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GROUND WATER MANAGEMENT AND ITS CONSERVATION: NEED OF THE HOURS IN RAINFED AREAS

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ABSTRACT

In rainfed agro-ecosystems, agricultural production is highly dependent on uncertain and uneven rainfall patterns, making groundwater conservation and management critically important. Irregular precipitation often results in seasonal water deficits, increasing dependence on groundwater resources for both irrigation and domestic purposes. Sustainable groundwater management in such regions requires efficient water-use strategies, enhancement of natural and artificial recharge processes, and minimization of water losses. Practices such as rainwater harvesting, artificial recharge structures, and integrated watershed management play a significant role in replenishing aquifers and stabilizing groundwater levels. In addition, the adoption of water-efficient irrigation technologies, including drip and sprinkler systems, can substantially reduce water demand while maintaining crop productivity. Uncontrolled groundwater extraction combined with inadequate recharge leads to declining water tables, deterioration of water quality, and heightened risks to food security. Community participation and capacity-building initiatives are essential for promoting responsible water-use practices and ensuring long-term sustainability. Encouraging local stakeholders to adopt water-saving measures can help prevent further groundwater depletion. Overall, groundwater conservation is vital for securing water availability in rainfed regions, and proactive, scientifically informed management is necessary to enhance resilience to climate variability and change.

***Keyword*:** Rainfed agriculture, Groundwater conservation, Rainwater harvesting, Integrated watershed management.

Introduction

India encompasses a wide range of ecosystems and climatic conditions, reflected in its diverse agro-ecological zones. Of the 21 recognized agro-ecological zones, at least 11 fall under dry semi-arid, hot arid, cold arid, dry sub-humid, and semi-arid climatic categories. These regions are inherently vulnerable to water scarcity and recurrent droughts. Rainfed agriculture accounts for nearly 66% of India's total agricultural area, making crop productivity highly dependent on the amount, temporal distribution, and efficient utilization of rainfall. Consequently, India's ability to achieve sustainable agricultural production is closely linked to effective water resource management, including conservation, reuse, and efficient allocation.

Irrigated agriculture has played a pivotal role in enhancing agronomic productivity across the country. Out of approximately 162 million hectares of cultivable land, about one-third is currently under irrigation. The expansion of irrigated area was particularly pronounced during the latter half of the twentieth century, increasing from 33.7 million hectares in 1975 to 41.8 million hectares in 1985, 50.1 million hectares in 1995, 54.8 million hectares in 1998, and 55.8 million hectares by 2003. Annually, India receives rainfall equivalent to more than 400 million hectare-meters of water. However, only about 150 million hectare-meters (37.5%) effectively contribute to soil moisture, while nearly 180 million hectare-meters (45%) are lost as surface runoff, and the remaining 17.5% is lost through other pathways, highlighting substantial inefficiencies in rainfall utilization (Bhaskar, 2002).

