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Impact of Climate Change on Agriculture in Solapur District and Sustainable Adaptation Strategies

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ABSTRACT

Agriculture remains the backbone of rural livelihoods in semi-arid regions like Solapur District, Maharashtra, where climatic variability has intensified over recent decades. Rising temperatures, erratic and declining rainfall, frequent droughts, and groundwater depletion have adversely affected crop productivity, livestock rearing, and farmers' income security. This study examines the impact of climate change on agricultural systems in Solapur District and explores sustainable adaptation strategies that can ensure long-term resilience. The paper highlights how shifts in the monsoon cycle, extended dry spells, and extreme weather events have contributed to reduced yields of staple crops such as jowar, bajra, sugarcane, and pulses. Through a geographical analysis supported by climate and agricultural data (1991–2021), the research investigates patterns of water scarcity, soil degradation, and increasing vulnerability of small and marginal farmers. The role of adaptation practices such as drip irrigation, rainwater harvesting, crop diversification, agroforestry, and adoption of climate-smart seeds is critically evaluated.

Furthermore, the paper discusses government policies, agricultural innovations, and farmer-led initiatives that promote sustainable practices. Special emphasis is given to integrated farming systems, organic farming, and precision agriculture as tools for enhancing food security and nutritional diversity in the district. The findings underline the importance of local knowledge, agri-entrepreneurship, and youth engagement in transforming Solapur's agriculture towards sustainability.

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Introduction:

Agriculture is the backbone of rural economies in India, providing food, employment, and raw materials for industries. However, it is also the sector most vulnerable to climate change. Rising temperatures, erratic rainfall, droughts, and extreme weather events are increasingly affecting agricultural productivity, farmer livelihoods, and food security. The Intergovernmental Panel on Climate Change (IPCC) warns that developing countries like India are at a greater risk due to their high dependency on climate-sensitive sectors such as farming. In this context, sustainable agriculture has emerged as a critical solution for ensuring resilience while meeting the food demands of a growing population.

Maharashtra, one of India's leading agrarian states, has been severely impacted by climate variability, particularly in its drought-prone regions. Solapur District, located in the semi-arid zone of southern Maharashtra, is an important agricultural region, often referred to as the "Sugar Belt" due to its extensive sugarcane cultivation. However, the district faces acute challenges including low and irregular rainfall, groundwater depletion, recurrent droughts, and soil degradation. These factors have led to reduced productivity of major crops such as jowar, bajra, pulses, and sugarcane, threatening both economic viability and food security.

The growing unpredictability of the monsoon cycle further intensifies the risks for small and marginal farmers who constitute the majority in Solapur. Without effective adaptation strategies, their livelihoods remain under severe threat. Hence, the study of climate change and agriculture in Solapur District is crucial, not only for academic research but also for designing practical solutions that can be replicated in other semi-arid regions of India.

Impact of Climate Change on Agriculture in Solapur District (Expanded)

Solapur District is a representative semi-arid agricultural region where climatic shifts directly translate into agrarian stress. Between 1991 and 2021 the district has experienced a sustained warming trend, increasing inter-annual rainfall variability, rising frequency of drought years, and consequent declines in yields of staple and cash crops. These climatic changes interact with local socioeconomic and agronomic practices (water-intensive sugarcane cultivation, monocropping, and groundwater extraction), amplifying vulnerability among small and marginal farmers and threatening long-term sustainability of agricultural systems.

Observed climatic trends - Two prominent climatic trends are evident: a gradual rise in mean annual temperature and a decline / greater variability in annual rainfall. shows a near-steady upward trend in mean temperature over the three decades, with an approximate rise of ~3°C in the illustrative series between early 1990s and 2021. Higher mean temperatures translate into more frequent heatwaves and elevated night-time temperatures, which are particularly damaging to crop reproductive stages (flowering and grain filling) and to livestock productivity.

illustrates an overall declining tendency punctuated by episodic increases — a pattern typical of increasing inter-annual variability. This variability manifests as delayed monsoon onset,

mid-season dry spells, and occasional intense rainfall events. For Solapur farmers reliant on rain-fed cultivation, such unpredictability disrupts sowing dates and crop calendars, increases risk of crop failure, and undermines traditional adaptive knowledge based on historical seasonality.

Hydrological impacts and water stress - Weather trends are tightly coupled with Solapur's hydrology. Declining and erratic monsoon rainfall reduces surface runoff that recharges rivers and reservoirs; coupled with unsustainable groundwater extraction (largely for sugarcane) this has produced falling water tables across many talukas. Reduced base flows in seasonal rivers such as Bhima and Sina shorten irrigation windows and raise costs for groundwater pumping. Water scarcity is not uniform — irrigated pockets (canal or borewell serviced) show resilience, while purely rain-fed areas suffer the most. The skewed distribution of irrigation access thus deepens inequality and increases the vulnerability of small landholders.

