

A district level assessment of vulnerability of Indian agriculture to climate change

C. A. Rama Rao^{1,*}, B. M. K. Raju¹, A. V. M. Subba Rao¹, K. V. Rao¹,
V. U. M. Rao¹, Kausalya Ramachandran¹, B. Venkateswarlu², A. K. Sikka³,
M. Srinivasa Rao¹, M. Maheswari¹ and Ch. Srinivasa Rao¹

¹ICAR-Central Research Institute for Dryland Agriculture, Hyderabad 500 059, India

²Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani 431 462, India

³Natural Resource Management Division, ICAR, New Delhi 110 012, India

Assessing vulnerability to climate change and variability is an important first step in evolving appropriate adaptation strategies to changing climate. Such an analysis also helps in targeting adaptation investments, specific to more vulnerable regions. Adopting the definition of vulnerability given by IPCC, vulnerability was assessed for 572 rural districts of India. Thirty eight indicators reflecting sensitivity, adaptive capacity and exposure were chosen to construct the composite vulnerability index. Climate projections of the PRECIS model for A1B scenario for the period 2021–2050 were considered to capture the future climate. The data on these indicators were normalized based on the nature of relationship. They were then combined into three indices for sensitivity, exposure and adaptive capacity, which were then averaged with weights given by experts, to obtain the relative vulnerability index. Based on the index, all the districts were divided into five categories with equal number of districts. One more district was added to ‘very high’ and ‘high’ categories. The analysis showed that districts with higher levels of vulnerability are located in the western and peninsular India. It is also observed that the highly fertile Indo-Gangetic Plains are relatively more sensitive, but less vulnerable because of higher adaptive capacity and lower exposure.

Keywords: Agriculture, adaptive capacity and exposure, climate change, sensitivity, vulnerability.

THE Intergovernmental Panel on Climate Change (IPCC)¹ in its recent assessment report observed considerable changes in global temperature, precipitation patterns and incidence of extreme weather events. Climate change is probably the most complex and challenging environmental problem faced by the world today² and is increasingly recognized as a potent threat to agriculture in general and to food security in particular. IPCC³ defines climate change as ‘a change in the state of the climate that can be identified (e.g. using statistical tests), by changes in the

mean and/or variability of its properties, and that persists for an extended period, typically decades or longer’. Although climate change is global in its occurrence and consequences, it is developing countries like India, that face more adverse consequences. Globally, climate change is seen as a failure of market mechanisms, wherein polluters have not had to pay for the negative externalities⁴.

Climate change projections made for India indicate an overall increase in temperature by 1–4°C and precipitation by 9–16% towards 2050s (ref. 5). However, different regions are expected to experience differential change in the amount of rainfall in the coming decades⁶. Another significant aspect of climate change is the increased frequency of occurrence of extreme events such as droughts, floods and cyclones. All these expected changes will have adverse impacts on climate-sensitive sectors such as agriculture, forest and coastal ecosystems, availability of water for different sectors and on human health.

The international negotiations on climate change have now rightly recognized that adaptation is as important as mitigation, when dealing with climate change. The world is already committed to a certain extent of climate change and even drastic mitigation efforts will not prevent the projected rise in temperature till 2100. Therefore, adaptive measures to deal with climate variability and change need greater attention, in terms of policy, research and institutional interventions. In order to develop and target appropriate adaptive measures, it is important to identify regions that are relatively more affected by climate change. This ‘identification process involves assessment of vulnerability of different regions’⁷.

This paper presents the analysis of vulnerability of agriculture to climate change and variability at the district level, considering the fact that most of the development planning and programme implementation is done at district level in India. Also, most of the non-climatic data, integral to assessment of vulnerability to climate change and adaptation planning, is available at district level. Thus, this analysis is useful in identifying the districts that are relatively more vulnerable to climate change, so that the necessary investments can be targeted. It is also

*For correspondence. (e-mail: carrao@crida.in)

useful to identify sources of vulnerability that are critical to developing appropriate adaptation measures, in terms of technologies, investments and policies.

Vulnerability assessment – a review

‘Vulnerability’ has emerged as a cross-cutting multidisciplinary theme of research in the current context, characterized by rapid changes in environmental, economic and social systems⁸. Accordingly, vulnerability is viewed differently by different individuals and organizations, depending on the context in which they operate. For example, vulnerability is viewed as susceptibility to a natural hazard, or refers to the frequency of occurrence of a hazard in the literature related to disaster management. In contrast, development economics views vulnerability as the propensity of the entity to face a negative outcome in terms of poverty, food insecurity or loss of welfare and does not always link this negative outcome to a specific risk. In the context of climate change and agriculture, vulnerability refers to the propensity of the entity to face a climate shock, suffer loss in production and/or income from agriculture, though the latter is not always specified explicitly⁹. Vulnerability is essentially an *ex-ante* concept and refers to the possibility of being hit or probability of being harmed by a stress or shock¹⁰.

