Assessment of Vulnerability in three agro-climatic zones of Chhattisgarh with reference to climate change

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Abstract

The present study was conducted at the Department of Agrometeorology, IGKV Raipur (C.G.) from 2019 to 2021, to assess the zone-level vulnerability in three agro-climatic zones of Chhattisgarh with respect to climate change. The data on various components were collected from the Census directorate of Chhattisgarh (2001 and 2011), Department of Agrometeorology, Raipur and the report of Directorate of economics & statistics Raipur, C.G. for the period of 2000 to 2018 and divided into three different study periods i.e. 2000–2005, 2006–2010 and 2011–2018. We have used Hiremath & Shiyani and Iyenger & Sudershan's methodology to contract the vulnerability index. The outcome of the study indicates that the agricultural sector played a major role and contributed significantly to quantifying the vulnerability followed by climatic and demographic indicators during all three study periods. Results of the composite vulnerability index indicate that Bastar Plateau agro-climatic zone (BP ACZ) was categorized as a more vulnerable zone followed by the Northern Hills agro-climatic zone (NH ACZ) and Chhattisgarh Plain agro-climatic zone (CGP ACZ) in decreasing order of vulnerability in all the study periods. Zone-wise classification of degree of vulnerability, Chhattisgarh Plain agro-climatic zone (CGP ACZ) and the Northern Hills agro-climatic zone (NH ACZ) was categorized as highly vulnerable category, while Bastar Plateau agro-climatic zone (BP ACZ) fell under the Very highly vulnerable category, during all the three study period. We have not found the less vulnerable, moderately vulnerable and vulnerable categories of the zone during all the three study periods.

Introduction

Climate is one of the most important determinants of agricultural production. Throughout the world, there is significant concern about the impacts of climate change and its variability on agricultural production. Climate change may affect agriculture and consequently the livelihoods of people due to changes in temperature, rainfall, soil moisture, soil fertility, the length of the growing season, an increase in the probability of extreme events such as droughts, extreme heatwaves, heavy rainfall, cyclones, flooding of the coastal areas, erosion etc. According to the Intergovernmental Panel on Climate Change (2007) definition, vulnerability in the context of climate change is “the degree to which a system is susceptible to and unable to cope with the adverse effects of climate change, including climate variability & extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity”. According to the sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC), “Heat waves and humid heat stress will be more intense and frequent during the 21st century. In terms of monsoon, both annual and summer monsoon precipitation will increase during the 21st century, with enhanced interannual variability” (IPCC, 2021).

Chhattisgarh is divided into three distinct Agro-climatic zones viz., Chhattisgarh plains, Bastar plateau and Northern hills and it covers 50.52%, 28.62% and 20.86% geographic area, respectively. Similarly, topographically also the state varies a lot from high elevated areas of the state making it differ in their climatic elements also. There is a wide variability of annual rainfall also on average a total of 1200–1600 mm. Annual rainfall is recorded in different parts of Chhattisgarh on about 64–91 rainy days (About 85% of rainfall in C.G. is concentrated in four monsoon months i.e. June-September). It has been recorded that 1000–1200 mm, 1200–1400 mm and 1400–1600 mm annual rainfall are received in Chhattisgarh plains, Bastar plateau and northern hills, respectively **(Atlas, Department of Agrometeorology).**

Chhattisgarh, too, realizes the effect of climate change. Available evidence suggests that there is a high probability of an increase in the frequency and intensity of climate-related natural hazards due to climate change and hence an increase in potential threats due to climate change-related natural disasters. In the absence of state-level climate models and vulnerability studies, it will be difficult to manage it as low community awareness and information, Chhattisgarh is potentially extremely sensitive and vulnerable to climate change and its impacts. Earlier climate change study was carried out to assess the regional climate changes in Chhattisgarh state in central India and their impacts on agriculture (Sastri, 2010).

Methodology

The data on various components were collected from the Census directorate of Chhattisgarh (2001 and 2011), Department of Agrometeorology, Raipur and the report of Directorate of economics & statistics Raipur, (C.G.) for the period of 2000 to 2018 and divided into three study periods viz., 2000 to 2005, 2006 to 2010 and 2011 to 2018. The decadal demographic data i.e. population density and literacy rate for the period 2001 and 2011 were collected for Chhattisgarh state from the Census directorate of Chhattisgarh. The long term gridded annual and seasonal Rainfall data (mm), annual maximum and minimum temperature (°C) data for the period 2000–2018 were collected from the Department of Agrometeorology, I.G.K.V. Raipur, C.G. and agricultural data for the period from 2000 to 2018, Crop data (Rice, Maize, Pigeon Pea, Wheat and Chickpea), cropping intensity, the area under cultivation and Irrigation intensity were collected from the report of Directorate of economics & statistics, Raipur C.G. (the Year 2000–2018).

