Transformative impact of various groundwater recharge and water conservation measures on different aquifer systems in India

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Groundwater contributes to 9% of India's GDP; 64% of irrigation, 85% of rural water supply and over 50% of urban water demand. Over the last decade, 54% of India's shallow wells became defunct due to declining groundwater levels and thus deep wells have been constructed. This shift to deeper wells has led to more groundwater withdrawal than natural recharge resulting in over-extraction. Most of States and Central Government agencies focus on groundwater recharge and conservation to address sustainability through schemes like Jal Shakti Abhiyan and MGNREGA. These interventions between 2017 and 2020 led to a notable 12.46 bcm increase in groundwater resources in hard-rock aquifers. This study's findings would assist policymakers and administrators in evaluating the effectiveness of schemes for different aquifer, and drawing their attention to suggests design changes for more effective recharge of groundwater.

Keywords: Aquifer systems, artificial recharge, groundwater, transformative impact, water conservation.

GROUNDWATER is replenished and recharged primarily from a steady and incessant spell of rainfall during the monsoon season. Rainfall varies substantially across the complex and diverse hydrogeological settings of India, with extreme precipitation in the northeastern regions and the windward side of the Western Ghats; heavy precipitation in most of eastern India; moderate precipitation in areas of West Bengal, Bihar, Odisha, Madhya Pradesh, Andhra Pradesh, and in the leeward side of the Western Ghats; scanty precipitation in areas of Maharashtra, Gujarat, Karnataka, Tamil Nadu, Andhra Pradesh, Madhya Pradesh, Punjab, Haryana and western Uttar Pradesh, and is the desert and semi-desert areas of western India and parts of Jammu and Kashmir, such as the Ladakh plateau, a cold desert region.

Groundwater recharge is a hydrologic process where water from the surface seeps downward due to gravity and rock characteristics (porosity, permeability, intersecting fracture systems) and gets collected in the aquifers. These receive groundwater discharge, including natural discharge through springs and base flow to the surface, and anthropogenic discharge by pumping water from the wells. The number of pumping wells has been increasing exponentially with the rising demand for agricultural production coupled with an expanding population and rapid industrialization. On the other hand, the recharge rates are decreasing with massive urbanization and changes in rainfall patterns. This has led to a situation wherein the rate of groundwater discharge is more than natural recharge, resulting in several environmental issues like decline in groundwater level, drying up of wells, reduction in hydraulic properties in shallow aquifers, increased energy consumption for lifting water from progressively deeper levels, quality deterioration, issues of sustainability of sources, reduction in groundwater flow to rivers, contamination and no flow in rivers. These scenarios have adverse and devastating effects on the environment and slow economic growth in the country. Thus, there is a need for a paradigm shift in groundwater management. The importance of groundwater, specifically its management, has been considered necessary for national development. For this, artificial recharge of groundwater has emerged as a vital management approach. In the present study, we quantify the spatial variability of groundwater recharge and analyse the impact of these interventions on different aquifer systems in India.

A distinct aspect of this study is the estimation of replenishable groundwater resources in 6965 units (blocks/mandals/taluks/districts/firkas/valleys), which has been jointly carried out by the Central Ground Water Board (CGWB) and the State Departments dealing with groundwater. Resources were assessed using the principles and norms of the Groundwater Resources Estimation Committee[1]. The methodology adopted for resource assessment was based on estimating the lumped parameter model. The water balance equation of the groundwater system used in the assessment of resources can be expressed as:

$$\Delta S = \text{Inflow} - \text{outflow}, \tag{1}$$

where ΔS is the change in groundwater storage.

The inflow into the system includes recharge from rainfall and other sources during the monsoon and non-monsoon periods. Recharge from other sources considers the various sources of inflow like recharge from canals, surface-water irrigation, groundwater irrigation, tanks and ponds, and artificial recharge and water conservation structures. The sum of the recharge components (rainfall and other sources) is the total annual groundwater recharge. The components of outflow in the system include groundwater extraction, transpiration, evaporation and baseflow. Groundwater extraction is the sum of extraction for various purposes like irrigation, domestic and industrial.

