Measuring Adaptive Capacity of Indian Agriculture to Climate Change: An Application of Indicator Approach

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Abstract

The present study is an attempt to examine the adaptive capacity of mainstream agro-climatic regions in India to climate change. The study uses unit-level data from the 77th round of NSSO and district-level data from the Population Census 2011, and Agricultural Census 2015-16. This study first normalized the differential data using an indicator approach, and then calculated an adaptive capacity index for different mainstream agro-climatic regions of India, excluding the Island region. A total of 31 indicators, covering three dimensions - environmental, social, and economic, to capture the regional extent and dimensions of climate change adaptations in Indian agriculture were used to construct an adaptive capacity index. The result shows Eastern Himalayan Region (EHR) had the highest environmental resource capacity (i.e., 0.702 index value), making it the best agro-climatic region to deal with changing climate. On the other hand, the East Coast Plains and Hills Region (ECPHR) had the lowest adaptive capacity (i.e., 0.438 index value), due to its relatively low environmental resource capacity. This indicates that environmental factors are essential to maintain higher resource capacity in dealing with climate change. Despite having higher economic and social resource capacities, the Western Dry Region (WDR) and the Trans-Gangetic Plain Region (TGPR) have lower environmental resource capacities. However, these agro-climatic regions rank 7 and 4, respectively, in the adaptive capacity index. The results provide the grass-roots status of Indian farmers' adaptive capacity across regional dimensions. The study emphasized the need for more research into the prospects for successful involvement in local and regional risk assessment and the improvement of adaptive capability.

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1. Introduction

The main cause of the observed increase in temperature during the mid-20th century is attributed to the influence of human activities on climate change. During the period from 1880 to 2012, the global average surface temperature increased by 0.80°C (Intergovernmental Panel on Climate Change, 2013b). According to the IPCC (2013b), several locations worldwide have already seen significant warming at a regional level. Approximately 20-40% of the global population has experienced a temperature increase of above 1.50°C. The current increase in temperature has already caused significant changes to both human and ecological systems, such as an increase in droughts, floods, and other forms of severe weather. It led to rising sea levels and a loss of biodiversity. The alterations are giving rise to unparalleled hazards for susceptible groups, such as farmers (Mysiak et al., 2016). Most vulnerable individuals residing in low- and middle-income nations, such as India, depend on agriculture and face periodic food insecurity, which is partially associated with increasing migration and poverty (IPCC, 2012b). Globally, a multitude of ecosystems face the threat of significant consequences (IPCC, 2014a). The expansion of the global economy has led to longer life expectancy and higher income levels in many parts of the world. However, despite these positive developments, there are still regions that suffer from widespread poverty and extreme inequality in terms of income distribution and access to resources. These conditions further exacerbate the vulnerability of these regions to the impacts of climate change, in addition to the existing problems of environmental degradation and pollution (Dryzek, 2016).

About 22% of India's GDP comes from agriculture, making it a major economic sector. Because it employs 58% of the population, it also has a significant impact on employment. Furthermore, agriculture fulfils the nation's food and nutritional requirements, supplies raw materials for industries, and contributes to about 14% of total exports (Swain, 2014).

According to the predicted climatic changes, India is predicted to suffer from significant agricultural losses, ranking among the highest in the world (Guntukula 2020). According to Aggarwal (2008), even after taking into account the impact of carbon fertilisation, India is still projected to see a crop output decline of 10 to 40% by 2100 owing to rising temperatures and unpredictable rainfall patterns. Hence, given the swiftly shifting climatic conditions and the diminishing water supplies, it is imperative for farmers to implement suitable adaptation strategies in order to mitigate the negative consequences (Jatav, 2020). Nevertheless, the implementation of adaptation strategies incurs economic expenses and limits farmers' ability to adapt enough (Jatav, 2023). Indeed, this is particularly true in the Indian context, where a significant majority (i.e., 80%) of Indian farmers are smallholders and typically possess little financial resources (Jatav and Sanatan, 2022; Jatav, 2024).

Adaptation to climate change will be highly crucial in the 1.5° C warmer world as major consequences would be seen in every area (IPCC, 2014a). Climate adaptation choices include several types of responses, including structural, physical, institutional, and social measures. The efficacy of these alternatives primarily relies on factors such as governance, political determination, adaptable capabilities, and financial resources (Sovacool et al., 2015). According to the simulation findings, if warming is limited to 1.50° C, there will be a decrease in the number of individuals who are affected by hunger, water stress, and sickness (Clements, 2009). The findings also suggest that implementing measures to adapt to climate change might reduce the vulnerability of impoverished populations to the risks of flooding and drought, particularly in African and Asian nations (Winsemius et al., 2018). As far as regional advantages to climate change adaptations are concerned, obstacles for impoverished communities pertaining to food and water security, clean energy availability, and environmental well-being are expected to be fewer at 1.5° C as opposed to 2° C (Byers et al., 2016).

Moreover, previous studies have either measured the adaptation ability of farmers in a village or made comparisons between two districts or regions (Gupta and Bandyopadhyay, 2014; Datta and Bhagirath, 2022; Dasgupta et al., 2022). Furthermore, field survey-based studies primarily focus on identifying the determinants of adaptive capacity, which may limit the generalizability of results to countries such as India, given their diverse socioeconomic and geographical characteristics. This research gap is bridged by this study. The main aim of this study is to measure the adaptive capacity of Indian farmers to changing climates.

