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Climate Change and Agricultural Productivity in Rajasthan: Challenges and Sustainability Pathways

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Climate Change, Agricultural Productivity, Rajasthan Agriculture, Crop Yield Variability, Climate Resilience, Sustainable Agriculture.

ABSTRACT

Climate change ranks among the biggest challenges related to agriculture systems. Agricultural lands in arid and semi-arid regions are more susceptible to the changing climate patterns. Rajasthan is one such state where agriculture mostly depends on the vagaries of the monsoon. Climate change has taken a toll on Rajasthan's agricultural sector with high temperatures, unpredictable rainfall patterns, recurring droughts and depletion of groundwater levels affecting the productivity, cropping pattern and farmers income directly. Studies revealed that with every 1.2° rise in temperature there has been considerable loss in productivity of major crops like wheat and millets affecting the food security of the region. Some studies indicate the possibility of decline being compensated with the availability of adaptive technologies rendering loss estimates inconclusive. Other negative impacts reviewed include shifts in cropping pattern, reduced certainty in production and increasing vulnerability of small holder farmers. Studies also warn against oversimplification of declaring climate change as the reason behind changes in cropping patterns as market demand, policy incentives etc. also affect decisions farmers make. Suggestions to cope with climatic shocks include cultivation of climate resilient crops, micro irrigation, etc. Many of these are sustainable agricultural practices but lack popularity due to the high cost and lack of institutional support. The study reveals an immediate need to address climate change effects through proper policy intervention and technological innovations along with adaptation measures taken by farmers themselves. Literature also presents a mixed review with some stating technological advances can help make agriculture more resilient to climate change and some stating that policies and climate change adaptation strategies must be designed based on the ground realities of farmers, their resources and the socio-economic conditions. To achieve inclusive growth in the agricultural sector of Rajasthan, there is a strong need to build climate resilience as well as resolve these contradictions.. ......

1. INTRODUCTION

Climate change refers to long-term shifts in temperature, precipitation, and broader climatic variability, largely driven by anthropogenic activities such as greenhouse gas emissions, deforestation, and industrialization (Intergovernmental Panel on Climate Change [IPCC], 2022). Its implications for agriculture are profound, given that agricultural systems are highly dependent on climatic stability. In India, where agriculture remains the primary source of livelihood for millions, climate change has emerged as a major threat (NITI Aayog, 2019). Rajasthan, with its arid and semi-arid climate, scanty water resources, extreme temperature fluctuations, and reliance on monsoon rainfall, is particularly susceptible to these changes (Central Ground Water Board [CGWB], 2022).

Agriculture in Rajasthan is central to the state's economy, employing nearly 44 percent of the population and underpinning socio-economic stability (Government of Rajasthan, 2023). However, the sector is predominantly rain-fed, with limited irrigation

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coverage, which heightens vulnerability to climatic variability such as droughts, heat waves, and erratic rainfall (India Meteorological Department [IMD], 2024). Rising temperatures constitute one of the most pressing challenges. Elevated heat accelerates crop maturation, shortens grain-filling periods, and reduces yields. Heat stress also depletes soil moisture and intensifies evapotranspiration, exacerbating water scarcity (Kumar & Singh, 2020). In Rajasthan, where baseline temperatures are already high, further increases magnify water stress and undermine agricultural productivity.

Rainfall variability is another critical factor. Climate change has distorted the spatial and temporal distribution of monsoon rains, leading to delayed onset, uneven distribution, and premature withdrawal. Such variability disrupts cropping seasons and reduces production stability. Studies indicate that Kharif crops in Rajasthan are highly sensitive to rainfall fluctuations, with production instability exceeding 20 percent, underscoring the region's vulnerability (Mukherji, Shah, & Verma, 2021). Drought frequency and intensity have also increased, reducing soil moisture and groundwater recharge, thereby causing crop failures, livestock losses, and financial distress among farmers (World Bank, 2017).

Groundwater depletion compounds these challenges. Excessive extraction, coupled with declining rainfall, has led to significant reductions in groundwater levels. Surveys reveal that over 80 percent of farmers perceive climate change as a driver of reduced groundwater availability and irrigation difficulties (Sayre & Taraz, 2019; Sidhu, Kandlikar, &Ramankutty, 2020). Cropping patterns have also shifted, with farmers moving away from traditional crops such as bajra (pearl millet) toward commercially viable alternatives like soybean and maize. While diversification may enhance income, it also exposes farmers to market volatility and climate sensitivity (Gupta, 2023).

