

Haveli rainwater harvesting system and its role in socio-hydrological processes and agricultural sustainability

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ABSTRACT

The Haveli water system is a traditional, community-managed rainwater harvesting practice in the Bundelkhand region of central India, developed over centuries to cope with recurrent droughts and erratic rainfall. This paper critically examines the Haveli system as a decentralized, field-based water management strategy, synthesizing evidence on its historical roots, technical design, hydrological performance, social organization, and role in enhancing agricultural productivity and water security. Drawing on recent hydrological studies and watershed assessments, the paper highlights how Havelis capture monsoon runoff, recharge shallow aquifers, raise groundwater levels, and support rabi agriculture in the region's fragile vertisol landscapes. It also analyzes the social and institutional dimensions of Haveli management, including community ownership, equity in water access, and the erosion of traditional institutions that has contributed to the system's decline. The paper further discusses the environmental benefits of Havelis in reducing soil erosion, improving soil fertility, and rehabilitating degraded land, as well as the challenges posed by land use change, climate variability, and policy neglect. It evaluates contemporary revival efforts that integrate traditional Haveli knowledge with scientific design and participatory watershed management, and outlines policy recommendations for mainstreaming this indigenous system into sustainable water governance in Bundelkhand.

Keywords: Bundelkhand region, Climate resilience, Groundwater recharge, Haveli system, Semi-arid ecosystems, Traditional water harvesting

INTRODUCTION

Bundelkhand, a semi-arid region spanning parts of Uttar Pradesh and Madhya Pradesh, is chronically vulnerable to drought, erratic rainfall, and groundwater depletion (Gupta *et al.*, 2014). The region's black cotton soils (vertisols) have high clay content, which swells when wet and cracks when dry, making conventional irrigation difficult and increasing runoff and erosion (Bhattacharjee and Ahmad, 2023). In this fragile agro-ecological setting, communities developed the Haveli system as a decentralized, field-based water harvesting technique

to capture and store monsoon runoff for post-monsoon (rabi) agriculture (Jana *et al.*, 2017). A Haveli is essentially a seasonal reservoir created by constructing an earthen embankment (bund) across a gentle slope in a farmer's field, forming a shallow basin that traps rainwater during the kharif (monsoon) season. The stored water is used to recharge groundwater and to provide residual soil moisture and supplemental irrigation for rabi crops like wheat, mustard, and chickpea. After the monsoon, the water is drained and the moist Haveli bed is cultivated, often yielding higher productivity than surrounding fields.

At the field-application end, studies on drip-based further show how irrigation method and water quality affect root-zone moisture availability over time—reinforcing that the benefits of increased water availability are maximized when on-farm delivery maintains adequate moisture in the crop root zone (Singh *et al.*, 2020a,b). At the farm scale, the key benefit is increasing effective water for crops by reducing runoff/erosion losses and retaining more rainfall within the field–soil system. Empirical studies show that interventions which curb runoff and soil loss (e.g., mulching, intensified/interplanted cropping) can improve rainfall partitioning and root-zone moisture conditions, strengthening crop response under water stress (Kadam *et al.*, 2026; Singh *et al.*, 2025a,b; Quamar *et al.*, 2025; Kumar *et al.*, 2022). More broadly, reviews of biological and mechanical soil–water conservation measures report consistent reductions in runoff/sediment yield and improved in-situ moisture outcomes—consistent with the functional pathway targeted by field bunding and small water-harvesting structures supporting rabi irrigation reliability (Singh *et al.*, 2025c; Yadav *et al.*, 2024).

In recent decades, many Havelis fell into disrepair due to neglect, changing land use, and institutional breakdown, exacerbating water scarcity

in Bundelkhand (Fig. 1). However, renewed interest in traditional knowledge and watershed-based interventions has led to the scientific assessment and revival of the Haveli system as a climate-resilient, low-cost water management strategy (Singh *et al.*, 2022).

