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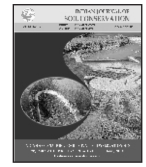

Assessment of vulnerability to climate change: A case study of Karnataka

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ABSTRACT

Identification and assessing the extent of vulnerability to climate change is an essential pre-requisite for reducing climate change impacts. Drawing upon published literature on vulnerability assessment, a total of 27 environmental and socio-economic indicators were identified and analyzed to measure district-wise vulnerability status in Karnataka, which is one of the most drought prone states of country. Selected indicators were first normalized and then multiplied by appropriate weights to compute the exposure, sensitivity adaptive capacity and vulnerability indices. Scores of Exposure-Sensitivity Index (ESI) suggest that Bidar (rank first, 1.378) and Gulbarga (rank second, 1.203) are the most prone and susceptible districts to climate change whereas Dakshin Kannada is the least vulnerable district in the State. Three-fourths of the districts of northern Karnataka are categorized under very high to high degree of vulnerability. Around 51% of area of the state supporting 42% of the human population is highly vulnerable to climatic change. These prioritized areas, based on rank and degree of vulnerability, should be given immediate attention, and measures ought to be taken by internalizing region specific needs and by carrying out necessary changes in allocation of funds and resources to address the growing challenge of climate change.

1. INTRODUCTION

Rainfed agriculture, particularly in the arid and semi-arid regions, is highly susceptible to the adverse impact of climate change because of having limited options available for coping with variability of rainfall and temperature (Rao *et al.,* 2011). India is one of the most vulnerable countries to climate change (FAO, 2002) and is also considered as one of the most drought-prone countries in the world (Shetty *et al.*, 2013). Rainfed areas, which constitute 55% of the cultivated area and support two-thirds of livestock and 40% of the human population of the country, are highly vulnerable to climate change (Mondal *et al.,* 2014 and Mondal *et al.,* 2015) .

For India, the IPCC (2007) report projected an increase of 2.7-4.3°C in temperature by 2080s, an increase in rainfall of 6-8% and sea level rise of 88 cm by 2100. There is high likelihood that the projected scenario will have far-reaching, dramatic and detrimental consequences for livelihood - and possibly for survival - of rural communities who depend on agriculture, fisheries and animal husbandry. For instance, the forecasts made by the Indian Council of Agricultural Research (ICAR) using crop simulation models incorporating future projections, warned that climate change is projected to reduce production of timely sown irrigated wheat by about six percent by 2020 and the extent of reduction (by 18%) is alarmingly high for late sown wheat. Similarly, a four to six percent fall in the yield of irrigated and rainfed rice, respectively has been foreseen by 2020 due to climate changes (Shetty *et al.,* 2013). Moreover, the projected impacts are likely to further aggravate yield fluctuations in many crops, and all these together will have an adverse impact on food security of the country.

Vulnerability assessment is an established tool for ensuring policy responses to climatic variability and helps in identifying vulnerable regions. Assessment of vulnerability to climate change is almost vital for developing countries, especially countries like India, which is highly vulnerable and has poor adaptive capacity to cope with the challenges of climate change (Panda, 2009). Vulnerability to climate change has been defined by various authors as the extent to which a system or society is prone, or at risk to, and is unable to deal with the negative effects of climate change and variability (IPCC, 2007). In response to climate change, identification of vulnerable nations or regions can act as an entry point for understanding and addressing the processes that cause and exacerbate vulnerability (O'Brien *et al.,* 2004). Vulnerability analysis helps assessing the potential impacts of multiple and interacting socio-economic and environmental changes for specific group or region. With this background, we have attempted to develop a vulnerability index which can be used to assess the relative status of vulnerability in different districts of Karnataka and will also facilitate prioritization of districts, based on vulnerability index score, for designing region-specific plans to address the growing challenges of climate change.

2. MATERIALS AND METHODS

This study is based on secondary data collected from various published reports of various government departments *viz.,* Central Ground Water Board (CGWB); Ministry of Water Resources (MoWR), Government of India, Directorate of Economics and Statistics (DES), Department of Agriculture, Planning, Programme Monitoring and Statistics Department and Rural Development and Panchayathi Raj Department, Government of Karnataka. Data on various indicators were collected and then categorized to suit three aspects of vulnerability (exposure, sensitivity and adaptive capacity) for all 30 districts of the State.

