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Mapping agricultural vulnerability of Tamil Nadu, India to climate change: a dynamic approach to take forward the vulnerability assessment methodology

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Abstract Vulnerability of a system is determined not only by the severity of climate change that occurs over the system but also by the system's own sensitivity and adaptive capacity to cope with new change in climatic condition. This study while examining the agricultural vulnerability of Tamil Nadu State in India to climate change, tries to improve upon the vulnerability assessment methodology. It chooses the growth and instability of certain performance indicators to capture the relative vulnerability positioning of the districts of Tamil Nadu. The normalized indicators are assigned weights based on the proportional acreage of major crops in each district with respect to the State. The weighted component indicators are then aggregated into a single index by merely adding them. In addition this study also categorizes the districts beyond ranking to have a meaningful characterization of the different stages of vulnerability. The results thus obtained reveal the fact that all districts in an agro climatic zone does not fall under the same category of vulnerability which exemplifies the need for the State to prioritize research and development issues and effective decision making through "Location-Performance-Vulnerability" based adaptation strategies. In doing so, one must take into account the local community's understanding of climate change

1 Introduction

Earth's temperature has been relatively constant over many centuries in the past as the incoming solar energy was nearly in balance with outgoing radiation. Since the advent of Industrial Revolution in 1750s, the unscrupulous emission of green house gases coupled with pollutants have altered the established energy balance of the atmosphere by absorbing the outgoing radiation and made the Earth warmer by 0.85 °C. This trend is going to aggravate as the annual mean surface air temperature is projected to rise up to 3.7 °C by the end of this century based on different Representative Concentration Pathway (RCP) Scenarios (IPCC 2013). The consequence of global warming has already manifested in the form of frequent

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warm and drought years, declining glaciers and snow cover, heavy precipitation and flash floods, sea level rise, etc.

It is very likely that such extreme events will continue to become more frequent, posing potential threat to ecosystems including agricultural production and productivity. The impact of such an unprecedented climate change will be particularly severe on the tropical regions, which mainly consists of developing countries like India, as they suffer the jeopardy of various non-climatic stresses viz. increasing population, poverty, unequal access to resources, food insecurity and incidence of diseases (Rao et al. 2010). This exemplifies the fact that vulnerability of a system is determined not only by the severity of climate change that occurs over the system but also by the system's own sensitivity and adaptive capacity to cope with new change in climatic condition.

Policy response to climate change includes mitigation of green house gases and adaptation to potential impacts caused by the changing climate (Kavi kumar 2010). As the developed and developing countries are still at loggerheads regarding whom to bear the responsibility for reducing green house gases, there is an urgent need to explore suitable adaptation strategies which make the ecosystem more resilient to absorb larger shocks due to climate change (Vincent and Cull 2010). This paved way for many vulnerability assessment studies done across the world to identify the comparatively vulnerable entities at National (Moss et al. 2001; Vincent 2004), zonal (Heltberg and Bonch-Osmolovskiy 2011), provincial/State (Brenkert and Malone 2005; Gbetibouo and Ringler 2009), district (TERI 2003; O'Brien et al. 2004; Palanisami et al. 2009; Patnaik and Narayanan 2005; Palanisami et al. 2010; Ravindranath et al. 2011), community (Balasubramanian et al. 2009; Young et al. 2010) and household (Deressa et al. 2008; Hahn et al. 2009; Vincent and Cull 2010; Tesso et al. 2012) levels, enabling the policy makers to prioritize adaptation measures with limited resources at their disposal.

In the process, many developments did happen in the methodology, in terms of choosing the indicators of vulnerability, normalizing them, assigning weights, aggregating them into a single index and categorizing the entities based on their degree of vulnerability.

In order to engage with the international community to deal with the climate change threat, India had developed the National Action Plan on Climate Change (NAPCC) in 2008. At the same time, recognising that the impacts of climate change will vary across states, sectors, locations and populations, and that different approaches will need to be adopted to fit specific sub-national contexts and conditions, all Indian States were asked to formulate State Action Plans in line with the NAPCC. Accordingly, The Tamil Nadu Government has prepared the draft "Tamil Nadu State Action Plan for Climate Change" in October (2013) which laid emphasis on 'Adaptation' as climate response strategy of Tamil Nadu, while at the same time leveraging opportunities for "mitigation". The envisioned policy document while strives to enable the State to assess the vulnerability of the State to climate risks, has expressed concern over non-availability of any systematic study to assess the adverse effects of climate change on agriculture.

In this context, the present study assumes significance as it sets out to identify the relatively vulnerable districts of Tamil Nadu State in India to climate change with respect to agriculture, a primary occupation which contributes 7 % to Gross State Domestic Product, engages 31 % of the State's labour force and thereby impacts the livelihood of around 70 % of the State's population. In the process it endeavours to evolve appropriate methodology for vulnerability mapping which will go a long way in guiding the policy makers to formulate suitable adaptation strategies to overcome the adverse impacts of climate change on the quintessential sector of the State. The thrust of this work is to add impetus to the vulnerability assessment methodology developed by many ingenious researchers.

2 Study area

Tamil Nadu, the southernmost State of India is situated between 76°15′ and 80°20′ east longitudes; and between 8°5′ and 13°35′ north latitudes. Its climate is tropical in nature with a perceptible variation between summer and winter temperatures. Incidentally, Tamil Nadu gets almost half of its total annual rainfall of 921 mm during the north-east monsoon season between October and December, when rest of the country remains dry except coastal parts of Andhra Pradesh, Kerala and Karnataka.

Agriculture, as an occupation is very much a gambling at the hands of monsoon with regular occurrence of flood and drought. Besides, it is beleaguered with number of adverse characteristics like predominance of marginal and small holdings, tendency of risk aversion due to insecure tenancy, wide seasonal variations and presence of a large proportion of tradition-loving farmers. The physiography of Tamil Nadu is classified into seven agro-climatic zones viz. North-Eastern, North-Western, Western, High Altitude, Cauvery Delta, Southern and High Rainfall Zones. The varied agro-climatic conditions enable the State to grow a multitude of crops including cereals, millets, pulses, oilseeds, cash crops, fibers, vegetables, fruits, spices and plantation crops of which rice is by far the most important crop and being cultivated in all the agro climatic zones.

