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Khadin Rainwater Harvesting: A Historical and Ecological Perspective on Sustainable Agriculture in Arid Zone of Rajasthan

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Abstract

In the arid landscape of Western Rajasthan, where erratic and minimal rainfall (<250 mm annually) presents significant challenges to sustainable water management and soil moisture conservation, the Khadin system—a traditional rainwater harvesting technique developed by the Paliwal Brahmins in the 15th century in Jaisalmer—offers an enduring, nature-based solution. Combining environmental conservation with enhanced soil and water management, Khadin exemplifies indigenous resilience in arid agriculture.

The Khadin system consists of a long earthen embankment constructed across gently sloping terrain, designed to capture and retain surface runoff from adjacent rocky catchments. This trapped water percolates into the soil, enriching it with moisture and nutrients, enabling the rainfed cultivation of Rabi crops such as wheat, barley, chickpea, and mustard. Beyond its agricultural utility, Khadin significantly enhances groundwater recharge (35-50%), improves soil fertility, and mitigates salinity (20-30%), making it a holistic ecological system.

This study explores the historical evolution, geographical distribution, and environmental significance of the Khadin system through an interdisciplinary lens, emphasizing its role as a community-driven conservation practice. Additionally, it evaluates Khadin's relevance in addressing contemporary challenges such as water scarcity, desertification, and climate variability. The paper argues for the revival and policy integration of Khadin as a sustainable water management strategy, advocating for modern adaptations, including GIS-based catchment optimization and agroforestry integration. Revisiting the environmental history of Khadin aims to bridge traditional knowledge with modern conservation frameworks, reinforcing its importance in India and beyond.

Keywords: Khadin system, Rainwater harvesting, Crop production

1. Introduction

Rajasthan, India's largest state, is at the forefront of the country's battle against desertification, groundwater depletion, and increasing water stress. The state faces severe land degradation and a rapidly declining water table, exacerbating agricultural and ecological vulnerabilities (Ministry of Environment, Forest and Climate Change [MoEFCC], 2023). Groundwater extraction rates have risen from 35% in 1984 to a staggering 151.07% in 2023, surpassing natural recharge levels and signaling an impending crisis (Central Ground Water Board [CGWB], 2023). In Jaipur, the state capital, the groundwater table has dropped by an average of 25 meters over the last decade, with more than 40% of wells now exceeding depths of 40 meters (Centre for Water and Sanitation [CWAS], 2023). These alarming trends highlight the urgent need for sustainable water management strategies, particularly in Rajasthan's most vulnerable regions.

Situated within this context, Jaisalmer—the largest district in Rajasthan, spanning 38,401 km²—faces some of the most extreme manifestations of aridity and land degradation (Rajasthan Foundation, n.d.). Located in the westernmost part of India, Jaisalmer shares an international boundary with Pakistan and is characterized by its position in the Thar Desert, an ecosystem marked by erratic precipitation, high evaporation rates (>2,000 mm annually), and severe water stress (Krishi Vigyan Kendra, n.d.). The region falls under the Hyper-Arid Partially Irrigated Western Plain Zone (Zone 1c), with an average annual rainfall of approximately 160 mm and summer temperatures reaching 49.2°C, while winters drop to as low as 1°C (Krishi Vigyan Kendra, n.d.; DCMSME, n.d.). These extreme climatic conditions make conventional irrigation methods unsustainable, necessitating innovative and adaptive water conservation strategies.

India has a long history of indigenous water harvesting systems, including tanks, stepwells, baoris, and Khadin, which have historically enabled agricultural sustainability in arid and semi-arid landscapes (Agarwal & Narain, 1997). However, many of these systems have fallen into disuse due to socioeconomic, cultural, and policy shifts, leading to the deterioration of local water management institutions (Kumar et al., 2006). While modern irrigation infrastructure has expanded, it has often come at the cost of unsustainable groundwater depletion and ecological degradation, further worsening water security concerns in dryland regions (Muralidharan & Athawale, 1998).

The Jaisalmer district exemplifies the critical need to revive traditional water management practices such as Khadin—a community-driven rainwater harvesting system designed to retain monsoon runoff for agricultural use (Srinivasan & Babu, 2000). The Khadin system, historically developed by the Paliwal Brahmins in the 15th century, relies on long embankments constructed across gently sloping terrain to collect and store rainwater, improving soil moisture retention and enabling the cultivation of Rabi crops such as wheat, mustard, chickpea, cumin, and taramira (Eruca sativa) (Krishi Vigyan Kendra, n.d.). Unlike modern groundwater-dependent irrigation, which depletes already scarce resources, Khadin harnesses seasonal runoff, ensuring rainfed cultivation in one of the world's driest landscapes (Srinivasan & Babu, 2000).

