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Climate change vulnerability index for Cauvery delta Districts of Tamil Nadu

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Abstract
In India, Tamil Nadu is considered to be the one of the most vulnerable states which if frequently prone to various climate change events like drought and flood impacting agriculture and allied activities. Objective of this research is to develop the vulnerability index to climate change in the Cauvery delta districts. Identification of vulnerability indices is necessary due to the region's vulnerability to climate change and its disastrous repercussions, which will aid local government authorities in creating proactive policies for improved disaster management. The study implemented the vulnerability method according to Iyengar and Sudarshan to evaluate vulnerability for 4 components (demographic, climatic, agricultural, occupational). A hierarchy of vulnerability classification is advanced by using the various sectors in accordance with the various indicators. The study was conducted to assess the vulnerability level of Thanjavur, Tiruvarur and Nagapattinam districts of Tamil Nadu by developing the vulnerability indices during a year. Based on the fractile intervals, the level of vulnerability was classified as less vulnerable, moderately vulnerable, vulnerable, highly vulnerable, vulnerable and very highly vulnerable. The finding of the study reveals that all the three districts (Thanjavur, Tiruvarur and Nagapattinam) were in vulnerable stage. Tiruvarur district ranked in first position in the overall vulnerability of climate change, followed by Thanjavur and Nagapattinam district. Assessing agricultures sensitivity to climate changeis a prerequisite for developing and disseminating climate-smart solution. Decision makers and planners require this data to develop appropriate strategies for mitigating the negative effects of climate change and to prioritize sensitive region for resource allocation.

Keywords: Climate change, vulnerability index, Cauvery delta districts, vulnerability method

Introduction

The effect of climate change evident all over the world; however, the vulnerability to climate change differs across sectors and regions. India was ranked among the most vulnerable country due to lack of infrastructure, capital education, adaptive capacity, mitigation strategy and adaptation options (Maplecroft 2015). According to the IPCC (Intergovernmental Panel on Climate Change), vulnerability is defined as "the degree to which a system is susceptible to and unable to cope with adverse effects of climate change, including climate variability and extremes". Vulnerability encompasses a number of concepts and elements, including sensitivity to harm and a lack of capacity to cope and adapt.". (IPCC: Fifth Assessment Report 2014) [2]. Vulnerability assessment is a useful adaptation planning tool for mitigating climate risks (IPCC 2014) [2]. The IPCC third assessment report specifically identified the Asian region as most vulnerable to climate change related impact due to its poor adaptive human systems (Lal *et al*., 2001) [18].

Recent research has evaluated the socioeconomic susceptibility to specific disasters like cyclones, droughts, and floods. Malakar and Mishra (2016) [5] examined the socioeconomic susceptibility to climate change in eleven cities spread throughout India's several bioclimatic zones. Tripathy (2014) [15] examined the socioeconomic sensitivity of Uttar Pradesh to climate change and illustrated that socioeconomically disadvantaged populations are more vulnerable to the effects of climate change. Because of the effects of climate change, there has been a noticeable decrease in the acreage and production of various important crops, including paddy, groundnuts, and sugarcane, by between 5.2 and 9.5 percent throughout the state. It is expected that overall production for these crops would decline between 9.00 to 22.00 percent by 2020 (Palanisami *et al*., 2009) [6]. Coastal areas are severely prone tonatural disasters and climate change by other environmental challenges like development of salinity, soil infertility, water logging condition, flooding and storm surges, etc.

