Groundwater Resource Assessment of India

A scientific approach towards making the invisible visible

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Groundwater has become a fundamental resource for meeting the freshwater needs of various sectors in India. The sustainable development and efficient management of this limited resource is challenging, esp. in Indian context which has a unique and very diverse hydrogeological and geological setup. For quantification and prioritizing the areas for groundwater management interventions, the annual assessment is carried out jointly by Central Ground Water Board (CGWB) and State Ground Water Departments. The current assessment of 2024 estimates total annual groundwater recharge at 446.90 billion cubic meter (bcm) and extraction at 245.64 bcm, with an overall stage of extraction 60.47%. Out of 6,746 assessment units (Blocks/ Mandals/ Taluks etc.) 751 (11.13%) are 'Over-exploited', 206 (3.05%) are 'Critical', 711 (10.54%) are 'Semi-critical', and 4,951 (73.39%) are 'Safe'. Additionally, 127 (1.88%) units have saline groundwater resources. Compared to 2017, groundwater recharge has increased by 15 bcm, while extraction declined by 3 bcm. The assessment results are being utilized for regulation for groundwater extraction, planning, policy making and implementation of groundwater management strategies of the country.

It is rightly said that we can manage only what we can measure. This statement assumes even more relevance for resources that are invisible in nature and its quantum cannot be witnessed (World Bank, 2012). Groundwater, stored within the aquifers beneath the surface, is the backbone of India's agriculture and drinking water security, contributing nearly 62% to irrigation, 85% to rural water supply, and 50% to urban water supply (World Bank 2012; Foster and Willetts 2019). Groundwater extraction from aquifers to meet various requirements of the growing population has raised concerns about overexploitation of the resources, decline in water level and deterioration in groundwater quality in several parts of the country (Bhanja et al. 2017; Saha & Ray 2018). The adverse effect has caused tragedy for the people, with some areas facing not only reduced access to groundwater but also compromised water quality. Considering these, scientific and judicious management of the country's groundwater resources is the need of the hour, which fundamentally requires accurate assessment.

The National Water Policy of 2012 emphasizes periodic, scientifically-based assessments of groundwater resources, including evaluating trends in water availability due to factors such as climate change during water resource planning. Following that, Groundwater Resource Assessment is carried out at periodical intervals jointly by Central Ground Water Board and State Ground Water Departments and under the guidance of the respective State Level Committee (SLC) on Groundwater Assessment at State Levels and under the overall supervision of the Central Level Expert Group (CLEG). Such joint exercises have been taken up earlier in 1980, 1995, 2004, 2009, 2011, 2013, 2017, 2020 and 2022. From 2022, the exercise is being carried out annually (CGWB Achieve, 2022).

The dynamic groundwater resource assessment in India is carried out using a mass balance approach based on the lumped model framework,

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as defined in the Groundwater Estimation Committee (GEC), 2015 methodology. The methodology defines the approach: i) Estimation of Annual Groundwater Recharge by accounting for contributions from various sources such as rainfall, surface water bodies, return flow from irrigation, and recharge from water conservation structures, ii) from this total recharge, a provision is made for natural discharge, and the remaining component is considered as the Annual Extractable Groundwater Resource, iii) the Annual Groundwater Extraction is estimated based on groundwater usage across sectors, including agriculture, industry, and domestic, iv) Stage of Groundwater Extraction is then calculated as the ratio of annual extraction to extractable resource, expressed in percentage, v) finally, assessment units (AUs) are categorized into four classes Safe (≤70%), Semi-Critical (>70%–≤90%), Critical (>90%–≤100%), and Over-Exploited (>100%)—based on the stage of extraction (GEC, CGWB 2015).

