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Off-season vegetable cultivation in Diara lands: a climate-resilient strategy for sustainable livelihoods among marginal farmers of India

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Abstract
Increasing threats posed by climate change and weather vagaries, marginal and smallholder farmers in India face soaring unpredictability in their traditional farming systems. Riverbed or diara land cultivation has emerged as a climate-resilient, low-input indigenous practice that offers an adaptive solution for off-season vegetable production. Off-season riverbed vegetable cultivation in India, with a particular focus on its relevance to climate change adaptation and sustainable livelihood support for marginal farmers is a dire need of the hour to escalate farmers' income and uplift their standard of living. This review explores the ecological, agronomic, and socio-economic dimensions of riverbed farming, particularly focusing on cucurbitaceous crops. These systems anchor natural landforms coupled with traditional knowledge to enhance income, reduce climate vulnerability, and conserve agrobiodiversity highlighting how the continuous selection and seed-saving practices of local communities contribute to crop adaptability and genetic diversity, emerging as a valuable resource for sustainable livelihood enhancement in climate-vulnerable regions.

Keywords: Climate-resilient agriculture, off-season diara land farming, sustainable livelihoods, marginal farmers, indigenous practices

Introduction

Climate change poses significant threats to the agricultural livelihoods of marginal and smallholder farmers in India. Increasingly erratic monsoons, frequent floods, and prolonged dry spells have disrupted conventional cropping cycles, especially in rainfed and low-input farming systems. In this context, riverbed (diara) cultivation has gained attention as an indigenous, climate-resilient strategy for off-season vegetable production that directly supports livelihood security. Diara lands are formed in bowl-shaped depressions between river levees that offer unique agro-ecological niches that become cultivable post-monsoon. Traditionally used for growing vegetables particularly cucurbitaceous crops, these lands now represent an important agricultural innovation that aligns with principles of climate-smart agriculture, ecological intensification, and sustainable rural development. Marginal and landless farmers in India are becoming increasingly vulnerable to climate-driven disruptions like extreme rainfall, heat waves, and droughts that severely affect their livelihoods and food security. Off-season vegetable forcing in 'diara' lands (riverbeds) is a traditional and highly profitable agricultural practice in India. It involves cultivating high-value crops, primarily cucurbits, in the fertile, sandy soil of riverbeds during the dry season (October to May) (Kumari *et al.*, 2018) [5]. This method leverages residual moisture from the monsoon, enabling farmers to produce vegetables when their market prices are at a peak. It makes use of underutilized, fertile land, does not require land ownership, and can generate early, high-yield returns, offering both income and resilience. Marginal farmers, the major part of the food producing farming, operate on fragmented and often degraded landholdings, with limited access to formal credit, technology, and irrigation infrastructure. As climate change intensifies, bringing with it increased variability in rainfall, more frequent droughts and floods, and shifting cropping seasons, the vulnerabilities of marginal farmers have grown disproportionately (Somanathan and Mehta, 2021).While it provides a crucial source of income for landless and marginal farmers, this practice is inherently vulnerable to the impacts of climate change, which manifest as unpredictable rainfall, extreme temperatures, and changes in river flow (Diwan and Singh, 2019) [3, 17]. Off-season vegetable cultivation on riverbeds emerges as a promising adaptive strategy in times of changing climate regime. The very foundation of this farming system, the annual alluvial deposition and water recession cycle, is being disrupted, posing a significant threat to its sustainability and the livelihoods dependent on it (Shafi and Rahaman, 2018) [16].

Diara land and its agro-ecological relevance

The term diara (from the Hindi word *diya*, meaning earthen lamp) reflects the topography and geomorphology of these lands with shallow depressions that collect water during the rainy season and dry out afterward, creating fertile and moisture-retentive beds ideal for seasonal cropping. Remote sensing and Geographical Information System (GIS) is a reliable technique to prepare a comprehensive inventory of land use pattern of valuable natural resource areas like diara lands for detection of spatial and temporal changes (Manchanda *et al.,* 2002; Mini *et al.,* 2007; Kumar *et al.*, 2013) [4, 6, 8]. These lands are known by various regional names: khaddar, char, kachhar, doab, nad, and nadiari are vast tracts of land that form due to the annual deposition of silt and clay by Himalayan rivers like the Ganges, Brahmaputra, Kosi, Teesta, Torsha, Ramganga, Saryu and southern rivers like Tapti, Narmada, Krishna and their myriad number of tributaries. This alluvion and diluvion process creates a unique soil environment that is highly fertile but largely sandy. While seemingly unsuitable for agriculture, the subterranean moisture from the adjacent river and the newly deposited silt make these lands viable for cultivation.

