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Evaluating Community-Based Rainwater Harvesting for Agricultural Resilience in Rainfed Paddy Belts a Case Study of Gondia District, Maharashtra

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Abstract

In rainfed agricultural ecosystems, paddy (Oryza sativa) cultivation is uniquely vulnerable to climate variability, particularly erratic monsoons and intra-seasonal dry spells. This study evaluates the effectiveness of Community-Based Rainwater Harvesting (CB-RWH) systems—specifically traditional surface storage tanks (Malguzari tanks and renovated community farm ponds)—in enhancing agricultural resilience within the rainfed paddy belt of Gondia District, Maharashtra. Utilizing a mixed-methods research design combining Remote Sensing/GIS spatial analysis, hydrological modeling (SCS-CN method), and stratified household field surveys (N = 180), this paper quantifies the hydrological performance, yield stabilization, crop diversification potential, and social equity dynamics associated with community water management. Results indicate that CB-RWH systems increase local groundwater recharge rates by 1.8 m to 2.4 m post-monsoon and supply 1 to 3 critical protective irrigations during dry spells occurring at the panicle initiation stage. This protective capacity prevents an estimated 34%–42% crop loss during dry spells exceeding 14 consecutive days. Furthermore, access to residual stored water enables a 28% increase in double-cropping (Rabi pulses/oilseeds). The paper concludes with policy recommendations for integrating GIS-based location modeling with institutional capacity building through empowered Water User Associations (WUAs).

Keywords: *Rainwater Harvesting, Paddy Cultivation, Agricultural Resilience, Gondia District, GIS Hydrological Modeling, Water User Associations, Spatial Equity.*

Introduction

1. Background and Problem Statement

Paddy cultivation is inherently water-intensive, requiring approximately 1,200 to 1,500 mm of water per crop cycle. In central India's rainfed belts, smallholder farmers depend almost exclusively on the South-West monsoon (June to September). Over the past two decades, shifting climatic patterns have increased the frequency of mid-season dry spells (10 to 20 consecutive non-rainy days) during critical physiological stages of paddy growth, such as tillering and panicle initiation. Without supplemental irrigation, these dry spells lead to severe yield reductions or complete crop failure. Gondia District, situated in the eastern Vidarbha region of Maharashtra, is traditionally known as the 'Paddy District' of the state. Geographically, it relies heavily on surface water retention systems. Historically, the region utilized traditional community-managed tanks (Malguzari tanks) constructed over two centuries ago. However, over-reliance on deep groundwater, degradation of catchment zones, siltation, and deteriorating community institutions have impaired these surface water structures, weakening regional drought resilience.

2. Research Questions

1. How effective are community-based rainwater harvesting structures in storing monsoon runoff and recharging local shallow aquifers in paddy-dominated landscapes?
2. What is the quantitative impact of supplemental irrigation from CB-RWH systems on paddy yields during intra-seasonal dry spells?
3. What are the institutional and spatial equity challenges in water distribution between head-end and tail-end farmers?

