Lecture 21
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CM 615

Climate change Impacts & Adaptation

Climate risk, Adaptation & Agriculture in India

Sharma et al 2020 ERL

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Title: Increasing agricultural risk to hydro-climatic extremes in India

- Examined the effects of climate change on rice and wheat yields in India

- India’s population: ~1.46 billion (~17.8% of the global population).
- Agriculture: A crucial economic sector and key source of employment (Economic Survey 2017–18, GOI).
- Food insecurity: ~20% of India's population faces food insecurity (Wheeler & Von Braun, 2013).
- Food demand: Crop production must double to meet future needs and reduce poverty.
- Climate change impacts: Increasing occurrences of extreme events—
    - Precipitation extremes
    - Droughts
    - High maximum temperatures, minimum temperatures

- Agricultural growth is already hindered due to these climate extremes.
- Future risks: Impacts on agriculture will likely intensify with the increasing trend in extreme events.

Title: Increasing agricultural risk to hydro-climatic extremes in India

- Proposed a novel unified country-level framework to quantify decadal agricultural risks from hydro-meteorological exposures and adaptive consequences.

- Identified increased risks for rice and wheat in the recent decade, with wheat risks being twice as high as rice.

- Increasing crop risks driven by:
  - Decreasing number of cultivators.
  - Increasing minimum temperatures during the wheat growing season.

Title: Increasing agricultural risk to hydro-climatic extremes in India

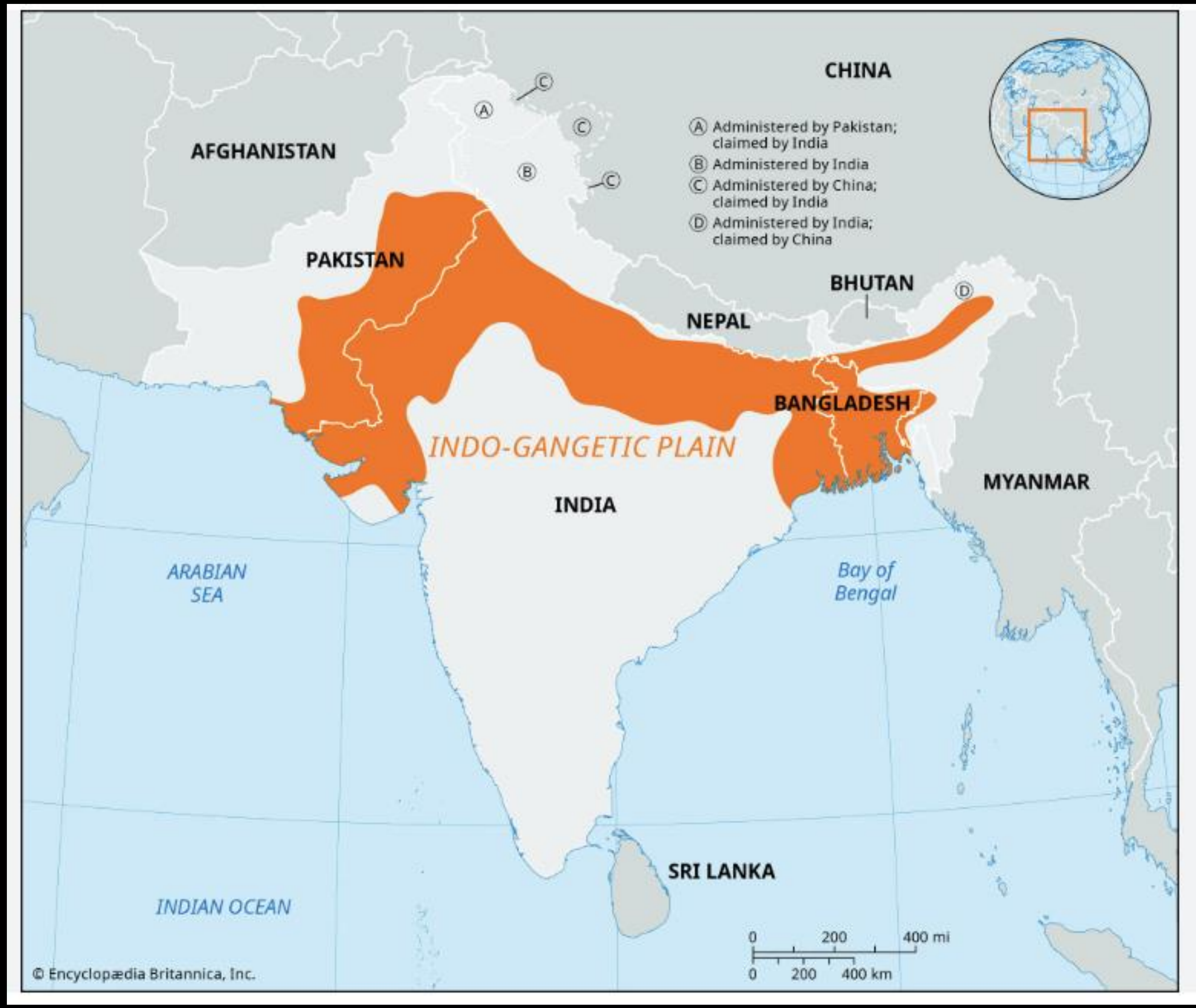
- Hydro-climatic hazards (precipitation extremes and droughts) more alarming for crop risks than temperature extremes.

- Results highlight the sensitivity of India's agriculture to multiple agro-ecological and climatic components.

- Recommendations for informed planning of adaptive measures to ensure sustainable food security.