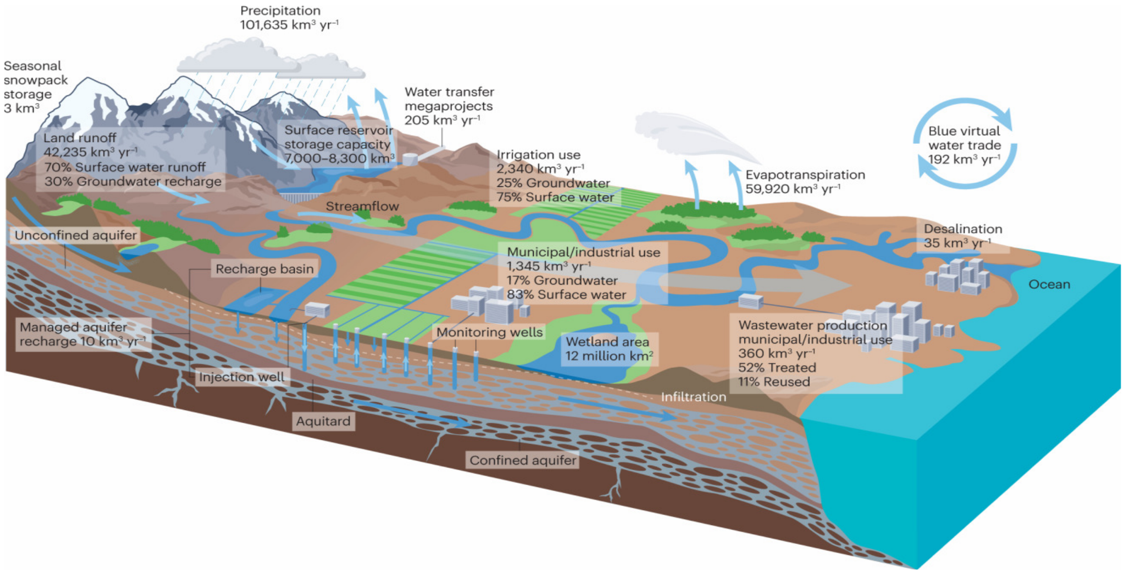

Fig. 1 : Global water resources and the role of groundwater in a resilient water future.
(Source: https://tse2.mm.bing.net/th/id/OIP.SUhWltTnITbff3y3uvPGAwAAAA?rs=1&pid=ImgDetMain)

Currently, two-thirds of livestock and 40% of humans reside in rainfed areas, which make up 55% of the nation's net sown area (NRAA 2012). These regions are prone to drought; almost half of them are categorized as "severe," meaning that droughts occur there almost constantly. According to the data that is currently available, 15 million hectares of rainfed cropland are located in the desert region, which receives less than 500 mm of annual rainfall; another 15 million hectares are located in the zone with 500–750 mm of annual rainfall; and 42 million hectares are located in the zone with 750–1100 mm of annual rainfall. Rainfed crops in India are among the least productive (less than 1 t ha^{-1}).

Rainfed agriculture makes about 60% of all farmed land, of which 48% is used for food crops and 68% for non-food crops. Regarding crop types, rainfed conditions are used for 45% of cereals, 66% of oilseeds, and 77% of pulses (Singh, 2014).

Table 1 : Rainfall received in different geographical regions of India

Rainfall (mm/yr−1)	Geographical Area (106 ha)	Rainwater Received (106 ha-m)
100–500	52.1	15.6
500–750	40.3	25.2
750–1000	65.9	57.6
1000–2500	106.4	205.9
> 2500	32.6	95.7
Total	**297.3**	**400**

(Source : Rattan Lal, 2008.)

Table 2 : Water resources of India

Parameter	Value	Units
Annual internal renewable water resources	1850	Km^3
Per capita internal water resources (2006)	1666	Km^3
Annual river flow from external sources	235	Km^3
Annual withdrawal of water		Km^3
• Volume	380	Km^3
• Per capita withdrawal (2006)	537	M^3
• Proportion of internal resources	20.54	%
• Proportion of total resources	18.23	%

(Source : Lal, 2008.)

Ground Water

According to the latest Groundwater Resource Assessment (2022), India receives an annual groundwater recharge of approximately 437.60 billion cubic meters (BCM). Of this, the annually extractable groundwater resource is estimated at 398.08 BCM, while the actual groundwater withdrawal is about 239.16 BCM, as indicated in Figure 2. This results in an average national stage of groundwater development of around 60.08%, with extraction levels above 70% categorized as critical. Notably, several groundwater blocks in states such as Punjab, Haryana, Delhi, and Rajasthan exhibit extraction rates exceeding 100%, reflecting acute groundwater overexploitation.

Furthermore, the Comptroller and Auditor General (CAG) of India, in its 2021 report, highlighted a steady increase in groundwater extraction from 58% in 2004 to 63% in 2017, surpassing natural recharge rates. Continued overexploitation at this pace poses a serious risk to national water security, with projections indicating that nearly 80% of India's drinking water sources could be threatened within the next two decades if corrective measures are not implemented (Vajiram & Ravi, 2023). India is the largest consumer of groundwater globally, accounting for more than one-quarter of total worldwide groundwater use. In 2023, the country extracted approximately 241.34 billion cubic meters (BCM) of groundwater annually. Groundwater forms the backbone of India's water security, supplying nearly 62% of the total irrigation demand. This high level of dependence underscores the critical role of groundwater resources in sustaining agricultural production and supporting national water requirements.