Considering the relevance of indicators to study area and availability of data, indicators were selected to measure all the three dimensions of vulnerability index. Following the methodology used by Kumar *et al.* (2014), the selected indicators were first normalized to make the indicators units free. The functional relationships between the indicators and exposure or sensitivity or adaptive capacity were established before the normalization of indicators. There are two types of functional relationship: (a) positive relationship - exposure/sensitivity/adaptive capacity increases with increase in the value of indicator, and (b) negative relationship - when exposure/sensitivity/ adaptive capacity decrease with increase in the value of indicator.

The data were arranged in the form of a rectangular matrix with rows representing districts and columns representing indicators. Let there be N (j=1,..,2,….,N) districts and selected data on M (i=1, 2,….M) number of indicators. Thus, the matrix will contain N rows and M columns. Let x_{ij} be the value of the i^{th} indicator corresponding to j^{th} district. If the variable has positive functional relationship with exposure/sensitivity/adaptive capacity, then normalization can be done using equation 1.

Let Y_{ij} be the index for the i^{th} indicator related to j^{th} district.

$$Y_{ij} = \frac{x_{ij} - Min\{x_{ij}\}}{Max\{x_{ij}\} - Min\{x_{ij}\}} \quad ...(1)$$

And if the variable has negative functional relationship with exposure / sensitivity / adaptive capacity, then the normalization can be done using equation 2.

$$Y_{ij} = \frac{Max\{x_{ij}\} - x_{ij}}{Max\{x_{ij}\} - Min\{x_{ij}\}} \quad ...(2)$$

Where, $Max\{x_{ij}\}$ and $Min\{x_{ij}\}$ are the maximum and minimum values of i^{th} indicator among all the N districts, respectively, x_{ij} is the actual/observed value of i^{th} indicator for j^{th} district.

For all indices N=1,.... 2, j., 30 as there are 30 districts in the state, i=1,2,....M, which are 7, 12 and 8 indicators for Exposure Index (EI), Sensitivity Index (SI) and Adaptive CapacityIindex (ACI), respectively.

For example, EI for j^{th} district was computed by using equation 3.

$$EI_j \sum_{i=}^{M} (w_i * Y_{ij}); \quad ...(3)$$

Where, $\sum_{i=1}^{M} w_i = 1$, and EI_j, represent the exposure index for j^{th} district and w_i, represents the weight associated with the i^{th} indicator included in exposure index.

Iyengar and Sudarshan (1982) linked the weight to variance of indicator across the districts for assessing aspects of development in the states of Andhra Pradesh and Karnataka. Using their postulation and assuming that the weights in our case vary inversely as the variance of the normalized index, we obtain equation 4.

$$w_i = c / \sqrt{var\ (Y_{ij})} \quad ...(4)$$

Where, c is a normalised constant such that-

$$c = \| \sum_{i=1}^{M} 1/\sqrt{var\ (Y_{ij})} \|^{-1} \quad ...(5)$$

The choice of the weights in this manner would ensure that large variation in any one of the indicators would not unduly dominate the contribution of the rest of the indicators and distort the inter-district comparisons. Similar to the method followed for the computation of EI_j, the SI_j and ACI_j were also computed for all the 30 districts, using equations 1 to 5.

Finally, vulnerability index for all the districts was computed by combining the scores of sensitivity, exposure and adaptive capacity index as per equation 6, given below:

$$VI_J = (EI_J + SI_J - AD_J) \quad ...(6)$$

Where, VI_J is vulnerability index for j^{th} district; AD_J is ACI for j^{th} district, EI_J is EI for j^{th} district and SI_J is SI for j^{th} district. Quartile analysis was carried out to classify districts in four groups indicating 'very high', 'high', 'medium' and 'low' degree of exposure, sensitivity, adaptive capacity and vulnerability.