Motivation

- Lobell and Field, 2007: Noted a **negative impact** of rising temperatures on global yields of wheat, maize, and barley.
- Pathak et al, 2003: Found that increased minimum temperatures in the Indo-Gangetic plains led to **decreased rice and wheat yields**.
- Rupa Kumar et al, 2002: Observed significant associations between yields of major Indian crops (rice, maize, wheat) and the stability of Indian Summer Monsoon Rainfall (ISMR).
- Studies report a **recent decrease in ISMR magnitude**.
- **These findings suggest potential further decreases in crop yields, posing risks to food security in India.**

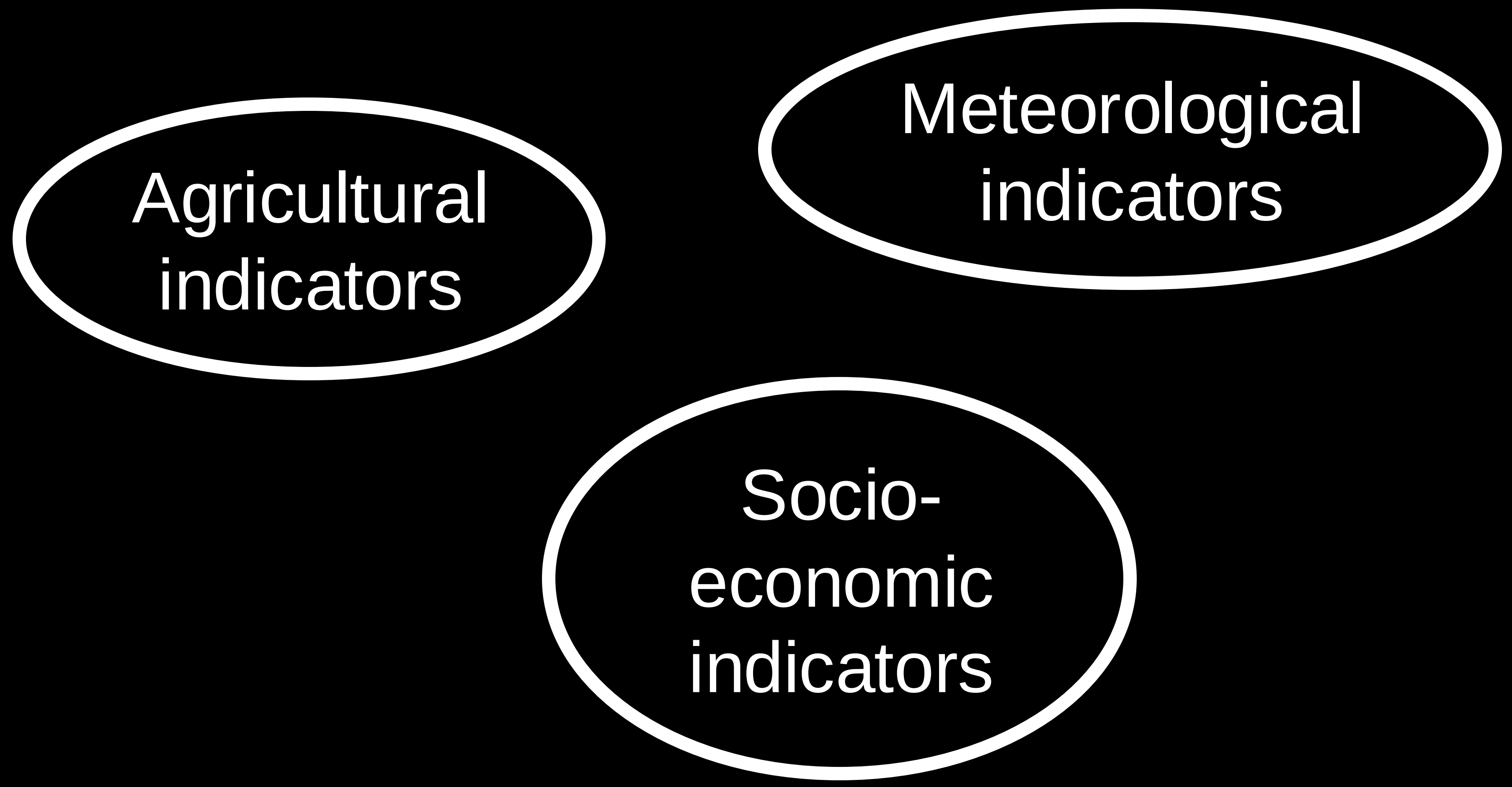


Motivation

- Previous studies on future food security often used projected scenarios with climate model outputs to simulate various crop models over large areas.

- These simulations are crucial for understanding climate-crop interactions.

- However, they come with uncertainties due to:
  - **Different initial and boundary conditions.**
  - **Various convective schemes in climate models**.



- Additional uncertainty arises from **using different crop models, regardless of their sophistication**.

Motivation

- Previous studies followed the definition of 'vulnerability' from the IPCC's third Assessment Report (AR3):
  - Defined as a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

- The IPCC's fifth Assessment Report (AR5) significantly modified this definition:
  - Introduced the term 'risk' as a function of 'exposure', 'hazard', and 'vulnerability'.

Objective

- Objective: Develop a fine-resolution district-level agricultural vulnerability map for India.
- Indicators: Agricultural, hydro-meteorological, and socio-economic indicators from reliable data portals (2001 and 2011 census decades).
- Framework: Comprehensive agricultural risk and vulnerability analyses based on IPCC AR5 framework.
- Crops: Focus on rice and wheat, which accounted for **78%** of total food grains produced in 2015-16.
- Economic Impact: Agriculture shared approximately **14%** of India's GDP.
- Data Selection: Indicators chosen based on data parity, continuity, and consistency.
- Novel Framework: Assessed agricultural risk considering vulnerability and three hydro-climatic hazards (precipitation extremes, temperature extremes, drought).
- Risk Definition: Followed IPCC AR5 definition of **'risk'** (more holistic than AR3's 'vulnerability').
- Risk Maps: Advanced cartographic products to prioritize regions with high agricultural vulnerability/risk.
- Adaptations: Results may facilitate development of suitable adaptations or innovative options under different hydro-climatic extreme conditions.

