**Adapting Rajasthan’s Agriculture to Climate Change with Solar Parks**

**Abstract**

Climate change poses a profound threat to agriculture worldwide, disrupting food systems, compromising livelihoods, and undermining long-term environmental sustainability. In India, where agriculture remains a primary source of income for a significant portion of the population, climate-induced stresses such as rising temperatures, erratic rainfall, prolonged droughts, and extreme weather events are increasingly affecting both crop yields and livestock productivity. This paper delves into the global and national implications of climate change on agriculture, with a focused regional analysis of Rajasthan one of India’s most climate-vulnerable and arid states. It critically analyses the socioeconomic consequences for marginal and smallholder farmers, who are disproportionately affected due to limited adaptive capacity. In response to these growing challenges, the paper evaluates the integration of renewable energy particularly solar energy into the agricultural ecosystem. By synthesizing climate data, field-level observations, and case studies, this paper presents a comprehensive set of adaptation and mitigation strategies tailored for arid and semi-arid agricultural regions.

Keywords: climate change, agriculture, Rajasthan, solar energy, adaptation

**1. Introduction**

Agriculture is intrinsically linked to climate and weather conditions, making it particularly vulnerable to climate change. Climate change involves long-term shifts in temperature, rainfall, and extreme weather events like droughts and floods. Rural communities in developing countries are particularly vulnerable due to their reliance on climate-sensitive livelihoods and limited capacity to adapt **(UNFCCC, 2009).** Rising global temperatures, altered precipitation patterns, and increased frequency of extreme weather events are disrupting agricultural productivity, threatening food security, and exacerbating rural poverty. In India, where over half the workforce is engaged in agriculture, the impact is pronounced. Rajasthan, one of the most climate-stressed states in India, provides a compelling case for studying these dynamics due to its unique agro-climatic conditions and water scarcity.

Various studies have highlighted diverse socio-economic and demographic factors influencing farmers’ knowledge, awareness, and adaptation strategies to climate change. **Adewale (2012)**, **Satishkumar *et al.* (2013)**, **Mohanraj and Karthikeyan (2014)**, **Neethi (2014)**, **Meghwal (2016)**, and **Muthulaxmi (2016)** found that most respondents fell in the middle-age bracket, while **Billah et al. (2015)** and **Meghwal (2016)** noted a significant proportion of young farmers in coastal and inland areas respectively. On the education front, **Ogunleye and Yekinni (2012)** reported that most respondents lacked formal education, which limited their knowledge of climate change, whereas **Mohanraj and Karthikeyan (2014)** and **Muthulaxmi (2016)** revealed a relatively educated farming population. Income levels varied widely, with studies by **Satishkumar *et al.* (2013)**, **Meghwal (2016)**, and **Neethi (2014)** reporting prevalence of low-income groups, while **Muthulaxmi (2016)** noted a larger proportion of middle- and high-income farmers. Landholding patterns showed dominance of marginal and small holdings as seen in the works of **Idrisa *et al.* (2012)**, **Shadap (2014)**, **Meghwal (2016)**, and **Muthulaxmi (2016)**, although **Kankate *et al*. (2018)** noted a higher number of medium landholders. In terms of farming experience, **Rao (2016)** emphasized its role in influencing adaptation practices. Occupationally, farmers were largely engaged in cultivation or mixed activities, as observed by **Kabir *et al*. (2016)** and **Kharjana *et al*. (2017)**.

Social participation was predominantly moderate across studies by **Lad and Deshmukh (2014)**, **Mohanraj and Karthikeyan (2014)**, and **Shadap (2014)**, with involvement in community groups aiding climate-related decisions (**Hariadi and Widhiningsih, 2015**). **Singh (2010)**, **Idrisa *et al*. (2012)**, and **Muthulaxmi (2016)** all noted that access to mass media played a critical role in climate awareness. Extension contact was found to be moderate by **Kankate *et al*. (2018)**, while **Jha and Gupta (2021)** pointed to weak institutional support as a limiting factor. **Ozor *et al*. (2012)** and **Yohanna *et al*. (2014)** emphasized the importance of both formal and informal networks for climate-related information.