“All agricultural, climatic and demographic data were available district-wise and for zone-wise vulnerability analysis, we have converted these all data in agro-climatic zone wise. All these data were used to construct a vulnerability index.”

Table 1 Functional relationship of indicators and sub-indicators with vulnerability to climate change

S. NO.	Indicators	Sub-Indicators	Functional Relationship
1.	Demographic Indicators	i. Density of population (persons per square kilometre)	↑
		ii. Literacy rate (percentage)	↓
2.	Climatic Indicators	i. Annual rainfall (mm)	↑
		ii. Seasonal rainfall (mm)	↑
		iii. Annual maximum temperature (°C)	↑
		iv. Annual minimum temperature (°C)	↑
3.	Agricultural Indicators	i. Production of Rice crop (Q/ hectare)	↓
		ii. Productivity of Rice crop (Q/ hectare)	↓
		iii. Production of Maize crop (Q/ hectare)	↓
		iv. Productivity of Maize crop (Q/ hectare)	↓
		v. Production of Pigeon Pea crop (Q/ hectare)	↓
		vi. Productivity of Pigeon Pea crop (Q/ hectare)	↓
		vii. Production of Wheat crop (Q/ hectare)	↓
		viii. Productivity of Wheat crop (Q/ hectare)	↓
		ix. Production of Chick Pea crop (Q/ hectare)	↓
		x. Productivity of Chick Pea crop (Q/ hectare)	↓
		xi. Cropping intensity (percentage)	↓
		xii. Irrigation intensity (percentage)	↓
		xiii. Aera under Cultivation (hec.)	↓

Methodology for calculation of the Vulnerability index: Normalization of indicators using functional relationship

We calculated the geometric mean of demographic, climatic and agricultural indicators through the dimension index was calculated with the help of the formula given by Hiremath and Shiyani (2013). The dimension index was categorized into two types of functional relationships was possible i.e. ↑ (positive) functional relationship and ↓ (negative) functional relationship in Table 1. Dimension index scores will lie between 0 and 1. The value 1 will correspond to that zone with maximum value and 0 will correspond to the zone with minimum value.

In this case we say that the variables have ↑ (positive) functional relationship with vulnerability and the normalization is done using the formula-

$$\textbf{Dimension index} = \frac{(\text{Actual } X_I - \text{Minimum } X_I)}{(\text{Maximum } X_I - \text{Minimum } X_I)} \qquad \ldots(1)$$

Where,

Actual X_I = Actual value of respective indicator

Minimum X_I = Minimum value of respective indicator

Maximum X_I = Maximum value of respective indicator

In this case we say that the variables have ↓ (negative) functional relationship with vulnerability and the normalization is done using the formula-

$$\textbf{Dimension index} = \frac{(\text{Maximum } X_I - \text{Actual } X_I)}{(\text{Maximum } X_I - \text{Minimum } X_I)} \qquad \ldots(2)$$

This method of normalization that takes into account the functional relationship between the variable and vulnerability was important in the construction of the indices. If the functional relation is ignored and the variables are normalized simply by applying formula (1), the resulting index will be misleading (Hiremath and Shiyani, 2013).

Iyenger and Sudershan's method for construction of vulnerability index

The method of simple averages gives equal importance to all the indicators which are not necessarily correct. Hence many authors prefer to give weights to the indicators. Iyengar and Sudarshan (1982) developed a method to work out a composite index from multivariate data and it was used to rank the zones in terms of their economic performance. This methodology is statistically sound and well suited for the development of the composite index of vulnerability to climate change also.

A brief discussion about the methodology is given below-

It is assumed that there are M zones, K sub-indicator of indicators vulnerability and xij, i = 1, 2, ….M ; j = 1, 2, ….k are the normalized scores. The level or stage of development of i^t zone, $\bar{y}_t$ is assumed to be a linear sum xij as

$$\bar{y}_t = \sum_{j=1}^{k} WjXij \qquad \ldots(3)$$

Where, w's (0 < w < 1 and $\sum_{j=1}^{k} W$j = 1) are the weights. In Iyenger and Sudarshan's method, the weights are assumed to vary inversely as the variance over the zone in the respective sub-indicators of indicators vulnerability. That is, the weight wj is determined by

$$\mathbf{W_j} = \mathbf{c}/\sqrt{var\ xij}$$

Where, c is a normalizing constant such that

$$C = \left\| \sum_{j=1}^{k} 1/\sqrt{varxij} \right\|^{-1}$$

The determination 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 inter-zone comparisons. The vulnerability index so computed lies between 0 and 1, with 1 indicating maximum vulnerability and 0 indicating no vulnerability at all.

