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District-specific prioritisation of Climate-Smart Agriculture interventions in Odisha, India

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Abstract

Background: Agriculture in Odisha faces increasing vulnerability to climate variability due to recurrent droughts, floods, cyclones, and widespread soil degradation across diverse agro-ecological zones. Climate-Smart Agriculture (CSA) offers an integrated framework to enhance productivity, strengthen climate adaptation, and reduce greenhouse gas emissions. However, effective CSA implementation requires district-specific prioritisation grounded in field-level evidence and farmer participation rather than uniform, state-wide approaches.

Methods: A participatory CSA prioritisation exercise was conducted across nine climatically vulnerable districts of Odisha, representing coastal, central, and western agro-ecologies. Fifteen CSA intervention groups encompassing eighty-three individual practices were evaluated using a structured, multi-stage methodology. Experts from Krishi Vigyan Kendras (KVKs) and line departments assigned relative weights to the three CSA pillars, i.e., productivity, adaptation, and mitigation, and scored interventions across seven performance indicators using a standardised scale ranging from -10 to +10. Field-level validation involved more than 350 stakeholders, including KVK scientists, departmental officials, farmers, Farmer Producer Organisation (FPO) members, and women Self-Help Groups (SHGs), to assess feasibility and contextual relevance.

Results: Water management, soil health management, integrated farming systems, crop diversification, and market creation with value-chain development consistently ranked among the top CSA intervention groups. In western Odisha, 70-80% of farmers reported the absence of reliable Rabi irrigation, while coastal districts faced recurrent flooding and soil salinity stress. Weak extension outreach, inadequate irrigation infrastructure, and limited mechanisms for creating viable markets constrained CSA adoption. District-specific, farmer-validated CSA portfolios therefore emerged as critical for enhancing climate resilience and long-term agricultural sustainability in Odisha.

Keywords: Climate-Smart Agriculture, participatory prioritisation, Odisha, Sustainability

Introduction

Agriculture in Odisha faces high vulnerability to climate variability due to recurrent droughts, floods, cyclones, and progressive soil and water degradation. During 2023-24, nearly 4.23 million hectares ($\approx 49.5\%$) of Odisha's total cropped area remained rainfed across Kharif and Rabi seasons, highlighting the state's continued dependence on monsoon rainfall, making farm production systems particularly sensitive to rainfall variability and extreme weather events (Government of Odisha, 2024). Coastal districts experience frequent flooding and salinity intrusion (Hazra *et al.*, 2022) ^[7], while western districts face long-lasting water scarcity, declining groundwater levels, and seasonal crop failures (Swain & Swain, 2011) ^[11]. These challenges have resulted in yield instability, declining resource-use efficiency, and increased livelihood vulnerability among small and marginal farmers.

Climate-Smart Agriculture (CSA) has been widely recognised as an integrated approach to simultaneously enhance agricultural productivity, strengthen adaptation to climate change, and reduce greenhouse gas (GHG) emissions (FAO, 2013; Nayak *et al.*, 2020) ^[8]. However,

effective operationalisation of CSA requires context-specific prioritisation that accounts for agro-ecological diversity, resource constraints, and farmer adoption potential.

To address the gap, the Centre for Study of Science, Technology and Policy, in collaboration with the Department of Agriculture and Farmers' Empowerment (DA&FE), Government of Odisha, undertook a state-wide CSA scoping assessment. The assessment integrated resource-use profiling, district-level GHG emissions, and climate risk exposure, leading to the identification of nine priority districts, i.e. Bolangir, Nabarangpur, Nuapada, Kendrapara, Puri, Bhadrak, Angul, Jajpur, and Bargarh, where climate vulnerability and production constraints converge.

