*Original Research Article*

Mapping of Climate Change Impact through the Climate Vulnerability Index in India

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ABSTRACT

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| India has a diverse range of climates and agro-ecosystems, making it necessary to identify the country's most vulnerable states to the climate change. This study analyses the Climate Vulnerability Index (CVI) comprising both crop and dairy indicators for 18 states of India. The computation of index was based on the Intergovernmental Panel on Climate Change (IPCC) approach. The state-wise vulnerability indices were calculated and categorized as Exposure Index (EI), Sensitivity Index (SI), Adaptive Capacity Index (ACI) and overall Climate Vulnerability Index (CVI). The states were classified as high, moderate and less vulnerable on the basis of magnitude of the index. Tamil Nadu has the highest exposure Index to climate (0.84) and the lowest was in Odisha (0.26). In case of sensitivity, the highest was in Bihar (0.79), while the lowest was in Punjab (0.17). The highest adaptive capacity was observed in West Bengal (0.52) and the lowest was in Odisha (0.20). Overall, CVI was highest in Tamil Nadu (0.71) and lowest in Punjab (0.42). |

*Keywords: Climate Vulnerability Index (CVI), Principal Component Analysis (PCA), exposure, sensitivity, adaptive capacity, IPCC approach, climate change*

1. INTRODUCTION

The footmark of climate change seen in every corner of the globe. The Intergovernmental Panel on Climate Change (IPCC) in 2014, Identifying the significant signal of ongoing climate change and its adversative effects on biophysical and socio-economic systems. It is crucial to note that the impact of climate change is not uniform across regions and time. Unpredictable weather patterns, escalating sea levels and melting glaciers are major events due to climate change.

The German Watch Global Climate Risk Index for 2019, which positioned India as the 7th most vulnerable out of 181 countries, stresses the country's high exposure and vulnerability to extreme weather events, based on quantified impacts in terms of fatalities and economic losses from 2000 to 2019 (Eckstein et al., 2021). The growing frequency and intensity of climate change-related events, such as heatwaves, floods, and monsoons, coupled with the depletion of groundwater reserves etc. are imposing substantial challenges on India's natural environment, economy, and society. During 2023, 09 cyclonic disturbances, developed over the North Indian Ocean (NIO) against the normal of 11.2 per year during 1965- 2022. (IMD, 2023). And in 2022, 15 states in India grappled with the multifaceted consequences of heatwaves, underscoring the risks posed to well-being and GDP (IMD, 2022). The adverse impacts, including health crises, agricultural setbacks, and water scarcity, highlight the urgent need for comprehensive climate action. India’s first-ever climate change assessment report carried out in 2020, has revealed that the country’s average temperature is expected to rise by 4.4 degree Celsius by the end of the year 2100 (Krishnan et al., 2020). Floods, which have already incurred a cost of US$26.3 billion, have further stressed the economic toll, exceedingly approximately 0.5% of the country's GDP (World Meteorological Organization, 2021). Many scientists analyse the potential impact on financial and social ramifications of climate-related vulnerability in India, projecting a staggering cost of US$35 trillion over the next 50 years, particularly impacting critical sectors like health and agricultural (Anonymous, 2021).

This non-uniform impact across globe demands a systematic assessment of vulnerability for agro-ecosystems, economic factors, social groups etc. serving as a critical step to identify appropriate adaptation measures for combating climate change and coping with current climate risks, as emphasized by O'Brien et al. (2008).

This study's primary goal is to conduct a climate change impact through the Climate Vulnerability Index in India, employing the contextual approach of vulnerability, which will be helpful in the developing of mitigating and also identify the adaptation strategies for the region.

1. How can the Climate Vulnerability Index (CVI) be effectively utilized to identify and categorize the most vulnerable states and regions in India?
2. What is the significance of the prioritizing investments for climate adaptation in the country?
3. In what ways does the research contribute to enhancing decision-making processes related to climate resilience by employing the Climate Vulnerability Index.

2. methodology

**2.1 Study Area and Sources of Data**

India, identified as the 7th most vulnerable country to climate extremes, serves as the focal point of this study. Among the 29 states in India as of 2023, nine were excluded due to a lack of climate-related data from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Post this exclusion, the study focuses on the remaining 20 states, excluding Telangana due to its formation in 2014, leading to unavailability of rural population density and literacy data, while Jharkhand was excluded due to limitations related to its crop diversification index. Consequently, this study focuses on an in-depth analysis of the climate vulnerability index for the remaining 18 states in India.