2. Materials and Methods

2.1 Study Area and Data Sources

The present study covers 14 mainstream agro-climatic zones, excluding the Island zone. As far as spatial characteristics are concerns, the Himalayan region is distributed into two agro-climatic regions, viz., Western Himalayan Region and Eastern Himalayan Region, and covers about 18.44% of geographical area. Gangetic Plain Region has distributed into four agro-climatic zones, viz., Lower Gangetic Plain, Middle Gangetic Plain, Upper Gangetic Plain & Trans Gangetic Plain, and covers about 15.89% of geographical area. Plateau and Hills region has distributed into four agro-climatic regions, viz., Eastern Plateau & Hills, Central Plateau & Hills, Western Plateau & Hills and Southern Plateau & Hills, and covers 44.19% of geographical area. Coastal Plains and Hill region has distributed into two regions, viz., East Coast Plains & Hills and West Coast Plains & Ghats, and covers 9.69% of geographical area. While Gujarat Plains & Hills and Western Dry regions jointly cover about 11.53% of geographical area (Singh et al., 2020).

As far as climatic conditions of all agro-climatic zones are concerns, it varies from cold arid to humid in the Himalayan region, and humid to dry in Gangetic Plains. Plateau regions remain semi-arid to dry, while coastal regions having semi-arid to dry sub-humid climate conditions. Gujarat plains climatic conditions vary from arid to dry sub-humid, while Western Dry region climate varies from arid to extremely arid (Jatav and Kalu, 2023).

The present study has used NSSO's 77th round (2019-20), agriculture census (2015-16), Census (2011) Indian Meteorological department, Government of India, and Ministry of Agriculture and Farmers Welfare, Government of India data to develop adaptive capacity index for different agro-climatic regions of India.

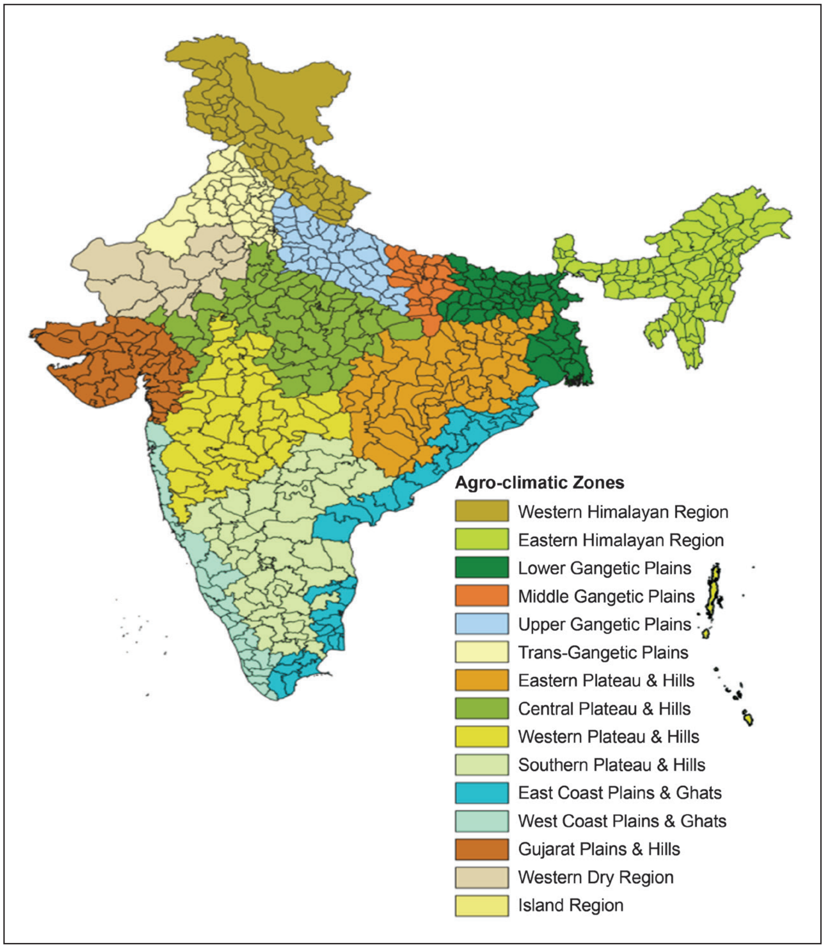

Figure 1: Mainstream Agro-climatic Regions of India

Source: Author's preparation, 2024. Note: Map has been drawn using GIS, not to be scaled.

2.2 Rationalisation of Adaptive Capacity Indicators

Researchers are now making a concerted effort to understand why some individuals are more adept at adjusting to shifting climate circumstances. This topic has been explored by several scholars, including Hassan and Nhemachena (2008), Pelling et al. (2008), Deressa et al. (2008, 2009), Paavola (2008), Asian Development Bank

(2014), and Newton et al. (2016). The discrepancy in the availability of resources is extensively recorded. When confronted with change, some people and organisations possess the ability to promptly and comprehensively innovate and adjust in order to minimise damage and capitalise on potential advantages. Variations in adaptive capacity may account for the disparity between the theoretically achievable amount of adaptation and the actual level of adaptation (Fussel and Klein, 2006). Gaining insight into these distinctions is anticipated to be valuable for both theoretical and practical application in the realm of adaptation research.

Adaptive capacity refers to a human system's ability to adjust to climate change, including fluctuations and extreme occurrences, to mitigate potential damage, capitalize on opportunities, and manage the ensuing consequences. (Adger et al., 2003). The adaptive capacity of a system depends on the availability of financial resources, human resources, and adaptation alternatives. This capacity varies depending on the specific risks and sectors involved. For example, an area that is well equipped to manage floods may consider a heat wave to be unforeseen (Fussel and Klein, 2006). Considering the information provided, this part examines the process of choosing reasonable and practically feasible indicators for adaptive ability. The indicators are categorised into three major groups, namely environment resources capacity, social resources capacity, and economic resources capacity (Fig. 2).

2.2.1 Environmental Resources Capacity Indicators

Scholars working on environmental issues, including climate change, generally agree that recent decades have seen a drastic change in climate parameters. We are witnessing a sudden shift in climate patterns, leading to sudden floods, droughts, and cyclonic activity worldwide, with the intensity of these events being comparatively higher in Asian and African countries than in European ones. This further intensifies the degree of vulnerability and lowers adaptive capacity against climate change.