3 The choice of vulnerability indicators

The first step in vulnerability assessment is the identification of suitable indicators that fully account for the complexity of the system under study. There have been several attempts made at district/province scale to identify suitable indicators to quantify the vulnerability of agriculture sector to climate change (Table 1).

Exposure is the nature and degree to which a system is exposed to climate change. On perusal of Table 1, it is observed that number of extreme rainfall events along with change and variance in temperature and rainfall have made up the indicators of exposure. For this study, growth and instability in monsoon rains have been taken as comprehensive indicators of exposure. Since growth and instability in temperature have not shown any appreciable difference across the State over the study period, it was not considered for inclusion.

Sensitivity is the degree to which a system is adversely affected by climate change. Thus the indicators of sensitivity are those variables which would have a direct relationship with vulnerability. The information in Table 1 shows that the sensitivity indicators are interspersed across categories. Notwithstanding, proportion of net area sown, agricultural GDP, soil and vegetation degradation, labour force engaged in agriculture, small holdings, rural population, ailing people, population below poverty line and area under rainfed/dryland crops form the major indicators of sensitivity. These indicators are generally demographic in nature, directly influencing the performance of agriculture in

Table 1 Indicators used in various studies to quantify the agricultural vulnerability to climate change

Sl. No.	Author(s)	Study area	Scale	Category	Indicator	Functional relationship with vulnerability
1.	TERI (2003) and O'Brien et al. (2004)	India	District	A. Exposure/Sensitivity	1. Number of extreme rainfall events	Direct
					2. Dryness index	Direct
				B. Adaptive capacity	1. Proportion of productive soil	Inverse
					2. Proportion of groundwater availability	Inverse
					3. Proportion of workers employed in agriculture	Direct
					4. Proportion of landless agricultural labours	Direct
					5. Literacy rate	Inverse
					6. Degree of gender equity	Inverse
					7. Net irrigated area	Inverse
					8. Infrastructure Development Index	Inverse
2.	Gbetibouo and Ringler (2009)	South Africa	Province	A. Exposure	1. Number of drought/flood events	Direct
					2. Change in temperature from base year	Direct
					3. Change in precipitation from base year	Direct
				B. Sensitivity	1. Proportion of irrigated land	Inverse
					2. Combined soil and vegetation degradation	Direct
					3. Proportion of small-scale farming operations	Direct
					4. Rural population per unit area	Direct
					5. Crop diversification index	Inverse
					6. No. of farmer-members of organized agriculture	Inverse
				C. Adaptive capacity	1. Literacy rate	Inverse
					2. Proportion of people infected by HIV	Direct
					3. Access to credit	Inverse
					4. Net farm income	Inverse
					5. Proportion of people below poverty line	Direct
					6. Average farm size	Inverse

Table 1 (continued)

Sl. No.	Author(s)	Study area	Scale	Category	Indicator	Functional relationship with vulnerability
					7. Share of agricultural GDP	Direct
					8. Total value of farm assets	Inverse
					9. Infrastructure index	Inverse
3.	Palanisami et al. (2009) and (2010)	Tamil Nadu State and Godavari River Basin, India	District	A. Demography	1. Density of population	Direct
					2. Literacy rate	Inverse
					3. Infant mortality rate	Direct
				B. Climate	1. Variance in annual rainfall	Direct
					2. Variance in south-west monsoon rainfall	Direct
					3. Variance in north-east monsoon rainfall	Direct
					4. Variance in maximum temperature	Direct
					5. Variance in minimum temperature	Direct
					6. Variance in diurnal temperature	Direct
				C. Agriculture	1. Production of food grains	Inverse
					2. Productivity of major crops	Inverse
					3. Cropping intensity	Inverse
					4. Irrigation intensity	Inverse
					5. Livestock population	Inverse
					6. Forest area	Inverse
				D. Occupation	1. Number of cultivators per ha	Direct
					2. Total main workers per ha	Direct
					3. Agricultural workers per ha	Direct
					4. Marginal workers per ha	Direct
					5. Industrial workers per ha	Direct
					6. Non-workers per ha	Direct
				E. Geography	1. Coastal length	Direct

Table 1 (continued)

Sl. No.	Author(s)	Study area	Scale	Category	Indicator	Functional relationship with vulnerability
					2. Geographical area	Direct
4.	Ravindranath et al. (2011)	North-East India	District	A. Exposure	1. Variation of rainfall over a series of years	Direct
					2. Inter-annual variability of rainfall	Direct
					3. Rural population density	Direct
					4. Proportion of farm holdings less than 2 ha	Direct
					5. Net sown area	Direct
					6. Net annual groundwater availability	Inverse
				B. Sensitivity	1. Area under rainfed/dryland crops	Direct
				C. Adaptive capacity	1. Area under irrigated crops	Inverse
					2. Area under high yielding varieties	Inverse
					3. Amount of fertilizer consumed	Inverse
					4. Amount of manure used	Inverse
					5. Mean rainfed crop yield	Inverse

a particular area. Hence, instability in area and yield of major crops has been taken as a comprehensive performance indicator of sensitivity.

Thirdly, adaptive capacity is the ability of a system to adjust to climate change. In order to demonstrate the adaptive capacity of a region to climate change, socio-economic indicators like literacy rate, gender equity, access to credit, net farm income, value of farm assets, fertilizer consumption, livestock population, forest area, extent of productive soil, ground water, area under High Yielding Varieties and organized agriculture have been used. Similarly to represent the bio-physical indicators of adaptive capacity, production and productivity of foodgrains, crop diversification index, cropping intensity, irrigation intensity have been utilized.

This study considers only the bio-physical indicators in a dynamic way by capturing the changes in adaptive capacity over time (O'Brien et al. 2004; Young et al. 2010), since the socio-economic indicators are merely a precursor of the bio-physical indicators. Thus, the various exposure, sensitivity and adaptive capacity indicators of climate change used in the present study in order to map the agricultural vulnerability of Tamil Nadu are summarised in Table 2.

4 Data

District level data on area and yield of 13 major crops viz. rice, finger millet, sorghum, pearl millet, maize, banana, chillies, groundnut, onion, cotton, sunflower, sesame and sugarcane that are being cultivated across Tamil Nadu, Net Sown Area and Gross Cropped Area were collected for a period of 31 years from 1980–'81 to 2010–'11 from the annual reports of Fertilizer Association of India, New Delhi. District level monthly rainfall data for the same period were obtained from the various issues of Season and Crop Report, Department of Economics and Statistics, Tamil Nadu.

