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Climate risk, vulnerability and resilience: Supporting livelihood of smallholders in semiarid India

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ABSTRACT

Using panel data from 256 smallholder households from 2006 to 2014 in three semiarid regions India, this study develops a framework for quantifying vulnerability and resilience by accounting for a smallholder household's ability to adapt and respond to climatic risk. Findings indicate that although smallholders with smaller land-holdings are more vulnerable to climatic risk (drought, in our case), they are also more resilient than their counterparts. Results reveal that cropping intensity and crop risk increase the vulnerability of smallholders to climatic risk, but large farms are less vulnerable. Diversification in on-farm enterprises, like livestock units, and off-farm income sources, play significant roles in increasing smallholder households' resilience to climatic risk. Other drivers of resiliency include the choice of cash and risky crops, borrowing capacity, liquid investments, and the ability to regain yields.

1. Introduction

As part of its Fourth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC, 2007) confirmed that climate change is real, and climatic variability such as drought is projected to increase in frequency, severity, and duration. Climatic risk, like drought, is a complex phenomenon that damages agricultural, environmental, and socio-economic systems. In both developed and developing countries, drought is a major threat to livelihoods, food security, and economic development. The semiarid and arid regions of the tropics are among the world's most vulnerable areas prone to drought disasters. Climate models show that semiarid parts around the globe are likely to experience increased variability in rainfall and more extended drought periods in the coming decades (IPCC, 2007; IPCC, 2014). In agrarian economies such as India, climatic changes threaten both food security and economic development (Edame et al., 2011; Burney et al., 2014; Hatfield et al., 2018).

In the face of significant challenges arising from climate change and drought, many questions remain unanswered. How have farmers responded to drought? Why are some farmers able to respond to drought but others are not? How can smallholders prepare for climate variability in the future? Some studies exploring farmers' adaptation strategies to both climate change and drought have led us to understand that farm households engage in several risk management strategies to cope with climatic fluctuations. These include crop choices and diversification (Birthal et al., 2019; Lin, 2011; Makate et al., 2016; Anik and Khan, 2012), redesigning cropping systems (Lei et al., 2016; Kumar et al., 2011), and adjusting their livelihood activities (Selvaraju et al., 2006; Murendo et al., 2011). Although efforts to evaluate drought risk, impacts, and adaptation have produced extensive and insightful literature, their application in policy-driven assessments has been limited by a lack of metrics.

Vulnerability, resilience, and adaptive capacity have emerged as the three central components of climate risk research. Together they provide a framework for examining climate risk's impacts on the food security of smallholder households in agrarian, developing, and emerging economies like India. Managing vulnerability and enhancing resilience against drought is critical for exploring adaptation strategies for poverty reduction and agricultural sustainability. Most research on the impacts of climate change and adaptation startegies focuses on assessing vulnerability, both qualitatively and quantitatively (Singh et al., 2014; Sam et al., 2017; Harvey et al., 2014; Notenbaert et al., 2013).

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However, very few studies have focused on resilience (Keil et al., 2008). Vulnerability and resilience are two complex and interrelated concepts in climate change research. Vulnerability focuses on exposure, sensitivity, and adaptive capacity before the natural shock takes place (pre-shock). On the other hand, resilience focuses on the dynamics of households and communities to respond to and recover from natural shock (post-shock). A smallholder household, therefore, is considered resilient when it is less vulnerable to natural shocks across time and can recover from those shocks (Perez et al., 2015).

Developing an adequate measure of both vulnerability and resilience is therefore critical in supporting adaptation strategies that reduce the impact of climatic variability (drought, in our case) among smallholder populations. Developing such measures at the household level is difficult because of the lack of high-frequency panel data that can provide insights into the relationship between climate events and household-level variables. Furthermore, identifying the causes of vulnerability can help address the underlying structural issues, and understanding resilience can guide where to direct resources for fundamental change.

The objective of this study is twofold. The first is to develop a framework to estimate the vulnerability and resilience of smallholder households to climate risk (droughts). The second is to characterize and identify the drivers of vulnerability and resilience to drought. Specifically, we examine the adaptation strategies of smallholders to manage vulnerability and to enhance resilience to climatic risks. We have used the Village Dynamics Studies in South Asia (VDSA)[1] panel datasets that provide an abundance of rich data, particularly well-suited to this analytical task. Findings from this study can provide empirical evidence to policymakers to help them formulate adaptation policies and strategies to manage drought risk, reduce vulnerability, and increase adaptive capacity.

The paper is structured in the following sections. Section 2 provides a brief introduction to the data. Section 3 develops the analytical framework, and Section 4 presents the study's results. The final section discusses policy implications and conclusions.

2. Data

We considered data available for six of the longest-running VDSA villages located in three different agro-climatic regions: Aurepalle and Dokur in the Mahabubnagar region (Telangana), Kanzara and Kinkhed in the Akola region (Maharashtra), and Kalman and Shirapur in the Solapur region (Maharashtra) in India (Fig. 1). These regions vary considerably in their agricultural, socio-economic and environmental conditions (see Table 1). The study villages fall in the semiarid tropics (SAT) region of the south and southwestern parts of India (Deb et al., 2016). Aurepalle and Dokur have erratic rainfall and red soil with heterogeneous soil quality. On the other hand, Shirapur and Kalman have deep, black soils in lowlands and shallower, lighter- colored soils in uplands. Rainfall is erratic in Shirapur and Kalman. In Kanzara and Kinkhed, soils are black and of homogeneous quality, and rainfall is relatively assured (Walker and Ryan, 1990; Rao et al., 2009; and Deb et al., 2014). Based on the VSDA's broader objectives, the villages were carefully chosen to represent a variety of SAT villages based on geography, cropping patterns, weather patterns, soil type, irrigation, education, caste structures, technology adoption, land distribution, and other socio-economic factors.

This study uses micro-level survey data collected from rural farm households in the semiarid tropical regions of India between 2006 and 2014. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) conducted the survey under the VDSA project. The household surveys collected information on various socio-economic variables, including farm inputs and outputs, price, markets, climate, and farm household characteristics. The household panel data has been collected by ICRISAT's resident field investigators who lived in the villages to revisit the same households periodically over the years. The availability of such high-frequency household panel data provides the best platform to draw insights into the relationship between climatic shocks and household-level variables. Note that the sample is of smallholder households who were present in all three periods—pre-drought, drought, and post-drought during the 2006–2014 period. The sample panel data thus contains 256 households—76 from Akola, 62 from Mahabubnagar, and 118 from Solapur regions.

2.1. Identification of drought years

We considered rainfall distribution data for the period 1990–2013, which is based on rainfall observations collected at the village level by the resident field investigators. Column 4 of Table 2 reports the long-term normal level of annual rainfall in the villages, which ranges from 391 mm to 958 mm. We follow the India Meteorological Department (IMD)[2], which defines meteorological drought as a situation when the seasonal rainfall received over the area is less than 75 % of its long-term average value (normal rainfall). A drought is classified as a "moderate drought" if the rainfall deficit is between 26 % and 50 % and as "severe drought" when the deficit exceeds 50 % of the normal rainfall of that particular region. Kanzara and Kinkhed villages, which had the highest annual normal rainfall among three regions (958 mm), had no event of severe drought over the 14 years (1990–2013) and only a moderate drought in 4% of the years. On the other hand, Aurepalle village received the lowest amount of rainfall (391 mm) in a year, leading to a 44 % chance of moderate drought and a 17 % chance of severe drought (Table 2). Devarkadra and Madgul Mandals (a sub-district consisting of 10–15 villages) in the Mahbubnagar region have much higher chances of drought occurrences than the villages/Mandals in the Akola and Solapur regions. The frequency of drought in the Akola and Solapur regions was quite low, compared to the frequency in the Mahabubnagar region. The frequency of drought occurrence was highest in Madgul Mandal (about 60 %) with 43 % and 17 % chances of moderate and severe drought, respectively. Finally, it is worth noting that Murtizapur Mandal did not experience any severe drought during the 1990–2013 period. Fig. 2 summarizes the drought years in the regions and indicates pre- and post-drought years considered for this study.