These districts represent contrasting agro-climatic zones and farming systems, yet collectively account for a large share of Odisha's climate-exposed agricultural area. To translate analytical insights into actionable strategies, extensive field-based stakeholder consultations were undertaken across all nine districts. The objective was to validate scoping study findings, document ground-level practices and constraints, and identify locally relevant CSA interventions through

participatory engagement with farmers, Krishi Vigyan Kendra (KVK) scientists, line department officials, Farmer Producer Organisations (FPOs), and women Self-Help Groups (SHGs). This field-based approach bridges the gap between data-driven assessment and implementation planning by aligning scientific evidence with farmer experiences. By integrating expert knowledge with stakeholder validation, the study generates district-specific, farmer-endorsed CSA portfolios, providing a robust foundation for strengthening climate resilience and guiding district-level CSA action planning in Odisha.

Materials and Methods

The study conducted during 2025 adopted a participatory and evidence-based methodology to identify and validate Climate-Smart Agriculture (CSA) interventions across nine climatically vulnerable districts of Odisha. The approach was based on the CSA prioritisation framework proposed by Nayak *et al.* (2020) [8] and subsequently adapted by CSTEP to suit district-level implementation planning. The methodology integrated analytical rigour with stakeholder engagement to ensure that the prioritised interventions were scientifically robust, context-specific, and feasible to adopt.

Study design and stakeholder engagement

The CSA prioritisation process was implemented in three sequential phases: (i) expert-led prioritisation, (ii) farmer-level validation, and (iii) synthesis of district-specific CSA portfolios. Out of nine districts, initial orientation and pilot learning were conducted during a comprehensive field visit to Puri district, following which a two-member CSTEP team carried out field visits across the remaining eight districts. Field investigations were conducted across nine districts of Odisha in three phases representing different agro-ecological regions (Fig. 1).

The expert-led prioritisation phase involved consultations with district-level representatives from the DA&FE, i.e., Directorates of Agriculture and Food Production, Horticulture and Soil Conservation & Watershed Development, as well as scientists and staff from the Krishi Vigyan Kendras (KVKs). These groups, collectively referred to as “Experts,” representatives of Farmer Producer Organisations (FPOs), Self-Help Groups (SHGs), and individual farmers. All focus group discussions (FGDs) were facilitated by trained CSTEP personnel, supported by local civil society partners.