Tamil Nadu has undergone many administrative changes over the years. The erstwhile 16 districts that were present during the beginning of the study period 1980–'81 doubled at present through segregation process over the years. For analytical convenience the data of carved out districts were aggregated to form the data of districts that existed during 1980–'81 (Appendix Table 7). Among the 16 districts, Chennai, Kanniyakumari and The Nilgiris were excluded as they are not the major annual crops growing districts.

5 Methodology

5.1 Simpson index of diversification

The extent of diversified cropping pattern followed in a district has been calculated by using the Simpson Index of Diversification (SID) by the formula:

$$\mathrm{SID} = 1 - \sum \left(\mathrm{a_j}/\mathrm{A}\right)^2$$

where, a_j is the area under the j^{th} crop and A is the gross cropped area

5.2 Cropping intensity index

Cropping intensity refers to cultivating a number of crops from the same field in an agricultural year. It is expressed in percentage as:

$$\text{Cropping Intensity} = \frac{\text{Gross cropped area}}{\text{Net sown area}} \times 100$$

Thus, higher cropping intensity means that a higher portion of the net area is being cropped more than once during an agricultural year. This also implies higher productivity per unit of arable land.

5.3 Compound annual growth rate

The growth in area and yield of a crop, SWM rainfall, NEM rainfall, crop diversification, net cultivated area and cropping intensity during the study period has been calculated using the formula given below and expressed in percentage.

$$Y_t = AB^t \quad (1)$$

where,

Y_t Area/yield of major crops in t^{th} period
A Constant
B (1+r)
r Compound growth rate
t Time variable (1, 2, 3……, n)

After log transformation and estimation of the above function as $\ln Y_t = \ln A + t \ln B$, compound annual growth rate has been estimated as:

$$r = \{\text{Antilog}(B) - 1\} \times 100 \quad (2)$$

Table 2 Indicators and their functional relationship with vulnerability

Sl. No.	Indicator	Component	Relationship with vulnerability
1.	Exposure	a) Growth in SWM rainfall	Inverse
		b) Instability in SWM rainfall	Direct
		c) Growth in NEM rainfall	Inverse
		d) Instability in NEM rainfall	Direct
2.	Sensitivity	a) Instability in area of major crops	Direct
		b) Instability in yield of major crops	Direct
3.	Adaptive Capacity	a) Growth in area of major crops	Inverse
		b) Growth in yield of major crops	Inverse
		c) Growth in Crop Diversification	Inverse
		d) Growth in Net Cultivated Area	Inverse
		e) Growth in Cropping Intensity	Inverse

SWM indicates South West Monsoon, NEM indicates North East Monsoon

5.4 Cuddy-Della Valle instability index

The instability in the area and yield of a crop, SWM rainfall and NEM rainfall during the study period were calculated using the formula given by Cuddy and Della Valle 1982:

$$I = CV \times \left(1 - \overline{R}^2\right)^{0.5}$$

where,

I	Instability index (per cent)
CV	Coefficient of variation (per cent)
$\overline{R}^2$	Adjusted coefficient of determination

6 Normalization

Since each of the indicators is measured on different scales, it is necessary to carry out some sort of standardization to ensure that they are comparable (Vincent 2004). Based on the methodology developed by Anand and Sen (1994) for the calculation of Human Development Index (HDI), the values of all the indicators were normalized to values between 0 and 1. Conditioning that higher the value of an indicator greater the vulnerability and this follows two ways of normalization process. If vulnerability increases with increase in the value of the indicator, the normalization is achieved by the formula:

$$Y_i = \frac{\left(X_i - \mathrm{Min}\, X_j\right)}{\left(\mathrm{Max}\, X_j - \mathrm{Min}\, X_j\right)} \tag{3}$$

On the other hand, if vulnerability decreases with increase in the value of the indicator, the normalization is achieved by the formula:

$$Y_i = \frac{\left(\mathrm{Max}\, X_j - X_i\right)}{\left(\mathrm{Max}\, X_j - \mathrm{Min}\, X_j\right)} \tag{4}$$

where,

Y_i	is the normalized value of j^{th} indicator with respect to i^{th} district (i=1, 2, …,13)
X_i	is the actual value of the indicator with respect to i^{th} district
Min X_j and Max X_j	are the minimum and maximum values respectively of j^{th} indicator (j=1,2, …,11) among all the districts

7 Assignment of weights to indicators

After standardizing the indicators, they were assigned weights based on their degree of influence on vulnerability. A review of literature indicates four methods that are being used in order to assign weights to indicators of agricultural vulnerability viz. (1) equal weight (TERI 2003; O'Brien et al. 2004; Hahn et al. 2009), (2) Inverse of variance (Palanisami et al. 2009; Palanisami et al. 2010), (3) expert opinion (Ravindranath et al. 2011) and (4) Principal Component Analysis (PCA) (Deressa et al. 2008; Gbetibouo and Ringler 2009; Tesso et al. 2012). Of these, the arbitrary strategy of assigning equal weights to indicators would mislead the calculations because, all indicators cannot have equal influence on vulnerability. Assigning higher weights to indicators showing lower variance may very well ensure that large variation in any of the indicators would not unduly dominate the contribution of rest of the indicators and distort inter regional comparisons, but on the downside this approach would suppress the pronouncement of relevant indicators. Similarly, expert opinion is often constrained by the availability of expert knowledge in smaller communities and difficulties in reaching a consensus among panel members. PCA assumes that the variable indicators are linearly related. When non-linearity is present, the component analysis is not appropriate. Further, one cannot assign any specific meaning to the transformed variables, since they are artificial orthogonal variables not directly identifiable with a particular economic magnitude (Koutsoyiannis 2007).

Since the indicators identified for this study are very precise, a highly logical method has been adopted to assign weights. Since all the 13 crops are not grown evenly in all the 13 districts, giving equal importance to a crop for all districts will distort the results. Hence different weights have been assigned to the districts for each crop based on its proportional acreage with respect to the State (Table 3).

