability assessments seek to not only pinpoint the systems or community groups most at risk but also comprehend the root causes (Rajesh *et al.*, 2014). Adding to this, Rajesh *et al.* (2018) highlighted the need for intrinsic vulnerability assessments that categorise households into different vulnerability categories for appropriate government interventions. Realizing the need for such assessment, our study aims to contribute to this emerging literature on vulnerability assessment methods.

Ethiopia emphasises large-scale commercialisation of agriculture through institutionalising climate resilient green economy strategies, strengthening formal safety nets and an improved land tenure system (CRGE, 2012). Despite considerable efforts made, Ethiopian agriculture remains negatively impacted by frequent climate shocks which leads to substantial welfare losses for smallholder farmers (Gezie, 2019). Rural poverty and vulnerability are persistent all over the country with on average 29.6% of the rural population living below the nationally defined poverty line between 2006 and 2017 (FAO, 2019), with differences alongside basic socio-economic characteristics. Hence, intrinsic vulnerability assessment is essential to get an insight into the presence of differential vulnerabilities among households within a community (Rajesh *et al.*, 2018).

There exist various studies on vulnerability of smallholder farmers to climate change in Ethiopia (Asfaw *et al.*, 2021; Dendir and Simane, 2019; Deressa, 2010; Tesso *et al.*, 2012; Teshome, 2016). Some of the studies were carried out at the national level (Deressa, 2010; Tesso *et al.*, 2012), but none showed differences in terms of the magnitude of vulnerability of smallholder farmers on the basis of their socio-economic attributes at the grassroot level. Other vulnerability studies were based on the risk-hazard framework (Abeje *et al.*, 2019; Dendir and Simane, 2019; Teshome, 2016) that ignores the inherent socio-economic and livelihood characteristics of a household which are equally important in determining vulnerability. Moreover, most studies in Ethiopia (Dendir and Simane, 2019; Deressa, 2010; Teshome, 2016; Tesso *et al.*, 2012) focus on spatial dimensions and often reveal mixed findings. For instance, Dendir and Simane (2019) highlighted that lowland areas are more vulnerable to climate-induced risks, while a study conducted by Tesso *et al.* (2012) showed people in the lowland areas are less vulnerable compared to highlanders. The conflicting findings indicate that different other factors, even within the same spatial dimension, determine the magnitude of vulnerability; hence, further investigations are needed.

Furthermore, most vulnerability assessments have been restricted to the use of numeric variables for capturing different vulnerability indicators because of the difficulty involved in analysing categorical data (Meulman, 2007). It is important to note, however, that limiting the analysis to numeric variables may miss crucial information such as perceptions and opinions of people, which can have a profound influence on climate change vulnerability (Rajesh *et al.*, 2014; Rajesh *et al.*, 2018). The absence of an appropriate methodological framework to address this challenge in current vulnerability research is a critical knowledge gap. Recognising the need for such technique and adding on to this growing field of vulnerability assessment, our study [2] uses categorical principal component analysis (CATPCA) for assessing inherent vulnerability of smallholder farmers in Northwest Ethiopia.

Hence, our study was designed to fill the existing knowledge gap through intrinsic vulnerability assessment and contribute by providing policymakers with a useful tool for identifying vulnerable households and developing effective adaptation strategies. The next section discusses the theoretical framework of intrinsic vulnerability, while the methodology used in the study is described in Section 3. Findings related to the intrinsic vulnerability of smallholder farmers in Northwest Ethiopia are presented and discussed in Section 4, while Section 5 concludes.

2. Theoretical framework of intrinsic vulnerability

Vulnerability is the most accustomed concept in climate and disaster risk science, ecology and development-related literature and "has been a powerful analytical tool for describing states of susceptibility to harm, powerlessness, and marginality of both physical and social systems" (Adger, 2006, p. 268). In terms of conceptualising the word vulnerability, numerous technical definitions have been coined in the context of economic, social and environmental studies (Füssel, 2007; Connelly *et al.*, 2018; Sharma and Ravindranath, 2019). This implies that there is no precise and universal definition for vulnerability as pointed out by Adger (2006). Yet it is valuable to give a brief overview of the term vulnerability and how it has been conceptualised by different scholars from various knowledge domains, which also provides context for understanding the reason why the IPCC reconceptualised vulnerability in 2014.

In the climate change literature, the dominant specifications of the vulnerability concept are either *contextual* or *outcome* vulnerability. Füssel (2007) explains how the *contextual* interpretation of vulnerability is rooted in the field of political economy which considers vulnerability to be the result of "structure not nature, technology, or agency" (p. 159). On the other hand, Adger (2006) points out that *outcome* vulnerability is mainly embedded in political ecology discourses that represent a concept which syndicates both possible impacts of climate shocks and the capacity to adapt to the changing climate. In disaster-risk literature, vulnerability is considered as "the characteristics and circumstances of a community, a system or asset that make it susceptible to the damaging effects of a hazard" (UN-ISDR, 2006, p. 30). This implies that vulnerability is part and parcel of risk which interacts with hazard and exposure.

The most recent and revised definition of vulnerability is the one provided by the IPCC-AR5, where vulnerability is conceived as "*[...]* the propensity or predisposition of a system to be adversely affected encompassing a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt [...] is considered independent of a physical system" (IPCC, 2014, p. 33). The utmost purpose in addressing climate change is to reduce the risks to natural and social systems. In this regard, the impact-risk framework presented in the IPCC Working Group II Report (2014) posits that the risk of impact from climatic and non-climatic hazard (s) is caused by the interaction of hazard, exposure and vulnerability. Separating hazard and exposure from the concept of vulnerability in the IPCC, 2014 report is a paradigm change from the IPCC 2007 report (Sharma and Ravindranath, 2019). This paradigm change presents vulnerability as an internal property of a system delinked from exposure to hazard which is seen as an external and independent factor (IPCC, 2014). This shift in thinking also has imperative implications for assessing vulnerability. Unlike the IPCC 2007 report, which presents vulnerability as the result of the interaction between exposure, sensitivity and adaptive capability, the IPCC, 2014 framework only includes sensitivity and adaptive capacity indicators (Sharma and Ravindranath, 2019). The degree of vulnerability is, therefore, considered to depend on the intrinsic socio-economic characteristics of a system regardless of whether it is exposed to external stresses. In other words, the level of vulnerability is shaped by non-climatic factors and multidimensional inequalities (Esteves *et al.*, 2016), often produced by uneven development processes (Alare *et al.*, 2022).

