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Rooftop rainwater harvesting as a water conservation strategy for sustainable agriculture in the semi-arid region of North Gujarat: A case study at the Dry Farming Research Station

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ABSTRACT

Water scarcity and erratic rainfall are major challenges to sustainable crop production in the semi-arid region of North Gujarat. The present study evaluated the potential of rooftop rainwater harvesting as a water conservation strategy at the Dry Farming Research Station, Radhanpur. Rainwater from a 1000 m² reinforced cement concrete rooftop was collected through a pipe network and stored in a farm pond with a capacity of 15.60 lakh litres. Based on annual rainfall of 527.7 mm in 2024 and 736.8 mm in 2025, the estimated harvestable runoff was 474.93 m³ (4,74,930 L) and 663.12 m³ (6,63,120 L), respectively. The stored water was utilized through an automated drip irrigation system to provide supplemental irrigation during critical crop growth stages, thereby reducing moisture stress and improving water-use efficiency. The study demonstrated that rooftop rainwater harvesting is a simple, cost-effective and sustainable approach for enhancing water availability, reducing dependence on groundwater and improving agricultural resilience in semi-arid regions. Technology has significant potential for wider adoption in water-scarce areas of North Gujarat and similar agro-climatic regions.

Keywords: Rooftop rainwater harvesting, rainfed agriculture, farm pond, water conservation

INTRODUCTION

India ranks first in rainfed agriculture globally in both area (86 M ha) and the value of produce. Rainfed regions in India contribute substantially toward food grain production including 44% of rice, 87% of coarse cereals (sorghum bicolor), pearl millet (*Pennisetum glaucum*), maize (*Zea mays*) and 85% of food legumes, 72% of oilseeds, 65% of cotton and 90% of minor millets. Overall, the rainfed areas produce 40% of the food grains, support two-thirds of the livestock population and are critical to food security, equity and sustainability (Venkateswarlu *et al.*, 2015). In India, about 75–80% of annual rainfall is received through the southwest monsoon during June to September and Gujarat region receives maximum rainfall i.e. 96% of its annual rainfall in southwest monsoon (Indian meteorological department, 2022). The distribution of rainfall is highly variable both spatially and temporally which creating challenges for sustainable crop production particularly in dryland regions.

Gujarat state is in the western part of India and comprises diverse agro-climatic zones but predominantly falls under semi-arid to arid regions. Particularly, North Gujarat experiences low and erratic rainfall (400–800 mm) with

uneven distribution. In addition, high evapotranspiration, declining groundwater levels and salinity problems are major issues in crop production in this region. Crop production in such environments is largely dependent on stored soil moisture and limited irrigation resources. Frequent dry spells during crop growth stages cause moisture stress, resulting in reduced yield and instability in production. Therefore, efficient management and conservation of available water resources are essential for sustaining agricultural production in these regions.

Rooftop rainwater harvesting refers to the collection of rainwater from rooftops for future utilization. It reduces dependency on groundwater resources and provides an additional source of water for irrigation, domestic purposes, livestock and groundwater recharge. Rooftop rainwater harvesting has gained importance due to its simplicity, low operational cost and high runoff collection efficiency. In this system, rainfall received on rooftop surfaces is collected through drainage networks and stored in suitable structures such as farm ponds, tanks or recharge systems. The stored water can subsequently be used for supplemental irrigation during critical crop growth stages when rainfall is insufficient.

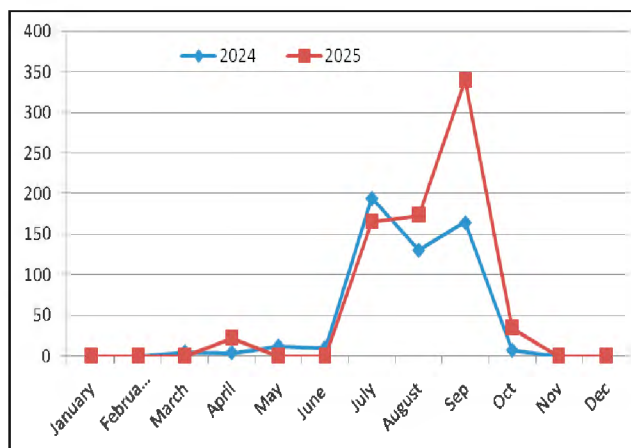
Gujarat has considerable potential for rooftop rainwater

harvesting due to its climatic conditions and seasonal rainfall pattern. Such systems can contribute significantly to water conservation, particularly in arid and semi-arid areas where rainfall occurs mainly during a short monsoon period. Patan district where the study location is situated, receives substantial monsoon rainfall, indicating considerable scope for harvesting and utilizing rainwater for agricultural purposes.

