



Sustainable water management in rainfed agriculture of central India: A systematic review of rainwater harvesting, irrigation efficiency and smallholder resilience

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Abstract

Rainfed agriculture remains central to rural livelihoods in Central India, yet crop performance is exposed to monsoon variability, dry spells, soil-moisture losses and uneven access to irrigation. This review synthesizes evidence on three linked pathways for more sustainable agricultural water management: rainwater harvesting, irrigation and soil-moisture-use efficiency, and smallholder resilience. The geographic emphasis is Madhya Pradesh and the Bundelkhand landscape, with relevant evidence from Maharashtra, Chhattisgarh and wider Indian dryland systems. Literature was located through structured searches of accessible scholarly search results, publisher platforms and institutional repositories, followed by reference chaining. The synthesis applies the transparency principles of PRISMA 2020 but does not claim a completed PRISMA-compliant review because subscription-database exports and a reproducible record-level screening log were not available for this draft. The evidence indicates that farm ponds, check dams, field bunding, infiltration structures and rehabilitation of traditional systems such as haveli cultivation can moderate intra-seasonal water stress when their siting and capacity match rainfall-runoff conditions. Studies from Bundelkhand report higher shallow-groundwater availability, conversion of some fallow land to cultivation, improved cropping intensity and higher farm income after integrated water-management interventions. However, benefits are context-dependent and can be offset by evaporation, sedimentation, poor maintenance, inequitable asset access, excessive groundwater pumping and reduced downstream flows. Micro-irrigation can improve delivery efficiency, but technology adoption alone does not guarantee basin-scale water savings if irrigated areas or water-intensive crops expand. The review recommends a landscape approach that combines in-situ moisture conservation, fit-for-purpose storage, protective irrigation, groundwater budgeting, participatory governance and long-term monitoring of livelihood and ecological outcomes.

Keywords: Rainfed agriculture, Central India, rainwater harvesting, farm ponds, irrigation efficiency, groundwater recharge, smallholder resilience, watershed management

Introduction

Rainfed agriculture is not simply agriculture practised where irrigation is absent, it is a production system in which the timing, intensity and distribution of rainfall interact with soils, crops, farm assets and local institutions. In India, rainfed areas account for a substantial share of cultivated land and production, and they remain important for pulses, oilseeds, millets, cotton and the livelihoods of small and marginal farmers (Press Information Bureau [PIB], 2026, Rockström *et al.*, 2010) ^[15, 16]. Yet, rainfall received during the monsoon is often poorly synchronized with crop water demand: intense rainfall may be lost as runoff, while dry spells during flowering or grain filling can sharply reduce yield. The policy problem is therefore not only how much rain falls, but how much water enters the soil, is stored safely, can be accessed at critical growth stages and remains available without undermining other users or ecosystems. India's traditional water-harvesting systems, including tanks and field-level storage, have a long history, but their continued relevance depends on local maintenance and adaptation to changing hydrology (Agarwal & Narain, 2003) ^[1]. Central India contains highly varied agroecological conditions, including black-soil plateaus, hard-rock aquifers, forested uplands and the semi-arid Bundelkhand region. A single intervention package is unlikely to work across all such contexts. Rainfall trends also need careful interpretation. For East Madhya Pradesh, Kumar *et al.*

(2024) ^[8] identified statistically significant long-term declines in annual and monsoon rainfall, whereas their analysis did not identify equivalent trends across all periods and subdivisions. Meshram *et al.* (2017) ^[10] similarly examined long-term precipitation variability in Chhattisgarh, underscoring the importance of state- and district-specific hydroclimatic assessment rather than assuming one uniform Central Indian rainfall trajectory. The broader rainfed-agriculture literature argues for a shift from maximizing water capture in isolation to managing water, soil and crops together (Rockström *et al.*, 2010) ^[16]. In practice, this means integrating in-situ moisture conservation, runoff harvesting, groundwater recharge, supplementary irrigation and agronomic choices. Evidence from Bundelkhand suggests that traditional practices such as the haveli system can be adapted through engineering improvements and supported by monitoring, while research from multiple semi-arid watersheds highlights substantial but spatially uneven potential for rainwater harvesting (Garg *et al.*, 2022, Singh *et al.*, 2022) ^[6]. At the same time, water interventions create distributional questions: who owns the pond, who controls a well, whose land receives recharge, and how much runoff is retained upstream? This review addresses four questions: (1) which rainwater-harvesting approaches have the strongest evidence in Central Indian rainfed landscapes, (2) how can irrigation efficiency and soil-water productivity be improved, (3) under what

conditions do these interventions strengthen smallholder resilience, and (4) what ecological, institutional and evidence gaps limit sustainable scaling? Its contribution is a regionally focused synthesis that connects hydrological performance to farm-level decisions, equity and landscape-scale sustainability.

