



भारतीय कृषि अनुसंधान परिषद
महात्मा गांधी समेकित कृषि
अनुसंधान संस्थान, मोतिहारी

ICAR–Mahatma Gandhi
Integrated Farming
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वर्षा जल संचयन और जल
संसाधन प्रबंधन: एक मार्गदर्शिका

RAINWATER HARVESTING
AND WATER RESOURCE
MANAGEMENT: A GUIDE

सतत जल सुरक्षा, समृद्ध भविष्य
Sustainable Water Security, Prosperous Future



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वर्षा जल संचयन और जल संसाधन प्रबंधन: एक मार्गदर्शिका

Rainwater Harvesting and Water Resource Management: A Guide



भारत अनुप
ICAR

भारतीय कृषि अनुसंधान परिषद

Indian Council of Agricultural Research

महात्मा गांधी समेकित कृषि अनुसंधान संस्थान, पिपराकोठी, मोतिहारी

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FORWARD



Water is one of the most valuable natural resources and a fundamental prerequisite for sustainable agricultural development. In the eastern Indo-Gangetic Plains, particularly in Bihar, agriculture faces a unique hydrological challenge. Every year, large areas are affected by floods and prolonged waterlogging during the monsoon season, while the same regions experience water scarcity during the post-monsoon and summer months. This seasonal paradox highlights the need for scientific approaches to harvest, conserve, store, and efficiently utilize rainwater for ensuring year-round agricultural productivity, livelihood security, and climate resilience.

The ICAR–Mahatma Gandhi Integrated Farming Research Institute (ICAR–MGIFRI), Piprakothi, has been entrusted with the mandate of developing Integrated Farming System (IFS) models for flood-prone and

waterlogged ecosystems of eastern India. Efficient water resource management forms the cornerstone of this mandate, as sustainable agriculture in these regions depends on the scientific management of excess monsoon water through well-designed water harvesting structures and its productive utilization across diversified farming enterprises.

Over the years, the Institute has established a comprehensive network of water harvesting structures under various research projects, including farm ponds, fish ponds, rooftop rainwater harvesting systems, underground storage tanks, and other water conservation structures. These assets not only provide a reliable source of water for irrigation, horticulture, fisheries, livestock, and other IFS components but also serve as valuable research and demonstration facilities for scientists, students, extension personnel, and farmers. They contribute significantly to improving water-use efficiency, reducing dependence on groundwater, enhancing climate resilience, and promoting sustainable natural resource management.

This technical bulletin, "Rainwater Harvesting and Water Resource Management: A Guide," presents a systematic documentation of the Institute's water harvesting infrastructure developed under different research projects. The bulletin provides comprehensive information on engineering design principles, storage capacity estimation, operation and maintenance practices, water utilization in Integrated Farming Systems, and the application of emerging technologies such as the Internet of Things (IoT), automation, remote sensing, and smart sensors for efficient water resource management.

I am confident that this publication will serve as a valuable reference for researchers, agricultural engineers, planners, extension professionals, policymakers, students, and progressive farmers interested in scientific rainwater harvesting and Integrated Farming Systems. The experiences and technical information presented herein will encourage the wider adoption of water harvesting technologies, particularly in flood-prone and waterlogged regions, thereby strengthening climate-resilient agriculture and sustainable rural development.

I congratulate Dr. A. K. Jadhav, Scientist (Fruit Science), for his dedicated efforts in compiling this comprehensive technical bulletin. I also acknowledge the valuable contributions of the Principal Investigators, scientists, engineers, technical staff, and supporting personnel whose collective efforts have led to the establishment, management, and documentation of the Institute's water harvesting structures. I extend my best wishes for the successful dissemination and utilization of this publication.

(Dr. Raghvendra Singh)
Director, ICAR–MGIFRI

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Note

This technical bulletin has been prepared by ICAR–MGIFRI to disseminate scientific knowledge on rainwater harvesting, groundwater recharge, and sustainable water management practices. The information presented is based on published scientific literature, research findings, and field experiences. The bulletin is intended for educational, research, extension, and capacity-building purposes.

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Disclaimer

The information presented in this bulletin is intended solely for educational and extension purposes. Although every effort has been made to ensure the accuracy of the information, the authors and ICAR–MGIFRI shall not be responsible for any loss or damage arising from the use of the contents. Users are advised to adopt technologies based on local agro-climatic conditions and recommendations of concerned experts.



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Introduction and Fundamental Concepts of Rainwater Harvesting

1.1 Introduction

Water is one of the most valuable natural resources supporting agriculture, food security, ecosystems, and human livelihoods. Although India receives substantial annual rainfall, its uneven distribution across regions and seasons often leads to floods during the monsoon and water scarcity during the dry months. Efficient conservation and management of rainwater are therefore essential for sustainable agricultural development and climate resilience.

1.2 Water Resources in India

India receives an average annual rainfall of about 1,170 mm, which provides significant water resources. However, nearly 75–80% of the rainfall occurs during the southwest monsoon, resulting in large runoff losses. Agriculture accounts for nearly 80% of freshwater use, making efficient water harvesting and irrigation management critical for ensuring food security and sustainable use of water resources (Figure 1.1).

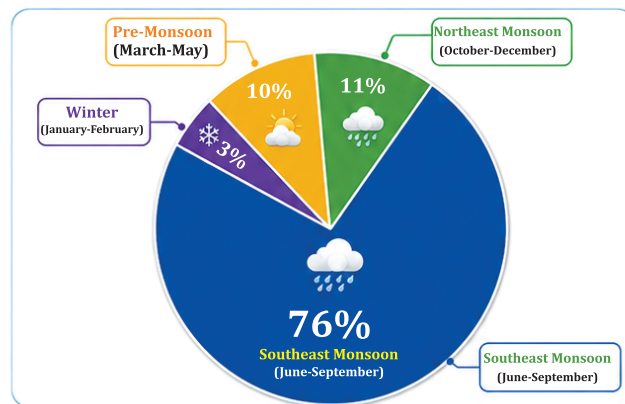


Figure 1.1. Seasonal Distribution and average share of Annual Rainfall in India. Source: IMD long-term climatological normal (1981–2020), Government of India.

1.3 Rainwater Harvesting

Rainwater harvesting (RWH) is the activity of directly collecting, and storing rainwater at the surface or in sub-surface aquifers before it is lost as surface runoff. The fundamental concept is based on making optimum use of rainwater at the place where it falls, essentially treating it like a "bank account" where surplus water is deposited for withdrawal during periods of deficiency.

The Need for Rainwater Harvesting The urgency for RWH stems from a global and national water crisis characterized by:

Dwindling Resources: In India, per capita water availability has dropped from 5,177 m³ in 1951 to approximately 1,869 m³ today, with projections suggesting further declines to 1,235 m³ by 2050. The graph clearly demonstrates an approximately 71% decline in per-capita water

availability between 1951 and 2021 due primarily to population growth while renewable water resources remained relatively constant (Figure 1.2).

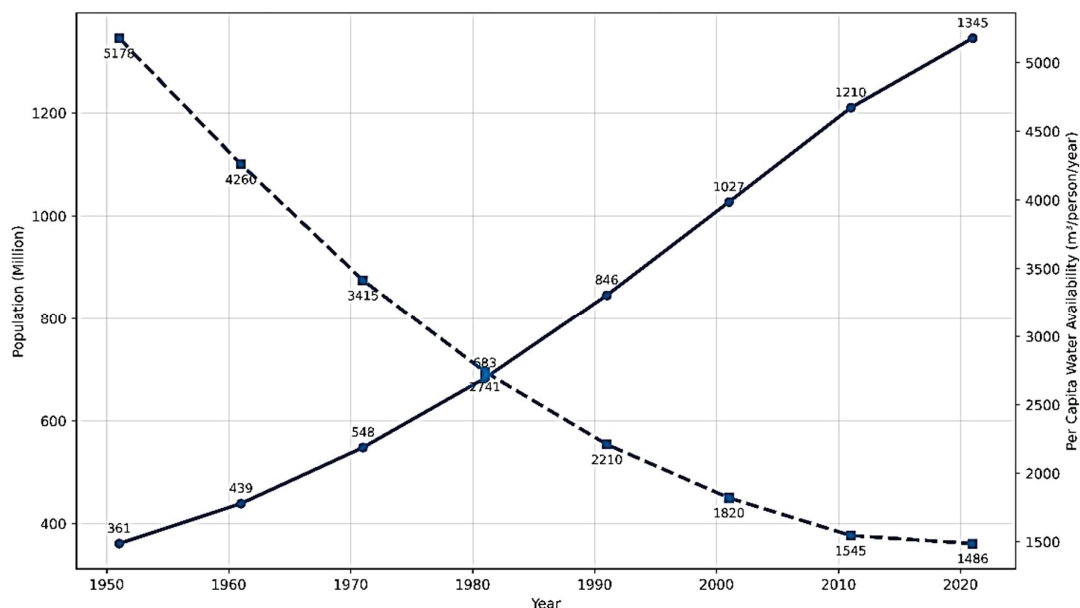


Figure 1.2. Declining trend in per capita annual water availability in India (1951–2021), highlighting the increasing pressure on available freshwater resources due to rapid population growth. Source: Prepared by the authors using Census of India population data and Central Water Commission (CWC), Ministry of Jal Shakti, Government of India.

The Urban Paradox: Many urban areas face the simultaneous challenges of acute water scarcity and frequent flooding during rains, reflecting a managerial failure to utilize surplus seasonal water.

Groundwater Depletion: Indiscriminate pumping has led to alarming declines in water tables—for example, in Delhi, levels have dropped by up to 30 meters in some districts since 1960.

India is projected to become a water-stressed nation as per capita annual water availability continues to decline due to rapid population growth, urbanization, and increasing demand across agricultural, domestic, industrial, and energy sectors (Table 1.1). Agriculture will continue to remain the largest consumer of water, accounting for the highest share of total demand, followed by domestic, industrial, and energy sectors. The projected increase in water demand highlights the urgent need for efficient water resource management through rainwater harvesting, groundwater recharge, micro-irrigation, recycling of wastewater, and adoption of water-efficient technologies to ensure long-term water security and sustainable agricultural development.

Table 1.1 Projected sector-wise water demand in India for 2025 and 2050 (BCM/year).

Sector	2025 (BCM/year)	2050 (BCM/year)
Agriculture	688	807
Domestic	73	111
Industry	67	81
Energy	15	70

Source: Adapted from NCIWRD (1999) and NITI Aayog (2018). *Note: 1 BCM = 1,000 million cubic metres

1.4 Fundamental Concepts

Hydrologic Cycle: RWH leverages the never-ending exchange of water between the atmosphere and the earth, capturing precipitation (rain, snow, sleet) to replenish terrestrial sources.

Resource Paradigm Shift: There is a move away from unsustainable, energy-intensive centralized water supply systems toward decentralized self-sufficiency.

Rainwater Endowment vs. Potential: The total water received as rainfall over an area is the "endowment," while the "potential" is the portion that can be effectively harvested after accounting for losses like evaporation and spillage.

Rainfall–Runoff Relationship: The rainfall–runoff relationship describes the proportion of rainfall that infiltrates into the soil and the proportion that flows over the land surface as runoff. When rainfall intensity exceeds the infiltration capacity of the soil, excess water becomes surface runoff. The amount of runoff depends on several factors, including rainfall intensity and duration, soil type, land slope, vegetation cover, antecedent soil moisture, and land use. In agricultural watersheds, uncontrolled runoff often results in soil erosion, nutrient loss, flooding, and wastage of valuable freshwater resources. Rainwater harvesting systems are designed to intercept and store a portion of this runoff, thereby reducing runoff losses, enhancing groundwater recharge, and providing stored water for irrigation and other productive uses during dry periods.

Catchment: A catchment is the surface area that receives rainfall and contributes runoff to a rainwater harvesting system. It may include rooftops, agricultural fields, paved areas, or natural land surfaces.

Storage: Storage refers to the collection and retention of harvested rainwater in structures such as farm ponds, tanks, reservoirs, or underground storage systems for use during periods of water scarcity.

Recharge: Recharge is the process of allowing harvested rainwater to infiltrate into the ground to replenish groundwater aquifers through recharge pits, trenches, wells, or percolation tanks.

Reuse: Reuse is the productive utilization of harvested rainwater for purposes such as irrigation, horticulture, livestock, fisheries, cleaning, and other nonpotable applications, thereby reducing dependence on freshwater sources.

1.5 Rainfall Characteristics of Bihar

Bihar exhibits considerable spatial and temporal variability in rainfall, which strongly influences agricultural production and water availability. Analysis of long-term rainfall data indicates that the eastern and north-eastern districts, including Kishanganj, Araria, Purnia, Katihar, Bhagalpur, and Banka, consistently receive the highest annual and seasonal rainfall (Figure 1.3a). However, decadal comparisons reveal a gradual decline in winter, monsoon, and post-monsoon rainfall during recent decades, while pre-monsoon rainfall showed relatively higher values during earlier periods. Furthermore, the proportion of districts experiencing below-normal rainfall has increased markedly over time, indicating a shift towards more frequent rainfall deficits across Bihar (Figure 1.3.b). These changing rainfall patterns emphasize the need for scientific rainwater harvesting, improved storage infrastructure, and efficient utilization of excess monsoon water to address seasonal water scarcity and enhance climate resilience.

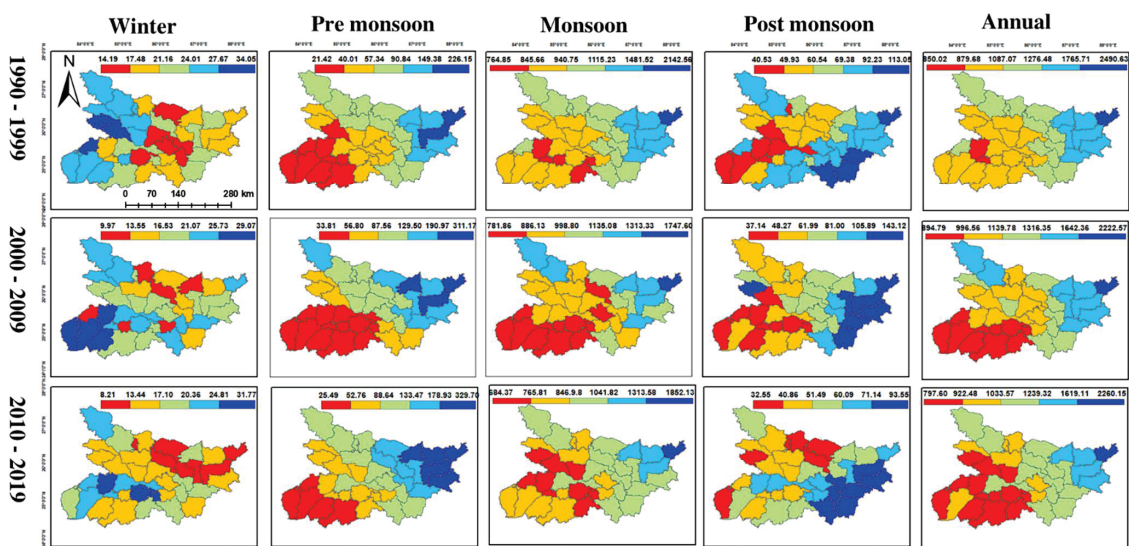


Figure 1.3a. Spatial distribution of decadal mean seasonal and annual rainfall across districts of Bihar (Source: Banerjee et al., 2026).

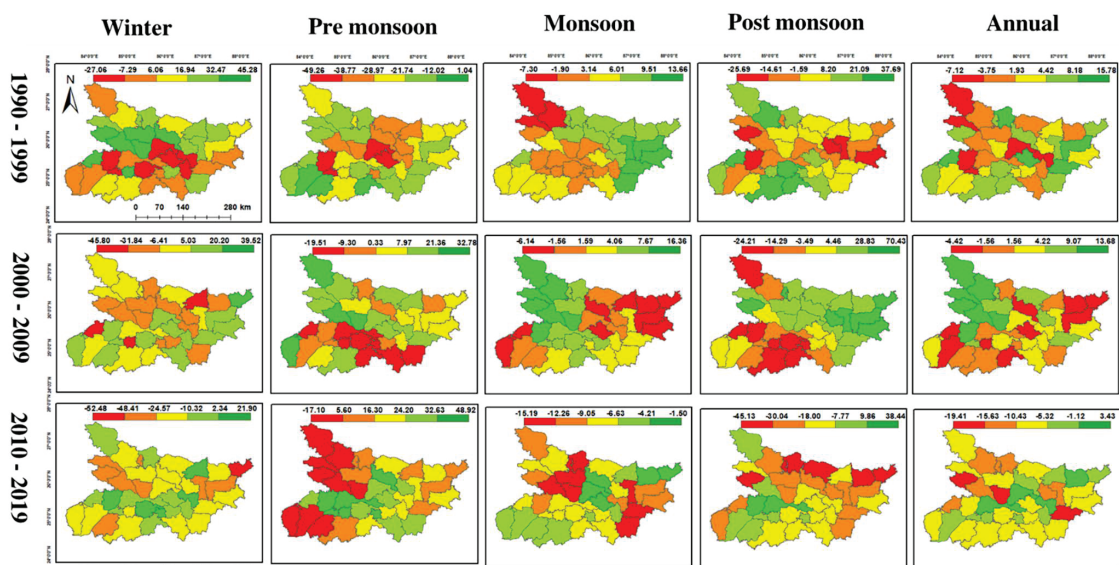


Figure 1.3b. Spatial distribution of decadal mean seasonal and annual percent departure of rainfall (PDR %) across districts of Bihar (Source: Banerjee et al., 2026).