On knowledge and awareness of climate change, studies such as **Idrisa *et al*. (2012)**, **Ogunleye and Yekinni (2012)**, **Shadap (2014)**, **Marshall *et al.* (2014)**, **Meghwal (2016)**, **Muthulaxmi (2016)**, and **Belay et al. (2022)** highlighted a range from low to high awareness, largely influenced by education and media access. Adaptation strategies were extensively documented by **OECD (2010)**, **Mudiwa (2011)**, **Agrawal *et al.* (2014)**, **Dhanya and Ramachandran (2016)**, **Tripathi and Mishra (2016)**, **Zizinga *et al*. (2017)**, **Alam *et al*. (2017)**, **Nanjappan and Parameswaranaik (2019)**, **Mihiretu *et al.* (2020)**, **Destaw and Fenta (2021)**, and **Belay *et al.* (2022)**. According to **Mohapatra *et al.* (2022),** key factors influencing adaptation include the household head's education level, farming experience, type of financial assistance received, agricultural training, landholding size, access to agricultural institutions, the distance between the home and farmland, and availability of storage facilities. According to the Livelihood Vulnerability Index, the majority of households fall into the moderately vulnerable category. These studies noted widespread practices like crop diversification, altering planting schedules, tree planting, soil and water conservation, and investment in irrigation, with adaptation largely shaped by education, landholding, access to extension services, income, and institutional support.

**2. Global Impacts of Climate Change on Agriculture**

Climate change has transformed agricultural systems worldwide. Key global effects include:

* **Temperature Rise:** Shortened growing seasons and heat stress on crops.
* **Precipitation Variability:** Irregular rainfall affects irrigation and crop planning.
* **Extreme Weather Events:** Floods, droughts, and storms cause sudden crop failures.
* **Pest and Disease Spread:** Warmer climates facilitate the spread of pests and invasive species.
* **Food Security Concerns:** Particularly in developing countries with resource-poor farmers.

These disruptions necessitate climate-resilient crops, sustainable practices, and international cooperation to address food system vulnerabilities.

**3. Climate Change in Agriculture**

India’s agriculture is highly monsoon-dependent and vulnerable to climate variations. Key impacts include:

**3.1 Crop Productivity**

**Acc. to Times of India, 2012**. A study indicated that for every degree Celsius rise in seasonal temperature, wheat yields in Rajasthan decrease by approximately 2.49 quintals per hectare, while mustard yields drop by about 0.92 quintals per hectare.

**Erratic Rainfall Effects**: In Udaipur district, farmers experienced crop failures due to sudden rains and pest infestations. For instance, in September, when harvesting was underway, unexpected rains destroyed the remaining crops, leading to significant financial losses. **(Jain, 2023) a**

**3.2 Water Resources**

* **Groundwater Depletion:** In Bundi district, 21.14% of farmers reported a substantial reduction in groundwater levels due to high temperatures and lack of timely rains. This depletion hampers irrigation efforts, further affecting crop productivity.
* Conversely, districts like Jaisalmer and Hanumangarh have seen an increase in irrigation intensity from 2006 to 2016. This trend indicates a growing reliance on irrigation to compensate for erratic rainfall, putting additional pressure on water resources. **(Rishi, 2021)**

**3.3 Livestock Sector**

* **Heat Stress:** Heat stress can lead to reduced feed intake, lower milk yields, and decreased fertility rates. In dairy animals, it can disrupt estrous cycles and lower semen quality in males, complicating breeding efforts**. (Mahale, 2024)**
* **Fodder Shortages:** Erratic rainfall patterns and prolonged dry spells are reducing the availability of water and pasturelands. For instance, in Laporiya village, average annual rainfall has decreased from over 500 mm to about 300 mm in recent years, affecting the growth of fodder crops and water availability for livestock. **(Jain, 2023)b**

**4. Methodology**

This study follows a systematic review approach to identify and evaluate literature on climate impacts on agriculture in Rajasthan and solar energy as a mitigation and adaptation strategy. Data collected from academic databases like google scholar, science direct etc. and government reports like SAPCC, IPCC etc.

**Regional Focus: Rajasthan**

India’s hot arid zone spans approximately 246,790 square kilometers, predominantly covering the majority of Rajasthan’s districts. This region is characterized by sparse and unpredictable rainfall along with high average maximum temperatures **(Manga et al., 2015).** Rajasthan is highly vulnerable due to its arid climate, water scarcity, and reliance on rain-fed agriculture.