Soil health is equally affected. Altered temperature and rainfall regimes influence soil moisture, nutrient availability, and microbial activity, leading to declining fertility and sustainability. Climate stress, combined with soil degradation, creates a vicious cycle that further diminishes productivity (Pearce & Turner, 1990). Socio-economic impacts are evident as well: small and marginal farmers, with limited access to resources and technology, face reduced incomes, heightened food insecurity, and increased vulnerability. In severe cases, agricultural distress has triggered migration and socio-economic instability (Tal, 2013).

To address these challenges, climate-smart agriculture has been promoted as a solution. Practices such as conservation agriculture, efficient irrigation, crop diversification, and adoption of drought-resistant varieties aim to enhance resilience while reducing emissions (NICRA, 2023). Government initiatives, including the National Innovations in Climate Resilient Agriculture (NICRA), seek to strengthen adaptive capacity by improving resource management, crop production, and farmer training (Government of India, 2023).

In sum, climate change poses a serious threat to agricultural production and productivity in Rajasthan. Addressing these challenges requires an interdisciplinary strategy that integrates policy responses, technological innovations, and social participation. The present study critically reviews the literature, provides comparative analysis, and discusses the multifaceted effects of climate change on agriculture in Rajasthan.

The growing body of literature from 2020–2025 provides compelling evidence that climate change is not only altering global climatic systems but also radically transforming agricultural production and productivity, particularly in fragile regions such as Rajasthan. Agricultural activities are inherently climate-related, and global warming directly affects temperature regimes, rainfall distribution, and the frequency of extreme weather events. The IPCC (2021) highlights that anthropogenic climate change has intensified extreme climatic events like heatwaves, prolonged droughts, and unpredictable rainfall patterns which directly undermine cropping systems and agricultural sustainability. Semi-arid regions like Rajasthan face disproportionate risks due to their ecological vulnerability and reliance on monsoon rainfall.

Among the most influential contributions, Ortiz-Bobea et al. (2021) quantify the long-term effects of climate change on agricultural productivity, concluding that global productivity has declined by about 21% due to climate stressors. This decline is most pronounced in warmer regions where crops already operate near their thermal thresholds. Rajasthan, with its high baseline temperatures, is particularly prone to additional warming, which exacerbates heat stress and accelerates yield losses. Zhao et al. (2017) further demonstrate that each 1°C rise in global temperature sharply reduces yields of staple crops, underscoring the vulnerability of Rajasthan's agriculture where even slight temperature changes disrupt phenological processes such as flowering and grain filling.

Water scarcity emerges as another critical dimension. Jain et al. (2021) show that over-extraction of groundwater, combined with declining recharge rates due to erratic rainfall, has created unsustainable irrigation patterns. In Rajasthan, where irrigation infrastructure is limited, groundwater serves as a vital buffer against climatic uncertainty. Yet, its depletion has eroded irrigation efficiency, leaving crops increasingly exposed to climate shocks. Reddy et al. (2022) corroborate this by linking groundwater depletion directly to declining productivity in water-intensive crops.

Soil degradation compounds these vulnerabilities. Pandey et al. (2022) argue that rising temperatures and altered precipitation regimes degrade soil properties, reducing moisture retention, nutrient availability, and microbial activity. In Rajasthan, where soils are already erosion-prone, this feedback loop accelerates land degradation and undermines long-term sustainability.

The socio-economic consequences are equally profound. Rao et al. (2023) show that climate variability increases production costs through higher input requirements while simultaneously reducing yields, thereby eroding farm profitability. Singh and Patel (2023) highlight that such pressures heighten indebtedness, income variability, and even migration, underscoring that climate change is not merely an environmental challenge but a socio-economic crisis.

Adaptive responses are emerging but remain uneven. Gupta et al. (2023) note that farmers are shifting toward drought-resistant crops such as millets, pulses, and oilseeds. While this enhances resilience, it also exposes farmers to market volatility and price fluctuations, revealing the need for supportive institutional frameworks. Jat et al. (2022) and Meena & Singh (2024) emphasize that climate-smart practices-conservation tillage, crop diversification, integrated nutrient management, and sustainable irrigation-can significantly improve resilience. However, adoption is constrained by financial barriers, limited awareness, and weak extension services.

At the policy level, the FAO (2023) stresses that technological innovation, institutional support, and farmer participation must converge in localized strategies tailored to agro-climatic realities. Bhardwaj et al. (2024) extend this argument by showing that climate stress also undermines livestock productivity, reinforcing the need for holistic adaptation across crop-livestock systems. Finally, Joshi and Meena (2025) highlight governance gaps, noting that while government programs promote climate-resilient agriculture, their impact is diluted by poor coordination, inadequate funding, and weak institutional capacity.