1.6 Rainwater Harvesting in Bihar

Bihar is predominantly an agricultural state where farming depends largely on monsoon rainfall. The state receives approximately 1,000–1,300 mm of annual rainfall, with most of it occurring between June and September. Northern Bihar frequently experiences floods and prolonged waterlogging during the monsoon, while many areas face water shortages during the rabi and summer seasons. This seasonal imbalance highlights the importance of rainwater harvesting for sustainable agriculture.

1.7 Water Resources of Bihar

Bihar is endowed with several major rivers, including the Ganga, Gandak, Kosi, Bagmati, Kamla, Burhi Gandak, and Sone. Although these rivers carry large quantities of water during the monsoon, a significant portion is lost as runoff. Scientific water harvesting through farm ponds, fish ponds, rooftop systems, and traditional water bodies can effectively store surplus rainwater for productive use.

1.8 Traditional Water Harvesting Systems

The Ahar–Pyne system is one of the oldest and most efficient traditional water harvesting systems of Bihar. Along with village ponds and community tanks, these structures have historically supported irrigation, groundwater recharge, fisheries, and flood management. Their conservation and modernization can significantly strengthen water security in the state.

1.9 Government Initiatives

The Government of India and the Government of Bihar actively promote rainwater harvesting through programmes such as Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Jal Jeevan Hariyali Mission, MGNREGA, Atal Bhujal Yojana (national groundwater management), Amrit Sarovar Mission, watershed development programmes, and various initiatives of the Water Resources Department. These programmes encourage the construction of farm ponds, rooftop harvesting systems, and groundwater recharge structures.

1.10 Objectives of Rainwater Harvesting

- To conserve and efficiently utilize excess monsoon rainfall by capturing, storing, and reusing rainwater for irrigation and other productive purposes during periods of water scarcity.
- To enhance water resource sustainability through groundwater recharge, reduction of surface runoff, soil erosion, and flood impacts, while improving overall water-use efficiency.
- To strengthen climate-resilient and sustainable agriculture by supporting Integrated Farming Systems (IFS), improving water security, and enhancing agricultural productivity and rural livelihoods.

1.11 Institute's Strategic Vision for Rainwater Harvesting

ICAR–MGIFRI, Piprakothi, envisions rainwater harvesting as a cornerstone of climate-resilient agriculture in the flood-prone and waterlogged ecosystems of the eastern Indo-Gangetic Plains. The Institute's strategy focuses on transforming excess monsoon runoff into a productive resource through scientifically designed water harvesting structures integrated with crop, horticulture, fisheries, livestock, and other components of Integrated Farming Systems (IFS). By capturing and storing surplus rainwater, the Institute aims to reduce dependence on groundwater, improve irrigation reliability during dry periods, enhance water-use efficiency, and strengthen the resilience of farming systems against climate variability. The strategic vision also emphasizes adoption of advanced technologies such as GIS-based planning, IoT-enabled water level monitoring, automated

irrigation systems, remote sensing, and decision-support tools for efficient water resource management. Through research, demonstration, capacity building, and technology dissemination, ICAR–MGIFRI seeks to develop sustainable and scalable water harvesting models that can be widely adopted across Bihar and other flood-prone regions of the country, thereby contributing to water security, agricultural productivity, and long-term natural resource conservation.

1.12 Challenges and Future Scope

Major challenges include siltation of ponds, inadequate maintenance, groundwater depletion, encroachment of traditional water bodies, and changing rainfall patterns. Future efforts should focus on scientific design, regular maintenance, micro-irrigation, IoT-based water level monitoring, GIS mapping, automation, and digital water resource management for improving the efficiency of water harvesting systems (Figure 1.4).

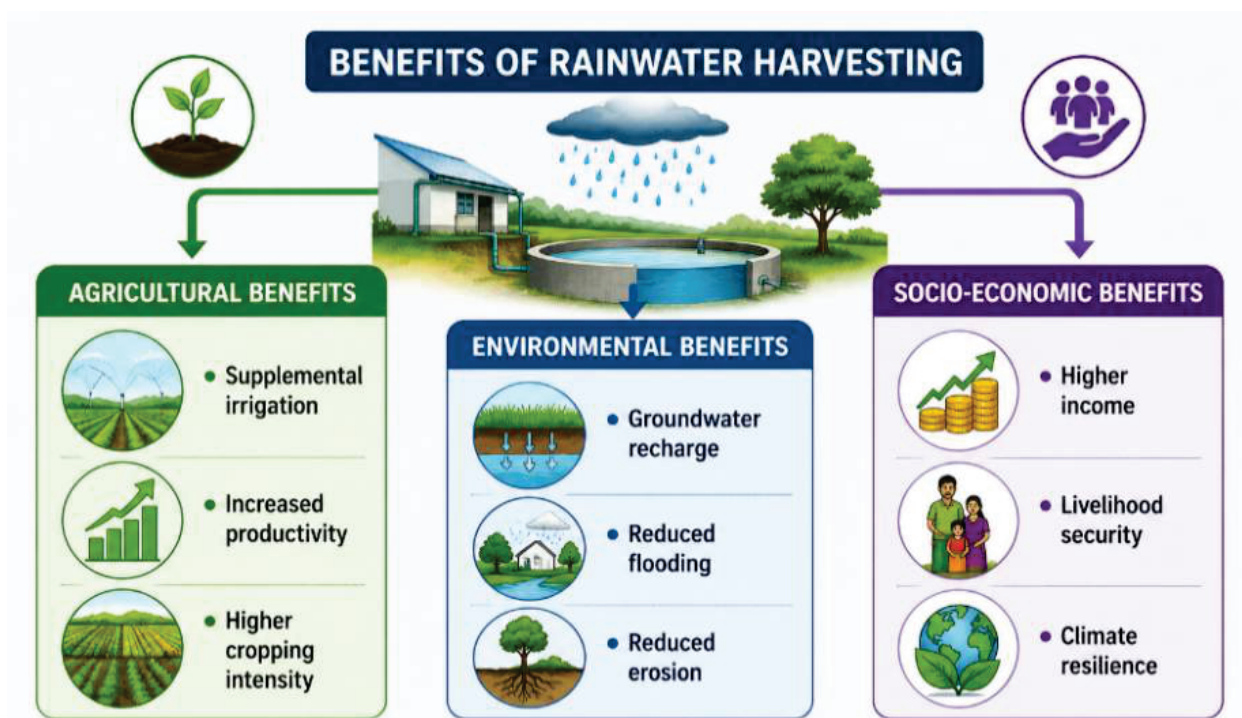


Figure 1.4. Major agricultural, environmental, and socio-economic benefits of rainwater harvesting (*Prepared by the authors using AI-assisted illustration 2026*)



Hydrology and Water Harvesting Potential Assessment

Hydrological assessment is the foundation for designing any rainwater harvesting (RWH) system, involving the calculation of available water and how much can be effectively captured for use or recharge.

The success of a rainwater harvesting system depends not merely on the amount of rainfall received, but on how rainfall interacts with the catchment and how much of it can be collected, stored, recharged, and productively utilized. A sound understanding of catchment hydrology is therefore essential for the planning and design of water harvesting interventions.

Hydrological assessment provides a quantitative basis for estimating water availability, identifying suitable harvesting opportunities, selecting appropriate structures, and determining their storage capacity. It considers rainfall characteristics, catchment area, topography, soil and land-use conditions, runoff behaviour, water demand, and various storage losses. Such assessment is particularly important in agricultural and Integrated Farming Systems (IFS), where harvested water may support supplemental irrigation, livestock, fisheries, horticulture, groundwater recharge, and other farm enterprises during periods of water scarcity.

2.1 Hydrological Cycle and Rainfall–Runoff Relationship

The hydrological cycle describes the continuous movement of water between the atmosphere, land surface, water bodies, soil, and groundwater. Solar energy drives evaporation from water and land surfaces and transpiration from vegetation (Figure 2.1). Water vapour subsequently condenses in the atmosphere and returns to the earth as precipitation. Once rainfall reaches the land surface, it may be intercepted by vegetation, infiltrate into the soil, evaporate, percolate to groundwater, or flow over the surface as runoff.

From the perspective of rainwater harvesting, the partitioning of rainfall after it reaches a catchment is particularly important. In simplified form:

Rainfall = Interception + Infiltration + Evapotranspiration + Surface Runoff ± Change in Storage

The relative magnitude of these components varies considerably with rainfall intensity and duration, soil characteristics, antecedent moisture, land use, vegetation, slope, and surface condition.

The principal hydrological components relevant to water harvesting are described below.

Precipitation: Precipitation is the primary input to the hydrological system. For most rainwater harvesting applications, rainfall is the dominant form of precipitation and determines the overall quantity and temporal availability of water that may potentially be harvested.

Interception: Before rainfall reaches the ground, a portion may be intercepted by vegetation, buildings, crop canopies, and other surfaces. Some of this intercepted water subsequently evaporates and therefore does not contribute directly to runoff or groundwater recharge.

Infiltration: Infiltration is the entry of water into the soil surface. Its rate depends on soil texture and structure, antecedent soil moisture, vegetation, surface condition, compaction, and rainfall intensity. Infiltrated water replenishes soil moisture and may subsequently percolate downward to recharge groundwater.

Surface runoff: When rainfall exceeds the combined capacity of interception, surface storage, and infiltration, excess water moves over the land surface as runoff. This runoff may eventually enter natural drainage channels, streams, ponds, reservoirs, or constructed water harvesting structures. For surface-storage systems such as farm ponds and check dams, runoff is the principal source of harvestable water.

Evapotranspiration: Evapotranspiration represents the combined loss of water through evaporation from soil and water surfaces and transpiration through vegetation. It is an important component of the catchment water balance and can substantially influence both runoff availability and the useful storage life of harvested water.

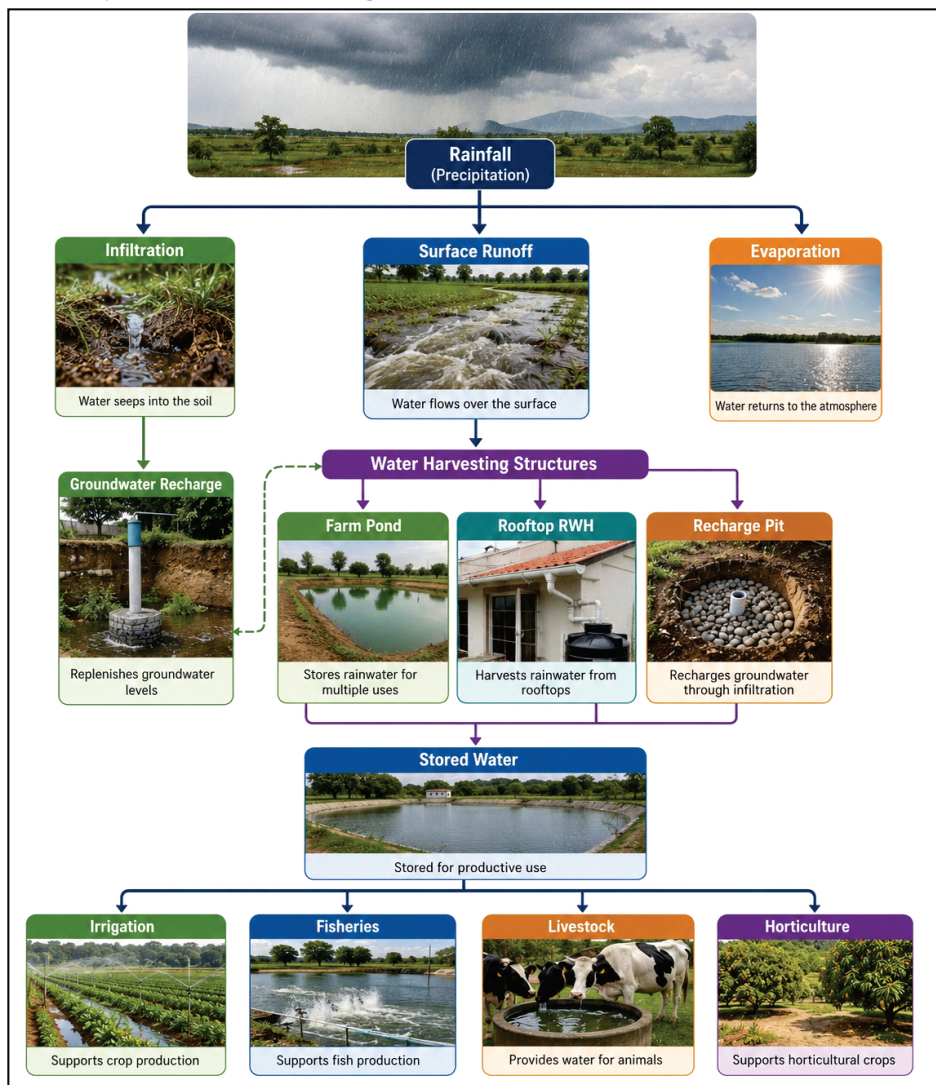


Figure 2.1. Hydrological cycle showing the major pathways of rainfall and opportunities for rainwater harvesting and groundwater recharge (Prepared by the authors using AI-assisted illustration 2026)

Groundwater recharge: A portion of infiltrated water moves below the root zone and may eventually replenish groundwater aquifers. Recharge can be enhanced through interventions such as recharge pits, trenches, percolation tanks, recharge shafts, and suitable check dams. Understanding these processes is fundamental because a water harvesting system does not capture rainfall directly in its entirety. Rather, it captures a portion of the water remaining after various hydrological losses and transformations have occurred.

2.2 Rainwater Endowment, Runoff Potential and Harvesting Potential —●

Three related but distinct concepts are useful when assessing the water resource available from a catchment: rainwater endowment, runoff potential, and practically harvestable water. Distinguishing between them avoids overestimation of the amount of water that can actually be stored and used.

2.2.1 Rainwater Endowment

Rainwater endowment is the total volume of rainfall received over a specified area, without accounting for any hydrological losses.

It can be estimated as:

$$V_r = P \times A$$

where:

- V_r = total volume of rainfall received,
- P = rainfall depth, and
- A = catchment area.

For practical calculations:

$$\text{Rainwater endowment (m}^3\text{)} = \text{Rainfall (mm)} \times \text{Catchment area (m}^2\text{)} / 1000$$

A particularly useful field relationship is:

$$1 \text{ mm of rainfall over } 1 \text{ m}^2 = 1 \text{ litre of water}$$

Similarly:

$$1 \text{ mm of rainfall over } 1 \text{ hectare} = 10 \text{ m}^3 \text{ of water}$$

2.2.2 Runoff or Theoretical Harvesting Potential

Only a fraction of the rainfall received by a catchment becomes runoff. A simple estimate of runoff volume can be obtained using a runoff coefficient:

$$V = P \times A \times C / 1000$$

where:

- V = estimated runoff volume (m^3),
- P = rainfall (mm),
- A = catchment area (m^2), and
- C = runoff coefficient (dimensionless)

The runoff coefficient represents the fraction of rainfall expected to appear as runoff after accounting, in an approximate manner, for infiltration, interception, surface retention, and related losses.

For example, if the 1-ha catchment receiving 1,200 mm rainfall has an assumed runoff coefficient of 0.30:

Estimated runoff

$$= 1,200 \times 10,000 \times 0.30 / 1000$$

$$= 3,600 \text{ m}^3$$

Thus, although the annual rainwater endowment is $12,000 \text{ m}^3$, the estimated runoff available from the catchment is only about $3,600 \text{ m}^3$ under the assumed conditions.

2.2.3 Practically Harvestable Water

Even the estimated runoff cannot necessarily be stored and utilized in full. Additional losses may occur during conveyance and storage through spillage, evaporation, seepage, first-flush diversion in rooftop systems, operational losses, and overflow when rainfall exceeds available storage capacity.

Therefore:

Rainwater endowment > Runoff potential $\geq$ Practically harvestable water

This distinction is particularly important when sizing water harvesting structures. Designing a structure solely on the basis of annual rainfall volume can lead to unrealistic estimates of available water and uneconomical storage capacity.

2.3 Runoff Coefficient and Runoff Estimation

The runoff coefficient (C) is a dimensionless factor expressing the proportion of rainfall that contributes to runoff from a particular surface or catchment. Its value generally ranges from near zero for highly permeable surfaces to values approaching one for relatively impervious surfaces (Table 2.1).