Review scope and conceptual framing

The review uses ‘Central India’ as a functional rather than strictly administrative category. Highest weight is assigned to studies explicitly located in Bundelkhand, Madhya Pradesh and adjacent central Indian landscapes. Evidence from Maharashtra and wider Indian rainfed systems is used where it clarifies farm-pond performance, micro-irrigation adoption or watershed processes, it is not treated as automatically transferable to every district in the region. ‘Smallholder resilience’ refers to the capacity of farm households to sustain production, manage climatic shocks, protect productive assets and recover from poor rainfall seasons without exhausting groundwater or worsening inequality. The analytical framework links four stages: rainfall and runoff processes, capture, infiltration and storage, efficient allocation of water to crops, and household and ecosystem outcomes. Water infrastructure is treated as an enabling asset rather than a standalone solution. Whether it produces resilience depends on reliable maintenance, complementary agronomy, farmer access, energy costs and local rules for groundwater and surface-water use (Garg *et al.*, 2020, Van Meter *et al.*, 2014) [4, 24].

Materials and methods

1. Search strategy

A structured search was conducted for this manuscript with a cutoff date of 22 October 2026. Search coverage used web-indexed scholarly records and accessible publisher and institutional sources, including Springer Nature, Scientific Reports/Nature, Frontiers, ICAR e-Pubs, the ICRISAT Open Access Repository, FAO, CEEW and the PRISMA statement website. Reference lists of regionally relevant studies were followed to identify foundational work on groundwater recharge, watershed development and rainwater harvesting. Search phrases included combinations of: ‘Central India rainfed agriculture water management’, ‘Bundelkhand rainwater harvesting groundwater resilience’, ‘Haveli cultivation Central India’, ‘farm pond supplemental irrigation India’, ‘watershed development livelihood India’, ‘micro-irrigation adoption India review’, ‘Madhya Pradesh rainfall variability’, ‘Chhattisgarh precipitation trend’, and ‘rainwater harvesting systematic review productivity resilience’.

2. Eligibility and synthesis

Eligible sources were English-language peer-reviewed research articles, systematic or narrative reviews, and reports from recognized scientific or public institutions published mainly between 2000 and 22 October 2026. Earlier foundational references were retained where needed to interpret traditional water-harvesting systems. Studies were prioritised if they reported hydrological or agronomic outcomes, household or institutional dimensions, or clearly described methods relevant to Central Indian rainfed agriculture. Urban-only rainwater harvesting and unrelated irrigation studies were excluded unless they contributed a transferable analytical principle. Evidence was grouped into

rainfall-runoff and storage, irrigation/application efficiency, crop and livelihood outcomes, and governance/trade-offs. Because interventions, rainfall regimes and outcome measures varied widely, findings were synthesized narratively rather than pooled into a single effect size.

3. Reporting and limitations of the search

The review uses PRISMA 2020 [13] as a transparency reference (Page *et al.*, 2021), but this file is a protocol-guided systematic-review draft rather than a fully audited PRISMA review. Direct exports from subscription databases such as Scopus and Web of Science, independent dual-reviewer screening, duplicate logs and a complete record-level inclusion spreadsheet were not available during preparation. For that reason, no invented PRISMA flow counts or claims of exhaustive database coverage are reported. Before journal submission, the search should be rerun in the databases required by the target journal, with full search strings, dates, deduplication, screening decisions and a completed PRISMA flow diagram documented.