8 Aggregation of component indices

Having derived the weighted vulnerability indices of component indicators for each of the study districts, they have to be aggregated into a single index in order to compare the districts for their relative agricultural vulnerability to climate change. In several studies (Vincent 2004; Hahn et al. 2009; Palanisami et al. 2009; Patnaik and Narayanan 2005; Vincent and Cull 2010; Palanisami et al. 2010; Heltberg and Bonch-Osmolovskiy 2011; Ravindranath et al. 2011; Khajuria and Ravindranath 2012) aggregation was done by taking weighted average of the component indices. By this technique, both the causative and counteracting indicators of vulnerability would offset each other and subsequently distort the results.

Alternatively, deducting the exposure and sensitivity indices from the adaptive capacity indices (Deressa et al. 2008; Tesso et al. 2012) would amount to double jeopardy because the component indicators were already normalized based on their functional relationship with vulnerability. Hence this study merely sums up the component indices of exposure, sensitivity and adaptive capacity to arrive at the composite vulnerability index (O'Brien et al. 2004).

The overall equation summarising the model employed for deriving the Agricultural Vulnerability Index (AVI) of a district (i) is thus:

$$\begin{aligned}\mathrm{AVI_i} = {} & 1 \times \mathrm{G(SWM_i)} + 1 \times \mathrm{G(NEM_i)} + 1 \times \mathrm{I(SWM_i)} + 1 \times \mathrm{I(NEM_i)} + \sum \mathrm{w_i} \times \mathrm{G}\left(\text{area of crop}_\mathrm{j}\right) \\ & + \sum \mathrm{w_i} \times \mathrm{G}\left(\text{yield of crop}_\mathrm{j}\right) + \sum \mathrm{w_i} \times \mathrm{I}\left(\text{area of crop}_\mathrm{j}\right) + \sum \mathrm{w_i} \times \mathrm{I}(\text{yield of crop}_\mathrm{i}) \\ & + 1 \times \mathrm{G(CD_i)} + 1 \times \mathrm{G(NCA_i)} + 1 \times \mathrm{G(CI_i)}\end{aligned}$$

where,

$\mathrm{AVI_i}$	Agricultural Vulnerability Index
$\mathrm{G(SWM_i)}$	Growth in South West Monsoon
$\mathrm{G(NEM_i)}$	Growth in North East Monsoon

Table 3 District-wise acreage under major crops in proportion to the State (TE 2010-11)

District	Rice	Finger millet	Sorghum	Pearl millet	Maize	Banana	Chillies	Groundnut	Onion	Cotton	Sunflower	Sesame	Sugarcane
	(%)												
Chengalpattu	9.2	0.4	0	0.8	0	1.3	1	7.1	0	0	0.5	1.6	2.4
South Arcot	13.7	1	1.2	25.1	6.3	5.3	0.6	13.8	0.7	10.8	4	12.4	28.3
North Arcot	8.1	9.1	3.2	10.7	0.8	8.8	1.4	28.5	0.3	6.6	7.3	3.2	13.6
Salem	2.2	10.1	13.6	2.8	13.7	5	2.2	12.6	8.7	14.7	6.2	7	10
Dharmapuri	2	70.1	8.2	2.6	0.3	2.7	1.8	6.2	1.1	7.6	8.2	1.7	6.7
Coimbatore	0.4	0.1	22.6	0.5	12.3	11.2	3.1	3.7	13	1.2	1.9	3.8	2.8
Erode	2	7.8	0	0.4	5.8	9.5	0.6	5	5.1	1.3	3.1	21.8	11.6
Tiruchirapalli	6.4	0.1	22.2	9.1	21.2	12.4	7.3	8	42.7	35.1	33.8	14.9	7.5
Pudukottai	5	0	0.1	0	1.2	3	0.1	4.3	0	0	0.3	1.7	2.4
Thanjavur	26.3	0	0	0	0.7	4.2	0.1	3	0	1.3	0.2	14.9	5
Madurai	4.9	0.3	19.4	19.9	23.3	11.5	4.5	3.7	13.3	7.9	10	4.9	5
Ramanathapuram	12.8	0.9	4.9	6.5	5.5	1.7	51.3	3.7	4.6	8.3	7.5	6.5	3
Tirunelveli	5.6	0.3	4.4	21.6	9	17.1	26	0.6	10.6	5.3	17	4.5	1.8
Kanyakumari	0.9	0	0	0	0	5.5	0	0	0	0	0	0	0
The Nilgiris	0	0	0	0	0	0.9	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100	100	100	100	100

$I(SWM_i)$	Instability in South West Monsoon
$I(NEM_i)$	Instability in North East Monsoon
$G(CD_i)$	Growth in Crop diversification
$G(NCA_i)$	Growth in Net Cultivated Area
$G(CI_i)$	Growth in Crop Intensity
w_i	Weight assigned to growth and instability in area and yield of particular crop with respect to the district i
j	study crops 1 to 13

9 Categorization of districts

For classificatory purpose, a simple ranking of the districts based on their respective index would be enough. However for a meaningful characterization of different stages of vulnerability, suitable fractile classification from an assumed distribution is needed (Palanisami et al. 2009). Beta distribution, a continuous probability distribution is suitable for this purpose. It is generally skewed and takes values in the interval (0, 1), parameterized by two shape parameters, denoted by α and β (Iyengar and Sudarshan 1982). This distribution has the probability density given by:

$$f(z) = \frac{z^{\alpha-1}(1-z)^{\beta-1}}{B(\alpha,\beta)},\ 0 < z < 1\ and\ \alpha,\ \beta > 0 \tag{5}$$

where, z is the normalized AVI.

$B(\alpha, \beta)$ is the beta function defined by:

$$B(\alpha,\beta) = \int_0^1 z^{\alpha-1}(1-z)^{\beta-1}dz \tag{6}$$

The two shape parameters α and β can be estimated using the method of moments with the first two moments as follows:

$$\text{Sample mean}\left(\overline{z}\right) = \frac{1}{N}\sum_{i=1}^{N} z_i \tag{7}$$

$$\text{Sample variance}\left(\overline{v}\right) = \frac{1}{N-1}\sum_{i=1}^{N}\left(z_i-\overline{z}\right)^2 \tag{8}$$

Thus,

$$\widehat{\alpha} = \overline{z}\left(\frac{\overline{z}\left(1-\overline{z}\right)}{\overline{v}}-1\right) \tag{9}$$

$$\widehat{\beta} = \left(1-\overline{z}\right)\left(\frac{\overline{z}\left(1-\overline{z}\right)}{\overline{v}}-1\right) \tag{10}$$

Let $(0, z_1)$, (z_1, z_2), (z_2, z_3) and (z_3, z_4) and $(z_4, 1)$ be the linear intervals such that each interval has the same probability weight of 20 %. These fractile intervals can be used to characterize the various stages of vulnerability.