A higher coefficient indicates that a larger proportion of rainfall becomes runoff, whereas a lower coefficient indicates greater infiltration, interception, depression storage, or other losses.

Table 2.1 Indicative Runoff Coefficients for Different Catchment Surfaces:

Surface	Runoff coefficient
Roof Catchments:	
RCC Roof	0.60–0.80
GI Sheet	0.70–0.90
Tiles	0.80–0.90
Ground Surface Coverings	
Brick pavement	0.70–0.85
Concrete pavement	0.70–0.95
Untreated Natural Surfaces	
Soil (slope <10%): 0.00 – 0.30	0.10–0.30
Lawns/Sandy Soil: 0.05 – 0.20	0.05–0.20
Rocky Material: 0.20 – 0.50	0.20–0.50

Source: Adapted from Central Ground Water Board (CGWB), 2020; Central Public Health and Environmental Engineering Organisation (CPHEEO), 2019; FAO, 1991.

Note: These values are indicative rather than universal design constants. The appropriate coefficient should be selected considering local rainfall characteristics, slope, soil, land use, vegetation, surface condition, antecedent moisture, and the time scale of analysis. Locally validated values should be preferred wherever available.

For simple preliminary assessments, the runoff-coefficient method is useful because it requires limited data. For larger agricultural catchments, watersheds, or event-based design, more detailed methods such as the SCS/NRCS Curve Number method may provide a better representation of runoff behaviour.

2.4 Factors Affecting Runoff Generation and Harvesting Potential

The amount of runoff generated from a catchment is controlled by the interaction of climatic, soil, topographic, and land-surface characteristics.

Rainfall characteristics: Rainfall amount, intensity, duration, frequency, and temporal distribution strongly influence runoff. High-intensity rainfall may exceed the infiltration capacity of the soil and generate substantial runoff within a short period. In contrast, low-intensity rainfall may infiltrate more effectively and contribute less surface runoff.

Annual rainfall alone is therefore insufficient for design. Two locations receiving the same annual rainfall may have very different water harvesting potential if their rainfall distribution and storm characteristics differ.

Catchment area and shape: The catchment area determines the total area contributing runoff to a harvesting structure. Catchment shape and drainage configuration influence the timing and concentration of runoff reaching the outlet.

Accurate catchment delineation is particularly important for farm ponds, check dams, nala bunds, and watershed-scale structures.

Soil characteristics: Soil texture, structure, depth, permeability, infiltration capacity, and compaction strongly affect rainfall partitioning.

Sandy and well-structured soils generally allow greater infiltration and may generate relatively less surface runoff, whereas compacted, shallow, clayey, or poorly permeable soils may generate higher runoff under comparable rainfall conditions.

Antecedent soil moisture: The moisture condition of the soil before a rainfall event has a major influence on runoff generation. A dry soil profile can initially absorb a greater proportion of rainfall, whereas a wet or saturated soil has limited additional storage capacity and tends to generate runoff more rapidly.

This factor becomes especially important during successive monsoon storms.

Land use and land cover: Land use determines how rainfall interacts with the catchment surface. Built-up and paved areas generally produce rapid runoff, while agricultural land, grassland, and forested areas tend to promote infiltration and delay runoff.

Changes in land use can therefore significantly alter catchment hydrology over time.

Vegetation cover: Vegetation intercepts rainfall, reduces raindrop impact, slows overland flow, improves soil structure, and promotes infiltration. Dense vegetation generally reduces peak runoff and soil erosion compared with sparsely vegetated or degraded land.

Surface slope and roughness: Steeper slopes generally accelerate overland flow and reduce the time available for infiltration. Smooth and compact surfaces favour rapid runoff, while rough surfaces increase surface detention and may promote infiltration.

Slope should therefore be considered together with soil, land cover, and rainfall characteristics rather than as an isolated factor.

2.5 Hydrological Assessment for Water Harvesting Design

A systematic hydrological assessment helps answer four fundamental design questions:

How much water is available? Where does it flow? How much can be captured? How much storage is actually required?

The major steps are as follows.

2.5.1 Rainfall Analysis

- Long-term rainfall records should be analysed to understand:
- Mean annual rainfall,
- Seasonal rainfall distribution,
- Monthly rainfall pattern,
- Number of rainy days,
- Rainfall intensity and duration where relevant,

- Interannual variability, and
- Dependable or probability-based rainfall

For agricultural water harvesting, dependable rainfall may be more useful for planning than simple average rainfall because average values can overstate the water likely to be available in dry or below-normal years.

2.5.2 Catchment Delineation and Characterization

The area contributing runoff to the proposed harvesting structure should be identified and measured.

Important characteristics include:

- Catchment area,
- Elevation and slope,
- Drainage pattern,
- Soil type and hydrologic soil group,
- Land use/land cover,
- Vegetation,
- Surface condition, and
- Existing water bodies and drainage structures

For larger catchments, topographic maps, Digital Elevation Models (DEM), GIS, remote sensing, and field verification can be used for catchment delineation and characterization.

2.5.3 Runoff Estimation

Runoff estimation determines the quantity of water likely to reach the proposed harvesting structure.

The choice of method depends on the scale and purpose of assessment.

For preliminary estimates and relatively simple catchments, the runoff-coefficient method may be adequate. For agricultural watersheds where soil type, land use, and antecedent moisture substantially influence runoff, the SCS/NRCS Curve Number method can provide a more detailed estimate.

2.5.4 Water Demand Assessment

The usefulness of harvested water depends not only on supply but also on demand.

Water requirements may include:

- Supplemental or protective irrigation,
- Livestock,
- Fisheries and aquaculture,
- Horticulture,
- Nursery raising,
- Domestic or institutional non-potable uses,
- Groundwater recharge, and
- Other components of integrated farming systems.

Demand should preferably be estimated over time—daily, monthly, or crop-stage-wise—rather than only as a single annual total.

2.5.5 Water Balance and Storage Assessment

A harvesting structure should be viewed as a dynamic storage system.

A simplified water balance may be expressed as:

Change in storage = Inflow – Outflow

where inflows may include catchment runoff and direct rainfall over the storage surface, while outflows may include:

- Water withdrawal,
- Evaporation,
- Seepage,
- Controlled release, and
- Overflow or spillage

A more detailed representation is:

$$S_t = S_{t-1} + Q_t + P_t - D_t - E_t - L_t - O_t$$

where:

- S_t = storage at the end of the time period,
- S_{t-1} = storage at the beginning of the time period,
- Q_t = catchment runoff inflow,
- P_t = direct rainfall contribution,
- D_t = water demand or withdrawal,
- E_t = evaporation loss,
- L_t = seepage and other losses, and
- O_t = overflow/spillage.

Monthly or daily water-balance analysis is often more informative than simply comparing annual runoff with annual demand because rainfall and water demand rarely occur at the same time.

2.5.6 Reliability Assessment

Rainfall varies considerably from year to year. A system designed only from average annual rainfall may fail to provide the expected water supply during dry years.

Reliability assessment examines how frequently the proposed system can meet a specified demand under historical or simulated rainfall conditions.

For critical applications, long-term rainfall records and probability-based analysis should therefore be used to evaluate system performance.

2.6 SCS/NRCS Curve Number Method for Runoff Estimation

For agricultural and watershed catchments, runoff is strongly influenced by soil characteristics, land use, hydrological condition, and antecedent moisture. The Soil Conservation Service Curve Number (SCS-CN) method, now commonly referred to as the NRCS Curve Number method, provides a practical approach for estimating direct runoff from rainfall events.

The method expresses runoff as:

$$Q = (P - I_a)^2 / (P - I_a + S), \text{ for } P > I_a$$

and:

$$Q = 0, \text{ for } P \leq I_a$$

where:

- Q = direct runoff depth (mm),
- P = rainfall depth (mm),

- I_a = initial abstraction (mm), and
- S = potential maximum retention after runoff begins (mm).

The commonly used conventional relationship is:

$$I_a = 0.2S$$

giving:

$$Q = (P - 0.2S)^2 / (P + 0.8S)$$

for $P > 0.2S$.

The potential maximum retention, S , is related to the Curve Number (CN) as:

$$S = (25400/CN) - 254$$

where S is expressed in millimetres.

Curve Number values range from approximately 30 to 100. A higher CN generally indicates greater runoff potential, while a lower CN indicates greater infiltration and storage potential.

Selection of CN depends mainly on:

- Hydrologic soil group,
- Land use and land cover,
- Treatment or management practice,
- Hydrologic condition, and
- Antecedent moisture conditions

The method is particularly useful for estimating runoff from agricultural watersheds and for preliminary sizing of farm ponds and related harvesting structures.

Design note: Curve Numbers should be selected from appropriate standard or locally validated tables. Where local calibration or observed runoff data are available, they should be preferred over generalized values.

2.7 Matching Water Availability with Storage Requirement

A common misconception in water harvesting design is that the storage structure should be large enough to hold the entire estimated annual runoff.

This is rarely necessary or economical.

The required storage capacity depends on the timing of runoff generation and water use, not merely their annual totals.

For example, a catchment may generate 5,000 m³ of runoff annually, but if water is continuously withdrawn for irrigation during the rainy season, a pond considerably smaller than 5,000 m³ may be adequate because the storage is repeatedly filled and depleted.

Conversely, if most runoff occurs within a short monsoon period and the water must be stored for use several months later, a larger storage capacity may be required.

Optimum storage should therefore consider:

Available runoff + temporal distribution of rainfall + water demand pattern + evaporation and seepage losses + allowable overflow + economic feasibility

This approach helps avoid both under-design, which results in frequent water shortages, and over-design, which increases land requirement and construction cost without proportional benefit.

2.8 Design Considerations for Water Harvesting Structures

Once the hydrological potential has been assessed, the proposed structure should be designed according to site conditions and intended use.

Catchment and runoff availability: The catchment must be capable of generating sufficient runoff to fill or replenish the proposed storage. Oversizing a pond relative to its contributing catchment may result in chronically underfilled storage.

Intended use of harvested water: The end use determines both storage requirement and water-quality considerations. Irrigation, livestock, fisheries, groundwater recharge, and domestic applications have different requirements.

In Integrated Farming Systems, multipurpose storage may provide greater benefits by supporting several enterprises from the same harvested-water resource.

Soil and geological conditions: Soil texture, permeability, depth, and subsurface geology influence the suitability of a site for storage or recharge.

Sites with highly permeable soils may require lining where the objective is surface-water storage. The same permeability may be advantageous where groundwater recharge is the primary objective.

Topography and drainage: Natural depressions and favourable topographic locations can reduce excavation and construction costs. The selected site should intercept adequate runoff without causing undesirable waterlogging, erosion, or drainage obstruction upstream.

Seepage losses: Excessive seepage can substantially reduce useful storage. Depending on local conditions, seepage may be controlled through soil compaction, clay puddling, bentonite treatment, masonry or concrete lining, or suitable geomembranes.

However, seepage should not automatically be considered undesirable where groundwater recharge is an intended function.

Evaporation losses: Open-water storage is subject to evaporation, particularly during hot and dry periods. Evaporation losses should be included in seasonal water-balance calculations, especially where water must be stored for several months.

Freeboard and safety: Water-storage structures should not be designed to store water up to the crest or top edge. Adequate freeboard should be provided to accommodate wave action, short-term inflow fluctuations, settlement, and operational safety.

Farm ponds and embankment structures should also have a safe provision for handling excess runoff through a properly designed spillway or overflow arrangement.

Storage period: The required storage period depends on rainfall distribution and intended use. Water intended for protective irrigation during short dry spells requires a different design approach from water intended to meet demand throughout a long post-monsoon dry season.

2.9 Geometric Sizing of Water Storage Structures

After determining the required storage capacity from hydrological and demand analysis, the physical dimensions of the storage structure can be calculated.

It is important to distinguish between required storage capacity and geometric volume. Hydrological analysis determines how much water should be stored; geometric design determines the dimensions required to provide that storage (Table 2.2).

2.9.1 Circular or Cylindrical Storage Tank

For a cylindrical tank:

$$V = \pi r^2 H$$

where:

- V = volume (m^3),
- r = internal radius of the tank (m), and
- H = effective water depth (m).

Capacity in litres:

$$\text{Capacity (L)} = V \times 1000$$

The effective storage depth should be distinguished from the total structural height, as provision may be required for freeboard and dead storage.

2.9.2 Rectangular Storage Tank

For a rectangular tank with vertical sides:

$$V = L \times B \times H$$

where:

- L = internal length (m),
- B = internal width (m), and
- H = effective water depth (m).

This equation is applicable to rectangular tanks having essentially vertical sides and a uniform plan area with depth.

2.9.3 Earthen Pond with Sloping Sides

Farm ponds generally have side slopes; therefore, the top dimensions are larger than the bottom dimensions.

Where the top, middle, and bottom areas are known, the prismoidal formula can be used:

$$V = H/6 (A_\beta + 4A_m + A_t)$$

where:

- V = pond volume (m^3),
- H = water depth (m),
- A_β = bottom area (m^2),
- A_m = plan area at mid-depth (m^2), and
- A_t = top water-surface area (m^2).

This method provides an accurate estimate where pond dimensions change approximately linearly with depth.

2.9.4 Frustum Approximation

Where only top and bottom areas are available, the following relationship may be used for a frustum-type geometry:

$$V = H/3 [A_\beta + A_t + \sqrt{(A_\beta A_t)}]$$

The appropriate geometric formula should be selected according to the actual shape of the structure.

Table 2.2 Summary of Common Storage-Volume Formulae

Structure	Volume formula	Application
Cylindrical tank	$V = \pi r^2 H$	Circular tank with vertical sides
Rectangular tank	$V = L \times B \times H$	Rectangular tank with vertical sides
Sloping-sided pond	$V = H/6 (A_\beta + 4A_m + A_t)$	Accurate where dimensions vary linearly with depth
Frustum approximation	$V = H/3 [A_\beta + A_t + \sqrt{(A_\beta A_t)}]$	Useful when top and bottom areas are known

2.10 Worked Example: From Rainfall to Farm-Pond Storage

Consider a 2-ha agricultural catchment receiving 1,100 mm of annual rainfall. Assume a preliminary runoff coefficient of 0.30.

Step 1: Estimate total rainwater endowment

Catchment area = 2 ha = 20,000 m²

Rainwater endowment:

$$= 1,100 \times 20,000 / 1000$$

$$= 22,000 \text{ m}^3/\text{year}$$

Thus, approximately 22 million litres of rainfall are received over the catchment annually.

Step 2: Estimate runoff potential

Estimated runoff:

$$= 1,100 \times 20,000 \times 0.30 / 1000$$

$$= 6,600 \text{ m}^3/\text{year}$$

Therefore, the theoretical annual runoff potential is approximately 6,600 m³.

Step 3: Interpret the result

A 6,600-m³ annual runoff estimate does not automatically imply that a 6,600-m³ pond should be constructed.

The actual pond capacity should be determined after considering:

- Seasonal distribution of runoff,
- Frequency and magnitude of runoff-producing storms,
- Crop and other water demands,
- Irrigation withdrawals during the rainy season,
- Evaporation and seepage,
- Expected number of filling cycles,
- Available land and excavation cost, and
- Provision for safe overflow

If analysis shows that a 3,000-m³ useful storage capacity is adequate to meet the intended demand, the pond should be geometrically designed to provide approximately that useful storage, together with appropriate dead storage, freeboard, side slopes, and spillway provision.

This example illustrates the central principle of water harvesting design:

Rainfall determines the gross water resource; catchment hydrology determines runoff; water demand and losses determine required storage; and engineering design determines the final dimensions of the structure.

2.11 Role of GIS and Remote Sensing in Hydrological Potential Assessment

For watershed- and landscape-scale planning, Geographic Information Systems (GIS) and remote sensing provide valuable tools for identifying areas with favourable water harvesting potential.

Important spatial layers may include:

- Rainfall,
- Digital elevation model (dem),
- Slope,
- Drainage network and drainage density,
- Land use/land cover,
- Soil characteristics,

- Geology and geomorphology,
- Groundwater conditions, and
- Existing water bodies and infrastructure

DEM-based analysis can be used to delineate watersheds and sub-watersheds, identify flow direction and flow accumulation, derive slope, and locate natural drainage pathways.

When combined through appropriate suitability criteria or multi-criteria analysis, these datasets can help identify potential locations for farm ponds, check dams, percolation tanks, recharge structures, and other water harvesting interventions.

However, GIS-based suitability maps should be considered decision-support tools rather than substitutes for field investigation. Final site selection should include field verification of drainage, soil and geological conditions, land ownership, accessibility, structural feasibility, and likely social and environmental impacts.

2.12 From Hydrological Assessment to Water Harvesting Design

Hydrological assessment and structural design should form a continuous decision-making process rather than separate activities.