The study retrieved a comprehensive dataset covering various climate variables, as well as crops and animal husbandry production for the 18 selected states in India. The climate data, including state-level rainfall and temperature records spanning 57 years (1958-2015), were sourced from ICRISAT. Concurrently, state-level crop production data, covering aspects such as area, yield of major crops, net sown area, and gross cropped area for the agricultural years 2017–19, were gathered from published report by respective state governments. Additionally, state-level dairy production data for the same period were obtained from the Department of Animal Husbandry and Veterinary Sciences report of India, alongside insights from the Livestock Census and other official reports.

**2.2 Vulnerability Estimation**

Vulnerability is the function of the character, magnitude and rate of climate variation to which a system is exposed, the sensitivity and adaptive capacity. According to Local Government Division (2023), calculation of CVI was calculated with the given formula:

The amalgamation of exposure and sensitivity in Equation (1) is referred to as 'potential impact', and a high index score in this context can signify significant harm, if the region or production system has a high degree of index score. Consequently, the vulnerability level of a region is determined by the magnitude of potential impact relative to the adaptive capacity of that region or production system, as elucidated by Sendhil et al. (2018) and Balaganesh et al. (2020).

**2.2.1 Steps in vulnerability assessment**

The following steps have been used to assess the state level climate vulnerability index.

**Step 1: Identification of suitable indicators**

The selection of indicators holds an importance in vulnerability assessment studies. Therefore, meticulous attention has been devoted to finalizing the total 28 variables, out of which 9 for exposure index, 8 sensitivity and 11 for adaptive index were selected through a comprehensive review of published literature, ensuring a well-informed understanding of the prior functional relationships, as detailed in Tables 1.

**Table 1. Identification of suitable indicators**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sr. No** | **Variables** | **Unit** | **Variable label** | **Functional relationship** |
|  | **Exposure** | | | |
| 1 | Trend in kharif minimum temperature | Coefficient of trend | K\_Min\_T | + |
| 2 | Trend in rabi minimum temperature | Coefficient of trend | R\_Min\_T | + |
| 3 | Trend in summer minimum temperature | Coefficient of trend | S\_Min\_T | + |
| 4 | Trend in kharif maximum temperature | Coefficient of trend | K\_Max\_T | + |
| 5 | Trend in rabi maximum temperature | Coefficient of trend | R\_Max\_T | + |
| 6 | Trend in summer maximum temperature | Coefficient of trend | S\_Max\_T | + |
| 7 | Trend in kharif precipitation | Coefficient of trend | K\_Pre | + |
| 8 | Trend in rabi precipitation | Coefficient of trend | R\_Pre | + |
| 9 | Trend in summer precipitation | Coefficient of trend | S\_Pre | + |
|  | **Sensitivity** | | | |
| 1 | Area of major crops to the total cropped area | % | AMC/TCA | + |
| 2 | Yield of major crops | kg/ha | YMC | - |
| 3 | Share of gross unirrigated area to gross sown area | % | GUA/GSA | + |
| 4 | Milk production | 000 tonnes | MP | - |
| 5 | Stage of ground water extraction | % | GWE | - |
| 6 | Average farm size | Ha | AFS | - |
| 7 | Rural population density | No. of persons/km2 | RPD | + |
| 8 | Share of small & marginal farmers to total farmers | % | SMF/TF | + |
|  | **Adaptive Capacity** | | | |
| 1 | Crop diversification |  | CD | + |
| 2 | Cropping intensity | % | CI | + |
| 3 | Irrigation intensity | % | II | + |
| 4 | Literacy rate | % | LR | + |
| 5 | Share of area under pasture & grazing land to gross sown area | % | P&G/GSA | + |
| 6 | Density of dairy animals | No. of animal/km2 | DDA | + |
| 7 | Proportion of area insured to gross sown area | % | AI/GSA | + |
| 8 | Share of GSVA of agriculture sector to its GSDP | % | GSVA\_A/GSDP | + |
| 9 | Share of indigenous population per 1000 bovine population | Number | IP/1000\_BP | + |
| 10 | Number of Veterinary Institutions per 1000 bovine population | Number | VI/1000\_BP | + |
| 11 | Number of Artificial Insemination (AI) centres per 1000 female bovine | Number | AI/1000\_BP | + |

**Step 2: Normalization of the indicators**

To ensure comparability among indicators measured on different scales, normalization is imperative, as emphasized by Vincent (2004), Varadan and Kumar (2015), Kale et al. (2016), Kumar et al. (2016), Ponnusamy et al. (2016), Mahida and Sendhil (2017), Sendhil et al. (2018) and Balaganesh et al. (2020). In instances where indicators exhibit a positive functional relationship with their respective index, the normalization process involves applying the following equation.