Results and discussion

1. Rainfall variability creates a timing and access problem

The core constraint in many rainfed systems is the mismatch between rainfall availability and crop demand. A season can have near-normal total rainfall and still produce crop stress if rain arrives in a few heavy events separated by extended dry spells. High-intensity rainfall can generate runoff and soil erosion before infiltrating the root zone, while late-season rainfall may be less useful to a crop at an earlier critical stage. The Madhya Pradesh rainfall analysis by Kumar *et al.* (2024) [8] illustrates why planning should use subregional and temporal information instead of relying only on annual totals. For Chhattisgarh, Meshram *et al.* (2017) [10] provide a state-specific basis for examining long-term precipitation trends, although farm-level decisions additionally require local soil, slope, crop calendar and rainfall-event data.

A practical implication is that water management should be designed around the sequence of dry spells, runoff events and crop stages. In-situ conservation—such as contour or graded bunds, tied ridges where suitable, residue retention, vegetative barriers and improved soil organic matter—slows runoff and increases infiltration. Ex-situ storage can then capture a portion of the surplus for protective irrigation. These are complementary actions: a storage pond cannot compensate for severely degraded fields if runoff and sediment are not controlled at source, and soil-moisture conservation alone may not bridge a long dry spell where root-zone storage is limited (Rockström *et al.*, 2010 [16], FAO, n.d.). In Central Indian Vertisols, research on the traditional haveli system has also documented benefits related to carbon sequestration and biological soil fertility, reinforcing the value of integrated soil-and-water management (Sahu *et al.*, 2015) [17].

2. Rainwater harvesting: technologies and observed outcomes

The evidence points to a portfolio of options rather than a universally optimal structure. Farm ponds can provide a small volume of water for life-saving irrigation, pre-sowing irrigation or high-value crops. Check dams and masonry structures can slow runoff and support recharge, field

bunding and infiltration structures improve retention, and traditional systems such as haveli cultivation store monsoon runoff temporarily, allowing residual moisture and shallow groundwater to support post-monsoon cropping. Appropriate design depends on the catchment-to-command relationship, soil infiltration, evaporation, seepage, local geology, land availability, maintenance capacity and expected rainfall. An intervention should be sized using site hydrology rather than copied from a nearby village.

A ten-year runoff assessment in western Vidarbha reported approximately 450 m³ of runoff collectible per hectare of catchment under the studied conditions. The authors estimated this could provide a 5 cm protective irrigation depth for about 0.91 ha, and reported higher soybean and chickpea yields when harvested water was delivered through micro-irrigation (Patode *et al.*, 2024) ^[14]. These results are useful for design illustration, not a universal coefficient: runoff yield will vary with rainfall intensity, soil, slope, land cover, pond losses and catchment condition. Farm-pond guidance developed across the All India Coordinated Research Project on Dryland Agriculture likewise stresses agroecology-specific dimensions and measures to limit seepage and evaporation (Shirahatti *et al.*, 2022) ^[20].

Region-specific watershed studies show potentially meaningful hydrological and livelihood gains. In a monitored Bundelkhand landscape, rejuvenation of haveli structures and associated interventions increased shallow dug-well hydraulic head by a reported 2–5 m, helped bring

approximately one-fifth of permanent fallow land into cultivation and raised household net income to two or three times the baseline reported by the study (Singh *et al.*, 2022) ^[6]. In the Parasai-Sindh watershed, a package including haveli renovation, check dams, field bunding and crop demonstrations created about 100,000 m³ of rainwater-storage capacity, crop productivity and household income improved compared with baseline conditions (Garg *et al.*, 2020) ^[4]. These are multi-component interventions, so the outcomes should not be attributed to one structure alone.

At a broader scale, Garg *et al.* (2022) ^[6] analysed 25 agricultural watersheds across Indian semi-arid tropics. They reported gains in groundwater availability, cropping intensity and farmers' income in intervention watersheds, while emphasizing that the suitability of rainwater harvesting varies geographically. More than 70% of the studied semi-arid tropical area was assessed as having medium-to-high potential, but local trade-offs remain especially important in low-runoff environments and in average rainfall years. Kumar *et al.* (2016) ^[9], using farm-level evidence from five rainfed states, found that the performance of rainwater-harvesting structures was influenced by location, size, runoff potential, village-level technical support, farmers' assets and the ability to use stored water productively. Collectively, these findings indicate that infrastructure performance is social and institutional as well as hydraulic.