1. Least vulnerable	if $0<z_i<z_1$
2. Moderately vulnerable	if $z_1<z_i<z_2$
3. Vulnerable	if $z_2<z_i<z_3$
4. Highly vulnerable	if $z_3<z_i<z_4$
5. Most vulnerable	if $z_4<z_i<1$

10 Results and discussion

Finally the relative agricultural vulnerability of each district in Tamil Nadu to climate change has been arrived at by feeding the data collected with respect to various indicators of vulnerability into several stages of transformation as detailed above. Before that, in order to fully understand the determinants of agricultural vulnerability, the exposure, sensitivity and adaptive capacity levels across the districts have been studied separately as under.

10.1 The exposure index

On perusal of Table 4, it has been found that, notwithstanding a relatively stable monsoonal rainfall, Chengalpattu stands out to be the most exposed district to climate change with an Index of 2.43 (Fig. 1) due to declining SWM in combination with a stagnant NEM. On the other hand, the increasing trend in monsoonal rainfall could not save Coimbatore from second highest exposure level to climate change because of their extreme inconsistency.

Table 4 Climate change exposure level across districts of Tamil Nadu

Rank	District	% Growth in SWM rainfall	% Growth in NEM rainfall	% Instability in SWM rainfall	% Instability in NEM rainfall
1	Chengalpattu	−0.91	0.05	7.78	12.49
2	Coimbatore	1.25	1.00	37.70	14.89
3	Salem	−1.17	1.29	7.10	16.68
4	Thanjavur	−1.32	1.44	12.30	14.40
5	North Arcot	−0.64	0.45	9.51	12.48
6	Tiruchirapalli	−1.19	1.43	10.07	14.35
7	Erode	−1.38	1.41	10.93	13.03
8	Madurai	−0.77	1.01	8.64	13.90
9	Ramanathapuram	−1.12	0.82	8.25	11.78
10	South Arcot	−1.21	0.79	13.19	6.94
11	Tirunelveli	0.78	0.70	13.25	11.54
12	Dharmapuri	−0.01	2.13	6.59	16.55
13	Pudukottai	−0.51	1.80	10.64	11.77

SWM indicates South West Monsoon, NEM indicates North East Monsoon

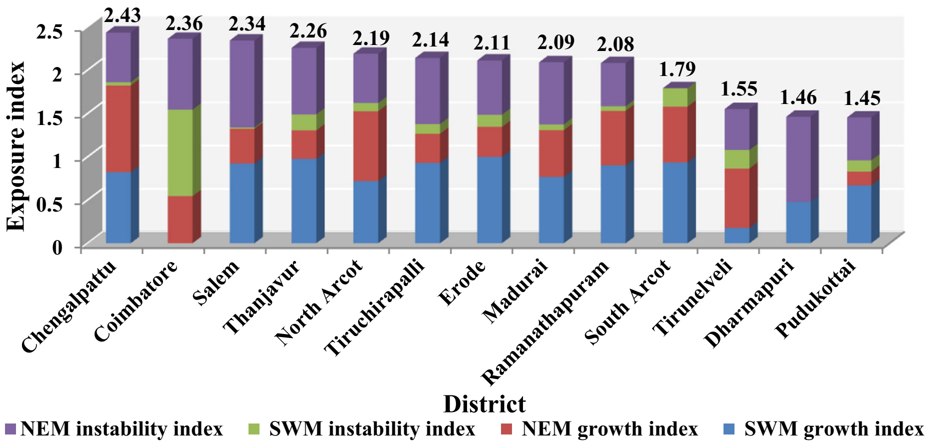

Fig. 1 Climate change exposure index across districts of Tamil Nadu

Similarly, Salem, Thanjavur, Tiruchirapalli, Erode, Madurai and Ramanathapuram were also highly exposed to climate change with the Index hovering above 2.00 due to deeply declining SWM and highly erratic NEM while declining SWM and stagnant NEM were the cause of concern with respect to North Arcot. Conversely, an increasing trend in NEM and relatively stable monsoonal rainfall render South Arcot, Tirunelveli, Dharmapuri and Pudukottai less exposed to climate change with the Index lingering around 1.50.

10.2 The sensitivity index

The sensitivity level across the districts has been scrutinized by analysing the instability in area and yield of only their proportionally major crops (see Table 3). Table 5 in general reveals the fact that, higher the crop diversification more is the exposure of agriculture to climate change and hence greater is the sensitivity of a district to climate change. Thus Tiruchirapalli which boasts a highly diversified cropping pattern by significantly contributing 11 out of 13 major crops to the State, becomes the most sensitive district to climate change with a towering Index of 1.56 (Fig. 2) due to extremely high instability in the cultivation of maize, cotton and sunflower. Salem which significantly grows 8 crops ranks second in sensitivity with an Index of 0.89 due to high instability in maize and sesame cultivation. This is closely followed by Dharmapuri, Tirunelveli and North Arcot due to high instability in the cultivation of cotton, maize and banana respectively; and sunflower in common.

On the other hand, Erode, Ramanathapuram, South Arcot and Thanjavur are moderately sensitive with their modest instability in the acreage of banana, sunflower, cotton and sesame respectively. Further, Pudukottai and Chengalpattu are least sensitive to climate change due to relatively stable cultivation of rice and groundnut, their only major crops.