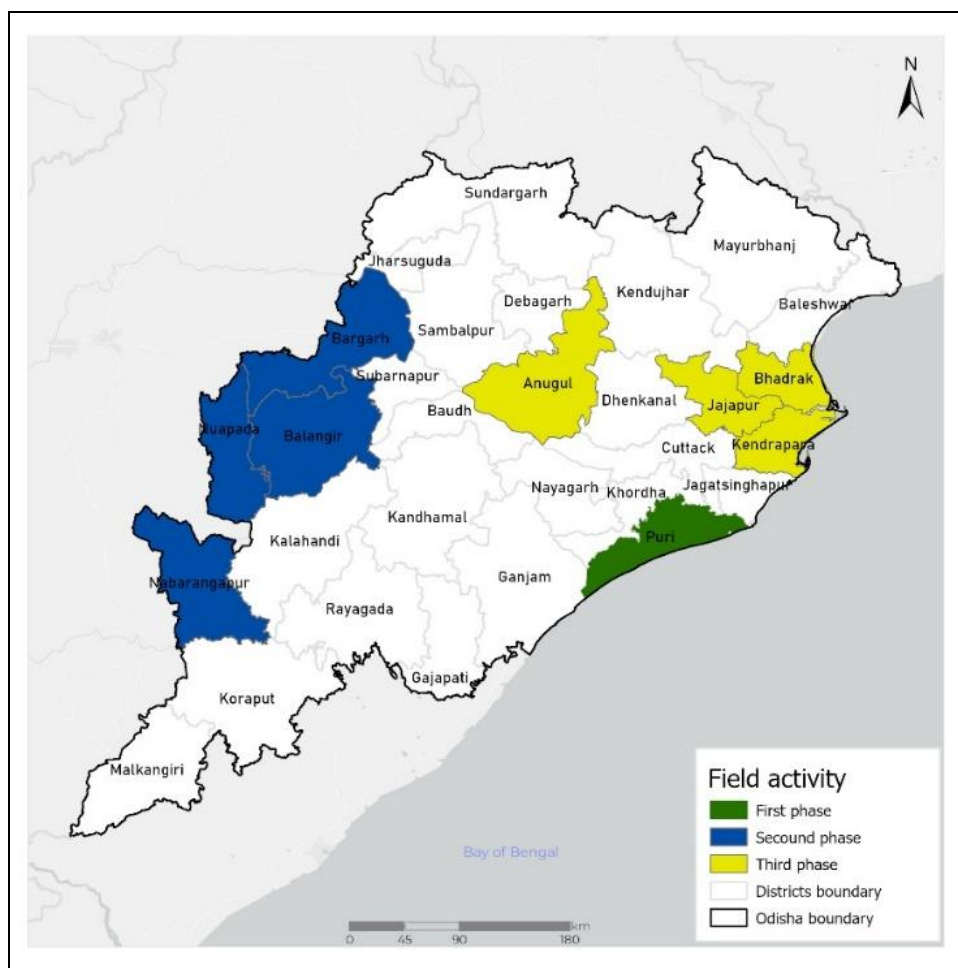


Fig 1: Locations of field investigations conducted across selected districts of Odisha

Expert-led CSA prioritisation

Expert consultations were conducted through structured FGDs. Participants were first oriented to the three CSA pillars, i.e., productivity, adaptation, and mitigation, and

seven associated indicators: yield stability, income enhancement, nutrient-use efficiency, water-use efficiency, reduction of current climate vulnerability, reduction of future climate risk, and mitigation potential through energy

efficiency or carbon sequestration. Experts then assigned relative weights to the CSA pillars and indicators such that the total weight equalled 100 (Table 1).

Table 1: Weighting scheme for CSA pillars and performance indicators used for district-level prioritisation

Pillar	Value	Indicator	Weight	Value
Production		Does it increase yield or reduce yield variability?	w1	
		Does it increase income?	w2	
Adaptation		Does it improve nutrient use efficiency?	w3	
		Does it improve water use efficiency?	w4	
		Does it reduce current vulnerability and risk to climate variability?	w5	
		Does it reduce vulnerability and risk to future climate change?	w6	
Mitigation		Does it enhance energy efficiency/sequestration carbon or reduce GHG emissions?	w7	
Total	100	Total	100	

Fifteen CSA intervention groups encompassing eighty-three individual practices were then scored for each indicator using a standardised scale ranging from -10 (100% negative impact) to +10 (100% positive impact) (Table 2). Weighted composite scores were calculated to identify the top five CSA intervention groups for each district. Within these groups, individual interventions were further ranked based on scalability and contextual relevance.

Table 2: Scoring scale used for evaluating CSA intervention groups and practices

-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10
↓100%					↓50%					No Change					↑50%					↑100%

Farmer-level validation and synthesis

Farmer-level validation was conducted through FGDs involving farmers, FPO members, and SHG participants representing diverse agro-ecological and socio-economic contexts. Discussions focused on current farming practices, climate-related challenges, adoption barriers, and the perceived feasibility of expert-prioritised CSA interventions. In the final phase, insights from expert scoring and farmer validation were synthesised to develop district-specific CSA prioritisation matrices. This integration ensured that the final set of interventions was demand-driven, operationally feasible, and aligned with both policy priorities and local farming realities.

Results and field-level insights

Field investigations across nine districts revealed strong convergence in production constraints consistent with projected climate impacts on eastern Indian agriculture (Birthal *et al.*, 2014)^[3], climate risks and institutional gaps, alongside region-specific CSA interventions shaped by agro-ecological conditions.