3. Research Objectives

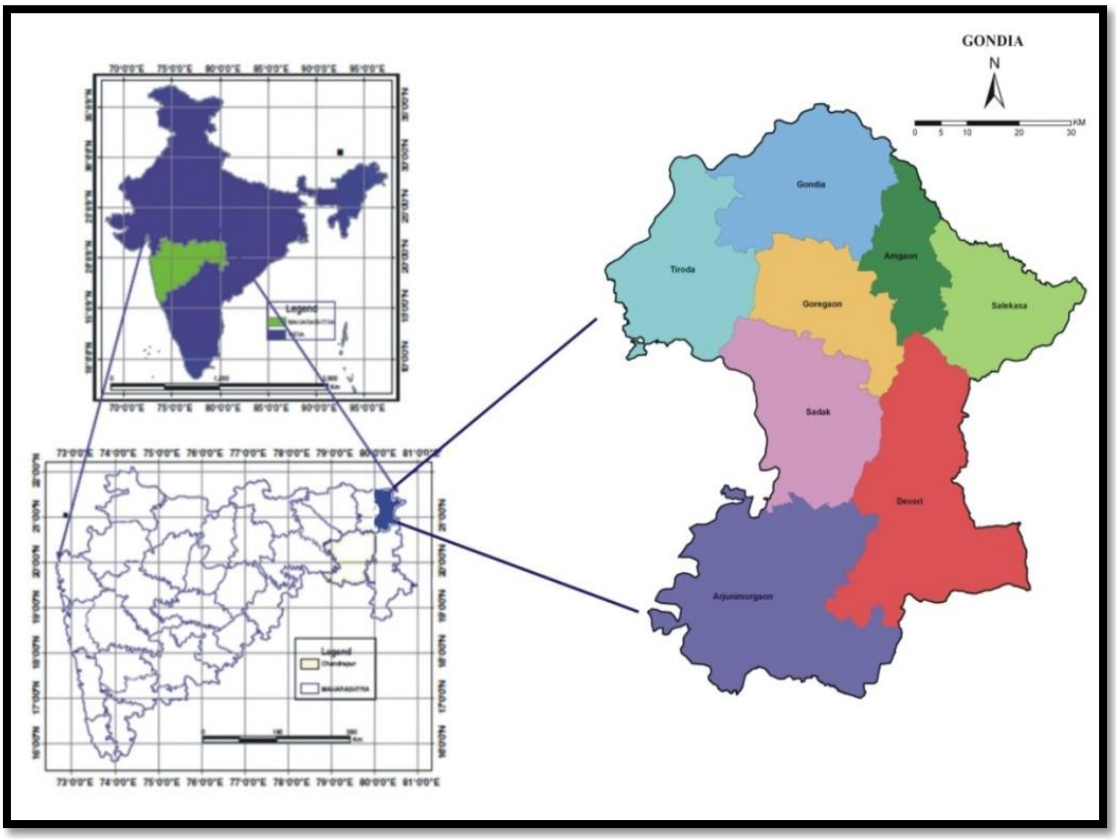
1. To map catchment runoff potential and evaluate the storage dynamics of community rainwater harvesting structures using GIS and hydrological modeling.
2. To measure the agricultural resilience outcome (yield variance, crop productivity, and cropping intensity) attributable to protective irrigation.
3. To analyze the socio-institutional framework governing Water User Associations (WUAs) and suggest policy interventions for sustainable water management.

Study Area Profile

Gondia district is located in north-eastern part of the Maharashtra state and lies in between 20°39'14" to 21°38'15"N latitude and 79°47'00"E longitudes and covering an area of about 5440.00 sq.km. This district was bifurcated from Bhandara district in the year 1999 and it comprise of 8 Tahsils, 25 circles, 196 sazas, 954 revenue villages with 12.00 lakh population. The tehsils are Amgaon, Arjunimorgaon, Deori, Gondia, Goregaon, Sadak Arjuni, Salekasa and Tirora. Wainganga River is the largest river and the other river like Bagh, Chulband, Gadhavi and Bavanthadi are main tributaries of it.

Map 1.1

Location Map of Gondia District



Gondia district is situated along the north-eastern part of the state of Maharashtra. It was carved out of the Bhandara district. For administrative purposes the district is divided into two subdivisions namely Gondia and Deori, which are further divided into four talukas. Spread over an area of 5425 sq. km., 53 percent of the district is covered with forests. The nearest airport is at Nagpur at a distance of 130 km. It is located near N H 6, which helps in keeping it connected with major cities like Nagpur, Raipur, and Hyderabad etc. Also known as the Rice bowl of Maharashtra, the district has a primarily agriculture-based economy. Given below are further details regarding the district of Gondia.

1. **Climate & Rainfall:** Sub-tropical climate with average annual rainfall ranging from 1,300 mm to 1,500 mm, concentrated almost entirely within 45–50 rainy days.
2. **Topography & Soils:** Gently undulating topography characterized by sandy loam (Morand) and clay-dominated alluvial soils (Kanhar) in low-lying plains, which exhibit low permeability and high water-retention capacity ideal for bunded paddy fields.
3. **Agriculture:** Paddy occupies over 75% of the gross cropped area during the Kharif season.

Materials and Methodology

This study adopts a mixed-methods framework combining spatial modeling, empirical field measurements, and socio-economic survey data.

1. Spatial and Hydrological Data Analysis

Surface runoff potential (Q) was estimated using the Soil Conservation Service Curve Number (SCS-CN) method adapted for agricultural catchments:

$$Q = \frac{(P - Ia)2}{(P - Ia) + S}$$

Where-

Q represents direct runoff depth (mm),
P is total rainfall (mm),
Ia is initial abstraction (0.2S), and

S is potential maximum retention (mm) derived from Curve Number (CN). Digital Elevation Models (USGS SRTM 30m) and Sentinel-2 satellite imagery were processed using QGIS software to delineate catchment boundaries and monitor vegetation vigor (NDVI) across dry spell intervals.