3. Analytical framework

3.1. Defining and measuring vulnerability and resilience

For a smallholder household, shock can manifest itself in many dimensions (climatic, biophysical, economic, and social). We chose to adopt a narrow view of vulnerability and resilience from the perspective of a smallholder household. The vulnerability here corresponds to the level of decline in agriculture production during a climatic shock, and resilience corresponds to the speed of recovery post-shock (Gitz and Meybeck, 2012; Asian Development Bank (ADB), 2009). Most of the research on drought's impacts on farm households concentrate on measuring either the crop income (CI) or the variations in crop productivity (CP) (Mishra et al., 2015; Biswas, 2017). However, CI and CP are intertwined, and studying them in isolation is unlikely to capture a drought's net impact on smallholder households. For example, a drought period may reduce the level of crop productivity but induce higher market prices for agricultural commodities, resulting in no significant impact on a household's CI. For these reasons, we chose to measure vulnerability and resilience using aggregate crop productivity and crop income index.

[1] For details please see http://vdsa.icrisat.ac.in/

[2] http://imd.gov.in/section/nhac/wxfaq.pdf

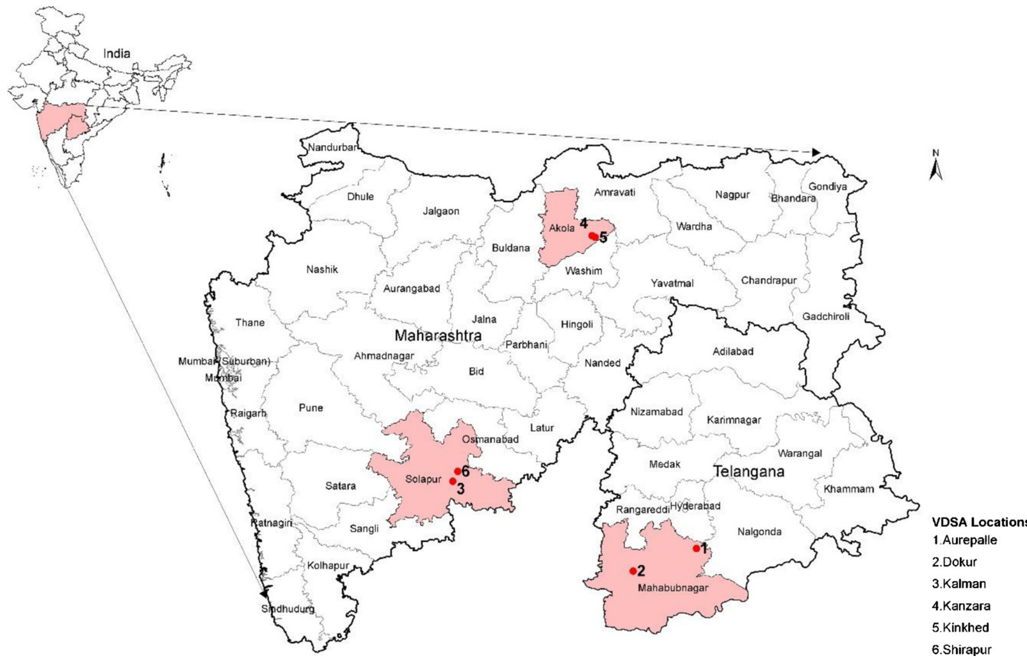

Fig. 1. Village-level study regions and locations, India.

Table 1
General characteristics of the three study regions, semiarid region, India.

Characteristics	Mahabubnagar (Aurepalle and Dokur)	Sholapur (Shirapur and Kalman)	Akola (Kanzara and Kinkheda)
Soil	Red soils; marked soil heterogeneity	Deep black soils in lowlands; shallow lighter soils in uplands	Black soils; fairly homogeneous
Rainfall	Rainfall unreliable; pronounced rainfall uncertainty at sowing	Rainfall unreliable; frequent crop failures	Rainfall unreliable
Major Crops (1975 – 1977)	Kharif (rainy season) crops: Paddy, castor and local Kharif sorghum.	Main crop season was Rabi (post rainy season)- Sorghum was the major crop.	Main crop season was Kharif season. Upland cotton, mung bean and sorghum were major crops.
Major Crops (2009 – 2014)	Kharif season crops: Paddy, cotton, castor, and kharif sorghum. Rabi season crops: groundnut and sunflower.	Major crop: Sugarcane Kharif season crops, pigeon pea, onion Rabi season crop: sorghum	Cotton is the major crop. Kharif season crops: pigeon pea, sorghum, soybean. Rabi season crop(s): wheat

Source: ICRISAT VLS-VDSA data set and Walker and Ryan, 1990, Deb et.al. 2014.

Table 2
Frequency of drought occurrence, by *Mandal*, 1990-2013, India.

Region	Mandal	Village	Normal rainfall (mm)	Moderate drought (%)	Severe drought (%)	Rainfall variability (CV)
Mahbubnagar	Devarkadra	Dokur	565	39	4	28
	Madgul	Aurepalle	391	44	17	33
Akola	Murtizapur	Kanzara & Kinkhed	958	4	0	24
Solapur	Mohol	Shirapur	708	17	13	35
	North Solapur	Kalman	792	17	4	30

Source: Normal rainfall from respective mandal (sub-district) offices and actual rainfall data collected by resident field instigators through rain gauge setup in each village.

3.2. Crop productivity index

Mixed cropping and intercropping are standard features of smallholder farming systems in India. Due to a diverse crop portfolio, and we are unable to compare the physical yields of different crops in absolute values. It emerged from the focus group discussions (FGDs) with farmers that in the event of a drought, a large proportion of dryland farmers suffer significant losses in crop yields. However, a few farmers in the same village can achieve comparatively much higher crop yields. Considering these issues, we followed Biswas (2017) in calculating a comparable Crop Productivity Index (CPI). The CPI accounts for the crop productivity and the land allocated to each crop in the smallholder's crop portfolio. We first computed an index of yield achievement ($I_{Y\ av.a,}$) for each crop and smallholder every year. This was done by dividing the actual yield (kg/ha/year) of each crop on each farm by the maximum annual yield per hectare of the same crop achieved in a particular village (Eq. 1) . The highest yield of a crop reported across all smallholders in a village and year was considered as the maximum