Indicators

Data	Indicator	Description	Justification	Data Source
Agricultural	Crop cultivable area for rice and wheat	Cultivable area under the crops in hectares.	Larger the cultivable area, higher the chances of agricultural productivity.	Directorate of Economics and Statistics-Government of India
	Normalized difference vegetation index (NDVI) for Kharif and Rabi seasons	A unitless vegetation index.	Value near to +1, better the regional vegetation and hence agricultural production (Pandey and Seto 2015).	Moderate Resolution Imaging Spectroradiometer-National Aeronautics and Space Administration (NASA)
Hydrological	Groundwater level (premonsoon and monsoon for Kharif, and postmonsoon and winter for Rabi season)	Depth of water table from the ground surface in meters.	Higher the number, more difficult it will be to extract the water for agriculture.	Central Ground Water Board of India
	Soil moisture (Kharif and Rabi season)	Soil moisture in volumetric unit.	Higher this number, more the soil water is available for agriculture.	European Space Agency (ESA) Climate Change Initiative
Meteorological	Wet spell length	Number of periods of 3 or more consecutive days when the standardized anomaly of long-term crop-growing season rainfall (1951-2013) was greater than 1.	Higher the count, harsher will be the conditions for agricultural production (Rajeevan *et al* 2010; Anandhi *et al* 2016).	India Meteorological Department
	Average wet spell length	Average of number of wet spell periods.		
	Maximum wet spell length	Maximum of number of wet spell periods.		
	Maximum (minimum) temperature warm spell length	Number of periods of 6 or more consecutive days when the maximum (minimum) temperature was greater than the 90th percentile of the long-term crop-growing season temperature.		
	Maximum (minimum) temperature average warm spell length	Average of number of maximum (minimum) temperature warm spell periods.		
	Maximum (minimum) temperature maximum warm spell length	Maximum of number of maximum (minimum) temperature warm spell periods.		
	Maximum (minimum) temperature cold spell length	Number of periods of 6 or more consecutive days when the maximum (minimum) temperature was less than the 10th percentile of the long-term crop-growing season temperature.		
	Maximum (minimum) temperature average cold spell length	Average of number of maximum (minimum) temperature cold spell periods.		
	Maximum (minimum) temperature maximum cold spell length	Maximum of number of maximum (minimum) temperature cold spell periods.		
	Crop-growth stage-wise temperature requirements	Number of days over which the maximum and minimum temperatures		

Data	Indicator	Description	Justification	Data Source
Socioeconomic	Tap water	Representing status of its availability. Here, quantified as the ratio of number of villages with a positive status to the total number of villages with in the district. For example, higher the ratio of "River/Canal", higher will be the chances of water availability in the district.	Indicators showing availability or proxy to the availability of the source of drinking/domestic/agricultural water in the district, which might be essential for the wellbeing of the locals and to ensure sustainable farming practices in the region.	Census of India
	Well water			
	Tank water			
	Tube well			
	Hand pump			
	River/Canal			
	Spring			
	Agricultural credit societies		Its presence may provide a platform for the agricultural workers for enhancing their indebtedness (Mohan 2006).	
	Power supply for agricultural use	Number of hours of power supply for agricultural use per day.	Greater the number, greater will be the power supply for irrigation.	
	Irrigated area	Irrigated area in hectares.	Larger area indicates larger spatial extent of the irrigated water supply.	
	Cultivators	Population dependent on agriculture. Here, quantified with respect to the total population of the district.	Higher the number, more will be the involvement in agriculture which may increase the productivity. Higher the number of marginal workers will also imply an increased opportunity and man-power in agriculture (Swanson *et al* 2007; Bryan *et al* 2015; National Indicators Framework 2018).	
	Agricultural labors			
	Marginal cultivators			
	Marginal labors			

Methodology

- Agricultural Vulnerability Estimation:
  - Based on district-level indicators classified into two segments: adaptation (positive, inversely related) and vulnerability (negative, directly related).
  - 40 indicators for rice and 42 for wheat were selected.
- Data Sources:
  - Census of India: Agricultural population, water availability, credit societies, power supply for agricultural use (Socio-economic).
  - India Meteorological Department (IMD): Wet spell, cold spell, warm spell, crop growth stage-wise temperature unfavorable durations (Meteorological).
  - Central Ground Water Board of India: Groundwater level (Hydrological).
  - European Space Agency Climate Change Initiative: Soil moisture (Hydrological).
  - Crop Production Statistics Information System of the GoI: Crop cultivable area and yield (Agricultural).
  - MODIS: Vegetation index (Agricultural).