10.3 The adaptive capacity index

On perusal of Table 6, in spite of showing an extremely progressive growth in the cultivation in maize, Tiruchirapalli is found to have the least adaptive capacity against climate change with an Index of 3.59 (Fig. 3) due to declining cultivation of sorghum, pearl millet, chillies, groundnut and sesame in addition to declining NCA and CI. In a similar fashion, Tirunelveli ranks second in the lack of adaptive capacity with an Index of 3.24 due to declining cultivation

Table 5 Climate change sensitivity level across districts of Tamil Nadu

Rank	District	(% Instability in area and yield of major crops)																									
		Rice		Finger millet		Sorghum		Pearl millet		Maize		Banana		Chillies		Groundnut		Onion		Cotton		Sunflower		Sesame		Sugarcane	
		A	Y	A	Y	A	Y	A	Y	A	Y	A	Y	A	Y	A	Y	A	Y	A	Y	A	Y	A	Y	A	Y
1	Tiruchirapalli					10	20	14	20	100	28	9	12	22	14	17	8	13	6	50	15	48	30	18	9	6	7
2	Salem			8	16	18	23			70	30					17	13	29	6	17	19			42	24	14	8
3	Dharmapuri			7	17	17	17													46	19	49	18				
4	Tirunelveli							21	9	39	67	13	10	22	17			9	13			54	26				
5	North Arcot	15	7	10	8			18	24			31	15			9	11					68	12			17	11
6	Madurai					9	12	21	25	11	28	14	13					19	8	6	19	44	11				
7	Coimbatore					10	14			9	60	24	39			10	16	27	8								
8	Erode			8	13							23	13											16	17	17	7
9	Ramanathapuram	5	14											9	14					15	15	34	17	17	21		
10	South Arcot	9	11					16	10							12	5			20	9			15	7	8	3
11	Thanjavur	5	11																					29	14		
12	Pudukottai	8	14													9	5										
13	Chengalpattu	8	10													8	7										

A indicates area; Y indicates yield

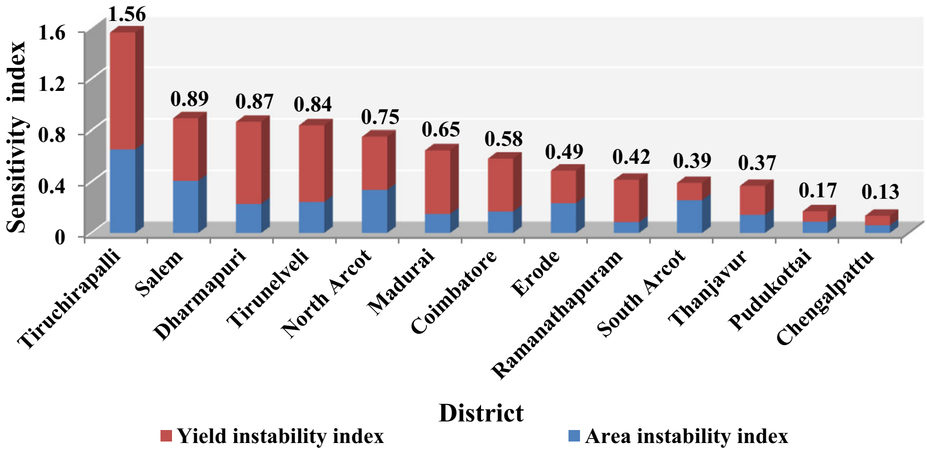

Fig. 2 Climate change sensitivity index across districts of Tamil Nadu

of pearl millet and sunflower; and declining NCA and CI. With the acreage in most of their major crops; and CD, NCA and CI keep declining over the years, Madurai and South Arcot share the third place in the lack of adaptive capacity with an Index of 3.15.

Due to their mixed agricultural performance, Dharmapuri, Coimbatore, Ramanathapuram, Pudukottai, Erode, North Arcot and Salem fall in the moderate range of adaptive capacity with the Index straddling between 2.00 to 3.00. With a reasonable growth in the yield of their major crops and increasing CD and CI, Chengalpattu and Thanjavur were found to have the highest adaptive capacity against climate change with the Index hovering around 1.50.

10.4 The overall agricultural vulnerability index

Thus the derived indices of all the three components of agricultural vulnerability are aggregated to codify the relative agricultural vulnerability among the districts of Tamil Nadu. The extreme exposure and sensitivity combined with least adaptive capacity rank (Fig. 4) and categorize (Fig. 5) Tiruchirapalli as the 'Most Vulnerable' district to climate change. Having moderate sensitivity but high exposure and low adaptive capacity, Madurai, Coimbatore, Tirunelveli and North Arcot fall under 'Vulnerable' category. With high to low exposure, sensitivity and adaptive capacity, Salem, South Arcot, Ramanathapuram, Dharmapuri and Erode are found to be 'Moderately Vulnerable' to climate change. Even though highly exposed to climate change, Chengalpattu and Thanjavur are 'Least Vulnerable' to climate change due to their low sensitivity and high adaptive capacity. On the other hand, even though less capacitated against climate change, Pudukottai is also 'Least Vulnerable' to climate change due its least exposure and sensitivity. Incidentally, no district falls under the 'Highly Vulnerable' category.

11 Conclusion and policy implication

While undertaking the examination of agricultural vulnerability of Tamil Nadu State in India, this study tried to improve upon the methodological aspect of vulnerability analysis. At the outset, this study did rely only on performance indicators instead of demographic indicators.

Table 6 Climate change adaptive capacity level across districts of Tamil Nadu

Rank	District	(% growth in area, yield, CD, NCA and CI of major crops)														
		Rice		Finger millet		Sorghum		Pearl millet		Maize		Banana		Chillies		Ground nut
		A	Y	A	Y	A	Y	A	Y	A	Y	A	Y	A	Y	A
1	Tiruchirapalli					−2.8	−1.2	−9.9	−0.9	28.0	2.6	1.2	1.7	−3.0	0.8	−1.7
2	Tirunelveli							−4.4	3.1	26.0	6.3	3.3	3.3	1.7	−1.4	
3	Madurai					−2.7	0.4	−2.5	−0.3	15.8	1.3	3.9	3.5			
4	South Arcot	0.3	0.6					−6.1	−0.4							−4.4
5	Dharmapuri			−1.3	1.0											
6	Coimbatore					−1.9	−2.4			2.8	2.6	9.3	−0.2			
7	Ramanathapuram	−0.2	1.9											2.8	0.8	
8	Pudukottai	−0.2	0.5													−3.2
9	Erode			−4.2	−1.0							7.3	2.4			
10	North Arcot	−0.7	1.4	−3.1	1.3			−2.6	−0.5	1.9	2.2	4.4	4.3			−2.2
11	Salem			−3.8	0.8	−5.1	0.6			15.0	1.4					−2.5
12	Chengalpattu	−1.6	2.0													−3.9
13	Thanjavur	−0.6	−0.4													

