Household Vulnerability to Climate Change and Identification of Target Beneficiaries to Implement Household-Specific Adaptation Strategies: A Quantitative Assessment

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ABSTRACT

This study investigated the climate change vulnerability of 6,214 households in the drought-prone districts of Telangana state in India. Principal component analysis (PCA) and cluster analysis were used to group farm households based on their level of vulnerability to climate change and to suggest a portfolio of adaptation strategies. The PCA revealed the presence of five components from 14 key variables: (1) access to irrigation; (2) credit access, landholding, and income from agriculture; (3) household size and income sources; (4) access to information and climate-smart adaptation practices; and (5) social capital. The first five components (eigenvalue ≥ 1) collectively accounted for 60.42 percent of the total variance. Three clusters emerged after the component scores were analyzed using K-means clustering: extremely vulnerable, moderately vulnerable, and resilient households. The results of the cluster analysis revealed that 79 percent of the households were extremely vulnerable, 11.20 percent were moderately vulnerable, and 9.65 percent were resilient. Moreover, 96 percent of marginal farmers and 94 percent of smallholder farmers were extremely vulnerable, while 19 percent of large farmers and 16 percent of medium farmers were moderately vulnerable. Interestingly, nearly 26 percent in the extremely vulnerable category and 19 percent in the moderately vulnerable category were large farmers, which contradicts previous assumptions. The findings of this study can guide development practitioners, policymakers, and donors in designing evidence-based programs focusing on households vulnerable to climate change.

Keywords: household vulnerability, climate change, principal component analysis, cluster analysis, Telangana, India

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INTRODUCTION

Globally, agriculture faces the emerging challenges of climate change and increased climate variability (IPCC 2014). Managing climate-related risks is a prime concern in the context of semi-arid tropics (Kadiyala et al. 2021). Identifying location-specific adaptation strategies are needed to advance investments that support communities that are at risk due to climate variability (Kelly et al. 2014; Porter et al. 2014; Wiebe et al. 2015). A considerable proportion of the global population is comprised of smallholder farmers. It is estimated that 450–500 million smallholder farmers account for 85 percent of the world's farms (Nagayets 2005). Smallholder farmers across the tropics face numerous challenges while farming, including extreme weather events, pest and disease outbreaks, and market shocks. These challenges often put their livelihoods at risk, causing food and income insecurity (O'Brien et al. 2004; Morton 2007). Since smallholder farmers rely on agriculture, they have limited capacity to cope with shocks. Any change that reduces productivity can have adverse impacts on their lives (Hertel and Rosch 2010; McDowell and Hess 2012). Climate change affects smallholder farmers by further aggravating the risks they face. Recent studies that used regional and global simulation models show that even a moderate increase in temperature can adversely affect the production of main cereals (rice, wheat, and maize) among smallholder farmers (Morton 2007).

India is an agrarian economy and a large proportion of its population depends on agriculture. Small and marginal farmers with diverse socioeconomic backgrounds who rely on rainfed agriculture have become more vulnerable to climate variability and change (Rao et al. 2016). Climate change factors such as increased temperature, reduced number of rainy days, and water stress have been documented to negatively affect paddy and wheat yields in some parts of India (Rao et al. 2016). It is estimated that by 2030, agricultural loss will exceed USD 7 billion and will affect the incomes of at least 10 percent of the population in India. Appropriate regional strategies and cost-effective climate-resilient measures can reduce the quantum of losses by 80 percent (Rao et al. 2016).

Thus, enhancing agricultural productivity is essential in ensuring the food and nutritional security of small and marginal farmers. Yet, there are variations in the degree of vulnerability to climate change at inter- and intra-regional levels. Vulnerability to climate change depends on a wide range of factors, including the local environment and farming practices (Esperón-Rodríguez, Bonifacio-Bautista, and Barradas 2016). Local biophysical conditions such as soil content and type of crop, and the extent of knowledge and awareness of climatic changes are other key factors. Additionally, the cost of maladaptation due to improper policies is bound to be high (Magnan 2014). Adaptation capacities, strategies, and preferences also vary across scales. Effective and efficient planning of climate change adaptation programs calls for an assessment of local vulnerabilities to gain greater insight into community needs and priorities. Such studies can also guide the formulation of evidence-based policies at the regional or macro level (Burton, Diringer, and Smith 2006; Piya, Maharjan, and Joshi 2012, 2019). Researchers working at the macro level have failed to catch the nuances of smaller areas. Hence, there is a need to explore climate change adaptation at the micro or local level. Even at the local level, it is critical to prioritize aid or policy action for the most marginalized sections of the community. The urgency of promoting local adaptation options alongside global mitigation strategies is gaining ground and is considered an effective way to cope with climate change.