Small and often landless farmers grow vegetables on riverbeds to enhance their income, strengthen food security, and build resilience against climate and market fluctuations., because of availability of natural fertile soils with minimal inputs, producing high-value vegetable crops during market-scarce periods, often fetching premium prices. Diara land cultivation is fundamentally an agro-ecological practice that leverages the natural resources of the riverine ecosystem. The system works in harmony with the annual flood cycle, utilizing the fertile silt deposits and subterranean moisture (capillary and seepage moisture) to grow high-value crops like cucurbits during the dry season. This reliance on natural processes minimizes the need for external inputs such as chemical fertilizers and irrigation, thereby reducing the system's carbon footprint and production costs. The deep root systems of these crops make them inherently resilient to surface droughts, a key adaptive trait in a climate-volatile region (Singh, 2012) [19].

As climate change intensifies, characterized by more erratic rainfall, prolonged droughts, and intense floods, the resilience of diara land farming becomes even more apparent. The adaptive capacity of the traditional practices and local landraces are inherently resilient. The deep taproot system of the crops, combined with the subterranean moisture, makes them less vulnerable to surface droughts. Furthermore, the annual flooding and deposition of fresh silt replenish soil fertility, a natural process that negates the need for significant chemical fertilizers. This is a classic example of agroecological adaptation, where farmers work with natural processes rather than against them.

Biodiversity and resilience of the landraces

The genetic diversity of landrace seeds acts as a natural insurance policy against climate shocks. A diverse population is more likely to contain individuals with traits that can withstand new pests, diseases, or extreme weather events, ensuring that the entire crop is not wiped out. This contrasts sharply with monoculture systems that rely on a few genetically uniform, high-input varieties. Off-season vegetable forcing in diara lands offers a compelling case for a pro-poor, climate-resilient, and culturally embedded model of sustainable agriculture. It provides a means for marginal farmers to generate income, enhance food security, and remain connected to their land, all working in harmony with the natural rhythm of the riverine ecosystem. The synergy of traditional seeds with climate-smart practices optimizes resource use and risk mitigation. For instance, cultivation of drought-tolerant seeds alongside soil moisture-enhancing techniques significantly boosts yield outcomes even during dry spells (Mpala *et al*., 2024) [9]. Diversification of vegetable crops with traditional varieties supports nutritional security and market resilience, addressing both ecological and socio-economic dimensions of farming in diara lands. Off-season cucurbit forcing in riverbeds exemplifies an agro-ecological practice sustained by living, gendered traditions, even as it navigates the pressures of migration, modernization, and ecological change. Inherent agro-ecological value systems in the indigenous marginal farming community towards off-season riverbed cucurbit cultivation ensure water conservation, soil replenishment, and extension of local production cycles.

The agroecological features of indigenous innovation

- Natural moisture retention after floods
- Silt deposition, enhancing soil fertility
- Isolation from main farmland, reducing pest pressure
- Early crop establishment enabling market advantage
- Use of landraces suited to local microclimates
- Seed saving and in-situ selection for adaptive traits
- Minimal use of external inputs (chemical fertilizers, irrigation etc.)
- Farming with traditional tools and family labour

Off-season riverbed forcing of cucurbits: traditional agro-ecology

Traditional practices like selecting seed types, timing sowing to monsoon recession, managing soil moisture and silt in riverbeds, improvised irrigation and shading, pest control using natural materials consumed entwined with ecological knowledge of soil–water management, seed selection for fast-maturing cucurbits, mood-determined planting times ("lunar planting"), pest–beneficial insect patterns in the moisture-retentive riverbeds to extend the growing season are the key factors of successful forcing. Off-season vegetable forcing in this context refers to the practice of growing vegetables, especially cucurbitaceous crops, during November to May, when the river water recedes. These crops are "forced" to grow under sub-optimal conditions, using specific techniques to manage soil temperature and moisture. The deep taproot systems of cucurbits, such as bottle gourd, bitter gourd, and watermelon, are particularly well-suited for this environment, as they can access the subsurface moisture and nutrients. In India, nearly 68% of the total area under cucurbit cultivation is located on riverbeds, which account for about 75–80% of the country's cucurbit output. Diara cultivation represents an indigenous agricultural innovation developed by local farmers through generations of experiential learning. The technique of vegetable forcing by early sowing in riverbeds to supply off-season produce maximizes market returns during low-supply windows (February to June). This system provides a low-capital, high-return model for marginal farmers, integrating well with the socio-economic realities of rural India. Farmers cultivate various vegetables under severely variable conditions, drawing on deep-rooted agronomic knowledge passed across generations by means of oral teaching, apprenticeship, community rituals, women's lineage, and through ritual and cultural embeddings of observing lunar cycles, festivals, taboos, and storytelling. But there are threats to continuity of this knowledge flow systems due to seasonal distress labour migrations, unfair wages, unsafe work environments, formal schooling and subsequent youth migration that pull them away from farming vocation and there is serious dearth of documentation tools.