For classificatory purposes, a simple ranking of the zones based on the indices viz., $\bar{y}_t$ would be enough. However, meaningful characterizations of the different stages of vulnerability, and suitable fractile classification from an assumed probability distribution are needed.

A probability distribution that was suitable for this purpose was the Beta distribution, which is generally skewed and takes values in the interval (0, 1). This distribution has the probability density given by:

$$f(z) = \frac{Z^{a-1}(1-z)^{b-1}\,dx}{B(a,b)}, \quad 0 < z < 1 \text{ and } a, b > 0$$

Where, B (a, b) is the beta function defined by

$$B(a, b) = \int_0^1 x^{a-1}(1-x)^{b-1}dx$$

The two parameters *a* and *b* of the distribution can be estimated by using the method by Iyenger and Sudarshan (1982). The beta distribution is skewed. Let $(0,z_1)$, (z_1,z_2), (z_2,z_2), (z_3,z_4) and $(z_4,1)$ be the linear intervals such that each interval has the same probability weight of 20 per cent.

These fractile intervals were used to characterize the various stages of vulnerability as shown below:

1. Less vulnerable if $0 < \bar{y}_t < z_1$;
2. Moderately vulnerable if $z_1 < \bar{y}_t < z_2$;
3. Vulnerable if $z_2 < \bar{y}_t < z_3$;
4. Highly vulnerable if $z_3 < \bar{y}_t < z_4$; and
5. Very highly vulnerable if $z_4 < \bar{y}_t < 1$.

Results And Discussions

During 2000-2005, 2006-2010 and 2011-2018, zone-wise vulnerability Indices of Chhattisgarh state has been worked out for demographic, climatic and agricultural indicators. The zones have been ranked on the basis of vulnerability indices.**3.1 Zone wise Share to the Vulnerability to Climate Change for the Year 2000-2005**

Table 3.1 (a) Vulnerability index of 3 agro-climatic zones for period of 2000-2005

S. No.	Agro-Climatic Zone Name	Demographic Vulnerability Index	Rank	Climatic Vulnerability Index	Rank	Agricultural Vulnerability Index	Rank	Composite Vulnerability Index	Rank
1	NHZ	0.028	3	0.033	3	0.400	2	0.461	2
2	CGPZ	0.047	1	0.160	2	0.225	3	0.432	3
3	BPZ	0.046	2	0.206	1	0.433	1	0.685	1

A perusal of Table 3.1 (a) revealed that the Chhattisgarh Plain agro-climatic zone was ranked first (0.047) for vulnerability to climate change followed by Bastar Plateau agro-climatic zone (0.046), while Northern Hills Agro-climatic Zone was ranked last (0.028) in the terms of the demographic vulnerability index. On the basis of the climatic vulnerability index, Bastar Plateau agro-climatic zone was in first position (0.203) followed by the Chhattisgarh Plain agro-climatic zone (0.160) during the period of 2000-2005. The Northern Hills agro-climatic zone was in the last position (0.033) for the climatic vulnerability index. In terms of the agricultural vulnerability index, the Bastar Plateau agro-climatic zone was ranked first (0.433) followed by the Northern Hills agro-climatic zone (0.400), while Chhattisgarh Plain agro-climatic zone ranked the last (0.225) during the period of 2000-2005.

Table 3.1 (b) Indicator-wise contributions to the Vulnerability to Climate Change for the period of 2000-2005

(In percent)

S. No.	Agro-Climatic Zone	Demographic Vulnerability Index	Climatic Vulnerability Index	Agricultural Vulnerability Index	Total
1	NHZ	6.12	7.09	86.79	100
2	CGPZ	10.98	37.07	51.95	100
3	BPZ	6.76	30.04	63.20	100

It can be seen from the tables 3.1 (a) and (b) that on the basis of the composite vulnerability index Bastar Plateau agro-climatic zone was ranked first (0.685) followed by the Northern Hills agro-climatic zone (0.461), where agricultural sector contributes maximum 63.20 per cent followed by climatic sector (30.04) per cent and demographic sector (6.76 per cent), while the Chhattisgarh Plain agro-climatic zone was ranked the last (0.432), wherein the contribution of the climatic sector was maximum 51.95 per cent followed by agricultural sector (37.07 per cent) and demographic sector (10.98 per cent) during the period of 2000-2005.