Conversely, in cases where a negative functional relationship is observed, the normalization process employs the following equation.

**Step 3: Assignment of weights to indicators**

Subsequent to the normalization of indicators, weights were allocated based on their influence on vulnerability. Among the available methods for weight assignment, such as equal weights, inverse of variance, expert opinion and principal component analysis (PCA), each presenting its own set of advantages and disadvantages (Varadan and Kumar, 2015; Sendhil et al., 2018; Balaganesh et al., 2020), PCA emerged as the preferred technique in this study. The functional formulation is outlined as follows:

Where, Xt indicates the N -dimensional vector of variables influencing vulnerability; t represents the r × 1 common factor; Ft represents the factor loading; et represents the associated idiosyncratic error-term of order N × 1.

The weights from the PCA were calculated with the following equation.

Where, Wi represents the weight of the ith variable; Ej represents the Eigen value of the jth factor; Lij represents the loading value of the ith variable on jth factor.

**Step 4: Climate Vulnerability Index (CVI)**

Subsequently, the Exposure, Sensitivity, and Adaptive Capacity indices were computed individually, incorporating their respective indicators and calculated weights, as per the formulation provided by Sendhil et al. (2018) and Balaganesh et al. (2020).

Where, Xi represents the normalized value of ith variable; Wi is the weight of ith variable

Finally, Climate Vulnerability Index (CVI) was calculated as per the IPCC approach, using Eq. (1).

**Step 5: Categorization of States**

The states in India were classified into high, moderate, and low vulnerability categories based on the computed Climate Vulnerability Index (CVI), employing mean and standard deviation (SD) norm as outlined by Ayyoob et al. (2013), Rana et al. (2015), Kale et al. (2016), Sendhil et al. (2018) and Balaganesh et al. (2020). The categorization is detailed as follows:

* High = Index > (Mean + 0.5 SD)
* Moderate = (Mean – 0.5 SD) < Index < (Mean + 0.5 SD)
* Low = Index < (Mean – 0.5 SD)

3. results and discussion

The weightage of nine appropriate exposure index indicators, eight appropriate sensitivity index indicators, and eleven appropriate adaptive capacity index indicators is shown in Fig. 1. In PCA higher the weight of an attribute, the more relevant it is considered.

**Fig. 1. Weightage of suitable indicators of exposure, sensitivity and adaptive capacity**

Across various states in India, including Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Tamil Nadu, and West Bengal, the variable trend in kharif maximum temperature (K\_Max\_T) was found to have a higher weightage, indicating its greater relevance to the exposure index for these states. Moreover, the variable share of small & marginal farmers to total farmers (SMF/TF) was found to have a higher weightage across a number of Indian states, including West Bengal, Himachal Pradesh, Kerala, Odisha, Tamil Nadu, Uttar Pradesh, and Uttarakhand for sensitivity index. Furthermore, cropping intensity (CI) and proportion of area insured to gross sown area (AI/GSA) have a higher number of states with a high weightage among all adaptive capacity indicators. States like Assam, Haryana, Punjab, Uttar Pradesh, Uttarakhand, and West Bengal are highly weighted CI indicators, whereas Chhattisgarh, Madhya Pradesh, Maharashtra, Odisha, Rajasthan, and Tamil Nadu are highly weighted AI/GSA indicators. It indicated that, the variables with the high weightage are more important in formulating the different mitigating strategies to climate change.

