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SDG 15: Life on Land—Challenges in Sustainable Utilization and Conservation of Water Resources

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Abstract

Water is one of the most essential natural resources for sustaining life, ensuring agricultural productivity, and fostering socio-economic development. Its effective management and utilization are critical to reducing poverty, maintaining a stable climate, and promoting sustainable economic growth. However, increasing pressures from population growth, urbanization, and industrialization have significantly intensified the demand for water, creating numerous challenges. These include a decline in per capita water availability, falling groundwater levels in several regions, and saltwater intrusion into coastal aquifers. Additionally, rising pollution levels from agricultural runoff, industrial discharge, and untreated sewage have led to the deterioration of surface and groundwater quality, threatening both human health and ecosystems. Climate change has further compounded these challenges by altering rainfall patterns, increasing the frequency of extreme weather events, and disrupting the availability and distribution of water resources. Such changes not only impact water supply but also exacerbate vulnerabilities in agricultural systems, energy production, and public health. Addressing these multifaceted issues requires a comprehensive approach to water resource development, conservation, and management. This study critically explores the key challenges associated with water resource management and highlights the need for sustainable practices. It emphasizes adopting integrated water resource management (IWRM) strategies, promoting efficient water use technologies, and strengthening policies to address water scarcity and pollution. Furthermore, community participation and stakeholder engagement are essential to achieving long-term sustainability. By identifying gaps and proposing actionable solutions, this study contributes to the discourse on water resource management, aiming to ensure the availability and sustainability of water for future generations.

Keywords: Water resources, effective water management, sustainable development, groundwater depletion, saltwater intrusion, water pollution, climate change impacts, population growth, urbanization, industrialization, integrated water resource management, agricultural productivity, water scarcity, conservation strategies, sustainable water use

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INTRODUCTION

Natural resources are materials provided by the Earth that living organisms utilize for their needs and for creating other products. Resources such as land, air, water, and minerals are valuable raw materials derived from nature, which humans cannot artificially produce. Among these, water is an invaluable resource that is crucial for the survival of living beings, food production, and the economic development of nations. Its uniqueness and irreplaceability make it a precious gift from nature. The renewal and sustenance of life on Earth depend heavily on the availability of water. Seasonal

changes occur because of the global circulation of water, with three-quarters of the planet covered by it. This water is in constant motion across various environmental components, a process that is illustrated by the hydrological cycle. Known as a universal solvent, water has a unique ability to dissolve numerous substances, further emphasizing its indispensable role in life [1–3].

Water Distribution on Earth

Approximately 71% of Earth's surface is covered by water, with oceans holding approximately 96.5% of the total water. Water exists in various forms, including vapor in the atmosphere, ice in glaciers, and moisture in soil, aquifers, rivers, and lakes. Despite the abundance of water, most is saline and unsuitable for direct consumption. Only 2.5% of the Earth's water is freshwater, which is essential for sustaining life, and the majority of this freshwater is locked in ice caps or underground. Surface water constitutes just 1.2% of the total freshwater, and approximately 69% of this surface water is frozen as ground ice, with the remainder found in lakes, rivers, swamps, the atmosphere, and living organisms.

India's Natural Water Resources

India has diverse water resources, including oceans, glaciers, rivers, lakes, and groundwater. However, ocean water is saline, and glacier water is in solid form, making it unsuitable for immediate use. To address this, humans have built dams and reservoirs of varying capacities. Rainfall, an essential component of the hydrological cycle, is the primary source of water for these resources. India receives an average annual rainfall of approximately 1,170 mm, translating to approximately 4,000 cubic kilometers of rain annually [4].

Water Availability in India

India's annual average rainfall is approximately 3,880 billion cubic meters (BCM) with snow-covered mountains and an extensive river network. However, uneven rainfall distribution and high evaporation rates reduced the net available water resources to approximately 1,123 BCM. This included contributions from precipitation, surface water, and replenishable groundwater. Of these, 690 BCM is surface water, and 436 BCM comes from groundwater.

According to recent estimates, India's annual groundwater recharge is 437.60 BCM, while the extractable groundwater resource is 398.08 BCM after accounting for natural discharge. In 2022, India extracted 239.16 BCM of groundwater, making it the largest global user of groundwater (Figure 1).