3.2 Zone wise Share to the Vulnerability to Climate Change for the Year 2006-2010

Table 3.2 (a) Vulnerability index of 3 agro-climatic zones for period of 2006-2010

S. No.	Agro-Climatic Zone Name	Demographic Vulnerability Index	Rank	Climatic Vulnerability Index	Rank	Agricultural Vulnerability Index	Rank	Composite Vulnerability Index	Rank
1	NHZ	0.051	1	0.044	3	0.418	1	0.513	2
2	CGPZ	0.047	2	0.159	2	0.205	3	0.411	3
3	BPZ	0.046	3	0.193	1	0.402	2	0.641	1

A perusal of Table 3.2 (a) indicated that the Northern Hills agro-climatic zone was ranked first (0.051) for vulnerability to climate change followed by the Chhattisgarh Plateau agro-climatic zone (0.047) in terms of the demographic vulnerability index. The Bastar Plateau Agro-climatic Zone was ranked last (0.046) in the terms of the demographic vulnerability index. On the basis of the climatic vulnerability index, the Bastar Plateau agro-climatic zone was ranked first (0.193) followed by the Chhattisgarh Plain Agro-climatic Zone (0.159), while the Northern Hills agro-climatic zone was ranked last (0.044) during the period of 2006-2010. The Northern Hills agro-climatic zone was in first position (0.418) followed by the Bastar Plateau agro-climatic zone (0.402), while the Chhattisgarh Plain agro-climatic zone was in last position (0.205) according to agricultural vulnerability index.

Table 3.2 (b) Indicator-wise contributions to the Vulnerability with respect to Climate Change for the period of 2006-2010

(In percent)

S. No.	Agro-Climatic Zone	Demographic Vulnerability Index	Climatic Vulnerability Index	Agricultural Vulnerability Index	Total
1	NHZ	10.01	8.64	81.35	100
2	CGPZ	11.45	38.77	49.78	100
3	BPZ	7.19	30.07	62.74	100

It can be observed from tables 3.2 (a) and (b) that the Bastar Plateau agro-climatic zone was in first position (0.641), where the agricultural sector contributes a maximum of 62.74 per cent followed by the climatic sector (30.07 per cent) and demographic sector (7.19 per cent). The Chhattisgarh Plain agro-climatic zone was in the last position (0.411), where the maximum contribution of the agricultural sector was found (49.78 per cent) followed by the climatic sector (38.77 per cent) and demographic sector (11.45 per cent), respectively.

3.3 Zone wise Share to the Vulnerability to Climate Change for the Year 2011-2018

Table 3.3 (a) Vulnerability index of 3 agro-climatic zones for period of 2011-2018

S. No.	Agro-Climatic Zone Name	Demographic Vulnerability Index	Rank	Climatic Vulnerability Index	Rank	Agricultural Vulnerability Index	Rank	Composite Vulnerability Index	Rank
1	NHZ	0.0318	3	0.0259	3	0.4524	1	0.5101	2
2	CGPZ	0.0497	2	0.1290	2	0.2075	3	0.3863	3
3	BPZ	0.0504	1	0.1647	1	0.4361	2	0.6512	1

A perusal of Table 3.3 (a) indicated that Bastar Plateau agro-climatic zone was ranked first (0.0504) for vulnerability to climate change followed by the Chhattisgarh Plain agro-climatic zone (0.0497), while the Northern Hills agro-climatic zone was ranked last (0.0318) in terms of the demographic vulnerability index. On the basis of the climatic vulnerability index, the Bastar Plateau agro-climatic zone was ranked first (0.1647) followed by Chhattisgarh Plain agro-climatic zone (0.1290), while the Northern Hills agro-climatic zone was ranked last (0.0259) during the period of 2011-2018. The Northern Hills agro-climatic zone was ranked first (0.4524) based on the agricultural vulnerability index followed by Bastar Plateau agro-climatic zone (0.4361), while the Chhattisgarh Plain agro-climatic zone ranked last (0.2075).

Table 3.3 (b) Indicator-wise contributions to the Vulnerability to Climate Change for the period of 2011-2018

(In percent)

S. No.	Agro-Climatic Zone	Demographic Vulnerability Index	Climatic Vulnerability Index	Agricultural Vulnerability Index	Total
1	NHZ	6.23	5.08	88.69	100
2	CGPZ	12.86	33.41	53.73	100
3	BPZ	7.74	25.29	66.97	100

A close observation of tables 3.3 (a) and (b) revealed that the Bastar Plateau Agro-climatic Zone was in the first position (0.6512) for vulnerability to climate change where the maximum contribution of the agricultural sector is 66.97 per cent followed by climatic sector (25.29 per cent) and demographic sector (7.74 per cent), while the Chhattisgarh Plain Agro-climatic Zone was in last position (0.3863) where agricultural sector contributes 55.73 per cent followed by climatic sector (33.41 per cent) and demographic sector (12.86 per cent).