(Shamsuddoha and Chowdhury, 2007; Ranjan *et al*., 2006) [9, 19]. According to Singh *et al*. (2014) [20], a community's sensitivity to the effects of risks is influenced bya variety of elements, including physical, social, economic, and environmental factors or processes. The wide portion of the east coast from Chengalpet, South Arcot, Thanjavur, and Ramanathapuram to Tirunelveli have salt affected soils. The primary cause of this is excessive groundwater extraction. (Ground water year book- India, 2011-2012)

The current paper's objective is to identify the most susceptibl e districts and assess them using a set of indicators. It is crucial to calculate the vulnerability index for the various districts of Tamil Nadu because climate change is a vulnerability phenomenon that is influenced by several factors. Three districts in total have been chosen. (Thanjavur, Tiruvarur and Nagapattinam). The major available indicators were deputed from 2011 decade. It contributes to the discussion over vulnerability measurement by contrasting a narrow focus on economic or environmental vulnerability with a multi-dimensional approach to evaluate districts. In this context, the current study assumes significance as it seeks to identify the relatively climate change-vulnerable districts of Cauvery delta zone with regard to agriculture, a primary industry that employs 65 percentage of the grass cropped area., and that affects the livelihood of CDZ farmers. By assessing the district level vulnerability, by including residents of susceptible areas, adaptation is a local project that can be successful. They should know about how to cope with disasters events, and the resilience mechanism should be apprehended.

Review of literature

(Sarkar *et al.* 2010) [12] in their study they assessed the vulnerability of farming community in 24 south Pargana district of West Bengal and reported that majority of the respondents (47.00 percent) found in highly vulnerable group followed by (37.00 percent) in vulnerable group, while about 17.00 percent in moderate vulnerable group.

Latha Devi *et al*., (2016) [21] identified the livestock vulnerability index for livestock farmers. It was found that the farmers who had single livestock species (cattle) was vulnerable than others due to climatic variation. Frequently, the households suffered from animal feeding, management, crop and vegetable crop loss and it was found that sheep and goat was less vulnerable when compared to cattle where it could withstand extreme weather conditions.

Neha pandey (2018) [13] conducted a study on 'Farmers' Perception towards Climate Change and Adaptation in Bihar: A Gender Perspective' and found that majority of the respondents (55.83%) were under the category of medium vulnerability, while, 35.83 and 8.33 percent of them were belonged to category of low and high vulnerability.

Oo *et al*., (2018) [16] focus on farmers categories of coastal area in the Ayeyarwady delta basin, Myanmar largest river basin. The Livelihood Vulnerability Index was used with data from 178 farmers which includes 37 indicators. According to the findings of the study, farm households that do not adopt any adaptation strategies are more vulnerable than adapted households. It was found that farm households have lack of access to basic infrastructure, opportunities for additional income from agricultural or non-farm sources and sole dependence on agriculture made households more vulnerable to climate change.

According to a study conducted in Sukoharja and Klaten regencies of Indonesia among the paddy farmers, where the agricultural fields are especially prone to floods, whereas farmers in the Sonorejo village are vulnerable to climate change by an index of 0.363and 0.044, respectively estimated using LVI (Suryanto & Rahman 2019) [7].

Rudiarto & Pamungkas (2020) [15] assessed vulnerability on the north shore of Tegal city, Indonesia using the Livelihood Vulnerability Index (LVI). According to the findings, 22.25 percent of the fisheries area was vulnerable to flooding, and 32.20 percent of the household samples were impacted by climate related disaster. Fishermen who relied on coastal resources made up the majority of the 28 households.

According to Chaitanya Ashok Adhav (2021) [22], among the 34 districts, 11 were classified as very vulnerable to climate change (39.34 percent cropped land), 14 as moderately vulnerable (36.85 percent cropped area), and nine as less vulnerable (23.21 cropped area). The central Maharastra plateau zone has most of the most vulnerable districts. Districts from central and eastern Vidarbha sone are moderately vulnerable. North konkan coastal, scarcity zone, and western Maharastra are moderately vulnerable areas.

Description of Study Area

Climate: The maximum temperature of the Cauvery Delta Zone ranges from 32 ºC to 39.2 ºC during the month of April, May and June. Minimum temperature of 29.5 ºC to 24 ºC is felt during the month of November, December and January.