Rank	(% growth in area, yield, CD, NCA and CI of major crops)													
	Ground nut	Onion		Cotton		Sunflower		Sesame		Sugarcane				
	Y	A	Y	A	Y	A	Y	A	Y	A	Y	CD	NCA	CI
1	2.9	6.3	−1.2	3.7	0.5	3.5	5.2	−3.0	0.3	1.7	−0.8	0.1	−0.7	−0.1
2		3.4	0.7			−7.0	4.3					0.1	−1.0	−0.2
3		−0.4	0.3	−5.7	−0.5	−6.0	3.7					0.1	−0.6	−0.3

Table 6 (continued)

Rank	Ground nut	Onion		Cotton		Sunflower		Sesame		Sugarcane		CD	NCA	CI
	(% growth in area, yield, CD, NCA and CI of major crops)													
	Y	A	Y	A	Y	A	Y	A	Y	A	Y	CD	NCA	CI
4	3.6			−2.1	−1.1			−4.8	1.7	3.2	0.1	−0.1	−0.2	−0.4
5				0.8	−2.3	−9.3	2.6					0.1	−0.7	−0.2
6		−2.3	0.9									0.0	−0.4	−0.3
7				−5.1	−0.2	−7.4	4.1	−3.6	2.5			0.1	−1.1	0.0
8	2.2											0.1	−0.9	−0.4
9								0.6	4.0	3.9	0.7	0.1	−0.8	−0.2
10	2.6					8.2	5.4			1.3	0.1	0.0	−0.6	−0.1
11	1.7	−0.1	0.3	0.2	0.6			−2.5	4.6	3.0	−0.2	0.1	−0.3	0.0
12	5.3											0.2	−1.1	0.3
13								−3.0	1.3			0.6	−0.4	0.0

CD indicates Crop Diversification, NCA indicates Net Cultivated Area, CI indicates Cropping Intensity

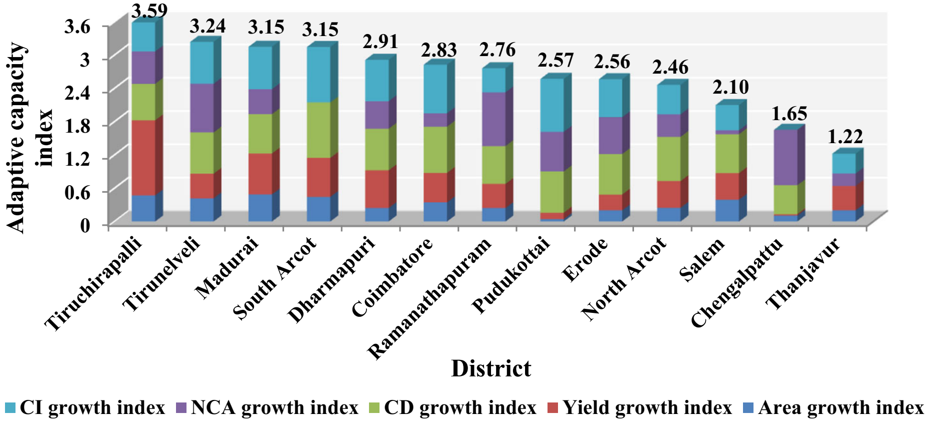

Fig. 3 Climate change adaptive capacity index across districts of Tamil Nadu

Secondly, it did involve dynamism into the analysis by choosing the growth and instability of appropriate vulnerability indicators instead of their cross sectional data at various points of time in order to show the progress of vulnerability (Patnaik and Narayanan 2005). Thirdly it did assigned weights to indicators of vulnerability in a highly logical manner instead of various arbitrary methods followed in other studies. Fourthly, the weighted component indicators have been aggregated into a single index by merely adding them instead of result distorting methods of averaging and deducting. In addition this study had categorized the districts beyond ranking them to have a meaningful characterization of the different stages of vulnerability.

The results thus obtained through this improved methodology revealed Chengalpattu to be the most exposed district to climate change followed by Coimbatore, Salem and Thanjavur while South Arcot, Tirunelveli, Dharmapuri and Pudukottai are least exposed. Tiruchirapalli, having the most diversified cropping pattern, has been found to be the most sensitive district to climate change followed by Salem, Dharmapuri, Tirunelveli and North Arcot. On the other hand, Pudukottai and Chengalpattu are least sensitive. Again, Tiruchirapalli is least capacitated against climate change followed by Tirunelveli, Madurai and South Arcot while Chengalpattu