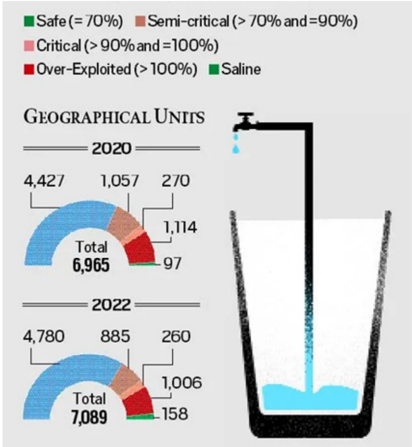

Fig. 2- Groundwater Extraction Stage
(**Source:**https://spao.shortpixel.ai/client/to_webp,q_lossy,ret_img,w_318,h_336/https://optimizeias.com/wp-content/uploads/2022/11/stage-of-groundwater-extraction.jpg)

Water is fundamental to all known forms of life on Earth. Of the approximately 1.4 billion cubic kilometers of water present on the planet, more than 97% exists as saline water in the oceans. Freshwater constitutes only about 3% of the total water resources, the majority of which is stored in inaccessible forms approximately 77.2% locked in the ice caps of Antarctica and Greenland, and about 22.2% occurring as fossil groundwater. As a result, only a very small fraction of freshwater is available at the surface and suitable for direct human use. The most readily accessible freshwater sources include rivers, streams, lakes, and reservoirs, which together account for merely about 0.60% of total freshwater. This fraction represents the renewable and sustainably usable freshwater resource critical for human consumption, agriculture, and ecosystem functioning Dr. S.N. Chatterjee (2008).

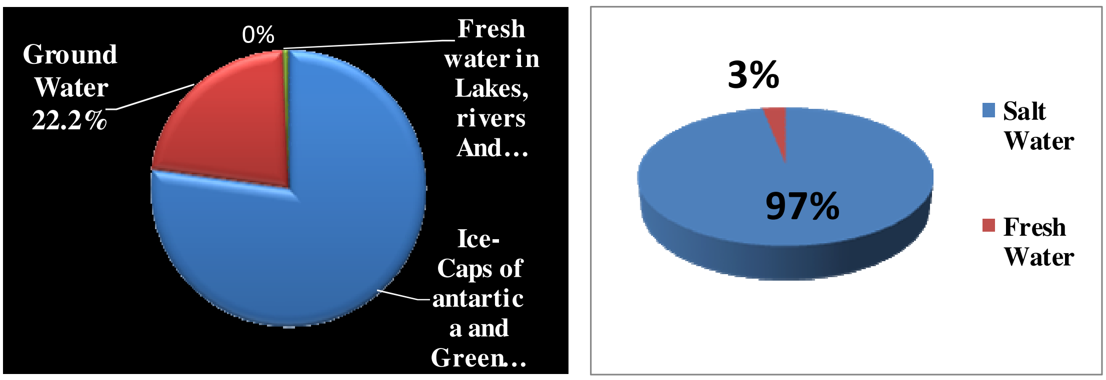

Fig. 3 : Global Distribution of Salt and Fresh Water
(**Source-2; Chatterjee, S. N. (2008)**)

During a rainfall event, water infiltrates the soil and moves through the unsaturated (vadose) zone, leading to an increase in soil moisture within the pore spaces. The water content in this zone subsequently decreases due to losses through evapotranspiration and downward percolation. Beneath the unsaturated zone lies the saturated zone, in which all pore spaces are completely filled with water and air is absent; this zone constitutes groundwater. The boundary separating the unsaturated and saturated zones is referred to as the water table and represents the upper surface of the groundwater system. This process illustrates the fundamental mechanism by which precipitation contributes to groundwater recharge.

As part of the subsurface component of the hydrologic cycle, rainfall infiltrates the land surface, percolates through the unsaturated zone, and enters the soil profile. Water loss from the soil zone primarily occurs through evapotranspiration, which includes evaporation from the soil surface and transpiration by plants. Immediately above the saturated zone, a partially saturated region known as the capillary fringe develops due to surface tension forces acting within fine soil pores, causing water to rise above the water table (U.S. Geological Survey Alley *et al.* 1999).