Increasing climate variability poses new challenges to traditional water harvesting systems. For instance, between June 1 and August 11, 2024, Jaisalmer received 259.9 mm of rainfall—134% above the seasonal average—highlighting the unpredictability of precipitation patterns and the need for adaptive water management strategies (Down To Earth, 2024). While such anomalous rainfall events may provide temporary relief, they also underscore the increasing volatility of climate systems, making water conservation efforts even more critical.

As groundwater tables decline and climate variability intensifies, revitalizing Khadin as a climate-resilient, sustainable water harvesting system is essential for ensuring long-term agricultural sustainability in Rajasthan's arid regions. By bridging traditional knowledge with contemporary conservation strategies, this study underscores the urgent need to restore and integrate Khadin within modern water management frameworks to mitigate desertification and enhance agricultural resilience.

This study examines the role of traditional rainwater harvesting systems, particularly Khadin, in enhancing water security, ecological sustainability, and agricultural resilience in Rajasthan's arid regions. Given the increasing water stress and declining groundwater levels, understanding the hydrological, agricultural, and economic significance of Khadin is essential.

Khadin has historically supported rainfed crop production by improving soil moisture retention and groundwater recharge, making it an integral part of sustainable agriculture in arid landscapes. This study explores its significance in crop cultivation and agricultural productivity in Rajasthan's water-scarce regions.

Furthermore, the study looks at broader socio-economic and policy challenges that have contributed to the decline of Khadin systems over time. By understanding these barriers, it aims to highlight the importance of integrating Khadin with modern water conservation strategies, ensuring its continued relevance in Rajasthan's evolving agricultural and water management landscape.

2. Overview of the Khadin System

2.1 Historical Background and Development

The Khadin system, a traditional runoff-based farming technique, was developed by the Paliwal Brahmins in the 15th century in Jaisalmer, Rajasthan. This system was specifically designed to conserve and utilize rainwater for agriculture in arid and hyper-arid regions, where groundwater extraction is impractical due to extreme water scarcity (Narain & Goyal, 2005). It shares strong parallels with ancient irrigation techniques, including the flood irrigation methods used in Iraq as early as 4500 BC (Prinz & Singh, n.d.), the sophisticated stone-bunded reservoirs employed by the Nabateans in the Middle East (Singh & Mishra, 2022), and the highly adaptive rainwater harvesting techniques practiced by the Negev Desert civilizations over 4000 years ago (Sharma & Yadav, 2021).

The system emerged as a response to erratic rainfall patterns in the Thar Desert, where annual precipitation is less than 250 mm. Unlike modern irrigation methods, Khadin farming relies entirely on conserved soil moisture, making it a sustainable alternative for agriculture in Rajasthan's harsh climatic conditions (Khan, 1996).

2.2 Structural Components and Functionality

The Khadin system consists of three major components that work together to optimize rainwater capture, soil moisture retention, and sustainable farming:

- **Catchment Area**: The surrounding rocky and gravelly terrain serves as a catchment that directs monsoon runoff into the lower-lying agricultural field. The catchment-to-cultivated land ratio is typically maintained around 10:1 to ensure adequate soil moisture retention (Yadav, 2023).
- **Earthen Embankment (Bund)**: A 100–300 m long earthen bund is constructed at the lower end of the slope to trap runoff and prevent water loss. Sluices and spillways are built into the bund to safely channel excess water and prevent erosion (CAZRI, 2005).
- **Cultivation Zone**: After the monsoon, the area behind the bund retains moisture-laden soil, enabling the growth of Rabi crops (such as wheat, mustard, barley, and gram) without additional irrigation. Alluvial sediments deposited by the runoff enhance soil fertility, reducing the need for chemical fertilizers (Narain & Goyal, 2005).

Figure 1 Lanela Khadin, Rajasthan

2.3 Hydrological and Agricultural Benefits

The Khadin system greatly improves soil moisture retention, groundwater recharge, and crop productivity. Studies in western Rajasthan provide quantitative insights into its impact:

- **Groundwater Recharge**: Approximately 11–48% of the water retained in a Khadin percolate into aquifers, raising groundwater levels by 0.8 to 2.2 meters annually (Khan, 1996). Wells downstream of Khadin fields often show a post-monsoon water level increase of about 1.2 meters (Sharma & Yadav, 2021).
- **Soil Moisture Retention**: Soil in Khadin fields can retain roughly 200–250 mm of moisture per meter of depth, supporting crops for 4–6 months after the monsoon (Singh & Mishra, 2022).
- **Crop Yields**: Farmers using Khadin farming report significantly higher yields — for example, about 36% higher for sorghum and 25% higher for green gram — compared to non-Khadin farms in similar regions (CAZRI, 2005).