Rainfall

The average annual rainfall of the region is 1150 mm. The North East monsoon receives approximately 67% (788mm) of the rainfall, while the South-Wet monsoon receives 25% (289mm). Very less rainfall is received during the winter i.e., about 3 percent (30mm) and around 5 percent (66mm) in summer. As can be seen, the sub-division receives the majority of its annual rainfall during the North-East monsoon period, which is accompanied by heavy rains and monsoon cyclones. Rainfall in this area has become more erratic in recent years.

Table 1: Disaster occurrence details in Thanjavur district

Years	Disaster occurrence	Crops affected
2000	Drought	Paddy
2001	Drought	Paddy
2002	Drought	Paddy
2005	Flood and crop damage	Paddy
2008	Drought	Paddy
2012	Drought	Paddy
2016	Drought	Paddy
2018	Gaja cyclone	Paddy

Source: Joint director of Agriculture, Nagapattinam

Table 2: Disaster occurrence details in Nagapattinam district

Years	Disaster occurrence	Crops affected
2000, 2001 & 2002	Drought	Paddy, pulses etc.
2004	Tsunami	Paddy
2005	Flood in Cauvery delta	Paddy
2008	Drought year	Paddy
2012	Drought year	Paddy
2016	Drought year	Paddy
2018	Gaja cyclone	Paddy

Source: Joint director of Agriculture, Nagapattinam

Table 3: Disaster occurrence details of Tiruvarur district

Years	Disasters occurred	Crops Affected
2001-2002	Flood	Paddy, Pulses, Groundnut
2002-2003	Drought	Paddy, coconut
2003-2004	Flood	Paddy
2004-2005	Flood	Paddy
2005-2006	Flood	Paddy
2006-2007	Flood	Paddy
2007-2008	Flood	Paddy, Pulses, Cotton, Gingely
2008-2009	Flood	Oilpalm, Sugarcane, Betelvine, Flowers, Vegetable, Banana
2009-2010	Drought in kuruvai	Paddy
2010-2011	Flood	Paddy
2011-2012	Thane cyclone	Paddy
2016-2017	Drought	Paddy
2018-2019	Gaja cyclone	Paddy
2019-2020	Flood (Burevi cyclone) and Pest attack (Gall midge)	Paddy
2020-2021	Flood, unseasonal rainfall	Paddy

Source: Joint director of Agriculture Tiruvarur

The data in the table depicts that frequent occurrence of disaster events in the Tiruvarur districts. This may leads to the reason that Tiruvarur district more vulnerable among the Cauvery delta zone.

Methodology

The data pertaining to various indicators (population, literacy rate, rainfall, food grains, livestock population etc.,) were gathered from various sources, *viz*., Department of Economics and Statistics, Tamil Nadu and Department of Horticulture, Tamil Nadu. The meteorological data were collected from the Regional meteorological center, Chennai. Methods with equal weights and methods with uneven weights are the two main approaches used to generate vulnerability indexes. For finding the vulnerability index (Without weights) Normalization and Simple average of scores are used and for assessing index (With weights) Iyenger and Sudarshan's (1982) method were used. The list of possible indicators is provided in Table 4.

Table 4: Vulnerability Indicators for Climate Change.

Sl. No	Components	Indicators
1	Demographic	a. Density of population (persons per sq.km)
		b. Literacy rate (percent)
2	Climatic	a. Variance of annual rainfall (mm2)
		b. Variance of Southwest monsoon (mm2)
		c. Variance of minimum temperature (°C)
		d. Variance of maximum temperature (°C)
3	Agricultural	a. Total food grains (Kg/ha)
		b. Cropping intensity (percent)
		c. Irrigation intensity (percent)
		d. Forest area (percent to geographic area)
		e. Total food crops (percent)
		f. Total non-food crops (percent)
		g. Net sown area (hectares)
		h. Livestock population (number per hectare of gross cropped area)
4	Occupational	a. Total main workers (per hectare of net area sown)
		b. Number of cultivators (per hectare of net area sown)
		c. Agricultural laborer's (per hectare of net sown area)
		d. Industrial workers (per hectare of net sown area)
		e. Marginal workers (per hectare of net sown area)
		f. Non-workers (per hectare of net sown area)

Construction of Vulnerability Index (Without weights)

There are various phases involved in generating an index. Selecting a study area, which can be further subdivided into several areas, is the initial step. A set of indicators is selected for each region for each of the four vulnerability components. Vulnerability changes over time; it is critical that all indicators for the specific year are considered. For each of the four components of vulnerability, a set of indicators is chosen in each region.