The Exposure Index of 9 meteorological indicators for the 18 states of India is presented in Table 2, The state with most exposures to climatic factors is Tamil Nadu (0.84), while Odisha had the lowest exposure (0.26) to climatic factors. The states were classified under high exposure to climatic factors follows as Tamil Nadu, Karnataka, Kerala, and Andhra Pradesh. The states fell into the moderate exposure category follow as Rajasthan, Bihar, Gujarat, Assam, Haryana, Uttar Pradesh, Maharashtra, and Madhya Pradesh; and Punjab, West Bengal, Himachal Pradesh, Uttarakhand, Chhattisgarh, and Odisha were categorized as having low exposure.

The Sensitivity index for the 18 states of India, as presented in Table 2, indicated that Bihar had the highest sensitivity (0.79), while Punjab exhibited the lowest sensitivity (0.17). The mean sensitivity index was calculated to be 0.58. A high divergence of 0.62 has been found in sensitivity due to its wider range among all the states. The categorization based on sensitivity levels revealed that seven states as Bihar, Assam, Kerala, Odisha, West Bangal, Uttarakhand and Chhattisgarh were classified as highly sensitive to climatic vulnerability of agricultural system, whereas another seven states as moderately sensitive, and four states as less sensitive.

The Adaptive Capacity index for the 18 states of India is illustrated in Table 2. West Bengal exhibited the highest adaptive capacity (0.52), while Odisha showed the lowest adaptive capacity (0.20). The mean adaptive capacity index was calculated to be 0.32, with a standard deviation of 0.08. A divergence of 0.32 has been observed in adaptive capacity. The categorization based on adaptive capacity levels revealed that four states were classified as highly adaptive to climate, seven states as moderately adaptive, and seven states possessed low adaptive capacity.

**Table 2. Exposure, sensitivity, adaptive capacity and climate vulnerability index for the states of India**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **States** | **Exposure Index** | | **Sensitivity Index** | | **Adaptive Capacity Index** | | **Climate Vulnerability** | |
| **Index** | **Category** | **Index** | **Category** | **Index** | **Category** | **Index** | **Category** |
| Andhra Pradesh | 0.68 | H | 0.60 | M | 0.30 | M | 0.66 | H |
| Assam | 0.48 | M | 0.74 | H | 0.26 | L | 0.65 | H |
| Bihar | 0.53 | M | 0.79 | H | 0.32 | M | 0.66 | H |
| Chhattisgarh | 0.36 | L | 0.66 | H | 0.25 | L | 0.59 | M |
| Gujarat | 0.49 | M | 0.51 | L | 0.35 | M | 0.55 | M |
| Haryana | 0.46 | M | 0.43 | L | 0.41 | H | 0.50 | L |
| Himachal Pradesh | 0.39 | L | 0.57 | M | 0.43 | H | 0.51 | L |
| Karnataka | 0.71 | H | 0.62 | M | 0.27 | L | 0.69 | H |
| Kerala | 0.70 | H | 0.71 | H | 0.32 | M | 0.70 | H |
| Madhya Pradesh | 0.45 | M | 0.54 | M | 0.37 | H | 0.54 | L |
| Maharashtra | 0.45 | M | 0.62 | M | 0.28 | L | 0.60 | M |
| Odisha | 0.26 | L | 0.71 | H | 0.20 | L | 0.59 | M |
| Punjab | 0.43 | L | 0.17 | L | 0.33 | M | 0.42 | L |
| Rajasthan | 0.55 | M | 0.34 | L | 0.33 | M | 0.52 | L |
| Tamil Nadu | 0.84 | H | 0.55 | M | 0.26 | L | 0.71 | H |
| Uttar Pradesh | 0.46 | M | 0.60 | M | 0.33 | M | 0.58 | M |
| Uttarakhand | 0.36 | L | 0.67 | H | 0.28 | L | 0.58 | M |
| West Bengal | 0.42 | L | 0.70 | H | 0.52 | H | 0.53 | L |
| Mean | 0.50 | | 0.58 | | 0.32 | | 0.59 | |
| SD | 0.15 | | 0.15 | | 0.08 | | 0.08 | |