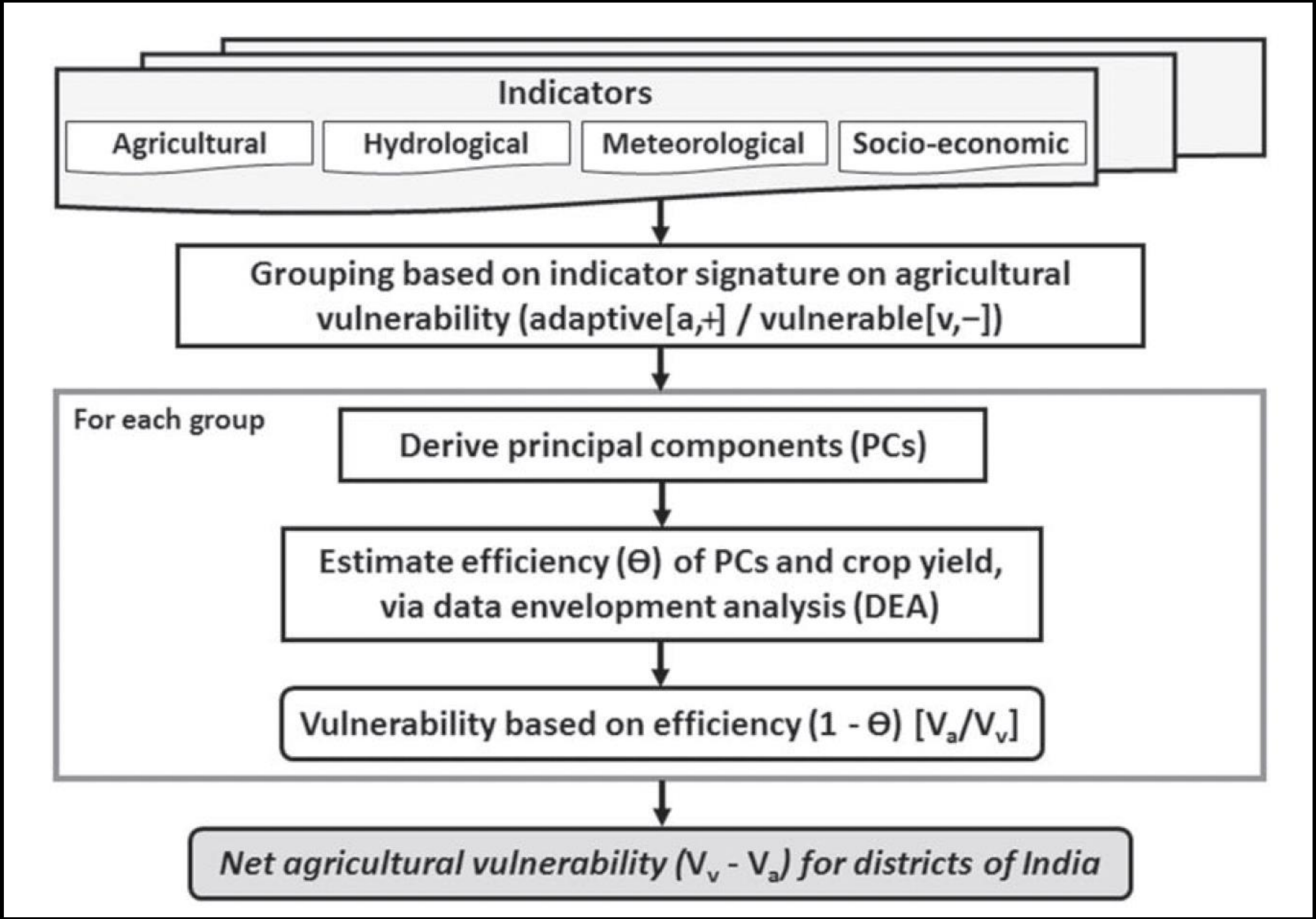
Methodology

- Census Data:
  Prepared once a decade.
  2001 census represents 1996–2005, 2011 census represents 2006–2015.
  Crop yield data available from 1998 to 2014.

- Common data duration: 1998–2013, divided into two intervals (1998–2005 and 2006–2013). Each interval's average represents the census year of 2001 and 2011.

- Meteorological Indicators:
  Derived based on IMD definitions for sowing to harvesting months:
    June to October for Kharif rice.
    November to March for Rabi wheat.

Methodological framework for mapping the agricultural vulnerability



Methodology

- Principal Component Analysis (PCA):
  - Performed for each segment to decorrelate the data matrix and make it dimensionless.
  - Selected Principal Components (PCs) explaining **80%** of the variability in indicators for 2001 and 2011 census decades.
  - PCA helps in reducing the complexity of the data by transforming it into a set of uncorrelated variables (principal components) that still retain most of the original data's variability. This makes it easier to analyze and compare the data across different districts.

Methodology

Decision Making Unit, here it is Districts of India

- Data Envelopment Analysis (DEA):
- DEA measures how efficiently DMUs convert multiple inputs (like resources) into multiple outputs (like products or services).
- Unlike traditional methods that require predefined functional relationships between inputs and outputs, DEA does not assume any specific functional form. This makes it flexible and suitable for complex systems.

  - PCs used as input in a **nonparametric** DEA framework to rank DMUs
  - Observed crop yield considered as output in the DEA framework.
  - Rankings derived in terms of efficiency (ϴ)
  - Technically efficient DMU (high ϴ) uses the same or fewer inputs to produce a given output compared to other DMUs.
  - Inefficient DMU (1-ϴ) is incapable of using available inputs to produce a given output, implying its vulnerability.

Standardization of Net Vulnerability

- In order to understand the relative vulnerability behaviour of each DMU (district)
  - Standardized the net vulnerability Vi for each DMU ‘i’ based on below equation
  - To obtain the agricultural vulnerability $V_{iRelative}$ of that DMU.
  - V_{min} and V_{max} are the minimum and maximum net vulnerability measures, respectively, among all the DMUs.

- $V_{iRelative} = \frac{V_i - V_{min}}{V_{max} - V_{min}}$

Methodology used to estimate hydroclimatic hazards and their impact on agricultural risk

- Hydroclimatic Hazards:
  - Derived from daily precipitation (**0.25°** resolution) and maximum temperature (**1°** resolution) data from IMD (1961–2011).
  - Meteorological data divided into three periods: 1961–1990, 1991–2000, and 2001–2011.