HISTORICAL EVOLUTION AND ORIGIN

The Haveli system in Bundelkhand is believed to have evolved over 300–500 years as an indigenous response to the region’s erratic rainfall and drought-prone conditions (Singh *et al.*, 2022). It emerged in the black soil (vertisol) landscapes of central India, where farmers needed to maximize the use of limited monsoon rains for both kharif and rabi agriculture. Historical evidence suggests that Havelis were traditionally constructed and maintained by small and marginal farmers, particularly those located in the upper reaches of the landscape, who captured surface runoff from their own fields and small catchments. The term Haveli in this context refers not to a mansion or palace, but to a traditional water harvesting tank or pond used for agricultural purposes (Singh *et al.*, 2023). Over generations, local communities refined the design and placement of Havelis based on empirical knowledge of local topography, soil types, and rainfall patterns. The

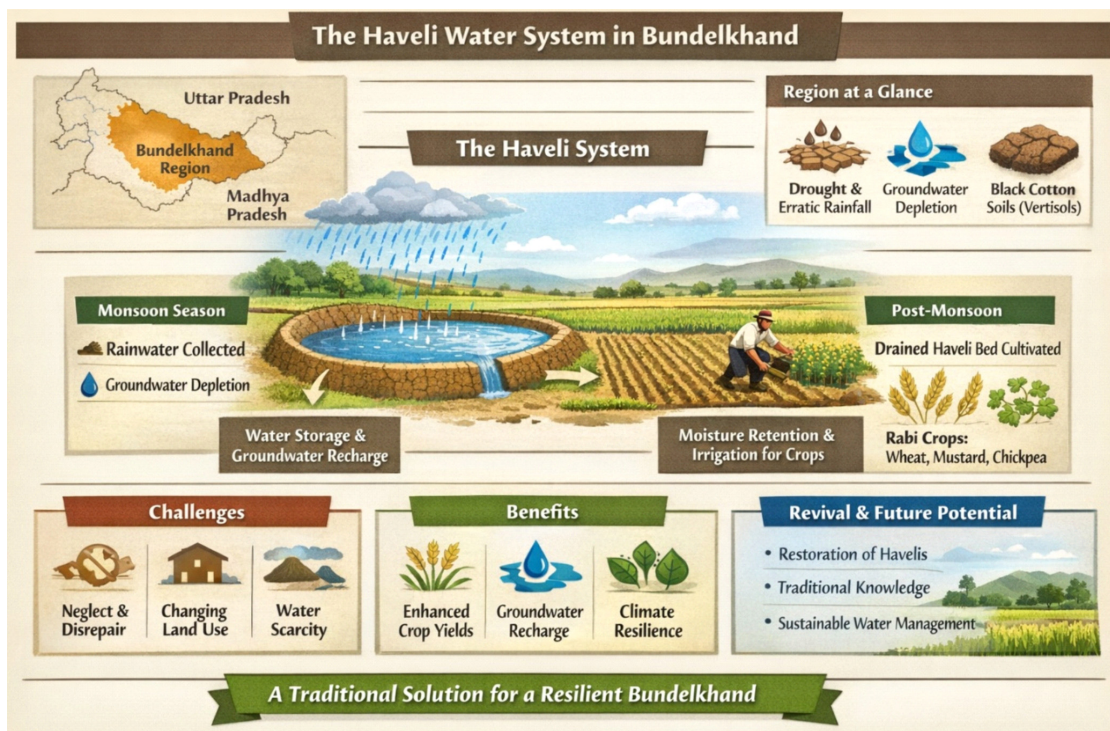


Fig. 1. Haveli water harvesting system in Bundelkhand for sustainable and resilient agriculture

system was closely tied to the agrarian calendar: during the kharif season (June–September), the Haveli acted as a reservoir, storing monsoon runoff; after the rains receded, the water was drained and the moist bed was used for rabi cultivation (October–February). Havelis were part of a broader network of traditional water harvesting structures in Bundelkhand, including tanks, wells, and small check dams, which together formed a decentralized water management system adapted to local conditions (Fig. 2). This indigenous knowledge was passed down orally and through practice, with communities collectively deciding on the location, size, and maintenance of Havelis. The historical

resilience of the Haveli system lies in its simplicity, low cost, and integration with local farming systems, making it a sustainable solution for water-scarce regions (Rao *et al.*, 2012).

TECHNICAL DESIGN AND HYDROLOGY

A typical Haveli consists of an earthen embankment (bund) constructed across the natural slope of the land, creating a shallow, bowl-shaped basin that intercepts and stores surface runoff (Table 1). The embankment is usually built using locally available soil, compacted to minimize seepage, and is oriented perpendicular to the direction of runoff flow. The length of the bund typically ranges from 50 to 150 m, with a width of 4–10 m and a height of 1–3 m, depending on the catchment size and topography (Singh *et al.*, 2023). The Haveli basin itself is generally 100–300 m in length and is designed to hold a storage capacity of about 50,000–100,000 m³, depending on the site. The catchment area contributing to a Haveli usually ranges from 20 to 200 hectares, consisting of agricultural fields and fallow land that generate runoff during the monsoon (WRD, 2018). The basin is often located in a depression or gently sloping area to maximize water collection while minimizing the risk of breaching during heavy rainfall. An outlet or spillway is provided at one end of the embankment to safely release excess water once the Haveli is full, preventing overtopping and embankment failure. In traditional designs, this outlet is a simple earthen channel, but in modern rejuvenation projects, it is often lined with masonry or concrete to improve durability and control (Iqbal and Riaz, 2024). After the monsoon, the stored water is gradually drained through this outlet, and the moist Haveli bed is prepared for rabi cropping.