*Note:* *H=High, M=Moderate and L=Low*

**Fig. 2 Radar pictorial of exposure, sensitivity and adaptive capacity indices**

The inter-index values of exposure, sensitivity and adaptive capacity revealed substantial variations, as depicted in Fig. 1. Across all states, the sensitivity index exceeded both exposure and adaptive capacity, with the exception of Andhra Pradesh, Haryana, Karnataka, Punjab, Rajasthan, and Tamil Nadu. In these six states, exposure to climate vulnerability surpassed the other two dimensions. States such as Himachal Pradesh and West Bengal exhibited higher adaptive capacity than exposure but lower sensitivity. Conversely, Punjab demonstrated higher adaptive capacity than sensitivity with lower exposure to climate. Notably, among exposure, sensitivity, and adaptive capacity to climate, none of the states registered a higher index with respect to adaptive capacity. In all states, either sensitivity or exposure held the highest position. The analysis of inter-index comparison revealed a consistent trend across all states, indicating lower adaptive capacity coupled with higher sensitivity and exposure. This collective pattern implies that the selected states are more susceptible to climate-related challenges, emphasizing the need for targeted interventions and adaptive strategies to enhance resilience in the face of climate vulnerabilities.

The highest potential impact (sum of exposure and sensitivity) was observed in Kerala (1.41), followed by Tamil Nadu (1.40), Karnataka and Bihar (1.32). It indicated that, these states are coming under the most effected by climate change. The highly vulnerable states, Kerala ranked the highest due to its third-highest sensitivity index (0.71) and third-highest exposure index (0.70), resulting in the highest potential impact (0.71 + 0.70 = 1.41) alongside a moderate adaptive capacity (0.32). This is attributed to the highest exposure weightage for the variable trend in kharif maximum temperature (4.16), followed by trends in summer maximum temperature (4.08) and kharif precipitation (4.01). For the sensitivity indicator in Kerala, the variable stage of ground water extraction influenced the index with a weight of 3.71 points, followed by the share of small & marginal farmers to total farmers (3.57) and average farm size (3.37).

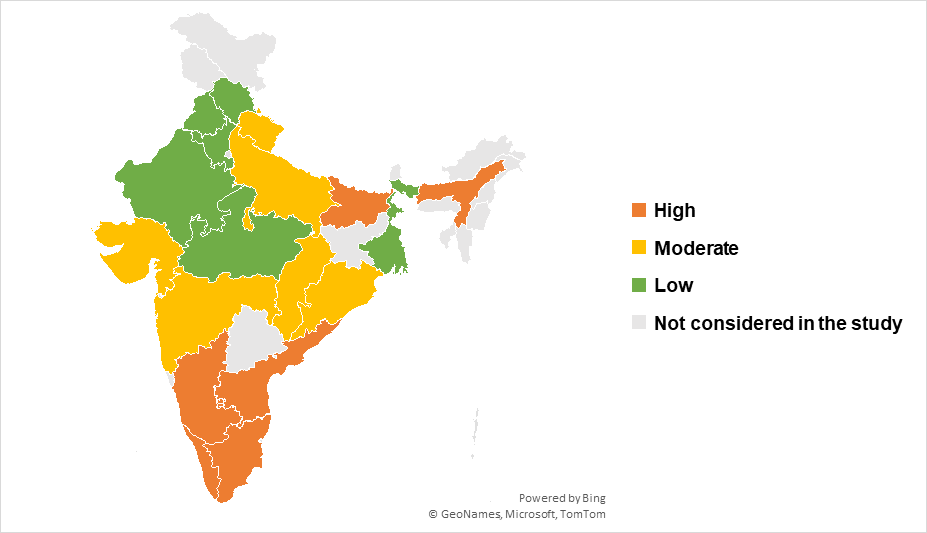
**Mapping of states**

Following the categorization of states as outlined in Table 2, climate vulnerability mapping was conducted for different states accordingly, as depicted in Fig. 2.

**Table 3. Identification of suitable indicators**

|  |  |  |  |
| --- | --- | --- | --- |
| **Agro-climatic zone** | **Categories of climate vulnerability** | | |
| **High** | **Moderate** | **Low** |
| Central plateau and hills | - | Uttar Pradesh | Madhya Pradesh, Rajasthan |
| East coast plains and hills | Andhra Pradesh, Tamil Nadu | Odisha | - |
| Eastern Himalayan | Assam | - | West Bengal |
| Eastern plateau and hills | - | Chhattisgarh, Maharashtra, Odisha | Madhya Pradesh, West Bengal |
| Gujarat plains and hills | - | Gujarat | - |
| Island | - | - | - |
| Lower Gangetic plain | - | - | West Bengal |
| Middle Gangetic plain | Bihar | Uttar Pradesh | - |
| Southern plateau and hills | Andhra Pradesh, Tamil Nadu, Karnataka | - | - |
| Trans Gangetic plain | - | - | Haryana, Punjab, Rajasthan |
| Upper Gangetic plain | - | Uttar Pradesh | - |
| West coast plains and ghat | Karnataka, Kerala, Tamil Nadu | Maharashtra | - |
| Western dry | - | - | Rajasthan |
| Western Himalayan | - | Uttarakhand | Himachal Pradesh |
| Western plateau and hills | - | Maharashtra | Madhya Pradesh |