As per Groundwater Resource Assessment of the Country for the year 2024, the total annual groundwater recharge in India has been estimated as 446.90 bcm, with an extractable resource of 406.19 bcm after accounting for natural discharge. Rainfall recharge during monsoon and non-monsoon periods is the primary contributor to total annual groundwater recharge, accounting for 270.91 bcm (61%) of the total recharge (Monsoon: 55%, Non-monsoon: 6%). The remaining 39% (175.68 bcm) comes from other sources like canal seepage, irrigation return flow, and recharge from tanks, ponds, and water conservation structures. Rainfall contributes over 70% of annual groundwater recharge in the Indian States/UTs: Assam, Goa, Gujarat, Jharkhand, Kerala, Madhya Pradesh, Manipur, Meghalaya, Mizoram, Rajasthan, Daman & Diu, and Lakshadweep. The total annual recharge into depth units (m), is highest (>0.20 m) in the Indus-Ganga-Brahmaputra alluvial belt covering States Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, and North-Eastern valleys, where abundant rainfall and alluvial formations support replenishment (Fig.1). The eastern coastal belt also has high groundwater recharge (>0.20 m). In contrast, arid regions like Rajasthan and northern Gujarat experience very low recharge (<0.075 m), while hard rock terrains in Southern and Central India have moderate recharge (0.075–0.20 m) due to lower infiltration and limited storage capacity (GEC, CGWB 2022).

The Total Annual Groundwater Extraction of the

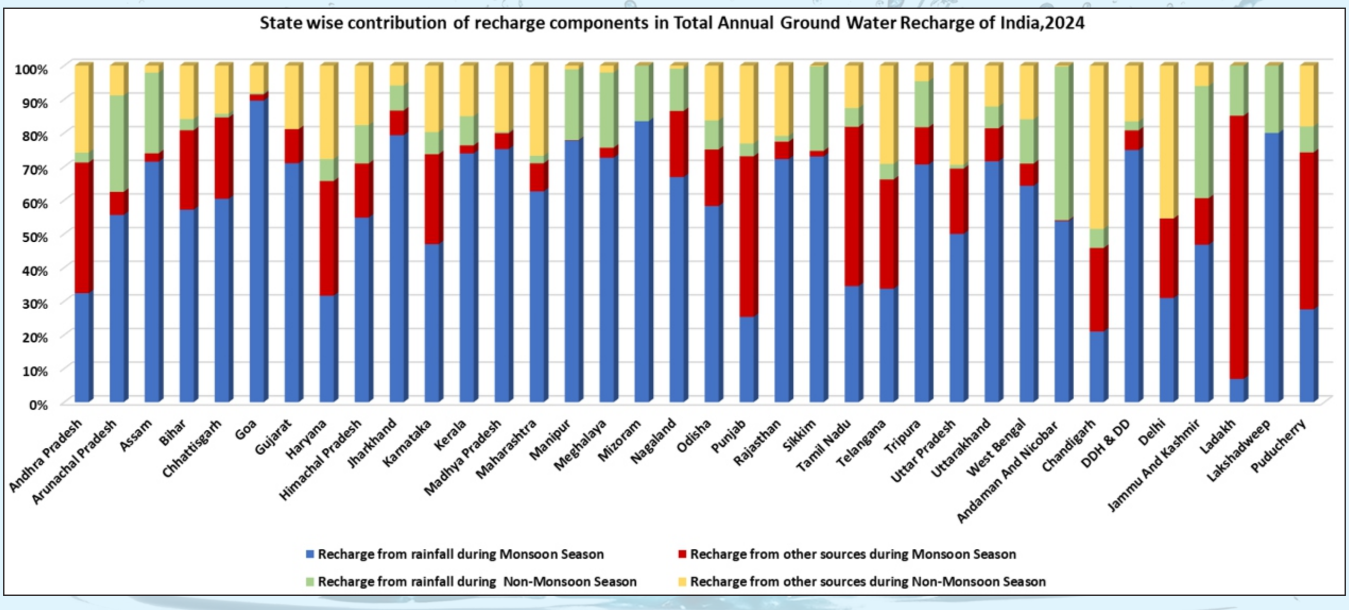

Fig.1: State wise contribution of recharge components in Total Annual Groundwater Recharge of India, 2024.