Table 1: Selected evidence relevant to rainfed water management and smallholder resilience in Central India

Study / setting	Evidence type	Reported finding relevant to this review	Interpretation / caveat
Kumar <i>et al.</i> (2016) ^[9] , five Indian rainfed states	Farm-level survey, stakeholder discussions and on-farm evidence	Performance depended on structure design and siting, catchment runoff, technical support, household assets and farmer participation.	Cross-state evidence, individual results should be contextualized before application in Central India.
Garg <i>et al.</i> (2020) ^[4] , Parasai-Sindh, Bundelkhand	Multi-component watershed case study	About 100,000 m ³ of storage capacity and reported improvement in groundwater availability, crop productivity and household income after integrated interventions.	Haveli renovation, check dams, bunding and demonstrations were implemented as a package.
Singh <i>et al.</i> (2021) ^[5] , Bundelkhand	Groundwater and water-balance analysis	Interventions increased recharge and supported a reported rise in cropping intensity from 120% to 180%.	Outcomes depend on rainfall sequence, aquifer conditions and extraction rates.
Singh <i>et al.</i> (2022) ^[6] , traditional haveli system	Landscape monitoring and historical-system assessment	Reported 2–5 m improvement in shallow-well hydraulic head and conversion of about 20% of permanent fallow land to cultivation.	One monitored pilot is not representative of every village or hydrological year.
Garg <i>et al.</i> (2022) ^[6] , 25 semi-arid watersheds	Meta-analysis of watershed data	Rainwater harvesting was associated with improved groundwater availability, crop intensification and income across multiple benchmark watersheds.	Substantial differences across soils, rainfall, design and treatment histories remain.
Kumar <i>et al.</i> (2024) ^[8] , Madhya Pradesh	Long- and short-term rainfall trend analysis	Long-term negative annual and monsoon rainfall trends were found for East Madhya Pradesh, but not consistently across all subregions or periods.	Supports localized climate assessment rather than uniform assumptions.
Patode <i>et al.</i> (2024) ^[14] , western Vidarbha	Ten-year runoff–pond relationship	Estimated about 450 m ³ ha ⁻¹ runoff from catchment and described protective-irrigation benefits for soybean and chickpea.	Design estimates are site-dependent and should not be copied without local hydrological calculations.
Nair and Thomas (2023) ^[11] , India	Review of micro-irrigation adoption	Subsidies alone were insufficient to explain adoption, household, farm, institutional and crop-choice factors mattered.	Application efficiency does not automatically yield basin-level water savings.
Silva <i>et al.</i> (2026) ^[21] , international RWH literature	Systematic review of 22 peer-reviewed articles	Benefits for water availability, productivity and cropping intensity were reported, alongside limited livelihood and long-term assessment.	Provides a broader comparator, this review narrows the focus to Central Indian landscapes.

3. Irrigation efficiency and water productivity

In rainfed settings, irrigation is often most valuable when it protects a crop from a critical dry spell rather than

attempting to irrigate the entire field throughout the season. Protective or supplementary irrigation can stabilize yield, improve the probability of harvest and encourage

investment in improved seed or nutrient management. The benefit depends on crop stage, soil moisture, volume available and the opportunity cost of water. Small, well-timed applications may deliver higher marginal returns than larger but poorly timed applications, particularly when total stored water is limited (Rockström *et al.*, 2010, Shirahatti *et al.*, 2022) ^[16, 20].

Drip irrigation and sprinklers can improve control over water delivery and reduce conveyance or application losses where crops, soils and farm layouts are suitable. But irrigation efficiency must be distinguished from water conservation. At field scale, a higher proportion of applied water may be beneficially used, at basin scale, water savings depend on what happens to water that would otherwise have returned to rivers or aquifers. Farmers may also expand irrigated area or switch toward thirstier crops after installing efficient technology. Nair and Thomas (2023) ^[11] therefore caution that subsidy-led adoption alone cannot guarantee conservation. Programmes need complementary crop planning, water accounting, groundwater rules and monitoring of actual withdrawals.