*Note: Arunachal Pradesh, Delhi, Goa, Jharkhand, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura and Telangana are omitted due to lack of data*.



**Fig. 3 Mapping of climate vulnerability in India**

The fifteen agro-climatic zones in India, encompass a diverse range of geographical and climatic conditions, each contributing to the nation's rich agricultural landscape. The analysis presented in Fig. 2 and Table 3 highlights that the entire Southern plateau and hills region falls under the highly vulnerable category, signifying elevated exposure and sensitivity to climate-related factors, coupled with a comparatively low adaptive capacity response. In contrast, the Lower Gangetic plain region, Trans Gangetic plain region and Western dry regions are categorized as less vulnerable to climate, indicating lower exposure and sensitivity to climate, along with sufficient adaptive capacity. The moderate vulnerable category encompasses the entire Upper Gangetic plain region and Gujarat plains and hills region.

4. Conclusion

The vulnerability assessment for the 18 states of India, based on exposure, sensitivity, adaptive capacity indices. The categorization of states, such as Punjab's lower vulnerability attributed to low exposure and sensitivity, and Tamil Nadu's higher vulnerability due to elevated exposure and sensitivity, emphasizes the nuanced factors influencing climate vulnerability. Furthermore, the agro-climatic zones in India exhibit a broad spectrum of vulnerability, with the entire Southern plateau and hills region identified as highly vulnerable, emphasizing the need for custom-made adaptation strategies in these areas. On the other hand, regions like the Lower Gangetic plain, Trans Gangetic plain, and Western dry regions demonstrate lower vulnerability, suggesting relatively favourable conditions. In summary, the comprehensive vulnerability assessment serves as a foundation for informed decision-making, enabling policymakers, researchers, and stakeholders to prioritize investment plan and implement targeted measures to enhance climate resilience across different states and agro-climatic zones in India. In light of the identified vulnerabilities and the potential impact of extreme climatic events, it is imperative to develop location-specific contingency planning to effectively address and mitigate the challenges anticipated in the near future.

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APPENDIX

**Table A1. Weightage of suitable indicators of exposure, sensitivity and adaptive capacity**

|  |  |
| --- | --- |
| **Variables** | **Weightage** |
| **Exposure** | |
| Trend in kharif minimum temperature | 3.024 |
| Trend in rabi minimum temperature | 3.288 |
| Trend in summer minimum temperature | 2.189 |
| Trend in kharif maximum temperature | 4.164 |
| Trend in rabi maximum temperature | 3.975 |
| Trend in summer maximum temperature | 4.085 |
| Trend in kharif precipitation | 4.017 |
| Trend in rabi precipitation | 1.540 |
| Trend in summer precipitation | 1.998 |
| **Sensitivity** | |
| Area of major crops to the total cropped area | 2.072 |
| Yield of major crops | 2.358 |
| Share of gross unirrigated area to gross sown area | 1.927 |
| Milk production | 1.994 |
| Stage of ground water extraction | 3.713 |
| Average farm size | 3.369 |
| Rural population density | 2.591 |
| Share of small & marginal farmers to total farmers | 3.571 |
| **Adaptive Capacity** | |
| Crop diversification | 3.378 |
| Cropping intensity | 3.586 |
| Irrigation intensity | 3.125 |
| Literacy rate | 3.090 |
| Share of area under pasture & grazing land to gross sown area | 2.167 |
| Density of dairy animals | 3.424 |
| Proportion of area insured to gross sown area | 3.547 |
| Share of GSVA of agriculture sector to its GSDP | 3.023 |
| Share of indigenous population per 1000 bovine population | 2.921 |
| Number of Veterinary Institutions per 1000 bovine population | 3.097 |
| Number of Artificial Insemination (AI) centres per 1000 female bovine | 1.540 |