MATERIALS AND METHODS

Study area and rainfall

The study was conducted at Dry Farming Research Station, Sardarkrushinagar Dantiwada Agricultural University, Radhanpur, which represents the arid to semi-arid region of North Gujarat. The area receives low and erratic rainfall (300–700 mm annually) with high evapotranspiration, light-textured soils and frequent moisture stress conditions. An automatic weather station has been installed at the centre and the daily rainfall data are recorded and utilized for analysis purposes and shown in Graph 1.



During year 2024, the station received a total rainfall of 527.7 mm, whereas during year 2025, the annual rainfall was 736.8 mm. The rainfall distribution showed a strong concentration during the southwest monsoon period, particularly from July to September. The uneven distribution of rainfall resulted in inadequate moisture availability during crop growth periods highlighting the importance of efficient rainwater harvesting and storage systems (Anonymous, 2026).

The rainfall data have been presented graphically to visualize seasonal trends and distribution patterns and its variability emphasizes the need for effective rainwater harvesting and storage systems for sustainable crop production. The major crops cultivated at the station include blackgram, greengram, sorghum and mothbean during the

kharif season while cumin, dill seed and chickpea are cultivated during the *rabi* season. These crops generally require approximately 250–400 mm water during their crop growth period. Since rainfall does not always coincide with crop water demand, supplemental irrigation becomes essential for achieving stable productivity.

Rooftop rainwater harvesting system design

The rooftop rainwater harvesting system is divided into three primary components: catchment, conveyance and storage structures.

1. Catchment

The office building of DFRS serves as the catchment area for the rooftop rainwater harvesting system. The building has an approximate rooftop area of 1000 m², including the main terrace and adjoining paved surfaces. The terrace is constructed of reinforced cement concrete (RCC) with a sloping design that facilitates efficient runoff collection. This slope ensures that rainwater flows naturally toward designated collection points, minimizing water stagnation and losses. Thus, the entire rooftop catchment area effectively contributes to the collection and channelling of rainwater into the harvesting system.



2. Conveyance (Pipe System)

Rainwater collected from the rooftop is conveyed to the storage structure through a well-designed network of downpipes. The system consisted of Downpipes of 110 mm diameter and Main conveyance pipeline of 140 mm diameter. The pipe network was installed with an appropriate slope to facilitate gravity flow and minimize water losses during transportation. Collection points were connected to the main conveyance pipeline, which transported harvested runoff directly to the farm pond. The pipeline system included covered ventilation openings to maintain smooth water flow and prevent interruption caused by air locking.



3. Storage structure (Farm pond)

The harvested rooftop runoff was stored in a farm pond constructed near the office building. The farm pond dimensions were:

Bottom size: 42 m × 14.5 m

Upper surface size: 46 m × 17.5 m

Depth: approximately 3–4 m

The pond had a gradual slope, with a depth of about 3 m at the inlet side and increasing to approximately 4 m toward the outlet side. This design improved sediment deposition, storage efficiency, and water retention capacity. The total storage capacity of the farm pond was 15.60 lakh litres. The stored water was later utilized for supplemental irrigation through an automated drip irrigation system.



Estimation of rainwater harvesting potential

The potential quantity of harvested rainwater was estimated using rooftop catchment area, annual rainfall, and runoff coefficient.

The standard equation used was:

$$R = A \times P \times C$$

Where,

R = Annual runoff (m³)

A = Catchment area (m²)

P = Annual rainfall (m)

C = Runoff coefficient

A runoff coefficient of 0.90 was considered for RCC rooftop surfaces due to their high runoff efficiency and minimal infiltration losses (Biswas and Mandal, 2014).