To revamp and analyse the intrinsic characteristics of a system, it is crucial to consider these two key components of vulnerability (i.e. adaptive capacity and sensitivity). Adaptive capacity is defined as the system's ability to adjust to the changing climate through flexibility and learning to maintain a desirable state (Gallopin, 2006; Nelson *et al.*, 2007) or to capitalise on opportunities while mitigating potential damages (Parry *et al.*, 2007). An array of conditions and resources influences adaptive capacity, including structures and institutions (Alare *et al.*, 2022), economic resources, social capital (Aldrich *et al.*, 2018), awareness and training (Brooks *et al.*, 2005; Deressa, 2010). Sensitivity is another factor that contributes to vulnerability, as it determines how much a system is impacted by climate-induced shocks, either negatively or positively (Parry, 2009), based on factors such as access to water (O’Brien *et al.*, 2004), land quality or agricultural productivity (Wiebe, 2003). This has led to the consideration of increasing a system’s adaptive capacity (Ali *et al.*, 2021) and reducing its sensitivity (Adger, 2006) when developing policies to reduce vulnerability and aid decision makers in the rational distribution of resources (Rajesh *et al.*, 2014).

Therefore, our study is based on this recent IPCC-AR5 framework in which intrinsic vulnerability assessment is undertaken aimed at ranking households and districts based on their level of vulnerability while also identifying drivers of vulnerability which can help key decision makers and development actors to design policies targeting the most vulnerable in a community.

3. Study setting

To study the extent to which smallholder farmers are intrinsically vulnerable to climate-induced shocks in northern parts of Ethiopia, we have selected districts from three different agro-ecological zones in Northwest Ethiopia. More specifically, *Dabat* district from the highland agro-ecology zone, *Mirab (West)-Belessa* district from the midland agro-ecology zone and *Misrak (East)-Belessa* district from the lowland agro-ecology zone. The geomorphological setup of the three districts is by large rugged and mountainous and prone to extreme climate shocks. Average annual temperature in the districts ranges between 22°C and 34°C, while the mean annual rainfall is situated between 1,110 mm to 980 mm (92% received during summer season) [Central Gondar Zone Agricultural Development Office (CGZADO), 2019].

The study districts are characterised by dominance of rainfed agriculture and are among the 48 districts out of 169 in *Amhara* national regional state that are frequently affected by extreme climate shocks (USAID, 2000). At the same time, the three districts are relatively close to each other which implies that the entire study population is similarly exposed to a climate stressor while having potentially different sensitivities and adaptive capacities with regard to that stressor when analysing inherent vulnerability (Carr and Thompson, 2014).

4. Methods, instruments and sampling procedure

The study mainly relies on primary and secondary data sources to develop an intrinsic vulnerability index. First, a cross-sectional household survey was conducted to collect data on factors that contribute to the vulnerability of rural smallholder farmers. Our study adopted a mixed method of convergent parallel design following Creswell (1999) with both types of data given equal priority during analysis.

Household survey data were collected from a multi-stage random sample of households from the three districts. The sample size (n) was derived from the formula developed to compute simple random sampling for finite population $= \left(\frac{Z^2 \; P(1-P)}{ME^2}\right)$*DEFF following Singh and Masuku (2014), where “*ME*” is the desired margin of error = 3%, “*z*” is the z-score value = 1.96 for a 95% confidence interval and “*p*” is the value of proportion rate for which the safest procedure is assumed to be 50% because of the absence of related literature. “*DEFF*” is the correction factor with the value of 1.5 to account for the heterogeneity between clusters. During pilot testing, 5% non-response rate was also considered based on feedback. Two villages were selected randomly in each of the three districts, while systematic random sampling was used to select respondents. A total of 1,680 respondents were included in the survey initially, but during data cleaning, 78 questionnaires had to be dropped which finally led to a random sample of 1,602 respondents.

Female and male respondents were interviewed by 8 female and 17 male enumerators, respectively, who were trained and supervised by the first author and four other team members. The survey was conducted between the end of July and the end of August 2019 using the Kobo-collect toolbox which has inbuilt systems of quality assurance and respecting *deleted for blind review* University ethical guidelines for data collection and processing. In parallel with survey data collection, four focus group discussion (FGDs) with a total of 36 participants were conducted to capture more in-depth insights into factors shaping socioeconomic vulnerability. Participants were purposely selected based on their farming and climate change experience. A panel of four moderators who received two-day training in participatory approaches such as village mapping and pairwise ranking facilitated the discussions using the local language.

4.1 Methodological framework of intrinsic vulnerability index

An intrinsic vulnerability index was constructed to examine the degree of vulnerability of smallholder farmers to climate change. The indicators involved in this study consist of two major contributing factors based on the new IPCC, 2014 vulnerability assessment paradigm, that is, sensitivity and adaptive capacity. To select indicators, an iterative process (Figure 1) was used drawing upon cross-validation among different sources (Esteves *et al.*, 2016; Rajesh *et al.*, 2018). First, the variables for each of the contributing factors were selected from a review of studies conducted in Ethiopia and other countries with similar contexts (Deressa, 2010; Esteves *et al.*, 2016; Fisher and Carr, 2015; Teshome, 2016). In addition, IPCC's AR5 framework (IPCC, 2014) and reconnaissance survey results on socio-economic and bio-physical characteristics of the study districts were used as well as knowledge and expertise of local community and stakeholders (Table 1).