Table 3: Illustrative Values of Runoff Coefficients for Rural Areas.

Running Coefficient C Soil Texture			
Soil Texture			
Topography & Vegetation	**Open Sandy Loam**	**Clay and Silt Loam**	**Tight clay**
Woodland			
Flat 0-5% slope	**0.10**	**0.30**	**0.40**
Rolling5-10% slope	**0.25**	**0.35**	**0.50**
Hilly 10-30% slope	**0.30**	**0.50**	**0.60**
Pasture			
Flat	**0.10**	**0.30**	**0.40**
Rolling	**0.16**	**0.36**	**0.55**
Hilly	**0.22**	**0.42**	**0.60**
Cultivated			
Flat	**0.30**	**0.50**	**0.60**
Rolling	**0.40**	**0.60**	**0.70**
Hilly	**0.52**	**0.72**	**0.82**

(Source: U.S. Department of Agriculture,2019)

Depletion of ground water causes and resource

Groundwater depletion represents a serious threat to ecosystems and human well-being. Water constitutes a major component of both the Earth system and living organisms, underscoring its fundamental role in sustaining life. While surface water resources such as rivers, lakes, and seas are readily visible, they are not always suitable for direct human consumption and often require extensive treatment. In contrast, groundwater is generally of higher natural quality and easier to purify, making it a particularly valuable resource.

Groundwater is indispensable across the planet, supporting both human and animal survival, as physiological processes cannot function without adequate water. Beyond basic survival, water is essential for domestic needs, energy generation, industrial operations, and agricultural production. Due to the growing demand for clean and reliable water supplies, which often exceed what can be provided by precipitation and surface water alone, societies increasingly depend on groundwater resources. Consequently, unsustainable groundwater extraction threatens ecological balance, water security, and long-term sustainability.

Causes of Groundwater Depletion

Groundwater is replenished through natural processes that are integral to the hydrologic cycle. Solar energy drives the evaporation of surface water from oceans, rivers, lakes, and other water bodies into the atmosphere. This water vapor subsequently condenses and returns to the Earth as precipitation in the form of rain or snow. Upon reaching the land surface, a portion of this precipitation infiltrates the soil, percolates downward, and contributes to groundwater recharge, while the remaining water flows as surface runoff into rivers, lakes, and oceans. In addition, rainwater collected from rooftops and land surfaces can also infiltrate the subsurface and help replenish aquifers.

Groundwater depletion occurs due to several key factors, including:

- Continuous and unregulated pumping of groundwater from aquifers.
- Prolonged extraction rates that exceed the natural recharge capacity of aquifers.
- High groundwater demand for agricultural activities, particularly irrigation.
- Imbalances between groundwater and seawater pressures, often leading to saline intrusion in coastal aquifers.
- Absence of effective measures and management practices for rainwater harvesting and aquifer recharge.

There are several ways that the loss of productive soil from agricultural areas can lead to groundwater depletion.

1. A reduction in the ability to hold water
2. An increase in runoff and soil erosion
3. Increased Need for Watering
4. Disruption of the Natural Water Cycle

When used improperly or excessively, rivers and canals can actually exacerbate water depletion, especially groundwater depletion. This comprises the shows fig 3.1.

1. excessive irrigation extraction;
2. diminished natural groundwater replenishment;
3. rivers and streams drying up;
4. pollution and siltation; and
5. salinity and waterlogging.

Undulating land which means land with natural rises and dips, like hills and valleys can lead to groundwater depletion under certain conditions Shows Fig. 3.2;

1. **Increased Surface Runoff**: Rainwater swiftly flows downhill rather than soaking into the ground on sloping or uneven terrain.
2. **Soil Erosion**: Soil erosion is more likely to occur on undulating land, particularly when it rains a lot. The porous layer that retains water is removed when topsoil erodes, allowing water to seep into the earth.
3. **Inadequate Water Management**: It might be difficult to construct efficient water harvesting structures (such as check dams, contour trenches, etc.) on steep or undulating terrain.
4. **Less Vegetation in Steep Areas**: Because it is more difficult for roots to stay in place on steep slopes, there is typically less vegetation. Without vegetation, there would be more runoff and less water retained in the ground since it slows down water flow and enhances infiltration.
5. **Seasonal Water Accumulation**: Groundwater recharge becomes uneven, and upland residents frequently drill deeper wells to access water, hastening the depletion of groundwater.