2. RESULTS & DISCUSSION:

The comparative analysis of climate change literature published between 2020 and 2025 demonstrates that its effects on agricultural production and productivity are multidimensional, but the extent and nature of these impacts vary across geographical, ecological, and socio-economic contexts. Global studies provide a broad picture of productivity decline, while regional analyses offer more nuanced insights into local vulnerabilities and adaptation challenges. Table 1 provides the detailed comparative analysis regarding the climate change impact with findings and limitations. For instance, Ortiz-Bobea et al. (2021) estimate that global agricultural productivity has declined by about 21% due to rising temperatures and climatic variability. Similarly, Lobell et al. (2011) and Zhao et al. (2017) establish a direct correlation between temperature increases and yield reductions, emphasizing that even minor thermal shifts can severely affect crop performance. Yet, these international studies often generalize outcomes and fail to capture the specific dynamics of regions such as Rajasthan, where climate, soil, and socio-economic conditions interact in complex ways.

Table 1: Comparative Analysis of Climate Change Impact

Author & Year	Study Area	Key Focus	Findings	Limitation
Singh et al. (2020)	India	Climate impact on agriculture	Yield reduction due to temp rise	Limited regional focus
Ortiz-Bobea et al. (2020)	Global	Productivity trends	Productivity decline by 21%	Generalized results
Birthal et al. (2021)	India	Climate variability	Wheat & rice yield decline	Data constraints
Kumar et al. (2021)	Semi-arid regions	Drought impact	Crop cycles reduction	Limited crop types
IPCC (2021)	Global	Climate extremes	Increased drought &	Broad analysis

			heatwaves	
Sharma et al. (2022)	Rajasthan	Farmer perception	Declining yields & rainfall change	Subjective data
Reddy et al. (2022)	India	Groundwater depletion	Reduced irrigation efficiency	Regional variability
Jat et al. (2022)	Rajasthan	Climate-smart agriculture	Improved productivity	Adoption barriers
Sahu et al. (2022)	India	Rainfall variability	Highproduction instability	Limited long-term data
Pandey et al. (2022)	India	Sustainability	Soil & water degradation	Policy gap
Lobell et al. (2023)	Global	Crop productivity	Declining yields in tropics	Generalization
Gupta et al. (2023)	Rajasthan	Cropping pattern	Shift to drought crops	Market risk
FAO (2023)	Global	Food security	Need for adaptation strategies	Policy challenges
Khan et al. (2023)	Arid regions	Climate variability	Reduced yield stability	Data limitations
Rao et al. (2023)	India	Economic impact	Increased costs	Limited farmer-level data
Choudharyet al. (2024)	Rajasthan	Rainfall trends	Increased variability	Localized study
Verma et al. (2024)	India	Heat stress	Reduced photosynthesis	Crop-specific
Meena & Singh (2024)	Rajasthan	Adaptation	Improved resilience	Adoption issues
Bhardwaj et al. (2024)	Rajasthan	Livestock impact	Productivity decline	Limited scope
Yadav et al. (2024)	Rajasthan	Farmer awareness	Low adoption of technology	Awareness gap
Singh et al. (2025)	Rajasthan	Productivity trends	Declining yield stability	Future uncertainty
Joshi & Meena (2025)	Rajasthan	Policy analysis	Need for implementation	Policy gaps

Source: Authors created table using existing literature

Region-specific research highlights these contextual differences. Gupta et al. (2023) and Choudhary et al. (2024) show that rainfall variability has intensified, leading to significant instability in crop production. Unlike global models that focus primarily on temperature effects, these studies underscore the critical role of monsoon variability in semi-arid regions. In Rajasthan, where agriculture is predominantly rain-fed, rainfall fluctuations are as consequential as temperature increases, illustrating the need for context-specific analysis.

Water scarcity emerges as a recurring theme across both global and regional literature, but the drivers and consequences differ. Jain et al. (2021) attribute groundwater depletion to over-extraction driven by irrigation demand, while Pandey et al. (2022) highlight declining rainfall and soil degradation as contributing factors. Reddy et al. (2022) link reduced irrigation efficiency and crop productivity directly to groundwater depletion. Comparative evidence suggests that water scarcity is not an isolated problem but the outcome of interactions between climatic stressors, agricultural practices, and resource management policies. These dynamics are particularly acute in Rajasthan, where limited water resources and high dependence on groundwater intensify vulnerability.

