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Research Paper

Water Resource: Science And Management

Shruthi Shetty[1], Bharathi Prakash[2*]
Research Scholar, Department of Bio Sciences, Mangalore University, and
Head/Asst Professor, Department of Microbiology, University College
**Corresponding author*
Orcid id: 0000-0002-4757-3821

Abstract: *Among the natural resources, water is an important resource from a biological point of view. In fact, the availability of water on Earth makes it possible for living beings to live and grow. Neither plants nor animals can give birth, grow and live on any planet. The existence of living things on Earth is made possible because of the availability of water, which is only on Earth rather than on any other planet. Among the natural resources, water plays an important role from all perspectives- environment, economic, human livelihood and, especially, land use in agriculture. Sustaining water resources has become a challenge in development. Hence, care must be taken in the utilisation, distribution, and sustainability of water resources. Environmental and geographic sciences, along with water resource management, must conduct a detailed analysis of the factors influencing water conservation for sustainable development. Against this backdrop, in this paper an attempt is made to analyse the present status of water resources - their availability and utilisation- and to identify factors that have to be focused on for their sustainability.*

Key Words: *Water; Environment; Sustainable development. Drinking water; Rainfall; Groundwater Level*

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I. Introduction

The science of water resources is primarily the scope of hydrology, the branch of knowledge that studies the distribution, movement, and quality of water on Earth. Such studies mainly focus on managing surface water and groundwater (aquifers) for human and ecological requirements. It also analyses the sustainable use of less than 1.0 per cent of accessible freshwater and examines strategies to combat scarcity through watershed management, natural hazards (floods, droughts), and improved water quality (Agnihotri G, Gouda KC, Das S, 2021).

Water is often seen as the simplest thing in nature. But it's not so, as it has several scientific characteristics that make us identify different types of it. Pure water is typically colourless, odourless, and tasteless. But it's not simple or plain, and it is vital for all living things on Earth. Only if there is water is there life, and where water is scarce, life must struggle. It is interesting to learn about dozens of water properties (Agnihotri G, Gouda KC, Das S, 2021).

Water is everywhere, from huge oceans to invisible water molecules making up water vapour in the air. Of course, we can see and feel the physical properties of water, but there are also many chemical, electrical, and atomic-scale properties of water that matter for all living and non-living things on Earth. The most obvious fact about water is that it is wet and interacts with surfaces, at least in liquid state. But many other facts make water the substance all life on Earth depends on. Water dissolves more substances than any other liquid, and because of that, it is known as the "Universal Solvent". This means that wherever water goes, whether through the ground or through our bodies, it carries valuable chemicals, minerals, and nutrients (Alves LM et al., 2021).

Pure water has a neutral pH value of 7, which is neither acidic (less than 7) nor basic (greater than 7). The water molecule is the most cohesive (sticky) among the non-metallic liquids; i.e., water molecules stick to

each other. Moreover, water molecules are also adhesive and because of that they stick to other surfaces. Both cohesion and adhesion make water molecules very sticky (Alves LM et al., 2021, Annual Report 2023-24).

Pure water, which is usually not found in the natural environment, does not produce electricity**.** Water becomes a conductor of electricity once it dissolves substances. Water has a high heat index, which means that it absorbs lot of heat before it begins to get hot. Because of this property, water is valuable to industries and in vehicle radiator as a coolant. Water's high heat index also helps regulate how quickly air temperature changes, which is why seasonal temperature shifts are gradual rather than sudden, especially near the oceans (Alves LM et al., 2021, Annual Report 2023-24).

Water has a very high surface tension. Water is sticky and elastic and tends to clump together in drops rather than spread out in a thin film, like rubbing alcohol. Surface tension drives capillary action, which allows water (and its dissolved substances) to move through plant roots and the tiny blood vessels in our bodies. Air pressure affects water's boiling point. The higher the altitude, the lower the air pressure, and the lower the boiling point of water. At sea level, water boils at 212°F (100°C), while at 5,000 feet, water boils at 202.9°F (94.9 °C) (Annual Report 2023-24).

