

# Climate Change and Variability: Mapping Vulnerability of Agriculture using Geospatial Technologies

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**ABSTRACT:** *Climate change and variability is of particular concern for India, since it has a direct impact on agriculture. It is expected to contribute to increase in temperature, rainfall variability and decrease in irrigation water supplies, greater frequency of extreme weather events and shifting seasons with serious effects on agriculture sector, forestry, food security, natural resources, economic activity, human health, and infrastructure which have deep influence on Indian national economy and livelihood (IPCC, 2014). Faced with these challenges, decision makers and planners need information to assist for preparedness, allocate resources effectively, and reduce impacts. To minimize the likely harm associated with climate change, people and society need an accurate assessment of the vulnerability of the ecosystem in which they inhabit. The key features of climate change vulnerability and adaptation are those related to variability and extremes, not specifically changed average conditions. The present study showed that geospatial technologies can be used to collate, reformat and standardize indicator level data at administrative level (here district) to generate vulnerability rating.*

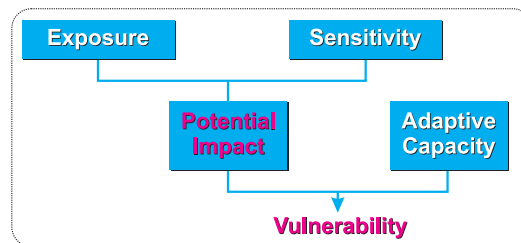
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Researchers have analysed the concept and definition of vulnerability and concluded that vulnerability has three components: (i) the susceptibility of society (i.e. converse of adaptive capacity) which depend upon attributes of society (ii) exposure to hazard (e.g. water stress) and (iii) coping abilities (Kates 1985; Chambers 1989; Blaikie et al. 1994; Bohle *et al.* 1994; Downing and Bakker 2000). However, vulnerability assessments are commonly subjective because of the intricacy of the issue of vulnerability, and vary between regions and hazards. Many factors affect vulnerability but their inclusion in assessment depend on data availability and study context. IPCC has theorized the concept of

Vulnerability (V) as a function of Exposure (E), Sensitivity (S) and Adaptive capacity (A).

Vulnerability assessment at different spatial scales has now become possible with the recent advances in geospatial technologies (i.e. remote sensing and GIS) integrating various spatial data (both short and long term), but there are still methodological problems in implementing model at larger scale. Besides, vulnerability maps convey a lot more to different stakeholders than tabulated categorical assessments. In view of the above, we present a case study to demonstrate a methodology to assess and map composite vulnerability of agriculture to climate variability and change for whole India at district level using geospatial technologies. It aimed at adopting a conceptual framework of vulnerability, generate spatial datasets of key factors contributing to vulnerability, estimate weights of factors and then generate vulnerability ranking maps of the districts. A novelty of this study was that it considered climatic, physical and socio-economic factors together to arrive at vulnerability rating.

Many approaches have been proposed for vulnerability assessment (Cutter, *et al.* 2003; Hayes *et al.* 2004), however there is no universally applicable metrics for vulnerability or its components (Schroter *et al.* 2005). Based on review of literature and expert discussion, we enumerate the following broad sequential steps to be taken in any vulnerability assessment: 1) Set clear aim(s) of vulnerability assessment, 2) Decide on a framework of vulnerability assessment, 3) Decide on the workable definition of hazard, 4) Type of vulnerability to be addressed (environmental/social/economic/composite), 5) Decide Spatial Scale, 6) Decide Temporal Scale, 7) Select Indicators, 8) Formulate indices, 9) Rating and weighting of indices, 10) Quantitative tools for combining indices to arrive at vulnerability rating, 11) Validation of assessment, 12) Communicating assessment, and 13) Adopt into decision support systems. In this study, we adopted the IPCC framework which considers vulnerability to climate change as a comprehensive multi-dimensional concept affected by large number of indicators which can be defined as a function of exposure (E), sensitivity (S) and adaptive capacity (A) as shown in Figure 1.