Socio-economic impacts represent another dimension where global and local perspectives diverge. International organizations such as the IPCC (2021) and FAO (2023) emphasize broad implications for food security, but regional studies provide deeper insights into farmer livelihoods. Rao et al. (2023) demonstrate that climate variability raises production costs and reduces profitability, while Singh and Patel (2023) show that yield instability contributes to indebtedness, income variability, and migration. These findings reveal a critical gap in global literature, which often overlooks micro-level socio-economic consequences. Comparative analysis thus indicates that effective responses to climate change must extend beyond environmental and technological interventions to include socio-economic support mechanisms tailored to local realities.

Table 2 displays the cross-context analysis of climate change and agricultural vulnerability with reference to the Rajasthan state. An important aspect of adaptation strategies highlighted in the literature is the divergence of opinion regarding their effectiveness. Jat et al. (2022) and Meena and Singh (2024) provide strong evidence that climate-smart agricultural practices-such as conservation tillage, crop diversification, and efficient irrigation systems-can significantly enhance resilience and productivity under climate stress. These practices reduce the negative impacts of variability and promote sustainability. However, other scholars, including Yadav et al. (2024), argue that adoption remains limited due to barriers such as lack of awareness, financial constraints, and weak institutional support. This contrast underscores a critical point: technological solutions exist, but their potential is curtailed by socio-economic and institutional bottlenecks. Effective policies must therefore accompany technological interventions to ensure widespread adoption.

One area of consensus across studies is the shift in cropping patterns as an adaptive response to climate change. Gupta et al. (2023) observe that farmers in Rajasthan increasingly cultivate drought-resistant crops such as millets and pulses to mitigate vulnerability to water scarcity and climatic fluctuations. While this transition enhances resilience, the literature also notes trade-offs, including exposure to market risks, changes in dietary preferences, and the need for new agronomic practices. This implies that adaptation strategies must be evaluated not only for their environmental benefits but also for their economic and social consequences.

Table 2: Cross-Context Analysis of Climate Change and Agricultural Vulnerability

Factor	Key Findings from Literature	Impact Level	Evidence Source	Rajasthan Relevance
Temperature Rise	Reduces crop yield, affects grain filling	Very High	Ortiz-Bobea et al. (2021), Zhao et al. (2017)	Severe due to already high temperatures
Rainfall Variability	Erratic monsoon disrupts cropping cycles	High	Sahu et al. (2022), Choudhary et al. (2024)	Critical (rain-fed agriculture)
Water Scarcity	Groundwater depletion reduces irrigation	Very High	Jain et al. (2021), Reddy et al. (2022)	Extreme dependency on groundwater
Soil Degradation	Decline in fertility & moisture retention	Medium-High	Pandey et al. (2022)	Already fragile soils worsen
Socio-economic Impact	Increased costs, farmer distress	High	Rao et al. (2023), Singh & Patel (2023)	High vulnerability of small farmers
Cropping Pattern Shift	Shift to millets/pulses	Medium	Gupta et al. (2023)	Adaptive but risky

Adaptation Strategies	Improve resilience but low adoption	Medium-High	Jat et al. (2022), Meena & Singh (2024)	Limited awareness

Source: Authors created table using existing literature

Despite substantial progress, several gaps remain in the literature. A major limitation is the lack of integration between biophysical and socio-economic analyses. Many studies focus either on climatic and environmental factors or on socio-economic impacts, but few provide a comprehensive framework that links both dimensions. Moreover, long-term empirical research on climate–agriculture interactions is scarce. Much of the existing work relies on short-term data or modeling approaches, which may not fully capture the complexity of agricultural systems under prolonged climate stress.

Another critical gap concerns policy implementation and governance. While studies such as Joshi and Meena (2025) emphasize the importance of policy interventions, the effectiveness of these measures at the ground level remains under-examined. In Rajasthan, where institutional capacity and governance play a decisive role in adaptation success, this omission is particularly significant. Without robust implementation mechanisms, even well-designed policies risk failing to deliver meaningful resilience.