For smallholders, the main barriers to efficient irrigation are often affordability, unreliable electricity, the cost of lifting water, clogging and maintenance of drip lines, availability of spare parts, fragmented holdings and uncertainty about how long a pond will retain water. The most appropriate intervention may be a low-pressure system, shared equipment or a portable pump rather than a capital-intensive package. Public support should finance maintenance and technical advice as well as installation. Farmer training should focus on irrigation scheduling, soil moisture monitoring and matching application depth to root-zone needs.

Water productivity should be assessed with multiple denominators: yield per unit of water applied, yield per unit of water consumed where evapotranspiration data are available, gross margin per unit of water, and stability of yield across variable seasons. Increased yield alone does not prove higher water productivity if extraction also rises sharply. Similarly, an increase in cropping intensity should be checked against groundwater trends and energy consumption. Research from Bundelkhand is particularly useful because it links shallow aquifer response and cropping changes, but long-term monitoring is still required to distinguish durable recharge benefits from short-lived storage gains (Singh *et al.*, 2021, Garg *et al.*, 2020) ^[4, 5].

4. Smallholder resilience: income stability, risk and equity

Resilience is more than average yield improvement. For smallholder households, a useful water intervention should reduce the probability of crop failure, protect household cash flow, limit distress borrowing, and preserve options in poor monsoon years. Harvested water can support earlier sowing, a rescue irrigation at flowering, or a small rabi crop that would otherwise remain fallow. The opportunity to grow vegetables or pulses may increase gross margin, but it can also increase production risk if markets, cold chains or input finance are weak. Diversification should therefore be considered alongside water storage rather than assumed to follow automatically from it.

Asset distribution strongly shapes who benefits. A privately owned farm pond may disproportionately benefit a household with a larger landholding, a suitable site and

capital to line the pond or pump stored water. Landless households and marginal farmers may benefit less unless programmes also support shared ponds, community wells, water-user groups, livestock needs and equitable access rules. Watershed meta-analysis has historically emphasized the importance of participation and institutional arrangements alongside technical works (Joshi *et al.*, 2005) ^[7]. Participation should be substantive: community members need meaningful influence over site selection, scheduling, maintenance contributions, conflict resolution and decisions about who receives water during scarcity. Traditional water systems offer lessons for resilience because they combine infrastructure, seasonal routines and local knowledge. Haveli cultivation involves temporary monsoon storage and post-monsoon use of residual soil moisture, but maintenance failures and changes in rainfall patterns can undermine old designs. Singh *et al.* (2022) ^[6] describe improvements to the system through engineered outlets and core walls, suggesting that adaptive innovation can preserve local knowledge without treating inherited structures as unchangeable. Such rehabilitation should still be based on local hydrology and ecological safeguards. The broader water-harvesting literature cautions against equating upstream gains with overall sustainability. Van Meter *et al.* (2014) ^[24] argue for evaluating rainwater harvesting through linked social, economic and environmental dimensions. Upstream storage may reduce downstream flow, recharge structures can benefit wells unevenly, and pumping from recharged aquifers can use more water than is sustainable over several dry years. Garg *et al.* (2022) ^[6] likewise discuss rainfall-dependent upstream–downstream trade-offs. Equity and resilience therefore require transparent rules, catchment-scale accounting and a minimum ecological allocation, not only construction targets.

5. Governance and sustainability safeguards

A robust watershed programme should sequence interventions from the field to the catchment. The first stage is diagnosis: map topography, soils, land use, aquifer type, runoff pathways, existing tanks and wells, crop calendars, water demand and tenure. The second stage prioritizes in-situ infiltration and soil conservation. The third stage adds appropriately designed storage and recharge measures at sites where runoff is available and impacts on downstream users are understood. The fourth stage connects available water to crop and irrigation choices. The fifth stage assigns responsibility for inspection, desilting, outlet repair, vegetation management and post-monsoon evaluation.

Groundwater recharge must not be treated as equivalent to an unlimited new supply. In hard-rock aquifers, storage is spatially discontinuous, recharge may occur only in favorable locations and years, and abstraction can quickly reduce water levels. Monitoring should record groundwater depth before and after monsoon, well recovery time, pumping hours and the area irrigated. Where groundwater is shared, locally agreed abstraction rules and crop choices may be more important than increasing the number of recharge structures. Shah (2009) ^[18] notes the close connection between groundwater, climate adaptation and energy policy in India, water interventions should accordingly avoid incentives that reduce pumping costs while encouraging unsustainable extraction.