**Fig. 1:** Vulnerability Framework

Various indicators were identified for assessing each component of vulnerability and are shown in Figure 2. These indicators were generated for each district of

the country using GIS. The exposure indicators were derived from monthly gridded temperature and rainfall layers and processed to derive trends for maximum and minimum temperature and while frequency of extreme high and low rainfall events was captured in terms of Standardized Precipitation Index (SPI) (Mckee *et al.* 1993), separately for *kharif* and *rabi* seasons. The study used gridded monthly precipitation, maximum and minimum temperature, time series data constructed by Climatic Research Unit (CRU TS 3.0) at a spatial resolution of  $0.5 \times 0.5$  degree. The gridded temperature data were used to calculate the rate of change over the years by fitting the linear time trend and monthly rainfall data to calculate SPI, an index of rainfall deviation, over the 1951-2009 period. The Digital Soil Map of the World and Derived Soil Properties (Version 3.5) produced by FAO (1995) at a finer resolution of  $5' \times 5'$  grid size by using the World Inventory of Soil Emissions (WISE) database was used. The digital maps of soil moisture storage capacity (mm) for 1 m profile depth and soil organic carbon content ( $\text{kg m}^{-2}$ ) were extracted and their average value was calculated for each district in GIS. The study utilized the FAO Global Map of Irrigation Areas (GMIA) version 4.0.1 having a grid size of  $5' \times 5'$  for calculating the irrigated area (Siebert *et al.* 2007). The status of groundwater exploitation was taken from the maps produced by Central Ground Water Board. District-wise productivity of food grains and net sown area statistics were obtained from the Agricultural Statistics published by the Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, for the period 2006 to 2009. Livestock density was compiled from the 18th Livestock Census (2007) published by the Department of Animal Husbandry and Dairying, Government of India. The district-wise statistics on human population density, number of villages electrified and the number of villages with paved roads were compiled from the Census of India (2011). The Human Development Index (HDI) was obtained from the Human Development reports of respective states, as produced by the UNDP. The annual NPK fertilizer consumption data was compiled from the reports of Fertilizer Association of India for the period 2006 to 2009.

A five-point ordered scale was used to rank from 'very-low' to 'very-high' for each indicator of exposure, sensitivity and adaptive capacity, according to their functional relationship with vulnerability *i.e.* if the indicator was directly related to vulnerability; higher ranks were given for higher values and vice versa. For deriving weights of each indicator in their respective component of exposure, sensitivity and adaptive capacity, pair-wise comparison approach of Analytic Hierarchy Process (Saaty1980) was employed. The overall consistency ratio of 0.09 was achieved, suggesting that weights were generated randomly (Figure 2). Once the scores were standardized and weight established for factors, exposure, sensitivity, adaptive capacity and vulnerability maps were prepared varying from 1 to 5 ('very low', 'low', 'moderate', 'high' and 'very high') by taking weighted sum of the rank of all relevant indicators.

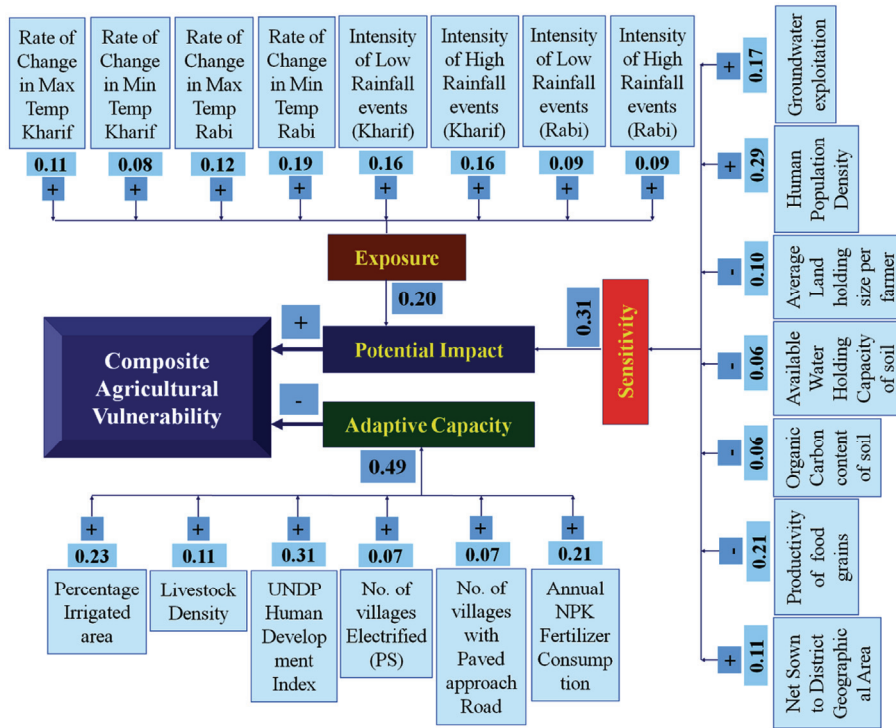
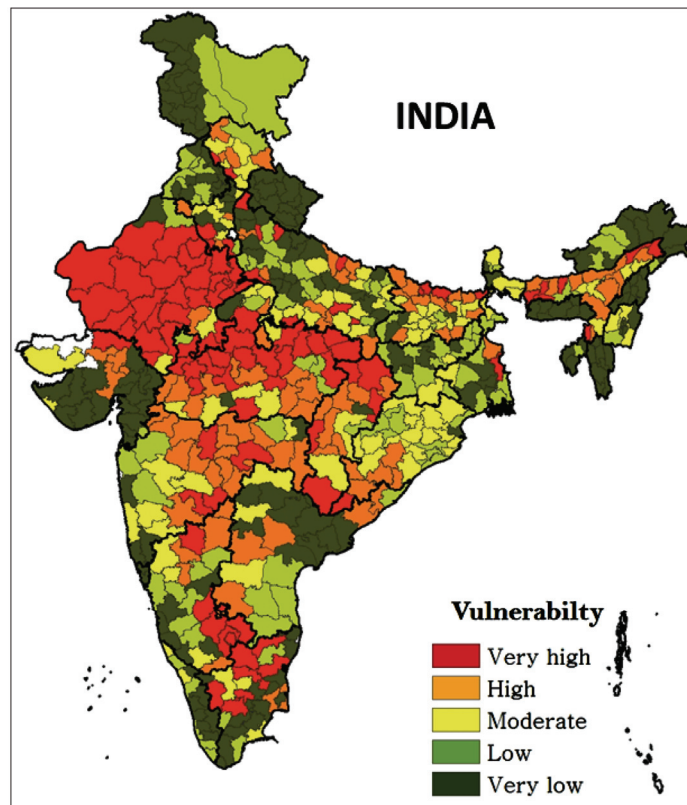