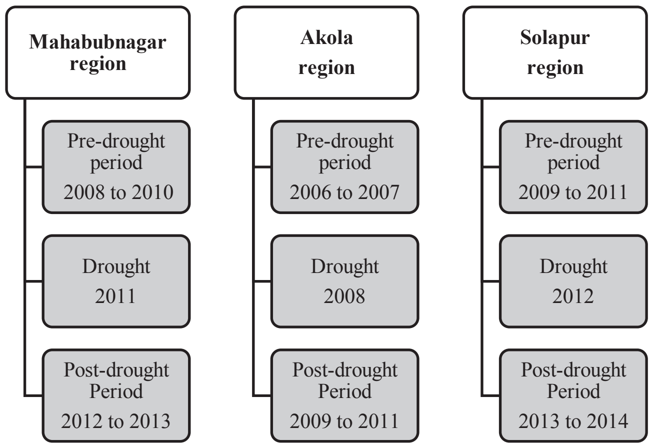

Fig. 2. Identifying drought, pre-drought and post- drought period, by region, India.
Source: ICRISAT VLS-VDSA database of six study villages

achievable annual yield limit of each crop. A high coefficient of variation (CV) in the yields of different crops in the selected villages demonstrates there was a large variation in crop yields across households during each of the periods: pre-drought, drought, and post-drought (Fig. 3). This measure will help in comparing agricultural productivity within the sample population with no externalities (Biswas, 2017). This ratio of actual yield of a crop to the maximum yield per hectare reflects and intuitively differentiates productivity efficiency levels of a crop across households and villages in the sample. Specifically, the Yield Achievement Index (YAI) is defined as:

$$YAI_{av.ai} = \frac{Y_{ai}}{Y_{a\,\max}} \tag{1}$$

where $YAI_{av.ai}$ is the yield achievement index of crop 'a' and household i, Y_{ai} represents yield (per hectare) of crop 'a' for household i, and $Y_{a\,\max}$ represents the highest yield (per hectare) of crop 'a' in the selected village. As a result, the maximum value $YAI_{av.ai}$ would range between 0 and 1. The relative cropping area of a crop is accounted for through a Weighted Yield Achievement Index (WYAI) for each crop. Specifically,

$$WYAI_{av.ai} = YAI_{av.ai}\cdot\frac{CA_a}{TCA} \tag{2}$$

where $WYAI_{av.ai}$ represents the WYAI of crop 'a' for household i; $YAI_{av.ai}$ is defined in Eq. 1; CA_a is the area under the selected crop, 'a'; and TCA is the total cropland area for household i. From the above equation, WYAI was considered high if it is closer to 1, and the WYAI for a household severely impacted by drought likely would be closer to zero (0). Finally, we define the Crop Productivity Index ($CRPI$) as:

$$CRPI = \sum_{j=1}^{N} (WYAI)j \tag{3}$$

where, $j = 1....N$ is the number of crops grown by the smallholders.

3.3. Crop income index

To normalize the crop income and make it unit-free, we have constructed a Crop Income Index (CII). The average per-hectare crop income during all three pre-drought, drought and post-drought periods has been taken together, and CII can be defined as:

$$CII = \frac{(\text{Actual income} - \text{Minimum income})}{(\text{Maximum income} - \text{Minimum income})} \tag{4}$$

The CII value will be unit-free and could range between values 0 and 1.

The CII and CRPI do not always move in the same direction. For instance, Fig. 4a and b show that about 43 % of smallholder households experienced an adverse impact of drought on both crop productivity and income, whereas 35 % smallholder households were impacted

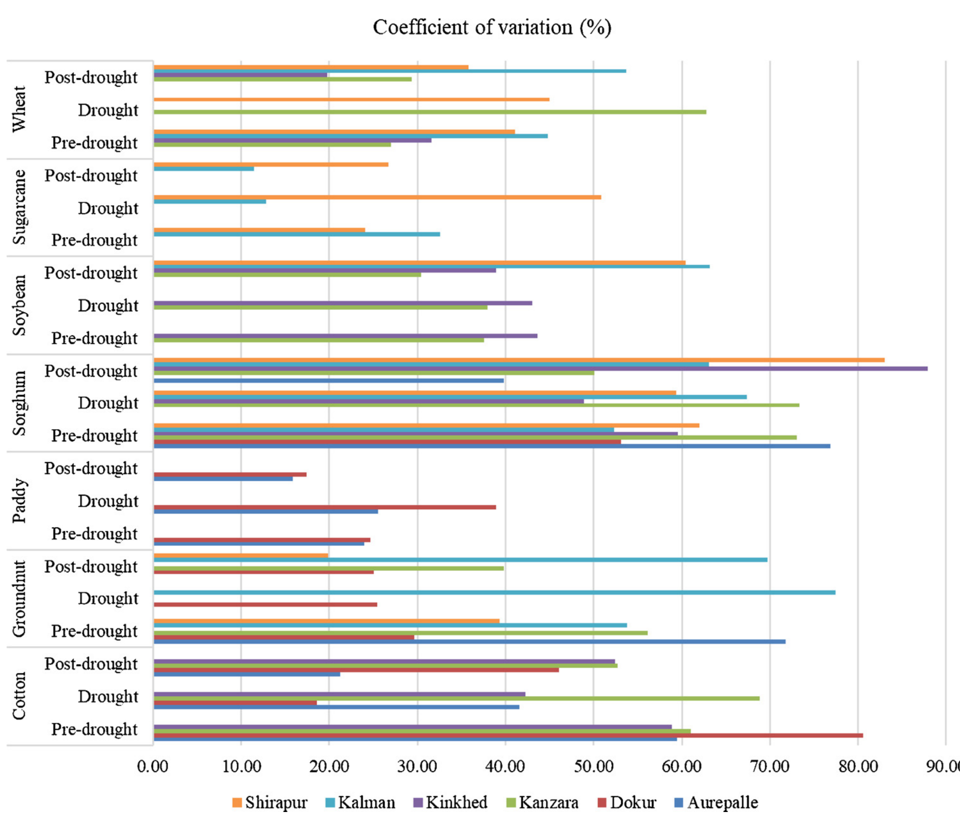

Fig. 3. Coefficient of variation (%) in crop yields, climatic risk periods, villages, India.

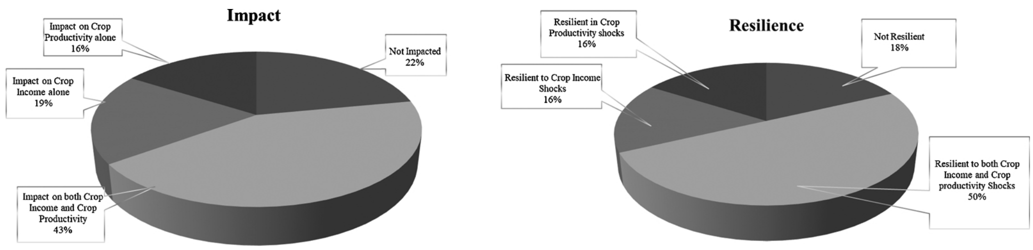

Fig. 4. a) Smallholder household vulnerability to drought, using crop income (CI), crop productivity (CP), and VRI.
Note: Figures in parentheses indicate the total percentage of households. b) Smallholder household resilience to drought, using crop income (CI), crop productivity (CP), and CRI
Note: Figures in parentheses indicate the total percentage of households.

Table 3
Distribution of households to vulnerability and resilience categories, semiarid region, India.

Households categories		Percentage of households
Not Impacted		41 (106)
Low to moderately impacted	Low resilience	11 (27)
	Moderate resilience	4 (10)
	High resilience	16 (41)
Highly impacted	Low resilience	9 (23)
	Moderate resilience	15 (40)
	High resilience	4 (9)
Overall		100 (256)

Note: Values in the parenthesis indicate number of households.
Source: ICRISAT VLS-VDSA database of six study villages.

either in terms of crop income or crop productivity. However, 22 % of smallholder households were not affected. Similarly, smallholder households' ability to bounce back post-drought varied when it came to crop income and crop productivity. About 50 % of smallholder households were resilient to both crop income and crop productivity shocks, but 18 % of smallholder households were not able to bounce back. Only 16 % of smallholder households were resilient in terms of regaining crop productivity, and another 16 % were resilient in terms of crop income. As a result, it is essential to combine the crop income and productivity indices for all three periods (pre-drought, drought, and post-drought) into one index that realistically measures smallholder households' vulnerability and resilience to drought. During the farmer group discussions, farmers expressed equal importance to crop productivity and crop income. As a result, we combine CII and CRPI with equal weights (50 – 50) to construct a Vulnerability and Resilience Index (VRI).