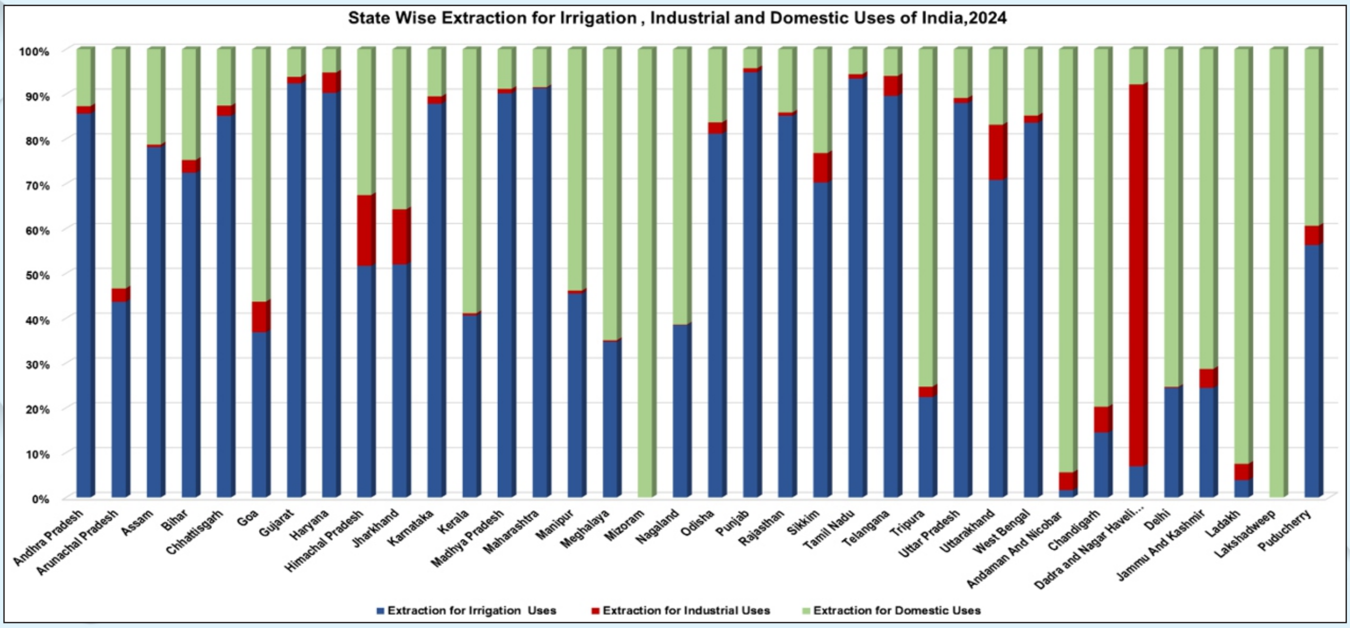

Fig.2: State wise % of Groundwater extraction for Irrigation, Industrial and Domestic Purposes, 2024.

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entire country for the year 2024 has been estimated as 245.64 bcm (Fig.2). The agriculture sector is the largest consumer of groundwater accounting for 87% of the total annual groundwater extraction, which amounts to 213.29 bcm. The domestic consumption accounts for 11% (28.07 bcm), while industrial use represents 2% (4.28 bcm) of total annual groundwater extraction of the country. In the states/UTs of, Arunachal Pradesh, Delhi, Goa, Kerala, Manipur, Meghalaya, Mizoram, Nagaland, Tripura, Andaman and Nicobar, Chandigarh, Jammu and Kashmir, Ladakh, Lakshadweep the groundwater extraction for domestic uses is more than 40 % (GEC, CGWB 2022).

The overall stage of groundwater extraction in the country is 60.47 %. The State/UT wise distribution of Stage of Groundwater Extraction is as follows (Fig.3):

- **Stage of Groundwater Extraction >100%:** Punjab, Rajasthan, Dadra and Nagar Haveli and Daman and Diu, Haryana, and Delhi.
- **Stage of Groundwater Extraction >90% to 100%:** Nil
- **Stage of Groundwater Extraction >70% to 90%:** Tamil Nadu, Uttar Pradesh, Puducherry and Chandigarh.
- **Stage of Groundwater Extraction <70%:** Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Chhattisgarh, Goa, Gujarat, Himachal Pradesh, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Mizoram, Nagaland, Odisha, Sikkim, Telangana, Tripura, Uttarakhand, West Bengal, Andaman and Nicobar, Jammu and Kashmir, Ladakh, Lakshadweep.