Table 3: Outcome Evaluation Matrix of Climate Change Effects

Study Type	Strength	Limitation	Key Contribution
Global Studies	Broad trends, strong models	Lack local detail	Show overall productivity decline
Regional (India)	Climate-specific insights	Limited micro-data	Link climate with yield
Rajasthan Studies	High contextual relevance	Small sample sizes	Highlight rainfall & drought issues
Socio-economic Studies	Farmer-level insights	Less climate modeling	Show livelihood impact
Adaptation Studies	Practical solutions	Adoption barriers	Show resilience pathways

Source: Authors created table using existing literature

The outcome evaluation matrix of climate change effects is presented in Table 3, whichshows that climate change impacts on agriculture are multidimensional, varied, and highly contextual. Global studies provide valuable insights into broad productivity declines, but regional analyses are indispensable for identifying local vulnerabilities and designing targeted interventions. What emerges is the necessity of integrated solutions that combine technological innovation, sustainable resource use, socio-economic support, and effective policy enforcement.For Rajasthan, this translates into region-specific strategies that address chronic water shortages, heightened climate variability, and the socio-economic fragility of farming communities, while simultaneously promoting sustainable agricultural practices. Without such coordinated efforts, the long-term sustainability of agriculture in Rajasthan remains critically at risk.

Climate change has become a critical determinant of agricultural production and productivity, particularly in arid and semi-arid regions such as Rajasthan. The literature shows that its effects are complex, extending beyond crop yields to soil quality, water availability, and the socio-economic stability of farmers (Chauhan & Kulshrestha, 2024). Among the most pronounced impacts is the rise in temperature, which directly influences crop growth and development. Extreme heat accelerates maturation, shortens grain-filling periods, and reduces yields. Physiological processes such as photosynthesis are also impaired under heat stress, further diminishing productivity (Sharma, 2026).

Rainfall variability is another major source of agricultural instability. Studies emphasize that unpredictable monsoon patterns, delayed precipitation, and uneven distribution of rainfall disrupt crop cycles and lower yields. In Rajasthan, where agriculture is predominantly rain-fed, such variability translates into heightened production risks and uncertainty (Tanwar & Koli, 2024; Mehta et al., 2025). Climate change has also increased the frequency and intensity of droughts, which reduce soil moisture and groundwater recharge, thereby worsening water scarcity (Yadav & Pal, 2023).

