

# A Comprehensive Analysis of India's Dynamic Groundwater Resources: An Expert Assessment of the 2024 National Compilation and the GEC-2015 Methodology

## Executive Summary

The "National Compilation on Dynamic Ground Water Resources of India, 2024" (GWRA-2024), meticulously prepared by the Central Ground Water Board (CGWB) in collaboration with state and union territory governments, provides a critical and comprehensive overview of the nation's groundwater situation. The report serves as an actionable guide and a scientific foundation for crafting effective policies and management strategies.<sup>1</sup> The latest assessment, conducted using the refined Ground Water Estimation Methodology - 2015 (GEC-2015), reveals a complex and multi-faceted picture of the country's most vital freshwater resource.

The key national-level figures for 2024 are as follows: the total annual groundwater recharge has been assessed at **446.90 billion cubic meters (bcm)**. After accounting for natural discharge, the total annual extractable groundwater resource stands at **406.19 bcm**. Total annual groundwater extraction for all uses is **245.64 bcm**, resulting in an average national stage of extraction of **60.47%**.<sup>1</sup>

A comparison of the 2024 assessment with the previous 2023 report reveals subtle but notable shifts in groundwater dynamics. While the long-term trend since 2017 shows an overall improvement, with a decline in the number of 'Over-exploited' units, the year-on-year data from 2023 to 2024 indicates a marginal increase in the national stage of extraction from 59.21% to 60.47%.<sup>1</sup> This change is primarily attributed to a slight decrease in recharge and a corresponding increase in extraction, particularly a reduction in return flow from irrigation.

A detailed analysis of the data confirms that groundwater is the lifeline of India's water security, playing a pivotal role in agriculture (87% of total extraction), domestic water supply (11%), and industrial needs (2%).<sup>1</sup> This dependence, coupled with regional hydrogeological diversity, results in a highly uneven distribution of stress on the resource. Over-exploitation is concentrated in the north-western alluvial plains (e.g., Punjab, Haryana), arid regions of the west (e.g., Rajasthan, Gujarat), and hard rock formations of the peninsular south (e.g., Karnataka, Tamil Nadu).<sup>1</sup>

The report and external research collectively underscore the imperative for a multi-pronged approach to sustainable management. While government initiatives such as the **Atal Bhujal Yojana** and the **Jal Shakti Abhiyan** have demonstrably led to positive results—evidenced by a consistent increase in recharge from water conservation structures—they have not yet been sufficient to overcome the demand-side pressures in many water-stressed regions.<sup>1</sup> The path forward requires not only continued investment in supply-side solutions but also bold policy reforms that address the economic and agricultural drivers of over-extraction. This must be complemented by methodological refinements, such as more frequent field studies and the integration of advanced technologies, to ensure that future assessments provide an even more accurate and actionable basis for decision-making.<sup>1</sup>

## Chapter 1: The Foundational Framework for Groundwater Assessment (GEC-2015)

The expert analysis of India's groundwater resources hinges on a thorough understanding of the technical framework used for their assessment. The GEC-2015 methodology serves as this foundational framework, providing the principles, assumptions, and computational procedures that transform raw data into the comprehensive national compilation. This chapter will deconstruct the core components of this methodology to provide the necessary context for interpreting the findings of the 2024 report.

### 1.1 The Principles of the Groundwater Estimation Methodology

The GEC-2015 methodology operates on the fundamental principle of the **water balance equation**:  $\text{Inflow} - \text{Outflow} = \text{Change in Storage}$ .<sup>1</sup> This equation models the aquifer system as a dynamic reservoir, where the volume of water changes based on the net effect of all additions (inflows) and subtractions (outflows). Inflows primarily consist of recharge from

various sources, while outflows include groundwater extraction and natural discharges like evapotranspiration and base flow.<sup>1</sup>