Out of 6,746 assessment units (Blocks/ Mandals/ Taluks etc.), 751 (11.13%) are 'Over-exploited', where groundwater extraction exceeds recharge. 206 (3.05%) are 'Critical' (90-100% stage of extraction), 711 (10.54%) are 'Semi-critical' (70-90% SoE), and 4,951 (73.39%) are 'Safe' (<70% SoE) (Fig.4). Additionally, 127 (1.88%) units have saline groundwater. States with over 25% Over-exploited and Critical units include Delhi, Haryana, Punjab, Rajasthan, Tamil Nadu, Dadra & Nagar Haveli, and Daman & Diu. Of India's 2.48 million sq. km recharge-worthy area, 16.93% is Over-exploited, 3.55% is Critical, 11.40% is Semi-Critical, 66.57% is Safe, and 1.55% is Saline. Regarding total extractable resources (406.19 bcm), 46.02 bcm (11.33%) is Over-exploited, 13.23 bcm (3.26%) is Critical, 45.76 bcm (11.27%) is Semi-Critical, and 301.17 bcm (74.14%) is Safe (GEC, CGWB 2022).

Artificial recharge and water conservation initiatives are being actively implemented through various schemes and programmes by both the Central and State Governments (Satapathy,

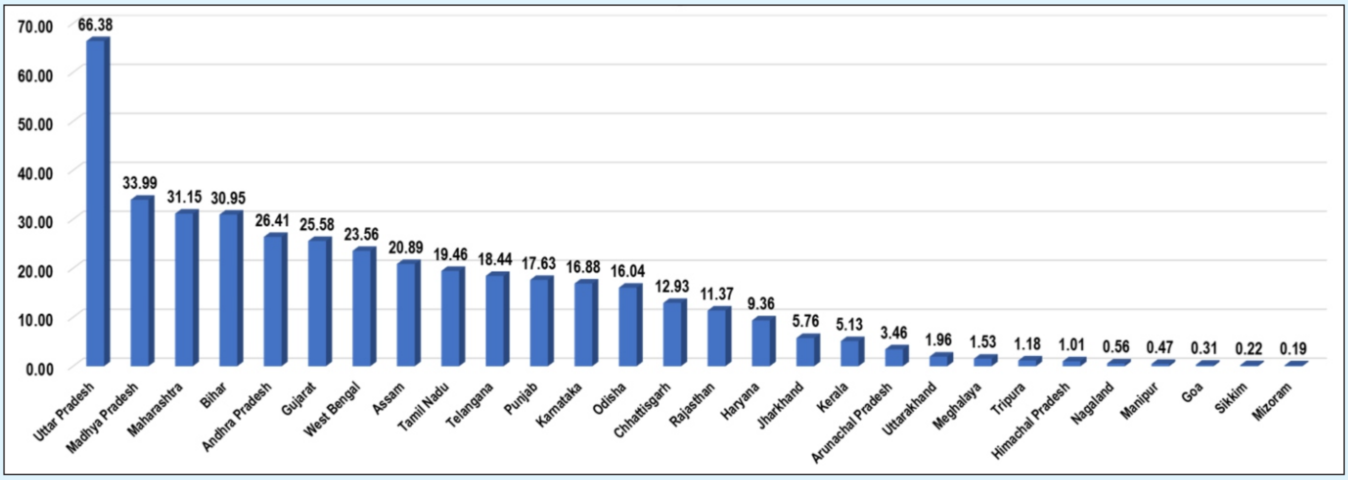

Fig.3: Stage of Groundwater Extraction of Major States.

2023). In recent years, the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), 2005, has emerged as a key driver of water conservation efforts across rural India. The Jal Shakti Abhiyan launched in 2019 with the motto “Catch the Rain, where it falls, when it falls” has further accelerated the implementation of decentralized water resource management practices. Atal Bhujal Yojana (ATAL JAL) with focus on community participation and demand side interventions for sustainable groundwater management in identified water stressed areas in 7 States has been taken up by Government of India. The Mission Amrit Sarovar was launched by the Central Government in 2022 to rejuvenate 75 water bodies in each district of the country. Ministry of Jal Shakti, Govt of India has circulated a Model Bill to all the States/UTs to enable them to enact suitable groundwater legislation for regulation of its development, which also includes provision of rainwater harvesting. So far, 19 States/UTs have adopted and implemented the groundwater legislation. Other Government interventions include the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Atal Mission for Rejuvenation and Urban Transformation (AMRUT), the Model Building Bye-Laws (2016), and the Urban and Regional Development Plan Formulation and Implementation Guidelines (2014), which intends to integrate water conservation across both urban and rural planning frameworks. The efforts towards artificial recharge of groundwater and water conservation, along with the impact of various schemes and initiatives, are bringing about transformative changes in the country's groundwater resources. These positive outcomes are also reflected in the results of resource assessments. In comparison to 2017, the groundwater recharge has increased from 431.86 bcm in 2017 to 446.90 bcm in 2024, with an increase of 15.04 bcm. Recharge from tanks, ponds and water conservation structures has increased by 11.36 bcm during this period (GEC, CGWB, 2017).