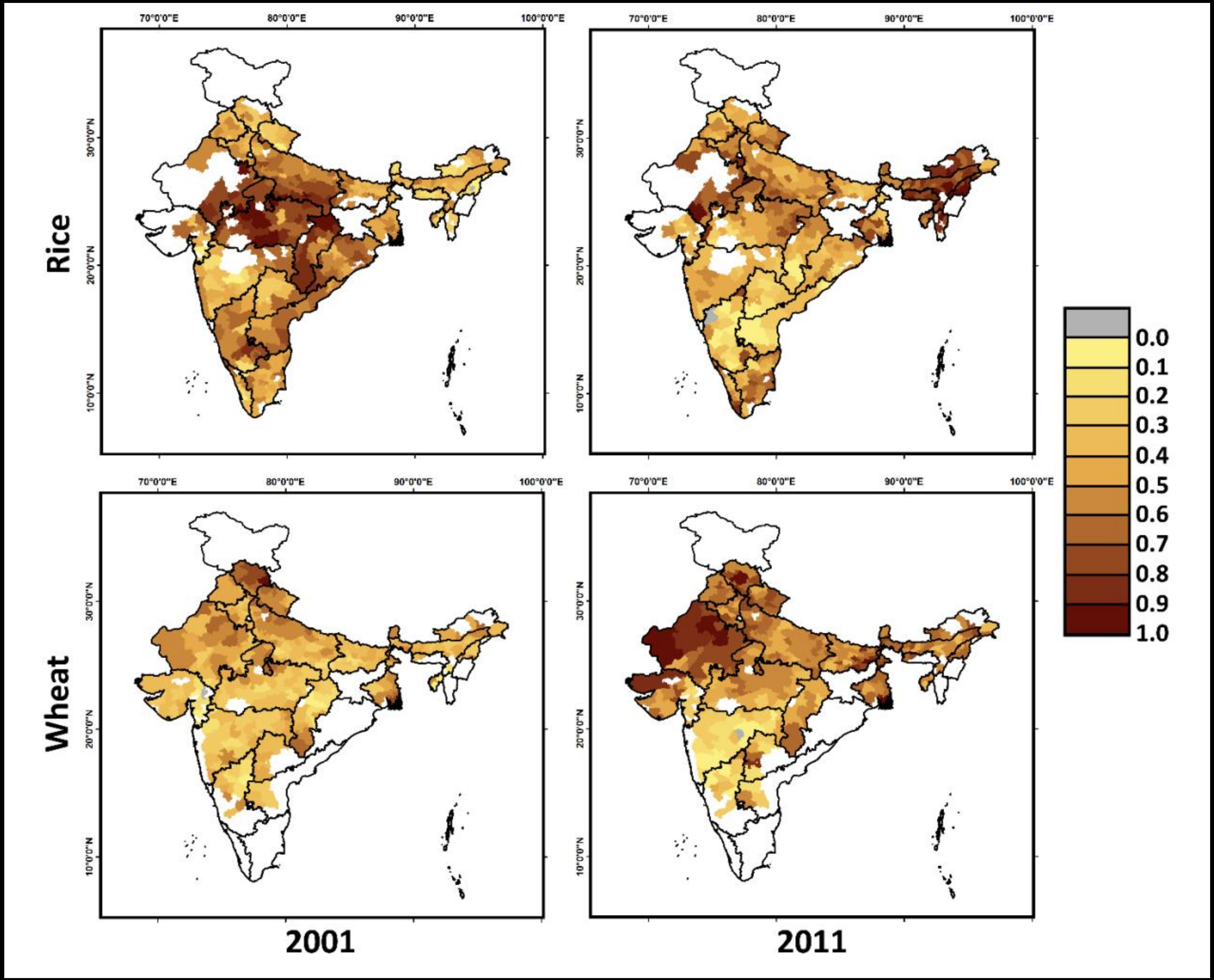
- Hazard Estimation:
  - Precipitation and temperature extremes estimated using frequency-based hazard estimation.
  - 1961–1990 used as the base period to obtain the 95th percentile threshold.
  - Threshold applied to other periods to determine hazard intensity.
  - 99.5th percentile exceedance probability considered as extreme events for the two decades.

Methodology used to estimate hydroclimatic hazards and their impact on agricultural risk

- Drought Estimation:
  - Applied the Standardized Precipitation Evapotranspiration Index (**SPEI**).
  - Hargreaves method used to derive potential evapotranspiration.
  - Nonparametric Gaussian kernel distribution used to obtain 3-month SPEI for the two decades.
  - SPEI **values ≤ -1.5** considered as **extreme events**.

- Hydroclimatic Hazard Probabilities:
  - Exceedance probabilities extracted by fitting kernel distribution.
  - Grid wise probability values aggregated at district-scale.

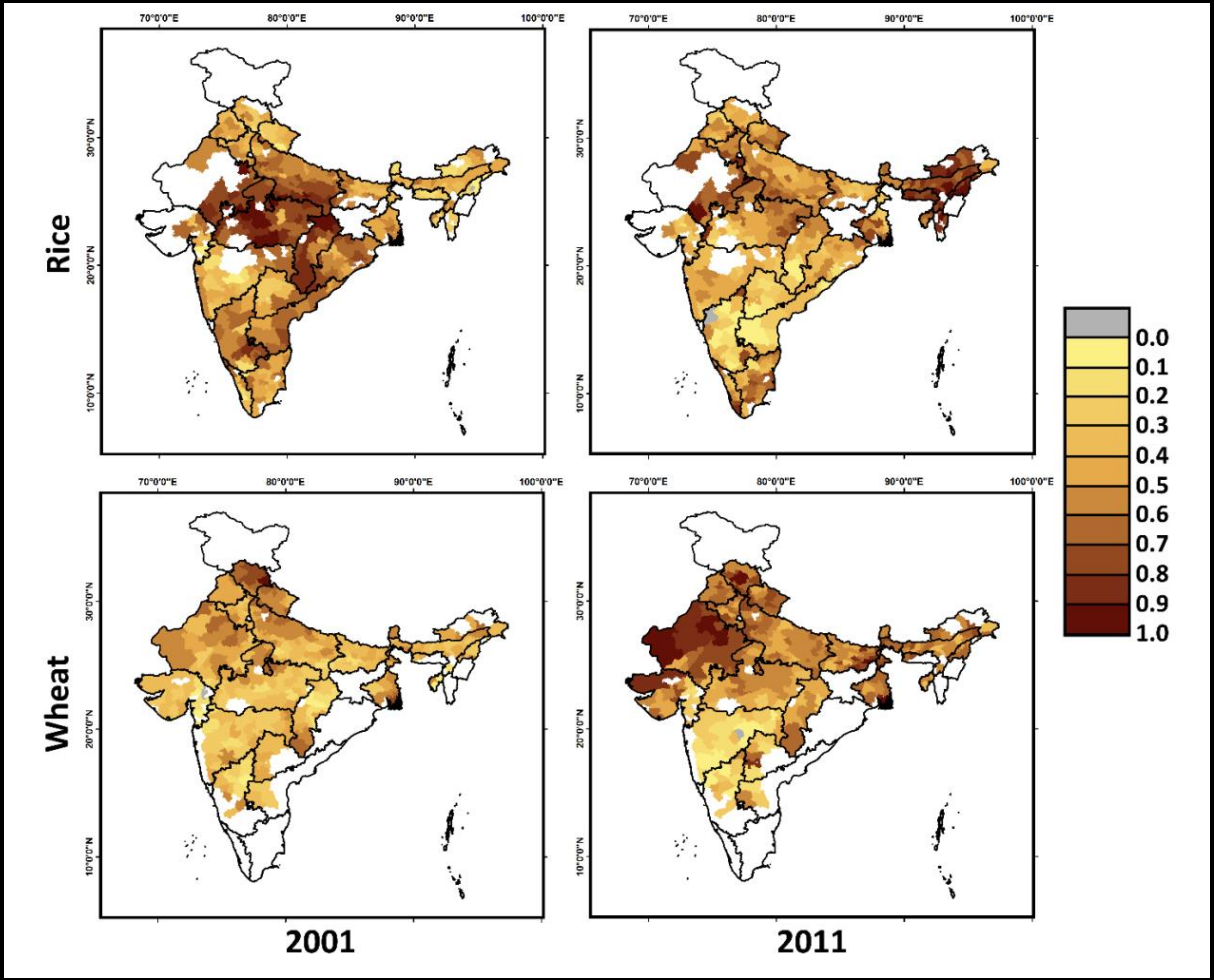
- Agricultural Risk:
  - Derived as a product of each hydroclimatic hazard component and agricultural vulnerability