Once indicators were identified, the next stage was to attach weights to each indicator. A review of literature highlights about four methods to assign weights to vulnerability indicators that embraces past experience and record of events of the researcher (Papathoma-köhle *et al.*, 2019); expert judgement (Žurovec *et al.*, 2017); equal weight (David and Heß, 2017); weight assignment using statistical tools like canonical correspondence analysis (Ravera *et al.*, 2016); and factor analysis including linear and non-principal component analysis (Gbetibouo *et al.*, 2010; Esteves *et al.*, 2016; Rajesh *et al.*, 2018). Assigning weights through expert judgement is not considered, as literature pointed out that there might be little agreement over the weights among experts (Lowry *et al.*, cited in Gbetibouo *et al.*, 2010). Assuming equal weights was also disregarded, as different indicators tend to have different levels of effect on vulnerability (Neset *et al.*, 2019).

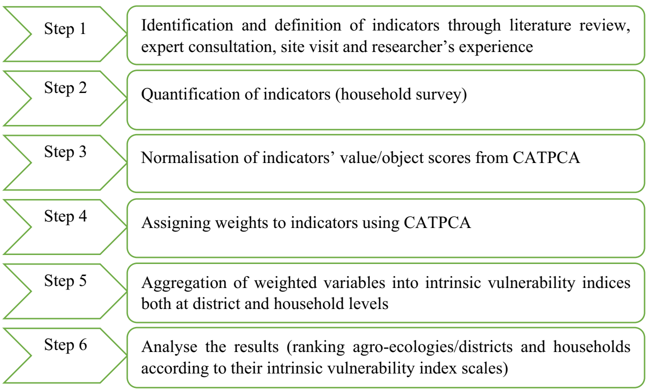

Figure 1.
Intrinsic vulnerability assessment framework

While several climate change studies (Abson *et al.*, 2012; Terence, 2013; Esteves *et al.*, 2016) consider principal components analysis (PCA) an appropriate way to attach weights, it has two major limitations. First, it postulates that the associations between variables are linear. Second, its interpretation is only functional if all the variables are assumed to be scaled numerically. As our vulnerability index includes a combination of variables that are measured at different levels (nominal, ordinal and numerical scale), we have opted for non-linear PCA. The latter has been suggested as a solution to the possible inappropriateness of applying linear PCA to categorical data when these variables may not fulfil the assumptions of linear relationships between variables (Meulman *et al.*, 2007; Costantini *et al.*, 2010). Hence, CATPCA was used to generate object scores across the principal components, thereby deriving an index of vulnerability to climate change for each household in the three districts.

4.2 Weighting system and index construction

Following a technique used by Dharmaratne and Attygalle (2018), our intrinsic vulnerability index was constructed in four steps. First, component loadings were generated for each household and all variables. The numbers of components to be extracted were determined through a combination of the Kaiser rule [3], scree plot rule [4] and the interpretability [5] of the rotated component matrix criteria. Because of the non-linear nature of the data, the varimax [6] rotation method was used to simplify the interpretation of the solution. For interpreting and classifying the components obtained from CATPCA, component loadings were examined and those variables which had loadings above 0.3 were retained following a similar cut-off level used by Karamali (2019). The suitability of the data for component loading analysis was assessed using Kaiser–Meyer–Olkin (KMO) [7] test before the extraction of the component loadings. The test produced an overall KMO static value of 7.32, confirming that components were sufficiently loaded. Second, the squared factor loadings for each variable were calculated. Next, variables were grouped into different intermediate composites that had the highest component loadings and later on aggregated by assigning a weight. The weights for each of the 36 variables were calculated using the matrix of rotated component loadings. Provided that the square of the component loadings represents the proportion of the total unit variance of the variable explained by the component, the weights for each of the variables would be the normalised squared factor loadings (Dalton-Greyling and Tregenna, 2014; Dharmaratne and Attygalle, 2018).

The normalised squared component loadings of variables using:

$$\begin{aligned} &\textit{Normalised squared component loadings of variable } i \\ &= \frac{(\textit{Component loadings of variable } i)^2}{\textit{Variance explained by component } j} \end{aligned} \tag{1}$$

However, as can be seen in Appendices 1 and 2 [8], the variance explained by each of the factors is not the same. Hence, the intermediate composite indicators were aggregated by attaching a weight which is equal to the percentage of explained variance in the data set. The percentage of explained variance was calculated using equation (2) following Dharmaratne and Attygalle (2018).

$$\begin{aligned} &\textit{Proportion of variance explained by the } j^{th} \textit{component} \\ &= \frac{\textit{Variance explained by the } j^{th} \textit{ component}}{\textit{Total variance explained by all components}} \end{aligned} \tag{2}$$

Then, each variable weight derived from equation (1) is multiplied by the corresponding factor weight derived from equation (2) for the final index calculation. The final weight was, therefore, calculated using:

$$Weight\ \ of\ \ variable\ \ i = C_j{*}NL_i \tag{3}$$

where C_j is the component weight of the jth factor and NL_i is the normalised squared factor loading of variable i.

Before developing an intrinsic vulnerable index, component loadings of each indicator needed to be standardised, as each of them had different functional relationships (either positive or negative) between the variables using equation (4). The standardisation procedure calibrates the intrinsic vulnerability values on a 0–1 scale. To facilitate interpretation and comparison, a similar scale was used as in Aroca-Jimenez *et al.* (2017) who developed an integrated social vulnerability index in urban areas prone to flash flooding.

Therefore, a standardised index value for adaptive capacity and sensitivity indicators was constructed using equation (4) following Esteves *et al.* (2016) and Terence (2013).

$$SIV_i = W_i{*}(C_i - X)/STD \tag{4}$$

where SIV_i represents the standardised index value for variable i and W_i represents the weight of the ith variable. C_i represents the factor loading of variable I, whereas X represents the mean indicator value and STD is the standard deviation of the indicator.