Similar efforts have been made in demand-side management by the government. The Bureau of Water Use Efficiency has been established under the National Water Mission to plan and implement a nationwide programme for promoting efficient water use across irrigation, domestic water supply, municipal, and industrial sectors. Considering the substantial extraction of

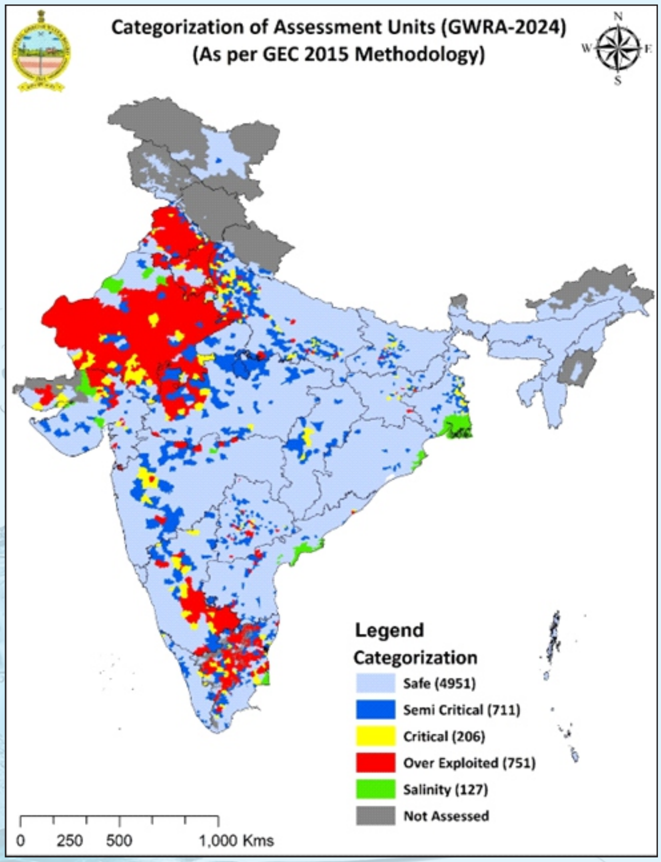

Fig.4: Categorization of Assessment Units, 2024.