HYDROLOGICAL FUNCTIONING

The Haveli system functions as a rainwater harvesting structure that intercepts surface runoff generated during the southwest monsoon (June–September) and stores it for later use. In a typical Bundelkhand watershed, about 18% of annual rainfall (around 135 mm out of 750 mm) is converted into surface runoff, which is captured by the Haveli. In wet years (rainfall >900 mm), runoff can reach 250–300 mm (30–35% of rainfall), while in dry years (<450 mm), most rainfall is absorbed in the soil and little surplus runoff is generated (Liansangpuii *et al.*, 2023).

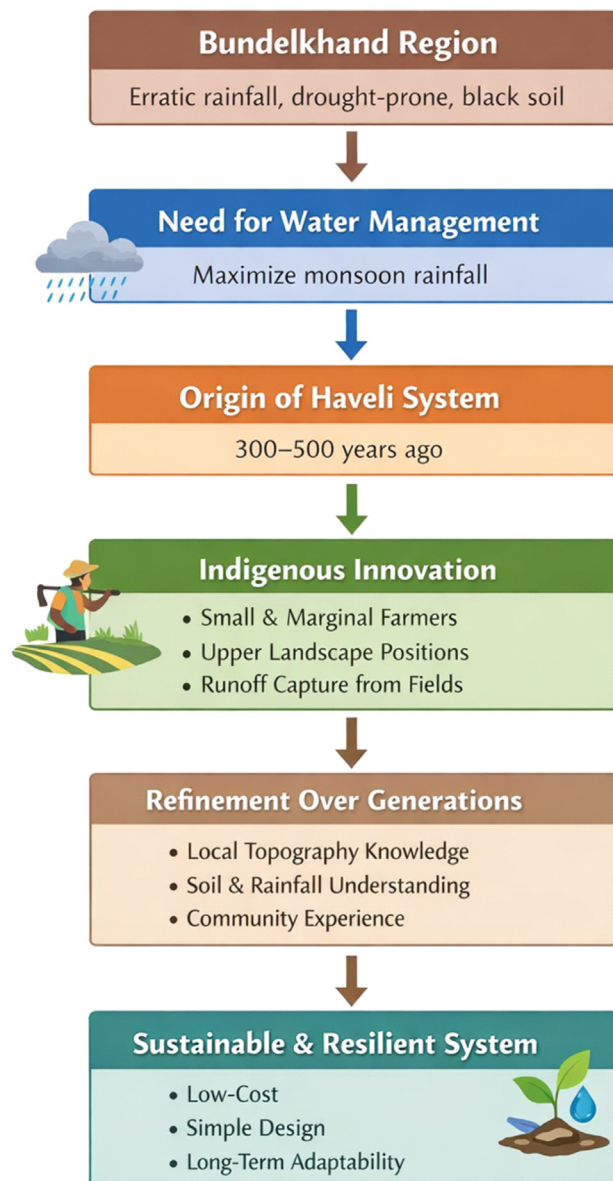


Fig. 2. Evolution of the Haveli system

Table 1. Technical and impact parameters of the Haveli system

Parameter	Value / Description	Reference
Groundwater table rise	2–6 meters	Liansangpuii <i>et al.</i> (2023)
Infiltration rate	0.1–5.0 mm day ⁻¹	Singh <i>et al.</i> (2023)
Crop yield increase	10–70%	Singh <i>et al.</i> (2021)
Soil organic carbon increase	20–40%	Kumar <i>et al.</i> (2021)
Household income growth	2–3 fold increase	Samuel <i>et al.</i> (2015)
Catchment-to-submergence ratio	20:1 to 50:1	Rao <i>et al.</i> (2012)

Hydrological studies in the Parasai–Sindh watershed of Jhansi district show that a rejuvenated Haveli can harvest about 1.9–2.0 times its storage capacity in wet years, 1.1–1.7 times in normal years, and only about 0.2 times in dry years (Liansangpuii *et al.*, 2023). The stored water in the Haveli is lost through three main pathways as evaporation from the water surface, percolation into the underlying soil and spillover through the outlet. Parasai–Sindh study of Liansangpuii *et al.* (2023) recorded 55,000–100,000 m³ percolation per year, contributing significantly to groundwater recharge, while evaporation losses were in the range of 12,000–22,000 m³ per year. Spillover occurs only when inflow exceeds storage capacity, and the volume spilled depends on rainfall intensity and duration.