To apply this principle across a vast and hydrogeologically diverse country like India, the methodology first establishes a standardized **groundwater year**. This year is defined as 12 calendar months beginning with the onset of the predominant monsoon season, and it is divided into a "Monsoon Season" and a "Non-monsoon Season".<sup>1</sup> This temporal division is crucial for capturing the distinct hydrological dynamics of the country, where over 75% of annual rainfall is received in just four months from June to September.<sup>1</sup> Data collection is timed to coincide with this cycle, with "Pre-monsoon" monitoring capturing the lowest water levels and "Post-monsoon" monitoring capturing the highest levels, which are then used to calculate the seasonal water level fluctuations.<sup>1</sup>

Another critical element is the definition of a specific **assessment unit**.<sup>1</sup> The type of unit is selected based on the predominant aquifer type in a given state or union territory. For areas predominantly characterized by

Alluvial Aquifers, administrative units like a **Block, Taluka, Mandal, or Firka** are used. Conversely, for areas with Non-Alluvial Aquifers, such as hard rock terrains, a Watershed is the preferred assessment unit.<sup>1</sup> This choice is not arbitrary; it reflects an understanding of the relationship between topography and hydrology. In undulating hard rock areas, watershed boundaries often align with groundwater divides, making it easier to accurately model the water balance. In the flatter alluvial plains, administrative units are more practical due to the difficulty of delineating distinct hydrological boundaries.<sup>1</sup> However, this distinction can present challenges when comparing data across states that use different unit types and requires careful handling during national-level aggregation.

## 1.2 Quantification of Recharge Components (Inflows)

The estimation of recharge is central to the entire assessment, as it determines the replenishable portion of the resource. Recharge from rainfall is the single largest contributor, accounting for roughly 61% of the total annual recharge for the country.<sup>1</sup> The GEC-2015 methodology provides two primary methods for its calculation:

1. **The Water Table Fluctuation Method (WTFM):** This is the method of choice when sufficient water level data is available.<sup>1</sup> It is based on a volumetric change approach, where the monsoon-season rise in the water table is measured and then multiplied by the area of the aquifer and its Specific Yield (the ratio of the volume of water that a rock or soil will yield by gravity to the total volume of the saturated aquifer). This is represented by the formula:

$$RRF = \Delta h \times A \times SY$$

where RRF is the rainfall recharge,  $\Delta h$  is the rise in water level, A is the area, and SY is the specific yield. This method is preferred because it directly accounts for the physical response of the aquifer to recharge events.<sup>1</sup>

2. **The Rainfall Infiltration Factor Method (RIFM):** When adequate water level data for WTFM is not available, an empirical approach is used. The RIFM estimates recharge by applying a pre-defined Rainfall Infiltration Factor to the net volume of rainfall (total rainfall minus a minimum threshold) over a given area. The formula is:

$$RRF = RFIF \times A \times 1000(R - a)$$

where RRF is the rainfall recharge, A is the area in hectares, RFIF is the Rainfall Infiltration Factor, R is the rainfall in mm, and a is the minimum threshold rainfall value.<sup>1</sup>

A critical component of the methodology is the normalization and validation procedure. Both recharge figures are normalized for "Normal Rainfall" to create a standard, average-year estimate. A "Percent Deviation" (PD) metric is then calculated to compare the results of the two methods. If the PD falls within a set tolerance range ( $\pm 20\%$ ), the WTFM result is accepted as the final recharge value. If the deviation is greater, the final figure is adjusted based on a multiple of the RIFM result.<sup>1</sup> This is a crucial self-correction mechanism to ensure that the final figures are not a product of anomalous data.