Why need of water conservation

Water is a finite and highly valuable resource, and its prudent use is essential. In many parts of India, especially during periods of high temperature, a significant proportion of the population faces water scarcity, highlighting the urgent need for water conservation. Water conservation involves the careful management and efficient use of water resources to ensure adequate availability for present and future needs.At the household level, water can be conserved through simple yet effective practices. These include turning off taps while brushing teeth, using a bucket for bathing instead of water-intensive showers, and ensuring that taps are properly closed after use. Students and households alike can play an important role by adopting such responsible water-use habits.Collective action through small, everyday changes can lead to substantial water savings. By promoting conscious water use, society can help secure a sustainable water future and ensure equitable access to this essential resource for all (SPM-NIWAS, 2025).

According to estimates by the Central Public Health and Environmental Engineering Organisation (CPHEEO), nearly 70–80% of the water supplied for domestic purposes is ultimately discharged as wastewater. Urban centres across the country generate substantial volumes of wastewater, ranging from small towns to large metropolitan areas. However, the existing sewage treatment infrastructure is inadequate to handle this load. The installed sewage treatment capacity remains significantly lower than the volume of wastewater generated, resulting in a large treatment deficit, estimated at about 26,468 million litres per day (MLD) (CPCB, 2009).

An assessment of state-wise wastewater generation indicates that Gujarat, West Bengal, Maharashtra, Delhi, and Uttar Pradesh together contribute the majority share, accounting for approximately 63% of the total wastewater produced in the country. In addition to domestic wastewater challenges, India exhibits very low industrial water productivity (IWP), estimated at only 3.42. This level is roughly one-third of that observed in industrially advanced countries such as the Republic of Korea and Japan, highlighting significant inefficiencies in industrial water use and the urgent need for improved water management and recycling practices (Singh 2013; WWAP 2006). By 2050, when an estimated 48.2 BCM (132 billion litres per day) of wastewater may be generated, accounting for 4.5% of the total irrigation water demand, this gap is predicted to widen even more (Bhardwaj 2005 & Anil Kumar Singh, 2014)

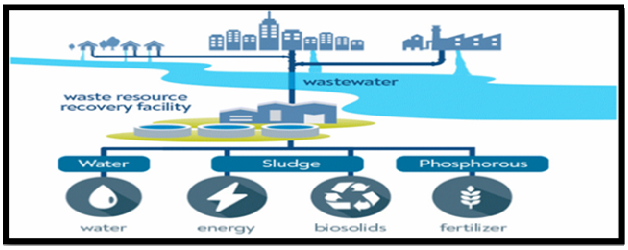

Fig. 4 : Stages and applications of wastewater treatment. (Source-Jaweria Shamshad *et al.,* 2024.)

Conventional wastewater treatment technologies are capital-intensive and require sophisticated operation and maintenance systems. According to estimates by the Central Pollution Control Board (CPCB, 2005), the installation of treatment facilities to manage all domestic wastewater would require an investment of approximately Rs. 7,560 crore. This estimated cost is nearly ten times higher than the financial allocation proposed by the Government of India for this purpose, highlighting the economic constraints associated with large-scale adoption of conventional wastewater treatment systems (Kumar, 2003). Sludge management, treatment, and removal have been identified as the most neglected operational components in India's sewage treatment plants (STPs). Recently, constructed wetlands have been acknowledged as a successful wastewater treatment method for use in agriculture (Kaur *et al.* 2011). Compared to traditional treatment systems, constructed wetlands are simpler to run, need less energy and material, have no problems with sludge disposal, and can be maintained by employees without specialized training. These systems are also less expensive to construct, maintain, and operate because they are driven by the sun, wind, soil, bacteria, plants, and animals. They should get more recognition.