Earlier studies on vulnerability assessment viewed it more as a biophysical impact of climate change. These impact assessments ‘superimpose future climate scenarios on an otherwise constant world to estimate the potential impacts of anthropogenic climate change on a climate-sensitive system’¹¹. The emphasis gradually shifted to derive policy lessons from vulnerability assessment, as the purpose of such assessment was to identify strategies that reduce vulnerability of systems or populations concerned. Recent studies on vulnerability recognize the importance of non-climatic factors in dealing with climate change. Vulnerability in the climate change context is generally related to the residual impact of climate change after accounting for possible adaptation. There are three major approaches to analysis of vulnerability to climate change.

Socio-economic approach

This mainly focuses on socio-economic and political status of individuals or social groups that vary in terms of education, wealth, health status, access to resources (credit, information, etc.), social capital and so on. This approach holds these variations responsible for differential vulnerability levels (e.g. Adger and Kelly)¹². Here, vulnerability is considered as a ‘starting point or state’ of the system before it encounters the hazard event.

Biophysical approach

This approach assesses the level of damage that a given environmental stress causes to both social and biological systems, and is generally identified with impact assessment or hazard-loss relationship. As opposed to the socio-economic approach, this focuses on the ‘end point’. In the context of crop production, this involves simulating or modelling how crop yields change under conditions that characterize climate variability or climate change^{13–17}.

Integrated approach

This combines both socio-economic and biophysical approaches to determine vulnerability. IPCC¹⁸ defines vulnerability as ‘the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity’. This definition accommodates this approach to vulnerability analysis. According to this definition, vulnerability has three components – adaptive capacity, sensitivity and exposure.

Sensitivity is defined as ‘the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli’. It is determined by demographic and environmental conditions of the region concerned. Exposure is defined as ‘the nature and degree to which a system is exposed to significant climatic variations’. Thus, exposure relates to climate stress upon a particular unit of analysis¹⁹. ‘A more complete measure of exposure to future climate change would require consideration of projected changes in climate in each analysis unit’²⁰. Adaptive capacity is ‘the ability of a system to adjust to climate change, including climate variability and extremes to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. It is considered to be ‘a function of wealth, technology, education, information, skills, infrastructure, access to resources, stability and management capabilities’¹⁸.

In this framework, adaptive capacity is largely consistent with socio-economic approach, while sensitivity with biophysical approach and both are internal dimensions. The component of exposure is viewed as an external dimension. While higher exposure and sensitivity mean higher vulnerability, adaptive capacity moderates vulnerability and hence is inversely related to vulnerability. Although lack of standard methods for combining the biophysical and socio-economic indicators is a limitation to this approach, it can be helpful in making policy decisions²¹.

Though there are different methods and approaches for assessing vulnerability, selection of a particular method is determined by the context, purpose and scale of analysis,

as well as by the availability of appropriate data. We have adopted the indicator method to construct vulnerability of agriculture to climate change and variability at the district level. Because of its transparency, this method was followed in many studies that assessed vulnerability. Deressa *et al.*²¹ ranked the seven Ethiopian states based on vulnerability indices constructed, following an integrated approach. Eriyagama *et al.*²⁰ analysed the relative vulnerability of districts in Sri Lanka using historical data on indicators related to three components of vulnerability. Studies on vulnerability to climate change in India are limited²². O'Brien *et al.*⁸ assessed the vulnerability to climate change and trade globalization of different districts in India, following the integrated approach. They identified districts that were relatively more vulnerable to climate change, to globalization of agricultural trade and to both. They have used climate projections for the period 2071–99 made using the HaDRM 2 climate model output. Palanisami *et al.*²³ assessed the vulnerability of districts in Tamil Nadu to climate change. They used indicators that represent demographic, agricultural and technological development, and constructed vulnerability index for different agro-climatic regions and districts in the state. This approach broadly classifies indicators into those related to physical, natural, human and financial resource endowments that determine the livelihood outcomes. Some studies²⁴ assessed vulnerability of coastal districts by combining a number of indicators related to adaptive capacity, sensitivity and exposure. Palanisami *et al.*²⁵ assessed the vulnerability of districts in the Krishna-Godavari basin based on indicators related to agriculture, demography, etc. Ravindranath *et al.*²⁶ assessed the vulnerability of districts in North-Eastern states by constructing separate vulnerability indices for agriculture, forestry and water sectors. They incorporated the data on climate projections into models that predict the forest cover, which were then included in the construction of vulnerability index following the IPCC framework.