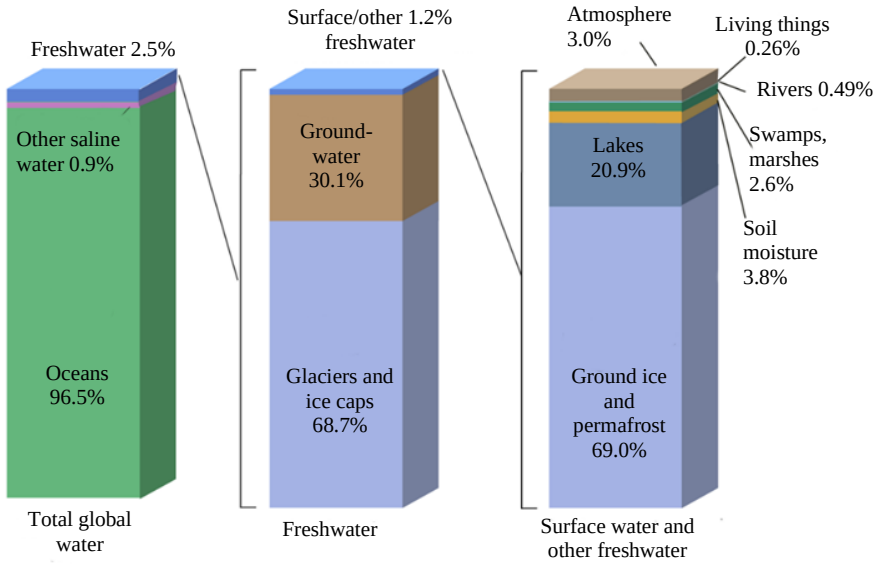

Figure 1. Graph of total water fresh and other water surface.
Source: Shiklomanov I. World freshwater resources. In: Gleick PH, editor. Water in Crisis: A Guide to the World's Freshwater Resources. New York: Oxford University Press; 1993. p. 13–24.

Challenges in Water Resource Management

Over the past few decades, rapid population growth, shifts in agricultural practices, changes in food consumption patterns, urbanization, and land-use alterations have placed immense pressure on India's water resources. Despite receiving significant rainfall during the monsoon season, only a small portion contributes to water reserves owing to inadequate storage infrastructure. Rivers in India experience 80% of their annual flow during the four-month southwest monsoon season.

According to international standards, India's per capita water availability was approximately 1,545 cubic meters in 2011. This is projected to decrease to 1,340 cubic meters by 2025 and 1,140 cubic meters by 2050 due to increasing population and urbanization. Moreover, the uneven spatial distribution of water resources exacerbates this challenge, leaving areas with higher population densities struggling with lower water availability (Figure 2) [5].

Pressure on Groundwater

The groundwater resources in India are vital for ensuring agricultural productivity and drinking water security. Groundwater contributes approximately 62% of the irrigation, 85% of the rural water supply, and 50% of the urban water supply. Although surface water is generally easier to access, the widespread availability of groundwater has led to its extensive exploitation for agricultural and drinking purposes. Approximately 89% of the groundwater is utilized for irrigation, while the remaining 11% is allocated for industrial and domestic use. Groundwater serves as the primary source of drinking water, supplying more than 80% of the domestic water needs in both urban and rural areas (Table 1).

Table 1. Average annual per capita availability trend of water in India.

S.N.	Parameter	Unit (billion cubic meters/year)
1	Annual water availability	1,869
2	Usable water	1,126
3	Surface water	690
4	Groundwater	436

Source: Central Water Commission, 2015.