3.4. Vulnerability and Resilience Index (VRI)

The VRI measures a smallholder household's vulnerability and resilience to droughts. The construction of the smallholder household's VRI was based on the composite score of CII and CRPI. Recall that we are interested in modeling the effect of CII and CRPI on the vulnerability and resilience of smallholder households. Thus, VRI, a composite index, can be represented as:

$$VRI_i = a_1 CII_i + a_2 CRPI_i \quad (5)$$

where VRI_i is the Vulnerability and Resilience Index for the household i; and a_1 a_2 are weights assigned to CII and CRPI, respectively. We assumed equal weights for CII and CRPI. Note that VRI measures vulnerability during the pre-drought-to-drought period and resilience during the drought-to-post-drought period. Finally, we define smallholder households as vulnerable if the VRI shows a significant positive deviation between the *pre- drought years and the drought year*. However, if the deviation is negative, then smallholder households are not impacted by drought. Similarly, smallholder households are resilient if the VRI shows a significant positive deviation between the *drought year and post-drought year*. Finally, based on the magnitude of the impact of the drought shock, we used the VRI during the pre-drought-to-drought period to categorize smallholder households into three groups: (1) not impacted; (2) moderately impacted; and (3) highly impacted. Similarly, based on the magnitude of a household's recovery from post-shock to pre-shock livelihood levels, we used VRI for the post-drought period to categorize smallholder households into three groups: low resilience, moderate resilience, and high resilience. However, smallholder households with similar degrees of vulnerability exhibit different levels of resilience, and smallholder households with similar levels of resilience have differing degrees of vulnerability. We classified smallholder households into seven categories that reflect their pre-drought vulnerability and post-drought resilience levels. These categories are non- impacted (I), low to moderately impacted and low resilience (II), low to moderately impacted and moderate resilience (III), low to moderately impacted and high resilience (IV), highly impacted and low resilience (V), highly impacted and moderate resilience (VI), and highly impacted and high resilience (VII). Details of households' distribution for the seven categories have been depicted in Table 3 and Fig. 5. The descriptive analysis in the study has considered these seven categories of households in the succeeding sections. Table 3 reveals that about 59 % of households were affected by droughts, and of that, 20 % were highly resilient and were able to bounce back quickly to pre-shock levels of livelihood. However, the other 39 % of households were of low to moderate resilience and could not fully recover from the shock.

Several factors determine smallholder households' *vulnerability and resilience* to droughts. These factors include socioeconomic characteristics and risk mitigation strategies that involve cropping decisions and livelihood strategies (farming and off-farm work). Assets are grouped

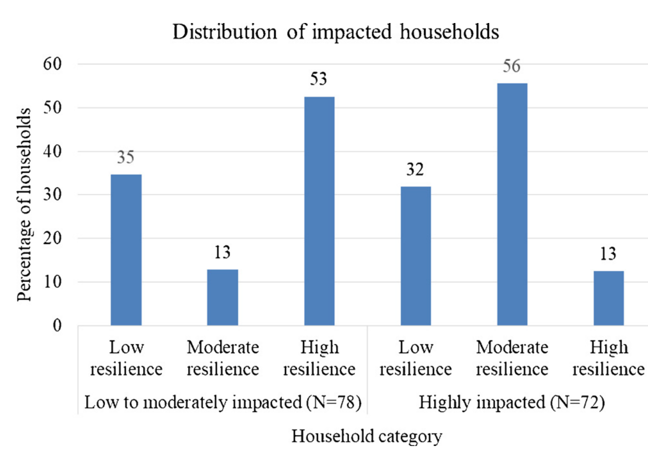

Fig. 5. Distribution of households in terms of impact and resilience, semiarid region, India.

into natural and physical capital (land and irrigation), economic capital (liquid assets, debt), and human capital (education, labor availability). A smallholder household's attitude toward risk is the result of both endogenous and exogenous factors. We explicitly modeled the risk profile of smallholder households using proxies for choice and diversification activities. We considered both farm-level cropping and household-level livelihood activities. Cropping-decision- related variables include crop diversity and crop portfolio risk. We estimated crop diversification levels using Simpson's Diversity Index (see Simpson, 1949; Kavitha et al., 2016; Adjimoti and Kwadzo, 2018). Additionally, we estimated the riskiness of each crop employing a single-index model (see Turvey et al., 1988; Bezabih and Di Falco, 2012; Veljanoska, 2014) using selected farm households' data from 2006–2014. Specifically,

$$CA_{ij} = \#945; + \beta GCA_i \quad (6)$$

where CA_{ij} represents the cultivated area of household i of crop j in a year, GCA_l represents the gross cropped area of household i in a year, and α β represents regression parameters, where β indicates the beta coefficient of each crop, indicating the level of riskiness associated with the crop. Crop portfolio risk is computed as the average beta coefficients of all the crops for a given household (see Fig. 6). Crop portfolio risk or 'crop yield beta' is used as one of the explanatory variables in analyzing the factors affecting vulnerability and resilience. Livelihood-decision-related variables include diversification of on- and off-farm activities, which are reflected by the share of income from other sources such as livestock and off-farm activities in the total household income, respectively. We use multinomial logistic regression models to estimate the determinants of smallholders' vulnerability and resilience to drought. The explanatory variables included critical natural and physical capital, economic capital, and human capital as well as crop portfolio risk and crop diversity.

Table 4 reports important socioeconomic, farm, and farming characteristics of smallholder households across the seven different categories during pre-drought, drought, and post-drought periods. The table reveals that among all categories and throughout the entire period, family size ranges from 4.64 to 6.20, and the dependency ratio was about $0.38 - 0.75$. The average operational landholdings were comparatively smaller for smallholders in the III, V, and VI categories. It is interesting to note that smallholder households with a greater share of cash crops in their crop portfolio were considerably affected by droughts, but also bounced back quickly to their pre-shock levels of livelihood. For example, smallholders in category VII who had 57 % in cash crops in the pre-drought period and were highly impacted had 59

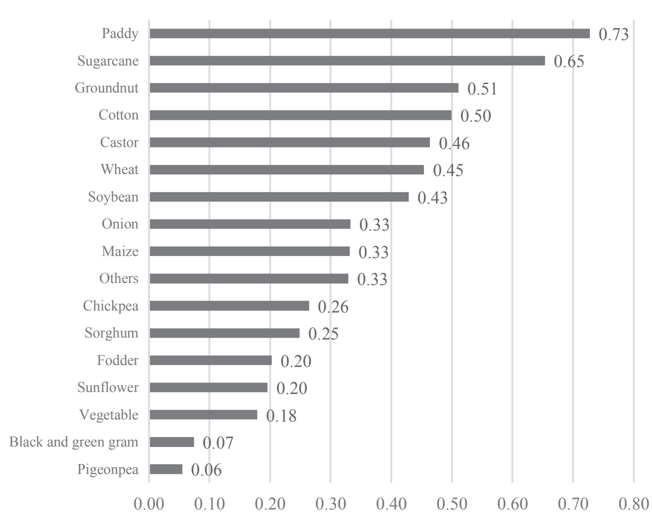

Fig. 6. Distribution of crop yield beta, by major crops, semiarid region, India. Source: Estimated based on the ICRISAT VLS-VDSA database of six study villages

% in cash crops in the post-drought period. In contrast, smallholders in the low to moderately impacted and low resilience category (II) had 49 % in cash crops both during the pre and post-drought periods. Cropping intensity during the drought year was comparatively lower and below 100 % ranging from 75 % to 96 % for all categories of smallholder households except one. In contrast, cropping intensity ranged from 109 % to 157 % in the pre-drought period, implying a direct impact of drought on crop cultivation. We noticed that in all smallholder household groups except the low to moderately impacted and high resilience households (category IV), the share of the irrigated area in the post-drought year did not recover to the pre- drought level. A plausible reason could be that smallholders may overexploit irrigation wells during drought, and the post-drought period may not be long enough for aquifers to recharge.