GROUNDWATER RECHARGE AND WATER BALANCE

One of the most important functions of the Haveli system is its role in recharging shallow groundwater aquifers (Fig. 3), which are the primary source of irrigation and domestic water in

**Fig. 3.** Typical Haveli indigenous water management system

Bundelkhand (Singh *et al.*, 2023). Monitoring of dug wells in the Parasai–Sindh watershed showed that after Haveli rejuvenation, groundwater levels rose by 2–6 m, with an increase in hydraulic head of 1.4–2.7 m compared to pre-rejuvenation conditions (Liansangpuii *et al.*, 2023).

In wet years, the hydraulic head increased by about 1.4 m due to Haveli recharge, while in normal years the increase was even higher (about 2.7 m), indicating that the system is particularly effective in normal rainfall conditions. This enhanced groundwater availability allowed farmers to irrigate rabi crops more reliably, reducing the risk of crop failure and increasing cropping intensity. According to water balance evaluations, the system's runoff harvesting efficiency is closely tied to annual precipitation cycles: in wet years, the structure captures approximately 28–34% of rainfall, while in normal years, this figure ranges from 16% to 27%. During extreme drought conditions, however, the harvest rate significantly diminishes to about 2.8%. A hallmark of the Haveli's efficiency is its capacity for subsurface recharge, as roughly 60–70% of all harvested water percolates into the aquifer, with the remaining volume lost to evaporation or spillover (Sharma *et al.*, 2005).

SOCIAL AND INSTITUTIONAL DIMENSIONS

Historically, the Haveli system was managed collectively by village communities, with farmers at the upstream end of the landscape taking the lead in constructing and maintaining the embankments (Samuel *et al.*, 2015). The system was embedded in local social institutions, where decisions about location, size, and maintenance of Havelis were made through community consensus, often mediated by village elders or traditional leaders (Fig. 4). This collective management ensured that the benefits of the Haveli were shared among upstream and downstream farmers: upstream farmers stored water in their fields, while downstream farmers benefited