On the other hand, the overall intrinsic vulnerability index for each household and district was calculated using equation (5) following Esteves *et al.* (2016), after running CATPCA with 36 indicator variables in 12-dimensional solutions.

$$IVI_j = \left(W_1{*}F_{1j}\right) + \left(W_2{*}F_{2j}\right) + \left(W_3{*}F_{3j}\right) + \left(W_4{*}F_{4j}\right) + \left(W_5{*}F_{5j}\right) + \ldots\ldots + \left(W_{12}{*}F_{12j}\right) \tag{5}$$

where IVI_j represents the intrinsic vulnerability index of household j. W_1, W_2, W_3, W_4, W_5, ..., W_{11} and W_{12} are the weights calculated for components 1, 2, 3, 4, 5, ..., 11 and 12 as mentioned above [equation (2)] and F_{1j}, F_{2j}, F_{3j}, F_{4j}, F_{5j}, . . ., F_{11j} and F_{12j} represent the unit less values/object scores generated for each factor for household j by running CATPCA.

To quantitatively assess the overall vulnerability index, a CATPCA with 36 indicators was run using SPSS 25. Low values representing higher degree of vulnerability for that indicator, while high values imply otherwise (Esteves *et al.*, 2016; Rajesh *et al.*, 2018). The cut-off point was decided following the recommendation by Esteves *et al.* (2016), whereby an intrinsic vulnerability index derived from CATPCA ranging from −1.0361 to −0.13758 indicates very high vulnerability, −0.13759 to 0.126440 high vulnerability, 0.126441 to 0.358895 moderate vulnerability, 0.358895 to 0.495423 low vulnerability, whereas an index value higher than 0.495423 indicates very low vulnerability.

5. Results and discussions

5.1 Adaptive capacity index (factors contributing to low adaptive capacity at district level)

CATPCA was run with seven-dimensional solutions, explaining more than 57.4% of the variation in the dataset, qualifying the tolerable value of explained variance for use in

Table 1. Adaptive capacity indicators and their index scores

Major component	Sub-components	Indicators/variables	Weight scaled to sum unit one	Mean	STDEV	Variable loadings/ scores	Indexed value of the variable
Adaptive capacity	Livestock ownership	Livestock ownership in TLU*	0.092	0.210	0.277	0.835	0.276
		Number of livestock died in TLU for the past 10 years	0.091	0.165	0.295	0.832	0.279
		Number of ploughing animals	0.039	0.079	0.191	0.351	0.077
	Income	Total annual income	0.080	0.217	0.318	0.902	0.236
		Annual farm income	0.059	0.229	0.269	0.667	0.135
		Annual nonfarm income	0.056	0.026	0.318	0.632	0.154
	Social and Institutional capital	Membership in farm cooperatives	0.053	0.109	0.256	0.649	0.154
		Leadership role in social associations	0.053	0.117	0.261	0.644	0.155
		Decision-making role	0.044	0.155	0.196	0.537	0.113
		Membership in Edir	0.040	0.126	0.172	0.484	0.110
		Membership in Ekub	0.030	0.044	0.218	0.365	0.068
	Crop diversification and yield	Annual crop yield	0.072	0.141	0.326	0.878	0.221
		Crop diversification	0.065	0.194	0.273	0.798	0.193
	Age and level of education	Age category	0.051	0.104	0.323	0.814	0.152
		Level of education	−0.025	−0.123	0.132	−0.406	0.068
	Access to agricultural inputs	Improved seed application	0.038	0.176	0.229	0.619	0.107
		Fertiliser application	0.0361	0.124	0.281	0.596	0.088
		Credit access	0.0356	0.104	0.259	0.587	0.093
	Demographic characteristics	Dependency ratio	0.0512	0.108	0.344	0.862	0.154
		Family size	0.0400	0.174	0.266	0.674	0.103

Note: The TLU conversion factors used are as follows: oxen = 1.1, cow = 1.0, heifer = 0.5, calves = 0.2, goats/sheep = 0.1, poultry = 0.01, donkeys = 0.5 and horse/mule = 0.8 (Shiferaw, 1991) subsequent analyses (Terence, 2013; Esteves *et al.*, 2016; Rajesh *et al.*, 2018). Cronbach's alpha of 0.961 indicates that the categorical principal components are internally consistent (Shukla *et al.*, 2016; Rajesh *et al.*, 2018). The rotated component loadings of the seven components extracted with varimax rotation are shown in Appendix 3. The intermediate composite indices were created by grouping variables together with the highest component loadings that are laying under the same dimension. Each of the intermediate composite indices was given a descriptive name as shown in Table 1 which indicates the status of all the adaptive capacity indicators analysed by categorising them according to their index scores using the cut-off points as suggested by Esteves *et al.* (2016) (Section 4.2).

Findings show a low index value of 0.068 related to the educational status of the household head. This suggests that households with the lowest adaptive capacity were particularly those with a lower educated household head. Respondents explained during FGDs that a household head who is not educated cannot read brochures, magazines and newsletters which are made accessible by extension agents to inform farmers about new agricultural innovations and technologies. This may directly impact the productivity of households fuelling their vulnerability to climate-induced shocks. In line with this result, an earlier study conducted by Weir (1999) on the impact of educational status on farm productivity in rural Ethiopia reported that education may enhance farm productivity and efficiency directly by improving the quality of labour. Similarly, a study by Ali *et al.* (2021) found that farmer's knowledge as well as access to information and consultation are the key factors that determine the level of adaptive capacity of households in the Rajshahi district of Bangladesh.

The composite index of adaptive capacity also shows that the number of ploughing animals in north-western Ethiopia contribute fairly highly to the level of vulnerability of households with an index value of 0.077. The average TLU per household was 3.1 which is far below the national average of 4.15 TLU/HH (Ghirotti, 1998). Livestock is an important agricultural input for crop production in Ethiopia with especially oxen and horses being used during ploughing. Therefore, a household with ploughing animals is more likely to perform farming operations more effectively than a household without it. Livestock also have dung from which most smallholder farmers make a dung-cake to generate income. Furthermore, livestock ownership acts as a hedge against food insecurity and serves to accumulate wealth that can be disposed of during times of need. Megersa *et al.* (2014) confirm the result of our study stating that cash income from animal product sales were the major hedging mechanisms at the time of food insecurity in Ethiopia.