4. Results and discussion

4.1. Impact of drought on crop productivity and cropped area

The Weighted Yield Achievement Index (WYAI), a measure of crop productivity, for essential crops in the study region for all seven categories of smallholder households is presented in Table 5. Within each group of smallholder households, we considered two different comparative scenarios: Scenario 1 (S1) reports the impact of drought (change in the cropped area and WYAI between pre- drought and drought years), and Scenario 2 (S2) indicates the smallholder household's capacity to bounce back after a shock (to its pre-drought level). Table 5 shows that the "not impacted" group of farmers was able to maintain or increase the crop productivity even during the drought year. Their WYAI of 0.61 means yields during the pre- drought were 61 % of the drought period. However, these farmers significantly reduced the area under cultivation for the most impacted crop, wheat– area under cultivation was 2.52 times greater pre-drought than during the drought. The same group also increased the WYAI levels (by 24 %) and cropped area (by 8%) during the post-drought to the pre-drought period (see columns 18 and 19 of Table 5). A noticeable difference in the ability to attain pre- drought crop yields post-shock also was seen among the groups. The "low to moderately impacted and highly resilient" households show higher WYAI of 1.50, 50 % increase, and maintained about the same cropped area, about 0.97 during the post-drought to the pre-drought period (see columns 18 and 19, row 9 and 10 of Table 5). "Highly impacted and highly resilient" smallholder households and the "not impacted" smallholder households report relatively higher WYAI post-shock, compared to other groups. Smallholders in the "highly resilient" categories not only regained crop yields in the post-drought period but also were more flexible to decrease or increase the area under different crops dynamically. For example, households in these categories increased cropped area sorghum and cotton and decreased it for paddy and soybean during the drought period. In the post- drought period, the households increased cultivated area in soybean and sugarcane and recovered the cultivated area under paddy and groundnut to the pre-drought level. Resilience is being attained by restoring/increasing crop area and yield in the post-drought period. However, highly resilient smallholders were focused more on regaining/increasing crop yields post-drought as a means of bouncing back. For the "highly resilient" household category, for example, the crop productivity increased by 95 %, and the cropped area increased by 20 % in the post-drought period (Table 5).

Results in Table 5 also provide insights into how drought affected various crops. Overall the drought had a more significant impact on sugarcane and wheat crops across all farm household categories (Table 5) and had a smaller effect on sorghum, cotton, groundnut, and soybean yields. In the case of the cotton crop, we found a negative impact of drought, mostly in terms of the cropped area. The smallholders in five household categories could not regain their pre-drought yield levels in groundnut and four household categories for sorghum

Table 4
Climatic vulnerability, resilience and characteristics of the sample households, semiarid region, India.

Household category			Family size Number	Dependency ratio	Operated area (Ha)	Irrigated area to operated area (%)	Cash crop to total crop area (%)	Cropping intensity (%)	Crop diversity index
Not Impacted (I)		Pre-drought	4.79	0.45	3.41	51.37	56.75	107.27	0.47
		Drought	4.64	0.38	3.50	46.76	48.80	94.55	0.44
		Post-drought	4.95	0.52	3.38	40.48	53.68	112.78	0.45
Low to moderately impacted	Low resilience (II)	Pre-drought	6.11	0.52	3.10	45.05	49.02	117.08	0.50
		Drought	6.07	0.50	3.01	45.76	50.52	96.41	0.38
		Post-drought	6.20	0.59	2.96	40.98	49.59	114.27	0.50
	Moderate resilience (III)	Pre-drought	5.93	0.43	2.63	46.54	47.13	117.47	0.47
		Drought	6.00	0.38	2.69	21.02	33.32	105.24	0.39
		Post-drought	5.67	0.58	2.61	26.60	58.88	109.51	0.50
	High resilience (IV)	Pre-drought	4.93	0.51	3.56	54.76	60.45	113.03	0.45
		Drought	4.78	0.55	3.69	50.65	40.00	97.92	0.33
		Post-drought	4.69	0.58	3.14	54.40	62.60	111.50	0.40
Highly impacted	Low resilience (V)	Pre-drought	5.39	0.71	2.05	25.85	32.68	157.08	0.35
		Drought	5.35	0.64	2.29	22.84	35.63	97.24	0.33
		Post-drought	5.36	0.69	2.77	20.05	63.02	115.17	0.45
	Moderate resilience (VI)	Pre-drought	4.84	0.42	2.13	36.07	45.11	125.78	0.42
		Drought	4.85	0.52	1.93	25.40	37.01	92.24	0.34
		Post-drought	4.85	0.59	1.83	26.98	69.23	130.83	0.40
	High resilience (VII)	Pre-drought	4.93	0.55	3.27	56.85	57.18	108.61	0.43
		Drought	5.33	0.62	3.39	60.19	40.73	75.01	0.29
		Post-drought	6.09	0.75	2.72	40.66	59.44	101.23	0.31

Source: ICRISAT VLS-VDSA database of six study villages.

crops. Cotton and soybean, however, recorded the highest recovery gains after the shock across most smallholder household categories in terms of WYAI, compared to the cropped area. The crop yield represented by WYAI for cotton was 1.32–2.87 times higher, and soybean yields were 1.1–3.15 times higher during post-drought (Table 5).

4.2. Impact of drought on smallholder household income

Table 6 compares incomes (crop, livestock, off-farm, and total) in the pre-drought, drought, and post-drought period for the seven categories of smallholder households. Surprisingly, smallholder households in "low to moderately impacted" category II and categories V of "highly impacted" households had comparatively higher total income and crop income in the pre-drought period. For the low-resilience households (category V), off-farm incomes remained the primary source of household income even during the drought period. However, this group's crop income was severely impacted by the drought, in absolute terms, and decreased further in the post-drought period. The "low to moderately impacted, high- resilience" smallholder households (Category IV) had the lowest total household income, at least during the pre-drought and drought periods. Additionally, this group's crop income was highly variable, reduced by almost 33 % in the drought year, compared to pre-drought years. However, the crop income bounced back (more than doubled) from the drought to the post-drought period.

Across the seven groups, smallholder households seem to offset crop income losses during the drought year by increasing their efforts in off-farm work. Off-farm earnings increased between 7%–31% during the drought year. However, it decreased for most of the household groups in the post-drought period, implying that smallholders allocate their efforts to alternative sources of earning money whenever they need it. Otherwise, they rely more on subsistence sources of income. An increase in the share of off-farm income in the total household income was comparatively higher for the highly impacted and resilient households, compared to non- impacted households. Income from livestock enterprise remained somewhat stable during the drought period for all the household groups—reflecting the resilient nature of livestock enterprises. For the impacted and high resilient farmers (category IV and VII), income from livestock and off-farm together

Table 5
Cultivated area and weighted yield achievement index (WYAI), under three scenarios* for major crops, semiarid region, India.

