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A spatial assessment of agricultural vulnerability to climate change using multidimensional data in Maharashtra state of India

PRAKASH G ATHARE[1]*, DHARAM RAJ SINGH[1], NALINI RANJAN KUMAR[2], GIRISH KUMAR JHA[3] and P VENKATESH[1]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

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ABSTRACT

This study aims to examine district-level agricultural vulnerability in the semi-arid and drought-prone state of Maharashtra. Using a multidimensional approach, suitable indicators for 34 districts were selected under exposure, sensitivity and adaptive capacity, aligning with the IPCC 2007 framework for vulnerability assessment. The analysis used temperature and rainfall data spanning 50 years (1968–2017). It also incorporated area and yield data from 2011 to 2020, along with other indicators for the year 2019–20. The composite agricultural vulnerability index (CAVI) score was obtained using proper normalization and assigning weights. The study revealed that the Marathwada and Vidarbha regions reported higher potential crop losses. Among the districts, Sangali was the most exposed (0.57), while Jalgaon was the least exposed (0.31) to climate variations. Ahmednagar exhibited the highest sensitivity (0.70), while Nagpur showed the lowest sensitivity (0.34) to climate change. Regarding adaptive capacity, Pune demonstrated the highest resilience (0.57) and Sindhudurg displayed the lowest score (0.23). CAVI highlighted that the Konkan region, along with western Maharashtra and eastern parts of Vidarbha, exhibited relatively lower vulnerability to climate change, due to factors such as lower potential crop loss and better adaptive capacity. In contrast, Marathwada and western Vidarbha regions were more vulnerable, facing significant crop production losses and higher exposure to climate variability. Hence, to build resilience to climate change and reduce crop production losses, crop planning needs to be adjusted according to the climatic conditions in these regions.

Keywords: Crop production loss, Climate change, Maharashtra, Agricultural vulnerability

Climate variability and extreme events have emerged as pressing concerns in the 21st century, presenting significant challenges to mitigate their impacts in agriculture. India is among the countries most vulnerable to the impacts of global warming, with the agriculture sector being significantly affected (Sendhil *et al.* 2018). It is projected that climate change will cause farm incomes to decrease by 15–18%, with potential losses escalating to 20–25% in rainfed regions (GoI 2018). According to climate modelling studies, semi-arid regions of India are likely to experience substantial shifts in the frequency and intensity of drought events (IPCC 2007). Maharashtra has also experienced a notable increase in both maximum and minimum temperatures from 1969 to 2006, coinciding with global changes in Earth's surface temperature and variations in extreme temperatures (Dhorde *et al.* 2017). Looking towards the near future, projections from The Energy and Resources Institute (TERI 2014) suggest that by 2030, the Vidarbha, Marathwada and Nasik regions may experience an average temperature increase of 1.2–1.5°C, while the Pune and Konkan regions could see a rise of 1.0–1.2°C. According to Todmal (2021), projections are indicating a significant rise in monsoon rainfall across all meteorological sub-divisions of Maharashtra by 2100, except for Konkan, with estimates indicating an increase of 150–210 mm.

Assessing vulnerability is important for proposing measures to address the negative impacts of climatic changes, aiding in the identification of vulnerable regions or the extent of vulnerability. The existing literature on vulnerability assessment in Maharashtra (Murali *et al*. 2020, Adhav *et al*. 2021, Swami and Parthasarathy 2021) has focused on various regions and farm households. However, there remains a lack of comprehensive analysis incorporating multidimensional factors, including the crop production loss index. Hence, this study adopts a multidimensional approach to analyse the spatial vulnerability of agriculture to climate change in Maharashtra. The aim is to provide

[1]ICAR-Indian Agricultural Research Institute, New Delhi; [2]ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi; [3]ICAR-Indian Agricultural Statistics Research Institute, New Delhi. *Corresponding author email: prakashathare121@gmail.com

policymakers with insights for developing district-specific crop planning strategies that enhance resilience to climate change and minimize crop production losses.