With the above context in mind, this study analyzed household vulnerability to climate change. The analysis was drawn from both quantitative and qualitative data. Data were obtained from the primary field survey and stakeholder consultations. Households in the drought-prone districts of Telangana state in India were classified into different groups or clusters based on their degree of vulnerability to climate change.

MATERIALS AND METHODS

Study Area

Telangana state is located on the Deccan Plateau of the Indian peninsula. It is bordered by Andhra Pradesh to the south and east, Maharastra to the north and northwest, Karnataka to the west, and Chhattisgarh to the northeast. It has a semi-arid climate and is prone to drought conditions, particularly in the districts of Ananthapuramu, Rangareddy, Mahabubnagar, and Nalgonda. The state is divided into three agro-climatic zones: northern Telangana zone, southern Telangana zone, and central Telangana zone. The average annual rainfall in Telangana is 900–1,150 mm, with the southwest monsoon contributing 82 percent of the annual rainfall.

Agriculture accounts for 16 percent of Telangana's gross domestic product, and 55.6 percent of the state's 39 million people depend on agriculture for their livelihoods (Planning Department, Government of Telangana 2020). The major crops grown are paddy, sorghum, sugarcane, pulses, maize, cotton, groundnut, turmeric, and chillies. Red, black, and laterite soils cover 48 percent, 25 percent, and 7 percent of the land area, respectively (Planning Department, Government of Telangana 2020). More than half of the cultivable area is rainfed. Recurring droughts, groundwater depletion, and reduced per capita land availability are major factors for decreased farm income. Increased drought conditions severely affect agricultural livelihoods and augment the vulnerability of and risks for farmers.

Study Design and Data Collection

This study used baseline census data collected in 2016–2017 for the project "Resilient Agricultural Households through Adaptation to Climate Change in Telangana (RAHACT) State," which was funded by the National Adaptation Fund for Climate Change. The surveyed districts were Mahabubnagar, Wanaparthy, and Nagarkurnool, from which 22 villages were selected randomly. The three districts have experienced frequent droughts in recent years, and the villages were selected based on their vulnerability to climate change. Figure 1 illustrates the location of the surveyed districts.

A structured tab-based questionnaire was developed and pilot tested. Local field enumerators were selected and trained for the tab-based field survey. In the 22 villages, face-to-face interviews were conducted among 6,214 household heads, of which 89.5 percent were male and 10.5 percent were female. The face-to-face interviews helped identify the beneficiaries of climate-smart agriculture interventions. Detailed data were collected on demographics; socioeconomics; land ownership, including the type of land; asset ownership, including both durable and non-durable assets; the value of assets owned; livestock ownership; sources of irrigation; cultivation practices such as changes in cropping pattern; sources of income; major climatic constraints faced; and current climate-smart adaptation practices. The socioeconomic, demographic, and biophysical data and institutional characteristics of the study setting were also taken into account. Table 1 describes the variables used in the analysis.

A stakeholders' workshop was organized to identify a portfolio of climate change adaptation strategies in different households based on their household characteristics. Stakeholders who participated in the workshop were officials from the Department of Agriculture, Government of Telangana; farmers' representatives; and scientists from the Professor Jayashankar Telangana State Agricultural University; the International Crops Research Institute for the Semi-Arid Tropics; and the Environment Protection Training and Research Institute, a premier agency in India that provides training, consultancy, and applied research services and extends advocacy in the area of environment protection and climate change adaptation.

Vulnerability Assessment

Climate change vulnerability is "the degree to which a system is susceptible to, and unable to cope

Figure 1. Location of surveyed districts (Mahabubnagar, Wanaparthy, and Nagarkurnool) in Telangana, India

with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and the variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC 2007). Vulnerability is seen as a prerequisite for the development of appropriate adaptation strategies and policies. Vulnerability assessments have been used to investigate the complex set of interactions between humans and their socio-physical environments (Hahn, Riederer, and Foster 2009; Panthi et al. 2016; Adu et al. 2018). They capture both natural and socioeconomic processes that lead to vulnerability by measuring the appropriate variables at the appropriate scale, with a suitable conceptual framework. Context-specific measurements that account for the livelihood conditions of the target population is considered effective. Vulnerability assessments and scale are entwined, not only in technical application but also in conceptualization (Fekete, Damm, and Birkmann 2010).Vulnerability assessments have two components: (a) identifying who is at risk of climatic and environmental changes and (b) prioritizing needs. Many scholars have used vulnerability assessments in different contexts (Deressa, Hassan, and Ringler 2009; Fellmann 2012; Shah et al. 2013; Aryal, Cockfield, and Maraseni 2014; Panthi et al. 2016). Yet, the vagueness of the concepts of vulnerability and