Coastal districts (Kendrapara, Bhadrak, Puri)

Agriculture in the coastal districts is predominantly paddy-based, with over 60-70% of cultivated area under Kharif rice, and is highly exposed to flooding, cyclones, waterlogging, and salinity intrusion. Field interactions indicated that approximately 40-55% of agricultural land remains fallow during the Rabi season due to poor drainage,

saline groundwater, and limited access to freshwater irrigation. Farmers reported progressive soil salinisation, declining soil fertility, and reduced crop choice, particularly in low-lying and estuarine landscapes.

Adoption of climate-resilient practices, such as submergence and saline-tolerant rice varieties (e.g., *Swarna Sub-1*), integrated rice-fish systems, and bio-saline farming, was observed in limited pockets (around 20-30% of villages), often facilitated by NGOs. However, scaling remains constrained by weak extension outreach, limited understanding of Soil Health Card recommendations, and inadequate post-harvest infrastructure. Farmers consistently emphasised the need for improved drainage, salinity management measures, cold storage facilities, and market linkages, along with better access to crop insurance and timely compensation following cyclonic events.

Western districts (Bolangir, Nuapada, Nabarangpur, Bargarh)

Western districts are characterised by predominantly rainfed agriculture, recurrent droughts, groundwater depletion, and widespread seasonal migration. Paddy, maize, pulses, and millets dominate cropping systems; however, 70-80% of farmers reported the absence of reliable Rabi irrigation, resulting in low cropping intensity beyond the Kharif season, a common constraint in rainfed production systems (Rockstrom *et al.*, 2010)^[9]. Borewell failure rates were high, with farmers indicating that only about 10-20% of borewells remained functional in several blocks, while farm ponds and water-harvesting structures were either absent or non-functional. Seasonal migration was reported by more than 50% of smallholder households, particularly in Nuapada and Bolangir, reflecting livelihood stress during the non-cropping period.

Farmers consistently reported soil degradation, micronutrient deficiencies (notably zinc and calcium), and declining organic matter, exacerbated by reduced livestock populations. CSA practices such as Direct Seeded Rice (DSR), residue retention, intercropping, millets, and integrated farming systems were viewed positively reflecting their documented role in improving soil health, nutrient availability, and yield stability (Shukla *et al.*, 2020; Behera *et al.*, 2020)^[10, 2], reflecting their documented role in improving resilience and income stability, yet adoption remained uneven due to limited technical support and access to quality inputs. Strengthening water-harvesting infrastructure, soil testing services, agroforestry systems, and FPO-led value chains was identified as critical for reducing production risk and seasonal migration in these drought-prone districts.

Central districts (Angul, Jajpur)

Central districts exhibited relatively diversified farming systems combining paddy, vegetables, pulses, oilseeds, and horticulture. Nevertheless, these districts face dual climate stress, with flooding in low-lying areas and drought or water scarcity in uplands. Field discussions suggested that around 50-60% of farmers continue to depend primarily on Kharif cultivation, while post-harvest losses affecting approximately 25-35% of horticultural produce were reported due to limited cold storage and weak aggregation mechanisms. At the same time, 20-30% of farmers reported

partial adoption of CSA practices, including DSR, crop diversification, and integrated farming systems.

In Angul, human-wildlife conflict involving elephants, wild boars, and monkeys was reported by over 30-40% of farmers in forest-adjacent blocks, discouraging crop intensification and long-term investment. In both Angul and Jajpur, soil fertility decline associated with prolonged chemical fertiliser use and inadequate organic inputs emerged as a major concern, consistent with patterns reported for intensively cultivated Indian soils (Bhattacharyya *et al.*, 2015) ^[1]. Farmers expressed strong demand for micro-irrigation systems, integrated nutrient management, improved market infrastructure, and extension-led demonstrations, alongside policy support for wildlife management and crop insurance coverage.