Beyond rainfall, the remaining 39% of recharge is derived from '**Other Sources**'.<sup>1</sup> These include seepage from canals, return flow from surface water and groundwater irrigation, and recharge from tanks, ponds, and water conservation structures. The GEC-2015 provides a comprehensive framework to estimate recharge from each of these sources, including specific norms for seepage from tanks and water conservation structures.<sup>1</sup> The report for 2024 highlights the importance of these sources, noting that the observed marginal decrease in national recharge is primarily attributed to a reduction in return flow from irrigation, a point that requires careful consideration.<sup>1</sup>

### 1.3 Quantification of Extraction Components (Outflows)

Groundwater extraction is a significant outflow component and a key metric for determining the sustainability of the resource. The GEC-2015 methodology acknowledges the inherent difficulty and lack of universal metering for measuring extraction, particularly from agricultural sources. Therefore, it proposes multiple methods for estimation, recommending that multiple techniques be used to calculate an average, more reliable figure.<sup>1</sup> The suggested methods include:

- **Unit Draft Method:** This involves estimating the average water withdrawn per well per day, the number of days a well is operated, and then multiplying that by the total number

of wells in a given assessment unit. This method also includes a normalization procedure to account for the inverse relationship between rainfall and pumping, with draft increasing in a drought year and decreasing in a year with high rainfall.<sup>1</sup>

- **Crop Water Requirement Method:** This approach estimates the water needed for specific crops in an area and assumes that a portion of this demand is met by groundwater.
- **Power Consumption Method:** This method estimates the volume of water extracted per unit of electricity consumed, a factor that varies with pump efficiency and depth to water level, and then uses total power consumption from agricultural feeders to estimate total extraction.<sup>1</sup>
- **Consumptive Use Method:** Used primarily for domestic and industrial water supply, this method relies on per-capita water needs and industrial water consumption norms.<sup>1</sup>

The GEC-2015's reliance on these indirect methods for calculating extraction underscores a fundamental challenge in groundwater management: the absence of widespread direct metering of water use. This is a structural limitation that can introduce uncertainty into the assessment and complicate the implementation of regulatory measures, as highlighted in external research on the topic.<sup>3</sup> This uncertainty makes the validation step, which compares the calculated data to actual water level trends, an even more critical part of the assessment process.

## 1.4 The Categorization and Validation Framework

The final step in the assessment is to synthesize the inflow and outflow data to classify the groundwater health of each assessment unit. This classification is crucial for informing policy and management decisions. The methodology categorizes units based on the **Stage of Groundwater Extraction**, which is defined as the total annual extraction as a percentage of the total annual extractable resources.<sup>1</sup> The categories are:

- **Safe:** Stage of extraction is less than 70%.<sup>1</sup>
- **Semi-critical:** Stage of extraction is between 70% and 90%.<sup>1</sup>
- **Critical:** Stage of extraction is between 90% and 100%.<sup>1</sup>
- **Over-exploited:** Stage of extraction is greater than 100%.<sup>1</sup>
- **Saline:** A distinct category for units where the water in the shallow aquifer is brackish or saline.<sup>1</sup>

A key strength of the GEC-2015 is its validation process, which uses long-term water level trends to verify the categorization of assessment units.<sup>1</sup> The methodology mandates that the water table trend for each unit be computed using linear regression on decadal water level

data.<sup>1</sup> A unit categorized as 'Over-exploited' with a rising water table trend, for instance, would be flagged for re-assessment, demonstrating a conflict between the calculated extraction and observed physical reality. This validation step adds an essential layer of rigor to the assessment and helps to mitigate the inherent uncertainties in the data collection process.<sup>1</sup>

## Chapter 2: A Data-Driven Assessment of India's Groundwater Resources (GWRA-2024)

Drawing on the methodological framework of GEC-2015, the 2024 national compilation presents a detailed and nuanced picture of India's groundwater situation. This chapter will analyze the key findings from the report, highlighting national and state-level trends, and providing a comparative analysis with the previous year's data to identify critical shifts in the groundwater landscape.