**4.1 Key Agricultural Characteristics**

* Major crops: **Wheat, mustard, gram, barley, millet, cotton**
* Livestock: **Cattle, buffaloes, goats, camels**

**4.2 Climatic trends and observed & Projected Climate Impacts**

According to **sharma *et al*. (2021).**  analysed that the min temperature varied from 6.8 C in January to 29.2 C in June in most of the districts of the Rajasthan and may is the hottest month of the year where the max temperatures shoot up to as high as about 42 C. Udaipur recorded lowest max temperature of 38.1 C, which may be because of its geographical location. Bikaner and Kota faced high mean temperature as compared to other districts. The analysis of mean monthly data further revealed that Kota and Bikaner recorded highest mean max temperature of 44.5 C in the year 2010 and 1978, respectively. Jaipur and Udaipur noted hottest in May in the year 1988, whereas Jodhpur observed the highest temperature of 43.1 C in the year 1998. Kota, Jaipur, and Udaipur received an average rainfall of more than 200 mm in monsoon months, whereas Bikaner received lowest rainfall with an average of 93 mm and 62.2 mm in the month of July and August. A further mining of data showed that the highest mean rainfall of 424.1 mm was received in the month of August during the year 1973 for Jodhpur district. In Kota, the rainfall as high as 675.8 mm was received in the year 2001. Similar figure was 630.0 mm in 1973, 256.1 mm in 1978, and 956.3 mm in 1981 for Udaipur, Bikaner, and Jaipur, respectively, in the month of July.

**Subhash and Sikka** **(2014)** examined the fact about the rational relationships of trends between rainfall and temperature over the homogenous regions in India. It found no direct relationship among increasing max temperature and increasing rainfall or season wise trend over meteorological subdivisions of India. However, it was concluded that the relation has wide scale temporal and spatial dependence. Both rainfall and temperature are critical considerations of crop yield; therefore, precise simulation of these variables is important for agricultural economics as well as meteorology.

| **Parameter** | **Impact** |
| --- | --- |
| Temperature | Increase by 0.6°C–1°C (last 50 years), projected rise up to 4°C **IMD (2024)** |
| Rainfall | 20% decline in some regions over 3 decades **SAPCC (2015)** |
| Drought Frequency | Increase by 10–15% |
| Wheat Yield | 1,400–1,500 kg/ha (vs. national avg. 2,700 kg/ha) |
| Mustard Yield Loss | 15–25% during heat stress periods |
| Groundwater Decline | 0.5 to 2 meters/year in several districts **CGWB (2015)** |

**4.3 Soil and Land Degradation NRSC (2019)**

* 38% of land desertified
* 14.6 million hectares affected
* Overgrazing and deforestation accelerating desertification

**4.4 Livestock Stress NDRI (2021)**

* Milk yield reduction by 20–30% in summer
* Reduced fertility and higher animal mortality

**5. Solar Parks in Rajasthan: Opportunities and Challenges**

**Solar Capacity**: Rajasthan has installed over 21,000 MW of solar energy capacity, with an additional 10,450 MW under construction. The state aims to reach 115 GW of renewable energy capacity by 2030, contributing significantly to India's national target of 500 GW. Rajasthan's extensive deployment of solar parks, notably the Bhadla Solar Park—the world's largest at 2,245 MW—demonstrates the state's commitment to combating climate change and advancing sustainable energy. With over 33,000 MW of renewable capacity and a goal of 115 GW by 2030, Rajasthan is a pivotal player in India's renewable energy landscape. The state's strategic initiatives, including the PM-KUSUM scheme, have solarized over 1,000 MW of agricultural power connections, enhanced daytime irrigation and reducing nighttime power shortages for farmers. Furthermore, the Integrated Clean Energy Policy 2024, which has attracted investments worth ₹6.57 lakh crore, emphasizes green hydrogen, battery storage, and wind-solar hybrid projects, aiming to make Rajasthan an energy-surplus state. However, challenges such as land acquisition, environmental concerns, and community displacement in ecologically sensitive areas like orans require careful planning and stakeholder engagement to ensure sustainable development. Overall, Rajasthan's solar initiatives not only contribute to mitigating climate change but also promote economic growth, energy security, and rural empowerment

Rajasthan has emerged as a key player in India’s solar energy sector, hosting one of the largest solar parks globally. The state has made significant progress in expanding its solar capacity and building the necessary infrastructure to transmit renewable energy across desert regions. With ongoing support from national and international initiatives, Rajasthan is well-positioned to play a leading role in the country’s solar energy transition. The agriculture sector in Rajasthan consumes about 44% of the state's total power. **Misra (2022).** Bhadla Solar Park stands as a testament to the potential of large-scale solar projects in high solar radiation zones. Its success highlights how effectively utilizing natural conditions can accelerate renewable energy adoption. As a result, Western Rajasthan has gained prominence as a model for sustainable energy development globally **Sisodia (2025).**

**5.1 Opportunities**

* **Solar-Powered Irrigation:** **Reduction in Electricity Subsidy Burden**

The Rajasthan government annually subsidizes approximately ₹16,000 crore for agricultural electricity consumption. By transitioning to solar-powered irrigation, the state could potentially reduce this subsidy by up to 50%, thereby alleviating fiscal pressures.

