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Rainwater conservation, management and governance in rainfed areas

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The success of rainfed agriculture depends on the rainfall availability and its distribution. In semi-arid regions, erratic rainfall patterns and prolonged dry spells during crop growing season results in severe moisture stress and lowers crop productivity. Hence, rainwater conservation practices including in-situ moisture conservation to increase the soil moisture availability and construction of water harvesting structures to ensure groundwater recharge and supplemental irrigation requirement are very important. In addition to the traditional knowledge of water management in watersheds, modern techniques like soil moisture-based (IoT) micro-irrigation technique increases the water-use efficiency. It is the need of the hour to implement sustainable solutions to address the water crisis in both rural and urban areas. However, the effectiveness of these practices depends on coordinated governance and community involvement.

Keywords: Groundwater sharing, *In-situ* moisture conservation, Rainfed areas, Water harvesting

IN rainfed areas, the delay in onset of monsoon, uneven distribution of rainfall, early withdrawal of monsoon and prolonged dry spells during crop growing season results in severe moisture stress, lowers crop productivity or even crop failure. Rainwater conservation is very crucial in India, where water scarcity and erratic rainfall patterns are prevalent and it is a need to address the climate change to ensure water security for both urban and rural areas. India receives a significant portion of its annual rainfall during the monsoon season and much of this water is lost as runoff due to inadequate infrastructure and inefficient management. Similarly, soil erosion removes the fertile top soil and reduces the productivity of the soil. Generally, groundwater is mainly used as the major source of freshwater that caters to the ever-growing domestic demand as well as agrarian and industrial demands, and it results in over-exploitation. Rainwater conservation practices, including *in-situ* moisture conservation to increase the soil moisture availability and construction of water harvesting structures like farm ponds, check dams, percolation tanks, and groundwater recharge structures help to meet the supplemental irrigation requirement and recharge of aquifers. In rainfed regions, along with traditional knowledge of water management in watersheds, modern techniques like soil moisture-based supplemental irrigation using micro-irrigation system increases the nutrient-use efficiency as well as water-use efficiency and helps to mitigate the impact of irregular rainfall patterns. Modern rainwater harvesting techniques such as rooftop rainwater collection, groundwater recharge, and construction of storage tanks, are now being promoted as sustainable solutions to address the water crisis in rural and urban areas. However, the effectiveness of these practices depends on coordinated governance and community involvement.

Rainwater conservation

The water harvesting practices include *in-situ* water conservation and water harvesting in storage structures. Rainwater harvesting technologies are highly location specific and certain practices evolved in each agro-ecological region have limited applicability in other regions. These practices can be adopted in regions having homogeneity in bio-physical attributes of soil, climate, topography, and crops/land uses. Greater emphasis needs to be given on involvement of farmers from the planning stage and extension support to expanding the interventions to large areas.

In-situ moisture conservation and water harvesting

In-situ rainwater harvesting is generally carried out through various agronomic and engineering measures. The agronomic measures for water conservation include practices like contour cultivation, cover cropping,

mulching, deep tillage, subsoiling, conservation furrows, contour farming and ridging. Contour cultivation is recommended for all types of soils having rainfall up to 1,000 mm and slope varying from 0.5–4%. In medium deep black soils in southern Rajasthan, summer deep ploughing with raised bed of 40 cm width is recommended. Subsoiling in Vertisols in alternate years with horizontal spacing of 1.5–2.0 m is recommended for Marathwada region of Maharashtra. Mulches are of different types, including soil mulch, stubble mulch, straw or stover mulch, live mulch, plastic mulch and vertical mulch. Conservation furrows are made by opening furrows parallel to rainfed crop rows across the land slope in 3–4 weeks after the germination of the main crop. Agronomic measures are preferred as they involve least disturbance of the land and are farmer's friendly. However, in situations where agronomic measures are insufficient due to topographic or climatic constraints, mechanical measures are recommended to improve soil moisture regime and conserve runoff water. The engineering measures include practices such as contour bunding, graded bunding, conservation bench terrace system, bench terracing, contour trenches, conservation ditches, ridge and furrow, raised bed system, compartmental bunding, tree base terracing and broad bed and furrow system. For Alfisols having slopes more than 1.5%, contour bunding is the most promising. Graded bunds are suggested in areas having higher rainfall with less permeable, deep heavy soils. Various moisture conservation practices corresponding to suitable slopes for effective implementation are listed.