Compared to earlier studies, the present study combines a richer set of indicators to construct the vulnerability index, for making relative assessment of the districts. Unlike most of the earlier studies, this study incorporates climate projections in the form of agriculturally relevant indicators/variables, such as incidence of dry spells, which would be more useful in planning technology development and policy formulation for adaptation. The study is comprehensive in terms of its coverage by including all 572 rural districts in the country.

Methodology

Selection of indicators

As mentioned earlier, the definition of vulnerability given by IPCC is adopted in this study. According to this, vulnerability is a function of the extent and degree to which

an entity is exposed, sensitivity of the entity to climate change and adaptive capacity to adapt to and cope with the changing climate. Considering that vulnerability intends to capture the residual impact of climate change after partly accounting for adaptation¹¹ that farmers undertake and the difficulties involved in quantifying potential and residual impacts at district level, the indicator method was chosen to assess vulnerability of agriculture to climate change at district level. Indicators are variables that reflect the underlying phenomenon of interest. It is this 'significance' to the phenomenon/issue being addressed that makes an indicator out of a variable. Further, indicators should ideally have a monotonic relationship with the underlying phenomenon over a reasonable range of values that they may take. In the present context, the three components of vulnerability – sensitivity, exposure and adaptive capacity – are represented through a number of indicators that would reflect them. These indicators were chosen from a broader list of indicators based on review of literature, discussions with experts and nature of relationship with the three components of vulnerability. It may be noted here that inclusion of indicators into dimensions of sensitivity or adaptive capacity is relatively more difficult and subjective²⁷. We have considered those indicators that determine the extent and intensity of possible effects of climate change and/or variability as reflecting sensitivity. Thus, variables like net sown area and rural population density (Table 1) determine the 'extent' of the problem, while indicators such as water holding capacity of soils, stage of ground water development (draft versus availability) frequency and intensity of occurrence of climate shocks determine intensity or degree of effect of such shock. Similarly, indicators that are relatively more responsive to policy measures such as irrigation are included in adaptive capacity. The determinants of exposure are derived from climate projections as done in previous studies^{8,21,26}. We used projections from PRECIS RCM for IPCC SRES A1B scenario for the purpose.

Table 1 lists indicators chosen to reflect the three dimensions of vulnerability.

Computation of vulnerability index

A data set with 38 indicators for 572 districts (as appearing in 2001 census) was developed. The indicators under each component were normalized and then combined to build composite indices for respective components following methodologies of UNDP²⁸ and UNDP²⁹. However, it differs as the minimum and maximum of indicator values are taken from the data set, rather than fixing the minimum and maximum values on *a priori* considerations. In case of rainfall, the maximum value is fixed at 1500 mm as most crops do not respond positively to rainfall above this. Similarly, maximum values were defined

Table 1. Indicators of sensitivity, exposure and adaptive capacity included in computation of vulnerability index

Sensitivity	Exposure (change w.r.t. baseline)	Adaptive capacity
Net sown area as % geographical area	Annual rainfall	Rural poor (%)
Degraded land and waste lands as % geographical area	June rainfall	SC/ST population (%)
Annual rainfall	July rainfall	Workforce in agriculture (%)
Cyclone proneness	Number of rainy days	Literacy (%)
Area prone to flood incidence as % geographical area	Maximum temperature	Gender gap
Drought proneness	Minimum temperature	Markets per 1 lakh holdings
Available Water holding capacity (AWHC) of the soil	Heat wave frequency	Paved roads (% villages)
Stage of groundwater development (Ratio of draft to availability)	Cold wave frequency	Rural electrification (% villages)
Rural population density	Frost occurrence	Net irrigated area (%)
Area owned by small and marginal farmers (%)	Drought proneness	Density of livestock population (adult cattle units per sq. km)
	Dry spells (≥ 14 days)	Fertilizer consumption (N + P + K per ha)
	Extreme rainfall events (100 mm in 3 days, one day highest, three days highest and 99 percentile)	Groundwater availability (ha m/sq. km)
		Share of agriculture in district domestic product

Scale of measurement of indicators, source of data and other details are available at Rama Rao *et al.*³².

for fertilizer consumption (400 kg/ha) and number of markets per lakh holdings (40).