Two methods have been adopted for the computation of recharge from rainfall, i.e. the rainfall infiltration factor method and the water table fluctuation method. The latter method is based on fluctuations observed only during

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Table 1. Spatial variability and impact of recharge on different aquifer systems

Recharge from other sources				
Principal aquifer	Area of coverage (km^2)	Recharge (bcm) from other sources (GWRA – 2017)	Recharge (bcm) from other sources (GWRA – 2020)	Change in recharge (bcm) (GWRA – 2020–2017)
Alluvium	945,754	78.83	80.53	1.70
Basalt	512,302	17.01	17.07	0.06
BGC	478,383	15.02	19.48	4.46
Sandstone	260,416	5.40	6.34	0.93
Gneiss	158,753	4.84	6.21	1.37
Schist	140,935	3.68	4.04	0.36
Charnockite	76,360	3.66	4.37	0.71
Shale	225,397	2.91	3.61	0.71
Laterite	40,926	2.00	2.16	0.16
Limestone	62,899	1.67	2.09	0.42
Khondalite	32,914	1.43	2.46	1.03
Granite	100,992	1.28	1.81	0.53
Quartzite	46,904	1.21	1.31	0.10
Intrusive	19,896	0.38	0.55	0.17
	3,171,238	143.62	156.08	12.46

GWRA, Ground Water Resources Assessment; BGC, Banded Gneissic Complex.

monsoon season in the groundwater storage system (eq. (2)).

$$\Delta S = R_{RF} + R_{STR} + R_{SWI} + R_{GWI} + R_{TP} + R_{WCS} \pm VF \pm LF - GE - T - E - B, \quad (2)$$

where ΔS is the change in storage, R_{RF} the rainfall recharge, R_{STR} the recharge from stream channels, R_{SWI} the recharge from surface-water irrigation (lift irrigation), R_{GWI} the recharge from groundwater irrigation, R_{TP} the recharge from tanks and ponds, R_{WCS} the recharge from water conservation structures, VF the vertical inter-aquifer flow, LF the lateral flow along the aquifer system (throughflow), GE the groundwater extraction, T the transpiration, E the evaporation and B is the base flow.

The rainfall infiltration factor method is used to estimate rainfall recharge during both monsoon and non-monsoon seasons. Recharge from rainfall is calculated using the equation

$$R_{RF} = RFIF * A * (R - a)/1000, \quad (3)$$

where R_{RF} is the rainfall recharge (HAM), A the area (ha), RFIF the rainfall infiltration factor, R the rainfall (mm) and a is the minimum threshold value above which rainfall induces groundwater recharge (mm).

Based on diverse and distinctive hydrogeological properties, depositional set-up, occurrence and movement of groundwater, lithological variations and climatological dissimilarities, India has been classified into 14 principal aquifers and 42 major aquifers[2]. The present study focuses on the control of spatial variability and the impact of the various interventions on the 14 principal aquifer systems. The difference between the recharge of groundwater resource assessment carried out in 2017 and 2020 was used to estimate the impact of the water conservation measures[3,4].

Recharge interventions and water conservation measures are being implemented by both the Central and State Governments through various schemes and programmes. During the last few years, the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), 2005, has become the focal force driving water conservation efforts across rural India. The national-level campaign of Jal Shakti Abhiyan (2019) to 'catch the rain where it falls and when it falls' for water conservation and water resource management focuses on accelerated implementation of this programme. The other steps taken by the Government of India for water conservation and minimizing its wastage include Pradhan Mantri Krishi Sinchayee Yojana, Atal Mission for Rejuvenation and Urban Transformation, Model Building Bye-Laws, 2016 and Urban and Regional Development Plan Formulation and Implementation Guidelines, 2014. Replication and scaling-up of water conservation and recharge interventions considering geographic, social and economic diversities are having transformative impacts and delivering higher development dividends.

The assessment of total change in the component of recharge from 2017 to 2020 showed an increase in groundwater resources to the tune of 12.46 bcm (Figure 1 and Table 1). The alluvial aquifers, which cover about 31% of the entire country, increased groundwater resources by ~1.70 bcm. The weathered and fractured aquifers of the Banded Gneissic Complex (BGC) covering 15% (478,383 km^2) of the area in India recorded the maximum increase of 4.46 bcm in groundwater resources. The jointed aquifers in basalt-covered areas occupying 16% (512,302 km^2) of the country, recorded a low increase in resources (0.06 bcm). Sandstone aquifers, which cover an area of 260,416 km^2 (8%), recorded a nearly 0.93 bcm increase in groundwater resources. Crystalline