Climate resilience and adaptation mechanisms

Plant-level resilience: root adaptations

Landraces grown in riverbeds exhibit aerenchyma formation, which facilitates oxygen transport in waterlogged soils—a crucial trait under flood-prone or hypoxic conditions (Yamauchi *et al.*,2013) [21]. These adaptive root systems support:

- Better growth in variable water regimes
- Resilience to monsoon-related stress

Diara cultivation contributes to in-situ conservation of agrobiodiversity by means of farmers' seed saving from well-performing plants, leading to continuous recombination and over generations, this creates a genetically diverse crop population adapted to micro-environmental fluctuations. This aligns with the bet-hedging strategy in evolutionary biology, wherein diverse traits within a population increase net fitness under uncertainty (Simons, 2011). Such diversity is crucial in the face of climate extremes. Given the low capital requirement, this system is especially suitable for climate-vulnerable regions and economically marginalized communities, offering a pathway toward livelihood diversification and risk reduction.

Climate change impacts and associated risks

Climate change is exacerbating the risks associated with diara farming, making it less predictable and more prone to crop failure. The primary climate-related challenges are:

- **Increased flood risk:** Erratic and intense rainfall events coupled with intense river water flow can lead to unseasonal or prolonged floods, which can submerge and destroy crops before they are harvested (Choudhary *et al*., 2019) [2]. This risk of total crop loss is a major disincentive for farmers and undermines the economic viability of the practice (Pal and Mondal, 2020) [11].

- **Temperature extremes:** Diara lands are highly susceptible to both cold waves and heat stress. Unseasonal cold spells and frost during the winter months can damage seedlings, while scorching heat during the pre-monsoon summer can harm the delicate vines and fruits, impacting yield and quality (Patel, 2016) [14].

- **Water scarcity:** While riverbeds naturally retain moisture, changes in rainfall patterns and increased water diversion upstream can lower the water table, reducing the subterranean moisture available for crops (Singh and Kumar, 2018) [5, 18]. This makes irrigation more challenging and costlier for farmers who lack the resources for advanced water management systems.

- **Soil degradation:** Altered flood patterns can lead to the deposition of coarse sand instead of fertile silt, reducing soil productivity over time. This necessitates a greater use of fertilizers, which increases costs and can have negative environmental impacts on the river ecosystem (Singh and Das, 2019) [17].

- Farmers are often discouraged from engaging in off-season vegetable cultivation due to challenges such as delayed flood recession, frost damage, stray cattle, and inadequate infrastructure like fencing, irrigation, and cold storage. Moreover, while traditional seeds are hardy, they often lack uniformity and desirable market traits, highlighting the need for participatory breeding to strengthen both resilience and commercial potential.

Climate-smart sustainable agricultural practices in diara farming

Despite these challenges, several indigenous and modern practices can enhance the climate resilience and sustainability of riverbed cultivation. These strategies focus on risk mitigation, resource efficiency, and adaptive capacity. Riverbed cultivation aligns closely with climate-resilient agriculture and diversification strategies followed by the marginal farmers:

Indigenous adaptive practices

- **Ditch and thatch systems:** Farmers traditionally dig deep ditches in the riverbed to access residual moisture and protect crops from strong winds and temperature fluctuations. They also use locally available materials like *Saccharum* grass (*sarkanda or Kash*) as a mulch to protect young plants from frost and scorching heat (Singh *et al*., 2012) [19].

- **Crop and variety selection:** In areas with lower water tables, farmers typically choose deep-rooted, drought-resistant cucurbits such as watermelon and bottle gourd, while shallow-rooted crops are grown nearer to the riverbanks. The use of traditional, locally adapted seed varieties further helps buffer against climate-related stresses.