3. RESULTS AND DISCUSSION

Exposure Index (EI)

Exposure refers to the rate and magnitude of change (for example increase in temperature) that an area is experiencing (IPCC, 2007). For computing district-wise exposure index, changes in terms of meteorological parameters were taken into account as given in Table 1. District-wise scores of EI and classification of districts under different degrees of exposure have been given in Table 2. Bidar (0.830), Gulbarga (0.706), Bijapur (0.689), Koppal (0.681), Gadag (0.678), Bagalkote (0.668) and Yadgir (0.664) districts emerged as highly exposed to climatic variability and were grouped, because of having score of EI more than 0.660 as per quartile analysis, under the 'very high degree' of exposure.

Key determinant indicators, which are accounted for this very high exposure to climatic variability, vary from district to district. For example, for Bidar district, a high extent of projected change in mean rainfall and very high variability in maximum and minimum temperatures were the dominant factors which led the district to secure the first rank in terms of exposure to climate change. However, in case of Gulbarga high value of exposure index can be attributed to high changes (projected) in minimum temperature coupled with higher variability in maximum temperature.

On the contrary, some districts *viz.,* Hassan (0.448) Shimoga (0.356) Chikmagalur (0.348), Uttar Kannada (0.321), Kodagu (0.314), Dakshin Kannada (0.120) and Udupi (0.078) were categorized under 'low degree of exposure' on account of very high annual rainfall, ranging from 1148 mm (Hassan) to 4252 mm (Udupi), and low fluctuations in temperature and rainfall during the year.

Table: 1
List of selected indicators to express the exposure, sensitivity and adaptive capacity and their functional relationship

Indicator	Measuring unit and functional relationship
Exposure Index[1]	
1. Projected change in Max. temperature	Percentage change over the base year (1961-1990) [+]
2. Projected change in Min. temperature	Percentage change over the base year(1961-1990) [+]
3. Projected change in annual rainfall	Percentage change over the base year (1961-1990) [+]
4. Variability in Max. temperature	Per cent (Coefficient of Variation) [+]
5. Variability in Min. temperature	Per cent (Coefficient of Variation) [+]
6. Variability in rainfall	Per cent (Coefficient of Variation) [+]
7. Normal Rainfall (mm)	Average annual rainfall in mm [-]
Sensitivity Index	
1. Irrigated area (KSDA, 2012)	Per cent of cropped area [-]
2. Irrigation intensity	Per cent [-]
3. Cropping intensity	Per cent [-]
4. Stage of groundwater development (CGWB, 2011)	Per cent annual draft over the annual recharge [+]
5. Affected population (Polluted drinking water) (GoK, 2012)	Per cent [+]
6. Land degradation index (Maji *et al.,* 2010)	Degraded area, Per cent of geographical area [+]
7. Forest area (KSDA, 2012)	Per cent of geographical area [-]
8. Land availability index (DES, 2012)	Average size of land holding (ha) [-]
9. Population density (DES, 2012)	Number of person per Square km [+]
10. Small and marginal farmers (KSDA, 2012)	Per cent of the total farmers [+]
11. Productivity index (GoK, 2010)	Foodgrain yield (kg per ha) [-]
12. Agricultural Dependence Index (KSDA, 2012)	Per cent share of agriculture and allied sector in district gross domestic product [+]
Adaptive Capacity Index	
1. Per Capita Income (DES, 2012)	₹ $person^{-1}$ (Current price 2011-12) [+]
2. Life expectancy (GoK, 2005)	Years [+]
3. Literacy rate (DES, 2012)	Per cent [+]
4. Infant Mortality rate (GoK, 2005)	Number per thousand live births [-]
5. Labour dependent on agricultural sector (KSDA, 2012)	Per cent of total labours [-]
6. Net Sown Area per capita (DES, 2011)	Hectare [+]
7. Infrastructure index (GOK, 2013)	Per cent habitation connected to all weather roads [+]
8. Number Livestock per agricultural holding	Number [+]

Note: Sign in square brackets indicate function relationship with their respective dimension of vulnerability *i.e.* exposure, sensitivity and adaptive capacity
for exposure index, indicators were taken from BCCI-K, 2011.

Sensitivity index (SI)

Sensitivity, in its general sense, is defined by Gallopín (2003) as the degree to which a system is modified or affected by an internal or external disturbance or set of disturbances. It measures responsiveness of a system/region to climatic influences which is shaped by both socio-economic and ecological conditions of region. Responsiveness or sensitivity of different districts was estimated by combining socio-economic indicators given in Table 1.

