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Climate vulnerability assessment in semi-arid and arid region of Rajasthan, India: An enquiry into the disadvantaged districts

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ABSTRACT

This paper assesses the district level climate vulnerability in the state of Rajasthan using large-scale data on climate and socio-economic variables.More than thirty indicators segregated into four components of exposure, sensitivity, adaptive capacity and crop production loss were combined to develop a composite index of vulnerability and homogenous districts were clustered into three categories, viz. low, medium and high.Wide inter-district variations were observed across the calculated indices. The result reveals that highest production losses occurred in Ganganagar district followed by Hanumangarh and Bharatpur. Pali was least exposed to the climatic variability, whereas Bundi had the maximum exposure.Jaisalmer rated the maximum sensitivity level. Further, Pratapgarh followed by Jaisalmer and Banswara had the lowest degree of adaptive capacity. On the whole, districts like Hanumangarh, Jaisalmer, Ganganagar, Bundi, Bharatpur, Jodhpur, Bikaner, Chittorgarh, Alwar, Baran and Pratapgarh exhibit high level of vulnerability to climatic change. While on the other spectrum Sirohi district was least vulnerable due to lower exposure, sensitivity, crop production loss and high adaptive capacity. The analysis, suggests the need for prioritizing vulnerable areas to arrest regional imbalances by encouraging need/ location based interventions for moderating the degree of vulnerability, whilst making agro-ecosystem in Rajasthan resilient to climatic aberrations.

Keywords : Climate Change, crop production loss,exposure, sensitivity, adaptive capacity, vulnerability

Globally, climate change poses significant risks across diverse ecosystems. In its sixth assessment report, the Intergovernmental Panel on Climate Change (IPCC, 2018) states that dryland regions and population dependent on agriculture-based livelihoods are disproportionately at a higher risk to the climate variability.The increasing frequency of inter-season variations in rainfall and temperature and other extreme events have significant impact on agriculture production and livelihoods particularly in India, where 60 per cent of the total cropped is still rainfed and large proportion of landholdings are small and fragmented (Jain *et al.,* 2015;Udmale *et al.,* 2014). It is increasingly recognized that variations in climate parameters is likely to exacerbate vulnerability of farming and rural communities in semi-arid tropics,which are already disadvantaged due to low and erratic precipitation pattern, lower soil fertility, higher frequency of droughts, weak institutional setup and inadequate access to resources (Bantilan and Anupama,2006, Singh *et al.,* 2014). Adaptation actions against the adverse effects of climate induced perturbations are pertinent to sustain crop productivity and livelihood of the farmers in short to medium run (Singh *et al.,* 2018). However, understanding the degree of vulnerability to climate change is a prelude for identification and prioritization of vulnerable areas, factors that serve as barriers to effective adaptation and for constructing suitable region–specific interventions to better cope up with current and future climate changes.

