POLICY BRIEF 73

Climate Resilience of Indian Agriculture across Agro-Climatic Zones

Naveen P Singh, Bhawna Ahuja, S K Srivastava, K V Rao, S K Bal and N R Kumar

Climate change emanating in the form of unpredictable weather patterns, seasonal shifts, and recurrence of natural hazards is increasingly considered as a threat multiplier to the path of sustainable development. In the recent 30th UN Climate Change Conference of the Parties (COP30) held at Brazil, the impetus has been placed on efforts to build resilience and adaptation to climate change. The pattern of climate vulnerability and the potential reaction to the stimulus, vary geographically and temporally based on the ecological zone, production systems and prefabricated social and economic conditions[1]. As the harmful effects of climate change intensify over time, it becomes essential to deploy measures that limits the vulnerability and builds resilience of socio- ecological system against climate shocks and stresses.

'Resilience' framework has been recognized as an important policy perspective within sustainability science and development paradigm[2]. The concept of resilience is central to both the vulnerability assessment and in achieving agriculture sustainability. Resilience is inherently a complex and multidimensional agenda. There are diverse set of factors relating to the economic, social, institutional, and technological arena that interact in complex phenomenon to influence the ability of a region to either moderate the existing climate vulnerability or to deal with future climate impacts. Mix of these factors is closely linked to the state of development[3] and is neither independent nor mutually exclusive. Limits to resilience emerge whenever the actual state of dimension exceeds/ fall short of thresholds/desired level. This leads to spatial variations in the capacity to deal with contemporary climate induced risks, which poses significant implications for agriculture sustainability.

In the recent years, robust elucidation of spatial dimension has become an important instrument of climate adaptation planning. This allows generation of socially economically and technologically differentiated and need-based interventions which assume a critical role in the course of developing climate-resilient pathways.

Table 1. List of indicators and weights used for resilience assessment

Environment (0.227)	Technology (0.262)	Socio-economic (0.256)	Institution & Infrastructure (0.255)
Forest coverage (0.235)	Food grain yield (0.157)	Share of primary sector in GDP (0.143)	Road Connectivity (0.140)
Stage of ground water extraction (0.212)	Fertilizer usage (0.133)	Households below poverty line (0.166)	Market Access (0.118)
Waste land (0.208)	Cropping intensity (0.151)	Agriculture worker (0.166)	Technical advice (0.176)
Rainfall deviation index (0.208)	Irrigation coverage (0.160)	Literacy rate (0.152)	Electrification (0.135)
Agriculture emission index (0.137)	Net sown area (0.147)	Population density (0.108)	Crop insurance (0.117)
	Livestock density (0.135)	Area under small and marginal land holdings (0.114)	Access to transport & communication facilities (0.179)
	Crop diversification index (0.118)	Agriculture credit (0.151)	Access to banks (0.135)

Note: Definition of indicators (unit of measurement), rationale, source of data and time period are available in Singh *et al.* (2021)[4].

Therefore, we present an analysis and discussion of multi-scalar and multi-indicator assessment, by profiling resilience across 14 Agro-climatic zones (excluding

Naveen P Singh (Principal Scientist), N R Kumar (Principal Scientist and Head), S K Srivastava (Sr. Scientist) and Bhawna Ahuja (Ex-Research Associate) are at ICAR-NIAP, New Delhi, K V Rao (Head, DRM Division) and S K Bal (Project Coordinator, Agromet) are at ICAR-CRIDA, Hyderabad.

[1] FAO. (2017). *The future of food and agriculture–trends and challenges.* Food and Agricultural Organization of UN, Rome.

[2] Smit, B. and Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, 16 (3), 282–292.

[3] Singh N. P., Anand, B., Singh, S. and Khan, M.A. (2019). Mainstreaming climate adaptation in Indian rural developmental agenda: a micro-macro convergence. *Climate Risk Management*, 24, 30-41.

[4] Singh, N.P., Anand, B., Singh, S., Srivastava, S.K., Rao, C.S., Rao, K.V., and Bal, S.K. (2021). Synergies and Trade-offs for Climate Resilient Agriculture in India: An Agro-Climatic Zone Assessment. *Climatic Change*, 164 (11), 1-26.

island region) in India[5], based on development of a Climate Resilient Agriculture (CRA) Index embracing four dimensions which stands at the intersection of agriculture and climate resilience.