- **Integrated farming systems:** Integrating vegetable cultivation with other activities, such as beekeeping for pollination or agro-forestry along the riverbanks, can diversify income, reduce risk, and enhance the overall resilience of the farming system.

- **Early warning systems and agri-advisories:** Timely weather forecasts and advisories can help farmers make informed decisions about sowing times and harvesting, minimizing losses from impending floods or extreme weather events disseminating climate-resilient technologies and practices to vulnerable regions as offered by Government initiatives like the National Innovations in Climate Resilient Agriculture (NICRA) project.

Synergies between traditional seeds and climate-smart agriculture (CSA) practices

Climate-smart agriculture (CSA), as defined by the Food and Agriculture Organization (FAO) and the World Bank, seeks to achieve three interconnected objectives: increasing agricultural productivity, enhancing adaptive capacity to climate variability, and mitigating greenhouse gas emissions. In India, smallholder farmers implementing CSA interventions like improved soil management and the adoption of drought-tolerant crop varieties have recorded yield increases of 20–30%, along with improvements in household income and soil carbon content. Traditional landraces (including cucurbits, legumes and other indigenous vegetables) already encapsulate adaptation to local microclimates, variable moisture regimes, pests, and soil conditions. Their genetic diversity provides a buffer against shocks (e.g. drought, flood) that modern high yielding but genetically narrow varieties may lack.

A critical component of CSA in the Indian context involves the integration of traditional seed varieties with modern climate-resilient practices. These indigenous seeds often preserved through community stewardship over generations, are genetically diverse and locally adapted, and exhibiting traits such as drought tolerance, pest resistance, and suitability for low-input conditions. In floodplain regions of Bihar, Gujarat, and Odisha, landraces of cucurbits and legumes have been successfully reintroduced through participatory varietal selection approach and community seed banks (Tripathy *et al*., 2020) [20]. These efforts have not only improved crop survival rates under erratic rainfall conditions but have also contributed to the conservation of agrobiodiversity. Relying on traditional varieties and landraces underscore their utility in breeding programmes, participatory variety selection, and community seed systems, which are shown to foster locally adapted germplasm, restorative seed stocks, and farmer empowerment.

The implementation of CSA in diara vegetable farming is characterized by a combination of context-specific agronomic practices. These include minimal tillage, organic mulching to retain soil moisture, the use of low-cost protective measures for seedlings, and strategic adjustments to cropping calendars to circumvent climatic extremes. For instance, the cultivation of bottle gourd and pumpkin during the post-monsoon period (November–January) allows farmers to utilize nutrient-rich alluvial soils while avoiding frost damage. Additionally, community-based seed systems have been instrumental in restoring degraded lands and ensuring seed sovereignty.

Key CSA interventions in diara vegetable production encompass the following areas:

- **Soil Health Management:** The application of compost, organic fertilizers, and mulch to enhance soil fertility, improves structure, and support moisture retention under variable rainfall conditions.

- **Crop Diversification and Rotation:** The introduction of diverse vegetable species and legume rotations to disrupt pest cycles, fix atmospheric nitrogen, and reduce the risk of complete crop failure.

- **Water Resource Management:** The adoption of techniques such as rainwater harvesting, contour bunding, potholing, and micro-irrigation to optimize water use efficiency and enhance drought resilience.

- **Agroforestry and Vegetative Buffering:** The integration of trees and shrubs along riverbanks and field boundaries to stabilize microclimates, increase carbon sequestration, and protect crops from temperature and wind extremes and support biodiversity conservation.

Empirical research indicates that these CSA strategies contribute significantly to yield stability, livelihood security, and the maintenance of ecosystem services in floodplain agricultural systems (Okoronkwo *et al*., 2024; Partey *et al*., 2018) [10, 13]. However, several impediments like seed availability, quality control, institutional support, and farmer awareness must be addressed. Traditional seeds are often saved informally and may suffer from degeneration but ensuring certification or quality standards without losing farmer control is a challenge. Nevertheless, the successful adoption of such practices remains contingent on access to technical knowledge, labour, inputs, and institutional support. Strengthening local governance mechanisms, extension services, and policy frameworks is therefore essential to scale CSA interventions effectively and equitably in vulnerable agroecological zones.