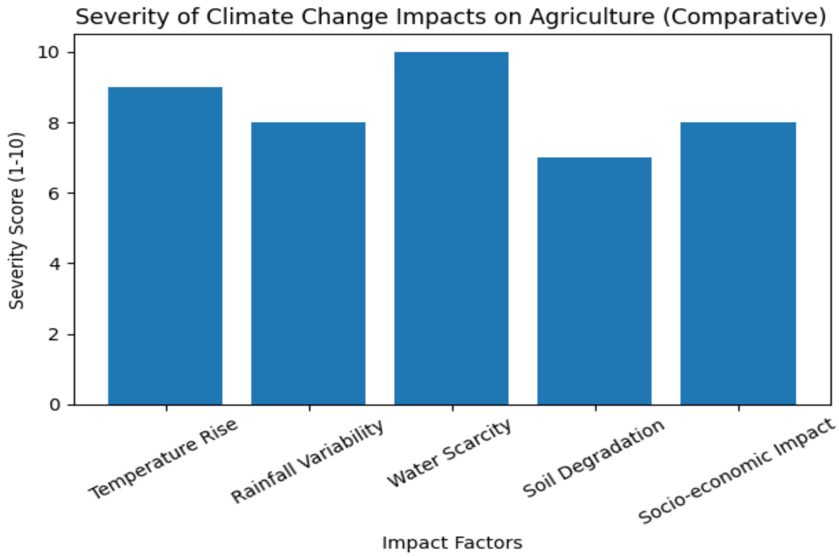

Fig.1. Severity of Climate Change Impact

Source: Authors created diagram using existing literature

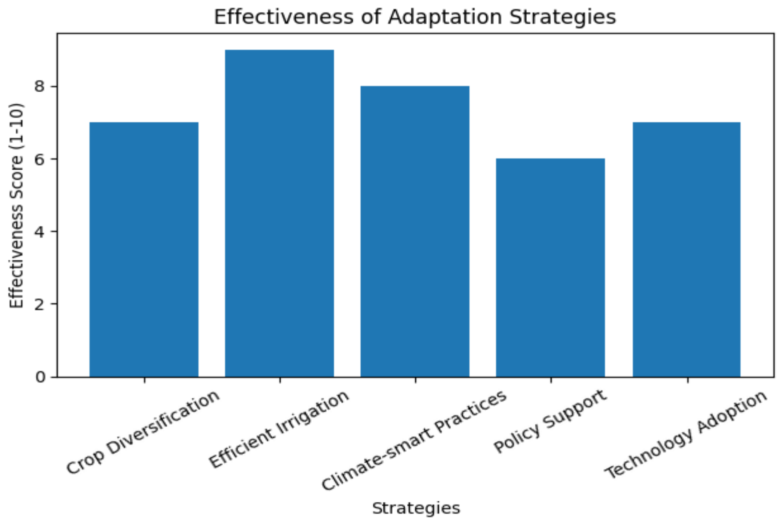

Fig. 2. Effectiveness of Adaptation Strategies

Source: Authors created diagram using existing literature

Water shortage has emerged as one of the most pressing challenges undermining agricultural sustainability. Intensive reliance on groundwater for irrigation, coupled with declining recharge rates, has led to severe depletion of this critical resource (Promila, 2022; Saran, 2023). The consequences are twofold: irrigation efficiency is reduced, and farmers are constrained in their ability to cultivate high-yield crop varieties. Rising temperatures and erratic rainfall further exacerbate these pressures by degrading soil quality, altering nutrient availability, and weakening soil structure (Chauhan & Kulshrestha, 2024).

The socio-economic consequences of climate change are equally significant. Small and marginal farmers, with limited access to resources, technology, and information, remain the most vulnerable group. Declining crop production combined with rising input costs erodes farm incomes and exposes households to economic shocks. In many cases, agricultural distress has triggered migration and shifts in livelihood patterns, intensifying social instability (Centre for Environment and Development Studies, 2024; UNICEF, 2024).

Despite these difficulties, the literature also points to promising adaptation strategies. Climate-smart agriculture-encompassing crop diversification, conservation practices, and efficient irrigation systems-has demonstrated potential to enhance resilience and productivity (Jakhar & Saini, 2023; Amulya et al., 2025). However, adoption remains limited due to barriers such as lack of awareness, financial constraints, and inadequate policy support. Addressing these barriers is therefore essential to translate technological solutions into widespread, sustainable practice. Ultimately, the solution to climate change impacts on agriculture must be multifaceted, involving technological innovation, policy intervention, and community participation. Enhancing resilience through sustainable agricultural practices, improved access to resources, and stronger institutional frameworks will be critical to ensuring long-term sustainability in Rajasthan.

3. CONCLUSION AND POLICY IMPLICATIONS:

Climate change has become one of the most pressing challenges facing global agriculture, with particularly severe consequences in fragile regions such as Rajasthan. The evidence reviewed here demonstrates that rising temperatures, unpredictable rainfall, recurrent droughts, and dwindling water resources have disrupted cropping patterns, reduced yields, and heightened production uncertainty. These climatic stresses threaten food security and undermine the livelihoods of farming communities.

Recent studies (2020–2025) reveal multiple pathways through which climate change undermines agricultural systems. Elevated temperatures accelerate crop maturation but reduce yields, rainfall variability disrupts planting and harvesting cycles, and water shortages-driven by declining rainfall and over-exploitation of groundwater-intensify vulnerability. Soil degradation and pest activity further compound these stresses, leading to long-term declines in productivity. The socio-economic consequences are equally critical: small and marginal farmers, who form the backbone of Rajasthan's agricultural population, are disproportionately affected due to their limited resources and adaptive capacity. Declining productivity translates into reduced incomes, indebtedness, and migration, contributing to social instability.

Despite these challenges, opportunities exist to mitigate climate impacts through adaptation. Climate-smart agriculture, encompassing crop diversification, drought-resistant varieties, efficient irrigation, and conservation practicesoffers pathways to enhance resilience and sustainability. Yet adoption remains constrained by financial barriers, lack of awareness, and weak institutional support. This underscores the need for policies that not only promote technological innovation but also address socio-economic and governance dimensions.

Enforce regulation of groundwater extraction and expand rainwater harvesting, watershed management, and micro-irrigation.

Provide subsidies and incentives for drought-resistant crops, conservation tillage, and integrated nutrient management.

Strengthen extension services to raise awareness and train farmers in climate-smart practices.

Establish targeted credit schemes, crop insurance, and safety nets to reduce indebtedness and migration pressures.

Support farmer cooperatives to improve market access and bargaining power.

Ensure effective implementation of national programs such as NICRA at the local level, with stronger monitoring and evaluation.

Encourage participatory governance involving farmers, researchers, and local communities.

Invest in long-term empirical studies, precision farming technologies, and digital advisory platforms.

Foster collaborations between universities, government, and the private sector to scale sustainable solutions.

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