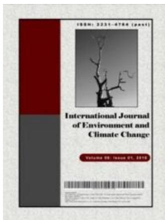

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Mapping a Climate Change Vulnerability Index: An Assessment in Agricultural, Geological and Demographic Sectors across the Districts of Karnataka (India)

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Climate change is a continuous phenomenon and over hundreds of years, the atmosphere has changed considerably around the world. Karnataka has the second largest drought prone area in the country next only to Rajasthan. Assessment of vulnerability index could play a major role in designing appropriate mitigation and adaptation policies to overcome the impacts of climate change. The vulnerability assessment is an exhaustive procedure determined by a large number of indicators. This study attempted to capture a picture of composite vulnerability index of different districts of Karnataka by considering agronomic, climatic and demographic indicators. The secondary data on climatic, agronomic and demographic factors were collected from various sources for the year 2017-18. The findings of the study as shown that the average vulnerability index for 30 districts is 0.577 and 16 districts placed above the average composite vulnerability index level. Bidar (0.655) is the most vulnerable district followed by Kolar (0.658) and Yadgir

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(0.638) districts. Shivamogga (0.440), Davanagere (0.486) and Udupi (0.486) districts exhibit the least vulnerability to changing climate. The results suggest that agricultural and climatic indicators are the major factors which influence vulnerability. So special attention should be given to agricultural and climatic sectors to minimize the impacts of climatic change in the most vulnerable districts.

Keywords: Vulnerability index; climate change; per capita income; sensitivity; exposure and adaptability.

1. INTRODUCTION

Agricultural economy in Karnataka is largely influenced by agro-climatic factors, water and other resource contributed by farmers, technology, infrastructure, tradition and social capital as also the market forces of demand and supply. Karnataka has the second largest drought prone area in the country next only to Rajasthan and water availability is one of the major concerns in the state. Karnataka's annual rainfall is 1,151 mm on an average, of which 80 per cent is received during the southwest monsoon, 12 per cent in the post monsoon period, 7 per cent during summer and 1 percent in rabi season. Groundwater potential of the area depends on rainfall and efforts to recharge. Change in climatic conditions directly affects the hydrological cycle and gradually the groundwater table. Obviously the economic impact of climate change will severely affect the food security as well as livelihood security including health security of farmers [1].

Climate change is a continuous phenomenon and over hundreds of years, the atmosphere has changed considerably around the world. However, the pace and pattern of changes in climatic factors in recent decades have turned into a matter of concern. Especially, since it is very hard to comprehend the effect of change in climatic factors at the small scale level even, say, at block or district levels [2]. The Intergovernmental Panel on Climate Change (IPCC), in its second evaluation report [3], characterizes vulnerability as the degree to which environmental change may harm or damage a system. It infers that vulnerability not only depends on a system of sensitivity, but also in addition, on its capacity to adjust to new climatic conditions, the level of economic development and institutions.

It is well known that poor people in the least developed nations are the most vulnerable against the effects of anthropogenic environmental change [4]. The poor are antagonistically affected by the environmental change since they live in vigorously affected nations and areas inside those nations, rely upon natural resource-based livelihood that are lopsidedly influenced by climate change.

People who live in the semi-arid and arid region, in low-lying seaside regions, in water-restricted or flood-inclined zones or on little islands are especially vulnerable to environmental change [5]. Obviously climate change will, in many parts of the world, antagonistically influence socio-economic status, including water resources, farming, forestry, fisheries and human settlements, natural resources and human wellbeing with creating nations being the most vulnerable [6].

There is a huge demand to create indicators of vulnerability and of adaptive capacity to decide the robustness of methodologies over time [7]. At the district level, vulnerability appraisals add to setting development needs and monitoring progress. Sectoral evaluations give details and focus to key improvement plans. In Karnataka, farmers and agriculture workers constitute 56 per cent of the aggregate workforce [8] and this is viewed as one of the main thrusts in deciding the vulnerabilities of farming families in Karnataka.

2. METHODOLOGY

The key target of this assessment is to analyse the climate vulnerability of different sectors across the districts of Karnataka (Fig. 1). Keeping in view of this appraisal the information relating to different indicators pertaining to agriculture year 2013-14 to 2017-18 were collected from various sources such as Karnataka State Natural Disaster Monitoring Centre (KSNDMC), Directorate of Economics and Statistics (DES) and Central Groundwater Board (CGB).