The portfolio of selected indicators was built on three major aspects; dimensionality of resilience, relevance of indicator in policy stance and data availability & accessibility. As shown in Table 1, a total of 26 indicators, relating to environment, technology, socio-economic and infrastructure & institution dimensions were employed to purport *inter* and *intra* Agro-climatic Zone (ACZ) differentials in the level of resilience using district level information.

For *inter*-ACZ comparison, district values were aggregated at ACZ level using three different types of weights which include proportion of geographical area for environmental indicators, net sown area for technological indicators and rural population for socio-economic and institutional & infrastructural indicators. Next, we employed Min-Max method as adopted by UNDP (1990)[6], to standardize indicators into a common range of (0, 1) depending on their functional relationship with the dimension. Finally, to construct of different dimensions indices and the CRA index, normalized values were combined *via additive* linear aggregation using suitable weights. Differentiated weights were assigned to the indicators using multivariate technique of Principal Component Analysis. Here it must be noted that for assessing *intra*- ACZ variations as reflected by district resilience, we used the same weightage across indicators as applied in examining the *inter*-ACZ variations. Further, based on their index scores, 14 ACZs and 616 districts were categorized into different homogenous groups based on quantile estimation and were mapped. It must be noted that the values of the estimated indices, does not reflect the absolute resilience, rather it only indicates the relative strength of ACZ/ district to withstand climate risks.

Inter-ACZ resilience

Environmental index

Environmental factors have implications for balanced ecosystem, climate change, biodiversity and agriculture which significantly influence the resilience capacity of a region. The relative status of ACZs showed that EPH, EHR, WCG and CPH exhibit high resilience in terms of environmental parameters (Table 2). Indo-Gangetic Plains (covering states of Bihar, Uttar Pradesh, Haryana, Punjab and West Bengal) emitted the highest amount of GHGs from the agricultural sector. Over the period from 1991-2015, WCG, LGP and MGP showed greater deviation in annual rainfall. The extent of waste land was higher in Himalayan hills and WDR, while it was lower in Gangetic Plains. Among the zones, EHR (north-eastern states and parts of West Bengal), WCG and EPH had the highest expanse of forest resources in the country. Environmental resilience was found to be the lowest in the TGP comprising states of Haryana and Punjab, WDR and parts of Rajasthan primarily due to lesser forest coverage extensive extraction of ground water resources relative to the availability.

Table 2. Categorization of Agro-climatic Zones

Indices of Resilience	High Resilience	Medium Resilience	Low Resilience
Environmental Index	CPH, EHR, EPH, WCG	ECH, GPH, UGP, WHR, WPH	LGP, MGP, SPH, TGP, WDR
Technological Index	LGP, MGP, TGP, UGP	CPH, ECH, SPH, GPH, WPH	EHR, EPH, ECG, WDR, CPH
Socio-Economic Index	ECH, TGP, WCG, WDR	EHR, GPH, SPH, WHR, WPH	CPH, EPH, LGP, MGP, UGP,
Institutional & Infrastructural Index	GPH, SPH, TGP, WCG	ECH, EPH, LGP, WHR, WPH	CPH, EHR, MGP, UGP, WDR
CRA Index	ECH, GPH, TGP, WCG	CPH, LGP, SPH, WHR, WPH	EHR, EPH, MGP, UGP, WDR

Note: Western Himalayan Region (WHR), Eastern Himalayan Region (EHR), Lower Gangetic Plains (LGP), Middle Gangetic Plains (MGP), Upper Gangetic Plains (UGP), Tans- Gangetic Plains (TGP), Eastern Plateau & Hills (EPH), Central Plateau & Hills (CPH), Western Plateau & Hills (WPH) , Southern Plateau & Hills (SPH), East Coast Plains & Hills (ECH), West Coast Plains & Ghats (WCG), Gujarat Plains & Hills (GPH), Western Dry Region (WDR)

Technological index

Technological factors alter resilience by impacting crop productivity, farm return and directing resources towards farm investment. Net sown area was relatively higher in Indo-Gangetic Plains and WPH (covering parts of Maharashtra and Madhya Pradesh). Cropping intensity was higher in LGP, while it was the least in SPH and WCG. Irrigation coverage was more than 60 percent in Indo-Gangetic Plains and CPH. On the other spectrum, access to irrigation was the lowest in Himalayan Region and Plateau & Hills regions. The application of fertilizer was relatively lesser in zones such as CPH, EHR and WDR. Indo-Gangetic Plains followed by ECH and CPH registered higher food grain yields, while WDR and WPH recorded the lowest. Further, higher livestock density was observed in LGP, UGP and EHR. Overall, Indo-Gangetic Plains exhibit high technological resilience among the zones.