Table 1. Description of variables used in the principal component analysis

Serial No.	Variable	Definition
1	Agriculture income	Income obtained from agricultural wages and crop income in Indian rupees
2	Livestock income	Income from livestock products in Indian rupees
3	Household size	Number of household members
4	Literacy	Number of years of education of household head
5	Age	Age of the household head
6	Social network	Number of social networks the household head is a part of and/or holds an important position in
7	Climate-smart adaptation practices	Number of climate-smart adaptation practices adopted by the household
8	Irrigation	Number of sources of irrigation to which the household has access
9	Pr_ir	The proportion of operational land under irrigation
10	Pr_rf	The proportion of operational land that is rainfed
11	Climate info	Access of household to short- and long-term climate information
12	Sources of income	Number of sources of income of the household
13	Operational holding	Size of operational holding of the household
14	Formal fin	Access to formal finance
15	Informal fin	Access to informal finance

capacity to adapt to climate change is not only recognized but often criticized in the literature (Janssen and Ostrom 2006; Hinkel 2011).

The unequal distribution of vulnerability within a community results from the interplay of various socioeconomic processes. To develop effective strategies, it is essential to understand the processes and specific factors that alter the impact of climate change. While most recent work on the subject has explored the vulnerability of communities, it has not generated enough attention and knowledge about the vulnerability at smaller scales, that is, individuals and households. Such knowledge will enable the development of targeted solutions and strategies. It will enhance the opportunity to mitigate and increase future social capacity and resilience effectively.

Economic vulnerability is seen as the susceptibility to loss of economic assets and productivity. This includes the loss of livelihoods such as asset support, wealth, and economic independence, along with financial deprivation, debt dependence, and the inability to recover from losses. There are lacunae in empirical evidence on the characteristics of communities dependent on agriculture that were either resilient or vulnerable to climate-related problems in the past at the household and community levels. It is important to build empirical evidence to increase knowledge of how communities confront the impacts of climate-related problems. Such evidence provides useful insights into the structure and drivers of vulnerability (Eakin and Bojorquez-Tapia 2008).

There are many methods of analyzing vulnerability to climate change. The most common methods employed are the econometric and indicator methods. The econometric method is deeply rooted in poverty and development literature and falls into three categories: (1) vulnerability as expected poverty, (2) vulnerability as low expected utility, and (3) vulnerability as uninsured exposure to risk. All three share common characteristics, that is, they construct a measure of welfare loss attributed to shocks. The indicator method of quantifying vulnerability selects some indicators from a set of potential indicators. It combines them methodically to point out the levels of vulnerability. In this method, two approaches have been used in literature: (1) assigning an equal weight to all indicators of vulnerability and (2) assigning different weights to indicators based on expert judgment, PCA, or fuzzy logic.

This study employed PCA, a widely used data dimension reduction technique to identify the variables that explain the maximum variability in the data. The results from the PCA were used to classify households into different vulnerability groups using hierarchical agglomerative cluster analysis. This was done to identify and categorize them in the drought-prone Mahabubnagar district of Telangana.

Principal Component Analysis (PCA)

PCA is often used as a pre-processing step before clustering. It requires a minimum of 50 observations for adequate performance (Hair et al. 2009). This study used PCA because of its relative ease in identifying relationships between variables and the components or factors to be retained. PCA was used to extract components, while the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of sphericity were applied to measure the correlation between variables. Variables with a lower communality ($h<0.475$) were not considered in the PCA because they were not sufficiently correlated with the new factors received. The factors corresponding to eigenvalues ≥1 were selected to gain a better understanding of the components or factors received.

An orthogonal rotation was carried out using the Varimax rotation method. PCA with the Varimax rotation method revealed the presence of five components or factors. Bartlett's test of sphericity ($p=0.001$) and the $KMO=0.71$ indicated that the variables included in the analysis were correlated with each other. The components were selected based on the eigenvalue (≥1) criterion, as well as the cumulative variance explained by the factors taken together. Based on the eigenvalues, the first five components, which collectively accounted for 60.42 percent of the variance in the data, were retained (Appendix 1). Of the total 14 variables, only 10 correlated and loaded into specific components or factors. Table 2 presents the rotated component matrix using the component loadings. The variables were grouped into their respective factors and renamed according to their collective representation: (1) access to irrigation; (2) credit access, landholding, and income from agriculture; (3) household size and income sources; (4) access to information and climate-smart adaptation practices; and (5) social capital.

The regression method estimated factor scores, which were saved as new variables to be used as inputs in the cluster analysis (Hair et al. 2009). Table 2 shows the results of the component or factor analysis.

Design Issues in Cluster Analysis

Research design issues in cluster analysis include the detecting outliers, obtaining adequate sample size, selecting similar measures, and standardizing data (Hair et al. 2009; Nandi et al. 2015). Addressing these issues will make the analysis more robust. A minimum of 100 observations is considered sufficient to perform segmentation using cluster analysis. The sample size of 6,214 households is considered excellent in terms of drawing valid conclusions (Hair et al. 2009). In this study, squared Euclidean distance measures were used as measures of distance.