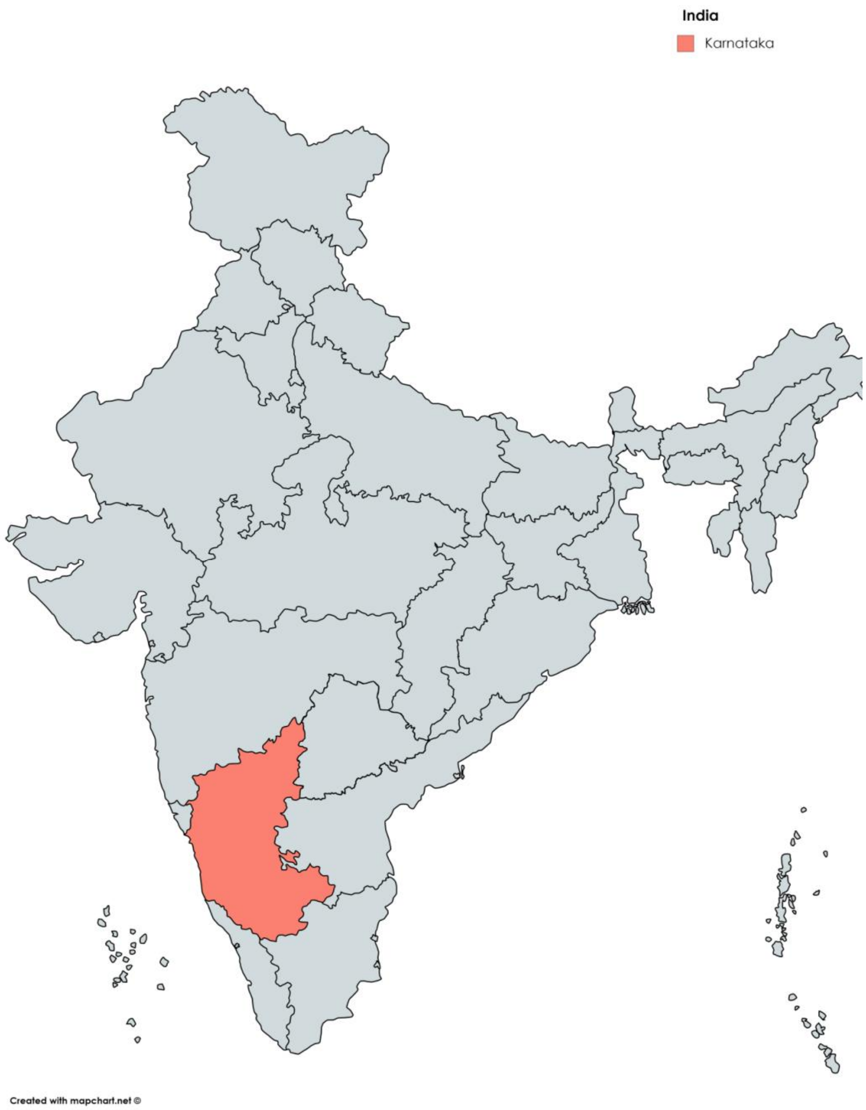

Fig. 1. Map showing Karnataka state in India

The vulnerability assesment is an exhaustive procedure influenced by a large number of indicators. However only the most significant and appropriate indicators were chosen for calculation of vulnerability index based on exposure, sensitivity and adaptability to varied climate. Parameters used in this study include.

Climatic components: Variance of annual rainfall (mm^2), Variance of South-West monsoon (mm^2), Variance of maximum temperature, Variance of minimum temperature and Variance of average temperature.

Agricultural Components**:** Geographical area (GA) (ha), Forest area (% of GA), Area under food crops (% of Gross Cropped Area(GCA)), Net sown area (% of GA), Livestock population (No. per ha of GCA), Irrigated area (% of GCA), Cropping intensity (%), Productivity of major crops (Paddy, Ragi, Jowar, Sugarcane, Maize, Groundnut, Sunflower, Cotton, Arecanut, Coconut, Redgram, Cowpea, Chilli), Depth of Groundwater (meter below ground level), Per capita income (Rs per person).