In a similar study on quantitative assessment of vulnerability Islam et al. (2013) reported that the tidal surge zone is the most vulnerable zone within the country in terms of agricultural, occupational and geographic vulnerability, while demographically least vulnerable, whereas the mixed ecological zone is very highly vulnerable in terms of climatic vulnerability.

3.4 Classification of the three agro-climatic zones under different degrees of vulnerability for the period of 2000-2005, 2006-2010 and 2011-2018

Using vulnerability indices by following beta distribution the zones of the state were categorized into less vulnerable, moderately vulnerable, vulnerable, highly vulnerable and very highly vulnerable categories. During the period of 2000-2005, Zi values are as follows 0.143, 0.274, 0.411, 0.548 and 0.685. Similarly Zi values for the study period of 2006-2010 are 0.128, 0.256, 0.385, 0.513 and 0.641. During the period of 2011-2018, Zi values are 0.130, 0.260, 0.391, 0.521 and 0.651 as shown in table 3.4. The results pertaining to the classification of the three agro-climatic zones under different degrees of composite vulnerability for the periods of 2000-2005, 2006-2010 and 2011-2018 are given in Table 3.5.

Table 3.4 Zi values of beta distribution for three agro-climatic zones of Chhattisgarh during the study periods of 2000-2005, 2006-2010 and 2011-2018

S. No.	Year Category	Less Vulnerable Category (1)	Moderately Vulnerable Category (2)	Vulnerable Category (3)	Highly Vulnerable Category (4)	Very Highly Vulnerable Category (5)
1	2000-05	0-0.137	0.137-0.274	0.274-0.411	0.411-0.548	0.548-0.685
2	2006-10	0-0.128	0.128-0.256	0.256-0.385	0.385-0.513	0.513-0.641
3	2011-18	0-0.130	0.130-0.260	0.260-0.391	0.391-0.521	0.521-0.651

Table 3.5 Classification the degree of composite vulnerability in three agro-climatic zones of Chhattisgarh for period of 2000-2005, 2006-2010 and 2011-2018

S. No.	Year	Less Vulnerable	Moderately Vulnerable	Vulnerable	Highly Vulnerable	Very Highly Vulnerable
	Category	Category (1)	Category (2)	Category (3)	Category (4)	Category (5)
1	2000-05	-	-	-	CGP ACZ (0.432) & NH ACZ (0.461)	BP ACZ (0.685)
2	2006-10	-	-	-	CGP ACZ (0.411) & NH ACZ (0.513)	BP ACZ (0.641)
3	2011-18	-	-	-	CGP ACZ (0.386) & NH ACZ (0.510)	BP ACZ (0.651)

It is quite clear from the table 3.5, Zone-wise classification of the degree of vulnerability results indicated that Chhattisgarh Plain agro-climatic zone (CGP ACZ) and the Northern Hills agro-climatic zone (NH ACZ) were categorized as highly vulnerable category, while Bastar Plateau agro-climatic zone (BP ACZ) fell under the Very highly vulnerable category, during all the three study periods. We have not found less vulnerable, moderately vulnerable and vulnerable categories of districts during all the three study periods.

Conclusion

The results of vulnerability analysis for the three zones of Chhattisgarh state revealed that the variables pertaining to agricultural vulnerability were major contributors to the composite vulnerability to climate change during the periods of 2000–2005, 2006–2010 and 2011–2018. Since the agricultural sector was found to have the greatest bearing there is a need to shift focus towards investments in adaptation research capacity: particularly, in the development of climate-proof crops (drought, flood-resistant and heat tolerant varieties) that can cope with a wide range of climatic conditions. An improvement in the agronomic practices of different crops such as timely planting, optimum plant densities and recommended cropping patterns/sequences can help to cope with the delayed rain, longer dry spells and earlier plant maturity. In order to enhance the resilience of the agriculture sector, new strategies must be built around 'green' agricultural technologies, such as adaptive plant breeding, forecasting of pests, rainwater harvesting and fertilizer micro-dosing.

Thus, the state of Chhattisgarh requires a development strategy that integrates climate change policies with sustainable development strategies to effectively combat climate change issues.

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