District-level agricultural vulnerability for rice (top panel) and wheat (bottom panel), computed through a robust DEA framework for the census decades 2001 and 2011.

Values approaching one represent the districts that displayed increasing vulnerability.

Here, the **white patches** inside the maps represent either non-rice/non-wheat-growing regions or districts with insufficient crop yield data.

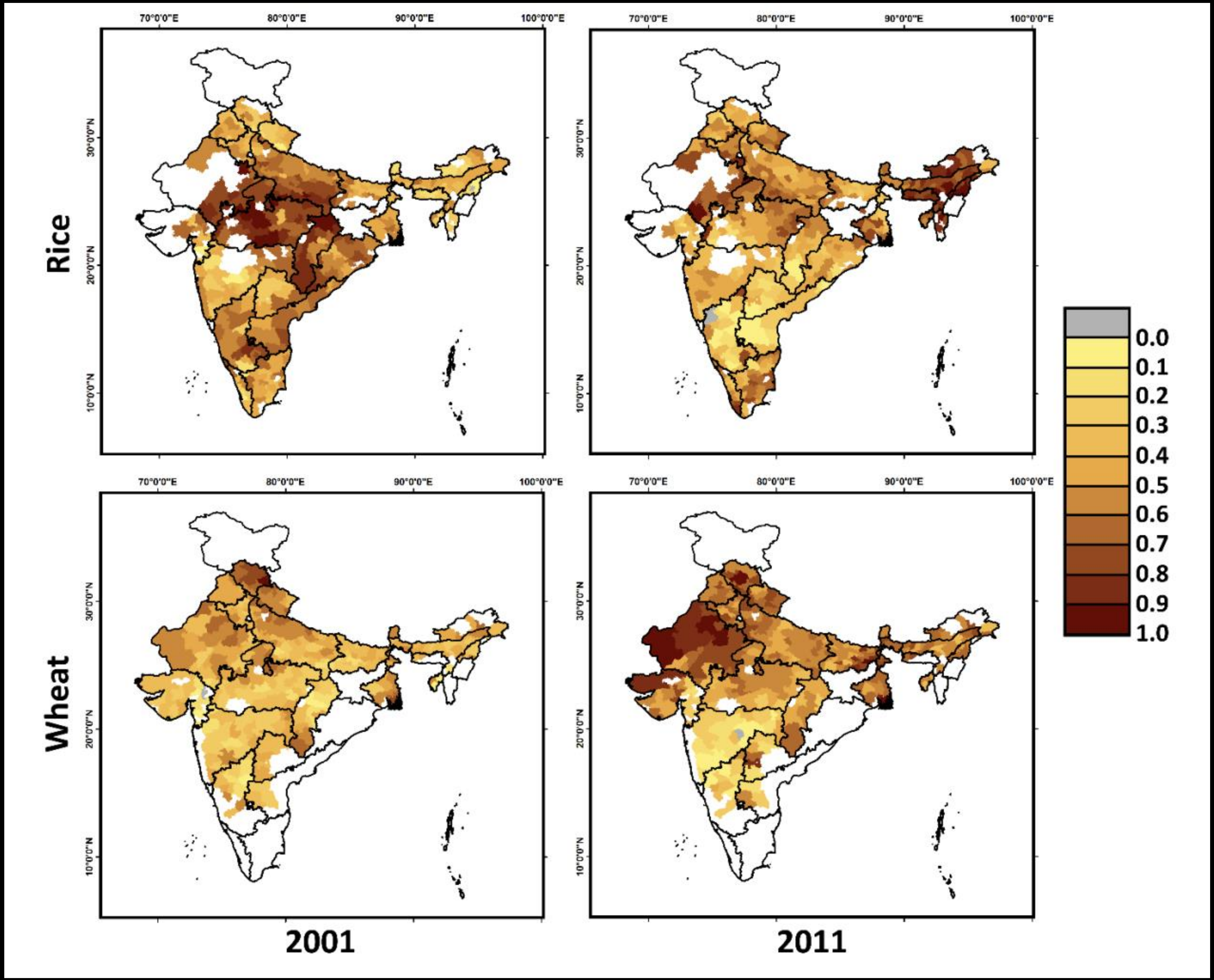


A PCA at 80% variability showed that the country-level rice vulnerability changes were mainly affected by the indicators of