Demographic components: Density of male population (Persons per sq. ha of GA), Density of female population (Persons per sq. ha of GA), Literacy rate of male (%) and Literacy rate of female (%).

Composite Vulnerability Index (CVI) is assessed for each district by using Iyenger and Sudarshan [9] technique for unequal weight. The assessed CVI is a total of three sub-sectors specifically Climatic Vulnerability, Agriculture Vulnerability and Demographic Vulnerability. Development of vulnerability index and Composite Vulnerability Index comprises of several steps.

Step 1: The information compiled pertaining to three components was transformed into suitable estimation units and arranged in a rectangular matrix with rows representing districts and columns representing indicators.

Step 2: Since every one of the sub-component is measured using different units and scale, they need to normalized first. The procedure developed by Anand and Sen [10] for construction of the Human Development Index (HDI) is used to normalize indicators. In any case, before doing normalization, it is imperative to distinguish the functional relationship between the indicators and vulnerability. Two kinds of practical relationships, vulnerability increases with the increase (decrease) in the value of indicators are conceivable.

For direct relationship:

$$Y_{ij} = \frac{X_{ij} - Min(X_{ij})}{Max(X_{ij}) - Min(X_{ij})}$$

For indirect relationship:

$$Y_{ij} = \frac{Max(X_{ij}) - X_{ij}}{Max(X_{ij}) - Min(X_{ij})}$$

Where,

Y_{ij}= is the normalized value
X_{ij} is the actual value of the indicator
$Min(X_{ij})$ and $Max(X_{ij})$ are the minimum and maximum actual values

Step 3: The degree of vulnerability ($\bar{y_i}$) is assumed to be the linear sum of X_{ij} as

$$\bar{y_i} = \sum_{j=i}^{k} w_j Y_{ij}$$

Where w_j's are weights and are determined by

$$w_j = \frac{c}{\sqrt{var(Y_{ij})}}$$

Where c is the normalizing constant

$$c = \left[\sum_{j=1}^{k} \frac{1}{\sqrt{var(Y_{ij})}}\right]^{-1}$$

The vulnerability index lies in the range of 0 and 1. A value of 1 indicates greatest vulnerability and 0 shows absence of vulnerability.

Table 1. List of indicators and their functional relationship with vulnerability

Components	Indicators	Functional relationship	Reference
Demographic	Density of population	Direct (↑)	Palanisami et al. [11]
	Literacy rate	Inverse (↓)	Palanisami et al. 2009
Climatic	Variance of rainfall	Direct (↑)	Ravindranath et al. [12]
	Variance of Temperature	Direct (↑)	Ravindranath et al. 2011
Agricultural	Productivity of major crops	Inverse (↓)	Hiremath and Shiyani, [13]
	Cropping intensity	Inverse (↓)	Hiremath and Shiyani, 2013
	Irrigated area	Inverse (↓)	Hiremath and Shiyani, 2013
	Forest area	Inverse (↓)	Hiremath and Shiyani, 2013
	Net sown area	Inverse (↓)	Hiremath and Shiyani, 2013
	Livestock population	Inverse (↓)	Hiremath and Shiyani, 2013
	Geographical area	Inverse (↓)	Palanisami et al. 2009
	Depth of Groundwater	Direct (↑)	Suresh et al. [14]
	Per capita income	Inverse (↓)	Suresh et al. 2016

3. RESULTS AND DISCUSSION

The Sector wise vulnerability indices and composite index were constructed for all the 30 districts of Karnataka. The districts were ranked based on extent of vulnerability index.

3.1 Component Wise Vulnerability Index

3.1.1 Climatic vulnerability index

To construct district level vulnerability index five climatic variables were used and the results are presented in the Table 2. The results show that the Kalaburagi district has the highest climate vulnerability index of 0.747 followed by Kolar (0.720), Bidar (0.720), Raichur (0.712) and Yadgir (0.711) districts. The districts of Kodagu and Udupi have only 0.278 and 0.215 vulnerability index respectively, the least in Karnataka state. We can observe highest vulnerability index values in northern districts of Karnataka which is due to large variations in rainfall and temperature during the year. These are the key determinant indicators which explain high climatic fluctuations among districts.