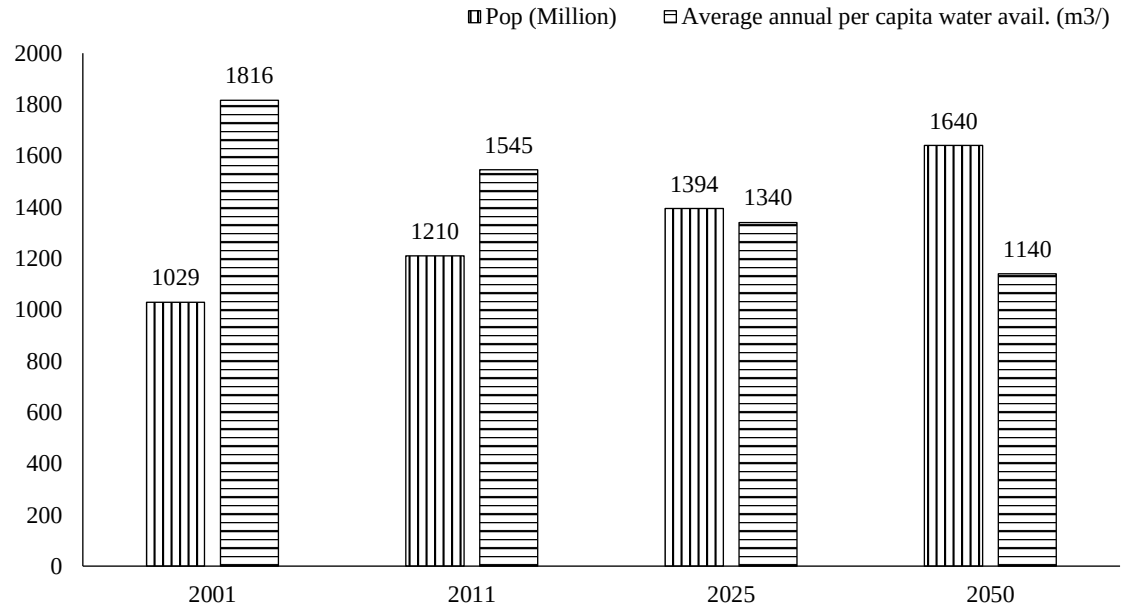

Figure 2. Average annual per capita water available.
Source: PIB, 2020.

Groundwater resources are classified as either critical or overexploited in several states. According to the Central Ground Water Board (CGWB), states such as Punjab, Haryana, Rajasthan, and Delhi have groundwater extraction rates exceeding 100%, indicating overuse where annual consumption surpasses annual replenishment. Similarly, states such as Himachal Pradesh, Tamil Nadu, and Uttar Pradesh, along with the Union Territory of Puducherry, have reported groundwater development rates of 70% or more. In contrast, groundwater utilization in other states remained below 70%. Over time, the demand for and extraction of groundwater has increased significantly in various regions.

PROJECTED WATER DEMAND IN INDIA

India's water supply has been severely impacted by the significant rural-to-urban migration brought about by the country's changing demographics over the past few decades. The need for water in other sectors of the economy is growing tremendously, along with the urban population. This will have several effects on the nation's overall water security, consumption trends, and management of water resources [6].

The five main categories of India's largest water resource users are: (i) irrigation, (ii) residential, (iii) industrial, (iv) energy, and (v) others (including evaporation losses and environmental requirements). The largest use of water resources among these is irrigation for agricultural purposes.

Water availability, usage trends, and overall resource management are affected by shifts in water demand across different industries. Approximately 78% of all water withdrawals in 2010 came from agriculture, which was the largest user of water. Population growth, rising food demand, and the need to boost agricultural production are expected to increase the water requirements of the agricultural sector. However, other sectors, including domestic use, industrial expansion, energy production, and various activities associated with urbanization will also increase water demand. Consequently, the agricultural sector's share of total water consumption is projected to decrease to 68.4% by 2050. Efficient water use can be promoted through the expansion of advanced irrigation systems, the adoption of less water-intensive crops, and adjustments in cropping patterns (Tables 2 and 3).

Table 2. State-wise groundwater extraction.

State	Category	Stage of GW extraction (%)	% of overexploited and critical blocks
Punjab	Overexploited	166%	80%
Rajasthan		140%	47%
Haryana		137%	63%
Delhi		120%	71%
Himachal Pradesh	Semi-critical	86%	50%
Tamil Nadu		81%	46%
Puducherry		74%	25%
Uttara Pradesh		70%	17%
Karnataka	Safe	70%	30%
Telangana		66%	23%
Gujarat		64%	12%
N.E. State		<10%	0%

Table 3. Projected water demand in India (by different use) in billion cubic meters.

Demand sector	2010	% Share in demand	2050	% Share in demand	% increase (2010–2050)
Irrigation	557	78.4	807	68.4	44.9
Drinking water	43	6.0	111	9.4	158.1
Industry	37	5.2	81	6.9	118.9
Energy	19	2.7	70	5.9	288.9
Other	54	7.7	111	9.4	105.6
Total	710	100.0	1180	100.0	50.5

Source: Basin Planning Directorate, CWC, XI Plan Document.