Operation and maintenance should be budgeted from the beginning. A pond with sediment accumulation, a broken

outlet or high seepage may lose functional capacity long before the structure fails visibly. Design and management should consider evaporation control where appropriate, silt traps, grassed waterways, safe spillways and periodic sediment removal. Water quality also matters if harvested water is used for horticulture or livestock. Structures should not be placed in ways that destabilize slopes, increase waterlogging or interrupt downstream ecological flows. A portfolio of small structures is not automatically safer or

more sustainable than a larger shared structure, performance must be assessed at the landscape level. Earlier research on storage structures in semi-arid India likewise shows that groundwater-recharge estimates need to be based on site conditions and measured water balances rather than on storage capacity alone (Sharda *et al.*, 2006) ^[19]. Recent policy analysis also calls for climate-adaptive agricultural water management that links water, food and energy considerations (Neog *et al.*, 2025) ^[12].

Table 2: Water-management options and conditions for sustainable use

Option	Main function	Best-fit conditions / use case	Key risk or design safeguard
In-situ moisture conservation (bunds, contour measures, residue and soil organic matter)	Increase infiltration, reduce runoff and protect root-zone moisture	Most cultivated slopes and fields where soil loss and quick runoff are important	Must fit slope, soil and drainage needs, avoid waterlogging and unsafe concentration of runoff.
Farm ponds and community ponds	Store runoff for protective irrigation, livestock or high-value crops	Suitable catchment, adequate seasonal runoff, safe overflow route and a viable command area	Evaporation, seepage, sedimentation, loss of cropped land, unequal access, size using a local water balance.
Check dams, nala bunds and recharge structures	Slow flow and facilitate infiltration / groundwater recharge	Appropriate stream geometry, geology and downstream-flow assessment	Potential downstream flow reduction and sediment accumulation, monitor wells and stream flow.
Traditional haveli/tank rehabilitation	Seasonal storage, residual moisture use and possible recharge	Places with surviving institutions or historical storage landscapes	Need updated outlet design, maintenance agreements and resilience to extreme rainfall.
Drip or sprinkler irrigation	Control delivery and improve application efficiency	Crops and farms where scheduling, equipment service and water source are suitable	Efficiency gains may be offset by area expansion or crop switching, track total withdrawals.
Community groundwater budgeting	Align abstraction with recharge and equity objectives	Shared aquifers or wells facing seasonal scarcity	Needs credible monitoring, participation and transparent rules, recharge alone is not a guarantee of sustainability.

6. Evidence gaps and priorities for research

Three evidence gaps are especially important. First, many case studies evaluate infrastructure and crop outcomes for a limited number of seasons, while resilience is fundamentally a multi-year property. Monitoring should span wet, normal and drought years and report failure as well as success. Second, livelihood outcomes are often described as income or crop yield, with less consistent attention to debt, labour, migration, gendered water access, nutrition, maintenance burden and risk exposure. The 2026 ^[21] international systematic review by Silva *et al.* found that explicit livelihood assessment and broader socioeconomic analysis were relatively limited within the literature it reviewed. A Central India research agenda should address precisely this gap rather than reproduce only hydrological indicators. Third, intervention impacts are difficult to compare because studies use different baselines, outcome definitions and spatial scales. A standard monitoring framework should combine rainfall and runoff, pond storage and losses, groundwater depth and recovery, irrigation volume, yield and gross margin, crop failure, household vulnerability, and

downstream water availability. Where feasible, studies should use comparison watersheds or matched non-intervention villages and publish the design, cost, maintenance history and rainfall context. Remote sensing may support land-cover and crop-intensity assessment, but field observations remain important for validating groundwater use, pond condition and distribution of benefits.

A further priority is to quantify when an intervention should not be built. Rainwater harvesting depends on the availability of surplus runoff, in dry years, runoff may be insufficient to satisfy both upstream and downstream demands. Garg *et al.* (2022) ^[6] emphasize the need to consider runoff potential and the water balance before scaling. Cost-effectiveness comparisons should assess not only construction cost per cubic metre stored but the cost per unit of reliable protective irrigation, per additional crop, or per reduction in downside yield risk. These measures are more directly connected to household resilience and sustainable public investment.