Further, available climate change literature indicates that anthropogenic causes are key drivers of rapid temperature increases (i.e., 0.85°C mean surface temperature has increased in the past 100 years). The IPCC (2014a) predicts a further increase of at least 1.50°C by the end of the 21st century. Many regions and systems anticipate greater risks from global warming at 1.50°C compared to today, necessitating adaptation both now and up to 1.50°C. Given that India is a climate-vulnerable and resource-scarce country in terms of ecological diversity and forest cover, it is imperative to examine the environmental capacity of the Indian farming system in general, and of its farmers in particular. Therefore, a thorough review of the literature led to the selection of ten indicators. Table 1 provides a detailed explanation for each indicator.

2.2.2 Social Resources Capacity Indicators

Social resources play a crucial role in helping societies cope with climate change, especially in India, where there are multiple livelihood vulnerabilities and complicated hierarchies (Singh, 2019a & b). Social vulnerability to a changing climate is also restricting farmers from coping with it. So, this study used six indicators to show how well Indian farmers' social resources were adapting to the changing climate. These were the literacy rate, the average age of farmers, the number of female-headed households, the number of joint families, the number of progressive farmers, and the number of farmers who left the country. All these indicators are assumed to be positively associated with the social resources capacity except female-headed households. The Indian society is male-dominant, and in the majority of cases, decisions in the family solely have to be made by the male counterpart. Hence, it is assumed the female-headed households have lower adaptive capacity compared with male-headed households. This assumption is also validated by Singh (2020a). He reported that in the majority, males owned property rights and had access to information and power to make decisions, while females, in the majority, were restricted to playing the role of housewife. Though females support in numerous ways, their role is limited within the family. Table 1 provides a detailed explanation for each indicator.

2.2.3 Economic Resources Capacity Indicators

The accessibility of economic resources helps in dealing with a changing climate. The economic resources index includes 15 indicators: average land size, area under marginal farms, transportation, livestock, membership in agricultural credit societies, crop insurance, remittance, institutional credit, tractors, agricultural training, working population, farmers working in MGNREGA, crop diversification, income from farm produce, and awareness of the minimum support price. For instance, there is clear evidence that average land size has declined from 1970-71 to 2015-16 (GoI, 2017).

This resulted in a sharp increase in marginal land holdings. The number of marginal farmers increased from 36,200 in 1970-71 to 100,251 in 2021-22 (GoI, 2017). Further, in 2021–22, it was observed that only 11.84% of farmers belonging to the scheduled caste and 8.65% of farmers belonging to the scheduled tribe owned land, while the rest of the 79.33% of land was owned by other social groups. This also highlights the susceptibility of Indian farmers to changing climate (Singh and Sanatan, 2018). In other words, we expect the adaptive capacity to cope with changing climate to decrease as the number of marginal farmer increases. Among the 15 considered indicators, this indicator is considered a negative impact on economic resources capacity, while the rest of the indicators are considered to have a positive relationship with the economic resources capacity indicators. For instance, better transportation connectivity helps in the mobility of farm produce, while ownership of livestock ensures regular income even in the off-cropping season. Further, access to credit from institutional sources at marginal interest rates also helps in dealing with rural distress, which leads to suicides. Access to credit motivates farmers to diversify their cropping patterns. All these efforts have started a series of actions and created a safety net against climate change. Table 1 provides a detailed explanation for each indicator.

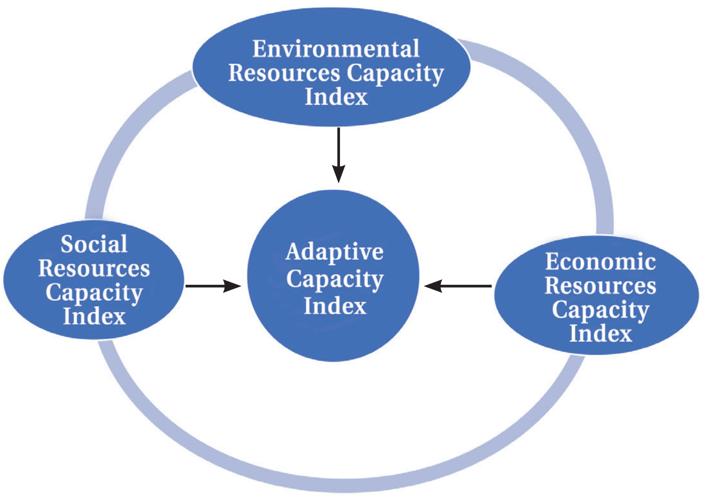

Figure 2: Conceptual framework for assessing the adaptive capacity to Climate Change

Source: Authors Conceptualization, 2024.

Table 1: Selected Rational Adaptive Capacity Indicators

Sub-components	Indicators	Description	Data Source	Literature Source
Environmental Resources Capacity Indicators (ECI)	Irrigation Intensity (%) (+)	Irrigation improves agricultural resilience and influences farmers' adaptive ability.	MoAFW, 2019	Birthal and Ali, 2005
	Forest Area (%) (+)	The expanse of forested land significantly contributes to improving farmers' adaptive ability.	MoAFW, 2019	World Bank, 2005
	Farmers' perception on natural calamities (%) (+)	The understanding of agricultural loss caused by natural catastrophes is positively associated with farmers' ability to adjust to climate change.	NSSO, 2019	Hahn et al., 2009
	Cropping Intensity (%) (+)	Higher cropping intensity significantly improves adaptive ability.	MoAFW, 2019	Birthal and Ali, 2005
	Rainfall variability (CV) (-)	Variability in rainfall adversely impacts adaptive capability.	IMD, 2019	Jatav and Kalu, 2023
	Minimum temperature variability (CV) (-)	The fluctuation of minimum temperatures negatively impacts adaptive capability.	IMD, 2019	Jatav and Kalu, 2023
	Agricultural chemical use intensity (kg/hm^2) (-)	The widespread use of agrochemicals negatively impacts the ecosystem and reduces farmers' adaptive potential.	MoAFW, 2019	Jatav and Kalu, 2023
	Agricultural land use intensity (+)	Land expansion negatively impacts ecological stability and reduces adaptive capacity.	MoAFW, 2019	Jatav and Kalu, 2023
	Ground Water Depletion (%) (-)	The depletion of groundwater impacts the hydrological cycle and therefore the adaptive ability of farmers.	CGWB, 2019	Jatav and Kalu, 2023
	Maximum temperature variability (CV) (-)	Extreme temperature fluctuations negatively impact farmers' adaptation capabilities.	IMD, 2019	Jatav and Kalu, 2023