The social capital sub-indicator shows that lack of participation in local social and financial institutions like *Edir* [9] and *Ekub* [10] is an important contributing factor to vulnerability with composite index values of 0.110 and 0.068. These types of social capital particularly prove instrumental in helping people surviving the aftermath of a disaster which was also earlier reported in Aldrich *et al.* (2018). The link between social and financial capital in determining the level of women's vulnerability to climate induced shocks is also underscored by one of the female interviewees who explained why she did not join one of the local institutions.

> One of the major reasons that I did not join is because I couldn't afford the monthly contributions paid to Edir and Ekub though I really need to join these associations. I would have been feeling more emotionally secured and protected.

The composite index values of indicators under the sub-category of crop diversification and crop yield (crop diversification with 0.193 and crop yield/productivity with 0.221) show that households with limited accessibility in terms of diversified livelihood options and which are dependent upon lower crop yield/productivity crops tend to have lower adaptive capacities. These findings lend support to an earlier study by Pandey and Jha (2012), who reported that farmers who do not diversify crop and livelihood options have lower adaptive capacities to climate change impacts.

The index values of 0.088 (fertiliser access), 0.107 (improved seed access) and 0.093 (credit access) confirm that households in the study areas generally lack agricultural inputs. Insights from the FGDs highlight that application of improved seeds and fertilisers was low in the three districts because of limited income sources as well as a lack of understanding of the cultivation mechanism. Along the same lines, Tessema (2019) reported that coping capacities of smallholder farmers in Ethiopia are severely hampered by inadequate supply of fertiliser and improved seeds.

5.2 Sensitivity index (factors contributing to higher sensitivity level for climate change at district level)

Following the same procedure as above, the number of components extracted for sensitivity index were 12 based on the results obtained from Kaiser's eigenvalue rule after running the maximum number (16) of dimensions (Appendix 2). On the other hand, the scree plot suggests three dimensions. Because the two criteria used gave conflicting suggestions, the interpretability criterion was used. After inspecting the component loadings, five dimensions were retained to maintain the interpretability of the solutions (Appendix 4). The final solution is accounted for nearly 48.9% of the dataset with a Cronbach's alpha of 0.930.

Table 2 highlights the status of all the sensitivity indicators analysed by categorising them according to their index scores, with low values denoting higher magnitude of sensitivity for that indicator while high values indicating otherwise. Accordingly, intrinsic vulnerability of households is attributed to high sensitivity because of long distance travelled to collect fuelwood with an index of 0.063, farmland productivity (0.046), long distance travelled to fetch drinking water (0.063), frequency of food intake per day (−0.041), food shortage months in a year (0.044), limited access and availability of fuelwood (−0.059) and inaccessibility of farmland to irrigation (0.026).

Findings reveal that distance to fetch water has an index value of 0.063, implying that households in the districts under study generally face water shortage and needed to travel long distance to fetch drinking water. Except for the households close to the *Mena* River, districts are drought-prone with degraded and bare land which further limits access to water for drinking as well as irrigation. During FGDs, most participants from *Misrak (East) Belessa* district expressed that fetching drinking water is mainly women's activity from sources supplied either by water walls or pumps. They also mentioned that when there is shortage, water is fetched from rivers by traveling up to four hours (for going and coming) starting early morning which is actually longer than the maximum distance standard of 1.5 km specified by the Ministry of Water, Irrigation and Electricity (Demie *et al.*, 2016). It has also been acknowledged that policies addressing socio-economic issues such as lack of access to water can significantly decrease households' intrinsic vulnerability (Rajesh *et al.*, 2014). One of the female interviewees in her 50s reported that:

Collecting water from a distant is impacting my daughter's academic calibre. She goes to water sources early morning and then to school late. Sometimes, she may not enter to classes or get punished. When my husband heard this situation there might be some quarrelling with him by saying why you send the girl for water while you are in your kitchen. He doesn't understand my responsibilities in the kitchen, and he doesn't help us even at times when he gets free.

Table 2. Sensitivity indicators and their index scores

Contributing factors	Major components	Indicators	Weight scaled to sum Unit 1	Mean	STDEV	Variable loadings/ scores	Indexed value of the variable
Sensitivity	Basic Infrastructure	Distance to the nearest input/output market	0.131	0.187	0.417	0.933	0.234
		Distance to the nearest health centre	0.130	0.189	0.415	0.931	0.233
	Food	Food stock reserve	0.068	0.161	0.309	0.679	0.115
		Sufficiency of Crops harvested	0.063	−0.219	0.250	−0.647	−0.108
		Seed reserve	0.052	0.008	0.325	0.586	0.092
		Frequency of food intake per day	0.029	−0.028	0.295	−0.441	−0.041
		Number of months with food shortage in a year	0.029	0.101	0.218	0.438	0.044
	Water	Access to river water	0.087	0.189	0.319	0.759	0.155
		Access to piped water	0.082	0.142	0.349	0.736	0.139
		Distance to the nearest water source	0.040	0.022	0.315	0.515	0.063
	Forest and/energy	Distance to the nearest fuel wood source	0.064	0.163	0.287	0.653	0.110
		Improved cooking stoves	0.051	0.100	0.290	0.584	0.086
		Availability of fuel wood	0.040	−0.040	0.323	−0.518	−0.059
	Land	Location of farmland to potential hazards	0.088	0.223	0.313	0.763	0.151
		Farmland productivity	0.027	−0.058	0.280	0.423	0.046
		Irrigated land in *kada*	0.019	0.021	0.242	0.353	0.026

Location of farmland and its productivity are generally considered important indicators of sensitivity (Antwi-Agyei *et al.*, 2015; Huong *et al.*, 2019; Wiebe, 2003). Earlier studies (Deressa, 2010) pointed out that, in Ethiopia, farmers' high level of sensitivity to climate shocks may to a large extent be attributed to the poor irrigation potential. Our own empirical findings suggest that many households lacked farmland that is potentially irrigable which is because the areas under study are frequently affected by drought, whereas also the mountainous topography makes irrigation difficult. Households in Northwest Ethiopia are also sensitive to food supply shocks as can be seen from Table 2. The substantial gap between food supply and demand is mainly attributed to the low performance of the agricultural sector which is to a large extent because of recurrent droughts that have affected Northwest Ethiopia for many years (Dercon and Hoddinott, 2005).