The five components identified in the PCA were used as inputs to perform cluster analysis (Hair et al. 2009). This was to verify the existence of homogenous groups and classify households into different vulnerability groups (clusters) based on the varying propensities toward climate change. The detailed analysis revealed that the households were grouped into three clusters. The component scores were analyzed using K-means clustering.

RESULTS AND DISCUSSION

Table 3 presents the classification of cluster households. The households were classified into three vulnerability groups (clusters) based on the varying propensities toward climate change.

Table 2. The rotated component matrix: Variables of households toward climate change resilience

Variables	Components or Factors					
	Access to Irrigation	Credit Access, Landholding, and Income from Agriculture	Household Size and Income Sources	Access to Information and Climate-smart Adaptation Practices	Social Capital	Com*
Sources of irrigation	0.865					0.800
Proportion of area under irrigation	0.966					0.935
Agricultural income		0.670				0.576
Access to formal credit		0.602				0.735
Access to informal credit		0.475				0.311
Operational landholding		0.801				0.653
Household size			0.656			0.489
Sources of income			0.774			0.630
Climate-smart adaptation practices				0.748		0.621
Climate information				0.814		0.671
Social network					0.806	0.693
Eigenvalue	2.79	2.10	1.40	1.11	1.04	
Variance %	19.95	15.05	10.00	8.00	7.42	
Total variance %	**19.95**	**35**	**45**	**53**	**60.42**	

Extraction method: PCA. Rotation method: Varimax with Kaiser normalization. Bartlett's test of sphericity = 0.001 and the KMO = 0.71.
* Communalities are estimates of the variance in an individual variable accounted for the factors in the factor solution.

Among the farmer categories, 32.59 percent were medium, 32.7 percent were semi-medium, 17.86 percent were small, 9.74 percent were marginal, and 7.11 percent were large farm households. Clusters 1, 2, and 3 constituted 79 percent, 11.2 percent, and 9.65 percent of the total households, respectively. These three clusters were classified as extremely vulnerable, moderately vulnerable, and resilient households based on the relative response of factor scores, as mentioned in Table 4.

Extremely Vulnerable Category (Cluster 1)

Households in Cluster 1 comprised 96 percent of marginal, 94 percent of small, 87 percent of semi-medium, 69 percent of medium, and 26 percent of large farm households (Table 3). These households had the least access to irrigation, credit facilities, and climate information; had a smaller household size and fewer income sources; and had adopted the fewest climate-smart adaptation practices. In this category, the proportion of irrigated area to the total landholding was low. Moreover, households in Cluster 1 had a smaller social network compared to resilient and moderately resilient household groups (Figure 2).

Moderately Vulnerable Category (Cluster 2)

Households in Cluster 2 comprised 19 percent of large, 16 percent of medium, 10 percent of semi-medium, 6 percent of small, and 4 percent of marginal farm households (Table 3). Compared to the extremely vulnerable households, the moderately vulnerable households had more access to irrigation and formal and informal credit, and higher landholding and income sources. However, these households had a smaller social network and lower access to climate information and had adopted fewer climate-smart adaptation practices compared to the extremely vulnerable households.

Table 3. Classification of cluster households by farmer category based on the operated area

Farmer Category1	Total	Extremely Vulnerable (%)	Moderately Vulnerable (%)	Resilient Households (%)	%
		Cluster 1	Cluster 2	Cluster 3	Cumulative
Large	442	26 (117)	19 (83)	55 (242)	100
Medium	2,025	69 (1,405)	16 (323)	15 (297)	100
Semi-medium	2,032	87 (1,775)	10 (202)	03 (55)	100
Small	1,110	94 (1,039)	06 (65)	00	100
Marginal	605	96 (581)	04 (24)	00	100
Total	**6,214**	**4,917**	**697**	**600**	**6,214**