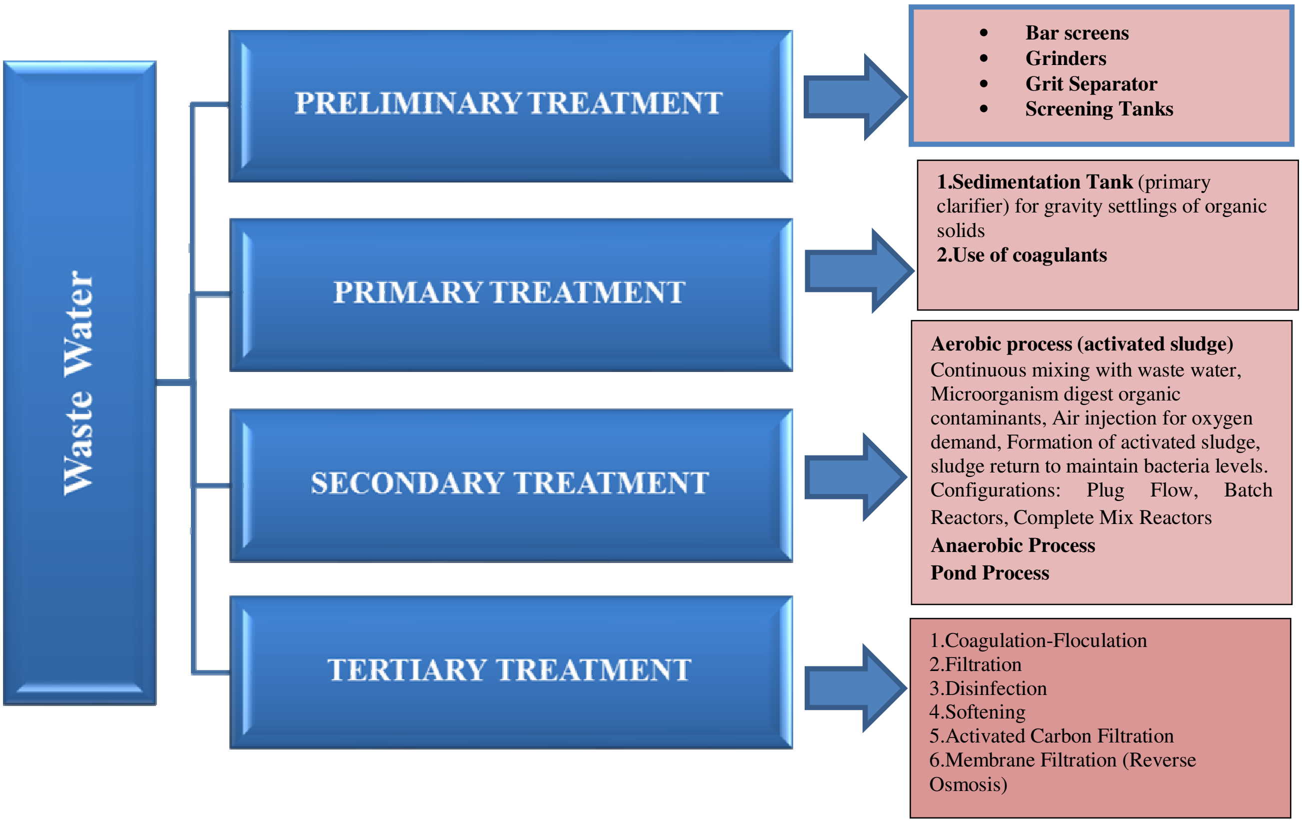

Fig. 5: Overview of wastewater treatment processes.

Conclusion

Groundwater management and conservation have become increasingly important in rainfed regions, where water availability is largely governed by erratic and uncertain rainfall patterns. Excessive groundwater withdrawal coupled with inadequate natural recharge has led to rapid aquifer depletion, posing serious risks to water security and agricultural sustainability. To safeguard groundwater resources, the adoption of sustainable interventions such as rainwater harvesting, artificial recharge structures, and water-efficient irrigation technologies is essential. Equally important is the active participation of local communities and the dissemination of knowledge related to water conservation practices, which can significantly enhance the long-term viability of groundwater resources. In rainfed areas, groundwater conservation is vital not only for maintaining agricultural productivity but also for sustaining rural livelihoods that depend heavily on these critical water reserves. Addressing water scarcity in these regions requires timely, coordinated, and science-based actions to ensure resilience and long-term sustainability.

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