With this backdrop, water being an important and essential resource, its utilisation really matters. Existing status of water resources and their utilisation patterns has to be studied to devise policy and methods of preserving it for sustainable development

II. Objectives

The main purpose of this paper is to discuss the science and the management of water resources on Earth in general and in India specifically. The specific objectives of the paper are:

1. To review the importance of water resources in maintaining environmental balance.
2. To examine the status of water resources, i.e. its availability and utilisation
3. To identify the need to preserve water resources for sustainable living

III. Methodology

The paper is descriptive and analytical. The status of Drinking water, groundwater level and rainfall trends has been analysed. Analysis of secondary data collected from authentic sources attempted to understand the changes and the present status of water resources. Rainfall data for about 124 years, seasonal and annual, have been used to analyse changing trends through percentage changes over the years. A literature review also helped achieve the above objectives.

Importance of Water Resources

Water is an essential compound on Earth that enables living things to live and supports non-living things that support life. Although research is ongoing to identify water on other planets, Earth is currently the only planet with water that supports life. Researchers have studied several dimensions of this resource; however, as dynamics change, sustaining water becomes increasingly important. Therefore, to monitor such an important natural resource, it is necessary to analyse its status frequently (Canter L. and Swor T., 2011, CWC., 2004).

Status of Drinking Water in India

In India, while access to improved sources of drinking water is high, with around 96% of households having access, a significant gap exists between urban and rural areas for other water sources. In 2020-21, 96.0 per cent of households had access to an improved source, but only 36.6 per cent had piped water, with a large rural-urban divide in access to piped water. In rural areas, hand pumps and tube wells are the most common sources, with 39.7 percent of households relying on them (Falkenmark, M et al., 1989)

Source of Drinking Water

Several sources of drinking water exist; this varies from region to region. About 36.6 percent of Indian households had piped water in 2020-21, though this varies significantly by location. Round 61.4 percent of urban households had piped water. In rural areas, only about 25.0 per cent of rural households have piped water. Hand pumps and tube wells are a primary source for many, especially in rural areas. About 39.7 percent of Indian households relied on them in 2020-21, with this being the most common source in rural areas. Around 7.3 percent of urban households used public taps as their source. This was more common in urban areas, where 9.8 per cent of households relied on it in 2020-21 (Ali H et al., 2021).

Data on access to drinking water in India comes from the National Sample Survey, which, in various rounds, has asked a large representative sample of Indian households what their principal source of drinking water is. The most recent such data comes from the 79th round of the survey, conducted in 2022-23, where over a million people across all states were surveyed (Ali H et al., 2021).

Hand pumps or tube wells are the single largest source of drinking water for rural Indians, while piped water is the biggest source for urban Indians. Bottled water has become a key source of drinking water, now serving almost 15.0 percent of urban households. However, drinking-water sources vary by state. Hand pumps or tube wells, meanwhile, serve 95.0 percent of rural Uttar Pradesh households, over 85.0 percent of rural Bihar households and 75.0 percent of West Bengal's rural households (Jain SK et al., 2007).

Bottled water (including home-delivered cans of water) has become an important source of drinking water in the southern states; in Andhra Pradesh, Karnataka, and Telangana in particular, over a quarter of households get their drinking water primarily from bottled water. In Kerala, however, household wells are the most important source of drinking water in both rural and urban areas (Jain SK et al., 2007).

Progress in Tap Water

While overall progress has been made on drinking water, tap water access has expanded only slowly in urban areas. Access to piped water is expanding in rural areas but tap water access still has a long way to go to become widespread. NSS survey data finds that 40.0 percent of rural households used piped water as their primary source of drinking water as of 2023.

Ground-up survey data such as that used above can often show who truly uses it as an asset or amenity. Such primary data may reveal patterns of use that top-down administrative datasets, often generated as by-products of government schemes and programmes, do not adequately capture. Consequently, ground-based surveys can complement administrative records by providing a more accurate understanding of actual access, usage, and dependence on resources at the local level. Administrative data from a scheme to provide tap water connections to every rural household report 2that over 60% of rural households had tap water connections by mid-2023. However, gaps between this administrative data and household survey data indicate that providing tap water connections may not directly translate into households getting their drinking water primarily from tap water. The NSS data shows that just 30% of rural households had tap in their own homes or yards as their primary source of drinking water (Burlig F et al., 2026).

Improved access to Drinking Water

The definition of access to water has expanded over the years to cover at least basic aspects of water quality. The World Bank defines people with access to "basic drinking water services" as people using safely managed water services as well as those using basic water services, which is drinking water from an improved source (piped water, boreholes or tube wells, protected dug wells, protected springs, and packaged or delivered water) provided the collection time is not more than 30 minutes for a round trip (Nakibuule B et al., 2026).