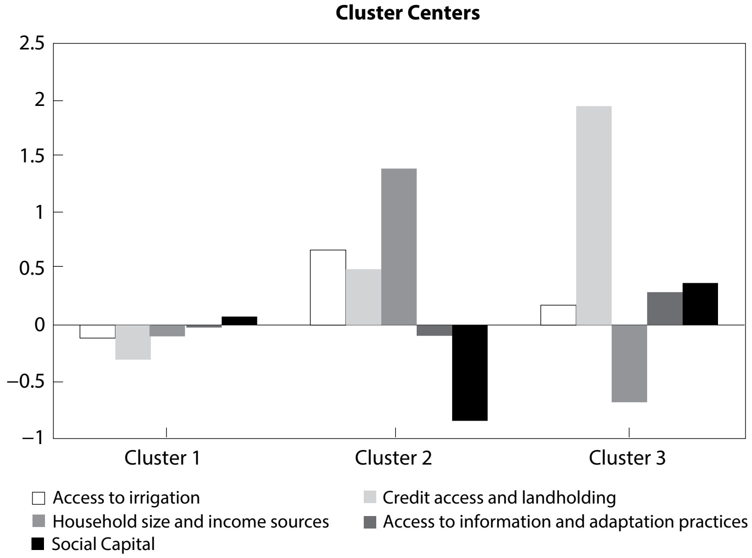
Note: [1]Farmer categories: Marginal – below 1 ha of operated area; Small – between 1.1 and 2 ha; Semi-medium – between 2.1 and 4 ha; Medium – between 4.1 and 10 ha; and Large – 10 ha and above (DA&FW, GoI 2011)
Source: Authors' compilation based on cluster membership during k-means cluster analysis. Figures in parentheses are the number of households

Table 4. Characterization of individual clusters based on component scores

Components	Cluster 1 (79%)	Cluster 2 (11.2%)	Cluster 3 (9.65%)	F	p-value
Access to irrigation	–0.11598	0.66604	0.17671	210.310	0.000
Credit access, landholding, and income from agriculture	–0.30740	0.49573	1.94324	2721.196	0.000
Household size and income sources	–0.11327	1.38913	–0.68545	1160.336	0.000
Access to information and climate-smart adaptation practices	–0.02209	–0.09560	0.29207	30.259	0.000
Social capital	0.07503	–0.85050	0.37313	341.413	0.000

Note: The cluster descriptors are based on component/factor scores. ANOVA with Tukey post hoc multiple-comparison test was used.

Figure 2. Cluster centers based on component/factor scores



Source: Authors' compilation

Resilient Households (Cluster 3)

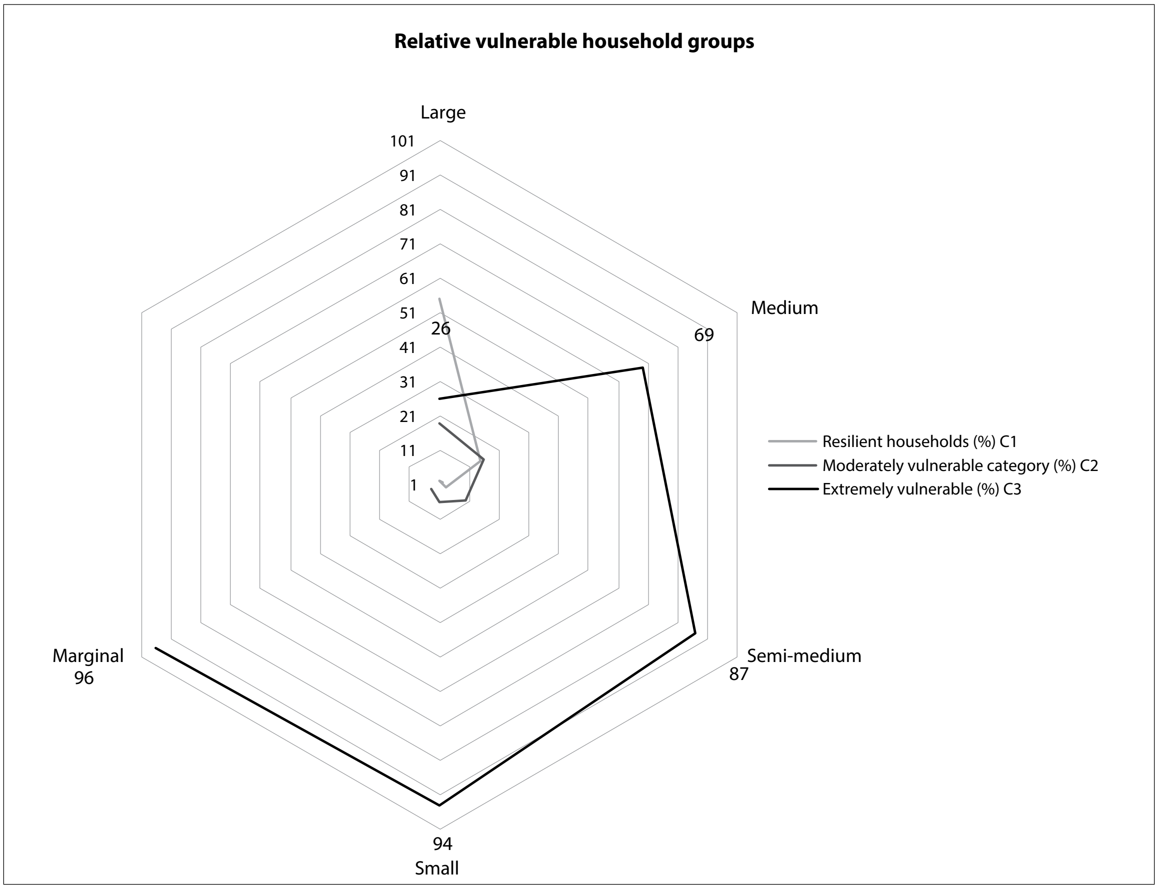
Households in Cluster 3 comprised 55 percent of large, 15 percent of medium, and 3 percent of semi-medium farm households. Cluster 3 was the most affluent group of households in the total sample. Compared to the extremely vulnerable and moderately vulnerable households, the resilient households had the largest landholdings, greatest access to formal and informal credit, and highest number of irrigation sources. Moreover, these households had a very large social network and more access to climate information and had adopted more climate-smart adaptation practices. However, households in Cluster 3 had a smaller household size and fewer income sources.