Across districts, a majority of farmers (~60-75%) expressed a strong willingness to adopt Climate-Smart Agriculture (CSA) practices when supported by timely access to quality inputs, hands-on training, and reliable market opportunities. Adoption, however, remained constrained by persistent gaps in last-mile extension delivery and uneven access to

advisory services, challenges widely documented in India's agricultural extension systems (Glendenning *et al.*, 2010) ^[5], along with limited availability of soil and water diagnostic services, inadequate irrigation infrastructure, and weak post-harvest systems. These constraints were most pronounced in rainfed western districts and saline-affected coastal zones, where institutional outreach and infrastructure deficits were more acute.

Women's participation was evident across districts through Self-Help Groups (SHGs), particularly in allied, livestock-based and value-added activities; nevertheless, less than one-third of women participants reported regular access to formal training, financial services, or decision-making platforms.

Overall, the field evidence underscores that district-specific CSA portfolios, grounded in farmer validation and aligned with local agro-climatic risks, are essential for improving productivity, resilience, and sustainability of agriculture in Odisha. District-wise climate risks, key constraints, and prioritised CSA intervention themes are summarised in

Table 3: Summary of district-wise climate risks, key constraints, and prioritised CSA intervention themes in Odisha

District /Zone	Dominant climate stress	Key production & institutional constraints	Prioritised CSA intervention themes
Kendrapara	Flooding, salinity, waterlogging	Rabi fallows, poor drainage, weak extension, limited market access	Flood- & saline-tolerant rice, rice-fish/duck systems, drainage improvement, soil health management
Bhadrak	Cyclones, salinity intrusion	Deep saline groundwater, soil degradation, and insurance gaps	Salinity management, AWD, organic inputs, precision irrigation, post-harvest infrastructure
Puri	Floods, cyclones, salinity	Waterlogging in monsoon, summer scarcity and weak aggregation	DSR, AWD, flood-resilient rice, integrated paddy-fish systems, diversification
Bolangir	Recurrent drought	Rainfed farming, borewell failure, soil acidity, migration	Water harvesting, DSR, diversification, micronutrient management, agroforestry
Nuapada	Drought, erratic rainfall	No Rabi irrigation, low soil testing access, migration	Check dams, farm ponds, millets, IFS, FPO-led value chains
Nabarangpur	Rainfed stress	Mono-cropping, declining soil fertility and weak markets	Intercropping, organic inputs, micro-irrigation, post-harvest value chains
Angul	Drought & wildlife conflict	Limited irrigation, human-wildlife damage, post-harvest losses	Micro-irrigation, diversification, solar fencing, soil health management
Jajpur	Floods & drought	Inconsistent irrigation, weak storage, and fragmented holdings	Improved varieties, mulching, agroforestry, women-led value addition
Bargarh	Water scarcity, floods	Soil fertility decline, poor cold storage, and wildlife damage	Farm ponds, micro-irrigation, INM, market linkage strengthening

Conclusion

This study demonstrates that field-based, participatory prioritisation provides a robust and scalable framework for identifying context-specific CSA interventions across Odisha's diverse agro-ecological zones. Despite regional heterogeneity, common constraints, i.e., limited access to assured irrigation, declining soil health, increasing climate extremes, and weak institutional outreach, consistently undermine agricultural productivity and resilience. The findings clearly show that CSA adoption is most effective when scientific assessment is complemented by farmer validation, ensuring that prioritised practices are technically sound, locally relevant, and operationally feasible.

The evidence further indicates that district-specific CSA portfolios centred on strengthening water security, improving resource-use efficiency, promoting crop and livelihood diversification, and enabling market and value-chain development offer a practical pathway for enhancing resilience and sustainability. Scaling these interventions will require stronger institutional convergence among extension systems, research organisations, Farmer Producer

Organisations (FPOs), and civil society, supported by targeted investments in irrigation infrastructure, extension services, and post-harvest systems. By embedding farmer perspectives within evidence-based planning and policy alignment, Odisha can advance toward a resilient, resource-efficient, and inclusive agricultural transition that balances productivity, livelihoods, and environmental sustainability.

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