- *Mulching:* Effective for all slopes to reduce evaporation and maintain soil moisture.
- *Contour farming:* Best suited for all slopes to reduce erosion and enhance moisture retention.
- *Terracing:* Very essential for steep slopes (15-30%) to construct stepped platforms that slow runoff and improve soil moisture conservation.
- *Zero tillage:* Applicable on flat to moderate sloping land (0-10%) to maintain soil structure and moisture without disturbing the soil.
- *Cover cropping:* Suitable for all slopes (0-30%) to protect soil, improve organic matter, and enhance moisture retention during off-seasons.
- *Crop rotation:* Effective on flat to moderately sloped land (0-15%) to improve soil health and moisture conservation.
- *Infiltration pits:* Best for flat to gently sloping land (0-5%) to enhance water infiltration and retain moisture.
- *Subsoiling:* Effective on flat to moderately sloped land (0-15%) to break up compacted layers for improved water infiltration.
- *Gully plugging:* Very important for steep slopes (15-30%) where erosion control is needed to retain water and improve moisture conservation.
- *Furrow diking:* Best for flat to moderate slopes to slow down water runoff and enhance soil moisture retention.
- *Stone bunds:* Suitable for moderate to steep slopes (5-

Broad bed and furrow system for crops

Gabions for controlling gully erosion

Ridge and furrow system for field crops

Tree-base terracing for perennial crops

30%) to create barriers that reduce soil erosion and enhance moisture retention.

- *Sand dune stabilization:* Effective in arid regions with gentle slopes (0-5%) to prevent moisture loss and stabilize sand dunes.
- *Soil amendments:* Suitable for all slopes (0-30%) to improve soil structure and increase water-holding capacity.

Soil amendments for enhancing moisture storage

Soil amendments offer practical and effective solutions for enhancing moisture storage, particularly in rainfed areas where water scarcity can severely impact agricultural productivity. When combined with rainwater conservation techniques, the soil amendments can play a vital role in water management in rainfed regions. Organic matter, such as compost, manure, and decomposed plant residues, are most widely used and effective amendments for moisture retention. Organic matter also supports beneficial microbial activity, which improves soil health, promotes water infiltration, and reduces evaporation from the soil surface. Additionally, biochar, a carbon-rich material produced by burning organic matter in a low-oxygen environment, is increasingly recognized for its ability to enhance soil moisture retention. Other soil amendments, such as clay minerals, gypsum, and synthetic polymers also play a crucial role in moisture conservation. In light-textured, sandy soils where water drains quickly, the addition of tank silt or clay minerals like bentonite can improve the soil's capacity to retain water. Gypsum, a calcium sulfate mineral, is particularly effective in improving the physical structure of compacted soils like heavy clays, allowing water to penetrate deeper into the soil and be stored in the root zone. Synthetic polymers and hydrogels, though less commonly used in traditional agriculture, act as sponges by absorbing and holding large amounts of water and releasing it slowly as the soil dries.

Water harvesting and supplemental irrigation

Rainwater harvesting can be achieved through construction or renovation of water harvesting structures like dugout ponds, check dams, percolation tanks, diversion bunds and *Jalkunds*. Supplemental irrigation is a critical practice for enhancing crop yields, particularly in rainfed regions where rainfall is erratic. It involves providing additional water to crops when natural rainfall is insufficient, especially during critical stages of plant development such as flowering, grain filling, or fruit formation. *Jalkunds* are small water harvesting structures suitable for hilly regions for providing supplemental irrigation to high value crops. Farm ponds could be lined or unlined depending on the soil and the purpose of water utilization. Check dams are suitable for moderate slopes (5-15%) in drainage lines to slow water flow, increase soil moisture and groundwater recharge.

Water management

The success of water harvesting and supplemental irrigation not rely solely on technical solutions; it also depends on effective governance and active community participation. Local communities play a crucial role in managing water-harvesting structures, maintaining them, and ensuring equitable distribution of water. Community-based water management systems, such as watershed development programs, have proven to be highly effective in rainfed areas. In addition to local engagement, effective water governance must focus on promoting equitable access to harvested water, ensuring that all community members benefit from the available water resources. Policies and regulations should also emphasize on sustainable use of both surface and groundwater resources to prevent over-extraction.

Reuse of harvested water for supplemental irrigation

In rainfed agricultural regions, the reuse of harvested rainwater for supplemental irrigation is a critical strategy for enhancing water security and improving crop productivity. Supplemental irrigation addresses this challenge by providing additional water when natural rainfall is insufficient, particularly during sensitive periods such as flowering, fruit development, and grain filling. The reuse of harvested water for supplemental irrigation offers a reliable alternative to groundwater extraction. Effective reuse of harvested water for supplemental irrigation involves the application of water-saving irrigation techniques (sprinkler, surface drip, sub-surface drip and rain gun) that maximize the efficiency of water use. Micro-irrigation is one of the most efficient methods, as it delivers water directly to the root zone of plants, minimizing water loss through evaporation or runoff. Soil moisture based micro-irrigation is an advanced method that ensures that plants receive just the right amount of water, helping to reduce the waste and optimize the use of harvested water.