Sub-components	Indicators	Description	Data Source	Literature Source
Social Resources Capacity Indicators (SCI)	Literacy Rate (%) (+)	The literacy rate is positively correlated with the adaptive ability of farmers.	Census, 2011	Deressa et al., 2009
	Average Age (Years) (+)	Younger farmers are anticipated to possess a greater ability to adapt to climate change.	Census, 2011	Hassan and Nhemachena, 2008
	Female-headed Households (%) (-)	Female-headed families are anticipated to possess a diminished adaptation potential in comparison to male-headed households.	NSSO, 2019	Deressa et al., 2008
	Joint family (%) (+)	Farmers living in joint families have increased resilience in coping with adversity and substantially boost adaptive ability.	NSSO, 2019	Deressa et al., 2009
	Progressive Farmers (%) (+)	Collaboration among farmers is anticipated to enhance adaptive capability.	NSSO, 2019	Deressa et al., 2008
	Out-migration (%) (+)	Out-migration is often used by farmers as a last mitigation option to cope with changes. When one or two family members relocate periodically for job, they not only remit funds to their relatives but also provide a consistent household income.	NSSO, 2019	Deressa et al., 2009
Economic Resources Capacity Indicators	Land Size (Hac.) (+)	Larger land size enhances adaptive ability to address climate change.	Agricultural Census, 2015-16	Chand et al., 2011
	Marginal Farmers Area (%) (-)	It is anticipated that marginal farmers possess less adaptation potential to climate change.	Agricultural Census, 2015-16	Chand et al., 2011
	Transportation (%) (+)	Road mobility substantially influences agricultural productivity and has a favourable correlation with adaptive capability.	Census, 2011	Sklenicka et al., 2014
	Livestock (%) (+)	Integrated crop-livestock systems improve nutrient cycling, maximize biomass consumption, and facilitate soil carbon buildup.	NSSO, 2019	World Bank, 2005
	Agri. Credit Societies (%) (+)	Affiliation with agricultural credit organizations enhances farmers' access to financial resources.	Census, 2011	Birthal and Ali, 2005

Sub-components	Indicators	Description	Data Source	Literature Source
	Crop Insurance (%) (+)	Crop insurance serves as a proactive strategy for mitigating the impacts of climate change. Consequently, increased insurance coverage enhances farmers' adaptation ability to climate change.	NSSO, 2019	Newton et al, 2016
	Remittance (%) (+)	Migrant workers provide remittances to their family, who then invest in agriculture, so improving adaptive capacity.	NSSO, 2019	Newton et al, 2016
	Institutional credit (%) (+)	Institutional agricultural loan is relatively more affordable and includes crop insurance coverage.	NSSO, 2019	Newton et al, 2016
	Tractors (%) (+)	Enhanced access to machinery, including tractors, improves the adaptive capacity of farmers.	NSSO, 2019	Huang and Wang, 2014
	Agri. Training (%) (+)	Agricultural training is essential for the efficient and sustainable use of agricultural resources.	NSSO, 2019	Newton et al, 2016
	Working population (%) (+)	Farmers between the ages of 15 and 45 who adopt compact modern technology demonstrate a higher likelihood of utilizing agricultural resources in an efficient and sustainable manner.	NSSO, 2019	Ellis, 2000
	MGNREGA (%) (+)	MGNREGA is essential for providing employment assurance to unskilled rural populations.	NSSO, 2019	Hassan and Nhemachena, 2008
	Crop diversification (+)	A higher SDI results in a lower level of economic risk.	NSSO, 2019	Paavola, 2008
	NSSO, 2019	A higher SDI results in a lower level of economic risk.	NSSO, 2019	Ziervogel et al., 2008 and Adger et al., 2003
	Farm income (%) (+)	A greater proportion of farm income signifies enhanced livelihood security for farmers, which in turn fosters increased adaptive capacity to climate change.	NSSO, 2019	Adger et al., 2003
	MSP (%) (+)	Understanding the minimum support price sets a suitable price for agricultural products and motivates farmers to grow market-oriented crops, thus improving their adaptive capacity.	NSSO, 2019	Hahn et al., 2009

Source: Author's Calculation, 2024. Note: (-) sign indicates negative relationship of indicator with targeted index, while (+) sign indicates positive relationship.

2.4 Estimation Method

Two ontological approaches exist for measuring adaptive capacity (IPCC, 2007; Smit and Wandel, 2006; Below et al., 2012). These represent inductive (data-driven) and deductive (theory-driven) approaches. The inductive approach utilized in this study emphasizes the identification of determinants, indicators, and a composite capacity index score derived from expert opinion or correlation with previous climate change-induced disasters. The approach employs proxy variables as a benchmark for assessing adaptive capacity.

This study employs the indicator method to evaluate the adaptive capacity of mainstream agro-climatic regions in India. The selected indicators effectively represent the focal development policy objective, employing a systematic approach to address climate change impacts, development linkages, and the economic, social, and environmental dimensions associated with the adaptive capacity of Indian agriculture (Halsnas and Trarup, 2009). The indicator approach for quantifying adaptive capacity utilized selected key indicators from a comprehensive set to systematically integrate these indicators, thereby reflecting the levels of adaptive capacity. Key indicators were chosen based on literature that outlines the extent and dimensions of adaptive capacity in various agro-ecological environments.