MATERIALS AND METHODS

Data sources: District-level data on relevant variables were collected for 34 districts of Maharashtra, excluding Mumbai city and Mumbai Suburban as the share of agriculture is negligible in these districts. Data on area and yield were collected for cereals (rice, wheat, sorghum, pearl millet, maize); pulses (chickpea, pigeonpea, greengram, blackgram and minor pulses); oilseeds (groundnut, soybean and sunflower); and two cash crops (cotton and sugarcane), from the Directorate of Economics and Statistics, Maharashtra, for the period of 2010–11 to 2019–20. Moreover, temperature and rainfall data for 50 years (1968–2017) were obtained from the Indian Meteorological Department, Government of India. Further data on other indicators for the year 2019–20 were collected from district reports, official documents issued by the Government of Maharashtra, the 20th Livestock Census, Pradhan Mantri Fasal Bima Yojana portal of the Ministry of Agriculture and Farmers Welfare, Government of India and the Central Ground Water Board (CGWB), Ministry of Water Resources, Government of India.

Vulnerability assessment: The district-level composite agricultural vulnerability index has been estimated using the following procedures:

Selection of the indicators: In any vulnerability assessment study, choosing appropriate indicators is one of the most important steps. Therefore, much care was taken to finalize the indicators for each index and their apriori functional relationships through a review of the literature and discussions with experts. Table 1 shows the different indicators selected for estimating exposure, sensitivity and adaptive capacity index, along with their descriptions and functional relationships with the respective index.

Normalization of the indicators: Normalization of indicators ensures that all the indicators are comparable, despite being measured on different units. If the value of indicator is positively related to its target index:

$$\text{Normalisation} = \frac{(\text{Actual value} - \text{Minimum value})}{(\text{Maximum value} - \text{Minimum value})}$$

If the variable exhibits a negative functional relationship with the target index:

$$\text{Normalisation} = \frac{(\text{Maximum value} - \text{Actual value})}{(\text{Maximum value} - \text{Minimum value})}$$

Assigning weights to the indicators: Generally, various methods are used for assigning weights to indicators, including equal weights, expert opinion, Principal Component Analysis (PCA) and the inverse of variance, but each of these methods has limitations (Acharya *et al.* 2021). To address the limitations of these individual methods, the average of PCA and inverse of variance methods is considered as the weight.

Further, the calculated weights are assigned to each variable and the index value for each district is estimated using the following formula:

$$\text{Index}_j = \sum_i^k w_i \times Z_{ij}$$

where, W_i, Weight corresponding to the i^{th} indicator; k, Total number of indicators; Z_{ij}, Normalised value of the i^{th} indicator for the j^{th} district and $\sum_i^k w_i = 1$, The summation of weight is equal to 1.

Estimation of crop production loss index (CPLI): For estimating the average crop loss across the districts, we used the information on potential crop loss caused by climate variability from 2010–11 to 2019–20. The total loss is divided into components such as area, yield and interaction deviation effect by using a formula developed by Kumar *et al.* (2016)

The district wise potential crop loss for a different crop group can be calculated as follows:

$$PL_i = \frac{1}{t_n}\left[\sum_{t=1}^{n} Y_t(A_m - A_t) + \sum_{t=1}^{n} A_t(Y_m - Y_t) + \sum_{t=1}^{n}(Y_m - Y_t)(A_m - A_t)\right]$$

where PL_i, Average production loss for particular crop in a district; A_t and Y_t, Actual area and yield for the year, respectively; A_m and Y_m, Potential (de-trended) area and yield in 2010–11 to 2019–20, respectively; $\sum_{t=1}^{n} Y_t(A_m - A_t)$, Area deviation; $\sum_{t=1}^{n} A_t(Y_m - Y_t)$, Yield deviation; and $\sum_{t=1}^{n} (Y_m - Y_t)(A_m - A_t)$, Area and yield interaction effect.

After normalizing the estimated production losses for cereals, pulses, oilseeds, sugarcane and cotton, weighted averages of these five indices were considered to construct a CPLI.

Composite agricultural vulnerability index (CAVI): Finally, the CAVI for each district was computed by following formula:

$$CAVI_j = (CPLI_j + EI_j + SI_j) - AC_j$$

where $CAVI_j$, Composite agricultural vulnerability index of the j^{th} district; $CPLI_j$, Crop production loss index of the j^{th} district; EI_j, Exposure index of the j^{th} district; SI_j, Sensitivity index of the j^{th} district; AC_j, Adaptive capacity index of the j^{th} district.