Socio-economic index

Socio-economic factors determine exposure to livelihood shocks, *via* extent of economic structure and progress in human development. The level of socio-economic resilience was found to be the highest in WCG and TGP. On an average, literacy rate was above 60 percent in all the zones, with relatively higher proportion of literates found in WCG, LGP, MGP and UGP exhibit higher population density. The prevalence of poverty was more

[5] GOI. (1989). *Agro-climatic regional planning: an overview*. Planning Commission, Government of India, New Delhi.

[6] UNDP. (1990). *Human Development Report 1990*. Oxford University Press, New York.

in EPH, MGP, UGP and CPH. Further, zones such as CPH, GPH and WDR registered a lower share of primary sector in their overall GDP. Large fraction of land was owned by small and marginal farmers in ECH, WCG, WHR and Gangetic Plains except TGP. In most of the ACZs, about half of the workforce consists of agricultural workers. The regional assessment also indicates that the disbursement of farm credit was more towards WCG and ECH primarily comprising southern states of Kerala, Andhra Pradesh and Tamil Nadu followed by TGP. On the other hand, EHR covering all north-eastern states and some parts of West Bengal had the lowest access to agriculture credit.

Institutional & infrastructural index

Institutions and physical infrastructure define entitlements and accessibility to financial and technical resources that structures resilience of a system. Among the zones, WCG, GPH, SPH and TGP were grouped under high level of resilience under the index. In the Himalayan regions, most parts of Gangetic region and WCG, a very low proportion of farmers availed crop insurance. It was found that technical advices were more accessible in SPH and TGP, while it was least in WDR, CPH and MGP. Among the zones, TGP had the largest access to markets for farm produce. In most of the ACZs, more than 90 percent of the villages were electrified, although improvement in electrification is required in MGP, EPH and CPH. Connectivity to roads was inadequate in zones such as WDR, EHR, and LGP. The penetration of banks in villages was relatively better in WCG while it was insufficient in EPH and EHR.