The indicators were standardized to employ a uniform scale reflecting their functional correlation with adaptive capacity; equation (1) was applied for a positive correlation, while equation (2) was utilized for a negative correlation with adaptive capacity (Pandey and Jha, 2012; Jatav and Kalu, 2023):

$$Index_{sv} = \frac{S_v - S_{min}}{S_{max} - S_{min}} \dots\dots\dots\dots\dots\dots\dots\dots (1)$$

$$Index_{sv} = \frac{S_{max} - S_v}{S_{max} - S_{min}} \dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Where, S_v is the actual value of the indicator at agro-climatic region level, and S_{min} and S_{max} are the minimum and maximum values of the indicator agro-climatic region (Hahn et al., 2009; Jatav, 2024). In this way, the indicators were normalized on a scale of 0 to 1.

2.5 Assigning Weight

The assignment of appropriate weights to various components is crucial in index construction; therefore, this study utilized the statistical weight method proposed by Iyengar and Sudarshan (1982).

$$W_i = \frac{1}{\sum_{i=1}^{n} \frac{1}{\sqrt{var(Index_{sv})}} * \sqrt{Var(Index_{sv})}} \ldots\ldots\ldots\ldots\ldots (3)$$

Where, *Wi* is the weight of ith indicator; and *Var*(*Index*$_{sv}$) is variance of standardized value of ith indicator in the jth agro-climatic region. The calculated weights were used to construct the component index P_i for the jth agro-climatic region using equation (4).

$$P_i = \frac{\sum_{i=1}^{n} Index_{sv} * W_i}{\sum_{i=1}^{n} W_i} \left(0 < W_i < 1, \sum_{i=1}^{n} W_i = 1\right) \ldots\ldots\ldots (4)$$

The adaptive capacity index for each agro-climatic region is determined by calculating the average of the size components, which include the environmental resources capacity index, social resources capacity index, and economic resources capacity index. The agro-climatic regions were ranked in descending order according to the index score derived from this study. A higher index score in an agro-climatic region indicates an increased adaptive capacity.

3. Results

3.1 Socioeconomic Status of Indian Farmers

The socioeconomic characteristics indicate that families are composed of young individuals who possess a high level of education and live in nuclear family arrangements (Table 2). Most farmers own marginal and tiny plots of land, often less than 2 hectares in size. Regarding technical proficiency, a mere 1.12% of farmers have received formal agricultural training. In contrast, around 18.98% and 16.53% of farmers have sought guidance from other farmers and self-help organisations (SHGs), respectively. MGNREGA served as the only source of hope during the off-cropping season, with around 45.07% of farmers engaging in MGNREGA to guarantee their livelihood stability. As a result of connections in the institutional credit system, around 60% of farmers have obtained loan from institutions, whereas farmers have a 52% rate of indebtedness. The situation extends beyond loans and include a lack of information about the Minimum Support Price (MSP). Furthermore, a mere 19.72% of farmers possess knowledge about the Minimum Support Price (MSP). Consequently, due to limited access to advanced technology and market trends, approximately 12.87% of farmers have not diversified their cropping pattern as an adaptation strategy to mitigate the negative effects of climate change and cope with market disruptions. There was just one encouraging aspect: farmers had a reasonable level of awareness about natural disasters. Approximately 63.89% of farmers acknowledged that natural disasters were the primary cause of crop losses.

Table 2: Socioeconomic Characteristics of Indian Farmers

Indicators	India
Average Family Size (Nos.)	5.27
Literacy Rate (%)	74.04
Average Age (Years)	29.89
Farmers taken Professional Training (%)	1.12
Seasonal Migration for Employment (%)	1.47
Average Annual Farm Income (Rs.)	52, 272
Average Land Size (Hac.)	1.15
Indebtedness Rate (%)	52.00
Farmers have taken Credit from Institutional Source (%)	60.00
Irrigation Intensity (%)	123.10
Cropping Intensity (%)	142.13
Area not available for Cultivation (%)	16.11
Farmers are Member of SHG (%)	16.53
Farmers having Livestock (%)	74.34
Farmers working under MGNREGA (%)	45.07

Indicators	India
Female-headed household (%)	12.97
Farmers aware of Minimum Support Price (%)	19.72
Farmers sharing Knowledge to Fellow Farmers (%)	18.98
Farmers receiving Remittances (%)	10.17
Farmers living in Joint Family (%)	40.45
Farmers growing more than one Crop in a Season (%)	12.87
Farmers perceived that Natural Calamities was main reason for Crop Loss (%)	63.89

Source: Estimated from NSSO, 77th round unit level data, 2019, Census, 2011, MoAFW, 2019.

3.2 Environmental Resources Capacity Index (ERCI)

Tackling climate change as a unified effort is a major current obstacle to maintaining the long-term viability of socio-ecological systems. Few et al. (2007) emphasised that the main obstacle is in establishing a significant connection between comprehending worldwide processes, local susceptibilities, and the ability to react. Communities that have more access to resources are likely to have a higher ability to respond sustainably to the actual or predicted effects of climate change. Access to both material and intangible resources not only enables practical actions, such as sustaining one's livelihood, but also fosters the development of purposeful lives and disrupts established social systems (Smit and Wandel, 2006).

Among the 14 agro-climatic regions of India, the Eastern Himalayan Region (EHR) demonstrates greater ecological sustainability, while the South Plateau & Hills Region (SPHR) exhibits significantly lower environmental sustainability (Table 2). The cross-indicator analysis identifies that the primary factors contributing to lower environmental sustainability in the SPHR, as opposed to the EHR, include reduced forest coverage, decreased livestock ownership, and lower cropping intensity. The EHR constitutes 24.13% of the total forest area, while the SPHR represents only 16.60%. Additionally, approximately 86.63% of farmers in EHR owned livestock, whereas the figure for SPHR is only 70.00%. Irrigation intensity measured 125.25% in EHR, compared to 116.73% in SPHR. Farmers in the SPHR employ a greater quantity of chemical fertilizers compared to those in the EHR.