A practical design sequence is:

Rainfall assessment → Catchment delineation → Catchment characterization → Runoff estimation → Water-demand assessment → Water-balance analysis → Required storage determination → Site selection → Geometric and structural design → Provision for losses and overflow → Utilization and management plan

For small rooftop systems, this process may involve relatively simple rainfall-runoff calculations. For farm ponds and agricultural catchments, soil, slope, land use, rainfall distribution, and crop-water demand become increasingly important. At watershed scale, GIS, remote sensing, hydrological modelling, and field surveys may be required.

The most effective water harvesting system is therefore not necessarily the structure with the largest storage capacity. It is the system in which catchment yield, storage capacity, water demand, site characteristics, and intended use are appropriately matched.

In the context of Integrated Farming Systems, this matching becomes especially valuable. Harvested water can serve as a strategic resource linking crop production, horticulture, fisheries, livestock, and other farm enterprises. A scientifically assessed and appropriately designed water harvesting system can therefore improve water-use efficiency, reduce vulnerability to dry spells, support crop diversification, enhance farm productivity, and strengthen resilience to increasing rainfall variability.



Rainwater Harvesting Systems and Their Components

3.1 Types of Rainwater Harvesting Systems

Rainwater harvesting systems are designed to collect, store, recharge, and efficiently utilize rainfall according to local climatic conditions and water requirements. Depending on the source of runoff and intended purpose, different rainwater harvesting systems and structures are adopted for domestic, agricultural, institutional, and groundwater recharge applications.

Rainwater harvesting systems can be classified based on the source of runoff, storage method, and intended use (Table 3.1). The selection of an appropriate system depends on rainfall pattern, land use, topography, soil characteristics, groundwater conditions, and water demand. Broadly, rainwater harvesting systems are categorized into rooftop rainwater harvesting, surface runoff harvesting, in-situ rainwater conservation, groundwater recharge systems, and integrated farm water harvesting systems.

3.2 Components of Water Resource Management

Water resource management involves the integrated planning, development, conservation, and efficient utilization of available water resources to meet agricultural, domestic, industrial, and environmental needs. The major components include surface water management, groundwater management, and rainwater management.

1. Surface Water Management: Surface water management focuses on the collection, storage, distribution, and efficient utilization of water from rainfall, rivers, reservoirs, ponds, lakes, and canals. Proper management helps reduce flood risks, enhances water availability during dry periods, and supports irrigation and other water needs.

2. Groundwater Management: Groundwater management aims to maintain sustainable aquifer levels through artificial recharge, regulated groundwater extraction, monitoring of groundwater levels, and conjunctive use of surface and groundwater resources.

3. Rainwater Management: Rainwater management emphasizes harvesting rainfall at the point where it falls through rooftop collection systems, farm ponds, recharge structures, and storage tanks to improve water availability, groundwater recharge, and climate resilience.

3.3 Rainwater Harvesting Structures

Rainwater harvesting structures are designed to collect, store, recharge, divert, or conserve rainwater according to local rainfall, topography, soil characteristics, and water demand. The selection of an appropriate structure depends on the intended use, available catchment area, and hydro geological conditions (Table 3.2).

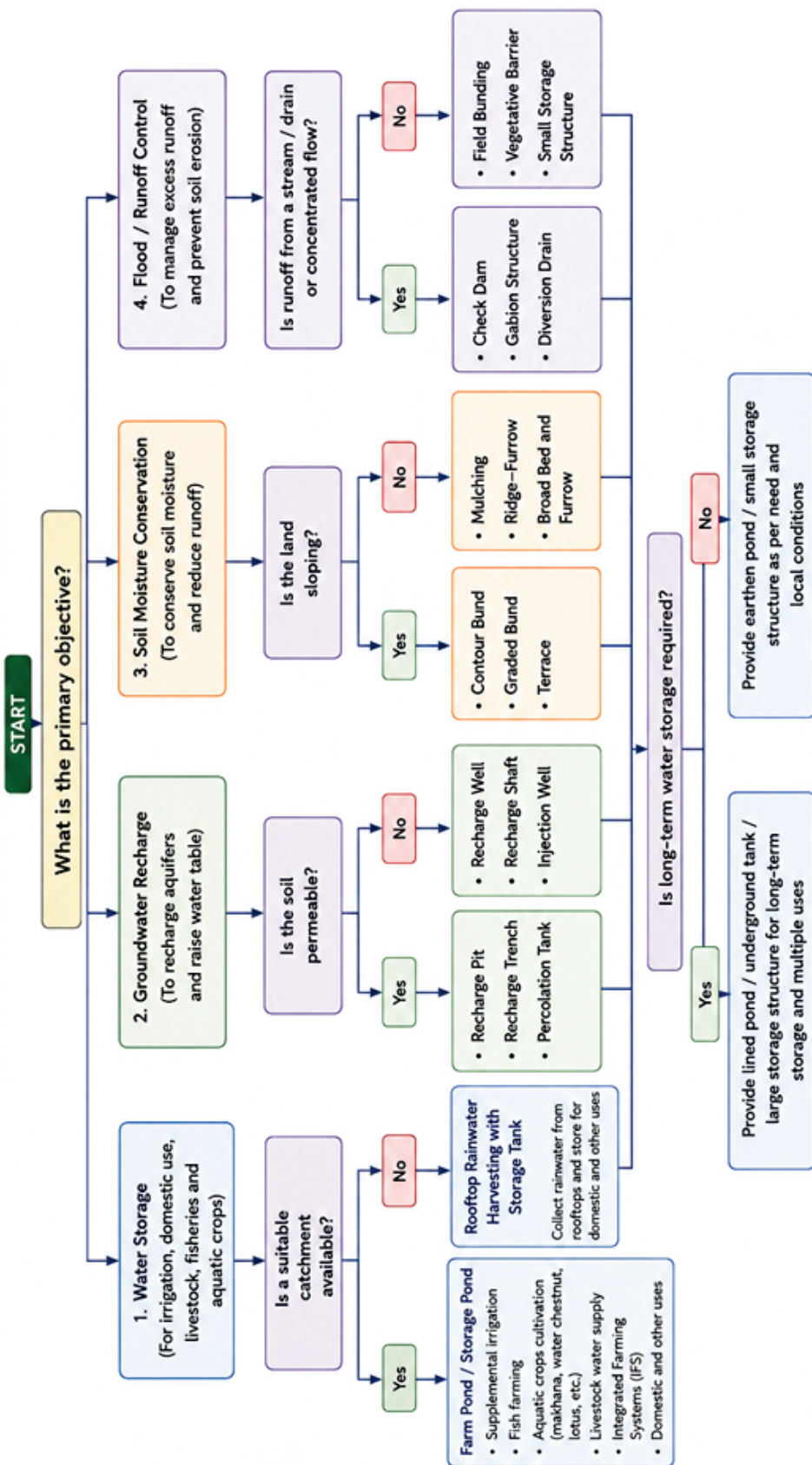
Table 3.1. Types of rainwater harvesting systems

Type	Source of Water	Typical Structures	Major Advantages	Major Uses
Rooftop Rainwater Harvesting	Roofs of residential, institutional and commercial buildings	Rooftop collection system, gutters, down pipes, storage tanks	Relatively clean water, low contamination, easy maintenance	Domestic water supply, laboratories, gardening, supplemental irrigation
Surface Runoff Harvesting	Agricultural fields, roads, open lands and drainage channels	Farm ponds, check dams, village ponds, percolation tanks, earthen reservoirs	Supplemental irrigation, flood mitigation, runoff conservation	irrigation, livestock water, fish farming, aquatic crop cultivation
Groundwater Recharge Systems	Rooftop runoff and surface runoff	Recharge pits, recharge trenches, recharge shafts, recharge wells, injection wells, percolation pits	Raises groundwater table, improves groundwater quality, reduces groundwater depletion	Groundwater recharge and drinking water security
In-situ Moisture Conservation	Rainfall retained within agricultural fields	Contour Bunding, compartment Bunding, ridge and furrow, broad bed furrow, mulching, conservation tillage	Conserves soil moisture, reduces runoff and soil erosion	Rainfed agriculture, dryland farming, crop production
Integrated Farm Water Harvesting Systems	Rooftop runoff, field runoff and surface drainage	Farm ponds integrated with irrigation, fisheries, livestock horticulture	Multiple water uses, improved water-use efficiency, enhanced farm income	Integrated Farming Systems (IFS), fish farming, horticulture, livestock, aquatic crop cultivation

Table 3.2. Common rainwater harvesting structures and their purpose

Structure	Primary Purpose
Rooftop Storage Tank	Collection and storage of rooftop rainwater for domestic, institutional, and laboratory use
Underground Storage Tank	Long-term storage of harvested rainwater with minimal evaporation losses
Farm Pond	Storage of runoff for supplemental irrigation, fish farming, aquatic crop cultivation, and livestock water supply
Percolation Tank	Groundwater recharge through infiltration
Check Dam	Reduce runoff velocity, store water temporarily, and recharge aquifers
Recharge Pit	Recharge shallow groundwater aquifers
Recharge Trench	Recharge groundwater along linear catchments and drainages
Recharge Shaft	Recharge deeper aquifers where the upper soil layer has low permeability
Recharge Well	Recharge existing wells and groundwater aquifers
Contour Bund	Reduce runoff, conserve soil moisture, and control soil erosion on sloping lands
Diversion Drain	Safely divert runoff to farm ponds, storage tanks, or recharge structures
Gabions Structure	Reduce flow velocity, trap sediments, and enhance groundwater recharge in small streams

Decision Support for Selecting Rainwater Harvesting Structures



Note: Final selection should be based on site survey, rainfall, topography, soil type, available space, water demand and technical-economic feasibility.

3.4 Components of Rainwater Harvesting Systems

A typical rainwater harvesting (RWH) system, whether designed for domestic use, institutional campuses, or large-scale groundwater recharge, consists of several basic components that work together to capture, transport, filter, and store or recharge rainwater (Figure 3.9).

3.4.1 Catchment Area

The catchment is the surface that receives rainfall directly and feeds the system.

- **Roof Catchments:** These are the most common in urban and institutional settings. Surfaces made of reinforced cement concrete (RCC), galvanized iron (GI) sheets, corrugated metal, or tiles are ideal as they are smooth and impervious.
- **Surface Catchments:** These include paved or unpaved ground areas, roads, and open spaces. While they can generate large volumes of runoff, they have a higher risk of contamination and are better suited for non-potable uses like lawn watering or as sources for groundwater recharge.
- **Quality Considerations:** Since rainwater is naturally pure, catchments must be kept clean; rooftops should be swept regularly, and thatched or lead-painted surfaces should be avoided if the water is intended for human consumption.

3.4.2 Transportation and Conveyance Systems

This subsystem collects water from the catchment and directs it to the storage or recharge units.

- **Gutters:** Fixed along the edges of sloping roofs, gutters can be semi-circular, rectangular, or trapezoidal. They are made from materials like PVC, GI sheets, aluminium, or even split bamboo. To handle high-intensity storms, gutters should be designed with 10–15% additional capacity to prevent spillage (Figure 3.1).



Figure 3.1. Roof gutter used for collecting and conveying rainwater from rooftop catchments. Source: ICAR-MGIFRI.

- **Conduits (Downpipes):** These are vertical pipelines that carry water from the gutters or roof to the storage facility. Commonly made of PVC or GI, their diameter is selected based on the roof area and regional rainfall intensity (Figure 3.2).



Figure 3.2. PVC conduit (downpipe) for rainwater conveyance. Source: ICAR-MGIFRI.

3.4.3 Primary Cleaning Mechanisms

- **Screens:** A coarse mesh or leaf screen is installed at the mouth of downpipes or along gutters to prevent large debris, twigs, and leaves from entering the system (Figure 3.3).

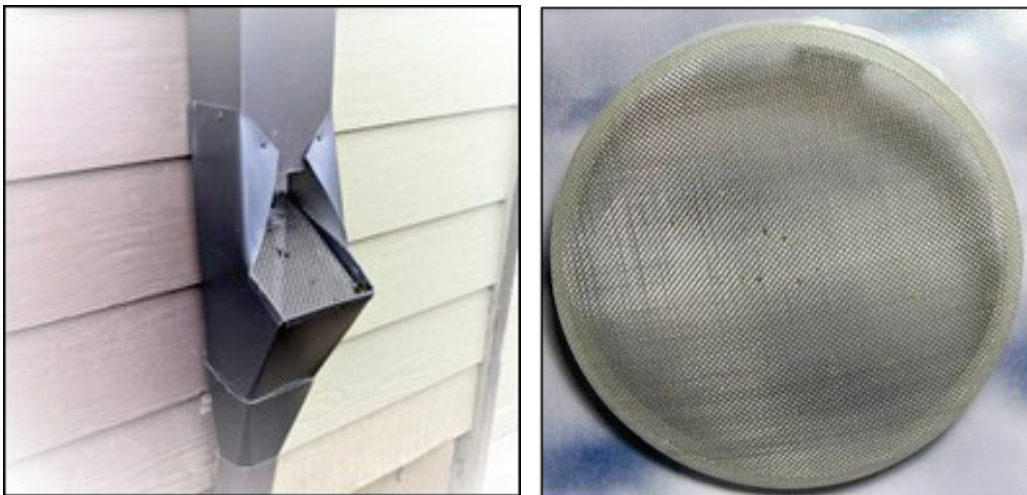


Figure 3.3. Inlet screen for filtration of debris and suspended matter. Source: Author's photograph.

- **First Flush Diversion:** This is a vital mechanism (often a valve or detachable pipe) used to divert the "first flush"—the initial spell of rain that washes off accumulated dust, bird droppings, and atmospheric pollutants. Diverting the first 10–20 minutes of rain significantly enhances the quality of the water entering the storage tank (Figure 3.4).



Figure 3.4. First Flush Diverter for excluding the initial contaminated rooftop runoff.
Source: Adapted and edited from Rain Harvesting Australia – First Flush Diverters

3.4.4 Filtration Systems

Filters remove suspended pollutants and microorganisms to make the water suitable for use.

Common Filter Types:

a. Sand and Charcoal Filters: These simple designs use layers of gravel, sand, and charcoal to remove turbidity, color, and certain microbes (Figure 3.5).

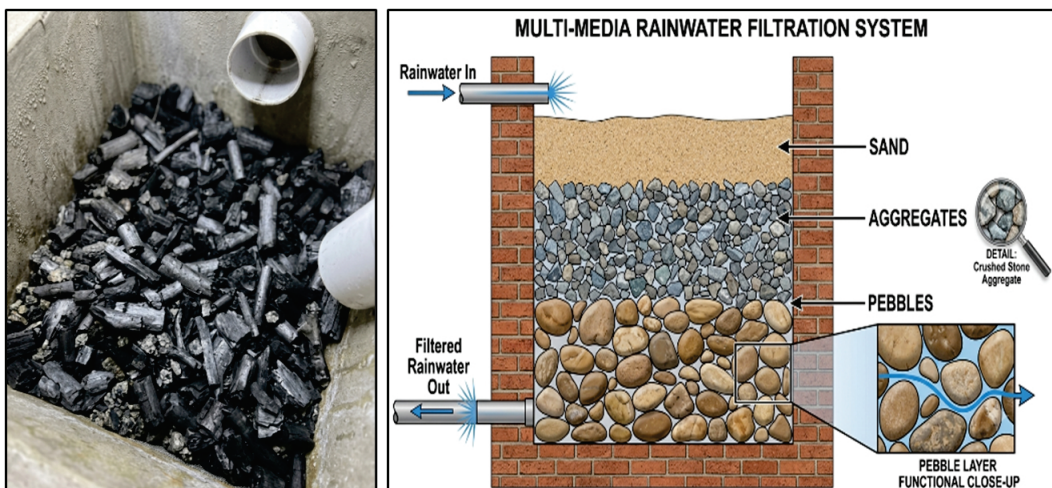


Figure 3.5. Sand and Charcoal Filter for primary filtration of harvested rainwater.
Source: Adapted and edited by the authors from NTO Tank – Rainwater Filter Design and N.S. Associates – Rainwater Harvesting Filters: Safe Water, Safe Lives.

b. Dewas Filter: A popular three-chamber PVC pipe filter filled with varying sizes of pebbles, often used for direct recharge into tube wells (Figure 3.6).