Conjunctive use of surface and groundwater, and ground water sharing

Conjunctive use refers to the coordinated and planned utilization of both surface water (such as rivers, ponds, and reservoirs) and groundwater (from wells and aquifers) in a way that optimizes the use of both sources. This approach helps farmers to meet their water needs more efficiently by balancing the use of surface and groundwater resources according to availability, demand, and environmental conditions. Successful implementation requires careful planning, management, and governance to ensure sustainability and equity. Over-extraction of either resource can lead to environmental and social consequences, such as the drying up of rivers or the depletion of community wells. Therefore, effective water governance is essential to regulate the allocation and use of water, prevent conflicts over resources, and promote practices that protect both surface and groundwater systems. Another challenge is the variability of surface water availability in rainfed regions. During periods of heavy

rainfall, surface water supplies may be abundant, but during extended dry spells, they can become scarce. In such cases, communities must rely more heavily on groundwater, increasing the risk of over-extraction. To manage this dynamic balance, local water management systems must be designed to allow for flexible switching between surface and groundwater use depending on seasonal and climatic conditions. Instead of digging bore wells without maintaining the spacing between wells, 3-4 bore wells can be linked together and the water can be shared among the community including the farmers not having bore wells to reduce the groundwater over-exploitation.

Adoption of suitable cropping patterns

Despite the clear benefits of adopting suitable cropping patterns with harvested rainwater, several challenges remain. One of the main challenges is the variability of rainfall, which makes it difficult to predict the amount of water that will be available for supplemental irrigation. Another challenge is the need for farmers to shift from traditional cropping patterns to those that are better aligned with water availability. Also selecting crops based on their water needs and carefully timing their planting to align with the availability of harvested water, farmers can optimize the benefits of rainwater harvesting and reduce the risks associated with unpredictable rainfall. Agroforestry integrates crops with trees or shrubs in the same field and helps in soil stabilization as well as improved water retention. Diverse cropping systems in rainfed areas offer unique advantages depending on the region's climate, soil type, and water availability; and they optimize the use of water and nutrients, and mitigate risks related to water scarcity and climate variability.

Policy related issues

Government initiatives, such as the *Jal Shakti Abhiyan*, along with grassroots level efforts by local communities contributed in increasing the awareness and action towards rainwater conservation. These efforts are vital in combating the effects of climate change, supporting agriculture, and ensuring access to clean drinking water, particularly in drought-prone areas. Effectiveness of rainwater harvesting is significantly influenced by policy-related issues that can either facilitate or hinder its implementation. A comprehensive and unified policy framework is essential for promoting rainwater harvesting. Financial incentives and support mechanisms play a pivotal role in encouraging farmers and communities to invest in rainwater harvesting (RWH) infrastructure. Additionally, effective governance requires the active participation of local communities in the management and maintenance of rainwater harvesting systems. Moreover, existing water-use policies often prioritize large-scale irrigation projects over decentralized systems like RWH, leading to an imbalance in water resource management. It is crucial for policies to recognize and integrate RWH as a vital component of comprehensive water management strategies, particularly in areas vulnerable to climate variability and drought. A robust monitoring and data collection mechanisms is necessary to assess the effectiveness of RWH projects. By tracking performance, water quality, and sustainability, policymakers can identify successful practices and scale them effectively. Government policies and regulations also plays a vital role in promoting conjunctive use. Policies should encourage the development of infrastructure for rainwater harvesting and groundwater recharge, as well as the monitoring of groundwater levels to prevent over-extraction. Additionally, water pricing mechanisms and incentives for adopting efficient irrigation technologies can also help to encourage the farmers to use water resources more judiciously and sustainably.

SUMMARY

Water harvesting and supplemental irrigation are essential strategies for improving water availability and increasing agricultural productivity in rainfed areas. By capturing and storing rainwater and using it judiciously during critical crop growth stages, farmers can enhance their resilience to erratic rainfall and drought conditions. Roof water harvesting, conjunctive use of surface and groundwater is an option to minimize the utilization of groundwater in urban and rural areas. Ground water sharing by linking 3-4 bore wells and the water can be shared among the community including the farmers without bore wells to reduce the groundwater over-exploitation. Government policies and regulations also play an essential role in promoting conjunctive use. In summary, addressing these policy-related issues is essential for maximizing the potential of rainwater harvesting, ensuring water security, and promoting sustainable agricultural practices in rainfed areas. Policies should encourage the development of infrastructure for rainwater harvesting and groundwater recharge, as well as the monitoring of groundwater levels to prevent over-extraction. Additionally, water pricing mechanisms and incentives for adopting efficient irrigation technologies can help encourage farmers to use water resources more judiciously and sustainably.

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