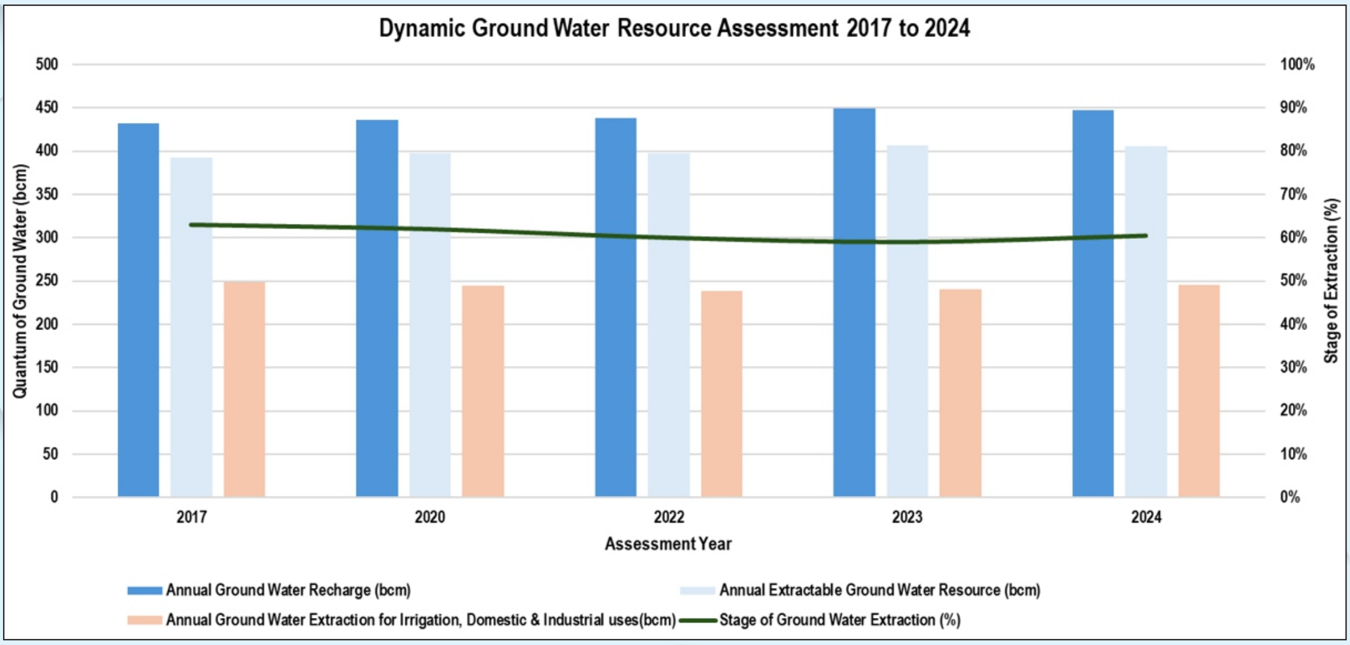

Fig.5: Dynamic Groundwater Resource Assessment, 2017 to 2024.

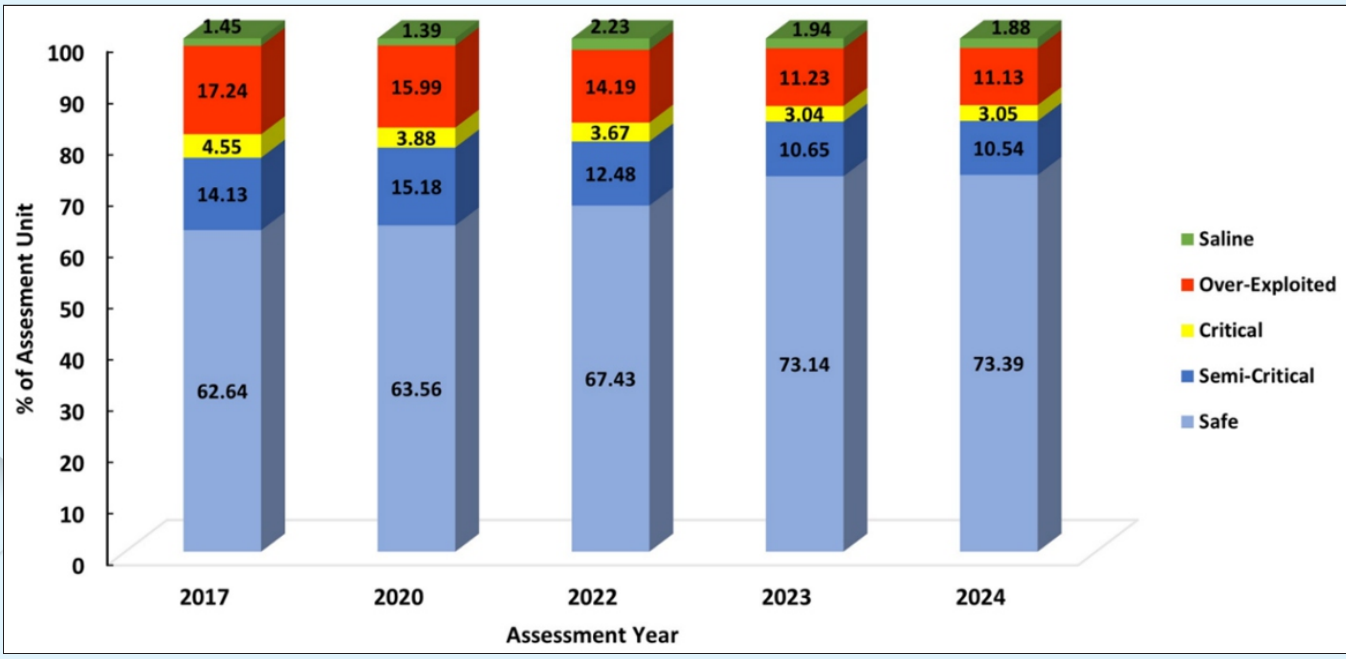

Fig.6: Categorization of % of Assessment Units (2017 to 2024).