A district with a higher index score is considered more vulnerable to climate change.

Classification of districts: Finally, districts were categorized into three groups, viz. high, moderate and low, based on mean and standard deviation norms (Kale *et al.* 2016, Sendhil *et al.* 2018, Balaganesh *et al.* 2020).

$$\text{Low} = \text{Index} < (\text{Mean} - 0.5 \times \text{SD})$$

$$\text{Moderate} = (\text{Mean} - 0.5 \times \text{SD}) < \text{Index} < (\text{Mean} + 0.5 \times \text{SD})$$

$$\text{High} = \text{Index} > (\text{Mean} + 0.5 \times \text{SD})$$

RESULTS AND DISCUSSION

Crop production loss index: Table 2 provides the district-wise crop production loss index (CPLI) score and the degree of production loss. Among all districts, Yavatmal

Table 1 List of indicators for exposure, sensitivity and adaptive capacity index

Exposure index			Sensitivity index			Adaptive capacity index		
Indicators	Description	Functional relationship	Indicators	Description	Functional relationship	Indicators	Description	Functional relationship
Growth in *kharif* season rainfall	Compound annual growth rate	-	Small and marginal farmers	Share of small and marginal farmers to total farmers	+	Per capita income	Per capita income	+
Growth in *rabi* season rainfall	Compound annual growth rate	-	Groundwater exploitation	Stage of groundwater exploitation	+	Crop insurance	Proportion of area insured to gross cropped area	+
Instability in *kharif* season rainfall	Cuddy-Della Valle instability index	+	Farm size	Average farm size (ha)	-	Crop diversification	Simpson diversification index	+
Instability in *rabi* season rainfall	Cuddy-Della Valle instability index	+	Degraded area	Proportion of degraded area to geographical area	+	Fertilizer consumption	kg/ha	+
Rate of change in maximum temperature (*kharif*)	Trend coefficient	+	Share of agriculture and allied activities	The proportion of GDP from agriculture and allied activities to total GDP	+	Road connectivity	Percent of villages having all-weather road	+
Rate of change in minimum temperature (*kharif*)	Trend coefficient	+	Irrigated area	Proportion of gross irrigated area to gross cropped area	-	Access to the market	Number of agricultural markets/1000 km^2	+
Rate of change in maximum temperature (*rabi*)	Trend coefficient	+	Forest area	Percentage of area under forest cover to the total geographical area	-	Livestock density	Number of livestock/km^2	+
Rate of change in minimum temperature (*rabi*)	Trend coefficient	+	Rural population to total population	Proportion of rural population to the total population	+	Rural electrification	Percentage of villages with electricity supply	+
Projected change in monsoon rainfall	Percentage	-	Cropping intensity	Gross cropped area/net sown area) × 100	-	Rural literacy rate	Percentage of literate rural population to rural population	+
			Productivity of food grains	kg/ha	-	Women's workforce participation rate	Percentage of women in the overall workforce	+
			Food availability	kg/person/year	-	Work under MGNREGA	Average number of days of employment provided per rural household in year	+
			Multidimensional poverty index	Index score	+			

was the most prone to the effects of climate change on crop production and reported the highest crop production loss, primarily due to losses in cotton and oilseed production. It is followed by Latur, Ahmednagar, Buldhana, Beed, Chhatrapati Sambhajinagar, Jalgaon, Parbhani, Hingoli and Amaravati. Most of the districts identified in the high production loss category were from the Marathwada and Vidarbha regions, primarily due to lower rainfall and its variation. The near-term future projection for 2030 also indicates an increase in annual mean temperature by 1.2–1.5°C in the Vidarbha and Marathwada regions (TERI 2014). Conversely, the Konkan region's districts exhibited resilience to climate change, as they had a lower CPLI and higher mean annual rainfall. Ratnagiri reported the least loss in crop production, followed by Sindhudurg, Palghar, Raigad, Thane, Gadchiroli, Gondia, Bhandara, Nandurbar, and Kolhapur. Among all crop groups, cereals had the highest share in total losses. According to Zachariah *et al*. (2020), the Marathwada region of Maharashtra experiences yield loss due to multiple factors, including a lack of precipitation and changes in cropping patterns from drought-resistant crops to water-intensive cash crops. Therefore, these regions need to be prioritized to minimize production loss. Previous studies also highlight the significance of considering potential losses for vulnerability assessment due to the annual variations in area and yield (Kumar *et al.* 2016, Sendhil *et al.* 2018, Singh and Nayak 2018) .