Two ways of rescaling as suggested by Iyengar and Sudarshan³⁰ were used to normalize indicators, depending on relationship of the indicator with the dimension

$$Z_i = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}},$$

when indicator is positively related to the phenomenon of dimension

$$Z_i = \frac{X_{\max} - X_i}{X_{\max} - X_{\min}},$$

when indicator is negatively related to the phenomenon of dimension, where Z_i is the normalized value of i th district w.r.t. the indicator X ; X_i is the value of indicator in original units for i th district; X_{\min} is minimum value of the indicator in original units across the districts and X_{\max} is maximum value of the indicator in original units across the districts. Three indices for sensitivity, exposure and adaptive capacity were constructed by obtaining a weighted mean (weights given in Table 2) of component indicators. These three indices were then averaged (with weights of 25, 40 and 35 to exposure, sensitivity and adaptive capacity respectively) to obtain vulnerability index, higher values of which indicate higher vulnerability and lower values indicate lower vulnerability. It is to be noted that this index is not an absolute measure of damage or risk due to climate change and it is only a relative measure of risk between the districts. It is however

helpful in targeting and prioritization of investments for adaptation.

The weight given to each indicator was based on review of literature and a series of discussions with a group of experts actively involved in research for developing appropriate adaptation, mitigation measures and strategies to deal with climate change.

These results were in agreement with those obtained using weights derived by subjecting the data to principal components analysis. These were then presented to relevant stakeholders before finalizing the output. All 572 districts were categorized into 5 equal quintiles of 114 districts each and one district at the margin was added to the two more vulnerable categories. Thus, 5 categories of districts with – very high vulnerability (115), high vulnerability (115), medium vulnerability (114), low vulnerability (114) and very low vulnerability (114) were identified. In case of districts with high and very high vulnerability, most important factors contributing to vulnerability component-wise were identified, based on the normalized values of indicators and weights assigned, to plan appropriate interventions and minimize vulnerability.

Findings and implications to interventions

Description of status based on individual indicators was skipped for space limitation. Only results pertaining to the three components of vulnerability are presented here. Most districts in North-West India have very high sensitivity, and those in the Indo-Gangetic plains of Uttar Pradesh, Bihar and West Bengal exhibit high sensitivity

Table 2. Weighting scheme followed in construction of vulnerability index

Exposure	Weight (%)	Sensitivity	Weight (%)	Adaptive capacity	Weight (%)
Change in annual rainfall	10	Net sown area as % geographical area	15	Rural poor (%)	10
Change in June rainfall	5	Degraded land as % geographical area	5	SC/ST population (%)	5
Change in July rainfall	15	Annual rainfall (normal)	20	Workforce in agriculture (%)	5
Change in number of rainy days	5	Cyclone proneness	5	Literacy (%)	5
Change in MaxT	8	Area prone to flood incidence	10	Gender gap	5
Change in MinT	10	Drought proneness	20	Markets per 1 lakh holdings	5
Change in extreme hot day frequency	5	AWHC of soil	5	Paved roads (% villages)	5
Change in extreme cold day frequency	3	Stage of groundwater development	10	Rural electrification (% villages)	5
Change in frost occurrence	2	Rural population density	5	Net irrigated area (%)	20
Change in drought proneness	12	Area operated by small and marginal farmers	5	Density of livestock population	8
Change in incidence of dry spells of ≥ 14 days	5			Fertilizer consumption	8
99 percentile rainfall	5			Ground water availability	15
Change in number of events with >100 mm rainfall in 3 days	5			Share of agriculture in district domestic product	4
Change in highest rainfall in a single day as % to annual normal	5				
Change in highest rainfall in 3 consecutive days as % to annual normal	5				

(Figure 1 a). Similarly, a number of districts in peninsular semi-arid regions are also highly sensitive. Sensitivity is found to be relatively low in the Eastern, North-Eastern, Northern parts and along the West Coast of the country. High to very high exposure is observed in the districts of Madhya Pradesh, Karnataka, Rajasthan, Gujarat, Maharashtra, Bihar, Tamil Nadu, North-Eastern states and Jammu & Kashmir (Figure 1 b). Districts with low and very low exposure are seen in Andhra Pradesh, Orissa, West Bengal, parts of Punjab, Haryana, Rajasthan and Uttar Pradesh. Adaptive capacity is found to be very low in the Eastern and North-Eastern states, Rajasthan, Madhya Pradesh, peninsular and hill regions (Figure 1 c). Adaptive capacity is high in Punjab, Haryana, western Uttar Pradesh, many districts along the East Coast and Tamil Nadu. Districts in Rajasthan, Gujarat, Madhya Pradesh, Karnataka, Maharashtra, Andhra Pradesh, Tamil Nadu, eastern Uttar Pradesh and Bihar exhibit very high and high vulnerability (Figure 1 d). Districts along the West Coast, northern Andhra Pradesh, North-Eastern states are relatively less vulnerable.