For instance, Prevalence of a high degree of anticipated change in mean precipitation and high inconsistency in minimum and maximum temperatures drove Kalaburagi district to the top of the chart.

3.1.2 Agriculture vulnerability index

Based on functional relationship of the indicators, Vulnerability index for agricultural parameters were calculated for each district and is presented in Table 3.

Table 2. Index of climate vulnerability across the various districts of Karnataka

Sl.No	Districts	Annual rainfall	S-W monsoon	Max temp	Min temp	Avg. temp	Index total
1	Kalaburagi	0.177	0.174	0.102	0.169	0.125	0.747
2	Kolar	0.170	0.183	0.189	0.107	0.073	0.720
3	Bidar	0.173	0.169	0.120	0.189	0.069	0.720
4	Raichur	0.183	0.183	0.082	0.127	0.138	0.712
5	Yadgir	0.181	0.177	0.088	0.130	0.135	0.711
6	Vijayapura	0.185	0.182	0.087	0.147	0.100	0.701
7	Ramanagara	0.163	0.178	0.165	0.085	0.103	0.693
8	Ballari	0.186	0.187	0.100	0.054	0.154	0.681
9	Koppala	0.183	0.184	0.063	0.096	0.141	0.667
10	Bagalkote	0.188	0.185	0.078	0.109	0.095	0.656
11	Dharwad	0.181	0.179	0.118	0.094	0.070	0.643
12	Davanagere	0.178	0.179	0.066	0.046	0.125	0.593
13	Gadag	0.189	0.186	0.061	0.075	0.082	0.593
14	Chitradurga	0.183	0.185	0.060	0.044	0.119	0.591
15	Chikkaballapura	0.176	0.183	0.055	0.077	0.094	0.585
16	Belagavi	0.174	0.166	0.058	0.103	0.083	0.584
17	Tumakuru	0.176	0.181	0.044	0.055	0.105	0.561
18	Haveri	0.179	0.174	0.072	0.051	0.082	0.559
19	Mandya	0.172	0.185	0.038	0.026	0.116	0.537
20	Mysuru	0.173	0.182	0.023	0.036	0.101	0.514
21	Chamarajanagara	0.172	0.189	0.000	0.028	0.086	0.475
22	Uttara kannada	0.078	0.074	0.139	0.077	0.106	0.474
23	Bengaluru rural	0.164	0.175	0.023	0.052	0.056	0.470
24	Bengaluru urban	0.157	0.168	0.015	0.038	0.055	0.431
25	Hassan	0.152	0.149	0.024	0.043	0.052	0.421
26	Chikkamagaluru	0.128	0.126	0.076	0.039	0.042	0.412
27	Shivamogga	0.103	0.082	0.053	0.058	0.076	0.372
28	Dakshina kannada	0.031	0.030	0.045	0.000	0.189	0.294
29	Kodagu	0.080	0.082	0.094	0.022	0.000	0.278
30	Udupi	0.000	0.000	0.024	0.022	0.170	0.215

Kodagu district secures first place with a total vulnerability index value of 0.787 followed by Bidar (0.761), Kolar (0.741) and Chitradurga (0.732) districts. Whereas Davanagere has been rated as least vulnerable district (0.524). Lower productivity, declined forest area, high groundwater table level, lower cropping intensity and low per capita income are the major factors which influence the high level of sensitivity leading to higher vulnerability index.