Figure 3 illustrates the relative vulnerability of households in the surveyed districts.

Adaptation and Resilience of Drought-Prone Households

From the results presented in Table 2, it can be observed that the first principal component, "access to irrigation", comprises two variables: sources of irrigation and proportion of area under irrigation. This component accounted for 19.95 percent of the total variance after Varimax rotation. This is described as a household's access to different types of irrigation sources, such as borewells, tanks, canals, and dug wells, and the percentage of irrigated land out of the total landholding per household. A household's access to different sources of irrigation and area under irrigation plays an important role in its income and vulnerability to climate change.

Figure 3. Comparison of households based on the degree of vulnerability to climate change



Farmers with access to irrigation can produce crops throughout the year and maintain food security. Thus, households with access to irrigation facilities are less vulnerable to changing rainfall patterns. Conversely, smallholder farmers who depend solely on rainfed agriculture are the most vulnerable to climate change. Harvey et al. (2014) found that improved irrigation facilities can help farmers augment production and bolster their protection against food insecurity due to climate risks. Access to inputs such as irrigation facilities and fertilizers can strengthen agricultural productivity and reduce the risk of climate change (Gbetibouo 2009; Minten, Randrianarisoa, and Barrett 2007).

The second component, "credit access, landholding, and income from agriculture", comprises four variables: access to formal credit, access to informal credit, size of the operational holding, and agricultural income. This component accounted for 15.05 percent of the total variance. Improved access to credit facilities in remote villages during lean periods and extreme weather events such as pest and disease outbreaks diminishes a household's vulnerability. In such extreme conditions, when there are no formal financial institutions nearby, many farmers depend on informal support from moneylenders. As a result, these farmers pay exorbitant interest rates. This situation puts them in a poverty trap. Providing households access to formal credit services can help them adopt innovative solutions and strategies to mitigate climate risks (Harvey et al. 2014).

The third component, "household size and income sources", accounted for 10 percent of the total variance. According to the 2011 population census of India, the average household size in a rural area is 4.94 persons and the average operational landholding is 1.15 ha (DA&FW, GoI 2011). Agriculture is an important source of livelihood and an indicator of wealth in rural areas. Households with large farms can produce more and adopt diverse mechanisms to cope with climate change, making them less vulnerable. For households in remote and marginal areas that limit climate-smart adaptation options, income diversification can help manage risk.

At the household level, a few studies have highlighted the importance of the size of operational holding and income diversification in managing climate risk. Atinkut and Mebrat (2016) found that farm and family size in Ethiopia are important variables that determine household vulnerability to climate change. A large household with a small farm is highly vulnerable compared to a small household with a large farm. Similarly, large households are more dependent on rainfed agriculture, making them vulnerable to extreme external weather shocks (Nkondze, Masuku, and Manyatsi 2013). Large households that depend on rainfed agriculture are more vulnerable to climate change, and large families are most affected by climatic shocks (Shewmake 2008). Moreover, household size (i.e., the number of working members in the household) and household per capita income affect rural livelihoods. Hence, large households tend to have greater vulnerability (Jan et al. 2012). Additionally, studies in different parts of Africa including Ethiopia showed that family size, credit access, and extension services are important determinants of adaptation to climate change (Nhemachena and Hassan 2007; Bryan et al. 2009; Deressa et al. 2009; Hisali, Birungi, and Buyinza 2011; Berman, Quinn, and Paavola 2015; Opiyo et al. 2016).