Figure 1. Inter-ACZ distribution based on CRA index

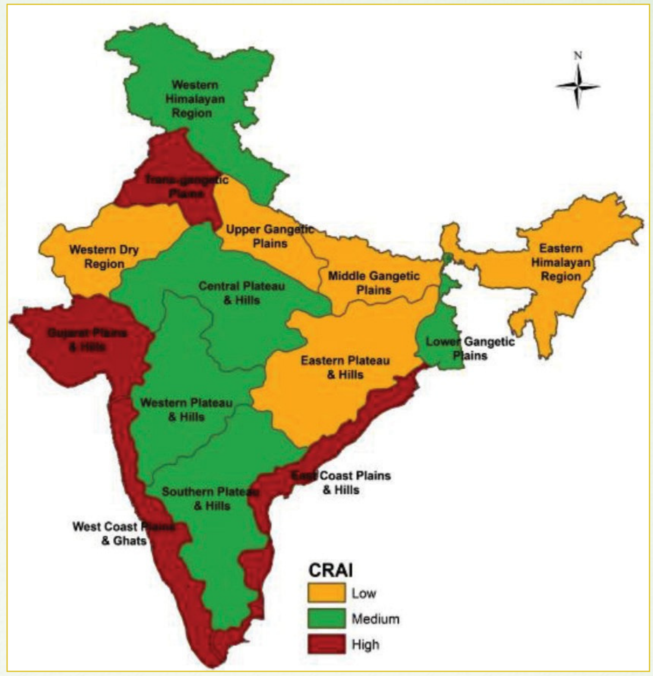
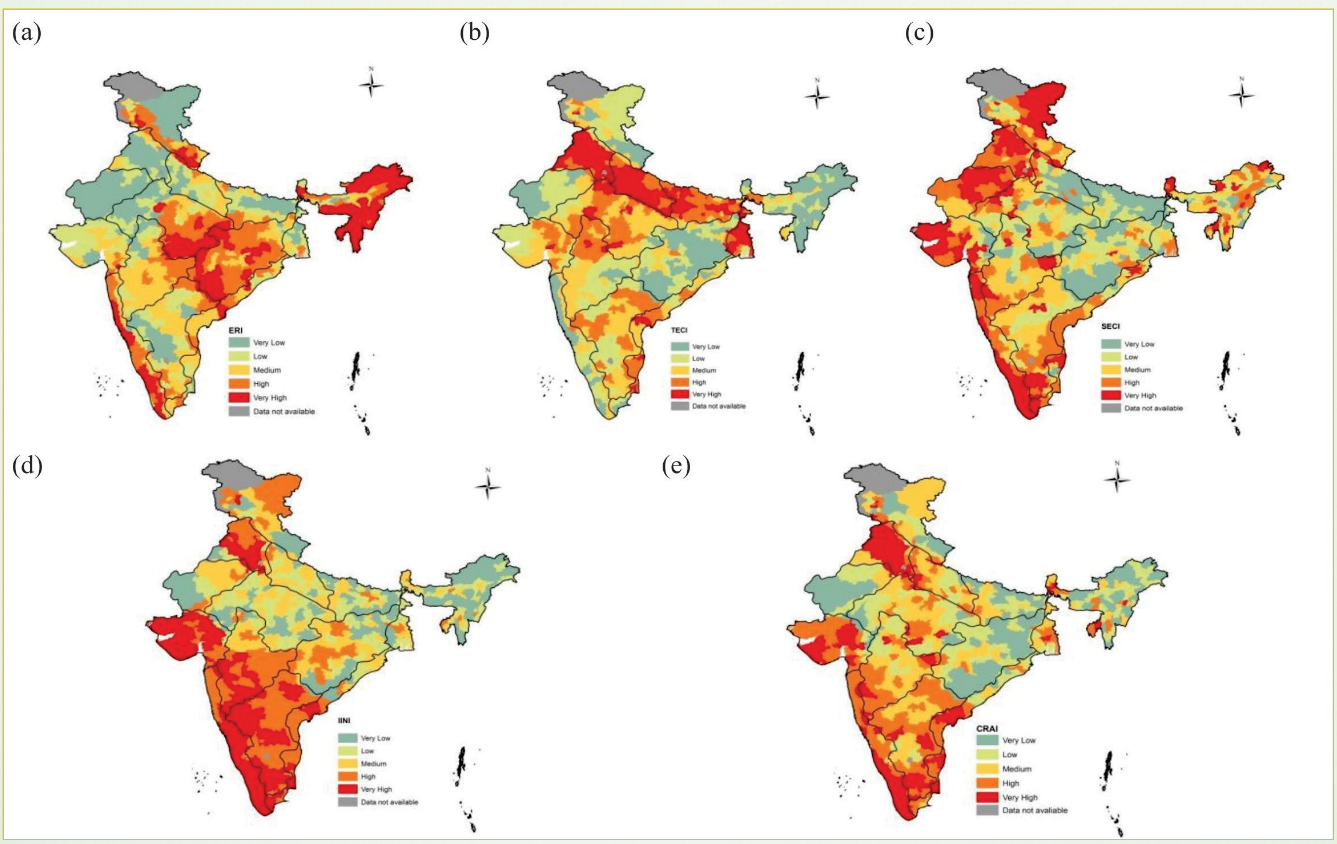


Figure 2. Maps (not to be scaled) showing intra-ACZ (district level) resilience (ACZ demarcation is shown with black boundary line) (a) Environmental Index, (b) Technological Index, (c) Socio-economic Index, (d) Institutional & Infrastructural Index, (e) CRA Index



Climate resilient agriculture index

Based on the relative performance of ACZs across different dimensions of resilience, the composite index was prepared (Figure 1). In the order of their ranking, high climate resilience was found in WCG, TGP, GPH and ECH. On the other hand, MGP (Bihar and parts of Uttar Pradesh) and EPH (primarily comprising Chhattisgarh, Jharkhand and Odisha) were rated the lowest in terms of CRA index. In addition, others zone namely WDR, EHR and UGP were also categorized under lower degree of resilience to climate risks