Rajasthan is the largest state in the country, spread over an area of 342, 239 sq. km. The topography of the state is dominated by the Aravalli hills and 70 per cent of desert in the western and north-western region, known as the Great Indian Thar Desert. Administratively, Rajasthan is segregated into 33 districts within 10 agro-climatic zones. The climate of the state vary from semi-arid to arid; with average annual temperature ranging between 0 and 50° C. The state receives an annual average rainfall which varies from 480mm to 750mm and about 90 per cent of which occurs during the south west monsoon period which starts from June and last until September. Nearly 75 per cent of Rajasthan's population resides in rural areas (Census, 2011) and is predominately engaged in agriculture and livestock rearing for their livelihoods. Out of the total cropped area of 18.262 Mha in the state, 75 per cent is rainfed, which makes its agro-ecosystem highly susceptible to the climate induced perturbation. Generally, the state is marked by scarcity of water resources due to relatively low and erratic precipitation pattern, a sizeable portion of which reverses back because of the arid conditions, leading to lower groundwater recharge (CGWB, 2017). Recurrence of drought is a major phenomenon in the state which severely affects food grain production and livestock,leading toinsecure livelihoods and migration. A study by Rathore (2005) found that, in 48 out of 102 years (1901-2002),Rajasthan was affected by drought of varied intensity,with highest frequency observed in the western and southern regions of the state. Moreover, in the year 2016, 19 out of 33 districts in Rajasthan were affected to famine or drought conditions. Desertification resulting from shifting of sand dunes and dust storm, overgrazing and rising population has been another serious environmental issue especially in the districts of Bikaner, Churu and Nagaur located close to the desert (Kundu *et al.,* 2015). Under future climate change, the state is likely to experience warming with annual mean temperature projected to increase by 2-2.5° C by 2021-2050 (Gopalakrishnan *et al.,* 2011), while rainfall is likely to show a slight decrease (Kumar *et al.,* 2006). These future projections of climate variability indicate greater frequency of extremes, evaporation and shortage of water,which will adversely affect crop yields and livelihood sustainability.Keeping this in view, this paper attempts to assess and quantify climate change vulnerability in semi-arid and arid regions of Rajasthan, India using multi-dimensional set of indicators.

MATERIALS AND METHODS

The study used district level data on climate and socio-economic indicators as shown in Table 1, to compute potential impact and vulnerability index,conceptualized as a combination of crop production loss, sensitivity, exposure and adaptive capacity index;

$$PI_j = E_j + S_j + CPL_j \tag{1}$$

$$V_j = (E_j + S_j + CPL_j) - AC_j \tag{2}$$

where, PIj is potential impact, Vj is vulnerability, Ej is exposure, Sj is sensitivity, $CPLj$ is crop production loss and ACj is adaptive capacity for the j^{th} district.The data on selected indicators was collected from Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, Indian Meteorological Department, Census of India, and Central Ground Water Board, Ministry of Water Resources, River Development and Ganga Rejuvenation.

Kumar *et al.* (2016) method was adopted for estimating crop production loss, which segregates crop losses into three different effects viz., area, yield and interaction effects, as shown in equation (3).To reduce the influence of agriculture technological advancement/ long-term trend,in order to determine the net effect of climate variations, both area and yield were first de-trended using a linear model.

$$CPL_i = \frac{1}{t_n}\left\{\sum_{t=1}^{n} Y_t\,(A_m - A_t) + \sum_{t=1}^{n} A_t(Y_m - Y_t) + \sum_{t=1}^{n}(A_m - A_t)\,(Y_m - Y_t)\right. \tag{3}$$

t = 1, 2, 3..............20

Where, PLi is an average production loss for a crop in a particular district, Yt and At are the actual area and yield during i[th] year, respectively. A_m and Y_m are potential area and yield achieved during the period from 1998- 2016, respectively.

Using Iyengar and Sudarshan (1982) methodology, selected indicators was normalized in the range of 0 and 1,based on their functional relationship with the component. Eq.(4) was employed for indicators positively related with the component, while eq. (5) was used for negative indicator;

$$Q_{ij} = \frac{K_{ij} - Min(X_{ij})}{Max(X_{ij}) - Min(X_{ij})} \tag{4}$$

$$Q_{ij} = \frac{Max(X_{ij}) - K_{ij}}{Max(X_{ij}) - Min(X_{ijk})} \tag{5}$$

i=1,2,....I *and* j=1,2,.....J

Where, Q_ij is the normalized index value, Kij is the actual/ observed value, Max(Xij) and Min(Xij) is the maximum and minimum value of i[th] indicator for the j[th] district. Further the weight assigned to each indicator was determined as follows;

$$[W_i = \frac{C}{\sqrt{\mathrm{Var}(Q_{ij})}}] \quad (6) \quad \text{Where,} \left| C = \frac{1}{\left\{\sum_{i=1}^{n} \frac{1}{\sqrt{\mathrm{Var}(Q_{ij})}}\right\}} \right| \quad (7)$$