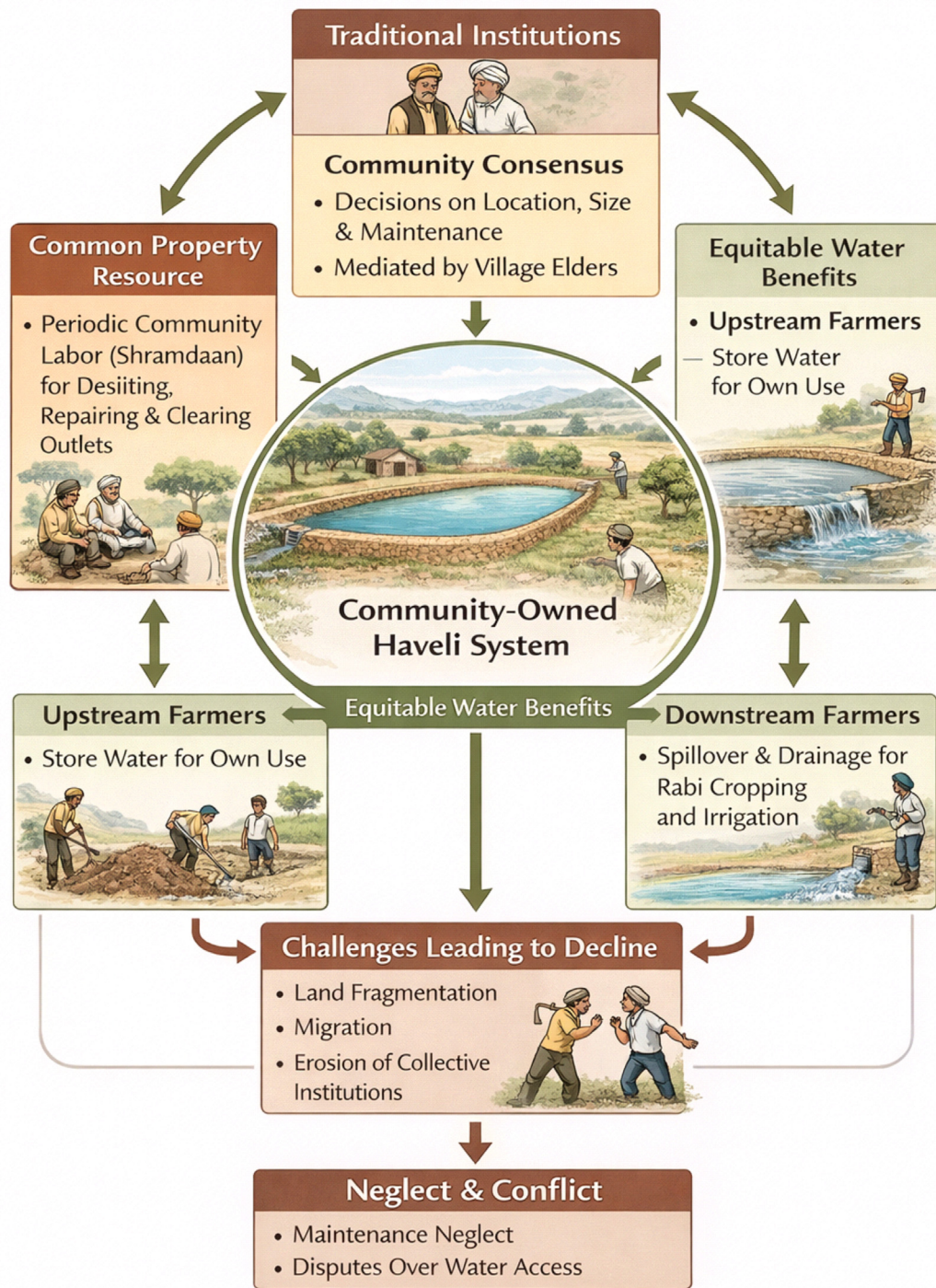


Fig. 4. Social and institutional dimensions of Haveli system

from the drainage and spillover water for pre-sowing irrigation and rabi cropping. In many villages, Havelis were maintained as common property resources, with periodic community labor (shramdaan) organized for desilting, repairing breaches, and clearing outlets. However, over time, this collective management eroded due to factors

such as land fragmentation, migration, and the weakening of traditional village institutions (Singh and Joshi, 2020). As a result, many Havelis fell into disrepair, and the responsibility for maintenance shifted from the community to individual landowners, who often lacked the resources or incentive to maintain the structures.

EQUITY AND ACCESS ISSUES

The Haveli system has important implications for equity and access to water, particularly in a region like Bundelkhand where small and marginal farmers dominate the agricultural landscape. Traditionally, Havelis were constructed by small farmers in the upper reaches, who had limited access to canal irrigation and depended heavily on rainfed agriculture. These upstream farmers benefited directly from the stored water for their own rabi crops, while downstream farmers, including landless laborers and smallholders, benefited indirectly from the drainage and spillover water, which improved soil moisture and groundwater levels in their fields (Singh *et al.*, 2023). This created a degree of horizontal equity, where water benefits were shared across different classes of farmers. However, in practice, access to Haveli water is not always equitable. In some villages, dominant landowning groups have exerted control over Havelis, limiting access for marginalized communities such as Scheduled Castes and landless laborers. Moreover, the decline of collective institutions has led to conflicts over water sharing, particularly in dry years when water is scarce. Modern revival projects have sought to address these equity issues by involving all stakeholders in planning and implementation, promoting inclusive participation, and ensuring that benefits reach the most vulnerable groups (Scanlon *et al.*, 2019). For example, watershed projects in Bundelkhand have included provisions for constructing Havelis in areas where marginalized communities can benefit, and for strengthening local water user groups to manage the structures collectively (Anonymous, 2023).

ENVIRONMENTAL AND AGRICULTURAL IMPACTS

Soil and land productivity

The Haveli system has significant positive impacts on soil health and land productivity in Bundelkhand's vertisols as given in Fig. 5. The repeated impounding of water in the Haveli basin leads to the deposition of fine sediments and organic matter, which improves soil fertility and structure over time (Singh and Singh, 2002). Studies show that Haveli fields are typically 15–25% more productive than surrounding fields, due to higher soil moisture, better nutrient status, and improved tillage. The accumulated silt and organic materials in

the Haveli bed enhance water-holding capacity and reduce soil cracking, making the land more suitable for rabi crops like wheat, mustard, and chickpea. In addition, the Haveli system helps to reduce soil erosion and land degradation by slowing down runoff and trapping sediments on agricultural land. This contributes to the rehabilitation of degraded landscapes, converting fallow and low-productivity land into productive agricultural fields (Singh *et al.*, 2021).