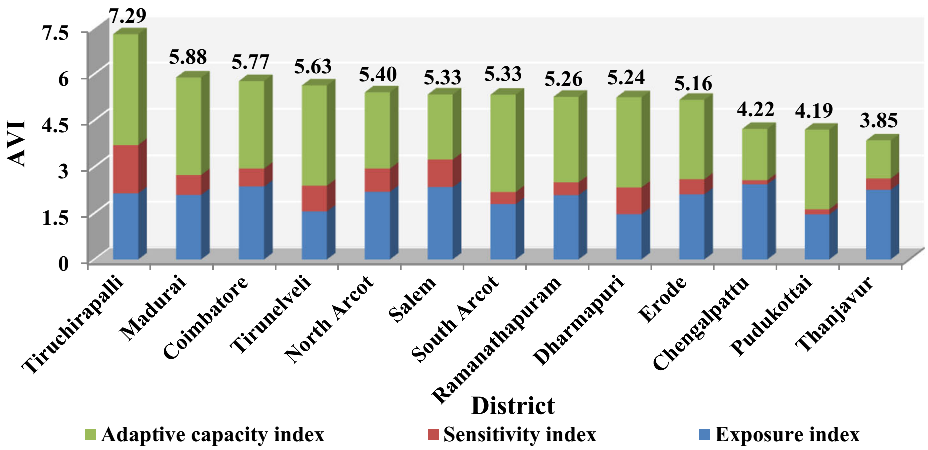

Fig. 4 Agricultural vulnerability index across districts of Tamil Nadu

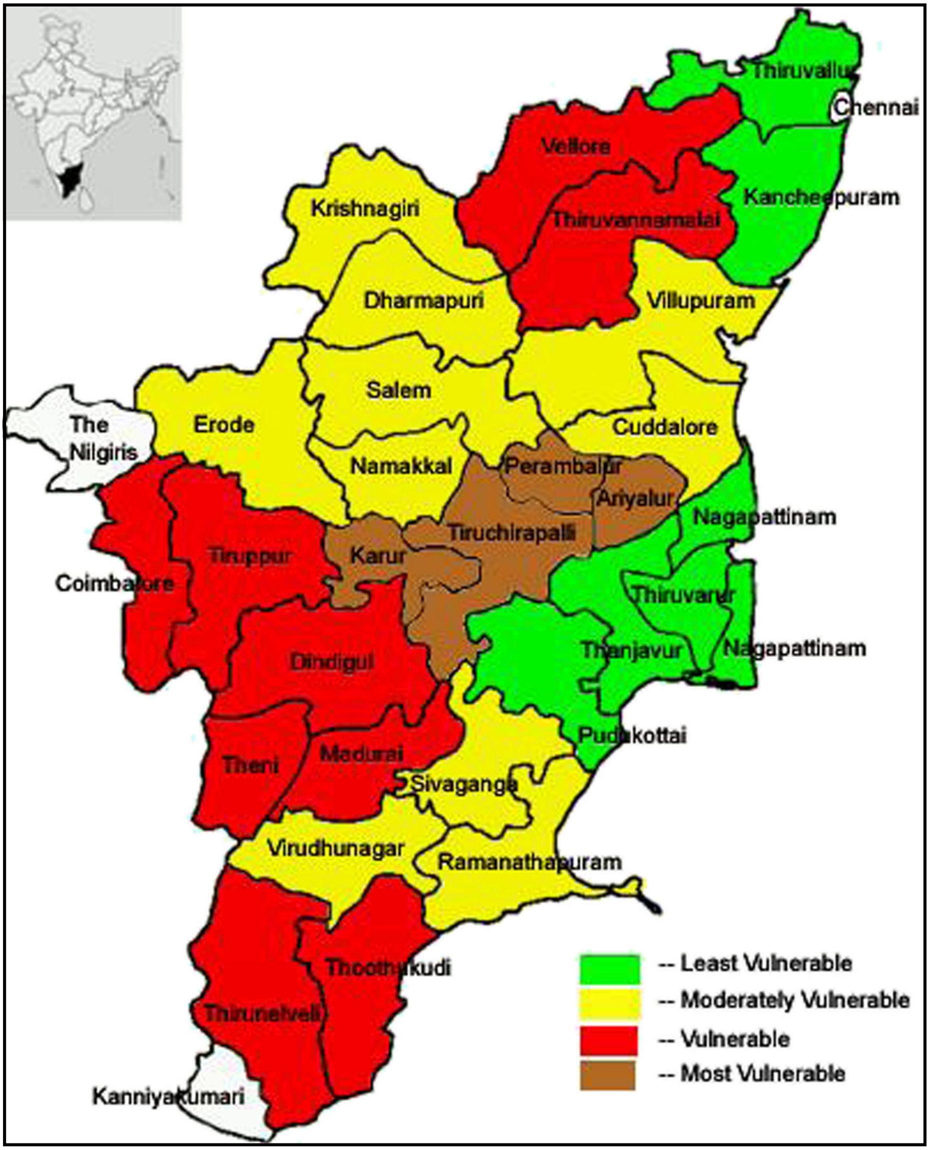

Fig. 5 Agricultural vulnerability mapping of Tamil Nadu to climate change

and Thanjavur were found to have the highest adaptive capacity. Thus Tiruchirapalli has been categorized as the 'Most Vulnerable' district even as Madurai, Coimbatore, Tirunelveli and North Arcot are 'Vulnerable' to climate change. While Salem, South Arcot, Ramanathapuram, Dharmapuri and Erode are found to be 'Moderately Vulnerable', Chengalpattu, Thanjavur and Pudukottai are 'Least Vulnerable' to climate change.

The fact that all districts in an agro climatic zone does not fall under the same category of vulnerability exemplifies the need for the State to prioritize research and development issues and effective decision making through "Location-Performance-Vulnerability" based adaptation strategies viz. developing new crop varieties, early weather warning system, innovative farm resource management techniques, dynamic crop insurance and income stabilization programmes in order to overcome the adverse impacts of climate change on the quintessential sector of the State. In doing so, one must take into account the local community's understanding of climate change, its impacts on agriculture, the indigenous adaptation measures that are being practised traditionally and the factors influencing in adopting them because indigenous knowledge is borne out of continuous experimentation, innovation and adaptations, blending many knowledge systems to solve local problems.

Appendix

Table 7 Chronology of district segregation in Tamil Nadu

Sl.No.	District	Year of bifurcation	Sl.No.	New Districts
1.	Chengalpattu	1997	1.	Kancheepuram
			2.	Thiruvallur
2.	South Arcot	1993	3.	Cuddalore
			4.	Villupuram
3.	North Arcot	1989	5.	Thiruvannamalai
			6.	Vellore
4.	Salem	1996	7.	Salem
			8.	Namakkal
5.	Dharmapuri	2004	9.	Dharmapuri
			10.	Krishnagiri
6.	Coimbatore	2009	11.	Coimbatore
			12.	Thiruppur
7.	Erode		13.	Erode
8.	Tiruchirapalli	1995	14.	Tiruchirapalli
			15.	Karur
			16.	Perambalur
		2007	17.	Ariyalur
9.	Pudukottai		18.	Pudukottai
10.	Thanjavur	1991	19.	Thanjavur
			20.	Nagapattinam
		1997	21.	Thiruvarur
11.	Madurai	1985	22.	Madurai
			23.	Dindigul
		1996	24.	Theni
12.	Ramanadhapuram	1985	25.	Ramanathapuram
			26.	Sivagangai
			27.	Virudhunagar
13.	Tirunelveli	1986	28.	Tirunelveli
			29.	Thoothukudi
14.	The Nilgiris		30.	The Nilgiris
15.	Kanniyakumari		31.	Kanniyakumari
16.	Chennai		32.	Chennai

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