cultivable area and number of agricultural labors from the adaptation segment,

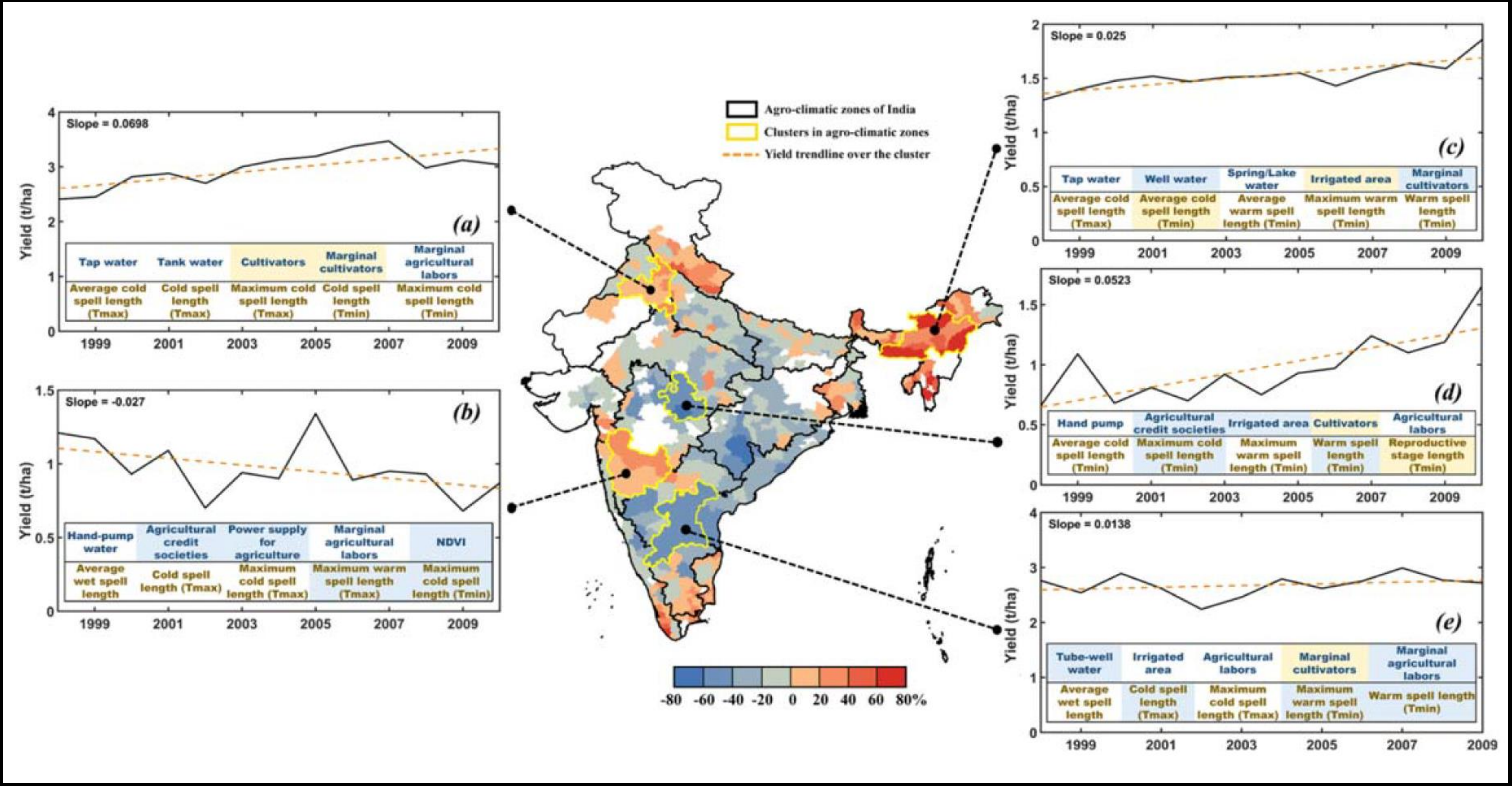
whereas

wet and warm spell lengths were the major influencers from Vvulnerability segment.



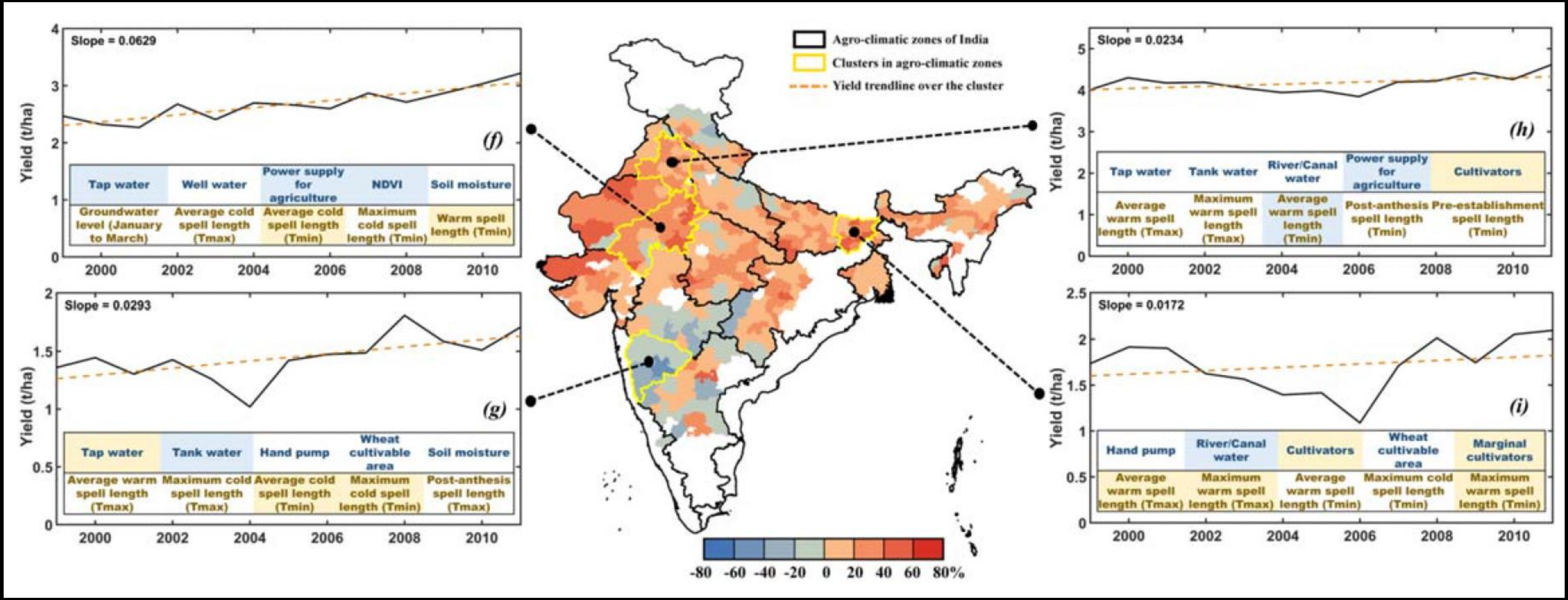
The country level changes in wheat vulnerability were primarily influenced by

growing season
soil moisture,
cultivable area and
groundwater levels in the sowing and cultivation stages.