Table 3 gives the distribution of districts with varying degree of vulnerability. It can be seen that most of the districts with very high and high vulnerability are in the states of Rajasthan, Gujarat, Uttar Pradesh, Madhya Pradesh, Karnataka and Maharashtra. Similarly, of the 115 districts that are highly vulnerable to climate change and variability, 18 are in Uttar Pradesh, 16 in Madhya Pradesh, 15 in Bihar, 9 in Haryana, 7 in Chhattisgarh and 6 each in Jharkhand, Gujarat and Rajasthan. Investments that enhance adaptive capacity and resilience may be targeted to these districts.

The most important factors responsible for vulnerability were identified in each component in case of more vulnerable districts, those with 'very high' and 'high' vulnerability. Thus, in case of variables that determine exposure of the district to climate change and variability, increase in drought incidence, increase in minimum temperature and decrease in rainfall during June and July, emerged as important factors suggesting the possible technological and other interventions needed. For example, changes in rainfall pattern are better tackled by a combination of measures such as altering sowing dates, altering crop duration to maturity and enabling supplemental irrigation wherever possible. In districts where likely increase in incidence of extreme rainfall events is an important source of vulnerability, interventions that protect human and physical resources along with a more coordinated settlement planning are needed. This increased frequency may be, wherever possible, seen as an opportunity to harvest and store water for later use. Low rainfall, high drought incidence, low available water holding capacity of soils, high flood proneness and larger area under agriculture are the most important sensitivity-related factors contributing to vulnerability. This suggests that the current approaches and interventions related to rainwater harvesting, watershed development and breeding for drought-tolerant crop varieties should continue to receive priority. In some districts, a very high proportion of land is under crop production pointing to the pressure on land. In such cases, there is a need to explore the possibility of enhancing non-farm employment opportunities. In case of adaptive capacity lacking or inadequate irrigation facilities, and low groundwater availability are important

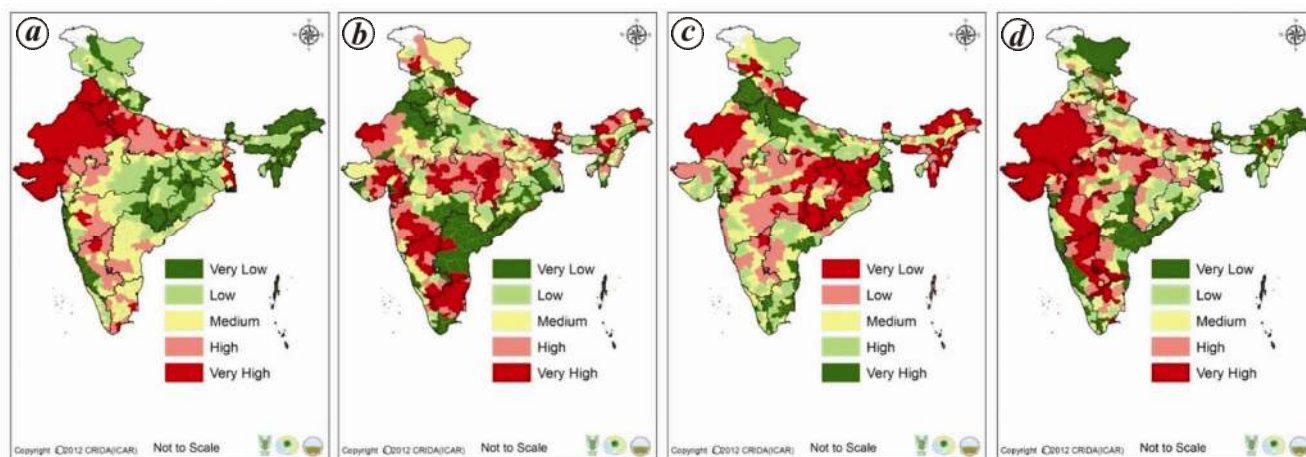


Figure 1. Classification of districts based on (a) sensitivity index, (b) exposure index, (c) Adaptive capacity index and (d) vulnerability index.