The fourth component, "access to information and climate-smart adaptation practices" is comprised of two variables: access to short- and long-term climate information and climate-smart adaptation practices adopted by the household. This component accounted for 8 percent of the total variance. Farmers, particularly smallholders, are the most vulnerable to climate change. Efforts to support farmers' adaptation to climate change are hindered by the lack of information on how farmers must respond to change. Information on how to tailor adaptation to specific regions is needed (Harvey et al. 2018). The climate in India is highly diverse, and the crops farmers grow, the type of soil they cultivate, and the resources they have access to vary considerably. Information at the national level may not help farmers at the regional level make sound decisions on mitigating climate risks. Hence, it is critical to provide customized information. Tali (2015) estimated that 32 percent of the rural population in India is illiterate. This, coupled with weak public extension systems, has resulted in information asymmetry among farmers about agriculture (Nandi and Nedumaran 2019). Generally, farmers tend to adopt agricultural practices based on their traditional beliefs, which makes them vulnerable to extreme weather risks. Providing them with tailored information about climate-smart adaptation practices will help them devise better adaptation strategies.

Harvey et al. (2014) reported that even though farmers in Madagascar had access to technical support on agriculture, they showed low adoption of management practices aimed at reducing vulnerability to climate risks, despite the prevalence of these risks. The study underlined the importance of extension services in transferring climate-related information and adaptation strategies to cope with climate change (Harvey et al. 2014). Moreover, reducing information asymmetry among farming households by improving access to climate information has been shown to be effective in convincing farmers to modify farming activities in response to climate change (Maddison 2007; Bryan et al. 2009). Reaching households through communication campaigns can alter farmers' planting schedules and management practices, as well as the types of varieties they use and the diversity of crops they cultivate. These are all low-cost options for reducing agricultural risks and are possible by promoting better extension services (FAO 2010). Households with better technical support and extension services can make informed decisions on crop choice, sowing or planting dates, and management strategies (Sanchez and Swaminathan 2005; Vogel and O'Brien 2006; Maddison 2007; Bryan et al. 2009). Studies in Ethiopia recorded that agricultural extension services and access to climate information determined farmers' preference of adaptation strategies and their choice of coping and adaptation measures (Deressa et al. 2009; Mulatu Debalke 2011; Ashraf, Routray, and Saeed 2014).

The fifth and last component, "social capital", consists of only one variable: the social network of households. This component accounted for 7.42 percent of the total variance. Farmers, particularly smallholders, are often deprived of access to institutional services in India (Dev 2012). They also lack resources to handle natural risks. Access to institutional services is vital in determining individual and community resilience and adaptive capacity to cope with climate change at the farm and household levels. For instance, improved access to information, credit, technology, irrigation facilities, and other critical inputs to agriculture, can prepare farmers for better and resilient farming. They will also be able to adjust their farming practices according to changes in climate. Through their collective action, farmers can protect their livelihoods from the negative impacts of climate change in the absence of sufficient agricultural extension services. Currently, extension personnel in India are fewer than the recommended ratio of 1:750 at the national level (Nandi and Nedumaran 2019). Hence, providing regular, timely services to farmers, particularly smallholder and marginal farmers, is difficult. Additionally, with labor scarcity and rising wages in agriculture (ICRISAT 2019), obtaining labor on time has become increasingly challenging and is not economically viable for most smallholder farmers. Therefore, the social network of households can help increase farmers' access to information, credit, climate-smart adaptation technologies, and other inputs.

Abid et al. (2017) found that social networks can play a critical role in enhancing the adaptive capacity of farming communities in Pakistan toward climate change. Social networks and social capital make it possible for farmers and communities to organize collectively to manage climate risks (Pelling and High 2005; Adger 2010). Adimassu and Kessler (2016) reported that access to resources, knowledge, labor, information, and social capital were factors affecting the choice of coping and adaptation strategies of farmers in Ethiopia. Village or community savings and group loans in which members pool resources and lend money to members in need are low-cost solutions that can help farmers overcome extreme weather events or lean seasons (Heltberg, Siegel, and Jorgensen 2009; Bhattamishra and Barrett 2010).

Given the diverse spatial and temporal impacts of climate change, there is no single recommended formula for adaptation. Various actors, including individuals, government agencies, non-governmental organizations, and private companies, are responsible for adaptation. The prompt delivery of policy responses can facilitate climate change adaptation effectively. Among the sampled households, those that were extremely vulnerable had the least access to irrigation, credit facilities, and climate information. They also had fewer income sources for diversification and smaller social networks and had adopted the fewest climate-smart adaptation practices. Appropriate irrigation technology, such as small-scale private irrigation, can be encouraged to ensure the efficient use of available water. Combining appropriate irrigation technology with less water-intensive crops can potentially reduce the vulnerability of farmers in the extremely vulnerable category.

Diversifying crop options to include less water-intensive and drought-tolerant crops such as millets; financing the construction of small on-farm water conservation structures to store rainwater; promoting livestock-based activities through centrally sponsored schemes; and increasing access to climate information are some potential adaptation options that emerged during stakeholder consultations. These can increase the resilience of farmers in the vulnerable categories. For the moderately vulnerable households, the main constraints were access to climate information, adoption of fewer climate-smart adaptation practices, and smaller social networks. Encouraging peer networks and technology demonstrations that help farmers understand how the technology works and what its benefits are, and combining them with climate-smart activities, can help improve their current situation.