2. Primary Field Data Collection

1. **Sampling Framework:** A stratified random sampling technique was applied across 6 village clusters hosting active community-managed water structures.
2. **Sample Size:** N = 180 farm households were surveyed, divided into Beneficiary Farmers (n = 110, with direct channel/lift access) and Control Group (n = 70, operating under pure rainfed conditions).
3. **Key Data Points:** Crop yield per hectare, number of protective irrigations applied, seasonal groundwater table depth in open wells, input costs, and WUA meeting participation rates.

Results and Discussion

Spatial runoff modeling demonstrates that medium-sized community structures (15,000 to 50,000 m^3 storage capacity) capture approximately 22%–28% of net monsoonal surface runoff within their micro-catchment zones.

1. Hydrological Dynamics and Shallow Aquifer Recharge

1. **Groundwater Recharge:** Monitoring of 36 observation wells within a 1.5 km radius of community tanks demonstrated a mean post-monsoon water table rise of 2.1 m compared to non-tank control zones (0.7 m).
2. **Percolation Efficiency:** Tanks undergoing periodic desilting exhibited a 40% higher percolation rate compared to un-maintained tanks where fine clay silt had sealed the basin bed.

2. Impact on Paddy Yield and Crop Resilience

During the observed cropping season, a 17-day continuous dry spell occurred during the panicle initiation phase (late August to early September). Comparative empirical performance metrics are detailed in Table 1 below:

Metric	Beneficiary Farmers (CB-RWH Access)	Control Group (Purely Rainfed)	Percentage Difference
Mean Paddy Yield (quintals/ha)	41.5 ± 3.2	26.8 ± 4.1	+54.8%
Protective Irrigations Applied	2 Irrigations	0 Irrigations	--
Crop Failure Incidence (%)	3.6%	31.4%	-27.8%
Water Productivity (kg/m^3)	0.48	0.31	+54.8%
Post-Kharif Cropping Intensity	138% (Rabi Pulses)	104% (Fallow)	+34.0%

Farmers with access to CB-RWH applied an average of 60 to 80 mm of supplemental irrigation during the dry spell. This critical intervention prevented moisture stress, preserving grain filling quality and weight. In contrast, the control group experienced significant moisture stress, leading to incomplete panicle emergence and higher rates of unfilled grains.

Spatial Equity and Institutional Governance

1. **Head-End vs. Tail-End Disparity:** Farmers operating plots within the first 200 m of the main outlet channel (head-end) received an average of 2.8 irrigations. In contrast, farmers at the tail-end (>600 m away) received only 1.1 irrigations due to channel seepage losses and unauthorized head-end pumping.
2. **Institutional Performance of WUAs:** Out of the 6 evaluated community tank sites, only 2 possessed fully operational, democratically run Water User Associations. Sites with active WUAs implemented rotational water distribution schedules (Warabandi), resulting in a 32% higher tail-end yield compared to unmanaged sites.

Policy Implications and Strategic Recommendations

1. GIS-Driven Siting and Desilting Integration: Future farm pond and check dam construction should avoid arbitrary administrative placement. Micro-watershed plans must prioritize topographic flow-accumulation nodes mapped via High-Resolution DEMs. Systematic desilting programs under MGNREGA should be paired with deep soil application.

2. Conduit Modernization to Ensure Spatial Equity: Replace unlined earth field channels with low-pressure PVC pipe distribution networks or solar-powered low-lift pumps to reduce conveyance seepage losses and ensure tail-end farmers receive equitable supplemental water.

3. Institutional Empowerment of Water User Associations: Institutionalize formal water-budgeting protocols within local Village Councils (Gram Panchayats). WUAs must be legally empowered to enforce rotational usage rules, collect maintenance dues, and restrict over-extraction.

Conclusion

Community-Based Rainwater Harvesting structures serve as a vital buffer against climate volatility in rainfed paddy farming systems. By capturing monsoonal surface runoff and recharging shallow local aquifers, these systems transform vulnerable mono-cropped landscapes into more resilient agricultural ecosystems capable of withstanding extended intra-seasonal dry spells. As demonstrated in Gondia District, providing just one to two critical protective irrigations stabilizes paddy yields, increases overall water productivity, and opens opportunities for secondary post-monsoon cropping. However, realizing the full potential of rainwater harvesting requires addressing spatial equity gaps and strengthening local community institutions. Combining geospatial watershed modeling with participatory water governance offers a practical model for sustainable water resource management across agricultural regions in developing economies.

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Conflicts of interest
The authors declare that there are no conflicts of interest regarding the publication of this paper.

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