where, W_i denotes the weight, and C is a normalizing constant. The estimated weights were multiplied with the normalized indicators and aggregated to construct index Z_j for the j[th] district;as given in equation (8)

$$Z_j = \frac{\sum_{i=1}^{I} Q_{ij} * W_i}{\sum_{i=1}^{I} w_i} \tag{8}$$

where,0<W i<1 and $\sum_{i=1}^{I} w_i$ =1

Based on the index scores, homogenous districts

Table 1: Metrics of indicators selected for computation of crop production loss, exposure, sensitivity and adaptive capacity index

Crop production loss	WE	Exposure	FR	WE	Sensitivity	FR	WE	Adaptive capacity	FR	WE
Food grain	18	*Annual*			Percentage of forest area	↓	14	Mean land size	↑	8
Wheat, Rice, Jowar, Maize		Maximum temp.	↑	10				Literacy rate	↑	10
Pulses	23	Minimum temp.	↑	6	Percentage of area not available for cultivation	↑	12	Percentage of HHs participating in MGNREGA	↑	10
Gram, Groundnut,		Rainfall	↑	12						
Masoor, Moong, Urad, Soyabean, Guar seed		*Kharif (June- September)*			Percentage of net sown area	↓	10	Percentage of population with formal training in agriculture	↑	10
		Maximum temp.	↑	9	Percentage of population Below	↑	30	Per capita income (2011-12 @constant Prices)	↑	11
Oilseed	21									
Lineseed,		Minimum temp.	↑	9						
Rapeseed & Mustard		Rainfall	↑	18	Poverty Line Sex Ratio (female/1000 male)	↑	10	Percentage of population with access to power supply	↑	10
Vegetable	22	*Rabi (October-March)*			Population density (persons/ sq. km)	↑	12	Percentage of livestock degraded land	↑	10
Potato, Onion		Maximum temp.	↑	12						
					Percentage of	↑	14	Agricultural credit societies	↑	9
Non-food grains	16	Minimum temp.	↑	12						
Cotton, Tobacco, Sugarcane,		Rainfall (mm)	↑	11				Percentage of agricultural labour	↓	11
Garlic, Dry Chilllies								Percentage of population with access to pucca approach road	↑	10

Note: WE: Weights (%); FR: Functional Relationship; ↑ - positive relationship; ↓ negative relationship

Table 2: Relative status of districts in Rajasthan in terms of crop production loss, exposure, sensitivity, adaptive capacity and vulnerability