Arrangement of Data

Each component of vulnerability's collected data was arranged into a rectangular matrix, with rows and columns designating districts and indicators, respectively. Assume M represents districts and K represents indicators. Let Xij represent the value of the indicator j for area i.

Normalization of Indicators

$$xij = \frac{xij - Min\ [Xij]}{Max\{Xij\} - Min\{Xij\}}$$

Vulnerability and the normalization were evaluated using the formula, the scores will lie between 0 and 1. The value 1 will be assigned to the district which has the maximum indicator value and 0 will be corresponded to district with minimum value.

Iyenger and Sudarshan's Method for Construction of Vulnerability Index

The Iyenger and Sudarshan approach was used to create the index. With the aid of a method for creating a composite index from multivariate data, it is useful to rank the districts according to their economic performance. This technique can be used to create a composite index of climate change vulnerability and is statistically relevant. All the 21 indicators were used to develop a vulnerability index for the year 2020 in the selected districts of Tamil Nadu, based on data availability. Based on 21 indicators 2 for demographic vulnerability, 4 for climatic vulnerability, 12 in agricultural vulnerability, and the remaining 6 were occupational vulnerability component.

A brief methodology is given below. It is assumed that M as regions/districts, K as indicators of vulnerability and xij, i= 1, 2,….M; j=1, 2,..k are the normalized scores.

The level of development of i-th zone, y1 is assumed to be a linear sum xij is

Where w's (0<w<1 and Σkj=1 wj=1) are the weights. The weights are assumed to vary inversely as the varianceover the areas in the corresponding indicators ofvulnerability in Iyenger& Sudarshan's method. Thatis, the weight (wj)is determined by

$wj = c/ \sqrt{var(xij)}$

Where c is a normalizing constant such that $c= [\Sigma^{k}_{j=1} 1/ \sqrt{var(x_{ij})}]^{-1}$

The weights chosen would guarantee that the large variance of the indicators had disproportionately dominated the contribution of the other indicators and skewed interregional comparisons. The vulnerability index ranges from 0 to 1, with 1 being the utmost vulnerability and 0 representing no vulnerability at all. Simple ranking of the districts based on the indices, such as would be enough. However, appropriate fractile classification from an assumed probability distribution is needed to characterize the various stages of vulnerability. The Beta distribution, which is often skewed and takes values in the range (0,1) as followed by Iyengar and Sudarshan (1982), has been utilized as a probability distribution that is suited for this use. This distribution has the probability density given by

The Beta distribution is skewed. Let (0, z1), (z1, z2), (z2, z2), (z3, z4) and (z4,1) be the linear intervals such that each interval has the same probability weight of 20 percent. These fractile intervals can be used to describe the various stages of vulnerability.

Fractile intervals

1. Less vulnerable in case of $0 < y_i < z1$
2. Moderately vulnerable incase of$z1 < y_i < z2$
3. Vulnerable in case of $z2 < y_i < z3$
4. Highly vulnerable if $z3 < y_i < z4$
5. Very highly vulnerable if $z4 < y_i < 1$

Results and Discussion

Finally, the relative agricultural vulnerability of selected district in Tamil Nadu (Thanjavur, Tiruvarur and Nagapattinam) for the year 2020 was presented. The vulnerability to climate change was calculated by feeding data collected on various indicators of vulnerability into several stages of transformation, as shown in the table below.