Growing Water Concerns in Urban Areas

India is the world's largest consumer of groundwater, with many cities heavily dependent on it for their daily needs. Rapid urbanization, population growth, and poor water resource management have led to a sharp decline in groundwater levels across the country. In many cities, excessive groundwater extraction has outpaced both natural and artificial recharge, causing alarming decreases in the water table. This has resulted in the depletion of aquifers, saltwater intrusion, and land subsidence in certain areas.

Effectively managing the growing demand for groundwater while safeguarding water resources and ensuring sustainable management practices remains a critical challenge for the nation, and various strategies have to be adopted, including water conservation measures, efficient water use practices, reuse and recycling of water, and integrated water resource management to meet the essential future water demand of different sectors in India [7–9]. Many regions in India are facing significant challenges in recharging their groundwater potential for the following reasons.

Excessive Extraction of Groundwater

One of the key reasons for the depletion of the groundwater level in India is excessive pumping for different purposes, such as irrigation, domestic water supply, and industrial use. The excessive extraction of groundwater is a global issue that leads to water scarcity, environmental degradation, and land subsidence in some areas.

This alarming problem can be prevented by the following measures:

Regulatory Measures

- Imposing groundwater extraction limits.
- Monitoring groundwater levels using the latest technologies will issue alerts when the groundwater falls below the critical level.
- Allocating water rights through a grant-based system ensures an equitable distribution of water and prevents overexploitation of groundwater [10].

Community Engagement and Awareness

- Raising awareness and educating the public through campaigns and educational programs on the importance of groundwater conservation.
- Encourage individuals to adopt water-saving practices, such as reducing water usage during showers, minimizing water waste in household chores, and fixing leaks in pipes and tanks.
- Empowering local communities by involving them in decision-making processes related to groundwater management and conservation.

Urbanization and Land Use Changes

Rapid urbanization contributes to the growth of impervious surfaces such as concrete and asphalt, which limits the area available for rainwater to infiltrate the ground. As cities expand, natural recharge zones, such as open green spaces and forests, are replaced by built-up infrastructure, further restricting groundwater replenishment. In India, where rainfall is often irregular, adequate percolation into the soil is prevented, hindering the recharge of aquifers [11].

Urbanization also drives population growth, which increases water demand for domestic needs such as drinking, cooking, and sanitation. Industrial sectors in urban areas consume large amounts of water for production, cooling, and cleaning. Furthermore, urban sprawl often encroaches on agricultural land, diminishing the water available for irrigation.

The expansion of urban areas increases the number of impervious surfaces, such as roads and buildings, which reduces the potential for rainwater to percolate into the ground, thus limiting groundwater recharge.

The reduction in infiltration rate increases surface runoff, thus causing erosion, flooding, and water pollution. Pollutants such as grease, oil, chemicals, sewage water, and industrial effluents are also carried by urban runoff, which can contaminate water bodies, thus deteriorating water quality.

To address these challenges, it is essential to adopt the following sustainable water management practices.

- Designing water-conscious cities that prioritize water conservation, integrate green infrastructure, and include efficient drainage systems and sustainable transportation networks.
- Encouraging water-efficient technologies, such as installing low-flow fixtures in households and industries and implementing rainwater harvesting systems.
- Recycling and treating wastewater for reuse in agriculture, industrial processes, and non-potable purposes.
- Preventing the contamination of water bodies, including surface reservoirs and groundwater aquifers, to preserve water quality.
- Adopting an integrated approach to water management, considering all water sources and their uses within a given area.
- Raising awareness among stakeholders of water resources regarding the necessity of water conservation and responsible water use.

Lack of Rainwater (Roof Water) Harvesting Structures

Roof water harvesting is a simple and effective technique for gathering and storing rainwater for subsequent use. The lack of this practice can have several negative effects on water management and conservation. Many cities in India have yet to revise their building bylaws to mandate the installation of rainwater harvesting systems. Such systems would capture and store rainwater during the monsoon, helping to recharge groundwater and alleviate water demand during dry spells; if rainwater is not harvested properly, it will lead to greater reliance on traditional water sources such as surface water and groundwater. This increased demand will lead to the overexploitation of these sources, causing depletion and degradation.