Table 3. Agricultural vulnerability index across the districts of Karnataka

District	Geographical area(Ha)	Forest area (% to GA)	Total food crops (% to GCA)	Net sown area (% to GA)	Livestock pon (No. per Ha of GCA)
Kodagu	0.008	0.032	0.055	0.027	0.065
Bidar	0.013	0.051	0.026	0.016	0.063
Kolar	0.007	0.051	0.012	0.027	0.057
Chitradurga	0.026	0.048	0.031	0.024	0.059
Koppal	0.014	0.051	0.018	0.010	0.062
Hassan	0.019	0.048	0.022	0.021	0.061
Gadag	0.010	0.049	0.020	0.001	0.064
Dakshin Kannada	0.011	0.036	0.013	0.034	0.063
Dharwad	0.008	0.049	0.023	0.003	0.064
Haveri	0.011	0.048	0.021	0.006	0.062
Chikballapura	0.008	0.046	0.016	0.024	0.058
Bengaluru Rural	0.000	0.051	0.026	0.022	0.061
Kalaburagi	0.036	0.052	0.006	0.009	0.064
Raichur	0.026	0.053	0.014	0.018	0.061
Tumkuru	0.035	0.051	0.037	0.024	0.059
Mysuru	0.017	0.047	0.021	0.016	0.062
Chamarajanagara	0.014	0.021	0.017	0.034	0.061
Yadgir	0.013	0.050	0.028	0.014	0.061
Ramanagara	0.005	0.041	0.019	0.024	0.060
Chikkamagaluru	0.021	0.035	0.032	0.027	0.063
Vijayapura	0.034	0.054	0.003	0.000	0.064
Bagalkot	0.018	0.046	0.005	0.010	0.060
Uttar Kannada	0.033	0.000	0.004	0.044	0.059
Udupi	0.006	0.035	0.015	0.035	0.061
Mandya	0.011	0.051	0.010	0.026	0.058
Belagavi	0.046	0.045	0.014	0.016	0.065
Bellari	0.026	0.046	0.019	0.020	0.057
Bengaluru Urban	0.000	0.053	0.017	0.041	0.000
Shivamogga	0.026	0.032	0.000	0.035	0.060
Davanagere	0.015	0.044	0.005	0.013	0.062

Contd….

Irrigated area (% to GCA)	Cropping intensity (%)	Productivity	Per capita income	Depth of groundwater (mbgl)	Index total
0.049	0.045	0.443	0.046	0.018	0.787
0.041	0.034	0.438	0.051	0.030	0.761
0.038	0.056	0.442	0.045	0.006	0.741
0.032	0.037	0.410	0.048	0.017	0.732
0.027	0.040	0.426	0.050	0.012	0.708
0.032	0.037	0.378	0.042	0.038	0.697
0.035	0.029	0.402	0.046	0.038	0.694
0.012	0.041	0.449	0.014	0.011	0.684
0.041	0.000	0.429	0.041	0.024	0.683
0.028	0.039	0.394	0.048	0.020	0.677
0.029	0.048	0.381	0.046	0.012	0.669

Irrigated area (% to GCA)	Cropping intensity (%)	Productivity	Per capita income	Depth of groundwater (mbgl)	Index total
0.034	0.057	0.358	0.037	0.020	0.667
0.040	0.041	0.332	0.051	0.033	0.663
0.023	0.039	0.379	0.049	0.000	0.663
0.025	0.044	0.345	0.040	0.003	0.662
0.026	0.024	0.371	0.045	0.030	0.661
0.019	0.037	0.392	0.044	0.017	0.657
0.023	0.034	0.379	0.051	0.003	0.655
0.034	0.053	0.352	0.039	0.028	0.654
0.036	0.035	0.353	0.029	0.021	0.651
0.025	0.053	0.348	0.050	0.018	0.649
0.014	0.036	0.378	0.041	0.037	0.646
0.024	0.050	0.364	0.043	0.021	0.644
0.027	0.045	0.386	0.024	0.007	0.641
0.005	0.033	0.356	0.039	0.039	0.628
0.011	0.027	0.325	0.049	0.025	0.623
0.014	0.032	0.297	0.040	0.013	0.564
0.029	0.049	0.361	0.000	0.003	0.552
0.000	0.047	0.266	0.036	0.025	0.527
0.012	0.049	0.267	0.048	0.010	0.524