Crop production and cropping intensity

The availability of stored water and improved groundwater levels through the Haveli system has led to significant increases in crop production and cropping intensity in Bundelkhand. In the Parasai–Sindh watershed, the rejuvenation of Havelis enabled farmers to convert about 20% of permanent fallow land into productive agriculture, increasing the area under rabi crops (Liansangpui *et al.*, 2023). Farmers reported reduced risk of crop failure and higher yields of rabi crops, particularly wheat and mustard, due to more reliable supplemental irrigation from shallow dug wells. In some cases, farmers shifted from low-income crops like chickpea and mustard to higher-value crops like wheat and barley, taking advantage of the improved water security (Yadav *et al.*, 2024).

Water security and livelihoods

Beyond agriculture, the Haveli system enhances water security for domestic and livestock use, particularly during the dry summer months. The recharge of shallow dug wells ensures that households have access to freshwater for drinking, cooking, and sanitation, reducing the drudgery of water collection, especially for women and children. Improved water availability also supports livestock rearing, a key component of rural livelihoods in Bundelkhand, by providing water for animals and enabling the cultivation of fodder crops in the Haveli bed. In this way, the Haveli system contributes to diversified livelihoods and greater resilience to climate variability and drought (Palsaniya *et al.*, 2025).

CHALLENGES AND DECLINE

Physical and technical challenges

Despite its benefits, the traditional Haveli system faces several physical and technical challenges that