It is assumed that households who are only depending on forest-based energy for cooking and lighting purpose are more sensitive to climate extremes. The same result has been reported by Yadava and Sinha (2020), revealing that access to energy sources transforms households' livelihood from traditional to modern which ultimately leads to an enhanced coping capacity of households when faced with climate extremes.

Finally, households (and particularly women) in the study area are also highly sensitive in terms of the long distance they have to travel to collect fuelwood and limited access to and availability of fuelwood. The village mapping exercise conducted in *East Belessa* by women belonging to female headed households, mapped the fuelwood sources they are using. One of the participants in her 40s stated:

> In our home, it's me and two of my daughters responsible to go collect fuelwood when we need it travelling nearly three to four hours by waking up early morning. But two of my sons will wake up in the morning to go collect animal feeds for the cattle to eat and at night they are supposed to bring the cattle back to home when cattle are left on fields.

This is in line with a study by Gebru and Bezu (2013) in northern parts of Ethiopia who showed that women and children on average spent 7 h on the collection of fuelwoods as a result of its scarcity because of climate change and deforestation.

5.3 Overall intrinsic vulnerability at district and household levels

The final composite index of intrinsic vulnerability was calculated by aggregating the two domains (i.e. sensitivity and adaptive capacity). The results of CATPCA generated object scores for all the households were combined with final weights assigned to each of the indicators [equation (5)] to obtain a standardised index for each household. A household with a lower standardised intrinsic vulnerability index is relatively more vulnerable compared to a household with a higher standardised intrinsic vulnerability index value (Esteves *et al.*, 2016; Rajesh *et al.*, 2018). To identify the distribution of intrinsic vulnerability in the households, the households were divided into five categories based on their standardised intrinsic vulnerability index scores following Esteves *et al.* (2016) (Figure 2).

The results shown in Figure 2 indicate that *Misrak (East) Belessa*/lowland agro-climatic zone had 30.03% and 25.07% of the households in the very high and high vulnerability categories followed by *Dabat*/highland agro-climatic zone with 28.91% and 23.47% of the households in the very high and high vulnerability categories, respectively. On the other hand, *Mirab (West) Belessa*/midland agro-climatic zone had nearly 19.07% and 21.65% of the households in the very high and high vulnerability categories, respectively. The highest vulnerability of the households in *Misrak Belessa* is mainly associated with lower levels of development characterised by low farmland productivity, low literacy rates, poor access to water (for irrigation) and severe food shortages. The results are consistent with Teshome

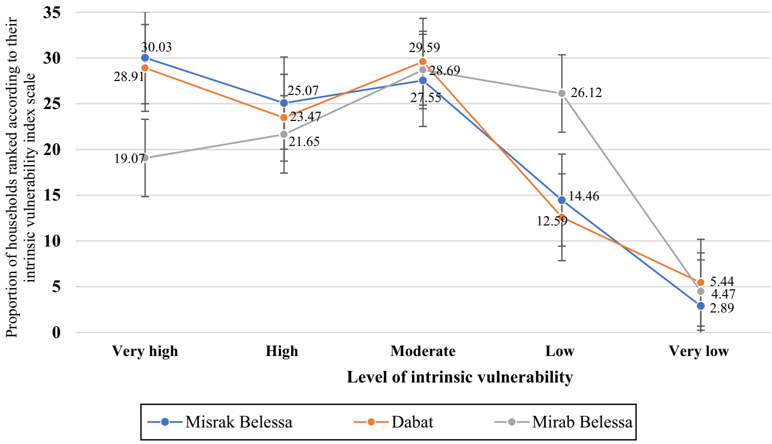

Figure 2.
Level of intrinsic vulnerability of households

(2016) who observed that farmers in the lowland agro-climatic zone were more vulnerable to the effects of climate-induced shocks compared to those in the highland and midland agro-climatic zone. On the other hand, Tesso *et al.* (2012) revealed that households in the highland agro-climatic zone were found to be more vulnerable to climate extremes and risks because of land degradation and less experience in adaptation. The lower vulnerability of the midland agro-climatic zone (as compared to the low and highland zones) was also reported in Simane *et al.* (2016).

In terms of overall vulnerability, our findings show that the majority of households fall within the very high to moderately high vulnerable category with 78.01% households having an index ranging from −1.0361 to 0.358895. The less vulnerable households (i.e. low to very low categories) had an index of 0.358896–2.3228 and constitute 21.99%. The findings further indicate that *Misrak Belessa*/lowland agro-climatic zone had 82.64% of the households in the very high to moderately high vulnerability category followed by *Dabat*/highland agro-climatic zone with 81.97% of the households, while in *Mirab Belessa*/midland, about 69.4% of the households are classified in the very high to moderately high vulnerable categories.