Household category and scenarios			Cotton		Groundnut		Paddy		Sorghum		Soybean		Sugarcane		Wheat		Overall	
			Area	WYAI	Area	WYAI	Area	WYAI	Area	WYAI	Area	WYAI	Area	WYAI	Area	WYAI	Area	WYAI
Not impacted		S1	1.17	0.64	0.44	0.30	0.82	0.84	0.81	0.54	0.69	0.59	0.82	1.11	2.52	1.46	0.83	0.61
		S2	0.73	1.44	1.86	1.43	1.33	1.27	0.96	1.03	1.46	1.42	1.60	1.02	0.88	1.14	1.08	1.24
Low to moderately impacted	Low resilience	S1	1.36	0.97	0.84	0.49	0.88	0.87	0.91	1.11	0.66	0.69	0.82	1.13	3.50	3.56	0.88	0.90
		S2	0.85	1.47	0.97	0.39	0.54	0.53	1.16	0.40	1.57	1.10	0.83	0.70	0.71	0.69	1.02	0.81
	Moderate resilience	S1	1.09	0.77	0.45	1.39	1.30	1.57	0.83	0.74	0.59	0.62	0.73	0.87	2.94	4.82	0.82	0.88
		S2	0.89	1.32	0.56	0.32	1.02	0.88	1.08	1.34	1.12	1.88	1.14	0.70	0.32	0.92	0.87	1.13
	High resilience	S1	1.04	0.83	0.36	18.84	0.99	1.14	0.68	0.91	0.49	0.65	1.35	2.90	2.23	1.70	0.77	0.86
		S2	0.97	1.80	1.16	0.14	1.39	1.31	0.81	0.97	1.29	1.85	0.94	1.50	0.61	1.51	0.97	1.50
Highly impacted	Low resilience	S1	1.48	0.51	0.25	0.89	0.00	0.00	0.54	0.83	0.60	0.45	0.87	1.76	10.66	9.72	0.86	1.06
		S2	0.93	2.58	3.50	0.44	0.00	0.00	1.27	0.62	1.22	1.56	1.24	0.43	0.59	0.49	0.98	0.66
	Moderate resilience	S1	1.01	1.11	–	–	0.83	1.60	0.63	1.54	0.48	0.36	1.06	2.17	2.39	1.88	0.85	1.45
		S2	1.28	1.74	0.70	0.45	1.28	0.96	0.97	0.47	1.61	3.15	1.30	0.96	0.72	0.89	1.24	1.10
	High resilience	S1	0.87	0.85	–	–	1.24	3.48	0.65	0.66	1.57	1.75	0.72	1.30	–	–	0.71	0.97
		S2	2.04	2.87	3.43	2.28	0.94	1.16	0.80	1.21	0.28	2.73	1.24	1.00	0.47	2.61	1.20	1.95

Source: Estimated based on ICRISAT VLS-VDSA database of six study villages.
* S1 = Proportion of pre-drought to drought year; S2 = Proportion of post-drought to pre-drought year.

Table 6
Smallholder household income, by sources, pre-drought, drought, and post-drought period, India.

Year	Source of income	Not Impacted (I)	Low to moderately impacted			Highly impacted		
			Low resilience (II)	Moderate resilience (III)	High resilience (IV)	Low resilience (V)	Moderate resilience (VI)	High resilience (VII)
Pre-drought	Crop income	54,679 (34.8)	104,425 (45.55)	69,984 (40.55)	49,084 (32.85)	143,168 (61.07)	79,301 (43.53)	52,281 (32.39)
	Livestock income	27,386 (17.43)	36,769 (16.04)	16,294 (9.44)	31,203 (20.88)	27,376 (11.68)	32,734 (17.97)	43,978 (27.25)
	Off-farm income	75,060 (47.77)	88,038 (38.41)	86,321 (50.01)	69,123 (46.26)	63,884 (27.25)	70,143 (38.5)	65,152 (40.36)
	Total income	157,125 (100)	229,232 (100)	172,599 (100)	149,409 (100)	234,427 (100)	182,178 (100)	161,411 (100)
Drought	Crop income	76,714 (41.88)	98,563 (39.37)	54,269 (30.28)	33,073 (22.67)	73,362 (42.51)	41,503 (25.47)	31,159 (19.71)
	Livestock income	26,470 (14.45)	36,304 (14.5)	13,305 (7.42)	37,340 (25.59)	23,050 (13.36)	25,111 (15.41)	46,995 (29.73)
	Off-farm income	79,973 (43.66)	115,478 (46.13)	111,671 (62.3)	75,485 (51.74)	76,183 (44.14)	96,360 (59.13)	79,931 (50.56)
	Total income	183,157 (100)	250,346 (100)	179,245 (100)	145,898 (100)	172,595 (100)	162,974 (100)	158,085 (100)
Post-drought	Crop income	69,855 (42.75)	69,275 (36.77)	57,312 (37.71)	69,873 (42.16)	67,597 (37.84)	59,203 (40.46)	73,543 (45.06)
	Livestock income	23,582 (14.43)	42,244 (22.42)	12,109 (7.97)	32,871 (19.84)	26,146 (14.64)	23,496 (16.06)	34,307 (21.02)
	Off-farm income	69,983 (42.82)	76,884 (40.81)	82,576 (54.33)	62,971 (38)	84,884 (47.52)	63,623 (43.48)	55,347 (33.91)
	Total income	163,420 (100)	188,403 (100)	151,998 (100)	165,715 (100)	178,626 (100)	146,323 (100)	163,197 (100)

Note: Figures in parentheses are percentage of total income.
Source: ICRISAT VLS-VDSA database of six study villages.

comprised about two-thirds of the total household income.

Fig. 6 reports the value of crop yield beta of individual crops for the sampled smallholder households. Interestingly, crops needing more water during growing stages were found to be riskier. For example, the paddy crop had the highest crop yield beta (ß = 0.73), followed by sugarcane (ß = 0.65), groundnut (ß = 0.51), and cotton (ß = 0.50). In contrast, pulse crops such as black and green gram (ß = 0.07) and pigeon pea (ß = 0.06) had the lowest crop yield beta.

4.3. Determinants of drought on vulnerability and resilience

Table 7 provides the summary statistics of factors affecting smallholders' vulnerability and resilience to droughts. We used multinomial logistic regression to estimate the empirical model. [3] Predicted marginal effects of factors affecting smallholders' vulnerability and resilience to droughts are reported in Tables 8 and 9. The marginal effects for smallholder households' vulnerability to climatic shocks like drought indicate that the family size and credit tend to have a positive and significant impact on the "low to moderately impacted" smallholder households (Table 8). Results suggest that an increase in family size and amount of credit increases the likelihood of smallholders being in the "low to moderately impacted" category, compared to the base group of "not impacted" households. Findings indicate that an additional family member increases the likelihood of being in the "low to moderately impacted" category, compared to the base group of "not impacted" households. On the other hand, climate shock, such as drought, may impact the debt repayment capacity of smallholder households. As such, an increase in debt increases the likelihood of being in the "low to moderately impacted" category of households, compared to the "not impacted" base category.

Table 8, Column 3, reveals that crop yield beta has a nonlinear effect on the "highly impacted" category of smallholder households. Results suggest that an increase in crop yield beta first increases the likelihood of being in the "highly impacted" category but decreases with the optimal choice of a risky crop portfolio. Findings suggest that planting a portfolio of crops with higher crop yield beta may rescue smallholders vulnerable to climatic shocks.[4] Smallholder households cultivating a higher-risk crop portfolio faced substantial drought risk but were also quick to recoup losses. Nevertheless, choosing a too-risky crop portfolio was not a resilience- enhancing option. Access to relevant information and awareness would be the key to designing a crop portfolio that is risky but highly remunerative. As a result, smallholders with a high-risk crop portfolio could exhibit higher levels of both vulnerability and resilience. Cotton, sorghum, and soybean were relatively stable crops as drought-impacted WYAI. In other words, an ideal combination of risky crops in the crop portfolio can help farm households in the semiarid tropics by increasing the households' adaptive capacity. By including relatively safe crops, such as legumes and dryland cereals, smallholders can limit their exposure to drought-induced losses. Our findings support crop diversification as one of the significant coping mechanisms to climatic risk.