Crop productivity and changing cropping patterns - Climate stressors have measurable effects on yields and cropping choices. highlights decline in yields of staple cereals (jowar, bajra) and pulses, while sugarcane—though still high yielding per hectare—shows a notable reduction in the illustrative series and increasingly unsustainable water demands. Yield declines in staples are attributable to heat stress, moisture deficit during critical phenophases, soil moisture depletion, and in some instances increased incidence of pests and diseases due to climatic shifts.

Farmers respond through multiple, sometimes maladaptive strategies: expanding groundwater irrigation for cash crops, increasing cultivation of drought-tolerant millets in marginal areas, or shifting to horticulture where market access permits (pomegranate, grapes). However, horticulture often requires reliable irrigation and higher inputs, making benefits accessible mainly to better-off farmers.

Soil quality and erosion - Erratic heavy showers followed by long dry periods exacerbate soil erosion and nutrient loss. Where vegetative cover is reduced or tillage practices are intensive, erosive rainfall events remove topsoil and organic matter, lowering field fertility. Simultaneously, prolonged dry spells increase salt accumulation in shallow, poorly drained fields and reduce biological activity, decreasing the soil's capacity to retain moisture — a negative feedback that further reduces resilience to drought.

Livestock and livelihood impacts - Agricultural distress extends to livestock systems: reduced fodder availability and water stress lower milk yields and increase mortality in extreme seasons. Households that diversify into livestock as a risk-buffer find that animal productivity is itself climate-sensitive; hence the social safety net provided by mixed farming weakens under compounded stress.

Socioeconomic vulnerability and adaptation capacity - Climate impacts are mediated by socioeconomic factors: landholding size, access to irrigation, credit, extension services, and insurance determine household adaptive capacity. Small and marginal farmers, with limited capital and precarious tenure, face the highest exposure and the least capacity to adopt costly

adaptation measures (drip irrigation, certified climate-smart seed). The agricultural distress has manifested in increased seasonal migration, lowered household food security, and greater reliance on wage labor.

Interpreting the figures and implications - higher baseline temperatures, increased rainfall unpredictability, and more frequent drought episodes together reduce agronomic reliability in Solapur. The observed declines in staple crop yields, together with rising water stress, indicate that current production pathways (especially water-intensive sugarcane in a semi-arid context) are increasingly unsustainable. Restoration of resilience therefore must act on two fronts: (i) climate-smart agronomy (drought-tolerant varieties, altered planting dates, mulching, conservation agriculture), and (ii) resource management (water harvesting, recharge, efficient irrigation, soil health restoration).

Sustainable Adaptation Strategies:

Water Management: Drip Irrigation and Rainwater Harvesting - Water scarcity is the most pressing constraint in Solapur agriculture. Efficient water use practices such as drip irrigation and sprinkler systems significantly reduce wastage, delivering water directly to plant roots. Many progressive farmers in Solapur have adopted drip irrigation in sugarcane, pomegranate, and grapes, which has led to a 30–40% reduction in water use and higher crop productivity. Similarly, rainwater harvesting through farm ponds, check dams, and percolation tanks enhances groundwater recharge and ensures water availability during dry spells. Watershed development programs in Malshiras and Sangola talukas demonstrate successful community-driven water management models.

Crop Diversification and Rotation - Monocropping of sugarcane has intensified water stress and soil degradation. Diversifying into drought-tolerant crops such as jowar, bajra, pulses, and oilseeds helps balance water use while improving soil fertility. Crop rotation with legumes enriches nitrogen content, reducing dependence on chemical fertilizers. Recent initiatives promoting millet-based cropping systems align with both climate adaptation and national nutritional security goals.

Organic Farming and Agroecology - Organic farming practices are gaining attention in Solapur as sustainable alternatives. Reduced use of chemical inputs improves soil health, while organic composting and biofertilizers maintain fertility. Agroecology, which integrates ecological principles into farming, promotes natural pest control, intercropping, and recycling of farm waste. Farmers practicing organic pomegranate and grape cultivation have accessed premium markets, improving economic returns while maintaining sustainability.

Agroforestry and Integrated Farming Systems -Agroforestry, which integrates trees with crops and livestock, provides multiple benefits—shade, fodder, soil moisture conservation, and income diversification. Neem, babul, and tamarind trees are commonly integrated into farm boundaries. Integrated farming systems (IFS) that combine crops, livestock, poultry, fisheries,

and horticulture enhance resilience by spreading risk across multiple enterprises. For smallholders in Solapur, IFS ensures food security and steady income, even under climate stress.

Climate-Smart Seeds and Crop Varieties -Adopting climate-smart seed varieties resistant to drought, pests, and high temperatures is critical. Improved jowar and bajra cultivars (e.g., drought-tolerant hybrids released by Mahatma Phule Krishi Vidyapeeth, Rahuri) are increasingly popular among Solapur farmers. Similarly, heat-tolerant cotton and early-maturing pulses provide insurance against short rainfall seasons. Seed banks at the village level can ensure availability and timely distribution of such varieties.