6. Conclusions and policy implications

Our study assesses socio-economic vulnerability and the major drives that influence climate change vulnerability of a particular household and district. In terms of overall vulnerability, our finding shows that the majority of households fall within the very high to moderately high vulnerable category. The findings further indicate that *Misrak Belessa*/lowland agro-climatic zone had the highest proportion of households in the very high to moderately high vulnerability category followed by *Dabat*/highland agro-climatic zone, while in *Mirab Belessa*/midland, a relatively lower proportion of the households are classified in the very high to moderately high vulnerable categories. According to this study adaptive capacity indicators related to educational status, livestock ownership, number of ploughing animals, level of participation in local social and financial institutions (like *Edir* and *Ekub)*, long distance to fetch water, access to agricultural inputs and extent of livelihood and crop diversification are the major drivers of socio-economic vulnerability in Northwest Ethiopia. In terms of sensitivity indicators, intrinsic vulnerability of the households in the three districts is attributed to high sensitivity because of long distance travelled to collect fuelwood, small and fragmented farmland size, long distance travelled to fetch drinking water, drinking water shortage, limited access to climate information, food shortage months in a year, limited access to market and inaccessibility of farmland to irrigation.

Drawing upon our study findings, resilience interventions in our research setting should target specific districts and particular households within the communities. Interventions including provision of basic facilities such as water, alternative sources of energy other than fuelwood, good market facilities and access to credit facilities and agricultural extension services will increase adaptive capacity to climate-induced shocks. Our study contributes to the existing vulnerability literature by showing how hazard-generic socio-economic indicators in the vulnerability assessment adopted by the IPCC (2014) are important to identify drives of vulnerability which ultimately may feed into a more fundamental treatment of vulnerability. From a policy intervention vantage point, addressing the drivers of vulnerability provides a reliable approach to reduce the current vulnerability level and manage potential climate change-induced risks of a system. Aside from that, the intrinsic vulnerability analysis could be used as a feasible framework to identify the most vulnerable groups of households, identify factors that lead households to be more vulnerability and prioritise realistic adaptation strategies relevant to the specific setting. Even though the findings of this study are confined to the climate-induced vulnerable areas in Northwest Ethiopia, the methodological framework and results may be applicable to other developing countries with similar socio-economic and environmental conditions elsewhere. Our study also opens doors for experimenting with multiple indicators and weighing them on different statistical parameters for different regions at a micro-scale (e.g. block level).

Notes

1. Intrinsic vulnerability is the predisposition of a community/system to suffer harm which is shaped by the inherent socio-economic and livelihood characteristics of a household (Rajesh *et al.*, 2014).
2. This study is part of a broader research project on gender and climate change funded by *deleted for blind review*.
3. Kaiser's rule is criteria based on the eigenvalue of each principal component which indicates the percentage of explained variation in the dataset. All principal components with a value greater than one are retained (Dalton-Greyling and Tregenna, 2014).
4. Scree plot rule is simply a graph which plots the eigenvalues against each principal component and the decision criteria to decide on the number of dimensions that should be retained by looking at the shape of the scree plot curve where the changes in direction become sharp (Dalton-Greyling and Tregenna, 2014).
5. Interpretability is a decision criteria to use as an option if Kaiser's eigenvalue rule and the scree's plot guideline do not have the same results on the number of components to be retained. According to Meulman *et al.* (2007), the number of extracted components should be interpretable.
6. Varimax is an iteration made to condense the number of variables with high loading on one dimension (Rajesh *et al.*, 2018).
7. KMO measures the sampling adequacy of the data (Dharmaratne and Attygalle, 2018).
8. Annexes are added as supplementary material.
9. Edir/Iddir is an indigenous financial and social institution or cultural cooperative in Ethiopia that offers mutual aid and financial assistance for those group members who need support (Aredo, 1993).

10. Ekub is a form of capital formation where community members gather and contribute a fixed amount of money to be paid weekly or monthly to a pool which is then rotated among the members until all get paid (Jembere, 2009).

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Appendix 1

Table A1. Model summary rotation[a] (total variance explained by each dimension of adaptive capacity indicators)

Dimension	Cronbach's alpha	Variance accounted for Total (Eigenvalue)	% of variance
1	0.643	1.925	9.626
2	0.609	1.600	7.999
3	0.249	1.109	5.546
4	0.360	1.021	5.103
5	0.142	1.006	5.029
6	0.223	1.006	5.028
7	0.185	1.004	5.019
8	0.255	1.004	5.018
9	0.273	1.003	5.013
10	0.088	1.002	5.012
11	0.252	1.002	5.012
12	0.103	1.002	5.010
13	0.048	1.002	5.009
14	0.151	1.001	5.007
15	0.105	1.001	5.004
16	0.286	1.000	4.999
17	0.296	0.998	4.991
18	0.444	0.959	4.793
19	0.049	0.325	1.626
20	−6.518	0.031	0.155
Total	1.000[b]	20.000	100.000

Notes: [a]Rotation method: Varimax with Kaiser normalisation; [b]Total Cronbach's alpha is based on the total eigenvalue

Appendix 2

Table A2. Model summary rotation[a] (total variance explained by each component of sensitivity) indicators

Dimension	Cronbach's alpha	Variance accounted for Total (Eigenvalue)	% of variance
1	0.494	1.797	11.230
2	0.058	1.002	6.261
3	0.146	1.001	6.258
4	0.069	1.001	6.257
5	0.081	1.001	6.257
6	0.070	1.001	6.255
7	0.161	1.001	6.255
8	0.040	1.001	6.253
9	0.134	1.000	6.252
10	0.015	1.000	6.252
11	0.148	1.000	6.250
12	0.065	1.000	6.249
13	0.147	0.999	6.245
14	0.262	0.996	6.226
15	0.272	0.994	6.215
16	−4.048	0.206	1.284
Total	1.000[b]	16.000	100.000

Notes: [a]Rotation method: Varimax with Kaiser normalisation; [b]Total Cronbach's alpha is based on the total eigenvalue

Appendix 3

Table A3. Rotated component loadings[a] (adaptive capacity indicators)