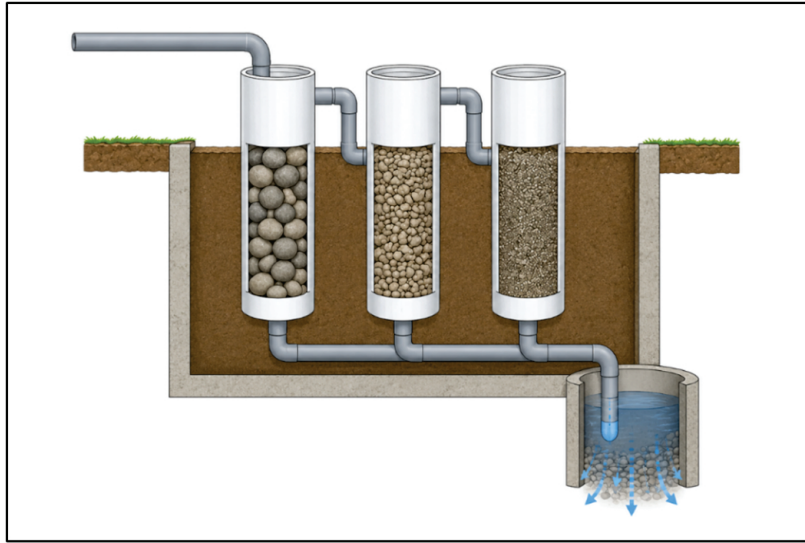


Figure 3.6. Dewas Filter for direct recharge of harvested rainwater into borewells.
Source: Created by the authors using AI-assisted illustration (2026).

c. Varun Filter: A specialized HDPE drum filter using sponge layers and coarse sand, designed to handle high-intensity rainfall from smaller roof areas (Figure 3.7).

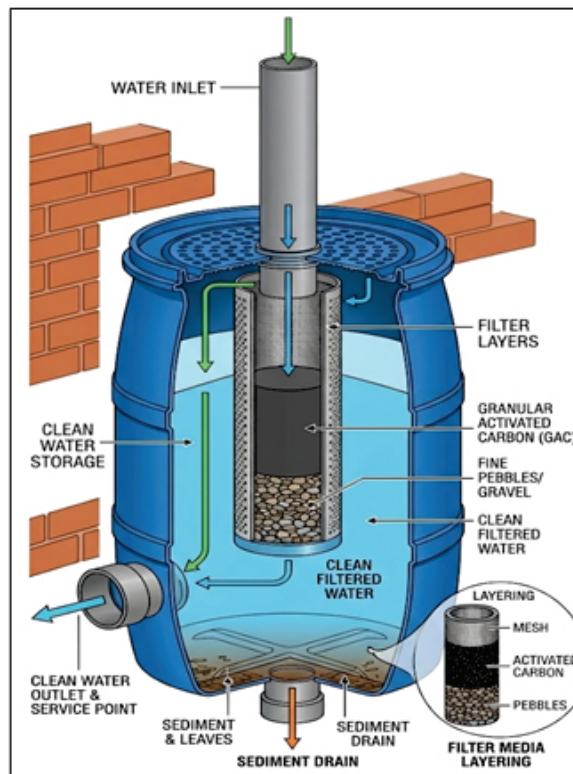


Figure 3.7. Barrel Filter used for filtration and groundwater recharge of harvested rainwater. Source: Created by the authors using AI-assisted illustration (2026).

D. Horizontal Roughening and Slow Sand Filters: These act as both physical and biological filters, using successive layers of media to kill microbes and remove fine solids.

E. Settlement Tanks: These serve as buffers where silt and floating impurities settle before the water reaches recharge structures (Figure 3.8).



Figure 3.8. Settlement Tank for sedimentation and removal of suspended particles.
Source: ICAR–MGIFRI.

3.4.5 Storage Facilities

Storage units (tanks or sumps) hold the harvested water for direct use during dry periods.

- **Configurations:** Tanks can be above ground (easier to inspect and distribute water via gravity), partially underground, or fully underground (saves space and keeps water cool).
- **Materials:** Reinforced cement concrete (RCC), ferro-cement (highly durable and cost-effective), masonry, and polyethylene (PVC) are standard choices.
- **Design Factors:** Capacity is determined by the number of users, daily water demand, and the duration of the dry season (dry season demand vs. supply approach).

3.4.6 Recharge Units

Where surface storage is not feasible, rainwater is used to augment groundwater.

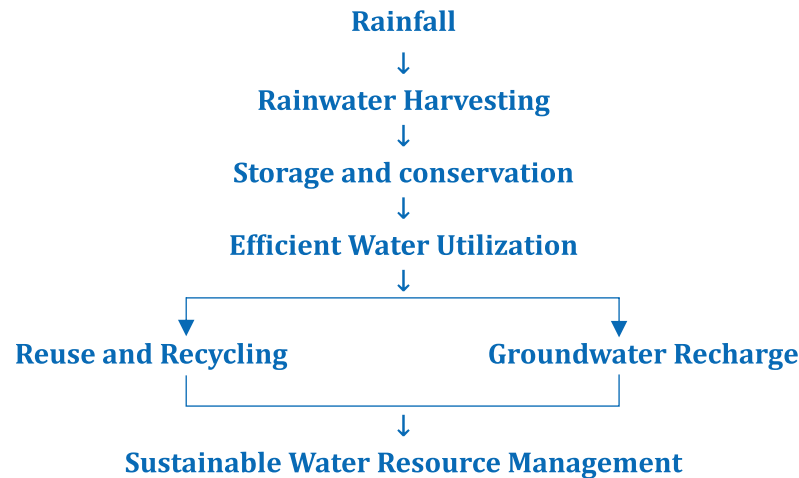
- **Direct Methods:** These include recharge pits, percolation pits, and recharge trenches filled with boulders and gravel to facilitate rapid infiltration into the soil.
- **Deep Recharge Methods:** Rainwater can be directed into existing or abandoned dug wells, bore wells, or recharge shafts to reach deeper aquifers directly.

3.4.7 Modern Modular Systems

Modern modular tank systems utilize subsurface infiltration storage boxes made from recycled plastics. These modules have 95% void space and have high load-bearing capacity, allowing them to be installed under trafficable areas like parking lots or driveways without taking up valuable surface space.

3.5 Integrated Water Resource Management (IWRM)

Integrated Water Resource Management (IWRM) is a coordinated approach to the planning, development, conservation, and management of water, land, and related resources to maximize economic and social benefits while ensuring environmental sustainability. It promotes the conjunctive use of rainwater, surface water, groundwater, recycled water, and water-efficient technologies to improve water security, enhance water-use efficiency, and strengthen climate resilience.



3.6 Integrated Water Resource Management (IWRM)

Efficient rainwater harvesting requires proper planning, design, operation, and regular maintenance to ensure optimum performance, water quality, and long-term sustainability. The following best management practices (BMPs) improve the efficiency, durability, and reliability of rainwater harvesting systems (Table 3.3).

Table 3.3. Best Management Practices for Rainwater Harvesting Systems

Practice	Benefit
Clean rooftops before the monsoon	Improves harvested water quality
Install a first flush diverter	Removes initial contaminants and debris
Install an appropriate filtration unit	Improves water quality before storage
Cover storage tanks	Prevents algal growth, mosquito breeding, and contamination
Desilt ponds annually	Maintains storage capacity and water quality
Repair embankments and linings	Prevents seepage, leakage, and structural damage
Monitor water levels regularly	Enables efficient water allocation and utilization
Adopt drip or sprinkler irrigation	Improves water-use efficiency and reduces losses
Plant grasses or vegetation on bunds	Controls soil erosion and stabilizes embankments
Reuse overflow water	Maximizes water-use efficiency and reduces wastage
Remove aquatic weeds periodically	Maintains storage capacity and improves water quality
Maintain inspection and maintenance records	Facilitates timely maintenance and improves system performance
Inspect gutters and downpipes before every rainy season	Ensures uninterrupted collection and conveyance of rainwater
Prevent contamination around recharge structures	Protects groundwater quality and enhances recharge efficiency

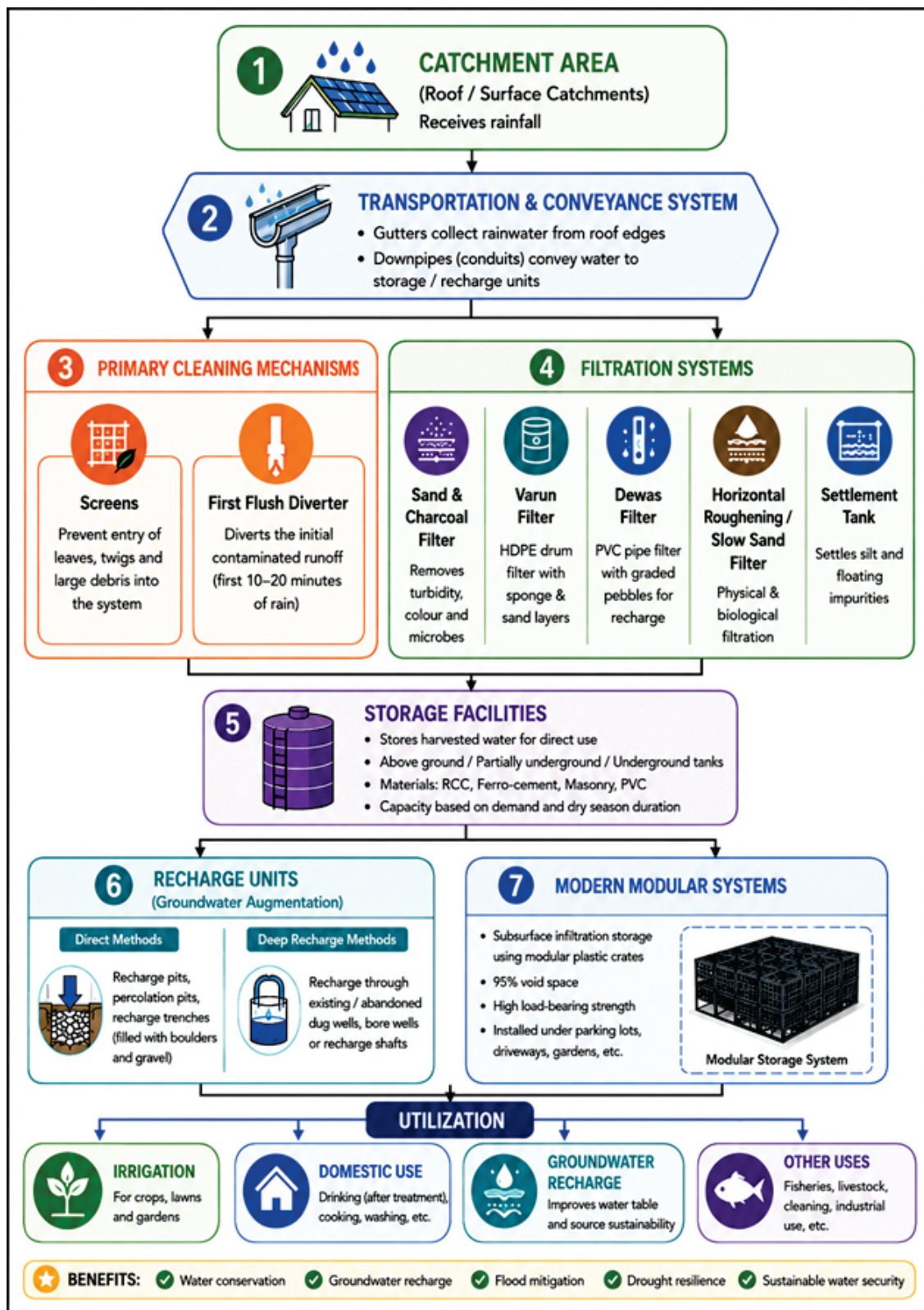


Figure 3.9. Components of rainwater harvesting system.
Source: Prepared by the authors using AI-assisted illustration (2026).



Storage, Water Filtration and Purification Solutions

Storage and purification are critical stages in a rainwater harvesting (RWH) system, ensuring that harvested water is available when needed and safe for its intended use. The storage tank is often the most significant investment, contributing nearly 70% to 80% of the total system cost.

4.1 Storage Facilities

Storage units, also known as cisterns or sumps, vary based on position, material, and purpose.

Positioning of Tanks:

- **Above Ground:** Easy to install off-the-shelf, easy to inspect, and allows for gravity-based distribution without pumping. However, they can affect building aesthetics and take up surface space (Figure 4.1).



Figure 4.1. Above-Ground Rainwater Storage Tank for temporary storage and utilization of harvested rainwater. Source: ICAR-MGIFRI.

- **Below Ground:** Generally cheaper and ideal for large volumes (10,000+ litres). They save surface space but require pumping to extract water and are harder to inspect for



Figure 4.2. Underground Rainwater Storage Tank for long-term storage of harvested rainwater. Source: ICAR-MGIFRI.

- **Partially Underground:** A compromise that minimizes aesthetic impact and can be easier to install than fully underground tanks.

Common Materials:

- **Plastic (HDPE Polyethylene):** Cheaper for small houses and ponds, easiest to install, and durable.
- **Reinforced Cement Concrete (RCC):** Highly durable and suitable for very large volumes, though expensive and requiring skilled labour.
- **Ferro-cement:** Offers excellent water tightness and durability at a lower cost than RCC.
- **Masonry (Brick):** Cheap and uses local materials but can be prone to leaks if not treated.

Agricultural and Traditional Storage:

- **Tanka:** A traditional underground cistern common in arid regions like Rajasthan for storing drinking water.
- **Farm Ponds:** Excavated or embankment-type structures used for supplemental irrigation. These may be unlined (for groundwater recharge) or lined with materials like LDPE sheets, soil-cement, or brick masonry to prevent seepage.
- **Jalkund:** A small-sized, low-cost plastic-lined pond (typically 10,000 to 30,000 litres) popular in hilly and humid regions like North East India for homestead irrigation.
- **Design and Sizing:** Capacity is determined by matching the tank volume to either the roof area (supply) or the daily demand of users during the dry season. A safety factor of 20% is often added to the calculated requirement.

4.2 Filtration and Purification Solutions

Rainwater is naturally pure but can become contaminated by atmospheric pollutants, dust, bird droppings, and organic debris on the catchment surface.

A. Primary Cleaning (First Flush): A manual or automatic valve diversions the first 15–20 minutes of rain, which carries the highest concentration of pollutants, away from the storage tank.

Filtration Systems:

- **Sand and Charcoal Filters:** Simple domestic filters using gravel, sand, and charcoal to remove turbidity, colour, and microorganisms.
- **Dewas Filter:** A three-chamber PVC pipe filter filled with varying sizes of pebbles (2–20 mm), widely used for direct recharge into tubewells.
- **Varun Filter:** An HDPE drum filter using sponge layers and coarse sand, capable of handling high-intensity rain (50 mm/hour) from 50 m² roofs.
- **Horizontal Roughening and Slow Sand Filters:** Physical and biological filters that successively reduce particle size and kill microbes, particularly effective in coastal areas.

B. Purification Treatments for Potability:

- **Alum Treatment:** Brownish harvested water can be treated with alum (0–100 mg/L) as a coagulant. The water should be swirled with alum in a settlement tank and allowed to sit for 2–3 hours to remove suspended particles (Figure 4.3, 4.4).



Figure 4.3. Alum Treatment for coagulation and clarification of harvested rainwater. Source: Authors photograph



Figure 4.4. Chlorination Unit for disinfection of stored rainwater. Source: Adapted from Jagran Josh

- **Solar Water Purifier (SWP):** A non-polluting system that uses solar energy to heat water in tubular collectors. Even on overcast days, it can reach 45°C for 3+ hours, which is sufficient to inactivate coliform bacteria (Figure 4.5).



Figure 4.5. Solar Water Purifier (SWP) for treatment of harvested rainwater using solar energy. Source: Created by the authors using AI-assisted illustration (2026).

- **Chlorination:** One 0.5g chlorine tablet can disinfect 20 litres of water, or 1g of bleaching powder can treat 200 litres.
- **Boiling:** Heating water to 60°C for 15 minutes or boiling for 10–20 minutes effectively removes biological contaminants. For drinking purposes, the final water quality should be verified against IS-10500:2012 standards using testing kits or laboratories

Artificial Groundwater Recharge Techniques

Artificial groundwater recharge is the deliberate process of augmenting groundwater reserves by facilitating the infiltration of surface water into aquifers at a rate greater than natural recharge. It is an effective strategy for improving groundwater availability, particularly in urban areas where impervious surfaces reduce natural infiltration and in regions experiencing groundwater depletion due to excessive extraction (Figure 5.1).