SI score for each district was computed, based on the relative strength of functional relationships of indicators with sensitivity and the value for all districts have been given in Table 2. Kolar secured first rank (highly sensitive to climate change), whereas Shimoga was rated (at 30th rank) as the least sensitive district in the state. High stage of groundwater development, wide spread problem of drinking water, less area under forest and low cropping intensity are the major factors rendering the highest level of sensitivity to Kolar district. In general, Kolar, Bengaluru (urban), Ramanagara, Chikballapur, Tumkur, Bidar and Belgaum were grouped as 'highly sensitive' to climate change.

Adaptive Capacity Index (ACI)

Adaptive capacity is the ability of a system to reduce to moderate levels, the potential effects of climate change and variability by either taking advantage of existing opportunities or undertaking measures to deal with its consequences (IPCC, 2007). It is also defined as the ability of a system to cope with actual or expected stress, including the ability of the system to initiate measures to prevent future damage and/or to extend the range of conditions to which it is adapted (Brooks *et al.,* 2005). It may also be a function of several factors, including income, education, information, skills, infrastructural access and management capabilities (Tol and Yohe, 2007). In this paper, Adaptive capacity is defined as the ability of a region to cope with the impacts of climate variability and was estimated by a set of proxy socio-economic indicators (given in Table 1). Relative robustness of the selected socio-economic indicators and their line of interaction with Adaptive capacity determined the relative status of Adaptive capacity of a district. The scores of ACI of all the districts have been given in Table 3. Bengaluru (Urban), Kodagu, Belgaum, Bangalore Rural, Dakshin Kannada, Bellary and Udupi emerged as districts having high degree of Adaptive capacity with their Adaptive capacity scores being 0.768, 0.580, 0.579, 0.568, 0.559, 0.514 and 0.500, respectively. Bengaluru (urban) secured first rank in terms of Adaptive capacity chiefly on account of very high per capita income, which was the highest among all the districts, high literacy rate, substantially sound on health parameters coupled with higher life expectancy and

Table: 2
Score of Exposure and Sensitivity Index and districts under various degrees of Exposure and Sensitivity

District	Exposure Index	Rank	Degree of Exposure	Sensitivity index	Rank	Degree of Sensitivity
Bagalkote	0.668	6	Very high	0.493	16	Medium
Belgaum	0.600	12	High	0.533	7	Very high
Bellary	0.659	8	High	0.483	18	Medium
Bengaluru (Rural)	0.571	17	Medium	0.486	17	Very high
Bengaluru (Urban)	0.540	19	Medium	0.602	2	Medium
Bidar	0.830	1	Very high	0.548	6	Very high
Bijapur	0.689	3	Very high	0.469	22	Medium
Chamrajnagara	0.452	23	Medium	0.502	13	High
Chikballapur	0.594	13	High	0.561	4	Very high
Chikmagalur	0.348	26	Low	0.518	11	High
Chitradurga	0.637	10	High	0.523	9	High
Dakshin Kannada	0.120	29	Low	0.439	25	Low
Davangere	0.586	14	High	0.477	20	Medium
Dharwad	0.581	15	High	0.364	29	Low
Gadag	0.678	5	Very high	0.521	10	High
Gulbarga	0.706	2	Very high	0.497	15	High
Hassan	0.448	24	Low	0.501	14	High
Haveri	0.539	20	Medium	0.515	12	High
Kodagu	0.314	28	Low	0.476	21	Medium
Kolar	0.574	16	Medium	0.613	1	Very high
Koppal	0.681	4	Very high	0.482	19	Medium
Mandya	0.544	18	Medium	0.531	8	High
Mysore	0.470	22	Medium	0.391	28	Low
Raichur	0.642	9	High	0.405	27	Low
Ramanagara	0.532	21	Medium	0.565	3	Very high
Shimoga	0.356	25	Low	0.333	30	Low
Tumkur	0.618	11	High	0.551	5	Very high
Udupi	0.078	30	Low	0.456	24	Low
Uttar kannada	0.321	27	Low	0.412	26	Low
Yadgir	0.664	7	Very high	0.458	23	Medium