Intra-ACZ: district level resilience

The geographical distribution of resilience is shown in Figure 2. Most of the districts falling within the Gangetic Plains region and WDR had *very* low level of environmental resilience. Out of 89 districts lying in the EHR, about 67 percent had *very* high environmental resilience. Among the districts with *very* low to low level of technological resilience about 54 percent were concentrated in the EHR and EPH. Districts lying in the SPH had medium level of socio-economic resilience. In addition, in WCG, *Raigarh, Sindhudurg, Thane, Dakshina Kannada, Kodagu, Udupi, Theni, Kanniyakumari,* and all districts within Goa and Kerala had *very* high level of socio-economic resilience. It can be seen that the districts in southern India particularly districts of Kerala state and those falling within GPH and TGP showed better institutional and infrastructural foundation.

Overall, in case of CRA index a total of 247 districts were placed at the bottom of the resilience pyramid. As shown in Table 3, among the 247 districts, 124 had *very* low level of resilience with 33 districts falling under north-eastern states forming part of EHR, 40 districts from EPH with maximum concentration from the state of Jharkhand, Odisha and Chhattisgarh and 24 districts from MGP largely from the state of Bihar. On the other hand, most of the districts in TGP and WCG showed *very* high resilience to manage climate risks.

Conclusion

Overall, it was observed that southern states majorly forming parts of WCG, ECH and SPH, had a greater strength to respond to the climate related risks. On the other hand, MGP and EPH recorded the least resilience to manage climatic stresses. Even within the ACZs, wide variations were observed among the districts. The analysis indicates that special policy attention must be given to north-eastern region, western dry region and eastern parts of the country.

With the escalating climatic risks, 'equal and increased urgency' to adaptation planning and resilience building

Table 3: Distribution of districts based on CRA index

ACZ	Very Low	Low	Medium	High	Very High
CPH	6	20	19	8	3
ECH	5	6	4	10	14
EHR	33	28	11	12	5
EPH	40	18	7	3	-
GPH	-	1	1	12	13
LGP	-	3	6	4	1
MGP	24	16	18	3	-
SPH	-	3	11	24	11
TGP	-	1	2	-	41
UGP	1	6	15	14	5
WCG	-	-	1	7	21
WDR	5	4	3	-	-
WHR	9	9	10	14	5
WPH	1	8	15	12	4

Note: List of districts showing very low and very high climate resilience in different ACZs is available in Singh *et al.* (2021).

is raised at both national and international deliberations. Thus, there is need to develop suitable location-need-context specific interventions and policy that builds resilience of agricultural system. In regions experiencing unsustainable groundwater extraction, including WDR and TGP, it is imperative to formulate a comprehensive water-resources management policy. Reducing emissions from agriculture demands coordinated research into feasible mitigation measures and the adoption of robust management practices across agricultural operations. Under a changing climate, ensuring equitable access to irrigation and promoting location-specific cropping patterns are essential for improving returns, enhancing water-use efficiency, and maximizing value creation. Moreover, to sustainably improve productivity, the adoption of micro-irrigation systems such as drip and sprinkler technologies must be expanded alongside targeted capacity-building at the farm level. In particular, diversifying to agro-forestry in ecologically fragile regions, increasing thrust on crop diversification and strengthening animal-based/ crop-livestock system promotes farm resilience. Further, strengthening credit support to the zones with limited access to finance especially the eastern region could expand both the *ex-ante* and *ex-post* climate response space. Moreover, developing action plans that emphasize awareness, natural-resource conservation, diversification, physical infrastructure development, stronger grassroots institutions, and the integration of climate adaptation into development policy is crucial for establishing climate-resilient pathways.

ICAR – NATIONAL INSTITUTE OF AGRICULTURAL ECONOMICS AND POLICY RESEARCH
(Indian Council of Agricultural Research)
P.B. No. 11305, Dev Prakash Shastri Marg, Pusa, New Delhi-110 012, INDIA
Phone : 91-11-25847628, 25848731, Fax : 91-11-25842684 E-mail : director-niap@icar.org.in
https://www.niap.res.in