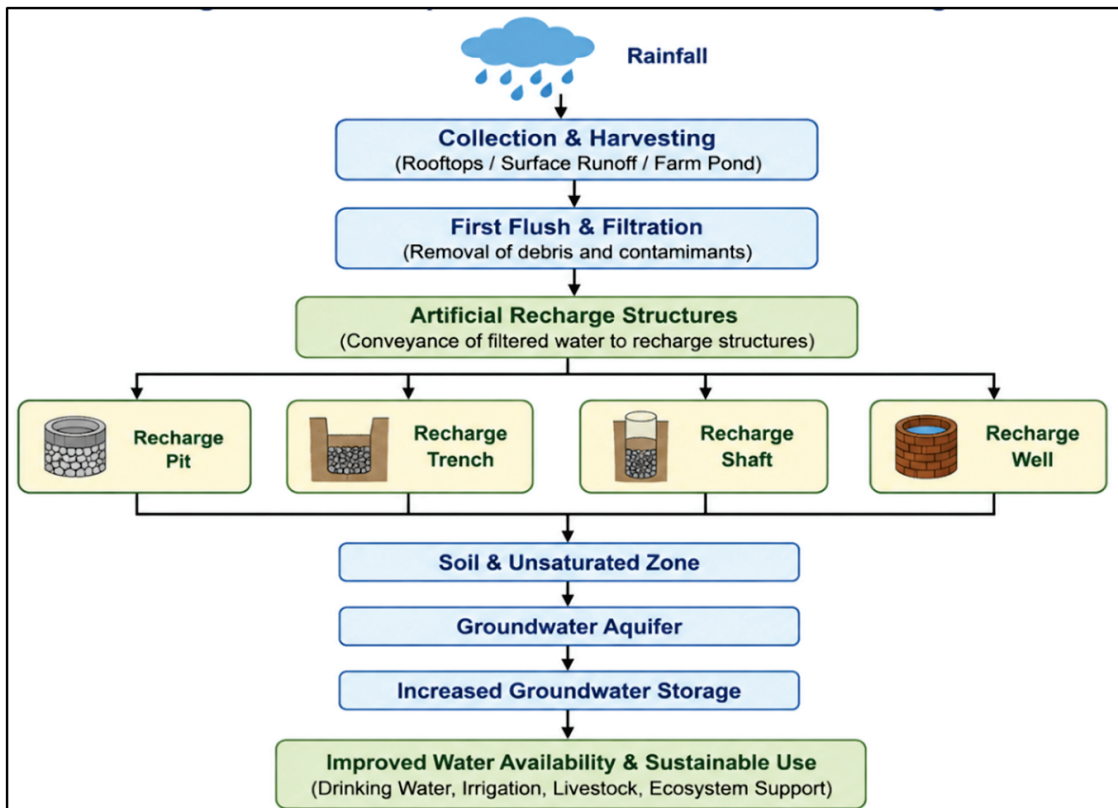


Figure 5.1 Concept of artificial groundwater recharge. Source: Created by the authors using AI-assisted illustration (2026).

5.1 Surface and Subsurface Recharge Techniques

These methods involve constructed facilities to direct water into the ground based on available catchment area and geological strata (Table 5.1).

- **Recharge Pits:** Best suited for shallow aquifers and buildings with roof areas up to 100 m². These pits are typically 1–2 m wide and 2–3 m deep, backfilled with layers of boulders (bottom), gravel, and coarse sand (top) to act as a filter (Figure 5.2, 5.5).
- **Recharge Trenches:** Ideal for buildings with roof areas between 200 and 300 m² where permeable strata are available at shallow depths. Suitable where long and narrow catchments are available. They are typically 0.5–1 m wide and 1–1.5 m deep,

following the land slope and filled with porous filter media (Figure 5.3).

- **Recharge Shafts:** Used where the shallow aquifer is located below a clayey surface. These shafts are 0.5–3 m in diameter and 10–15 m deep, terminating in a permeable aquifer or weathered formation. They are mechanically drilled and backfilled with boulders, gravel, and sand.
- **Percolation Pits:** Small, cost-effective pits (typically 60 x 60 x 60 cm) filled with pebbles or broken bricks (brick aggregates) and sand, often covered with perforated concrete slabs (Figure 5.4).



Figure 5.2. Recharge Pit.
Source: Adapted from Mission Green Mumbai



Figure 5.3. Recharge Trench.
Source: Created by the authors using AI-assisted illustration (2026).



Figure 5.4. Percolation Pit.
Source: Created by the authors using AI-assisted illustration (2026).

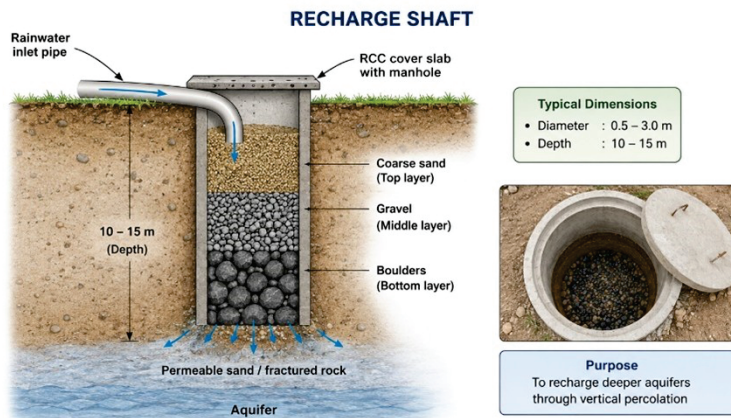


Figure 5.5. Recharge Pit. Source: Created by the authors using AI-assisted illustration (2026).

5.2 Recharge through Existing Water Structures

Converting abandoned or unused structures is a cost-effective way to implement recharge systems.

- **Abandoned Dug Wells/Open Wells:** Suitable for large buildings with roof areas exceeding 1000 m². Before use, the well must be cleaned and desilted. Recharge water should be guided through a pipe to the bottom of the well to avoid scouring and air entrapment.
- **Abandoned Hand Pumps:** Can be used for buildings with roof areas up to 150 m². Rooftop water is fed directly to the hand pump through a 100 mm pipe after passing through a filter.
- **Recharge Borewells (Gravity Recharge):** This technique is used where land availability is limited and the aquifer is deep or overlain by impermeable clay layers. Rooftop runoff is channelized directly into the well under gravity flow conditions.

5.3 Large-Scale and Watershed Structures

- **Percolation Tanks (PT):** These are prevalent structures in India, constructed across streams to impound water and allow it to percolate into the groundwater reservoir. They are effective in both alluvial and hard rock formations.
- **Check Dams and Nallah Bunds:** Constructed across streams (nala) to reduce runoff velocity, check erosion, and facilitate increased percolation.
- **Johad:** Crescent-shaped bunds built across sloping catchments to capture surface runoff and augment groundwater through percolation. Johads are traditional rainwater harvesting structures widely used in Rajasthan and other semi-arid regions for groundwater recharge.
- **Traditional Recharge Systems (Ahar-Pyne):** The Ahar-Pyne system of Bihar is a traditional water harvesting network consisting of embanked reservoirs (Ahars) connected to channels (Pyne) that store monsoon runoff, support irrigation, reduce flooding, and facilitate groundwater recharge.

5.4 Modern Recharge Technologies

- **Modular Rainwater Harvesting:** A subsurface infiltration system utilizing modular plastic cubes made from recycled plastics. These modules have 95% void space and possess high load-bearing strength, allowing them to be installed under trafficable areas like parking lots.
- **Inverted Filter System:** Designed to enhance the intake rate of runoff into bore wells or open wells, this system utilizes a point recharge unit filled in an inverted fashion (from boulders at the bottom to sand at the top).

Table 5.1. Selection guide for artificial groundwater recharge structures

Structure	Suitable catchment	Soil type	Approx. recharge depth	Best use
Recharge pit	Up to 100 m ² roof	Sandy/Loamy	Shallow aquifer	Individual houses
Recharge trench	100–300 m ²	Permeable soil	Shallow aquifer	Institutional buildings
Recharge shaft	>300 m ²	Clay over sandy layer	Deep aquifer	Urban areas
Recharge well	Existing open well	Alluvial formations	Existing aquifer	Farm and institutional campuses
Percolation tank	Large watershed	Sandy/Weathered rock	Regional recharge	Agriculture
Check dam	Seasonal stream	Hard rock/Alluvial	Local recharge	Watershed management

5.5 Site Selection Criteria

The effectiveness of artificial groundwater recharge depends largely on the proper selection of the recharge site. The following criteria should be considered while selecting a suitable location:

- **Permeable Soil:** Select locations with sandy, gravelly, or fractured soils that allow rapid infiltration of water.
- **Suitable Aquifer:** The recharge structure should be located where a shallow or productive aquifer is present to maximize groundwater recharge.
- **Adequate Catchment:** Ensure sufficient rooftop or surface runoff is available to provide an adequate quantity of water for recharge.
- **Safe Distance from Septic Tanks:** Recharge structures should be located at least 10–15 m away from septic tanks, soak pits, and sewage lines to prevent groundwater contamination.
- **Away from Pollution Sources:** Avoid sites near industrial effluents, waste disposal areas, fuel storage, or chemical contamination sources to protect groundwater quality.
- **Easy Accessibility:** The site should be easily accessible for construction, inspection, cleaning, and routine maintenance.

5.6 Advantages of Artificial Groundwater Recharge

- Improves groundwater availability
- Raises groundwater table
- Improves drinking water security
- Reduces runoff losses
- Prevents urban flooding
- Reduces pumping costs
- Improves well yield
- Supports drought resilience
- Enhances ecosystem sustainability

5.7 Limitations

- Not suitable in contaminated areas.
- Requires regular desilting.
- Ineffective in impermeable strata.
- Initial construction cost may be high.
- Performance depends on rainfall and geology.

5.8 Design and Maintenance Guidelines

5.8.1 Design Considerations

The design of an artificial groundwater recharge system should consider the following factors:

- Annual rainfall
- Catchment area
- Runoff coefficient
- Soil permeability
- Groundwater table depth
- Geological and hydrogeological conditions
- Water demand
- Availability of land
- Accessibility for operation and maintenance

5.8.2 Maintenance Guidelines

Silt Removal: Recharge water should be free from silt and suspended particles to prevent clogging of recharge structures. Settlement tanks or desilting chambers should be provided to trap sediments before water enters the recharge system.

First Flush Diversion: The initial runoff from each rainfall event should be diverted using a first flush device to prevent dust, debris, bird droppings, and other contaminants from entering the recharge structure.

Regular Cleaning: Filter media (sand, gravel, and pebbles) should be cleaned or replaced periodically to maintain recharge efficiency. Recharge wells should be redeveloped annually using an air compressor or suitable flushing method to remove accumulated sediments and restore infiltration capacity.

Safety Measures: Recharge shafts and wells should preferably be located at least 10–15 m away from building foundations and septic tanks. All recharge structures should be securely covered to prevent mosquito breeding, accidental falls, and entry of debris.

Activity	Frequency
Roof cleaning	Before monsoon
First flush cleaning	Every rainfall event
Filter media cleaning	3–6 months
Desilting	Annually (before monsoon)
Well inspection	Annually
Water quality testing	Once a year

Note: Site selection and design should also consider local topography, drainage pattern, groundwater depth, soil characteristics, and hydrogeological conditions to ensure efficient, safe, and sustainable groundwater recharge.

Do's and Don'ts

Do's	Don'ts
✓ Install a first flush device.	✗ Recharge contaminated or polluted water.
✓ Use properly designed filter media.	✗ Construct recharge structures near septic tanks, soak pits, or waste disposal sites.
✓ Desilt recharge structures regularly.	✗ Allow solid waste, leaves, or silt to enter recharge structures.
✓ Keep recharge wells and pits properly covered.	✗ Neglect routine inspection and annual maintenance
✓ Monitor groundwater levels and system performance periodically	✗ Discharge chemical or industrial wastewater into recharge systems.



Rainwater Harvesting for Agriculture and Livelihoods

Rainwater harvesting (RWH) is the cornerstone of sustainable agriculture in India, where approximately 67% of the net cultivated area is rainfed and relies solely on monsoons. By capturing surplus runoff, farmers can mitigate the risks of crop failure and transform subsistence farming into a profit-earning enterprise (Figure 6.1).

6.1 Role of Rainwater Harvesting in Agriculture

Rainwater harvesting plays a vital role in enhancing agricultural productivity, particularly in rainfed regions where crop production depends largely on monsoon rainfall. In India, about 52–55% of the net sown area is rainfed, and rainfall is concentrated within a short monsoon period of 3–4 months. Frequent dry spells during critical crop growth stages often result in moisture stress and yield reduction. By capturing and storing excess rainwater, farmers can provide supplemental irrigation during dry periods, improve cropping intensity and crop diversification, enhance water-use efficiency, and strengthen resilience to climate variability and drought.

6.2 Farm Ponds: The Foundation of Water Security

Farm ponds are one of the most effective rainwater harvesting structures for enhancing water security in agriculture. They collect and store excess monsoon runoff, providing a reliable source of water during dry spells and reducing dependence on erratic rainfall. Farm ponds support supplemental irrigation, improve cropping intensity, stabilize crop yields, and enhance water-use efficiency. Depending on local conditions, they also facilitate groundwater recharge, reduce surface runoff and soil erosion, and improve the micro-climate around cultivated fields.

Beyond irrigation, farm ponds serve multiple purposes under Integrated Farming Systems (IFS). Stored water can be utilized for fish farming, duck rearing, livestock watering, nursery raising, horticultural irrigation, and the cultivation of high-value aquatic crops such as makhana (*Euryale ferox*), water chestnut (*Trapa natans*), and lotus (*Nelumbo nucifera*), thereby diversifying farm enterprises and increasing farmers' income.

In Bihar, where annual rainfall ranges from approximately 1,000 to 1,700 mm, nearly 85–90% of rainfall is received during the southwest monsoon (June–September). Consequently, farm ponds play a crucial role in storing surplus monsoon runoff for use during moisture-stress periods. The Government of Bihar and Government of India have promoted farm pond development through programmes such as Pradhan Mantri Krishi Sinchayee Yojana (PMKSY – Har Khet Ko Pani), Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS), Rashtriya Krishi Vikas Yojana (RKVY), and various State Horticulture and Fisheries Department schemes.

At ICAR–MGIFRI farm ponds form an integral component of Integrated Farming System (IFS) models. Harvested rainwater is utilized for supplemental irrigation, fish farming, livestock water supply, groundwater recharge, and the cultivation of aquatic crops, demonstrating

efficient water-use and sustainable livelihood enhancement under eastern Indo-Gangetic Plain conditions.

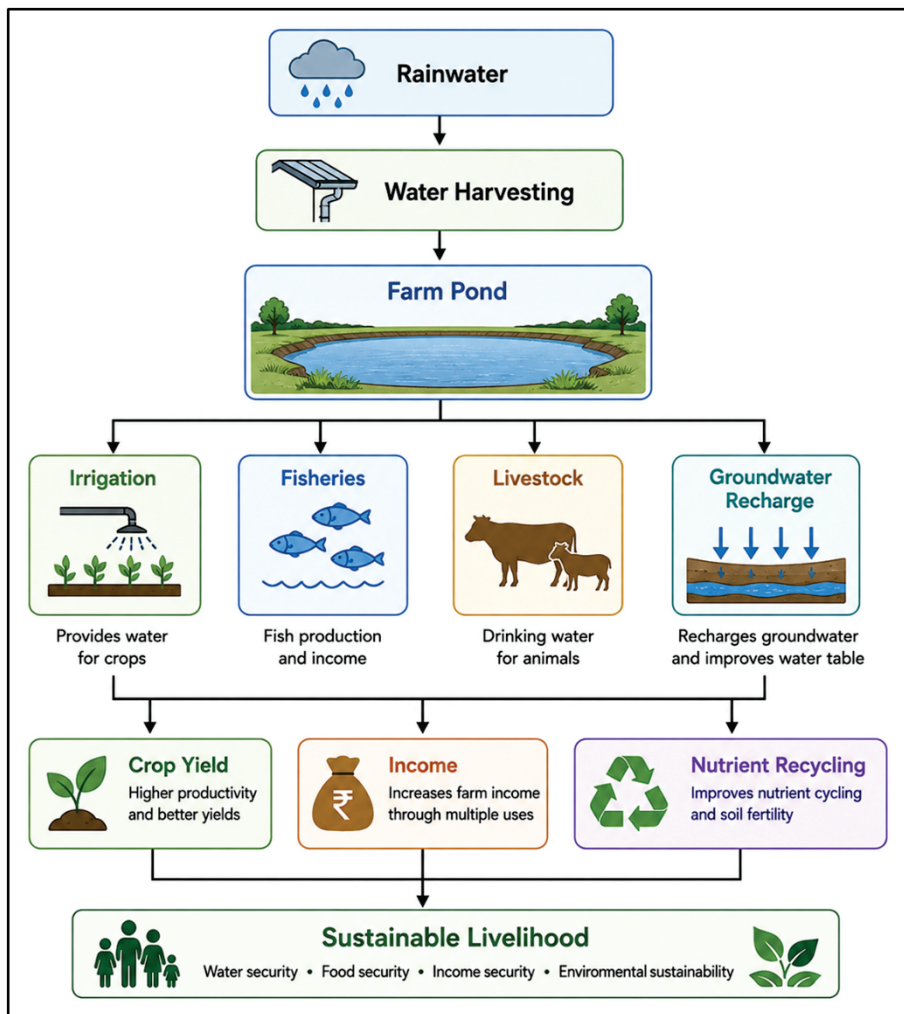


Figure 6.1. Multiple Uses of Harvested Rainwater in Integrated Farming Systems.
Source: Created by the authors using AI-assisted illustration (2026).

6.3 Farm Pond Design and Technology

Farm ponds should be designed considering rainfall, catchment area, runoff potential, soil characteristics, water demand, topography, and intended use. Proper design ensures adequate storage, minimum seepage losses, and long service life.