At the beginning of the 2000s, fewer than eight in ten Indians had access to basic drinking water, lower than in neighbouring Sri Lanka and below the world average. Over the last two decades, India has made steady progress. Nearly 95.0 per cent of Indian households now have access to basic drinking water, a rate of progress that has surpassed the world's average. Access to basic drinking water is better in urban than in rural areas in India (Nakibuule B et al., 2026).

Challenges to Manage

Water resources must be managed to sustain and there are several changes to manage it. Among them, three important ones are;

Groundwater depletion: India is the world's largest user of groundwater, and two-thirds of its districts are affected by extreme water depletion.

Water quality: Pollution from industrial and domestic waste is a major issue, with some of India's major rivers being highly polluted.

Water scarcity: India faces challenges from declining per capita water availability due to population growth.

Access to clean drinking water is one of the most important conditions for human health. Most Indians now have access to clean drinking water, but progress on tap water has been slower (Dangar S et al., 2021).

Groundwater Levels in India

India doesn't have one continuous, standardised "national groundwater level" series. In the 1970s, monitoring networks and methodology evolved to measure groundwater levels. But three separate lines of evidence (CGWB well-based assessments, regional academic studies, and NASA satellite gravity data) all point in the same direction: a mostly declining national picture, with sharp regional contrasts (Joshi SK et al., 2021).

National assessment data (Central Ground Water Board)

Central Ground Water Board (CGWB) and state groundwater departments have run joint national assessments periodically since 1980. However, the assessment methodology and classification criteria were not initially uniform across all regions. A more standardised framework for categorising groundwater assessment units was progressively established and refined in the subsequent decades, particularly after 2000. The key metric is the **"**Stage of Extraction**",** expressed as extraction as a percent of annually extractable resource, and the share of India's 7,000 assessment units (blocks/taluks) falling into Safe/Semi-critical/Critical/Over-exploited categories are given in **table-1** (Mechlem K et al., 2012)**.**

In 1974, India began regional well monitoring for the first time. In 1980, the first groundwater assessment was undertaken. In 2004, the percentage of units categorised as "safe" was 73.0 per cent, and the proportion of "over-exploited" units accounted for 14.0 per cent to 17.0 per cent of the total assessment units during 2004–2020. "Safe" units stood at 73.0 percent in 2009, before declining to 64.0 percent in 2020. "Semi-critical" units rose from 9.0 per cent in 2009 to 15.0 per cent in 2020. In 2022, 4,780 units (67%) were "Safe," 885 (12%) "Semi-critical," and 158 (2%) "Saline". In 2023, 698 units (10.65%) were semi-critical and 4,793 (73.14%) were safe; extraction rose marginally from 239.16 to 241.34 bcm, while the overall stage of extraction fell slightly from 60.08 percent to 59.26 percent, against an extractable resource of 407.21 bcm (Mechlem K et al., 2012)

Table-1: Share of India's 7,000 assessment units falling into different categories

Year	Ground water assessment Units (%)				
	Safe	Semi-critical	Critical	Over exploited	Stage of Extraction
2004	73.0	9.0	3.0-5.0	14.0-17.0	-
2009	73.0	9.0	3.0-5.0	14.0-17.0	-
2020	64.0	15.0	3.0-5.0	17.0	61.6
2022	67.0	12.0	3.0	14.0	59.6
2023	73.1	10.7	3	11	59.3

Source: CGWB, reports of various years

In the last 4-5 decades, India allowed largely unrestricted borewell drilling and supported electricity subsidies for agricultural pumping to cope with rainfall scarcity, and despite a slight rise in rainfall over the past four decades, groundwater levels have kept falling because consumption far exceeds recharge, worsened by construction paving over natural recharge areas (Gupta B and Rowan JS et al., 2025).

Trend of Rainfall in India

Rainfall in India over the last five years (2020-2024) has been characterised by high variability and extreme events, with the monsoon season (June-September) contributing over 75.0 per cent of the annual total. Recent trends show an average annual rainfall around 118 cm, with significant spatial variation across regions. In India in 2024, rainfall showed high spatial variability, with active monsoon periods. In 2023**,** rainfall was below-average monsoon in many parts, influenced by El Niño conditions, though with intense short-duration rainfall events. In 2022, rainfall was above-normal, characterised by heavy and sustained rainfall events in Central India. In 2021**,** rainfall was near-normal, with significant fluctuations in monthly distribution. In 2020, rainfall was above normal, marked by a wet monsoon season (Samantray P and Gouda KC, 2024).