District	Crop production loss index	Degree of crop production loss	Exposure index	Degree of exposure	Sensitivity index	Degree of sensitivity	Adaptive capacity index	Degree of adaptive capacity	Potential impact index	Vulnerability index	Degree of vulnerability
Sirohi	0.035	Low	0.437	Low	0.400	Medium	0.730	High	0.871	0.141	Low
Dungarpur	0.022	Low	0.442	Low	0.318	Low	0.456	Medium	0.782	0.326	Low
Pali	0.136	Medium	0.371	Low	0.396	Medium	0.576	High	0.903	0.327	Low
Jhunjhunun	0.178	Medium	0.443	Low	0.354	Low	0.595	High	0.974	0.379	Low
Ajmer	0.132	Medium	0.449	Medium	0.366	Low	0.554	High	0.948	0.394	Low
Jaipur	0.180	Medium	0.412	Low	0.366	Low	0.529	High	0.958	0.429	Low
Jalore	0.101	Low	0.398	Low	0.454	High	0.502	Medium	0.953	0.451	Low
Banswara	0.046	Low	0.438	Low	0.362	Low	0.384	Low	0.847	0.463	Low
Churu	0.146	Medium	0.460	Medium	0.423	High	0.539	High	1.029	0.489	Low
Jhalawar	0.155	Medium	0.484	High	0.373	Low	0.521	Medium	1.012	0.491	Low
Dausa	0.074	Low	0.466	High	0.408	Medium	0.451	Medium	0.949	0.498	Low
Rajsamand	0.065	Low	0.437	Low	0.414	Medium	0.396	Low	0.916	0.520	Medium
Udaipur	0.094	Low	0.473	High	0.388	Low	0.428	Low	0.955	0.526	Medium
Karauli	0.105	Low	0.468	High	0.389	Medium	0.422	Low	0.962	0.540	Medium
Barmer	0.039	Low	0.448	Medium	0.484	High	0.405	Low	0.971	0.566	Medium
Kota	0.261	High	0.499	High	0.317	Low	0.502	Medium	1.077	0.574	Medium
Bhilwara	0.173	Medium	0.468	High	0.409	Medium	0.462	Medium	1.050	0.588	Medium
Dhaulpur	0.128	Low	0.461	Medium	0.447	High	0.419	Low	1.036	0.617	Medium
Tonk	0.202	Medium	0.436	Low	0.412	Medium	0.432	Medium	1.050	0.618	Medium
Sawai Madhopur	0.156	Medium	0.450	Medium	0.414	Medium	0.388	Low	1.019	0.631	Medium
Sikar	0.236	Medium	0.455	Medium	0.413	Medium	0.465	Medium	1.103	0.638	Medium
Nagaur	0.362	High	0.432	Low	0.431	High	0.578	High	1.225	0.646	Medium
Pratapgarh	0.102	Low	0.518	High	0.383	Low	0.336	Low	1.003	0.667	High
Baran	0.351	High	0.451	Medium	0.375	Low	0.482	Medium	1.178	0.696	High
Alwar	0.344	High	0.449	Medium	0.401	Medium	0.492	Medium	1.194	0.703	High
Chittorgarh	0.273	High	0.482	High	0.405	Medium	0.420	Low	1.160	0.740	High
Bikaner	0.314	High	0.486	High	0.539	High	0.583	High	1.339	0.756	High
Jodhpur	0.439	High	0.443	Low	0.461	High	0.529	High	1.343	0.814	High
Bharatpur	0.469	High	0.446	Medium	0.372	Low	0.465	Medium	1.287	0.822	High
Bundi	0.332	High	0.520	High	0.412	Medium	0.409	Low	1.264	0.855	High
Ganganagar	0.643	High	0.458	Medium	0.432	High	0.620	High	1.533	0.913	High
Jaisalmer	0.150	Medium	0.486	High	0.658	High	0.348	Low	1.294	0.946	High
Hanumangarh	0.559	High	0.460	Medium	0.511	High	0.557	High	1.529	0.973	High

were clustered into 3 different categories;Low, Medium and High, using quartile estimation.

RESULTS AND DISCUSSION

Tables 2 depicts district-wise scores and degree of crop production loss, exposure, sensitivity, adaptive capacity and vulnerability, respectively.

Crop production loss index

During the period from 1998-2016 wide variation was observed in terms of crop loss index scores,ranging from the lowest score of 0.022 in Dungarpur to highest of 0.643 in Ganganagar. Eleven districts namely Dungarpur, Sirohi, Barmer, Banswara, Rajasmand, Dausa, Udaipur, Jalore, Pratapgarh, Karauli and Dhaulpur districts reported the lowest degree of crop production losses. While Ganganagar followed by Hanumangarh and Bharatpur occupied the top positions under the high crop loss zone, indicating relatively greater variation in production of food grains, non-food grains, oilseeds and vegetables crops.