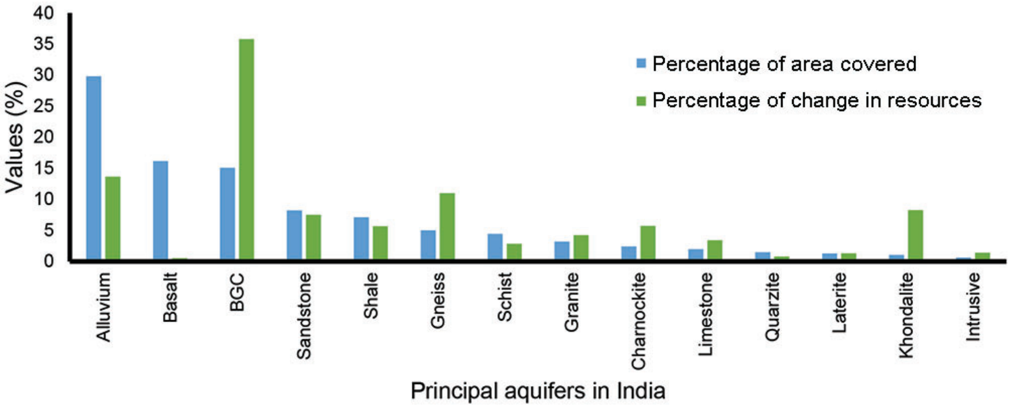

Figure 2. Area coverage of 14 principal aquifer systems in India and change in recharge from other sources.

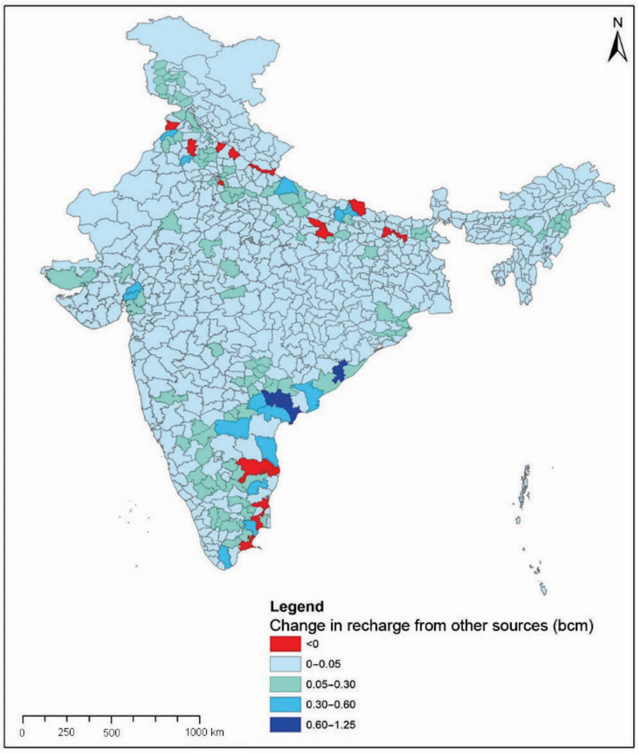

Figure 1. Spatial distribution of change in recharge from other sources.

aquifers, viz. gneiss (5%), granite (3.2%), charnockite (2.4%) and khondalite (1%), which cover 11.6% of the entire country recorded 3.6 bcm increase in groundwater resources. The impact of recharge measures was prominent in gneiss (1.37 bcm) and khondalite (1.03 bcm) aquifers compared to charnockite (0.71 bcm) and granite (0.53 bcm) aquifers. Shale aquifer covers about 7% of the area in the country, mostly in Chhattisgarh, Andhra Pradesh, Madhya Pradesh, Rajasthan and in the North East India as well as in the Himalayan terrain. This region showed a 0.71 bcm increase in groundwater resources. Schist and quartzite aquifers cover about 4.4% and 1.7% of the area respectively, in the country. They showed a negligible increase of 0.36 and 0.10 bcm respectively. A perusal of Figure 2 illustrates that the groundwater resources have increased substantially in the hard-rock aquifers (gneiss, BGC and khondalite) between 2017 and 2020. The impact of recharge and water conservation measures is more prominent in the hard-rock aquifers (Table 1). It is evident that the low matrix permeability of these hard-rock aquifers promotes more infiltration through discontinuities (fractures) than those with sorted grains (alluvium). However, the jointed basalt aquifer recorded relatively lower recharge through water conservation. The recharge from rainfall across the country was estimated at 280.06 bcm in 2020. Such results, as presented here, can help policymakers and administrators to plan and evolve changes in design for effectively increasing the recharge of groundwater in areas with aquifers having low recharge. The entire assessment has been performed using a cloud-based web system, INGRES. The data have been validated and checked at various stages.

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