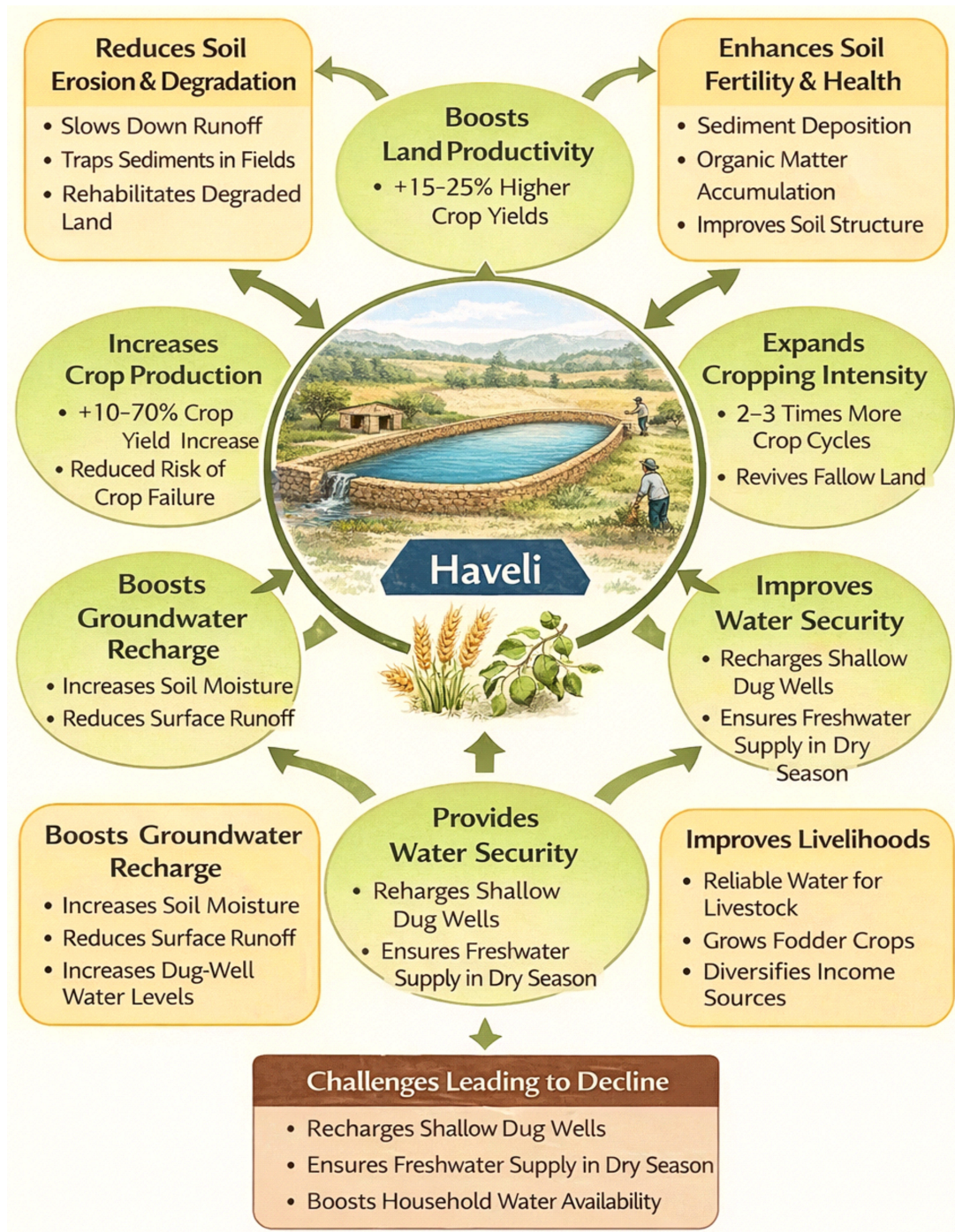


Fig. 5. Environmental and agricultural impacts of Haveli system

have contributed to its decline. The earthen embankments are prone to breaching during heavy rainfall, especially in years with intense storms, due to the coarse texture and low organic matter content of Bundelkhand's soils, which reduce soil bonding capacity (Anonymous, 2023). Poor design and construction quality further reduce the lifespan of

Havelis, with many structures lasting only 2–5 years before requiring major repairs or reconstruction. Inadequate outlet design can lead to overtopping and erosion, while siltation reduces storage capacity over time, requiring regular desilting that is often neglected. Moreover, the performance of Havelis is highly dependent on rainfall variability in dry years,