Table: 3
Score of adaptive capacity, exposure-sensitivity index and vulnerability index

District	ACI	R	Degree of AC	ESI	R	Degree of ESI	VI	R	Degree of Vulnerability
Bagalkote	0.422	18	Medium	1.161	7	Very high	0.739	10	High
Belgaum	0.579	3	Very high	1.134	13	High	0.554	19	Medium
Bellary	0.514	6	Very high	1.142	12	High	0.628	16	Medium
Bengaluru (Rural)	0.568	4	Very high	1.057	18	Medium	0.489	21	Medium
Bengaluru (Urban)	0.768	1	Very high	1.142	11	High	0.374	26	Low
Bidar	0.332	28	Low	1.378	1	Very high	1.046	1	Very high
Bijapur	0.394	19	Medium	1.159	9	High	0.765	7	Very high
Chamrajnagara	0.282	30	Low	0.954	21	Medium	0.672	15	High
Chikballapur	0.390	20	Medium	1.154	10	High	0.765	8	High
Chikmagalur	0.452	14	High	0.866	24	Low	0.414	24	Low
Chitradurga	0.486	10	High	1.160	8	High	0.674	14	High
Dakshin Kannada	0.559	5	Very high	0.559	29	Low	0.000	30	Low
Davangere	0.473	11	High	1.062	17	Medium	0.590	18	Medium
Dharwad	0.424	17	Medium	0.946	23	Medium	0.522	20	Medium
Gadag	0.444	15	High	1.199	3	Very high	0.755	9	High
Gulbarga	0.369	23	Medium	1.203	2	Very high	0.834	2	Very high
Hassan	0.471	13	High	0.949	22	Medium	0.478	22	Medium
Haveri	0.357	25	Low	1.054	19	Medium	0.697	12	High
Kodagu	0.580	2	Very high	0.790	26	Low	0.210	27	Low
Kolar	0.378	22	Medium	1.187	4	Very high	0.809	3	Very high
Koppal	0.385	21	Medium	1.163	6	Very high	0.778	5	Very high
Mandya	0.309	29	Low	1.075	16	Medium	0.766	6	Very high
Mysore	0.424	16	Medium	0.861	25	Low	0.437	23	Medium
Raichur	0.359	24	Low	1.046	20	Medium	0.687	13	High
Ramanagara	0.490	9	High	1.097	15	High	0.607	17	Medium
Shimoga	0.495	8	High	0.688	28	Low	0.194	28	Low
Tumkur	0.472	12	High	1.169	5	Very high	0.698	11	High
Udupi	0.500	7	Very high	0.533	30	Low	0.033	29	Low
Uttar kannada	0.334	26	Low	0.733	27	Low	0.399	25	Low
Yadgir	0.333	27	Low	1.123	14	High	0.790	4	Very high

Note: R, AC, ACI, ESI and VI indicate rank, adaptive capacity, adaptive capacity index, exposure-sensitivity index and vulnerability index, respectively

lesser infant mortality rate than that other districts. Wide range of Adaptive capacity scores, ranging from 0.334 to 0.282, shows that there are perceptible inter-district disparities among the districts. Uttar Kannada, Yadgir Bidar, Mandya and Chamrajnagara were placed under the 'low adaptive capacity' category since all these districts scored an Adaptive capacity value of < 0.367, which was the minimum criteria value as per quartile analysis.

Exposure-sensitivity and vulnerability index

Both exposure and sensitivity positively influence vulnerability, therefore both were added to make another index *i.e.* Exposure-Sensitivity Index (ESI) so as to give the compounded effect on vulnerability (Table 3). Districts were grouped into four categories - very high, high, medium and low degree of Exposure-Sensitivity (ES) scoring value of ESI more than 1.160, between 1.160 and 1.086, from 1.086 to 0.926 and less than 0.926, respectively and these categorized districts have been depicted in Fig. 1. A district having high ES and low AC will be highly vulnerable to climate change. How strength of ES and AC determine the vulnerability status of a district can be understood by taking the example of Bidar and Gulbarga district. These districts were (vulnerability rank 1 and 2, respectively) the most vulnerable districts on the account of being poor in adaptive capacity (with ACI rank of 28 and 23, respectively) and highly prone in terms of exposure-sensitivity (with their ESI rank of 1 and 2, respectively).