### 2.1 National Groundwater Dynamics: A 2024 Overview

The GWRA-2024 report aggregates data from 6,746 assessment units across the country to provide a high-level view of the nation's groundwater health.<sup>1</sup> The core statistics, which form the basis of all further analysis, are as follows:

- **Total Annual Groundwater Recharge:** 446.90 bcm
- **Annual Extractable Groundwater Resources:** 406.19 bcm
- **Total Annual Groundwater Extraction:** 245.64 bcm
- **Overall Stage of Groundwater Extraction:** 60.47%<sup>1</sup>

A more granular breakdown of these figures reveals the overwhelming dominance of the agriculture sector in groundwater use. The report indicates that **87%** of the total annual groundwater extraction is used for irrigation, amounting to 213.29 bcm. In stark contrast, domestic use accounts for only 11% (28.07 bcm), while industrial use represents a mere 2% (4.28 bcm).<sup>1</sup>

This distribution of water use is a central and defining feature of India's groundwater crisis. It clearly demonstrates that any national strategy for groundwater management must fundamentally address the practices, policies, and economic incentives within the agricultural sector. Policies aimed solely at industrial or domestic conservation would have a minimal

impact on the national water balance compared to even a small change in agricultural water use efficiency or cropping patterns.<sup>5</sup> The high reliance on groundwater for agriculture in a country with a large and growing population also points to the direct linkage between water security and food security, a critical interdependence known as the "water-food-energy nexus".<sup>5</sup>

## 2.2 Comparative Analysis: The 2024 Assessment vs. 2023

A year-on-year comparison provides a temporal context for the 2024 findings, revealing subtle but significant changes in the country's groundwater dynamics. While the long-term trends from the 2017 assessment to 2024 show an overall improvement—with the percentage of 'Over-exploited' units declining from 17.24% to 11.13% and 'Safe' units increasing from 62.6% to 73.4%—the immediate year-on-year data tells a more cautionary tale.<sup>1</sup>

The 2024 assessment figures compared to the 2023 figures are presented in the table below:

Metric	2023 Assessment	2024 Assessment	Change
Total Annual GW Recharge (bcm)	449.08	446.90	-2.18 bcm
Annual Extractable Resources (bcm)	407.21	406.19	-1.02 bcm
Annual GW Extraction (bcm)	241.34	245.64	+4.30 bcm
Stage of Extraction (%)	59.21%	60.47%	+1.26 percentage points

As the table shows, the total annual groundwater recharge decreased marginally from 449.08 bcm in 2023 to 446.90 bcm in 2024, leading to a corresponding decrease in the annual extractable resources from 407.21 bcm to 406.19 bcm.<sup>1</sup> Simultaneously, the total annual groundwater extraction increased from 241.34 bcm to 245.64 bcm. The combined effect of reduced recharge and increased extraction resulted in a marginal increase in the overall national stage of groundwater extraction, from 59.21% to 60.47%.<sup>1</sup>

The report attributes the decrease in total annual recharge primarily to changes in recharge from "Other Sources," specifically a reduction in return flow from irrigation. This is a complex point that can be interpreted in several ways. On one hand, it could be a positive sign of increased water use efficiency in agriculture, a key objective of national policies. More efficient irrigation techniques would lead to less water seeping back into the ground and becoming part of the "other sources" recharge component. On the other hand, it could simply be a consequence of reduced overall irrigation due to a less favorable monsoon, which would point to increased stress on the system. Regardless of the underlying cause, the net result—a higher national stage of extraction—serves as a cautionary signal. It indicates that the positive long-term trend, driven by successful conservation efforts since 2017, is not yet robust enough to withstand short-term fluctuations in weather or demand, and the system remains in a precarious state of equilibrium.<sup>1</sup>

## 2.3 Dissecting State-wise and Regional Groundwater Dynamics

The national averages mask profound regional variations in groundwater stress. The GWRA-2024 report provides a detailed state-by-state analysis that highlights these disparities, which are largely determined by a combination of geology, climate, and human activities. The report identifies three distinct hydrogeological archetypes of over-exploitation<sup>1</sup>:

1. **North-western Alluvial Plains:** States like Punjab, Haryana, and Uttar Pradesh are characterized by thick, porous alluvial formations with a high potential for recharge. However, they suffer from over-exploitation due to indiscriminate withdrawals.<sup>1</sup> The problem here is one of unsustainable demand, not a lack of resource. For example, Punjab's stage of extraction is a staggering **156.87%**, with 115 of its 153 assessment units categorized as 'Over-exploited'.<sup>1</sup> This is largely driven by water-intensive agricultural practices and the policies that support them.
2. **Western Arid Zones:** States in this region, such as Rajasthan and parts of Gujarat, face a different problem. Their arid climate results in limited natural groundwater recharge, making them highly vulnerable to over-extraction. The report highlights Rajasthan's stage of extraction at **149.86%**, with 214 of its 302 assessment units in the 'Over-exploited' category.<sup>1</sup>
3. **Southern Peninsular Hard Rock Terrains:** In this region, which covers nearly 70% of India's landmass, the primary challenge is the low storage and transmission capacity of crystalline aquifers.<sup>1</sup> States like Karnataka and Tamil Nadu suffer from over-exploitation because groundwater is confined to the shallow weathered zones and deeper fractures, which cannot sustain high-volume withdrawals. Tamil Nadu's stage of

extraction is 74.26%, with 106 of its 313 assessment units being 'Over-exploited'.<sup>1</sup>

The report also provides crucial data on the year-over-year changes in assessment unit categorization, offering tangible evidence of where management efforts are succeeding and where they are failing. Of the 6,746 units assessed nationwide, 128 units showed an improved status from 2023 to 2024, while 173 units deteriorated.<sup>1</sup> States like Telangana provide a clear example of this dynamic, where the stage of extraction increased significantly from 38.65% in 2023 to 45.91% in 2024, primarily due to a decrease in recharge from other sources.<sup>1</sup> Conversely, states like Chhattisgarh saw marginal improvements, with two units improving in status and only one deteriorating.<sup>1</sup> This granular data provides a strong basis for future targeted interventions.

State/Union Territory	Recharge (bcm)	Extraction (bcm)	Stage of Extraction (%)	Over-exploited Units
Andhra Pradesh	27.80	7.88	29.83	9
Bihar	34.15	14.10	45.54	4
Chhattisgarh	14.18	6.12	47.32	0
Haryana	10.32	12.72	135.96	88
Karnataka	18.74	11.55	68.44	45
Punjab	19.19	27.66	156.87	115
Rajasthan	12.58	17.05	149.86	214
Tamil Nadu	21.51	14.45	74.26	106
Telangana	20.40	8.47	45.91	32
Uttar Pradesh	72.84	46.76	70.45	59
West Bengal	25.89	10.75	45.63	0

## 2.4 The Multi-dimensional Challenge: Water Levels and Quality

The groundwater crisis is not solely a matter of quantitative resource depletion; it is also a question of physical water levels and chemical quality. The GWRA-2024 report provides a detailed analysis of these factors, which are essential for a comprehensive understanding of the situation.

- **Water Level Trends:** The report presents a complex picture when analyzing groundwater level fluctuations. A comparison of pre-monsoon water levels in 2023 with the decadal mean (2013-2022) indicates a positive trend, with **56.11%** of wells showing a rise in water levels.<sup>1</sup> This long-term trend suggests that conservation initiatives and favorable rainfall cycles over the past decade have contributed to the slow recovery of aquifers in some areas. However, a year-on-year comparison of pre-monsoon 2023 with pre-monsoon 2022 reveals a less optimistic short-term trend, with **58.12%** of wells showing a decline in water levels.<sup>1</sup> This suggests that the groundwater system is still under significant stress and that the overall positive trajectory is fragile and highly susceptible to annual fluctuations in rainfall and extraction.
- **Groundwater Quality:** The report explicitly acknowledges the importance of water quality, noting that 127 of the country's assessment units, representing **1.88%** of the total, have been categorized as 'Saline'.<sup>1</sup> The GEC-2015 methodology formalizes this by recommending that, in addition to the quantity-based categorization, each assessment unit should bear a **quality hazard identifier** for problems such as Arsenic, Fluoride, and Salinity.<sup>1</sup> This quality tag is a crucial component of the assessment, as it highlights that even units with a low stage of extraction can be unusable if the water quality is poor. Over-extraction in coastal areas can lead to saline water intrusion, while in inland areas it can mobilize naturally occurring pollutants like arsenic and fluoride or concentrate agricultural and industrial runoff, all of which pose significant health risks and compromise the usability of the resource.<sup>6</sup> The integration of these quality markers into the overall assessment is a significant step toward a more holistic understanding of groundwater health.