Discussion

The environmental sustainability of this long-standing practice comes from its use of naturally rejuvenated soil. Each year, nutrient-rich silt and clay accumulate, reducing the need for artificial fertilizers. This cuts production costs and lessens the environmental impact of chemical inputs (Kumar *et al*., 2018) [5]. Additionally, many deep-rooted diara crops can access underground moisture from receding floodwaters. As a result, they need less irrigation, making this system naturally water-efficient (Manna *et al*., 2025) [7]. This supports broader climate-resilient agriculture (CRA) principles by encouraging resource conservation and lowering reliance on external inputs. The sustainability advantages of riverbed farming stem from using naturally replenished fertile soils with minimal outside inputs. This leads to low-cost, high-return farming systems that yield early crops and require less use of mineral fertilizers (Adarsh *et al*., 2021; Ramjan *et al*., 2018) [1, 13] facing negligible weed and pest and disease problems, easily managed through simple cultural methods, thereby reducing harmful chemical use (Pandey *et al*., 2023) [12].

Diara cultivation is naturally resilient to climate change since it aligns well with monsoon flood patterns. It takes advantage of seasonally exposed riverbeds to grow crops during the off-season when standard farming areas may be less productive or face drought and heat stress. This adaptability is vital for supporting vulnerable farmers in India who encounter increasing climate variability and extreme weather, especially in flood-prone states like Bihar, Bengal, Assam and Uttar Pradesh. This robust adaptive strategy of climate risk-avoiding farming-cycle is connected closely to river flood patterns, with planting taking place after the monsoon as water recedes and harvesting done before the next rainy season, thus, secure livelihoods of the marginal farmers by providing consistent income during lean agricultural periods (Singh, 2012) [19]. Off-season food production gives farmers alternative income source, aiding the diversification of their livelihoods and boosting their resilience against failures in conventional crop cycles.

The socio-economic advantages for vulnerable farmers are significant. Riverbed cultivation serves as a pro-poor intervention by focusing on landless and marginal farmers. It allows them to gain economic benefits through growing high-value vegetables suited for diara lands, thus addressing rural poverty improving food and nutritional security. The high market value of off-season vegetables further boosts income opportunities, contributing to food security and community resilience. Quite a large number of farmers doing diara farming are landless and depend on these temporary land parcels for their livelihoods since traditional land records rarely cover these areas. The low-cost nature of this farming, paired with the high market value of the harvested vegetables, results in substantial net returns per unit area, offering a vital income source and enhancing household food security (Kumar *et al*., 2018) [5]. This practice not only provides economic stability but also empowers marginal communities by making productive use of an otherwise underused natural resource. Evidence indicates that riverbed vegetable farming can significantly increase incomes for some of India's most vulnerable households. ICAR's livelihood interventions (2010) along the *Gomti* and *Sarayu* rivers led to notable increases in both cultivated area and net income, with each beneficiary earning around INR 35,000 in one season, far exceeding previous earnings. These earnings are crucial for landless or marginal farmers, who typically have limited options for off-season income and are more susceptible to climate-driven challenges. Diara cultivation also enhances household food security by producing vegetables that are often consumed locally, leading to less reliance on bought produce (Tripathy *et al*., 2020) [20].

Conclusion

Off-season vegetable forcing in diara lands offers a promising model of sustainable, climate-resilient agriculture but is a precarious yet critical livelihood that supports the livelihoods of India's most vulnerable smallholder farmers. Rooted in traditional knowledge yet responsive to modern challenges, this indigenous system strengthens food security, enhances agrobiodiversity, and provides economic stability in a changing climate. The low input-high return, utilizing unused land, and alignment with long-term sustainable traditional practices should be systematically leveraged integrated with institutional efforts, policy frameworks, and appropriate technical investments across diverse agro-ecological zones. Off-season vegetable forcing in riverbeds has gained prominence as an adaptive strategy for marginal and landless cultivators seeking to mitigate livelihood vulnerabilities exacerbated by climate variability convergent to a unique ecological niche that permits early production of vegetables during winter and spring months, offering early entry advantage in rural and peri-urban markets as a strategic agro-ecological system capable of contributing to climate adaptation, food system resilience, equitable livelihoods and gender equity. Traditional knowledge must be documented and integrated into formal extension work. Integration of value chain support, market linkages and cold storage access, ought to turn diara farming into a sustainable livelihood resilience reducing poverty and hunger for rural smallholders empowering them with the right tools and information for utilization of this unique agricultural system bridging the gap between traditional knowledge and modern climate adaptation. As climate variability increasingly affects conventional farming, riverbed cultivation with low-input-high return facility, aligning with climate-resilient crop husbandry emerges as a viable sustainable adaptation strategy that enhances food security, agrobiodiversity, and income stability.

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