Fig. 2: Indicators their Weightage and Nature of Relation (+ or -) used for Deriving Composite Agricultural Vulnerability

Using the district-wise data of indicators along with their weights maps of Exposure, Sensitivity and Adaptive capacity were generated (not shown here). A ‘very-high’ to ‘high’ exposure was observed for most of Andhra Pradesh, Kerala, Tamil Nadu and southern Karnataka. High exposure was observed in J&K, Arunachal and Bundelkhand region of UP and MP. Punjab, Haryana and Uttarakhand districts showed low to very low exposure. The very high to high sensitivity was observed for most of the districts of Rajasthan and a few districts of southern Karnataka and northern Tamil Nadu. ‘High’ to ‘moderate’ sensitivity was also observed for most districts of Punjab and Haryana, parts of Bihar, MP and Maharashtra. The adaptive capacity was ‘very-low’ to ‘low’ in Rajasthan, MP, Chattisgarh, Odisha, Assam, Himachal Pradesh, Uttarakhand and parts of Maharashtra (Vidharbha region). ‘Moderate’ to ‘high’ adaptive capacity was found in Tamil Nadu, Kerala, Gujarat, Haryana and Uttar Pradesh. ‘Very-high’ adaptive capacity was found for most of the districts of Punjab and few in Haryana.

Combining the three component maps (E, S, and A) using weighted sum a vulnerability map of the India was generated (Figure 3). A ‘very-high’ vulnerability was observed for most districts of Rajasthan and northern districts of Madhya Pradesh (including Bundelkhand), owing to very high sensitivity and

low adaptive capacity of the agriculture in these regions. Similar was the case for southern districts of Karnataka. High-vulnerability was obtained for most districts of central India comprising of Maharashtra and Madhya Pradesh and also in most of Assam. Punjab, Haryana, Gujarat (Saurashtra), Uttarakhand, Kerala, southern Tamil Nadu, coastal Karnataka and Maharashtra, and parts of Western Uttar Pradesh showed very low to low vulnerability of agriculture to climate change.



**Fig. 3:** Map of Composite Vulnerability of Agriculture to Climate Change and Variability

Adaptation to climate change has the potential to substantially reduce many of the adverse impacts of climate change and enhance beneficial impacts. The key features of climate change vulnerability and adaptation are those related to variability and extremes, not specifically changed average conditions. Enhancement of adaptive capacity is a necessary condition for reducing vulnerability to climate induced changes in availability of water resources, frequency and intensity of extreme events like floods, droughts, heat and cold waves, and the associated impacts on agriculture and other livelihood options. The study showed that geospatial technologies can be used to collate, reformat and

standardize indicator level data at administrative level (here district) to generate vulnerability rating. It identified the districts which should be prioritized for undertaking adaption measures keeping in view the underlying causes of vulnerability. Overall, this study on vulnerability is expected to lead to replication of proposed methodology to other agricultural areas of the world in same or improved format so that better agricultural management plans could be attempted.

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