Results in Table 8, Column 2, show that the coefficients of share of livestock income in total income and of share of off-farm income in total income are negative and significant, suggesting that livestock and off-farm income play a considerable role in shielding smallholder households from climatic risks like droughts. Findings indicate that income diversification in other farming enterprises (e.g., livestock) and in off-farm activities decreases the likelihood of smallholders falling into the "highly impacted" category, compared to the "not impacted" base category of smallholders. In other words, higher shares of livestock and off-farm income in total income enable smallholders to diversify income

[3] Due to brevity and space limitation, additional statistical parameters for the MNL model are not presented here. Readers can request authors for additional MNL regression results.

[4] Farmers may have to plant both risky and non-risky crops, thereby increasing cropping portfolio, to withstand drought.

Table 7
Variable definition and summary statistics, sample households, semiarid region, India.

Variables	Vulnerability category			Resilience category (From among the impacted households)		
	Not impacted	Low to moderately impacted	Highly impacted	Low resilience	Moderate resilience	High resilience
Age of household head, (year)	48.07 (10.98)	49.84 (12.04)	48.79 (12.33)	51.58 (10.85)	49.36 (11.47)	49.17 (12.97)
Family size	4.79 (1.53)	5.47 (2.43)	5.03 (1.84)	5.69 (2.99)	4.84 (1.81)	5.24 (2.38)
Operated area (Ha)	3.41 (3.1)	3.28 (2.55)	2.25 (1.72)	2.7 (1.91)	2.98 (2.1)	2.25 (1.6)
Ratio of irrigated area to operated area	0.51 (0.39)	0.5 (0.38)	0.35 (0.39)	0.34 (0.38)	0.38 (0.37)	0.38 (0.4)
Ratio of cash crop area to total cropped area	0.57 (0.28)	0.55 (0.27)	0.43 (0.29)	0.55 (0.27)	0.59 (0.25)	0.72 (0.28)
Cropping intensity (%)	1.07 (0.37)	1.15 (0.36)	1.34 (0.94)	1.14 (0.36)	1.2 (0.38)	1.17 (0.51)
Crop diversity index (%)	47.1 (24.34)	47.18 (22.37)	39.98 (25.66)	44.24 (23.37)	50.38 (20.2)	33.64 (26.81)
Crop diversity index squared (%)	2805.62 (1981.27)	2720.04 (1818.59)	2247.58 (1866.17)	2491.93 (1928.58)	2938.28 (1804.75)	1836.43 (2071.98)
Yield beta (%)	28.16 (18.09)	29.25 (17.44)	32.41 (17.07)	24.31 (16.96)	25.48 (17.4)	37.94 (15.88)
Yield beta squared (%)	1117.47 (1241.31)	1155.54 (1237.88)	1337.84 (1222.41)	873.05 (1150.82)	945.99 (1054.84)	1686.93 (1175.77)
Ratio of livestock income to total income	0.17 (0.23)	0.16 (0.17)	0.14 (0.15)	0.17 (0.2)	0.12 (0.21)	0.12 (0.19)
Ratio of off-farm income to total income	0.53 (0.35)	0.46 (0.3)	0.44 (0.26)	0.51 (0.35)	0.45 (0.29)	0.48 (0.27)
Credit (in '0000′ INR)[1]	6 (7.87)	7.42 (8.98)	5.18 (5.97)	9.53 (16.71)	8.48 (18.68)	7.73 (9.73)
Liquid assets (in '0000′ INR)	16.06 (23.16)	16.98 (24.3)	13.63 (16.38)	31.67 (55.42)	17.18 (18.06)	22.89 (24.87)

Source: ICRISAT VLS-VDSA database of six study villages.
[1] INR is Indian rupee. Values in the parentheses indicating standard deviation (SD).

Table 8
Predicted marginal effects of factors affecting vulnerability of smallholders in India.

Variables	Marginal effect (*dy/dx*)	
	Low to moderately impacted	Highly impacted
Age of household head, (year)	0.0014 (0.0025)	0.0012 (0.0023)
Family size	0.0332** (0.0153)	0.0103 (0.0141)
Operated area (Ha)	0.0103 (0.0159)	−0.0363** (0.0181)
Ratio of irrigated area to operated area	0.0791 (0.0894)	−0.0222 (0.0801)
Ratio of cash crop area to total cropped area	0.0553 (0.131)	−0.1648 (0.112)
Cropping intensity	0.0461 (0.0707)	0.1390** (0.0592)
Crop diversity index (%)	0.0053 (0.0051)	−0.0054 (0.0044)
Crop diversity index squared (%)	−0.0001 (0.0001)	0.00004 (0.0001)
Crop yield beta (%)	−0.0012 (0.007)	0.0181*** (0.0064)
Crop yield beta squared (%)	0.00002 (0.0001)	−0.0002*** (0.0001)
Ratio of livestock income to total income	−0.0541 (0.1771)	−0.3066* (0.1688)
Ratio of off-farm income to total income	−0.1155 (0.1297)	−0.3453*** (0.1178)
Borrowings (in '0000′ INR)	0.0056* (0.0037)	−0.0072* (0.0043)
Liquid assets (in '0000′ INR)	−0.0007 (0.0016)	0.0007 (0.0016)

Figures in parentheses are standard errors: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: ICRISAT VLS-VDSA database of six study villages.

Table 9
Predicted marginal effects of factors affecting resilience of smallholders in India.

Variables	Marginal effect (*dy/dx*)	
	Moderate resilience	High resilience
Age of household head, (year)	−0.0004 (0.0033)	−0.0021 (0.0031)
Family size	−0.0475* (0.0181)	0.0250* (0.0155)
Operated area (hectare)	0.0693* (0.0262)	−0.0556* (0.0313)
Ratio of irrigated area to operated area	−0.0168 (0.1068)	0.1133 (0.106)
Ratio of cash crop area to total cropped area	0.0455 (0.162)	0.1798 (0.1409)
Cropping intensity	0.1093 (0.0952)	0.0598 (0.0945)
Crop diversity index (%)	0.0120* (0.0074)	−0.0097* (0.0058)
Crop diversity index squared (%)	−0.0001 (0.0001)	0.0001 (0.0001)
Crop yield beta (%)	−0.0112 (0.0081)	0.0210*** (0.0085)
Crop yield beta squared (%)	0.0002* (0.0001)	−0.0002* (0.0001)
Ratio of livestock income to total income	−0.2438 (0.1984)	−0.0666 (0.1961)
Ratio of off-farm income to total income	0.0682 (0.1724)	−0.0442 (0.1701)
Borrowings (in '0000′ INR)	0.0013 (0.0024)	−0.0019 (0.0032)
Liquid assets (in '0000′ INR)	−0.0045** (0.0023)	0.0012 (0.0016)

Figures in parentheses are standard errors: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: ICRISAT VLS-VDSA database of six study villages.

risks and decrease the probability that the smallholder households would be in the “highly impacted” category. In essence, they have more resources to withstand climatic shocks. Findings underscore the importance of livestock and off-farm income in reducing climatic shocks' impact on crop production. Income diversification strategies provide opportunities to cope with climatic shocks and enhance resilience.