Exposure index: The extent of exposure across districts reveals Sangali as the most exposed district to climate change (Table 2). CEEW (2021) also reported similar results and identified Sangli as the fifth most exposed district to climate variations. Regional exposure indicates that districts from the Konkan region fall under the high exposure category, followed by districts from the eastern parts of Vidarbha. These regions receive good rainfall but are characterized by high rainfall variability. The cropping pattern to such conditions gets affected due to this variability in rainfall. As per TERI's (2014) findings, coastal and western Maharashtra are projected to experience increased rainfall and temperature over the next decade. This poses a potential threat to the sensitive ecosystems in the area. In contrast, Jalgaon is the least exposed district to climate change with an index score of 0.31. It is followed by Nanded, Dhule, Chhatrapati Sambhajinagar, Parbhani, Jalana, Dharashiv, Nandurbar, Nashik, Latur, and Solapur. Most districts in the Marathwada and Khanesh regions are categorized as having lower exposure levels due to the less variation in *kharif* and *rabi* season rainfall and lower trends in maximum and minimum temperatures during these seasons.

Sensitivity index: The sensitivity index had an average score of 0.53 and a standard deviation of 0.078, highlighting significant differences in index values across the districts (Table 2). Ahmednagar (0.70) was identified as the most sensitive district to climate variability. All parameters except the multidimensional poverty index contributed to its highest index score. The districts of Nandurbar, Beed, Washim, Hingoli, Amravati, Osmanabad, Latur, Sangli, and Buldhana were considered highly sensitive due to their poor performance in terms of the proportion of small and marginal farmers, the level of groundwater exploitation and the contribution of agriculture and allied sectors to the GDP. People in rural areas are relatively more susceptible to extreme climatic events as infrastructure in rural areas, like roads, electricity and telecommunication, collapses due to natural calamities like storm surges, floods etc. (Maiti *et al.* 2015). Similarly, the share of agriculture and allied sectors in the GDP indicates relatively less developed secondary and tertiary sectors and makes the area more sensitive to climate change (Rao *et al.* 2013). Looking at the indicators score, the stage of groundwater exploitation, the share of degraded area, the share of agriculture and allied activities in the GDP and the multidimensional poverty index are mainly responsible for the high sensitivity of the district to climate change. Besides this, the sensitivity index score didn't show any regional pattern.

Adaptive capacity index: The district-wise adaptive capacity index scores range from 0.23–0.57, with an average score of 0.45 (Table 2). Out of 34 districts, 8 were categorized as highly adaptive, 19 as moderately adaptive and the remaining 7 as having low adaptive capacity to cope with climate change. The highest value of adaptive capacity highlights the district's ability to manage and withstand the negative impacts of climate change. Pune (0.57) secured first place in adaptive capacity influenced by crop diversification, technology adoption (fertilizer consumption) and per capita income. The districts of Nanded, Nashik, Ahmednagar, Beed, Kolhapur, Hingoli and Nandurbar emerged as the leading districts in adaptive capacity due to better performance with respect to indicators such as fertilizer consumption, crop diversification and livestock population density. The index score for Sindhudurg district (0.23) shows dismal performance in parameters like of diversification index, access to the agriculture market, livestock density and alternate employment opportunities (MGNREGA). Regional pattern identifies the poor adaptive capacity of Konkan region due to lower diversification index, livestock population density and area insured. In contrast, most of the district in the Marathwada and Vidarbha regions falls under the moderate category. In the case of Western Maharashtra and Khandesh, the district lies in moderate to low adaptive capacity. The gap between the highest and lowest adaptive capacity index indicated the existence of substantial inequality among these districts.