Variables	Extracted dimensions 1	2	3	4	5	6	7	Matrix of squared factor loadings 1	2	3	4	5	6	7
Livestock ownership in TLU	*0.835*	0.105	0.156	0.134	0.087	0.075	0.082	*0.301*	0.000	0.000	0.000	0.000	0.000	0.000
Number of ploughing animals	*0.832*	0.048	0.066	0.094	0.029	0.075	0.010	*0.298*	0.000	0.000	0.000	0.000	0.000	0.000
Number of livestock died in TLU for the past 10 years	*0.351*	0.010	0.056	−0.238	0.270	0.061	0.041	*0.053*	0.000	0.000	0.000	0.000	0.000	0.000
Total annual income	0.271	*0.902*	0.114	0.191	0.038	0.005	0.000	0.000	*0.213*	0.000	0.000	0.000	0.000	0.000
Annual farm income	0.510	*0.667*	0.123	0.274	0.044	−0.046	0.031	0.000	*0.244*	0.000	0.000	0.000	0.000	0.000
Annual nonfarm income	−0.420	*0.632*	0.026	−0.127	0.003	0.119	−0.052	0.000	*0.240*	0.000	0.000	0.000	0.000	0.000
Membership in farm cooperatives	0.171	−0.115	*0.649*	0.066	−0.066	0.004	0.050	0.000	0.000	*0.167*	0.000	0.000	0.000	0.000
Membership in Edir	0.139	0.047	*0.644*	−0.013	0.054	−0.203	0.148	0.000	0.000	*0.135*	0.000	0.000	0.000	0.000
Decision making role	0.045	0.207	*0.537*	0.034	0.060	0.241	−0.039	0.000	0.000	*0.077*	0.000	0.000	0.000	0.000
Leadership role in social associations	−0.011	0.049	*0.484*	0.090	0.197	0.076	0.001	0.000	0.000	*0.449*	0.000	0.000	0.000	0.000
Membership in Senbete	−0.117	0.246	*0.365*	−0.228	−0.069	0.175	−0.063	0.000	0.000	*0.371*	0.000	0.000	0.000	0.000
Crop diversification	0.016	0.034	0.031	*0.878*	−0.031	0.036	0.023	0.000	0.000	0.000	*0.507*	0.000	0.000	0.000
Annual crop yield	0.178	0.139	0.106	*0.798*	0.088	0.064	−0.014	0.000	0.000	0.000	*0.126*	0.000	0.000	0.000
Age category	0.052	−0.136	0.094	0.021	*0.814*	−0.066	−0.051	0.000	0.000	0.000	0.000	*0.529*	0.000	0.000
Level of education	−0.050	−0.144	−0.059	−0.038	*−0.406*	−0.129	−0.035	0.000	0.000	0.000	0.000	*0.419*	0.000	0.000
Improved seed application	0.061	0.072	0.344	0.126	0.054	*0.619*	−0.046	0.000	0.000	0.000	0.000	0.000	*0.300*	0.000
Fertiliser application	0.404	−0.060	0.064	0.075	−0.225	*0.596*	0.015	0.000	0.000	0.000	0.000	0.000	*0.279*	0.000
Credit access	−0.056	0.056	−0.155	−0.081	0.304	*0.587*	0.074	0.000	0.000	0.000	0.000	0.000	*0.270*	0.000
Dependency ratio	−0.015	0.036	0.067	−0.014	−0.203	0.019	*0.862*	0.000	0.000	0.000	0.000	0.000	0.000	*0.594*
Family size	0.156	−0.085	0.046	0.032	0.381	0.011	*0.674*	0.000	0.000	0.000	0.000	0.000	0.000	*0.363*

Notes: Variable principal normalisation. [a]Rotation method: Varimax with Kaiser normalisation

Appendix 4

Table A4. Rotated component loadings[a] used in the calculations to weight the composite index of sensitivity

Variables	Extracted dimensions 1	2	3	4	5	Matrix of squared factor loadings 1	2	3	4	5
Distance to the nearest market	*0.933*	0.019	−0.006	0.016	−0.025	*0.453*	0.000	0.000	0.000	0.000
Distance to the nearest health centre	*0.931*	0.018	0.025	−0.01	−0.02	*0.451*	0.000	0.000	0.000	0.000
Food stock reserve	0.083	*0.679*	0.003	0.167	−0.126	0.000	*0.246*	0.000	0.000	0.000
Sufficiency of crops harvested	−0.151	*−0.647*	−0.098	−0.201	−0.001	0.000	*0.226*	0.000	0.000	0.000
Seed reserve	−0.123	*0.586*	−0.105	−0.192	−0.122	0.000	*0.186*	0.000	0.000	0.000
Frequency of food intake per day	−0.057	*−0.441*	−0.152	0.271	0.239	0.000	*0.105*	0.000	0.000	0.000
Number of months with aid/year	−0.069	*0.438*	−0.01	−0.058	0.206	0.000	*0.104*	0.000	0.000	0.000
Access to river water	0.013	0.063	*0.759*	0.044	0.066	0.000	0.000	*0.390*	0.000	0.000
Access to pipped water	0.134	−0.029	*0.736*	−0.164	0.031	0.000	0.000	*0.367*	0.000	0.000
Number of months with water shortage in a year	−0.192	0.01	*0.515*	0.08	−0.303	0.000	0.000	*0.180*	0.000	0.000
Distance to the nearest fuelwood source	−0.039	0.163	−0.038	*0.653*	0.076	0.000	0.000	0.000	*0.326*	0.000
Improved cooking stoves	0.013	−0.202	0.052	*0.584*	0.051	0.000	0.000	0.000	*0.261*	0.000
Availability of Fuelwood	−0.056	−0.088	0.089	*−0.518*	0.372	0.000	0.000	0.000	*0.205*	0.000
Location of farmland to potential hazards	−0.028	0.151	0.048	0.181	*0.763*	0.000	0.000	0.000	0.000	*0.462*
Productivity of farmland	−0.211	−0.265	−0.186	−0.05	*0.423*					*0.142*
Distance to the nearest fuelwood	0.166	−0.256	−0.019	−0.138	*0.353*	0.000	0.000	0.000	0.000	*0.100*

Notes: Variable principal normalisation; [a]Rotation method: Varimax with Kaiser normalisation

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