Livestock and off-farm income actively contributed to farmers' adaptive capacity by enabling them to better manage crops during the droughts. Livestock especially seems to deliver stable revenues across the three periods (pre-drought, drought, and post-drought). Most of the households during the drought and post-shock period engaged in off-farm activities to relax their liquidity constraints. Livestock and off-farm income were crucial for enhancing adaptive capacity and households' ability to cope with drought; however, during the post-drought period, the farm households perhaps used these incomes for smoothening consumption, not for regaining crop production. The significant marginal effect of cropping intensity suggests that families with higher cropping intensity are more likely to be in the “highly impacted” category, compared to the “not impacted” base category of smallholders. The coefficient of farm size (operated area) is negative and statistically significant, indicating that large farms are less likely to be the “highly impacted” category than in the “not impacted” base category of smallholders. Three possible reasons could be economies of scale, large farms' ability to diversify production (enterprise diversification) quickly, and large farms' higher liquidity. Relatively larger landholders and resource-rich farmers are likely to have better access to drought-mitigating strategies for agriculture, including crop diversification and altering the timing of operations; income diversification and credit schemes; government responses, such as subsidies/taxes and improvement in agricultural markets; and the development and promotion of new crop varieties and advances in water management techniques, etc. (Smith and Lenhart, 1996; Mendelsohn, 2001; Smit and Skinner, 2002; Kurukulasuriya and Rosenthal, 2003; Hussain and Mudasser, 2007; Deressa et al., 2009). Finally, the significant marginal effects for credit indicate that an increase in the amount of credit decreases the likelihood of smallholders falling into the “highly impacted” category, compared to the “not impacted” base category of smallholders. Results show that an additional INR 10,000 in credit decreases the likelihood of the farmers falling into the “highly impacted” category by about 1%. A plausible explanation is that access to additional credit helps smallholders with consumption expenditures and farm production expenses.

Results in Table 9 report the predicted marginal effects of factors affecting smallholders' resilience to climatic shocks in semiarid India. The coefficient on crop yield beta is positive and statistically significant at the 1% level for the” high resilience” category of smallholder households, compared to the “low resilience” base category. Findings suggest that a high-risk crop portfolio increases the likelihood of being in the “high resilience” category. However, as indicated by the negative and significant coefficient of the squared term of crop yield beta, a substantially higher-risk crop portfolio decreases the likelihood of smallholders falling into the “high resilience” category, compared to the” low resilience” group. Crop diversity, which is considered a reliable adaptation strategy in drought-prone areas, contributed moderately to building resilience. The coefficient on the crop diversity index was positive and statistically significant at the 10 % level for the” moderate resilience” smallholder households' category, compared to the base category of “low resilience” smallholders. However, in the “high resilience” group, an increase in crop diversity decreases the likelihood of farmers falling into the “high resilience” category, compared to the “low resilience” group.

Finally, the marginal effect of liquid assets is negatively significant in the “moderate resilience” category, indicating that additional liquid assets decrease the likelihood of farmers being in the “moderate resilience” group, compared to the base group category of “low resilience.” A possible explanation could be that liquid assets such as savings may be directed toward financing consumption, thus preventing smallholders from bouncing back to pre-drought levels of yield and income. Our findings underscore the importance of credit or savings in moderately helped smallholder households reduce the impact of drought (vulnerability). Liquid assets that families perhaps use for maintaining consumption levels make their livelihood less precarious under drought conditions, and that might mean they need less effort to bouncing back. Aggregate household labor capacity is a resilience-enhancing factor. The risk averseness of low-resilient household groups might be due to inadequate access to information on climate, technology, and markets. Poor access to credit as well as loss aversion (Kahneman and Tversky, 1979) also might be essential drivers of the farmers' risk-averse nature. Households with lower income levels even opt for risk- avoiding options (Lybbert and Barrett, 2007).

5. Conclusions and policy implications

This paper presents a framework for quantifying vulnerability and resilience to climatic shock (drought) by accounting for smallholder households' ability to adapt and respond to climatic shocks. Exploring adaptation strategies that reduce vulnerability and enhance the resilience of smallholder households, we adopted a narrow view of both vulnerability and resilience to climate risk (drought). In that view, vulnerability is concerned only with a loss in crop income and crop production (productivity and acreage) following a climatic shock, and resilience is concerned with the speed of recovery to the pre-climatic-shock level. Our study shows that a majority of smallholder households in India have experienced a drought-induced decline in crop production that is not compensated by local price effects. For example, 18 % of smallholder households in the sample were unable to recover to their pre-climatic-shock levels of livelihood. Smallholder households employ *ex-ante* and *ex-post* mitigation measures to reduce the impact of climatic risks like drought. These adaptation strategies, in turn, are influenced by smallholders' asset base and risk attitudes. Natural, economic, and human capital plays a vital role in determining the vulnerability and resilience level of the smallholder household. A large proportion of smallholder households bounced back post-drought to a varying extent. Among the” low to moderately impacted” households, a majority of them (52 %) bounced back fully as a “high resilience” group. However, of the “highly impacted” families, only 14 % bounced back fully as a “high resilience” group.

Results from this study suggest that farmers' adaptive capacity and resilience is positively influenced by natural, economic, and human capital. It also is significantly influenced by several adaptation strategies, such as income and crop diversification activities pursued by the household. However, families' adaptive choices often are constrained by various factors (Bryan et al., 2009), including lack of capital and poor access to relevant information and knowledge. In the face of growing concerns over climate change and drought risk, policymakers can design policies that support farm-level adoption of risk management strategies, such as choice of crops, crop diversification, access to irrigation, and access to credit. The policymaker should consider agroecology and risk in targeting policy support so that appropriate technologies are promoted in the right context, for example, irrigation infrastructure where groundwater resources and cash crops are sustainable where the risk-return profile is suitable.

Comprehensive strategies to build and increase resilience should target specific categories of risks, dimensions of vulnerability across different time scales – *ex-ante*, during shock, and *ex-post*. For instance, before the shock, improved access to early detection of emerging climate risks can help farmers plan their cropping activities accordingly. Access to climate information and advisories will allow forward-looking adaptation that will result in both reducing the impact of shock and enhancing resilience (Mulwa et al., 2017; Shikuku et al., 2017). Access to safety nets and organized compensation systems during the shock will ensure that households can withstand the impacts of climatic shocks. The safety nets would enable resilience specifically for highly impacted households, which otherwise are unable to bounce back to the pre-shock level. Instruments such as crop insurance, price-stabilizing funds, and access to employment opportunities can have compensating effects on smallholder households. Post-shock, actions that progressively reduce the impact of previous climatic shocks can help build resilience, and policymakers should encourage such actions.

Additionally, agro-ecological and sustainable management of landscapes, especially common property resources and forests (Braatz, 2012), can be practiced. These management actions could help reduce vulnerability in the biophysical domain, with spillover effects on enhancing resilience. Although an enabling institutional and policy environment is essential for promoting adaptive capacity and resilience, most of the adaptation is facilitated and self-governed by farmers' human, social, and physical capital. We believe that our focus on understanding vulnerability and resilience at the household level will direct attention to the main actors in coping and adaptation. Quantitatively detecting and assessing the vulnerability, resilience, and adaptive behaviors of smallholder households are essential for formulating context- specific policy packages that target sustainable development and climate-related adaptation. A robust adaptation strategy for drought must balance ecological, economic, and social benefits. Future research could integrate market, financial, and biophysical risks into the above framework to better understand the drivers of vulnerability and resilience.

CRediT authorship contribution statement

Shalander Kumar: Conceptualization, Methodology, Writing - original draft, Supervision, Validation. **Ashok K. Mishra:** Conceptualization, Writing - review & editing, Visualization. **Soumitra Pramanik:** Investigation, Writing - original draft, Visualization. **Sravya Mamidanna:** Data curation, Writing - original draft. **Anthony Whitbread:** Writing - review & editing.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.landusepol.2020.104729.

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