- **Design and Types:** Depending on topography and soil, ponds are constructed as dugout (excavated pits), embankment (using a dam to impound water), or dugout-cum-embankment types. In high-rainfall regions like the North East, embankment-type ponds are favored for their high storage-to-earthwork ratio.
- **Sizing and Placement:** A common recommendation is to dedicate 10% to 12% of the farm area to a pond with a depth of approximately 3 meters. Strategic placement in a series along natural drainage lines can enhance moisture availability over large areas (25–50 ha).

- **Lining Solutions:** In porous soils like Alfisols or laterites, seepage control is vital. Cost-effective lining materials include soil-cement mortar (economical for laterite regions), LDPE sheets (which can reduce seepage by 93%), and silpaulin polyfilms. For black soils, cement mixed with murrum (1:6) has proven effective in minimizing cracks.

6.4 Supplemental Irrigation (SI)

The most critical application of harvested water is providing life-saving or supplemental irrigation during dry spells. In eastern India, one or two supplemental irrigations during prolonged dry spells can substantially improve crop productivity, particularly in rice, maize, pulses, oilseeds and vegetable crops.

- **Critical Growth Stages:** SI is most effective when applied during moisture-sensitive stages, particularly from flowering to grain filling.
- **Yield Stabilization:** A single supplemental irrigation of 100 mm can increase production by 28–36 million tonnes across India's rainfed districts. Case studies show that SI can double crop yields and provide the confidence necessary for farmers to invest in improved cultivars and fertilizers.

6.5 Rainwater Harvesting in Integrated Farming Systems

Integrated Farming Systems maximize water productivity by utilizing the same water for multiple purposes.

- **Multiple Use Protocols:** Water in farm ponds can be used for aquaculture (fish and prawn), livestock, and horticulture on pond embankments simultaneously with field crop irrigation.
- **Economic Synergy:** In Bihar, West Bengal and Orissa, rice-fish systems have shown a 3.2-fold increase in land productivity compared to mono-cropped rice. These systems are less risky due to the diversity of produce and improved nutrient cycling.

At ICAR–MGIFRI, harvested rainwater is integrated with crop production, horticulture, fisheries, livestock, and aquatic crop cultivation under Integrated Farming System (IFS) models, thereby improving water productivity and overall farm profitability.

6.6 Crop Diversification Using Harvested Water

Harvested rainwater enables farmers to diversify from traditional monocropping to multiple cropping systems by providing supplemental irrigation during moisture-stress periods. The availability of stored water increases cropping intensity, supports high-value crops, and improves farm income and resilience against climate variability (Table 6.1).

Table 6.1. Crop Diversification Opportunities Using Harvested Rainwater

Season	Crops
Kharif	Paddy, Maize, Vegetables
Rabi	Wheat, Mustard, Lentil, Pea
Summer	Mungbean, Vegetables
Perennial	Mango, Guava, Banana, Papaya

Crop diversification through harvested rainwater improves resource-use efficiency, reduces production risks, and enhances year-round farm income.

6.7 Livelihood and Socio-Economic Impact

RWH interventions directly correlate with poverty reduction and economic stability (Table 6.2).

- **Employment Generation:** Programs like NREGS (Kapildhara sub-scheme) utilize local labor for structure construction, providing immediate income transfers and long-term assets.
- **Risk Mitigation:** Harvested water provides a buffer against the vagaries of climate change, reducing migration and increasing the risk-bearing ability of smallholder farmers.
- **Equity and Social Value:** Community-managed ponds and the rejuvenation of traditional structures foster local participation and ensure a more democratic distribution of water resources compared to large-scale centralized projects.

Table 6.2 Benefits of Rainwater Harvesting for Livelihood Improvement

Benefit	Outcome
Supplemental irrigation	Higher crop productivity
Fish farming	Additional income
Aquatic crops	Enterprise diversification
Livestock	Reliable drinking water
Horticulture	Higher-value production
Groundwater recharge	Sustainable irrigation
Employment	Construction and maintenance
Climate resilience	Reduced drought risk

Adoption of rainwater harvesting improves farm resilience by stabilizing agricultural production, generating year-round employment, reducing dependence on groundwater, and enhancing livelihood opportunities through diversified farming enterprises.

6.9 Recommendations for Farmers

Recommendation	Expected Outcome
Construct farm ponds at suitable locations	Water availability throughout the year
Install drip or sprinkler irrigation	Higher water-use efficiency
Use harvested water for critical irrigation	Higher crop yield
Integrate fisheries and horticulture	Increased farm income
Maintain ponds annually	Longer service life
Utilize pond embankments	Additional income through fruit trees and fodder



Maintenance, Economics, and Scaling Up of Rainwater Harvesting

Ensuring the long-term performance of rainwater harvesting (RWH) systems requires regular maintenance, proper financial planning, and wider adoption through government support and community participation. Well-maintained systems provide reliable water supplies, improve groundwater recharge, reduce maintenance costs, and enhance the overall sustainability of water resources.

7.1 Maintenance of Rainwater Harvesting Systems

Regular inspection and maintenance are essential for ensuring the quality of harvested water, maintaining storage capacity, and extending the service life of rainwater harvesting structures (Table 7.1).

7.1.1 Rooftop and Conveyance Maintenance:

- Clean rooftops before the onset of the monsoon to remove dust, leaves, bird droppings, and other debris.
- Inspect and clean gutters and downpipes regularly to ensure free flow of rainwater.
- Clean screens, filters, and first-flush devices periodically, especially after the first few rainfall events.
- Repair damaged pipes, joints, and fittings immediately to prevent leakage.

7.1.2 Storage and Recharge Structure Maintenance:

- Clean storage tanks before and after the rainy season.
- Desilt farm ponds, percolation tanks, and recharge pits whenever sediment accumulation reduces storage capacity.
- Inspect embankments, spillways, and pond linings for cracks or erosion.
- Cover recharge wells and storage tanks properly to prevent mosquito breeding and contamination.
- Monitor groundwater recharge structures periodically to ensure proper infiltration.

Table 7.1 Recommended Maintenance Activities

Activity	Recommended Frequency	Purpose
Inspection of ponds and tanks	Monthly	Detect damage and leakage
Cleaning of silt traps and gutters	Before & after monsoon	Improve water quality
Desilting of ponds	Annually / As required	Restore storage capacity
Bund and embankment repair	Pre- & post-monsoon	Prevent erosion and failure
Water quality testing	Quarterly	Ensure suitability for intended use
Spillway cleaning	Before monsoon	Safe discharge of excess water
Vegetation control	Quarterly	Reduce obstruction and erosion
Water level monitoring	Weekly during monsoon	Track storage status

7.2 Economics of Rainwater Harvesting

Rainwater harvesting is a cost-effective investment that provides long-term economic, environmental, and social benefits. Although the initial construction cost varies depending on the type and size of the structure, the benefits generally outweigh the investment over time.

Major economic benefits include:

- Reduced irrigation cost
- Increased crop productivity
- Improved cropping intensity
- Enhanced groundwater availability
- Reduced dependence on external water sources
- Diversification into fisheries, horticulture, livestock, and aquatic crops
- Increased farm income and livelihood security

Economic studies conducted across different agro-climatic regions of India have demonstrated that rainwater harvesting systems provide favourable benefit–cost ratios, improve farm profitability, and generate long-term economic returns through enhanced agricultural productivity and diversified farming enterprises.

7.3 Scaling Up Strategies

Large-scale adoption of rainwater harvesting requires supportive policies, community participation, institutional collaboration, and technical guidance.

7.3.1 Government Initiatives Promoting Rainwater Harvesting and Water Resource Management

The Government of India and various State Governments have launched several programmes to promote rainwater harvesting, groundwater recharge, watershed development, efficient irrigation, and sustainable water resource management. These initiatives support water conservation through financial assistance, technical guidance, community participation, and convergence of different development programmes (Table 7.2).

These programmes support construction of farm ponds, recharge structures, watershed development, and water conservation measures.

7.4 Community Participation

Community participation plays a crucial role in ensuring the long-term success of rainwater harvesting systems through:

- Community-managed ponds
- Watershed committees
- Water user associations
- Farmer Producer Organizations (FPOs)
- Local Panchayats

7.5 Capacity Building

Adoption of rainwater harvesting can be enhanced through:

- Farmer training programmes
- Demonstration units
- Exposure visits
- Awareness campaigns

- School and college programmes
- Digital advisory services

7.6 Key Messages

- ✓ Harvest every drop of rain.
- ✓ Maintain rainwater harvesting structures regularly.
- ✓ Use harvested water efficiently.
- ✓ Promote groundwater recharge.
- ✓ Integrate rainwater harvesting with farming systems.
- ✓ Utilize government schemes for constructing rainwater harvesting structures.
- ✓ Adopt community-based water conservation practices.

Table 7.2 Government initiatives supporting rainwater harvesting and water resource management

Scheme	Ministry	Objective	Relevance to Rainwater Harvesting
Jal Shakti Abhiyan (JSA)	Ministry of Jal Shakti	Water conservation and rainwater harvesting through community participation	Promotes rooftop rainwater harvesting, recharge pits, ponds, check dams, desilting of water bodies and afforestation
Atal Bhujal Yojana (Atal Jal)	Ministry of Jal Shakti	Sustainable groundwater management in water-stressed areas	Encourages groundwater recharge, aquifer management and community-led water budgeting
Pradhan Mantri Krishi Sinchayee Yojana (PMKSY)	Ministry of Agriculture & Farmers Welfare	"Har Khet Ko Pani" and "Per Drop More Crop"	Supports farm ponds, micro-irrigation, rainwater harvesting structures and efficient irrigation systems
MGNREGA	Ministry of Rural Development	Employment generation through creation of durable rural assets	Construction of farm ponds, check dams contour bunds, percolation tanks, drainage channels and water conservation works
National Water Mission (NWM)	Ministry of Jal Shakti	Improve water-use efficiency and integrated water resources management	Promotes water conservation, rainwater harvesting, demand management and awareness programmes
Watershed Development Component under PMKSY (WDC–PMKSY)	Department of Land Resources	Sustainable watershed development in rainfed areas	Supports watershed treatment, contour bunding, check dams, farm ponds, vegetative barriers and groundwater recharge



Case Studies of Excellence: ICAR–MGIFRI Research Projects

8.1 Institutional Context

The Mahatma Gandhi Integrated Farming Research Institute (ICAR-MGIFRI) is geographically situated in a region characterized by high seasonal rainfall variability, severe monsoonal run-offs, and critical mid-season dry spells. As climate change accelerates weather extremes across Bihar and neighboring low-lying regions, the reliance on traditional groundwater abstraction via deep tube wells faces strict ecological and economic boundaries. To counter these vulnerabilities, ICAR-MGIFRI has intentionally executed a decentralized campus-wide network of Water Harvesting Structures (WHS). These infrastructures are designed not merely as passive storage units, but as dynamic, functional research cells supporting diverse Integrated Farming System (IFS) models (Figure 8.1).

Overview of Rainwater Harvesting Infrastructure at ICAR–MGIFRI

The ICAR–MGIFRI campus has developed an integrated network of rainwater harvesting and water storage structures to enhance water availability for research, demonstration, and Integrated Farming System (IFS) models. The campus includes farm ponds, fish ponds, lined and unlined storage ponds, rooftop rainwater harvesting systems, and other water conservation structures with varying storage capacities strategically distributed across the farm. These structures capture monsoon runoff, reduce surface water loss, promote groundwater recharge, and provide supplemental irrigation during dry periods. The harvested water also supports fisheries, horticulture, livestock, aquatic crop cultivation, and other farming system components, demonstrating an integrated approach to sustainable water resource management under Eastern Indian conditions.

8.2 Core Objectives of the Water Harvesting Framework

- Run-off Mitigation & Groundwater Recharge: Capturing peak monsoonal storm discharges to minimize campus soil erosion while facilitating sub-surface horizontal water movement.
- Climate-Resilient Research Support: Ensuring localized, high-security water availability for critical evaluation plots, horticultural nurseries, and multi-trophic aquaculture experiments.
- Integrated Farming System Evaluation: Serving as the central biological and physical pivot for combined crop-livestock-fish-duck farming research matrices.



Figure 8.1. Spatial distribution of rainwater harvesting structures and their storage capacities at ICAR–MGIFRI. Source: Prepared by Dr. Koushik Banerjee using ArcGIS Pro (v 10.8.2) and Google Earth (2026).

8.3 Comprehensive reconnaissance and inventory matrix

At present, the institute manages 32 distinct water harvesting structures distributed strategically across the experimental research farmlands. The cumulative storage volume of these structural units stands at 16,826.85 m³, translating into an asset capacity of approximately 1.68 crore litres of harvested rainwater (Table 8.1).

Table 8.1. Consolidated Institutional Summary Table

SN	Project / Unit Name	PI / Scientist In-Charge	No. of Structures	Total Capacity (m ³)	Lining Type	Current Status / Requirement
1	Auditorium Rooftop Rainwater Harvesting System	Farm IC	1	50.06	Cement Concrete	Functional; Requires repairs
	Office Building Rooftop Rainwater Harvesting System	Farm IC	1	473.79	Cement Concrete	Functional; Requires repairs
2	Fish-based IFS	Dr. Ravi Kumar	5	4,000.00	Earthen	Functional; Minor repairs
3	Poultry-Fish-Horti based IFS	Dr. A. K. Jadhav	2	3,905.00	Earthen	Functional; Requires bund repair & slope shaping
4	Land Shaping for Crop Diversification (Horti-IFS)	Dr. S. K. Purbey	10	4,662.00	HDPE (1400 m ³) / Earthen (3262 m ³)	Functional; Scope for strengthening
5	Goat-based IFS	Dr. P. K. Bharti	4	2,190.00	Earthen	2 Functional / 2 Need repair (bunds & slopes)
6	Rice-Fish-Duck IFS	Dr. S. K. Singh	9	1,546.00	Earthen	Functional; Requires bund repair & slope shaping
-	TOTAL CAMPUS OUTLAY	-	32	16,826.85	-	-

8.3 Project-Specific Architectural Deep-Dives

A. Auditorium Rooftop Rainwater Harvesting & Storage System

Scientist In-Charge: Farm IC

Location: Institute Research Farm (Behind Auditorium)

Features: Features rooftop catchments, PVC gutters, downpipes, a rectangular silt trap (8.5 ft × 5.5 ft), and an underground storage unit (Figure 8.2).

Structures & Dimensions: Circular Underground Tank: Diameter 15 ft (4.57 m), Depth 10 ft (3.05 m) | Volume: 50.06 m³

Technical Specifications:

- Lining Type: Cement Concrete
- Water Source: Rooftop Rainwater Catchment
- Primary Utilization: Irrigation of IFS unit, nursery operations, etc.

Status & Scope: Functional but actively requires repair and structural sealing.

(A)B. Office Building Rooftop Rainwater Harvesting & Storage System

Scientist In-Charge: Farm IC

Location: Institute Campus (Near Office Building)

Features: Features rooftop catchments, PVC gutters, downpipes, a rectangular silt trap (8.5 ft × 5.5 ft), and a surface storage unit (Figure 8.3).

Structures & Dimensions:

- Rectangular Tank: 68 ft × 22 ft × 10 ft (20.73 m × 6.71 m × 3.05 m)
- Volume: 423.73 m³

Technical Specifications:

- Lining Type: Cement Concrete
- Water Source: Rooftop Rainwater Catchment
- Primary Utilization: Irrigation of lawns, gardens, orchards, nursery operations, and campus cleaning.

Status & Scope: Functional but actively requires repair and structural sealing.

C. Fish-Based Integrated Farming System (IFS)

Scientist In-Charge: Dr. Ravi Kumar

Location: MGIFRI Research Farm (Figure 8.4)

Structures & Dimensions:

- 1 Large Unit: 60 m × 40 m × 1.5 m = 3,600 m³
- 4 Small Units: 10 m × 10 m × 1 m = 400 m³

Technical Specifications:

- Total Capacity: 4,000.00 m³
- Lining Type: Earthen
- Water Source: Rainwater, Surface Runoff, and Borewell backup
- Primary Utilization: Fish Culture and Fish-based IFS development.

Status & Scope: Functional; needs minor routine repairs. Scope to expand the total number of ponds.