Table 3. Distribution of districts according to the degree of vulnerability (2021–50) in different states

State	Vulnerability					Total
	Very high	High	Medium	Low	Very low	
A&N Islands	0	0	0	0	1	1
Andhra Pradesh	2	1	1	1	8	13
Arunachal Pradesh	0	0	0	5	9	14
Assam	1	1	1	7	13	23
Bihar	6	15	7	6	3	37
Chhattisgarh	0	7	4	5	0	16
Dadra & Nagar Haveli	0	0	0	0	1	1
Daman & Diu	1	0	0	0	0	1
Goa	0	0	0	0	1	1
Gujarat	14	6	1	1	3	25
Haryana	0	9	6	2	2	19
Himachal Pradesh	0	4	2	3	3	12
Jammu & Kashmir	0	1	6	3	4	14
Jharkhand	3	6	7	2	0	18
Karnataka	14	5	0	2	6	27
Kerala	0	0	4	7	3	14
Madhya Pradesh	14	16	9	4	2	45
Maharashtra	12	5	3	6	7	33
Manipur	0	0	3	3	3	9
Meghalaya	0	0	1	3	3	7
Mizoram	0	0	1	7	0	8
Nagaland	0	0	0	3	5	8
Orissa	0	1	9	14	6	30
Pondicherry	0	0	0	0	1	1
Punjab	1	4	4	6	2	17
Rajasthan	25	6	1	0	0	32
Sikkim	0	0	0	2	2	4
Tamilnadu	6	5	9	4	5	29
Telangana	0	1	2	0	6	9
Tripura	0	0	0	0	4	4
Uttar Pradesh	12	18	24	14	2	70
Uttarakhand	3	4	1	1	4	13
West Bengal	1	0	8	3	5	17
India	115	115	114	114	114	572

factors determining vulnerability. The importance of irrigation in agricultural development can hardly be over-emphasized. Making irrigation sustainable and more equitable is more important. The changing rainfall pattern, spatial and temporal, needs to be appropriately and ade-

quately factored in planning for expansion of irrigation facilities. It is also needed to give more emphasis on supplemental and critical irrigation using rainwater harvesting. The planning for irrigation should also consider developing appropriate crop plans/cropping pattern

that optimize returns to farmers as well as maximize returns to water use. The connotation of water use efficiency needs to be taken in its broader meaning. Strengthening adaptive capacity is also helpful for farmers in dealing with other development problems. In any case, consideration of information related to all indicators used in the construction of vulnerability index, will be helpful in identifying interventions that are more specific to the district. It may be added that considering any intervention that is not relevant to and useful in dealing with current problems of agriculture are less likely to be accepted by farming community, it is preferable to identify interventions that help farmers deal with future climatic stress as well as with current climatic variability.

Finally, a look at different indicators related to climatic projections also showed some districts where annual rainfall is likely to increase with more rainy days, which actually present some opportunities for improving crop production and productivity. Such opportunities can be gainfully harnessed which in fact will be a significant step towards making Indian agriculture more climate resilient and smart.

Scope and limitations: As mentioned, the analysis is done for 572 rural districts as appearing in 2001 Census of India. All Union Territories included in the analysis were considered as a single district. The vulnerability index constructed is relative in nature. Considering all the districts that vary widely with respect to indicators chosen together, will mean that the indicator is linearly related to the underlying phenomenon which may not be the case in reality. Climate projections for the country vary with corresponding models and different emission scenarios assumed. We have used only one model projection (A1B SRES scenario) because it showed 'reasonable skill in simulating the monsoon climate over India'⁵ and was considered as 'the most appropriate scenario as it represents high technological development, with the infusion of renewable energy technologies following a sustainable growth trajectory' (MoEF)³¹. Further, for a study of this scale, obtaining data on all the variables/indicators for a uniform reference period is extremely difficult. For most of the status variables like irrigation, net sown area, electrification, district domestic product, etc., we have used the most recent data available for each unit of analysis unless specified otherwise. The missing data are computed following appropriate methods such as using nearest neighbourhood value, average value of respective state, etc.

Note

The state of Andhra Pradesh was reorganized into states of Telangana and Andhra Pradesh on 2 June 2014 and a part of Khammam district in Telangana was placed in

Andhra Pradesh. This change was not accounted for in the analysis.

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