Table 3: Recommended indicators for monitoring programmes and future studies

Dimension	Suggested indicators	Why it matters
Hydrological performance	Event rainfall, runoff coefficient, storage volume, seepage / evaporation, groundwater depth, well recovery, downstream discharge	Distinguishes capture from actual water availability and detects hydrological trade-offs.
Irrigation and agronomy	Irrigation timing and volume, water applied per hectare, yield, yield variability, crop failure rate, soil moisture, cropping intensity	Tests whether stored water is used efficiently at critical growth stages.
Household resilience	Net farm income, gross margin per unit water, borrowing, input costs, crop/livestock diversity, seasonal migration, recovery after drought	Captures risk reduction rather than average yield alone.

Equity and governance	Share of small/marginal farmers benefiting, women's participation, water allocation rules, disputes, fee and maintenance contributions	Reveals unequal access and whether institutions can sustain collective assets.
Environmental sustainability	Soil loss, sedimentation, water quality, vegetation/land condition, downstream flow, groundwater abstraction and energy use	Checks whether farm gains are achieved without transferring costs to other users or ecosystems.
Financial performance	Capital cost, annual maintenance, service life, cost per reliable irrigation, cost per unit of yield stability gained	Improves comparison of public investment alternatives and supports realistic O&M budgets.

Practical recommendations for Central India

The evidence supports six connected recommendations. First, make district and micro-watershed plans rainfall- and aquifer-specific. Historical averages should be supplemented with rainfall-event intensity, dry-spell length, soil depth, land cover and runoff data. Second, prioritize soil moisture and infiltration before maximizing storage: farm bunds, residue retention, vegetative measures and soil organic matter can increase the fraction of rainfall available to crops. Third, design farm ponds, check dams and haveli rehabilitation using a full catchment-storage-command calculation and a documented downstream assessment. Fourth, allocate harvested water primarily to clearly defined protective-irrigation windows or crops that produce sufficient returns for the limited volume available.

Fifth, link subsidies for drip and sprinkler equipment to extension, repair services, crop-water planning, and reporting of total water use. The policy objective should be reliable production with sustainable withdrawal, not equipment adoption alone. Sixth, establish community-based operation and maintenance and groundwater budgeting. Village institutions should have access to monitoring information, a clear process for resolving conflicts, and agreed rules for sharing water during drought years. Public agencies should finance not only new works but maintenance, hydrological monitoring, and independent evaluation.

Implementation should be adaptive. In a high-runoff year, harvesting and recharge may create a buffer for later dry periods, in a drought year, the priority may shift toward soil moisture, drinking water, livestock and a limited protective irrigation allocation. In landscapes with little surplus runoff, investments that attempt to capture more water than the catchment can sustainably yield may be ineffective or inequitable. Consequently, the best programme is not the one that builds the most structures, but the one that demonstrably improves reliable water access and household resilience while keeping withdrawals and downstream impacts within sustainable limits.

Conclusion

Sustainable water management in Central India's rainfed agriculture requires a system-level approach that connects rainwater harvesting, irrigation efficiency, soil health, crop management and local governance. Evidence from Bundelkhand demonstrates that rejuvenated traditional haveli systems, check dams, field bunding and groundwater-management measures can contribute to improved water availability, crop intensification and household outcomes. Farm ponds and micro-irrigation can provide critical protective irrigation where water volumes, crop choices and management capacity are aligned. However, results are not universal: rainfall variability, soil and aquifer conditions, losses during storage, uneven access, maintenance gaps and upstream–downstream trade-offs all shape outcomes.

The central conclusion is that rainwater harvesting should be treated as part of an integrated water balance, not as a stand-alone infrastructure target. Irrigation efficiency must be assessed against total withdrawals, while resilience should be measured through reduced downside risk, livelihood stability and ecological sustainability. Future research needs reproducible systematic searches, longer-term comparisons, transparent costs and consistent hydrological, agronomic and socioeconomic indicators. For policy and practice, a locally designed and participatory portfolio—combining in-situ conservation, fit-for-purpose storage, supplementary irrigation, groundwater budgeting and equitable institutions—offers the strongest basis for sustainable and resilient rainfed farming.

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