groundwater for irrigation, significant emphasis has been placed on adopting advanced irrigation practices and expanding the coverage of micro-irrigation to reduce groundwater dependence. The Per Drop More Crop (PDMC) and accelerated irrigation benefit programme component are being implemented under PMKSY scheme with focuses on micro irrigation, and faster completion of major/medium irrigation projects. The Micro Irrigation Fund (MIF) has been launched by National Bank for Agriculture and Rural Development (NABARD) in 2018, to provide financial assistance to States/UTs for expanding micro-irrigation coverage, offering top-up subsidies, and incentivizing farmer adoption. The Rashtriya Krishi Vikas Yojana (RKVY), which grants flexibility and autonomy to states in planning and implementing agriculture development schemes, and the National Mission on Sustainable Agriculture (NMSA), under the National Action Plan on Climate Change (NAPCC), are being implemented for on-farm water management. In addition to Central Government efforts, several states such as Gujarat, Andhra Pradesh, Maharashtra, and Tamil Nadu have launched their own State Micro Irrigation Missions (Sujalam Sufalam), providing subsidies and support for micro-irrigation systems. As a result of these collective efforts, a noticeable change in groundwater extraction has been observed. The annual groundwater extraction for industrial, domestic, and irrigation purposes combined has decreased from 248.69 billion cubic meters (bcm) in 2017 to 245.64 bcm in 2024, reflecting a reduction of 3.05 bcm (Fig.5) (GEC, CGWB, 2017). The efforts for better irrigation practices and increase water efficiency has also been reflected in food grain production. India has been able to increase the food grain production from 196.81 million metric tons (mmt) to 323.55 mmt during 2000-01 to 2022-23 (an increase of 64%) without significant increase in groundwater extraction. The country wide stage of groundwater extraction has also reduced by 2.86%, in 2024 (60.47%) compared to 63.33% in 2017. The percentage of Over-Exploited, Critical, and Semi-Critical assessment units in the country has decreased from 35.8% in 2017 to 24.72% in 2024. Similarly, the percentage of Safe assessment units has increased from 62.6% in 2017 to 73.39% in 2024 (Fig. 6).

The findings from the Dynamic Groundwater Resource Assessments have been instrumental in planning and implementing groundwater regulation and management strategies across the country. The assessment results have guided policymakers in formulating several large-scale schemes, such as the Atal Bhujal Yojana, the PMKSY–Groundwater Component, and the Jal Shakti Abhiyan. Categorization of assessment units forms a basis for preparation of policies and implementation of regulatory measures by Central Ground Water Authority (CGWA) and State Ground Water authorities for groundwater extraction. Several scientific initiatives have also been planned in accordance with the results of resource assessment. Central Ground Water Board (CGWB) has taken up National Aquifer Mapping & Management Programme (NAQUIM), and high-resolution mapping of the aquifers through the state-of-the-art heli-borne geophysical surveys for mapping of aquifers, their characterization and formulation of management plans to ensure sustainability of the groundwater resources, with a focus on Over-exploited, Critical, and Semi-critical areas of the country.

Scientific collaborations have been initiated with premier institutions like, Bhabha Atomic Research Centre, Department of Atomic Energy for investigating the role of paleochannels in reviving the groundwater resources in northwestern part of India, aquifer mapping studies in Central Ganga Plains, groundwater recharge rate estimation using injected radiotracer techniques and evaluating sustainability of deep aquifers. All these projects have been implemented using advanced isotope hydrological techniques being developed by BARC and successful completion of these projects is encouraging further expansion of isotope techniques to other regions of India, capacity building, mutual collaborations and technical cooperation. The annual assessment of the groundwater resources using advanced techniques and integrating scientific data into planning, policy making and implementation has significantly improved the efficiency and sustainability of groundwater resources Nationwide.

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