Composite agricultural vulnerability index (CAVI): The CAVI score was estimated based on the relative strength of the potential impact and the district's adaptive capacity to face the negative effects of climate change (Fig. 1). It indicated a wide divergence in the CAVI score, with a mean value of 0.78 and a standard deviation of 0.17, revealing notable disparities across districts (Table 2). The Yavatmal district stands out as the most vulnerable, primarily due to its high CPLI coupled with moderate adaptive capacity. Other highly vulnerable districts include Latur, Ahmednagar, Sindhudurg, Buldhana, Akola, Amaravati, Beed, Washim

Table 2 District-wise crop production loss index, exposure, sensitivity, adaptive capacity index and composite agricultural vulnerability index

District	Crop production loss index		Exposure index		Sensitivity index		Adaptive capacity index		Composite agricultural vulnerability index	
	Index	Category	Index	Category	Index	Category	Index	Category	Index	Category
Yavatmal	0.65	H	0.53	H	0.50	M	0.45	M	1.24	H
Latur	0.46	H	0.40	L	0.59	H	0.41	M	1.04	H
Ahmednagar	0.36	H	0.49	M	0.70	H	0.55	H	0.99	H
Sindhudurg	0.01	L	0.57	H	0.56	M	0.23	L	0.91	H
Buldhana	0.35	H	0.43	M	0.58	H	0.46	M	0.90	H
Akola	0.26	M	0.48	M	0.55	M	0.40	L	0.89	H
Amravati	0.29	H	0.42	M	0.59	H	0.41	M	0.88	H
Beed	0.34	H	0.43	M	0.64	H	0.54	H	0.87	H
Washim	0.18	M	0.43	M	0.62	H	0.38	L	0.86	H
Sangli	0.17	M	0.57	H	0.59	H	0.49	M	0.84	H
Ratnagiri	0.00	L	0.52	H	0.56	M	0.27	L	0.82	M
Hingoli	0.29	H	0.41	M	0.62	H	0.52	H	0.80	M
Solapur	0.27	H	0.40	L	0.57	M	0.44	M	0.79	M
Chh. Sambhajinagar	0.33	H	0.35	L	0.56	M	0.45	M	0.77	M
Dharashiv	0.25	M	0.38	L	0.59	H	0.46	M	0.76	M
Wardha	0.13	M	0.56	H	0.52	M	0.47	M	0.74	M
Parbhani	0.29	H	0.35	L	0.52	M	0.46	M	0.70	M
Satara	0.13	M	0.48	M	0.57	M	0.49	M	0.68	M
Raigad	0.01	L	0.50	H	0.48	L	0.33	L	0.66	M
Gadchiroli	0.03	L	0.54	H	0.47	L	0.38	L	0.66	M
Chandrapur	0.13	M	0.54	H	0.44	L	0.45	M	0.65	L
Jalna	0.23	M	0.35	L	0.54	M	0.49	M	0.64	L
Jalgaon	0.31	H	0.31	L	0.51	M	0.49	M	0.64	L
Nanded	0.27	H	0.34	L	0.57	M	0.56	H	0.62	L
Nashik	0.22	M	0.40	L	0.55	M	0.55	H	0.61	L
Nandurbar	0.07	L	0.39	L	0.66	H	0.51	H	0.61	L
Pune	0.22	M	0.45	M	0.51	M	0.57	H	0.61	L
Thane	0.02	L	0.48	M	0.45	L	0.36	L	0.60	L
Nagpur	0.17	M	0.57	H	0.34	L	0.49	M	0.59	L
Dhule	0.19	M	0.35	L	0.54	M	0.49	M	0.58	L
Kolhapur	0.10	L	0.56	H	0.44	L	0.53	H	0.58	L
Palghar	0.01	L	0.51	H	0.48	L	0.43	M	0.58	L
Gondia	0.03	L	0.53	H	0.41	L	0.43	M	0.54	L
Bhandara	0.04	L	0.53	H	0.36	L	0.46	M	0.47	L

H, High; M, Moderate; and L, Low.

and Sangali (Fig. 2). Conversely, districts such as Bhandara, Gondia, Palghar, Kolhapur, Dhule, Nagpur, Thane, Pune, Nandurbar, Nashik, Nanded, Jalgaon, Jalna and Chandrapur exhibited lower vulnerability (Fig. 2). Notably, except for Jalna and Nanded, all districts in the Marathwada region were categorized as moderately to highly vulnerable. Jalna exhibited lower exposure but a moderate crop loss index, while Nanded displayed lower exposure alongside high adaptive capacity. Additionally, districts in the western part of Vidarbha, including Buldhana, Akola, Washim, Amaravati and Yavatmal, emerged as highly vulnerable. Overall, 10 districts were identified as highly vulnerable, 10 as moderately vulnerable and 14 as less vulnerable to climate change impacts.