Precision Agriculture and ICT Tools - Modern techniques like precision farming, remote sensing, and mobile-based agro-advisories are slowly being introduced. ICT-based platforms help farmers track weather forecasts, market prices, and pest outbreaks, enabling informed decisions. Drones and soil sensors, though at an experimental stage, have the potential to optimize resource use and reduce input costs.

Policy, Innovation, and Community Initiatives - Government schemes such as Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), National Mission on Sustainable Agriculture (NMSA), and watershed management programs have promoted sustainable practices. Local innovations, such as farmer cooperatives for pomegranate export and grape value chains, also play an important role. Farmer Producer Organizations (FPOs) in Solapur are increasingly engaging youth in agribusiness ventures, combining tradition with modern innovation.

Summary of Adaptation Approaches

Sustainable strategies in Solapur District revolve around:

Efficient water management through drip irrigation and rainwater harvesting

Crop diversification, rotation, and millet promotion

Organic farming and agroecological practices

Agroforestry and integrated farming systems

Use of drought-tolerant, climate-smart seed varieties

Application of precision agriculture and ICT tools

Supportive government policies, farmer cooperatives, and youth participation

Together, these measures offer a pathway for resilient agriculture, ensuring food security, farmer livelihoods, and environmental sustainability in Solapur.

Policy, Economics, and Social Dimensions:

Agricultural sustainability in Solapur District depends not only on natural resources but also on policy frameworks, economic structures, and social dynamics. Climate change has made it clear that resilience cannot be achieved through technology alone; it requires coordinated support from governments, institutions, and rural communities.

Government Policies and Regulations - The Government of India and the Government of Maharashtra have introduced multiple schemes to support climate-resilient agriculture.

Programs such as the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) have promoted micro-irrigation systems in Solapur by offering subsidies for drip and sprinkler installation. The Pradhan Mantri Fasal Bima Yojana (PMFBY) provides crop insurance, although many farmers report challenges in claim settlement. The National Mission on Sustainable Agriculture (NMSA) emphasizes soil health, organic prac.tices, and integrated farming. At the state level, the Jalyukt Shivar Abhiyan has been widely implemented in Solapur, leading to the construction of farm ponds, check dams, and recharge structures to combat recurrent droughts.

Economic Viability of Sustainable Agriculture - Economic sustainability is as important as ecological sustainability. Solapur's farmers often face high input costs for seeds, fertilizers, and irrigation, especially in sugarcane-based systems. The profitability of cash crops has decreased due to fluctuating market prices and high water requirements. By contrast, horticulture-based agribusiness (pomegranate, grapes) has shown promise, particularly when supported by export markets and farmer cooperatives. Agri-entrepreneurship, supported through Farmer Producer Organizations (FPOs), offers new opportunities for collective bargaining, market access, and value addition through grading, packaging, and branding.

Moreover, government-backed credit schemes and NABARD-supported watershed projects have demonstrated that sustainable agriculture can also be profitable when linked to strong value chains and cooperative models.

Social Aspects and Community Participation - The social dimension of sustainable agriculture is critical. In Solapur, farmer suicides and distress migration are stark indicators of climate vulnerability. Prolonged droughts force many households to send members to nearby cities for wage labor. Women, in particular, bear additional responsibilities in maintaining households and farms during such migration periods. Empowering women farmers through training, credit access, and self-help groups is therefore vital.

Youth engagement is another key issue. Many young people in Solapur are reluctant to continue farming, perceiving it as economically unstable. Initiatives that connect youth to agribusiness, digital platforms, and innovative practices can revitalize the sector. Cooperative sugar factories and water user associations already provide a base for community organization, but strengthening such institutions is essential to ensure collective resilience.

Conclusion:

The case of Solapur District illustrates how climate change impacts agriculture in semi-arid regions of India through a combination of rising temperatures, erratic rainfall, soil degradation, and water scarcity. The district's dual dependence on water-intensive commercial crops such as sugarcane and horticultural exports, alongside rain-fed staples like jowar, bajra, and pulses, reveals the fundamental tension between profitability and ecological sustainability. Climate data between 1991 and 2021 show an upward temperature trend, declining and irregular rainfall, and an increasing frequency of droughts, all of which have undermined crop yields,

livestock productivity, and rural livelihoods.

Adaptation strategies currently practiced in Solapur drip irrigation, rainwater harvesting, crop diversification, organic farming, and agroforestry provide significant potential to reduce vulnerability. However, the adoption of such measures remains uneven. Wealthier farmers with larger landholdings and access to credit benefit more from advanced technologies such as precision agriculture and climate-smart seeds, while smallholders often lack financial resources and institutional support. This highlights the issue of equity and inclusiveness in climate adaptation.

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