Policy Implications

Based on the findings, policymakers should pursue the following to increase the resilience of drought-prone households in Telangana:

1. ***Allocation of resources.*** According to Kolm (1996) (as cited by Paavola and Adger 2006), the best way to allocate assistance within regions is to use a vulnerability-based leximin rule. A leximin rule entails redistribution to the most affected along some criterion as a matter of priority. After the needs of the most vulnerable have been met, attention is directed to redistributing to the next affected. This principle would not require the establishment of separate priorities between types of adaptive measures. Context-specific climate-smart adaptation technologies can be identified through rapid appraisal, which combines common participatory rural appraisal and rapid rural appraisal. Ideally, policy formulation can target identified households, and enabling policies can be rolled out to enhance the adaptive capacity of said households based on the identified reasons for vulnerability for each of the categories. Consequently, this can increase the adoption of context-specific climate-smart adaptation technologies. Compared to a "one size fits all" approach, a tailored policy approach can potentially increase the resilience of households by enhancing their adaptive capacity. Thus, the results of this household-level study of villages in the districts of Mahabubnagar, Wanaparthy, and Nagarkurnool in Telangana will be useful in the planning and implementation of local development programs for long-term resilience.

2. ***Improved extension services.*** Agricultural extension services should be improved to ensure that farmers receive climate information and information on climate-smart adaptation strategies. Given the paucity of agricultural extension personnel, providing group extension, or linking extension services through producer organizations or local farmer associations, can advance the transfer

of information and technologies cost-effectively. The government should work with private entities and non-government organizations with proven extension models in public-private partnerships.

3. ***Improving low-cost technologies.*** There is a need to explore opportunities for donors to invest in low-cost infrastructure such as improved irrigation systems, improving credit access, and establishing more weather stations that can precisely predict weather conditions in a specific village or groups of villages.

CONCLUSION

The main objective of this study was to analyze household-level vulnerability to climate change by integrating both quantitative and qualitative information obtained from 6,214 respondents through primary field surveys and stakeholder consultations. The study found that household and farm characteristics such as number of sources of irrigation, proportion of area under irrigation, income from agriculture, number of sources of income, access to formal credit and climate information, household size, operational holding, social network, and number of climate-smart adaptation practices are significant factors that are correlated with household vulnerability. PCA revealed the presence of five components or factors, which were renamed according to their collective representation: (1) access to irrigation; (2) credit access, landholding, and income from agriculture; (3) household size and income sources; (4) access to information and climate-smart adaptation practices; and (5) social capital. After the component scores were analyzed using K-means clustering, three clusters emerged based on the relative response of the component scores: extremely vulnerable, moderately vulnerable, and resilient households. The results of the cluster analysis revealed that 79 percent of the households were extremely vulnerable, 11.2 percent were moderately vulnerable, and 9.65 percent were resilient. Majority of the extremely vulnerable farmers were marginal and smallholder farmers, while most of the moderately vulnerable farmers were large and medium farmers. Interestingly, nearly 26 percent in the extremely vulnerable category and 19 percent in the moderately vulnerable category were large farmers, which contradicts previous assumptions.

This study identified households that were vulnerable to climate change. Households in different vulnerability categories require different intervention strategies and support. Hence, investments must be strategic to households that are moderately to extremely vulnerable to climate variability and change. The findings of this study can inform policymakers and decision makers about the need for household-level climate vulnerability analysis, which can lead to government investments that can mitigate climate change impacts and safeguard vulnerable households with targeted information. Household-level climate vulnerability analysis also offers better agricultural adaptation strategies to reduce risks attributable to climate variability and extreme events. Given that households in different districts in Telangana have varying degrees of vulnerability to the impacts of climate change, targeted approaches should be designed and administered to ensure sustainable crop production.

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APPENDIX

1. Eigenvalues of principal component analysis

Component	Total Variance Explained								
	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.792	19.942	19.942	2.792	19.942	19.942	2.598	18.555	18.555
2	2.107	15.050	34.992	2.107	15.050	34.992	2.054	14.673	33.228
3	1.400	9.998	44.991	1.400	9.998	44.991	1.395	9.965	43.193
4	1.116	7.975	52.965	1.116	7.975	52.965	1.363	9.738	52.930
5	1.038	7.416	60.381	1.038	7.416	60.381	1.043	7.450	60.381
6	0.948	6.773	67.154						
7	0.894	6.388	73.542						
8	0.887	6.334	79.876						
9	0.755	5.391	85.267						
10	0.662	4.730	89.996						
11	0.610	4.359	94.355						
12	0.427	3.048	97.403						
13	0.275	1.961	99.365						
14	0.089	0.635	100.000						