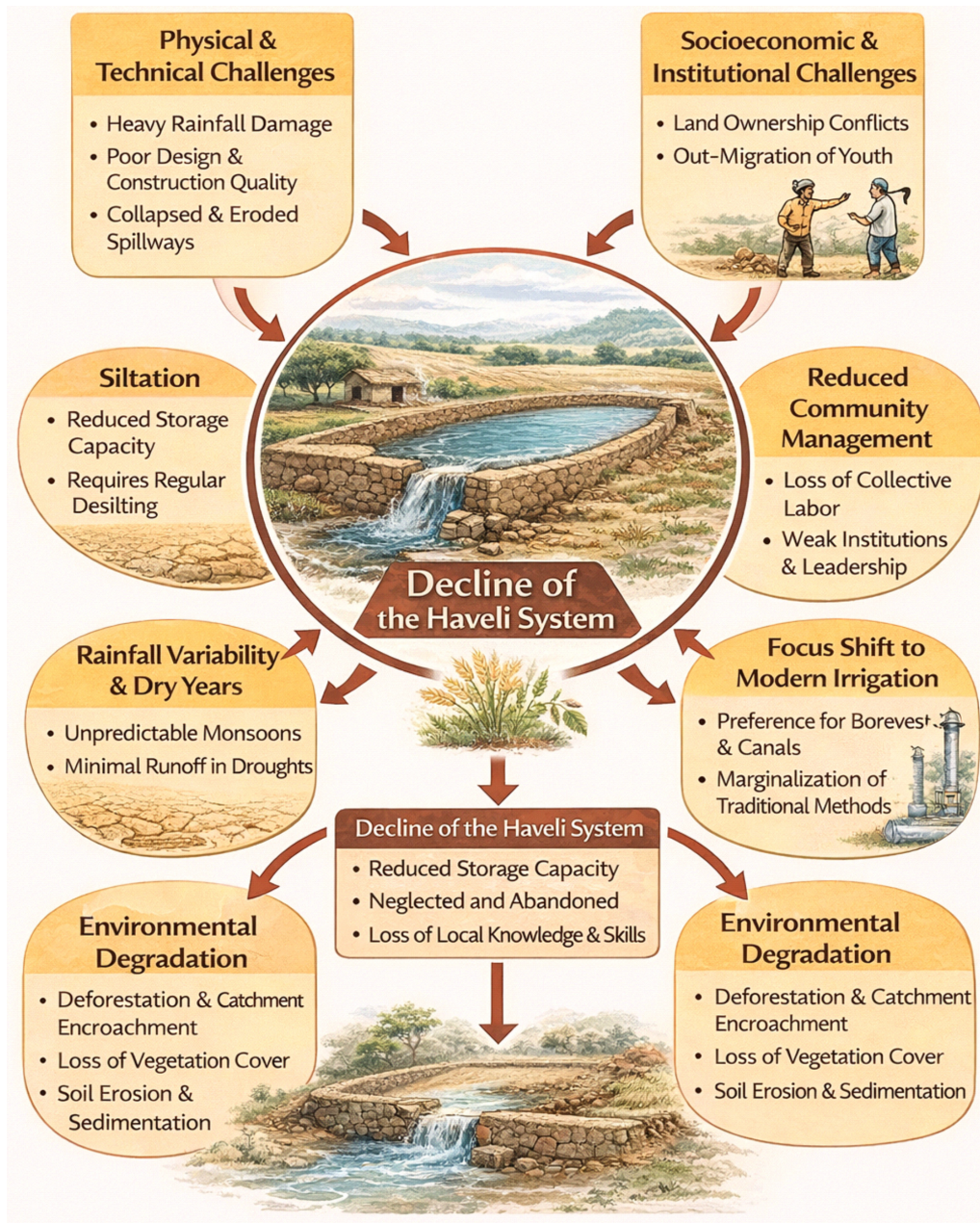


Fig. 6. Challenges and decline of Haveli system

Table 2. Multi-dimensional challenges to system sustainability

Dimension	Primary Challenges and Drivers of Decline	Reference(s)
Technical/physical	Embankment breaching; siltation; inadequate spillway design; low soil bonding capacity	Anonymous (2023); Iqbal and Riaz (2024)
Socio-economic	Land fragmentation; out-migration; shift to market-oriented farming	Singh <i>et al.</i> (2022)
Institutional	Erosion of collective labor (<i>shramdaan</i>); breakdown of traditional village leadership	Singh and Joshi, 2020; Samuel <i>et al.</i> (2015)
Policy/governance	Focus on centralized irrigation (canals/borewells); lack of formal maintenance funding	Anonymous (2023)
Environmental	Climate variability (extreme droughts); encroachment on catchments; deforestation	Sivanappan (2006); Iqbal and Riaz (2024)

little runoff is generated, limiting the amount of water that can be harvested and stored. This makes the system vulnerable to climate change and increasing rainfall variability, which are already being observed in Bundelkhand (Iqbal and Riaz, 2024).

Socioeconomic and institutional challenges

The decline of the Haveli system has also been driven by socioeconomic and institutional factors (Fig. 6; Table 2). Land fragmentation, out-migration of youth, and the shift from subsistence to market-oriented agriculture have weakened traditional community institutions that once managed Havelis collectively (Singh *et al.*, 2022). As a result, maintenance responsibilities have shifted to individual landowners, many of whom lack the labor, capital, or motivation to repair and desilt Havelis regularly. In some cases, land use changes, such as the conversion of agricultural land to non-agricultural uses, have further reduced the area available for Haveli construction and maintenance. Additionally, the focus of government and development programs on large-scale irrigation projects, tube wells, and centralized water supply schemes has marginalized traditional systems like the Haveli, leading to a loss of local knowledge and skills required for their construction and upkeep. Many farmers now perceive Havelis as outdated or less reliable compared to borewells and canals, even though these modern sources are often overexploited and unsustainable in the long run (Anonymous, 2023).

Weak institutional support and lack of clear policies for the maintenance and management of Havelis have further accelerated their decline. In the absence of formal recognition and funding, communities have found it difficult to mobilize resources for regular desilting, repair of embankments, and improvement of outlets, resulting in the gradual abandonment of many Haveli structures. At the same time, unclear land and water rights, especially in shared catchments, have led to conflicts among farmers, discouraging collective action for Haveli rejuvenation. Environmental degradation, including deforestation, loss of vegetation cover, and soil erosion in the catchment, has also reduced the effectiveness of Havelis by increasing sedimentation and reducing the quantity and quality of runoff water. Encroachment on Haveli beds and catchments for agriculture or construction

has further shrunk the area available for water storage and recharge, undermining the system's hydrological function (Sivanappan, 2006).

CONCLUSION

The Haveli system of Bundelkhand is a traditional agro-hydrological framework utilizing shallow embankment-based reservoirs to capture monsoon runoff. This mechanism facilitates localized infiltration, significantly enhancing soil moisture profiles and groundwater recharge within semi-arid landscapes. Hydrologically, Havelis optimize rabi (winter) crop productivity by providing reliable residual moisture and stabilizing shallow aquifer levels against rainfall variability. Historically, the system's resilience was underpinned by robust communal governance and equitable water-sharing protocols. However, land fragmentation, institutional erosion, and intensified climate volatility have led to widespread degradation. Empirical evidence suggests that integrating indigenous Haveli techniques with modern hydraulic engineering and participatory watershed management can restore landscape-level water security. Reinstating these structures within formal policy frameworks is critical for advancing climate-resilient agriculture and long-term food stability in drought-prone regions.

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