In conclusion, climate change and agriculture are intrinsically related and changes in climatic conditions at such a rapid pace have threatened global food security. In India, Maharashtra is one of the most vulnerable states to

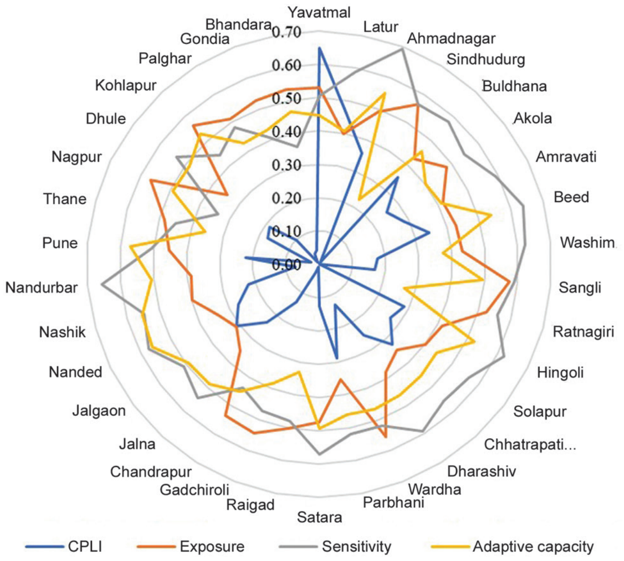

Fig. 1 Radar pictorial of crop production loss index, exposure, sensitivity and adaptive capacity indices.

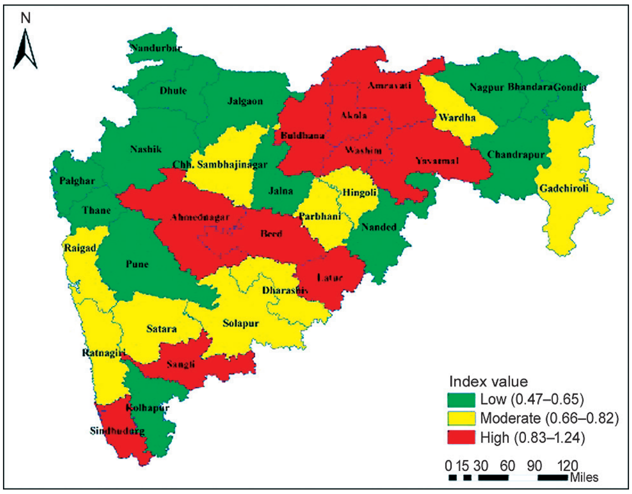

Fig. 2 Mapping of agricultural vulnerability in Maharashtra.

climate change impacting agriculture and allied activities. Therefore, this study has attempted to track the spatial variability in agricultural vulnerability to climate change to prioritize policy formulation for managing the associated risks. The exposure index indicated regional disparities, with districts from the Konkan and Eastern Vidarbha regions showing higher levels of exposure. Although these regions receive a good amount of rainfall, they are characterized by high rainfall variability. It has been observed that the Marathwada and Western Vidarbha regions are more vulnerable, facing significant crop production losses and higher exposure to climate variability. However, districts in the Konkan region, along with Western Maharashtra and Eastern parts of Vidarbha, exhibit relatively lower vulnerability to climate change, attributed to factors such as lower potential crop loss and better adaptive capacity. The study highlights the need for soil and water conservation measures, such as systems to effectively capture and store rainwater by constructing small-scale reservoirs, check dams and water harvesting structures, to reduce exposure to climate change. Additionally, timely and accurate information about extreme weather events can assist farmers in making informed decisions about planting, harvesting and resource allocation. To build resilience to climate change and reduce crop production losses in highly vulnerable areas, crop planning needs to be adjusted according to the climatic conditions in these regions.

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