Overall, the Khadin ensures maximum water retention with minimal runoff losses, making it more efficient than canal or tubewell irrigation systems (Yadav, 2023). Additionally, the slow percolation of water helps leach salts downward, preventing soil salinization and thus improving soil health and long-term productivity (Narain & Goyal, 2005).

2.4 Socio-Economic and Environmental Importance

Khadin farming contributes to drought resilience by providing reliable food and fodder during severe droughts, ensuring food security for local communities (Singh & Mishra, 2022). Reduced dependence on groundwater and fertilizers lowers input costs for farmers, with net returns from Khadin farming reported to be 42% higher for jowar and 54% higher for green gram compared to conventional farms (Khan, 1996). Moreover, Khadin prevents desertification by maintaining soil moisture and reducing land degradation (CAZRI, 2005). It also promotes sustainable agro-ecological balance, supporting biodiversity in arid landscapes (Yadav, 2023).

2.5 Limitations and Mitigation Strategies

Despite its many benefits, the Khadin system is not without challenges, but targeted interventions can enhance its effectiveness.

- Waterlogging during Monsoon: The accumulation of excess water restricts Kharif crop cultivation. Introducing water-tolerant and leguminous plants can optimize land use while ensuring sustainable productivity.
- Topographical Limitations: The system thrives only in sloping, rocky terrains. For flatter regions, alternative structures such as semi-circular bunds and contour trenches offer viable solutions.
- Infrastructure and Maintenance: Constructing and maintaining embankments require skilled labor. Locally sourced materials can be used to reduce costs while ensuring sustainability. Additionally, bioengineering methods, such as vetiver grass plantations, can reinforce embankments and reduce erosion.
- Climate Dependence and Economic Vulnerability: Since Khadin farming is entirely rainfall-dependent, integrating livestock rearing, beekeeping, and agroforestry can diversify income sources and strengthen farmers' economic resilience.

Khadins flourished for centuries but fell into disuse in the 20th century due to socio-political upheavals and the introduction of canal irrigation (Kumar et al., 2006).

3. Crop production and Economic Viability of the Khadin System

Evaluating the yield and economic viability of the traditional Khadin system compared to modern irrigation methods in Rajasthan reveals significant benefits associated with Khadin cultivation.

3.1 Crop Yield Enhancement through Khadin Systems

Studies have demonstrated that the implementation of Khadin systems leads to substantial increases in crop yields. Research indicates that cropping in Khadins has resulted in a 33% to 64% increase in grain yields for various crops. Specifically, average yields of 20-30 quintals per hectare for wheat and 13-25 quintals per hectare for chickpea have been reported without the application of specific agronomical practices or fertilizers in Jaisalmer (Goyal et al., 2018). These figures underscore the effectiveness of Khadin systems in boosting agricultural productivity in arid regions.

3.2 Economic Viability: Cost-Benefit Analysis

Studies highlight that Khadin-based agriculture significantly boosts farmers' incomes. A study by Kumar (2018) found that farmers using the Khadin system earned an additional ₹517,311 per hectare annually due to improved soil moisture and better yields. Over three years, the total financial gain per hectare was estimated at ₹1,879,888, with additional savings of ₹29,257 from reduced groundwater pumping.

The study also showed that for every ₹1 invested in a Khadin system, farmers received ₹2.55 in direct returns. When considering environmental and social benefits, including groundwater conservation and land preservation, this figure rose to ₹2.68.

These findings reinforce that Khadin farming is not just a sustainable water conservation method but also a strong financial investment for farmers in arid regions. Integrating Khadin systems into regional policies could further enhance agricultural resilience and economic stability.

3.3 Comparative Analysis: Khadin Systems vs. Modern Irrigation

When comparing Khadin systems to modern irrigation methods, several factors emerge:

- Water Use Efficiency: Khadin systems rely on harvested rainwater and surface runoff, eliminating dependence on groundwater. This promotes sustainable water use and reduces pressure on depleting aquifers.
- Cost Implications: The construction and maintenance of Khadin systems are relatively low-cost, utilizing locally available materials and traditional knowledge. In contrast, modern irrigation systems

often require significant capital investment and ongoing operational costs (Goyal et al., 2018).
- Environmental Impact: Khadin systems enhance groundwater recharge and soil fertility through the deposition of fine sediments, contributing to environmental sustainability. Modern irrigation methods may lead to issues such as soil salinization and depletion of water resources if not managed properly.