The PM-KUSUM scheme has enabled over 1,000 MW of solar capacity in Rajasthan, benefiting approximately 1.7 lakh farmers. This initiative provides daytime electricity for irrigation, improving water use efficiency and reducing nighttime power demands.

Under the PM-KUSUM scheme, farmers can lease barren or unused land for solar projects. For instance, a 1 MW solar plant in Kotputli generates 17 lakh units of electricity annually, offering the landowner an income of ₹50 lakh per year through a 25-year contract with the distribution company.

* **Job Creation:** New employment in solar energy sector. The integration of solar panels with agricultural activities, known as agrivoltaics, is gaining traction. This approach not only generates renewable energy but also supports crop production. So, institutions like the **Central Arid Zone Research Institute (CAZRI)** in Jodhpur are at the forefront of such research, developing technologies that combine solar energy with agriculture provide opportunities for agricultural scientist and extension officer posts.
* **Agri-Voltaics:** Dual-use of land for energy and crops. Agrivoltaics involves the dual use of land for both solar energy generation and agricultural production. In Rajasthan, this approach has been explored to optimize land use, enhance crop yields, and provide additional income streams for farmers. The integration of solar panels over farmland can create a microclimate that reduces evaporation rates, conserving water and improving crop resilience to climate stress

**5.2 Challenges**

**Solar plant expansion and environmental concerns in Jaisalmer, Rajasthan.**

The establishment of large-scale solar plants on traditional grazing lands (orans) has led to displacement of local communities and loss of biodiversity. High-tension power lines associated with solar projects pose a risk to endangered species, such as the Great Indian Bustard, due to collisions Local communities have expressed concerns over the lack of adequate consultation and compensation regarding land use changes.

**Others like:**

| **Issue** | **Description** |
| --- | --- |
| Land Use Conflict | Displacement of farmers and loss of grazing land |
| Soil Degradation | Risk of compaction, erosion, and increased desertification |
| Microclimate Change | Potential adverse effects on sensitive crops |
| Resource Competition | Water use for panel maintenance may strain scarce supplies |

Despite installing over 21,000 MW of solar capacity, only 4,000 MW is utilized within the state, with the remainder exported. Agriculture accounts for 40% of electricity consumption in Rajasthan, yet solar energy is not adequately harnessed for irrigation and other agricultural needs. The state continues to provide heavily subsidized power to farmers, leading to inefficiencies and missed opportunities for integrating solar solutions. **(Triparty, 2024)**

**Case studies**

1. **Adoption of climate-resilient agricultural practices**

The National Innovation on Climate Resilient Agriculture (NICRA) project in Jodhpur district introduced short-duration, drought-tolerant kharif crop varieties, leading to a 34.2% average yield increase. Additionally, improved livestock management practices enhanced farmers' income by 65.17%, highlighting the effectiveness of climate-resilient interventions. **(Kalash, 2023)**

1. **Success story: Nahargarh Ranthambore Agri-voltaic Project**

Project: 400 kW agri-voltaic installation at Nahargarh Ranthambore Heritage Property Implemented by: Vareyn Solar
Highlights: The project integrates solar panels with a half-hectare kitchen garden, producing crops like tomatoes, potatoes, and broccoli. The installation has exceeded energy production expectations and garnered industry accolades, including the "Best Agri-Voltaic Project Rajasthan 2023" award. The system contributes to the property's carbon-neutrality goals while maintaining aesthetic and operational integrity

1. **Failure story: Jaisalmer Orans and Solar Park Conflicts**

Issue: Displacement of traditional grazing lands (orans) for solar park development
Challenges:

* Local communities, primarily nomadic livestock herders, have lost access to sacred groves used for grazing.
* Employment opportunities at solar plants are limited and often low-paying, such as security guard roles, which do not align with the communities' skill sets.
* Ecologically sensitive areas, home to endangered species like the Great Indian Bustard, are being affected by infrastructure developments associated with solar parks. **(Singh, 2023)**

The integration of solar energy into agriculture in Rajasthan presents a promising pathway towards sustainable farming practices. While challenges such as land use conflicts and environmental concerns exist, the opportunities for economic empowerment, water conservation, and environmental benefits make solar adoption a viable solution. With continued government support and capacity-building initiatives, solar-powered agriculture can play a pivotal role in transforming Rajasthan's agricultural landscape.