The lack of rainwater harvesting can intensify water scarcity during dry periods in erratic rainfall regions. Increased flood risk occurs during heavy rainfall, as excess water can devastate drainage systems, leading to flooding and erosion. When rainwater is not harvested, it can carry pollutants such as chemicals, dust, and debris into water bodies, thus deteriorating the water quality.

Rainwater can be effectively harnessed by implementing the following solutions to reduce water scarcity and improve the overall water management and conservation of water resources.

- Mandating rainwater harvesting systems in new buildings and retrofitting existing ones.
- Enforcing strict regulations to ensure proper installation and maintenance of these systems.
- Offering subsidies for installing rainwater harvesting systems can encourage people to adopt this practice.
- Providing financial assistance for the repair and maintenance of the rainwater harvesting systems.
- Encouraging community-based organizations to promote rainwater harvesting.
- Organizing collective rainwater harvesting projects in residential areas and schools.
- Developing innovative and affordable rainwater harvesting technologies.
- Promoting the use of water-efficient fixtures and appliances.

Encroachment on Water Bodies

Natural water bodies such as ponds, lakes, and wetlands play a vital role in recharging groundwater. However, they are often encroached upon or repurposed for other uses, thereby diminishing their ability to replenish aquifers. According to the first-ever water body census by the Ministry of Jal Shakti, nearly 1,800 water bodies in urban areas have been encroached [6]. In Delhi alone, 216 of 893 water bodies (24.19%) were encroached, highlighting the city's inadequate efforts in water conservation.

Pollution and Contamination

Groundwater contamination from untreated sewage, industrial waste, and agricultural runoff pose significant challenges. This pollution renders groundwater unsuitable for use and hampers its recharging potential. Reports suggest that approximately 70% of surface water in India is unsafe for human consumption. Of the nearly 40 million liters of effluent entering rivers and water bodies daily, only a fraction undergoes proper treatment [7].

Inefficient Water Management

Leakages and losses in urban water supply systems result in a significant waste of treated water, reducing the amount available for recharge. Research by Mattoo (2019) indicates that 40–50% of potable water in India is wasted during distribution owing to leaking pipelines and water theft [8].

Technological Solutions

- Promoting efficient irrigation techniques by adopting efficient water loss-minimizing irrigation systems, such as drip irrigation and sprinkler systems.
- Developing innovative water-saving technologies by investing in research and development to reduce water consumption in various sectors.
- Rainwater harvesting systems should be installed to collect and store rainwater for later use and recharge groundwater aquifers.
- Reusing treated wastewater for irrigation and other non-potable purposes to conserve freshwater resources.

Inadequate Policy and Regulation

- Many cities lack comprehensive policies and regulations to promote groundwater recharge effectively. The absence of incentives for sustainable water use and penalties for non-compliance hinders progress in water conservation efforts.
- To overcome these challenges, cities must implement integrated water management strategies, including rainwater harvesting, protecting water bodies, ensuring efficient water distribution, and enforcing strict regulations to prevent over-extraction and pollution. Public awareness campaigns and community participation are equally important for fostering a sense of responsibility and commitment toward groundwater conservation and recharge.
- Develop comprehensive water management plans by integrating groundwater management with overall water management, considering both groundwater and surface water resources.
- Prioritize groundwater recharge by implementing measures to recharge groundwater aquifers through contour bunding, check dams, percolation ponds, and afforestation.
- Providing financial incentives to farmers through subsidies to promote water-saving technologies and practices.

CONCLUSION

Water is an important natural asset that must be used judiciously to promote the development of all sectors. However, the long-term unsustainable utilization and mismanagement of water resources can hamper the development process to a larger extent. Warning signs in various parts of the country must be addressed to ensure the sustainable growth of the nation. Special attention should be paid to water-intensive crops and industries that consume significant amounts of water. Institutional/regulatory measures and rules must be imposed for the effective use of water resources that will have to weigh the benefits and costs of these activities in terms of water use, especially with regard to the extraction of groundwater. Necessary steps should also be taken to reduce and control water pollution and rehabilitate irrigation tanks and water storage ponds. Above all, each individual should be conscious of the availability and proper utilization of this precious resource. Thus, prudent management of water resources is a pivotal element for the sustainable growth and development of the nation.

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