3.3 Social Resources Capacity Index (SRCI)

The connection between community change agents and the individuals they want to influence implies the existence of extensive networks that may facilitate social learning in response to the intricate problems presented by climate change. Pelling et al. (2008) argue that the impact of informal networks on adaptive capacity is determined by the quality, quantity, and goals of individuals who are linked within communities of practice, as well as the persons who bridge the boundaries between these communities and the objects they interact with.

This study has selected nine indicators to create a social resources capacity index for various agro-climatic regions of India. Among the agro-climatic regions, the Trans Gangetic Plain region (TGPR) has the highest social resource capacity (i.e., 0.529), while the East Coast Plains and Hills region (ECPHR) has the lowest social resource capacity to deal with changing climates (Table 3). The cross-indicator analysis shows that the population in the TGPR is relatively younger and literate compared with the ECPHR. In other words, about 76.29% of farmers in TGPR are literate, while only 68.73% of farmers in ECPHR are literate. This study assumes that households headed by women are less able to adapt, and the fact that only 8.77% of households in TGPR were headed by women was confirmed by the results. In ECPHR, that number rose to 18.15 %. On the contrary, joint family structure is assumed to be positively associated with the adaptive capacity. It is reported that about 42.24% of farmers lived in a joint family system in the TGPR, while only 21.98% of farmers lived in ECPHR.

3.4 Economic Resources Capacity Index (ERCI)

This study selected 15 indicators to create an economic resource capacity index for various agro-climatic regions of India. According to the data mentioned in Table 4, the western dry region, which includes parts of Rajasthan and Punjab, has the highest economic resource capacity, while the eastern Himalayan region, which includes north-eastern states such as Mizoram, Assam, Manipur, Tripura, Nagaland, and so on, has the lowest economic resource capacity among the agro-climatic regions.

The cross-indicator analysis shows that WDR has higher economic security than EHR because it has fewer marginal farmers, better access to all seasonal roads, more livestock ownership, higher membership in agriculture credit societies, larger insured cropped areas, higher remittances, better access to institutional credit, a higher working population, a diversified cropping pattern, and more awareness of the minimum support price. These are some of the main factors that make WDR more economically secure compared to EHR.

In other words, the mean land size in WDR was 0.51 hectare, while it was only 0.41 hectare in EHR. Further, only 29.62% of marginal farmers were reported in WDR, while 66.33% of marginal farmers were reported in EHR. Likewise, about 17.35% of farmers have taken credit from agricultural credit societies at a marginal interest rate in WDR, while only 10.30% of farmers have taken credit in EHR. Similarly, 89.28% of farmers owned livestock in WDR, while only 86.88% of farmers owned livestock in EHR. Furthermore, 84.64% of farmers have diversified their employment portfolio and worked in MGNEGA in WDR, while only 44.60% of farmers worked in MGNREGA in EHR. These statistics in totality revealed that farmers in the western dry region are relatively more economically secure than those in the eastern Himalayan region.

3.5 Adaptive Capacity Index (ACI)

The emphasis of a rapidly expanding field of study is the significance of adaptive ability in long-term adaptation to climate change. According to Adger (2003), adaptive capacity is triggered by a mix of factors including a shift in perceived risk or effect, attitudes, regulations, or market circumstances, together with a supporting institutional framework for networking. Household-scale evaluations of adaptive capacity, which prioritise vulnerability reduction, have their origins in the domains of hazard management, global environmental change, and sustainable lifestyles. Their goal is to acquire information that may improve the ability to minimise exposure and respond effectively to dangers.

The Eastern Himalayan Region (EHR) ranked top among agro-climatic regions due to its higher environmental resource capacity (environmental resource capacity index value, i.e., 0.702), while ECPHR's relatively limited environmental resource capacity resulted in a lower adaptive capacity (i.e., 0.438). This indicates that environmental factors are very important to maintain higher resource capacity in dealing with climate change (Table 5). Despite having higher economic and social resource capacities, the western dry region (WDR) and the trans-Gangetic plain region (TGPR) have lower environmental resource capacities. However, these agro-climatic regions rank 7 and 4 respectively in the adaptive capacity index.

Table 2: Rank of the 14 agro-climatic regions in environmental dimension of Adaptive Capacity to Changing Climate

Indicators	Agro- Climatic Regions													
	EHR	WHR	EPHR	CPHR	LGPR	WDR	ECPHR	WCPGR	GPHR	UGPR	MGPR	TGPR	WPHR	SPHR
Area under forests	0.923	0.739	1.000	0.516	0.405	0.289	0.785	0.625	0.411	0.041	0.081	0.000	0.582	0.468
Agricultural land use intensity	0.814	0.943	1.000	0.522	0.295	0.456	0.800	0.729	0.464	0.113	0.351	0.000	0.381	0.623
Agricultural chemical use intensity	1.000	0.899	0.795	0.604	0.031	0.853	0.546	0.865	0.364	0.254	0.652	0.119	0.000	0.246
Groundwater depletion	0.813	0.710	0.517	0.134	1.000	0.024	0.536	0.303	0.000	0.088	0.199	0.163	0.218	0.269
Rainfall variability	0.521	1.000	0.492	0.649	0.229	0.640	0.000	0.077	0.513	0.614	0.663	0.763	0.387	0.030
Minimum temperature variability	1.000	0.962	0.259	0.467	0.345	0.650	0.037	0.182	0.000	0.654	0.497	0.745	0.056	0.044
Maximum temperature variability	0.213	0.437	0.059	0.596	0.002	0.879	0.524	0.097	1.000	0.597	0.356	0.764	0.512	0.624
Cropping intensity	0.404	0.194	0.198	0.473	1.000	0.305	0.160	0.150	0.000	0.684	0.531	0.967	0.338	0.074
Farmers' perception on natural calamities	0.632	0.399	0.703	0.894	0.815	0.000	0.552	0.728	1.000	0.684	0.391	0.146	0.697	0.644