Table 4. Demographic vulnerability index across the districts of Karnataka

District	Density of male population	Density of female population	Literacy rate of male (%)	Literacy rate of female (%)	Index total
Bengaluru Urban	0.281	0.281	0.015	0.001	0.579
Yadgir	0.006	0.006	0.225	0.212	0.449
Raichur	0.006	0.006	0.165	0.176	0.353
Chamarajanagara	0.003	0.003	0.184	0.145	0.335
Kalaburagi	0.007	0.007	0.137	0.144	0.294
Bellari	0.010	0.010	0.120	0.129	0.270
Vijayapua	0.005	0.005	0.116	0.136	0.262
Ramanagara	0.011	0.012	0.119	0.112	0.255
Koppal	0.007	0.008	0.106	0.132	0.253
Bagalkot	0.010	0.010	0.101	0.128	0.249
Mandya	0.015	0.016	0.108	0.107	0.246
Chikkaballapura	0.011	0.011	0.112	0.112	0.245
Bidar	0.012	0.012	0.102	0.112	0.238
Mysuru	0.022	0.023	0.107	0.085	0.237
Belagavi	0.014	0.015	0.080	0.097	0.206
Kolar	0.016	0.017	0.083	0.086	0.202
Chitradurga	0.004	0.004	0.086	0.091	0.184
Davanagere	0.013	0.013	0.078	0.075	0.179
Tumakuru	0.008	0.008	0.075	0.083	0.174
Gadag	0.006	0.006	0.062	0.093	0.167
Bengaluru Rural	0.020	0.020	0.061	0.067	0.167
Hassan	0.008	0.009	0.069	0.077	0.163
Haveri	0.013	0.013	0.067	0.068	0.160
Dharwad	0.019	0.020	0.049	0.053	0.142
Chikkamagaluru	0.001	0.002	0.056	0.054	0.114
Shivamogga	0.005	0.005	0.052	0.046	0.107
Kodagu	0.000	0.000	0.043	0.030	0.073
Uttara Kannada	0.000	0.000	0.026	0.028	0.055
Udupi	0.011	0.014	0.013	0.013	0.051
Dakshina Kannada	0.018	0.021	0.000	0.000	0.039

In general Kodagu, Bidar, Kolar and Chitradurga districts are most sensitive districts and highly vulnerable to climate change. On the contrary, Davanagere, Shivamogga, Bellary and Bengaluru Urban districts are less sensitive and least vulnerable to changing climate.

3.1.3 Demographic vulnerability index

The districts having high population density coupled with a lower rate of literacy were identified as vulnerable districts with respect to demographic features.

Bengaluru Urban (0.579) district occupied the first place whereas Dakshina Kannada (0.039) district is placed in the last position with respect to demographic vulnerability (Table 4). Yadgir (0.449), Raichur (0.353), Chamarajnagara (0.335) and Kalaburagi (0.294) are the districts having higher degree of vulnerability index next to Bengaluru Urban district. The coastal districts of Dakshina Kannada, Udupi (0.051) and Uttara Kannada (0.055) are having lower vulnerability index and higher adaptive capacity to changing climate because of high literacy rate and lower population density.

3.2 Composite Vulnerability Index

Agricultural indicators, climatic indicators and demographic indicators were used to construct composite vulnerability index. Table 5 shows district wise composite vulnerability index which is calculated using all the three sub-components (Agricultural, Climatic and Demographic). Average composite vulnerability index for 30 districts is 0.584 and 17 districts placed above the average composite vulnerability index level. Districts having high composite vulnerability index will be highly vulnerable to climate change. Bidar (0.577) district is having the highest composite vulnerability index followed by Kolar (0.658) and Yadgir (0.638). These districts are most vulnerable districts and the results are in line with the report submitted by Anonymous [15] which used composite vulnerability index. They reported that Kalaburagi and Dakshina Kannada districts were the most and the least vulnerable districts, respectively. Higher composite index is observed mainly due to higher sensitivity of agricultural sector and larger exposure to climate change. Composite vulnerability index is lower for Shivamogga (0.440), Davanagere (0.486) and Udupi (0.486) districts because these districts are showing less vulnerability in terms of agriculture and climatic indicators. In addition also demographic variables such as population density and literacy rate have contributed to lowering of composite vulnerability index. At district level, contribution of each sub-component to composite index is not uniform. In general agricultural indicators contributed foremost, followed by climatic and demographic indicators. A study conducted by Hiremath and Shiyani (2013) reported that agriculture and occupation sector were the major sectors which have contributed most to composite vulnerability index in Saurashtra.