Figure 8.2. Auditorium rooftop rainwater harvesting and storage system showing (A) rooftop catchment, (B) PVC gutters and downpipes, and (C) storage tank at ICAR-MGIFRI, Piprakothi. Source: ICAR-MGIFRI



Figure 8.3. Office building rooftop rainwater harvesting and storage system showing (A) rooftop catchment, (B) PVC gutters, (C) downpipes, and (D) storage tank at ICAR-MGIFRI, Piprakothi. Source: ICAR-MGIFRI



Figure 8.4. Development of the 3,600 m³ Central Aquaculture Pond under the Fish-Based IFS model: (A) Pond during the initial construction phase; (B) Aerial view of the completed pond at peak water storage. Source: ICAR-MGIFRI

D. Poultry-Fish-Horti Based IFS

- Scientist In-Charge: Dr. A. K. Jadhav (Figure 8.5)
- Location: Institute Research Farm (Behind Auditorium)

Structures & Dimensions:

- Pond 1: Storage Volume = $2,159.60 \text{ m}^3$ (Top Area: 527.30 m^2 , Depth: 5.12 m)
- Pond 2: Storage Volume = $1,745.56 \text{ m}^3$ (Top Area: 515.18 m^2 , Depth: 4.20 m)

Technical Specifications:

- Total Capacity: $3,905.00 \text{ m}^3$
- Lining Type: Earthen (Established 2023)
- Water Source: Rainwater, Runoff, and Borewell
- Primary Utilization: Crop irrigation and fish rearing within the IFS model.

Status & Scope: Functional. Requires urgent repair of bunds and earth reshaping to secure proper slope stability.

E. Land Shaping for Crop Diversification & Horti-Based IFS (Low-Lying Areas of Bihar)

- Scientist In-Charge: Dr. S. K. Purbey (Principal Scientist)
- Location: MGIFRI Farm / Project Low Lying Zone (Figure 8.6)

Structures & Dimensions:

- 3 Units: $25 \text{ m} \times 14 \text{ m} \times 1.8 \text{ m} = 1,890 \text{ m}^3$
- 4 Units: $18 \text{ m} \times 14 \text{ m} \times 1.5 \text{ m} = 1,512 \text{ m}^3$
- 3 Units: $25 \text{ m} \times 14 \text{ m} \times 1.2 \text{ m} = 1,260 \text{ m}^3$

Technical Specifications:

- Total Capacity: $4,662.00 \text{ m}^3$
- Lining Type: $1,400 \text{ m}^3$ volume protected by HDPE Pond Liners; $3,262 \text{ m}^3$ volume is Earthen.
- Water Source: Rainwater, Runoff, and Borewell
- Primary Utilization: Fish culture, aquatic crops (Makhana / Water Chestnut), and research.

Status & Scope: Functional; ready for strengthening.

F. Goat-Based Integrated Farming System (IFS)

- Scientist In-Charge: Dr. P. K. Bharti (Figure 8.7)
- Location: Institute Research Farm (Near Goat Unit)

Structures & Dimensions:

- Pond I (Medium): $30 \text{ m} \times 20 \text{ m} \times 1.5 \text{ m} = 900 \text{ m}^3$
- Pond II & III (Small): $30 \text{ m} \times 6 \text{ m} \times 1.5 \text{ m} \times 2 \text{ units} = 540 \text{ m}^3$
- Pond IV: $25 \text{ m} \times 20 \text{ m} \times 1.5 \text{ m} = 750 \text{ m}^3$

Technical Specifications:

- Total Capacity: $2,190.00 \text{ m}^3$
- Lining Type: Earthen
- Water Source: Rainwater and Borewell
- Primary Utilization: Crop irrigation within the Goat-IFS layout.

Status & Scope: 2 Units are fully functional (Ponds I & II); 2 Units urgently need repair (Ponds III & IV require bund repairing and slope re-shaping).



Figure 8.5. Aerial view of the Poultry-Fish-Horti Based IFS showing the integrated pond complex with a combined water storage capacity of 3,905 m³, utilized for rainwater harvesting, irrigation, and fish production. Source: ICAR-MGIFRI



Figure 8.6. Land Shaping for Crop Diversification and Horti-Based IFS project showing (a) initial construction of water harvesting ponds, (b) HDPE-lined pond for efficient water storage, (c) earthen pond utilized for rainwater harvesting, and (d) cultivation of makhana in harvested water. Source: ICAR-MGIFRI

G. Rice-Fish-Duck IFS

Scientist In-Charge: Dr. S. K. Singh (Figure 8.8)

Location: Institute Research Farm

Structures & Dimensions:

- 9 Interconnected/Standardized Pond Units
- Unit Layout: Top (22 m × 6 m), Bottom (18 m × 3.5 m), Water Depth (1.8 m)
- Volumetric Output: 171.71 m^3 per unit × 9 units = $1,546 \text{ m}^3$

Technical Specifications:

- Total Capacity: $1,546.00 \text{ m}^3$
- Lining Type: Earthen (Established 2021)
- Water Source: Rainwater, Runoff, and Borewell
- Primary Utilization: Integrated crop irrigation and fish/duck rearing.

Status & Scope: Functional; structural degradation noted. Requires bund reinforcement and precise slope correction.

4. Present Status

Most water harvesting structures are functional and actively used for research, irrigation, and fish culture. However, a few structures require targeted interventions:

- Strengthening of pond bunds
- Desilting of storage basements
- Repair of eroded embankments
- Reshaping of side slopes to ensure structural stability
- Repair of rooftop rainwater harvesting components
- Regular maintenance of storage tanks and conveyance systems



Figure 8.7. Aerial view of the Goat-Based IFS model depicting water harvesting ponds with a combined storage capacity of 2,190 m³, supporting irrigation and integrated livestock-based farming. Source: ICAR-MGIFRI



Figure 8.8. Series of HDPE-lined ponds under the Rice–Fish–Duck IFS developed for efficient rainwater harvesting, fish production, and supplemental irrigation in integrated farming. Source: ICAR-MGIFRI



Future Scope of Rainwater Harvesting: Smart Technologies, IoT and Digital Water Management

Advances in digital agriculture, the Internet of Things (IoT), artificial intelligence (AI), Geographic Information Systems (GIS), remote sensing, automation, and cloud computing are transforming water resource management (Table 9.1). The integration of these technologies with rainwater harvesting systems enables real-time monitoring of water availability, improves irrigation scheduling, enhances water-use efficiency, reduces labour requirements, and supports data-driven decision-making for sustainable agriculture and Integrated Farming Systems (IFS).

9.1 Internet of Things (IoT) for Water Management

IoT-based monitoring systems connect water level sensors, weather stations, soil moisture sensors, pumps, and other field devices to cloud platforms for real-time monitoring and automated decision-making. These systems enable continuous monitoring of harvested water, storage capacity, and irrigation requirements through mobile applications or web dashboards (Figure 9.1).

9.2 Automated Water Level Monitoring

Ultrasonic, pressure-based, and radar sensors continuously measure water levels in ponds, tanks, and reservoirs. Real-time storage information helps optimize irrigation scheduling, estimate available water, and improve drought preparedness.

9.3 Smart Irrigation Systems

Smart irrigation systems integrate soil moisture sensors, weather data, crop water requirements, and automatic controllers to apply irrigation only when required, thereby reducing water losses and improving water-use efficiency.

9.4 Smart Water Quality Monitoring

Water quality sensors measure pH, electrical conductivity (EC), dissolved oxygen (DO), temperature, and turbidity to ensure harvested water is suitable for irrigation, fisheries, livestock, and domestic uses after appropriate treatment.

9.5 Solar-Powered Pump Automation

Solar-powered irrigation systems integrated with automated controllers and water level sensors reduce energy costs, improve irrigation reliability, and support sustainable water management in remote agricultural areas.

9.6 GIS, GPS and Remote Sensing

GIS, GPS, satellite imagery, and drone-based surveys facilitate mapping of rainwater harvesting structures, estimation of catchment areas, monitoring of storage capacity, identification of suitable recharge sites, and preparation of digital inventories for planning and management.

9.7 Artificial Intelligence and Decision Support

Artificial intelligence (AI) and decision support systems (DSS) analyse rainfall forecasts, soil moisture, weather conditions, crop water requirements, and available pond storage to generate optimized irrigation schedules, water allocation plans, and early warning advisories for drought and water scarcity.



Figure 9.1. IoT-based water level monitoring system installed for rainwater harvesting and water resource management at ICAR-MGIFRI, Piprakothi. Source: ICAR-MGIFRI

9.8 Digital Record Keeping

Cloud-based databases, mobile applications, and digital dashboards facilitate recording of rainfall, water storage, groundwater levels, maintenance activities, irrigation events, and water use, thereby improving institutional planning and long-term water resource management.

9.9 Future Research Opportunities

- Automated water budgeting using real-time sensor data.
- Stage-storage relationship modelling for farm ponds.
- AI-based irrigation scheduling.
- Climate-resilient water harvesting systems.
- Digital twins for water resource planning.
- Integration of IoT with Integrated Farming Systems.
- Drone-based monitoring of water harvesting structures.
- Remote sensing-based estimation of water storage.
- Smart decision support systems for farmers.

Table 9.1 Emerging Technologies for Water Harvesting Management

Technology	Application	Expected Benefit
Water Level Sensor	Pond/tank monitoring	Real-time storage information
Soil Moisture Sensor	Irrigation scheduling	Water saving
Flow Meter	Irrigation water measurement	Improved water accounting
Automatic Weather Station	Weather-based irrigation	Better irrigation planning
DO, pH & EC Sensors	Water quality monitoring	Improved fish and irrigation water quality
Solar Pump Automation	Automatic irrigation	Reduced energy cost
GIS & GPS	Mapping water harvesting structures	Efficient planning
Drone Survey	Inspection and monitoring	Rapid assessment
Cloud Dashboard	Data storage and visualization	Real-time monitoring
Artificial Intelligence (AI)	Irrigation decision support	Optimized water allocation
Mobile App	Remote monitoring and alerts	Easy farmer access

9.10 Future Outlook

Smart rainwater harvesting systems integrating IoT, artificial intelligence, cloud computing, GIS, remote sensing, and renewable energy are expected to play an increasingly important role in climate-smart agriculture. Future water management will shift from conventional storage systems to intelligent, sensor-based decision support systems capable of maximizing water productivity, improving resilience to climate change, and supporting sustainable Integrated Farming Systems.



Conclusions and Recommendations

Rainwater harvesting is a fundamental component of sustainable water resource management for enhancing water security, improving agricultural productivity, and strengthening climate resilience. Scientific planning, proper design, and efficient utilization of harvested rainwater can substantially reduce dependence on groundwater while ensuring reliable water availability for irrigation, livestock, fisheries, horticulture, and other farm enterprises. The rainwater harvesting systems developed at ICAR–Mahatma Gandhi Integrated Farming Research Institute (ICAR–MGIFRI), Pirakothi, demonstrate how integrated water resource management can support sustainable agriculture under the flood-prone conditions of the eastern Indo-Gangetic Plains.

10.1 Conclusions

The present assessment demonstrates that scientifically designed rainwater harvesting systems can effectively capture, store, and utilize monsoon rainfall for multiple agricultural and research purposes. The integrated approach adopted at ICAR–MGIFRI combines rooftop rainwater harvesting, farm ponds, fish ponds, recharge structures, and storage tanks with Integrated Farming Systems (IFS), thereby improving water-use efficiency, groundwater recharge, livelihood opportunities, and climate resilience. These interventions provide a practical model for research institutions, Krishi Vigyan Kendras (KVKs), and farming communities across eastern India.

10.2 Major Findings

The major outcomes of the present study are summarized below:

- A total of 32 rainwater harvesting and water storage structures have been developed under six major research and development projects at ICAR–MGIFRI.
- The combined storage capacity exceeds 16,800 m³ (approximately 1.68 crore litres), providing a substantial water reserve for research and agricultural activities.
- Harvested rainwater is utilized for supplemental irrigation, fish farming, horticulture, nursery management, livestock, groundwater recharge, and Integrated Farming System (IFS) research.
- Rooftop rainwater harvesting systems effectively utilize runoff from institute buildings, thereby reducing surface runoff losses and promoting water conservation.
- Farm ponds and storage reservoirs provide life-saving irrigation during dry spells, reducing dependence on groundwater and improving cropping intensity.
- Integrated utilization of harvested water has strengthened the sustainability and climate resilience of farming systems under the eastern Indo-Gangetic Plain conditions.
- The campus serves as a demonstration model for scientific rainwater harvesting, capacity building, and technology dissemination for farmers, students, and extension personnel.

10.3 Recommendations

To maximize the long-term benefits of rainwater harvesting systems, the following recommendations are proposed:

- Regularly inspect and repair pond embankments, spillways, recharge structures, and storage tanks.
- Desilt ponds, recharge pits, and storage reservoirs before each monsoon season to maintain storage capacity.
- Strengthen rooftop rainwater harvesting systems in institutional buildings and residential campuses.
- Install IoT-based water level sensors, automatic weather stations, and digital monitoring systems for real-time water resource management.
- Promote solar-powered pumping systems, drip irrigation, and sprinkler irrigation to improve water-use efficiency.
- Develop GIS-based digital inventories of rainwater harvesting structures for planning and monitoring.
- Implement annual operation and maintenance plans supported by routine water quality monitoring.
- Integrate harvested rainwater with diversified Integrated Farming Systems (crop–horticulture–livestock–fisheries–aquatic crops) to maximize water productivity.
- Enhance farmer training, demonstration programmes, and capacity-building activities through ICAR, KVKs, and State Departments.

10.4 Future Perspectives

Future water management should focus on integrating automation, Internet of Things (IoT), artificial intelligence (AI), Geographic Information Systems (GIS), remote sensing, drone-based monitoring, and decision-support systems with rainwater harvesting infrastructure. These emerging technologies will enable real-time monitoring of water storage, automated irrigation scheduling, predictive water budgeting, and efficient allocation of harvested water, thereby enhancing agricultural productivity, resource-use efficiency, and climate resilience.

10.5 Policy Implications

The successful implementation of rainwater harvesting systems at ICAR–MGIFRI demonstrates that scientifically planned water harvesting infrastructure can be effectively replicated in research farms, Krishi Vigyan Kendras (KVKs), educational institutions, government farms, and farmers' fields. Wider adoption of rainwater harvesting should be promoted through convergence with national and state programmes such as Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Jal Shakti Abhiyan, MGNREGS, National Water Mission, and Watershed Development Programmes. Investments in rainwater harvesting infrastructure, digital water monitoring, and climate-smart water management technologies will play a vital role in achieving sustainable agriculture, groundwater conservation, and water security in eastern India and similar agro-ecological regions.

10.6 Final Message

"Every drop of rain harvested is an investment in future water security." Scientific rainwater harvesting, combined with efficient water management, modern technologies, and integrated farming systems, offers a sustainable pathway towards climate-resilient agriculture, enhanced livelihoods, and long-term conservation of precious water resources. The experiences of ICAR–MGIFRI provide a practical and scalable model that can guide farmers, researchers, extension agencies, and policymakers in promoting sustainable water resource management across India.

References

- Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. Fao, rome, 300(9), D05109.
- Banerjee, K., Mandal, K.G., Purbey, S.K., Das, B., Nivesh, S., Paradkar, V. and Kumar, R., Samal, S.K. 2026. Assessing spatio-temporal trends, teleconnections and clustering of long-term seasonal rainfall of Bihar using innovative trend analysis & multivariate techniques. *Discov Appl Sci* (2026). <https://doi.org/10.1007/s42452-026-09171-2>
- Central Ground Water Board (CGWB). 2020. Master Plan for Artificial Recharge to Groundwater–2020. Ministry of Jal Shakti, Government of India, New Delhi.
- Central Public Health and Environmental Engineering Organisation (CPHEEO). 2019. Manual on Storm Water Drainage Systems. Ministry of Housing and Urban Affairs, Government of India, New Delhi.
- Central Public Works Department (CPWD). (2019). Rain Water Harvesting & Conservation Manual. Directorate General, Central Public Works Department, Ministry of Housing and Urban Affairs, Government of India.
- Central Water Commission (CWC). 2015. Water and Related Statistics. Ministry of Water Resources, River Development and Ganga Rejuvenation (now Ministry of Jal Shakti), Government of India, New Delhi.
- Eslamian, S., & Eslamian, F. (Eds.). (2021). *Handbook of Water Harvesting and Conservation: Case Studies and Application Examples*. John Wiley & Sons.
- Eslamian, S., Eslamian, F., & Wiley, J. (Eds.). (2021). *Handbook of water harvesting and conservation: Basic concepts and fundamentals*. Wiley.
- Food and Agriculture Organization (FAO). 1991. A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production. FAO, Rome.
- K.V. Rao, B.Venkateswarlu, K.L. Sahrawath, S.P. Wani, P.K. Mishra, S.Dixit, K. Srinivasa Reddy, Manoranjan Kumar and U.S. Saikia, (Eds) 2010. *Proceedings of National Workshopcum-Brain Storming on Rainwater Harvesting and Reuse through Farm Ponds: Experiences*.
- Kinkade-Levario, H. (2007). *Design for water: rainwater harvesting, stormwater catchment, and alternate water reuse*. New society publishers.
- National Commission for Integrated Water Resources Development (NCIWRD). 1999. *Integrated Water Resources Development: A Plan for Action*. Ministry of Water Resources, Government of India, New Delhi.
- NITI Aayog. 2018. *Composite Water Management Index: A Tool for Water Management*. Government of India, New Delhi.
- Raja, W., Khaki, Q. Z., & Kumar, P. (2026). *Wastewater Reuse in Buildings*.