Further, Bengaluru (urban) which, in spite of having poor rank in terms of ES (rank 11 and placed under high degree of ESI), but because of the high level of AC, was placed under the 'low degree' of vulnerability capacity (26th rank). Further, it can be said that Bidar, Gulbarga, Kolar, Yadir, Koppal, Mandya and Bijapur are the most vulnerable districts as evident by their vulnerability index score (more than 0.765) values to the tune of 1.046, 0.834, 0.809, 0.790, 0.778, 0.766 and 0.765, respectively. The average score of vulnerability index (0.580) with a high standard deviation (0.242) and a very wide range from lowest (0.002 of Dakshin Kannda) to highest (1.046 of Bidar), suggests that there are huge disparities among the districts in terms of their level of vulnerability to climate change. These large differences in vulnerability among districts suggest that policy makers should develop district-specific policies and address climate change issues at the local level to reduce the vulnerability of the districts' population.

Our findings are in conformity with vulnerability status reported by BCCI-K (2011) using a composite index (based on demographic, social, occupational, agricultural and climatic indicators) where they estimated that Gulbarga district is the most vulnerable district and Dakshin Kannada is the least vulnerable district in Karnataka. In our analysis Gulbarga and Dakshin Kannada secured 2nd and 30th rank in terms of vulnerability; this meager deviation can be attributed to the choice of indicators used to capture the vulnerability. Vulnerability status of different districts is depicted in Fig. 2. As indicated in the map, nearly all of north Karnataka spread over 12 districts, of which 9 have been placed under 'very high' to 'high' vulnerability status.

Since the identification of vulnerable area and population is necessary to address the ever-increasing challenges of climate change, our study suggests that in Karnataka, nearly 51% of the state's geographical area has 'high' to 'very high' degree of vulnerability, which consists of about 60% of the cultivated area and supports about 42% of the human population (Table 4). Interestingly, this area also is home for more than half of the rural population of the state, which is more susceptible to climate change impacts being highly dependent on agriculture, which is the most vulnerable sector to climate change.

4. CONCLUSIONS

District wise vulnerability assessment was carried out in Karnataka, which is one of the most drought prone states in India. A total of 27 indicators reflecting sensitivity,