Jayakumara (2015) [17] in his study the results obtained using this enhanced methodology showed that, Tirunelveli, Dharmapuri, and Pudukottai are the districts that are least sensitive to climate change, followed by Chengalpattu, Coimbatore, Salem, and Thanjavur.

The consequence of the entity's exposure (to the external challenge that creates vulnerability), sensitivity of the outcome to the external stressor, and adaptive capabilities in dealing with the stressor's negative influence on the entity's outcome. The four major specific components of vulnerability were taken. It represents the demographic factors, climatic factors, agricultural factors and occupational factors. Tables 5 and 3 show the final worked indicators for the district data.

Table 5: Vulnerability indices for year 2020 normalized score-without weights.

District	Density of Population	Literacy Rate	Variation in Annual Rainfall	Variation in SW Monsoon	Variation in Minimum temperature	Variation in Maximum temperature	Total Food Grains	Productivity Paddy
Thanjavur	1	0	1	0.267	0.763	0.457	0.825	1
Tiruvarur	0	0.231	0.865	0	1	1	1	0.993
Nagaipattinam	0.489	1	0	1	0	0	0	0

District	Crop Intensity	Irri Intensity	Forest Area	Total Food crops	Total Non-Food	Net sown area	Livestock	Main workers
Thanjavur	0.076	1	0	0	1	1	0	0.417
Tiruvarur	1	0.666	0.131	1	0	0.661	0.052	0
Nagaipattinam	0	0	1	0.782	0.214	0	1	1

District	No of cultivators	Agrl. labourers	Industrial	Marginal	Non-workers	Sum of scores	vulnerability index	Rank
Thanjavur	0	0.081	1	0	1	10.88	0.498	2
Tiruvarur	0.464	0	0	1	0.559	10.62	0.505	1
Nagaipattinam	1	1	0.9	0.149	0	9.53	0.454	3

Table 6: Vulnerability indices for year 2020 with weights

Districts	Vulnerability index
Thanjavur	0.496692
Tiruvarur	0.533671
Nagapattinam	0.479007

The various levels of susceptibility were described using the fractile intervals, as seen below:

0.4<0.496≤0.6- Thanjavur
0.4<0.533≤0.6- Tiruvarur
0.4<0.479≤0.6- Nagapattinam

As results shown in Table 5 and 6 among the districts, Tiruvarur district ranked in first position in the overall vulnerability of climate change, followed by Thanjavur and Nagapattinam district. It is because of their high sensitivity and exposure. These might be due to the agricultural and occupational indicators were the major factors contributing respectively. Finding

strategies which help in improving the adaptive capacity and diversifying the livelihood options helps in reducing the vulnerability of agricultural sector.

Conclusion

A total of 21 indicators fewer than four components were used to analyze the nexus between sensitivity and adaptive capacity and to develop a composite vulnerability index. The agricultural sector is the primary contributor to the overall vulnerability to climate change, according to district-level results. The vulnerability index was created using Iyenger and Sudarshan's method, and it resulted in the identification of the most vulnerable areas within these districts. The results of the study revealed that Tiruvarur district was ranked first in vulnerable category among all three districts. This assessment is crucial in determining where greater adaptation efforts are needed and helps to better identify vulnerability in order to develop an effective adaptation approach. Thus, the adaptive capacity of the farmers can be improved through raising the literacy level, improving the infrastructural facilities and improve the budget allocation for climate change projects. This urges that important policy and practical need in terms of the growing field of climate change adaptation.

There should be more pro-active economic restructuring programmes, especially for high-risk areas. Furthermore, appropriate policy decisions, such as mass adoption of micro irrigation at farmers' fields, must be implemented to protect the livelihoods of people who rely on agriculture and dairy farming. The findings also suggest that, in order to build resilience, district-specific adaptation and risk reduction methods should be incorporated into developmental planning. It also suggested that the farmers in vulnerable areas need technical assistance, extension services, useful information, and inputs.

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