4. Institutional and Policy Review

Rajasthan faces acute water scarcity, declining groundwater levels, and desertification. While the state has enacted various policies to address these challenges, traditional rainwater harvesting systems like Khadin remain underutilized. This section reviews Rajasthan-specific policies, identifies gaps in Khadin adoption, and suggests strategies for integration.

4.1 Key Water Conservation Policies in Rajasthan

- Rajasthan State Water Policy (2010): Advocates for the revival of traditional water harvesting systems but lacks implementation strategies (Government of Rajasthan, 2010).
- Rajasthan Water Resources Regulatory Act (2012): Establishes water allocation and regulation frameworks but does not explicitly include Khadin systems (Government of Rajasthan, 2012).
- Mukhyamantri Jal Swavlamban Abhiyan (MJSA, 2016): Aims at village-level water self-sufficiency but prioritizes generic water structures over traditional systems like Khadin (Government of Rajasthan, 2024).
- Rajasthan River Basin and Water Resources Planning Act (2015): Focuses on large-scale planning with minimal emphasis on traditional systems (Government of Rajasthan, 2015).
- Atal Bhujal Yojana (2020): Promotes groundwater conservation but lacks direct support for surface-runoff-dependent systems like Khadin (Rajasthan Groundwater Department, 2023).

4.2 Policy Gaps Hindering Khadin Adoption

1. Lack of Integration: Policies prioritize large-scale infrastructure while overlooking localized traditional methods (Bassi & Vedantam, 2013).
2. Inadequate Financial Support: No dedicated funding exists for Khadin restoration, unlike modern irrigation projects (Malik & Singh, 2023).
3. Limited Technical Training: Farmers lack access to structured training on Khadin construction and maintenance (CAZRI, 2008).
4. Regulatory Constraints: Government schemes often exclude Khadin systems due to rigid eligibility criteria (Government of Rajasthan, 2019).
5. Data Gaps: The absence of Khadin-specific records in official irrigation statistics limits policy attention (Singh & Sharma, 2020).

4.3 Lessons from Other Arid Regions

1. Alwar, Rajasthan: Community-led Johad revival increased groundwater levels and agricultural productivity (Tarun Bharat Sangh, 1999).
2. Saurashtra, Gujarat: State-backed rainwater harvesting efforts transformed water availability (IWMI, 2010).
3. Tunisia's Jessour System: Government-subsidized restoration improved soil moisture and drought resilience (Satoyama Initiative, 2011).

4.4 Recommendations for Khadin Integration

1. Explicit Policy Inclusion: Amend water policies to include Khadin as a viable water conservation method.

2. Financial Incentives: Introduce grants, subsidies, and tax breaks for Khadin rehabilitation.
3. Technical Training: Establish farmer training programs and pilot demonstration projects.
4. Community-Led Conservation: Empower local governance structures to maintain Khadin systems through participatory management.
5. Climate Adaptation Alignment: Integrate Khadin restoration into Rajasthan's State Action Plan on Climate Change.

   Rajasthan's policies acknowledge the importance of traditional water harvesting, yet gaps in implementation limit Khadin's potential. Learning from successful models in Alwar, Gujarat, and Tunisia, integrating Khadin into policy frameworks, financing mechanisms, and community-driven initiatives will promote sustainable water management in arid regions.

5. Challenges and Future Directions

5.1 Challenges

- Encroachment and Land Degradation – Rapid urbanization, land-use changes, and neglect have resulted in the degradation of traditional Khadin systems, reducing their water-holding capacity and agricultural viability.
- Lack of Institutional and Policy Support – Unlike modern irrigation projects, Khadin systems remain undervalued in government policies, with limited financial aid, research incentives, and structured revival programs (Bassi & Vedantam, 2013).
- Climate Variability and Rainfall Uncertainty – Increasing unpredictability in monsoon patterns, prolonged droughts, and intense rainfall events impact the effectiveness of Khadin-based farming, necessitating adaptive modifications.
- Declining Indigenous Knowledge and Maintenance Practices – Traditional expertise in Khadin construction and upkeep is diminishing due to generational shifts, migration, and the influence of modern irrigation methods.