RESULTS AND DISCUSSION

Rainfall Variability and Crop Water Requirement

The rainfall pattern at Dry Farming Research Station, Radhanpur showed considerable year-to-year variability. During 2024–25, the station received only 527.7 mm rainfall, whereas rainfall during 2025–26 increased to 736.8 mm. The rainfall was mainly concentrated during the monsoon months (July–September) and resulting in uneven availability of water throughout the crop growing season.

The major crops grown at DFRS include blackgram, greengram, sorghum and mothbean during *kharif* season and cumin, dill seed and chickpea during *rabi* season. These crops require approximately 250–400 mm water during their growth period. Under dry farming conditions, rainfall alone is often inadequate to meet crop evapotranspiration demand, particularly during prolonged dry spells. Therefore, supplemental irrigation from harvested rainwater plays an important role in sustaining crop growth and improving production stability.

Rooftop Rainwater Harvesting Potential

The rooftop rainwater harvesting system effectively collected runoff from the 1000 m² rooftop catchment area. Based on an annual rainfall of 527.7 mm and 736.8 mm during the year 2024 and 2025, respectively and a runoff coefficient of 0.90 the estimated annual harvestable runoff was:

For year 2024,

$$R = 1000 \text{ m}^2 \times 0.5277 \text{ m} \times 0.90 = 474.93 \text{ m}^3 \\ = 4,74,930 \text{ litre water}$$

For year 2025,

$$R = 1000 \text{ m}^2 \times 0.7368 \text{ m} \times 0.90 = 663.12 \text{ m}^3 \\ = 6,63,120 \text{ litre water}$$

The designed farm pond capacity of 15.60 lakh litres was higher than the estimated annual rooftop runoff volume. This additional storage capacity provides flexibility for storing runoff from future expansion of catchment areas and possible integration with field runoff harvesting systems. The combination of rooftop collection and farm pond storage ensured conservation of rainfall that would otherwise be lost as surface runoff.

Utilization of Harvested Water for Crop Production

The harvested rainwater provided supplemental irrigation during critical crop growth stages when rainfall was inadequate, thereby reducing moisture stress in *kharif*

season crop. The stored water was subsequently used for supplemental irrigation of *rabi* crops, particularly cumin and dill seed through an automated drip irrigation system. Drip irrigation ensured efficient application of stored water directly to the crop root zone, reducing evaporation losses and improving water-use efficiency. The harvested water reduced crop moisture stress, improved crop establishment, promoted better growth and development, and enhanced production stability under dry farming conditions. The system transformed the production environment from a completely rain-dependent system to a partially irrigated system thereby improving resilience to rainfall variability.

Role of Rooftop Rainwater Harvesting in Semi-Arid Agriculture

The results demonstrate that rooftop rainwater harvesting is a practical water conservation strategy for semi-arid regions. Unlike conventional irrigation sources, harvested rainwater provides locally available water without additional energy requirements for extraction. Integration of rainwater harvesting with efficient irrigation systems such as drip irrigation can significantly improve water productivity. Similar findings have been reported by Biswas and Mandal (2014), who highlighted the effectiveness of rainwater harvesting systems for improving water availability in water-scarce regions. The approach is particularly relevant for North Gujarat, where groundwater depletion, salinity problems and rainfall uncertainty limit agricultural sustainability.

CONCLUSION

The study demonstrated that rooftop rainwater harvesting is an effective and sustainable water conservation strategy for

the semi-arid region of North Gujarat. The system successfully harvested 4.75–6.63 lakh litres of rainwater annually from a 1000 m² rooftop catchment, providing a reliable source of supplemental irrigation during critical crop growth stages. Integration of harvested rainwater storage with drip irrigation improved water-use efficiency, reduced dependence on groundwater and enhanced crop resilience under variable rainfall conditions. The findings indicate that rooftop rainwater harvesting coupled with farm pond storage can contribute significantly to sustainable water resource management and agricultural productivity in dryland regions. Adoption of this technology at research farms and by farming communities can strengthen climate resilience and support sustainable agriculture in water-scarce areas.

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