Table 5. Composite index of vulnerability

Sl. no	Districts	Composite index	Sl. no	Districts	Composite index
1	Bidar	0.677	16	Chamarajanagar	0.579
2	Kolar	0.658	17	Mysuru	0.574
3	Yadgir	0.638	18	Tumkur	0.573
4	Koppal	0.636	19	Hassan	0.571
5	Raichur	0.628	20	Bengaluru rural	0.558
6	Chitradurga	0.628	21	Mandya	0.557
7	Kalaburagi	0.625	22	Belagavi	0.555
8	Ramanagara	0.604	23	Ballari	0.543
9	Vijayapura	0.602	24	Bengaluru urban	0.538
10	Gadag	0.599	25	Chikkkamagaluru	0.531
11	Dharwad	0.596	26	Uttara kannada	0.530
12	Kodagu	0.594	27	Dakshina kannada	0.528
13	Chikballapur	0.593	28	Udupi	0.486
14	Bagalkot	0.590	29	Davangere	0.486
15	Haveri	0.580	30	Shivamogga	0.440
Average=0.577					

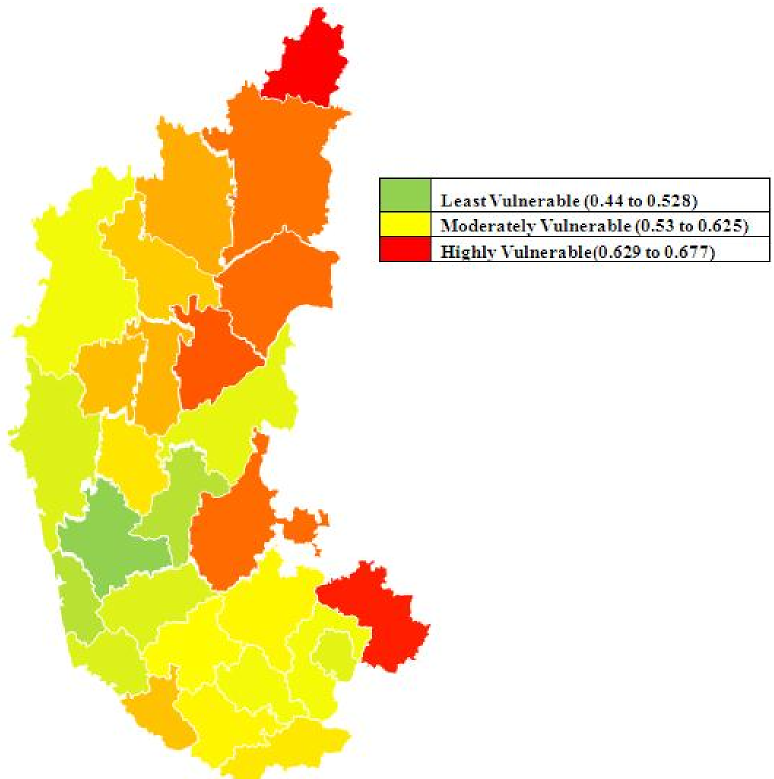

Fig. 2. Climate vulnerability of different districts of Karnataka (India)

4. CONCLUSION

Karnataka is the second most drought prone state after Rajasthan. District wise vulnerability mapping was carried out to calculate the vulnerability index of each district. Sector wise indicators were selected based on exposure, sensitivity and adaptive capacity to climate change. All the indicators were considered to calculate composite vulnerability index. Findings of the analysis shows that Bidar is the most vulnerable district and Shivamogga is the least vulnerable. Major component which is contributing to composite index is the Agricultural vulnerability. The results of agricultural vulnerability index analysis has highlighted the indicators such as productivity of the major crops, cropping intensity and per capita income are the major drivers in determining the vulnerability of districts. Therefore, it is suggested that Bidar, Kolar, Yadgir, Koppal and Chtradurga districts should be considered under on priority to minimize degree of vulnerability. There is a need to take up adaptive practices such as varietal selection according to prevailing weather, contingent cropping, soil and water conservation measures, *in-situ* moisture conservation, rainwater harvesting and augmenting recharging of groundwater for supplementary irrigation. In addition, better education and infrastructure development in rural areas will also play a catalytic role in enhancing adaptive capacity of these districts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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