Exposure index

Based on the calculated exposure scores during 1974-2015, it was found that Pali district (0.371) was least exposed to the climate variability, whereas Bundi (0.520) had the maximum exposure.Slower increase in both the maximum and minimum temperature in the *kharif* season and annual minimum temperature were the major determinants resulting in lower degree of exposure in the Pali, Jalore, Jaipur, Nagaur, Tonk, Rajsamand, Sirohi, Banswara, Dungarpur, Jhunjhunun and Jodhpur districts. On the other spectrum, due to increase in maximum and minimum temperatures in *rabi* season and higher rainfall during the *kharif* season, Dausa, Bhilwara, Karauli, Udaipur, Chittorgarh, Jhalawar, Bikaner, Jaisalmer, Kota, Pratapgarh and Bundi districts were placed under high degree of exposure.

Sensitivity index

Kota district with score of 0.317 was least sensitive on account of lesser degraded land, lower non-cultivable area and poverty levels.On the other hand districts like Jaisalmer, Bikaner, Hanumangarh, Barmer, Jodhpur, Jalore, Dhaulpur, Ganaganagar, Nagaur and Churu were highly sensitive to climatic aberrations. Among 33 districts, 12 districts had medium level of vulnerability.

Adaptive capacity index

Inter-district variations were observed in case of adaptive capacity. Pratapgarh with the score of 0.336 followed by Jaisalmer (0.348) and Banswara (0.384) had the least adaptive capacity to deal with weather variability resulting from small number households with formal training in agriculture, poor electricity connectivity, lowermean land size and livestock population.Sirohi district (0.730) had the highest capacity to cope against climatic aberrations.Factors like assured power supply, higher number of livestock, and greater participation in the MGNREGA resulted in a higher degree of adaptive capacity in the districts like, Sirohi, Ganganagar Jhunjhunu, Bikaner, Nagaur, Pali, Hanumangarh, Ajmer, Churu, Jodhpur and Jaipur.

Potential impact and vulnerability index

In terms of relative potential impact,Dungarpur district (0.782) was least impacted to climate change, whereas Ganganagar district (1.533) had the highest potential impact. Subtracting adaptive capacity from potential impact determines the vulnerability of the particular district. Sirohi district was least vulnerable, whereas Hanumangarh was most vulnerable to climate variability. In addition to Hanumangarh (0.973), Jaisalmer (0.946), Ganganagar (0.913), Bundi (0.855) and Bharatpur (0.822) were grouped as districts with high degree of vulnerability to climate change.On the other hand, on account of lower crop production losses, lesser sensitivity and higher degree of adaptive capacity Sirohi(0.141), Dungarpur (0.326). Pali, (0.327), Jhunjhunun (0.379), Ajmer (0.394), Jaipur (0.429), Jalore(0.451), Banswara (0.463), Churu (0.489) Jhalawar (0.491) and Dausa (0.498) reported lowest level vulnerability.

CONCLUSIONS

Climate change poses a serious threat to the food and livelihood security in the dry land regions and Rajasthan possessing large tract of land under arid environment, lower forest coverage and expanding desertification is at a greater risks. For formulating locally-tailored practices and policies that aims at enhancing resiliency to the weather variations, it is crucial to quantify the vulnerability status of the districts in the state. The present study found 11 out of 33 districts were highly vulnerable to the changing climatic conditions with Hanumangarh, Jaisalmer and Ganganagar having the highest degree of vulnerability. Lowest adaptive capacity was found in district like Pratapgarh, Jaisalmer, Banswara,Sawai, Madhopur, Rajsamand, Barmer, Bundi, Dholpur, Chittorgarh, Karauli and Udaipur reflecting the urgent need to strengthen the coping capacity in the districts by addressing in-situ barriers such as lack of power supply and long outages, infrastructure deficits and lack of opportunities (non-farm) to diversify livelihoods. Moreover, focus on grass-root demonstration and dissemination of climate–smart technologies, drought/heat tolerant crop varieties along with integrated water resource management approaches is crucial for minimizing production losses in Hanumangarh, Bharatpur and other districts in Rajasthan. Lastly, mainstreaming climate cognitions and adaptations in the current programmes and schemes of the state is important for sustainable growth in the future.

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