5.2 Strategies to overcome the challenges

- Technological Innovation for System Enhancement – Integrating GIS, remote sensing, hydrological modeling, and AI-based predictive analytics can optimize site selection, improve structural resilience, and enhance water retention capacity for sustainable agriculture.
- Policy Mainstreaming and Institutional Support – Embedding Khadin systems into government initiatives like Jal Shakti Abhiyan, Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), SDGs, and state-level water conservation programs can facilitate financial backing, technical assistance, and large-scale adoption.
- Community-Led Conservation and Capacity Building – Training local farmers and water-user groups in sustainable Khadin management, maintenance techniques, and crop diversification strategies can revitalize these systems while ensuring long-term engagement.
- Hybrid Water Management Approaches – Combining traditional Khadin wisdom with modern rainwater harvesting techniques and climate-resilient farming methods can create a more adaptive and efficient water resource management framework in arid regions.
- Research and Documentation of Best Practices – A comprehensive database on successful Khadin models, restoration projects, and community-led initiatives can serve as a knowledge repository for policymakers, researchers, and practitioners.

5.3 Future Research Directions

- Site Suitability Assessment – Leveraging Digital Elevation Models (DEM) and GIS to identify optimal locations for Khadin systems based on topographic features, soil properties, and hydrological parameters.
- Comparative Analysis of Irrigation Methods – Assessing the effectiveness of Khadin irrigation in comparison to modern techniques such as drip and sprinkler irrigation, focusing on moisture retention, crop productivity, and soil health.
- Soil Health and Nutrient Dynamics – Investigating the long-term influence of Khadin irrigation on soil fertility, salinity levels, and microbial biodiversity to develop sustainable land management strategies.
- Hydrological Performance and Water Conservation – Evaluating the water retention capacity and groundwater recharge potential of various Khadin designs to optimize water use efficiency in arid and semi-arid regions.
- Climate Change Resilience – Examining the adaptability of Khadin systems under shifting climatic conditions, including variations in rainfall intensity, temperature fluctuations, and increasing occurrences of extreme weather events.

This forward-looking research agenda will provide deeper insights into optimizing Khadin systems and integrating them with modern agricultural and water management practices. By continually learning and innovating, stakeholders can ensure that Khadin – as both an object of study and a living practice – thrives in the years to come.

6. Key Findings

The Khadin system, a centuries-old runoff farming technique, has consistently demonstrated remarkable efficiency in water conservation, soil moisture retention, and enhancing agricultural productivity in Rajasthan's arid landscapes. Empirical research and case studies affirm that Khadin-based fields yield significantly higher agricultural productivity than non-Khadin lands due to improved water-use efficiency and soil fertility (Goyal et al., 2018; Kumar, 2018).

Beyond its direct agricultural benefits, the Khadin system functions as a nature-based solution for climate resilience, contributing to groundwater recharge, mitigating desertification, and promoting sustainable land management in water-scarce regions. However, despite its proven effectiveness, several challenges threaten its continuity, including institutional neglect, insufficient financial support, and rapid urbanization, which encroach upon traditional Khadin sites and diminish local knowledge.

Revitalizing and scaling up Khadin-based farming requires a multifaceted approach that integrates policy reforms, scientific innovations, and grassroots participation. By embedding the Khadin system within national and global climate resilience strategies, policymakers and stakeholders can unlock its full potential—ensuring sustainable agriculture, water security, and long-term ecological stability across dryland regions.

7. Conclusion

Building upon the demonstrated efficiency and resilience of the Khadin system, this study underscores its critical role as a cost-effective, eco-friendly, and climate-adaptive intervention for sustainable agriculture in arid regions. Its ability to enhance soil moisture, recharge groundwater, and support climate-resilient farming highlights its significance in addressing contemporary challenges such as water scarcity, soil deg-

radation, and climate variability.
However, realizing the full potential of Khadin farming requires an integrated and collaborative approach. A combination of strong policy backing, scientific advancements, and community stewardship is essential for the revival and modernization of this traditional system. Governments, research institutions, and local communities must work together to integrate Khadin restoration into national water conservation policies, agro-ecological frameworks, and climate adaptation strategies.
By fostering institutional commitment, enhancing local capacities, and leveraging modern hydrological and remote sensing tools, the Khadin system can be revitalized as a scalable and replicable model for sustainable water resource management. Bridging traditional knowledge with contemporary science will not only secure rural livelihoods but also strengthen the resilience of dryland agriculture for future generations.

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