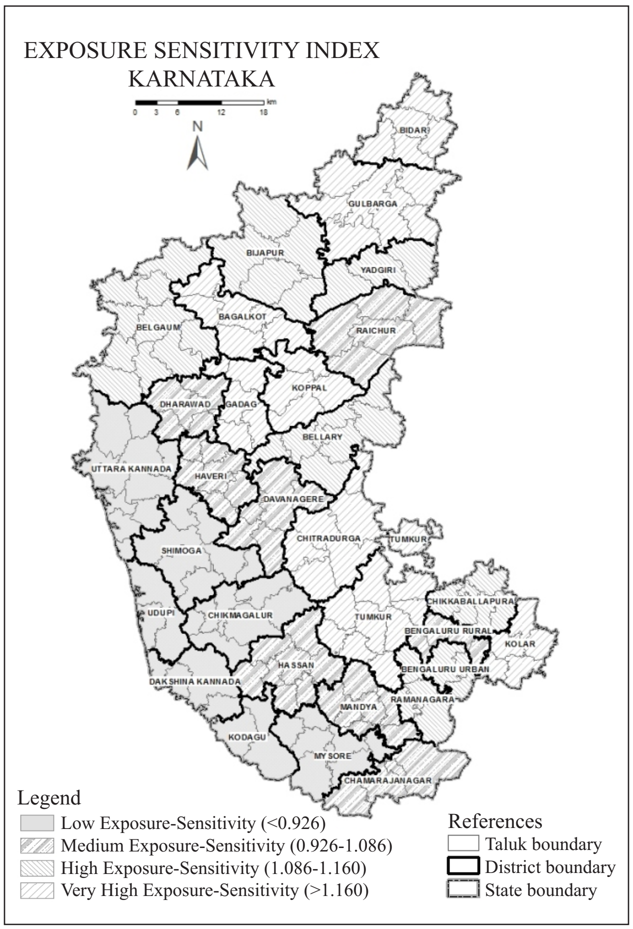

Fig. 1. District-wise degree of exposure-sensitivity to climate change

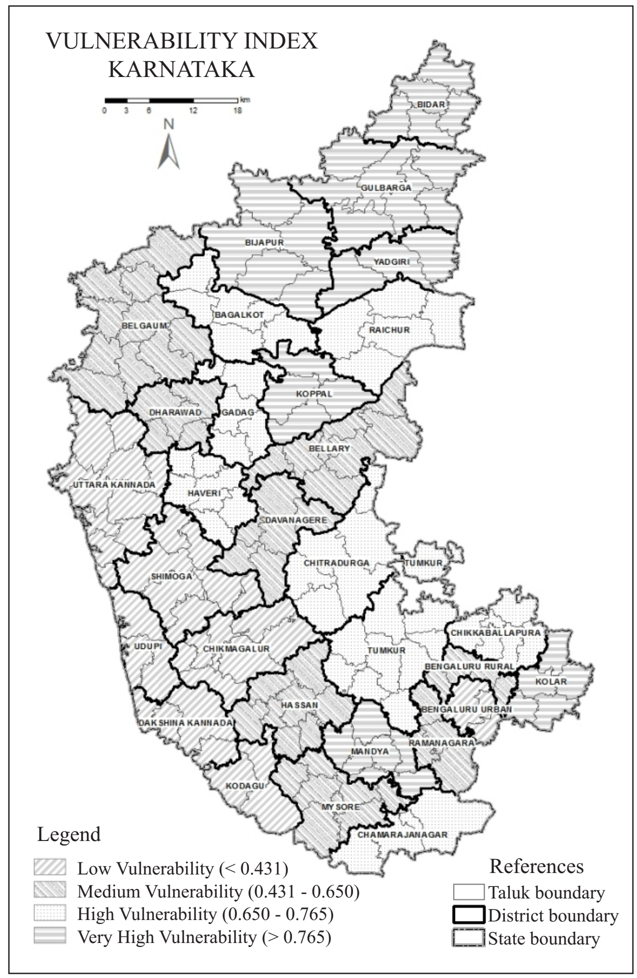

Fig. 2. District-wise status of vulnerability to climate change

Table: 4
Human population and cultivated area under different degrees of vulnerability (%)

Vulnerability Class	Geographical Area	Cultivated Area	Human Population	Rural Population	Urban Population
Very high	24.31	30.83	20.22	24.95	12.72
High	27.59	29.55	21.43	26.39	13.58
Medium	26.81	28.69	29.26	31.78	25.26
Low	21.29	10.93	29.09	16.89	48.44
Total	100.0	100.0	100.0	100.0	100.0

Note: 19.05 million hectare, 9.94 million hectare and 61.10 m is geographical area, cultivated area and human population of the state, respectively exposure and adaptive capacity were selected and all indicators were normalized to compute Exposure Index (EI), Sensitivity Index (SI) and Adaptive Capacity Index (ACI). Finally, all the three indices were combined to compute the vulnerability index. Quartile analysis was carried out to classify the districts into four groups representing 'very high', 'high', 'medium' and 'low degree of vulnerability'. Our analysis shows that Bidar is the most vulnerable district and Dakshin Kannada the least vulnerable district. Around 51% of area of the state sharing 42% of the human population, is highly vulnerable to climatic change. It is, therefore, suggested that these districts should be considered as prioritized areas to minimize the vulnerability due to the growing risk of climate change. To moderate the detrimental effects of exposure and reduce sensitivity, there is need to take the adaptive measures such as treating areas by soil and water conservations measures for containing soil erosion, conserving *in-situ* soil moisture and augmenting groundwater recharge and rainwater harvesting for supplemental irrigation. On the other side, with better health, education and rural infrastructure (especially road connectivity and electrification) and non-farm job opportunities in rural area, Adaptive capacity can also be enhanced. Therefore, there is a need to put in place a holistic approach moderating exposure level, reducing sensitivity and enhancing Adaptive capacity for sustaining the agricultural and livelihood in the wake of frequent climatic aberrations manifested in the form of low rainfall, moderate droughts and extreme water scarcity.

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