**6. Adaptation and Mitigation Strategies for Rajasthan**

Adaptation to climate change involves making adjustments in natural or human systems to minimize the negative impacts or take advantage of potential benefits arising from current or anticipated climate-related changes **(IPCC, 2007).**

1. **Climate-Resilient Crops:** Development of heat- and drought-tolerant varieties. Rajasthan’s climate-resilient crops like pearl millet (bajra), cluster bean (guar), moth bean, and sorghum (jowar) are well-suited to the state’s arid conditions and changing climate. These crops require less water, tolerate heat and drought, and ensure food and income security for farmers. Supported by government schemes and crop diversification efforts, they play a crucial role in adapting agriculture to climate change in the region.

For instance, a study in the Aravalli Hill Zone found that 75% of farmers adopted drought-tolerant and early-maturing crop varieties as a key adaptation strategy . Additionally, in Pali district, crop diversification led to significant increases in net returns, with wheat-muskmelon intercropping yielding up to a 17.5% increase in income during the rabi season . These examples underscore the importance of promoting climate-resilient crops to enhance food security and farmer livelihoods in Rajasthan. **(Jat, 2023)**

1. **Efficient Water Management:** Drip irrigation, check dams, canal expansion. Farmers are increasingly adopting solar-powered irrigation systems to mitigate the effects of erratic rainfall and reduce dependence on diesel or grid electricity. These systems provide reliable and cost-effective irrigation solutions, enhancing water-use efficiency and reducing operational costs.
2. **Policy and Insurance Support:** Expansion of PMFBY and SAPCC funding. Policy frameworks can mandate or incentivize climate-resilient infrastructure, support risk pooling mechanisms, and subsidize insurance premiums for vulnerable populations.
3. **Zoning solar parks in non-arable lands:** Zoning solar parks on non-arable lands is a strategic approach to balancing renewable energy expansion with agricultural preservation. By prioritizing areas unsuitable for farming—such as degraded, rocky, or barren lands—solar development can proceed without displacing food production or harming fertile soil. This land-use planning not only supports sustainable energy goals but also helps optimize land utility, minimizing environmental and social conflicts.

**7. Government-led Adaptation and Mitigation Measures**

1. **PM-KUSUM Scheme (Components A, B, and C)**

The Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) scheme is a pivotal initiative to solarize agriculture:

* Component A: Establishment of decentralized solar power plants (up to 2 MW) to supply power to the grid.
* Component B: Installation of standalone solar pumps for irrigation.
* Component C: Solarization of existing agricultural pumps and feeder-level solarization.

As of June 2023, Rajasthan has made significant progress in implementing these components, with the state ranking first in installed capacity under Component A and second in Component B.

1. **Saur Krishi Ajivika Yojana**

Under Component C of PM-KUSUM, the Rajasthan government has launched the Saur Krishi Ajivika Yojna to promote decentralized solar power plants in rural areas. This initiative aims to provide reliable daytime electricity to farmers, reducing dependence on conventional energy sources and enhancing agricultural productivity.

1. **Rajasthan Renewable Energy Policy, 2023**

The state has formulated the Rajasthan Renewable Energy Policy, 2023, to promote renewable energy integration, including solar power projects for agricultural use. The policy encourages the establishment of solar power projects for captive use and third-party sale, aiming to achieve a 'Net Zero' emission target by curtailing dependency on conventional energy sources

**7. Conclusion**

Rajasthan exemplifies the acute vulnerabilities of semi-arid regions to climate change. While the expansion of solar energy offers a promising sustainable development pathway, it must be balanced with agricultural and ecological needs. A holistic, participatory, and technology-driven approach is essential to build resilient farming systems. Cross-sectoral coordination between policymakers, researchers, and farmers will be pivotal in achieving food and livelihood security under changing climate conditions. From an agricultural perspective, the studies reveal that most farmers are middle-aged with small or marginal landholdings and limited income, making them highly vulnerable to climate change. Education, farming experience, and access to extension services and mass media significantly influence their awareness and adoption of climate-resilient practices. While awareness levels vary, many farmers are adapting through crop diversification, changing planting times, and soil and water conservation. Strengthening institutional support, improving access to climate information, and promoting education are essential for enhancing farmers’ adaptive capacity and ensuring sustainable agricultural development. Thus, the development of solar parks in Rajasthan is a vital step in addressing climate change. By harnessing its abundant solar potential, the state contributes significantly to clean energy goals while building resilience against climate-related challenges such as extreme heat and energy scarcity. Rajasthan's climate adaptation and mitigation strategy is a powerful example of synergy between renewable energy (solar parks) and climate-resilient agriculture. Through programs like PM-KUSUM, solar parks, agrivoltaics, and policy reform, the state is making strides toward net-zero emissions, water and energy security, and improved rural livelihoods.

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