Indicators	Agro- Climatic Regions													
	EHR	WHR	EPHR	CPHR	LGPR	WDR	ECPHR	WCPGR	GPHR	UGPR	MGPR	TGPR	WPHR	SPHR
Rank	1	2	3	4	5	6	7	8	9	10	11	12	13	14

Source: Author's estimation, 2024. **Note:** WHR, Western Himalayan Region; EHR, Eastern Himalayan Region; CPHR, Central Plateau and Hills Region; WDR, Western Dry Region; EPHR, Eastern Plateau and Hills Region; ; TGPR, Trans-Gangetic Plain Region; LGPR, Lower Gangetic Plain Region; UGPR, Upper Gangetic Plains Region; GPHR, Gujarat Plains and Hills Region; MGPR, Middle Gangetic Plains Region; ECPHR, East Coast Plains and Hills Region; WCPHR, West Coast Plains and Ghats Region; WPHR, Western Plateau and Hills Region; SPHR, Southern Plateau and Hills Region

Table 3: Rank of the 14 agro-climatic regions in social dimension of Adaptive Capacity to Changing Climate

Indicators/ ACZ	TGPR	MGPR	GPHR	CPHR	LGPR	WPHR	EHR	WCPGR	UGPR	WDR	EPHR	SPHR	WHR	ECPHR
Literacy Rate	0.713	0.623	0.730	0.641	0.722	0.716	0.721	0.821	0.660	0.596	0.658	0.672	0.711	0.687
Average Age	0.910	0.499	0.250	0.500	0.556	0.503	0.513	0.479	0.275	0.426	0.295	0.413	0.307	0.414
Female-headed house-holds	0.912	0.909	0.895	0.910	0.866	0.883	0.876	0.789	0.876	0.871	0.868	0.820	0.861	0.181
Joint Family	0.464	0.550	0.415	0.465	0.318	0.337	0.430	0.252	0.543	0.449	0.353	0.275	0.400	0.220
Pro-gressive Farmers	0.171	0.217	0.474	0.204	0.260	0.220	0.083	0.181	0.130	0.089	0.281	0.247	0.105	0.261
Out-migration	0.003	0.014	0.019	0.033	0.023	0.027	0.019	0.012	0.009	0.035	0.008	0.008	0.010	0.011
Social Resources Capacity Index	0.529	0.468	0.464	0.459	0.458	0.447	0.440	0.422	0.415	0.411	0.411	0.406	0.399	0.296
Rank	1	2	3	4	5	6	7	8	9	10	11	12	13	14

Source: Author's estimation, 2024.

Table 4: Rank of the 14 agro-climatic regions in Economic dimension of Adaptive Capacity to Changing Climate

Indicators/ ACZ	WDR	GPHR	WPHR	CPHR	SPHR	TGPR	MGPR	ECPHR	WCPGR	EPHR	WHR	LGPR	UGPR	EHR
Land size	0.507	0.499	0.561	0.523	0.628	0.473	0.559	0.449	0.424	0.327	0.380	0.642	0.004	0.515
marginal farmers Area	0.704	0.674	0.579	0.599	0.461	0.324	0.843	0.343	0.257	0.506	0.337	0.205	0.260	0.553
Transpor-tation	0.490	0.943	0.671	0.386	0.855	0.882	0.374	0.650	0.911	0.437	0.567	0.356	0.406	0.362
Livestock	0.893	0.822	0.732	0.876	0.710	0.936	0.790	0.639	0.586	0.608	0.865	0.725	0.819	0.574
Agri. Cred-it Societies	0.174	0.356	0.379	0.115	0.210	0.284	0.159	0.152	0.409	0.103	0.103	0.103	0.070	0.029
Crop In-surance	0.226	0.166	0.078	0.147	0.060	0.004	0.013	0.090	0.050	0.096	0.008	0.051	0.044	0.004
Remit-tances	0.105	0.028	0.061	0.081	0.086	0.084	0.090	0.263	0.180	0.067	0.140	0.152	0.196	0.020
Institu-tional Credit	0.470	0.606	0.614	0.543	0.666	0.559	0.435	0.536	0.653	0.405	0.494	0.306	0.584	0.357
Tractors	0.039	0.026	0.017	0.034	0.008	0.041	0.022	0.004	0.008	0.014	0.014	0.002	0.020	0.002
Agri. Training	0.002	0.007	0.012	0.007	0.035	0.011	0.009	0.016	0.021	0.011	0.009	0.015	0.003	0.008
Working Population	0.442	0.370	0.354	0.434	0.295	0.334	0.456	0.322	0.280	0.355	0.339	0.310	0.435	0.368
MGNREGA	0.846	0.221	0.452	0.635	0.455	0.058	0.162	0.618	0.307	0.677	0.446	0.589	0.261	0.674
Crop diversifica-tion	0.149	0.101	0.287	0.177	0.195	0.100	0.192	0.145	0.144	0.045	0.146	0.003	0.200	0.031
Farm Income	0.287	0.243	0.264	0.321	0.169	0.372	0.383	0.187	0.129	0.325	0.298	0.244	0.326	0.310
MSP	0.102	0.167	0.110	0.135	0.156	0.387	0.294	0.152	0.150	0.382	0.130	0.265	0.251	0.051

Indicators/ ACZ	WDR	GPHR	WPHR	CPHR	SPHR	TGPR	MGPR	ECPHR	WCPGR	EPHR	WHR	LGPR	UGPR	EHR
Economic Resources Capacity Index	0.362	0.349	0.345	0.334	0.333	0.323	0.319	0.304	0.301	0.290	0.285	0.264	0.259	0.257
Rank	1	2	3	4	5	6	7	8	9	10	11	12	13	14

Source: Author's estimation, 2024.