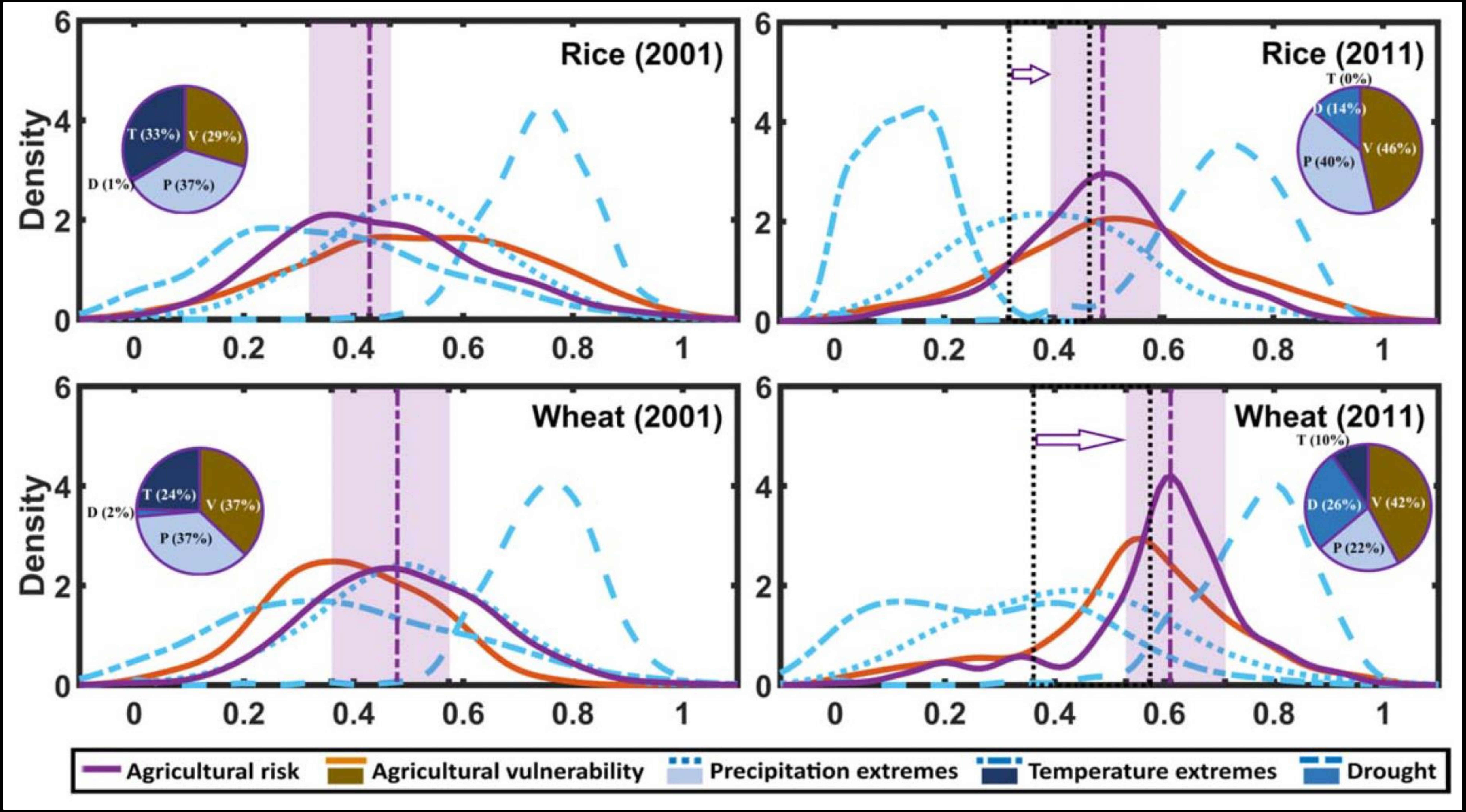
Decadal percentage changes in RICE vulnerability. Panels around the map represent Mann–Kendall trends and Sen's slope of crop yields for each cluster. Hotspots for clusters of districts located within the agro-climatic zones of trans-Gangetic plains (a), western plateau and hills (b), eastern Himalaya (c), central plateau and hills (d) and southern plateau and hills (e) were considered for rice.

Blue (orange) shading for indicators depict significant decreasing (increasing) impacts on decadal changes in the rice vulnerability.



Decadal percentage changes in WHEAT vulnerability. Panels around the map represent Mann–Kendall trends and Sen’s slope of crop yields for each cluster. Hotspots for clusters of districts located within the agro-climatic zones of trans-Gangetic plains (a), western plateau and hills (b), eastern Himalaya (c), central plateau and hills (d) and southern plateau and hills (e) were considered for rice.

Blue (orange) shading for indicators depict significant decreasing (increasing) impacts on decadal changes in the rice vulnerability.



Nation-wide spatial variability in the overall agricultural risk, agricultural vulnerability and hydro-climatic hazards in terms of nonparametric Gaussian kernel probability distribution function (PDF). Purple-shaded region represents the density band greater than 2 for overall agricultural risk; black dashed-box in 2011 plot explicitly shows the density band of earlier decade (2001), with a shift from 2001 to 2011 census decade being depicted by horizontal arrow. Vertical purple dashed–dotted line represents the median of overall agricultural risk PDF. Inset pie-charts shows the percentage area of agricultural vulnerability (V), precipitation extremes (P), temperature extremes (T) and drought (D) PDFs in the purple-shaded density band.