The main trends in rainfall are extreme variability, regional shifts, and Monsoon dependence**. O**verall rainfall volume hasn't shifted drastically; it is becoming more extreme, turning the monsoon from a beneficial to a hazardous phenomenon in certain areas. Regional shifts are evidenced by the fact that **r**ainfall is becoming more intense in arid areas like North-Western India while decreasing in traditionally wetter areas, such as the North-East, & more than 75.0 percent of the annual rainfall is received in the four rainy months of June to September, indicating more dependence on Monsoon (Samantray P and Gouda KC.,2024).

Rainy seasons in India as classified by Indian Meteorological Department (IMD) is given in **table-2**:

Table -2: IMD Classification of Rainy seasons

Seasons	Month	Share of Annual Rainfall
Winter	January February	Smallest, but critical for Rabi crops
Pre-Monsoon	March -May	Moderate, thunderstorm-driven
South West Monsoon	June-September	Provides approximately 75-80% of annual rainfall
Post-Monsoon	October-December	Secondary but crucial for southern states

Source: IMD Reports (17).

Season-wise variations in rainfall over a long period may help us understand changing trends. IMD's data series supports this attempt. Table 3 (NCIWRD.,1999) presents a decade-wise view of India's seasonal rainfall, built from IMD's 120+ year gridded rainfall record (1901–2024**)** (Samantray P and Gouda KC., 2024).

Table-3: Long-term seasonal trend of rainfall in India (1901–2024)

Seasons	Total Change (%) (1901-2024)	Share of Annual Rainfall
Winter	-25.0	Sharpest decline, and the only statistically significant one
Pre-Monsoon	-2.3	Slight decline
Southwest Monsoon	-2,5	Slight decline, not statistically significant
Post-Monsoon	+5.8	Only season rising

Source: IMD Reports various years (NCIWRD (1999)).

The winter decline is the only one that's statistically significant — meaning it's a robust shift, not just noise, while the monsoon's dip could reflect natural multi-decadal wet/dry epochs lasting 30-40 years rather than a real trend

Total annual rainfall across India has stayed broadly stable since the early 20th century, but the four seasons have diverged sharply. Table 4 clearly shows seasonal rainfall divergence in India over the last 125 years (NCIWRD, 1999)**.**

Table-4: Annual Rainfall in India (mm)(1901 t0 2024)

Year	Annual	Winter	Pre-monsoon	Monsoon	Post-Monsoon
1901	1027.3	70.-2	108.0	768.8	99.9
1911	1045.2	50.8	119.9	748.4	127.1
1921	1234.8	48.8	110.1	971.4	104.6
1931	1301.6	48.6	115.9	953.0	184.1
1941	1077.7	40.6	129.8	798.5	108.6
1951	1050.1	27.9	157.6	754.2	110.2
1961	1396.9	60.8	132.1	1051.1	152.9
1971	1217.4	38.4	138.5	913.0	127.5
1981	1170.7	49.0	149.9	885.2	94.5
1991	1148.6	39.7	145.4	856.5	107.0
2001	1078.7	17.4	128.4	810.4	122.4
2011	1131.6	33.3	120.1	911.1	67.1
2021	1233.7	38.0	156.0	872.3	177.4
2022	1257.0	58.5	130.2	924.8	144.1
2023	1102.8	22.4	147.9	821.6	110.7
2024	1206.6	26.9	126.7	935.9	117.3

Source: IMD's 120+ year gridded rainfall record (1901–2024).

In the last 124 years, the annual rainfall ranges between 1396.9 -1027.3 mm and the range of rainfall in winter is 70.6-17.4 mm and during pre-monsoon, it ranges between 157.6-108.0 mm. Monsoon rainfall ranges between 1051.1-748.4 mm and further, post-monsoon rainfall is in the range of 177.4-67.1 mm (Mujumdar PP, Tiwari VM 2019).

IV. Conclusion

Water is a natural resource, without which living beings cannot live on this earth. Even the composition or decomposition of non-living things requires water. Rainfall recycles groundwater and surface water annually. This is a natural process. Environmentally, these are to be in balance, or regular, as environmental balance is essential in terms for ensuring sufficient Forest area, with no air pollution, soil pollution and even water pollution. If these environmental damages are not controlled, long-term declines in rainfall and groundwater levels will occur. Even irregular rainfall, or seasonal divergence, is seen in India due to environmental imbalance caused by developmental activities that are not environmentally friendly. Therefore, utmost care must be taken while planning development or industrialisation so that it is sustainable.

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