Table 5: Rank of the 14 agro-climatic regions in Adaptive Capacity Index

ACZ	Environment Resource Capacity Index	Social Resources Capacity Index	Economic Resources Capacity Index	Adaptive Capacity Index	Rank
EHR	0.702	0.440	0.257	0.467	1
WHR	0.698	0.399	0.285	0.461	2
CPHR	0.539	0.459	0.334	0.444	3
TGPR	0.407	0.529	0.323	0.420	4
EPHR	0.558	0.411	0.290	0.420	5
GPHR	0.417	0.464	0.349	0.410	6
WDR	0.455	0.411	0.362	0.409	7
MGPR	0.413	0.468	0.319	0.400	8
LGPR	0.458	0.458	0.264	0.393	9
WPHR	0.352	0.447	0.345	0.381	10
WCPGR	0.417	0.422	0.301	0.380	11
UGPR	0.414	0.415	0.259	0.363	12

ACZ	Environment Resource Capacity Index	Social Resources Capacity Index	Economic Resources Capacity Index	Adaptive Capacity Index	Rank
SPHR	0.336	0.406	0.333	0.358	13
ECPHR	0.438	0.296	0.304	0.346	14

Source: Author/s estimation, 2024

4. Discussion

Policies regarding climate change adaptation need meticulous formulation due to their intricate context among impoverished and susceptible cultures exposed to a diverse array of hazards. They should be an essential component of a development process that ensures the incorporation of climate adaptation into all relevant sectors of society, while also considering other significant factors such as social, economic, and environmental concerns. Mertz et al. (2009) proposed that national-level strategies should include targeted investments in physical and institutional assets. These investments should aim to decrease susceptibility to climate change and enhance the capacity to adapt while avoiding any unintended negative consequences. The present study results also align with the Mertz et al. (2009). This study also observed that investment in environmental protection resources may offset the negative impact of climate change and enhance the adaptive capacity of Indian farmers living in diverse agro-climatic conditions. Further, Aggarwal (2008) projected that a rise in temperature would lead to more frequent hot extremes, floods, droughts, cyclones, and gradual glacier recession, which in turn would result in greater instability in food production and adaptive capacity for Indian farmers. These results also align with the present study. Due to higher variability in rainfall and temperature, it resulted in lower environmental resource capacity (Table 2) and increased the degree of vulnerability. Furthermore, Hassan and Nhemachena's (2008) study highlights the critical role of improved market access, extension and credit services, technology, and farm assets such as labour, land, and capital in assisting farmers in adapting to climate change. These findings also coincide with the results of the current study. This study also reported that access to extension services like consultation with agricultural experts, insurance, credit, and awareness of remunerative prices are key drivers responsible for adapting to a changing climate. Datta and Bhagirath's (2022) study highlights variations in natural, physical, and financial capital primarily account for the varying adaptive capacities among farming households. These results also align with our study on a broader spectrum. Our findings confirmed that lower social and economic resource capacity leads to lower adaptive capacity to deal with a changing climate.

5. Conclusion and Policy Recommendations

This research first inquired about the mechanisms of adaptation and the entities involved in the agricultural sector that undergo adaptation to address the challenges posed by climate change. This research utilises data collected at the household level and employs an indicator-based method to assess the adaptation potential of Indian farmers in the primary agro-climatic regions, with the exception of the island zone. The empirical findings emphasise that the scarcity of forest land in the Upper Gangetic Plains is constraining the farmers' ability. In the Eastern Himalayan region and the Eastern Plateau & Hills region, inexperienced farmers who lack training are depending on non-institutional sources and neglecting to protect their crops from natural disasters. Additionally, the Eastern Coast Plains & Hills region has the highest number of households headed by females, which further increases the vulnerability of the agriculture sector in this area. The limited availability of non-farm work, namely under the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), and the lack of crop diversification have reduced the capabilities of farmers in the Trans Gangetic Plains area. Similarly, farmers in the Western Dry region have faced restrictions in accessing climatic information. The overall analysis of the relative adaptation capacity index scores indicates that the Eastern Himalayan Region (EHR) exhibits the strongest adaptable ability, whilst the East Coast Plains and Hills Region (ECPHR) has the lowest adaptive capacity in addressing climate change.

This paper emphasised the need for more investigation into the possibilities for successful involvement in local and regional methods of vulnerability assessment and the improvement of adaptive capacity. This study's empirical findings indicate that female-headed households should be prioritized in both ongoing and new intervention projects concerning climate change and agriculture. Providing financial resources enables engagement in supplementary income-generating activities. This will contribute to diversifying their livelihood sources and improving their resilience to the impacts of climate change and variability. Possible adaptation options for the most vulnerable region include diversifying agricultural systems by cultivating crops that require less water, adopting advanced farming technology such as using different crop varieties, harvesters, and irrigation pumps, constructing dams and roads, and improving the plantation mangrove forest programme in the coastal area.

This study encompasses over 95% of India's geographical area. There are a few limitations of this study that may motivate researchers to do future research. First, tracking temperature and rainfall trends in different agro-climatic zones helps in robust climate policy for regional climate-resilient planning. Second, this study only gives a spatial picture of the adaptive capacity of farmers, while spatial-temporal analysis is better to track the progress of climate policies initiated by the Indian government and farmers. Third, this study's results only rely on secondary data, while success case studies give signals about how suggested policy enhances the adaptive capacity of farmers. Lastly, determinants of adaptive capacity are also important to effect climate adaptation policy; this study ignores this aspect. By using grassroots data, future researchers may identify the determinant.

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