## Chapter 3: Strategic Insights and the Path to Sustainable Groundwater Management

The detailed assessment of India's groundwater resources in the GWRA-2024 report provides

a critical foundation for strategic policy and management. This chapter synthesizes the findings, connects the data to existing policy initiatives, and offers a forward-looking perspective on how to achieve a sustainable and water-resilient future.

### 3.1 The Policy-Practice Nexus: Bridging the Gap

India has a robust framework of national policies and programs designed to manage its water resources. The GWRA-2024 data provides a valuable opportunity to evaluate the effectiveness of these initiatives. The report itself notes the transformative potential of programs like the **Atal Bhujal Yojana (ATAL JAL)** and the **Jal Shakti Abhiyan (JSA)**.<sup>1</sup> The ATAL JAL scheme, for instance, focuses on a community-led, data-driven approach to demand-side management in water-stressed areas of seven states, including Haryana, Gujarat, and Rajasthan.<sup>8</sup> The JSA, launched in 2019, has focused on supply-side interventions like rainwater harvesting and conservation.<sup>1</sup>

The effectiveness of these efforts is tangible in the data. Between 2017 and 2024, the recharge from "Tanks, Ponds and WCS" has shown a consistent increase, with a notable jump of 11.36 bcm during this period.<sup>2</sup> This provides direct evidence that supply-side interventions are working and are a key component in stabilizing groundwater levels.

However, a critical analysis of the data reveals a persistent disjunct. While recharge efforts are making a difference, they are not yet sufficient to overcome the pressures of demand, particularly from the agricultural sector. The fact that 87% of all groundwater extraction is for irrigation<sup>1</sup> points to a core challenge that is rooted in economic and political realities. Government policies, such as electricity subsidies for agricultural pumps and minimum support prices (MSPs) for water-intensive crops like paddy, create powerful incentives for over-extraction.<sup>5</sup> This forms a "water-food-energy nexus" where water management cannot be disentangled from food and energy policies. The long-term success of groundwater management will therefore require a holistic approach that reforms these underlying drivers of demand, not just a continued focus on supply-side augmentation.

### 3.2 Methodological Refinements and Future Assessment

The GEC-2015 methodology, used for the current assessment, provides a comprehensive and adaptable framework for estimating groundwater resources across India's diverse hydrogeology.<sup>1</sup> Its strengths include a standardized approach for data collection and analysis,

the use of a web-based platform (IN-GRES) for pan-India operationalization, and a robust validation process that links quantitative data to observed water level trends.<sup>1</sup>

However, the report itself outlines a path for continuous improvement to enhance the accuracy and relevance of future assessments.<sup>1</sup> The following opportunities for refinement are identified:

- **Refining Empirical Norms:** The methodology relies on a set of empirical factors, such as the Rainfall Infiltration Factor and Specific Yield values, which are applied uniformly across broad hydrogeological zones.<sup>1</sup> The report suggests that to improve accuracy, more in-depth field studies are needed to refine these norms based on local conditions, such as soil type and agro-climatic zones.<sup>1</sup>
- **Adopting Aquifer-Based Management:** The current practice of using administrative units as the basis for assessment, while practical, is not always hydrologically sound.<sup>1</sup> A more advanced approach would be to conduct assessments and implement management plans at the aquifer level, which represents a more natural and holistic hydrogeological unit. The report points to ongoing efforts like the **National Aquifer Mapping & Management Programme (NAQUIM 2.0)** and the use of high-resolution heli-borne geophysical surveys as steps in this direction.<sup>1</sup>
- **Temporal and Holistic Analysis:** The current methodology provides a detailed annual snapshot, but a more dynamic understanding is needed, particularly in hard rock areas where resource availability can fluctuate rapidly. The report recommends moving towards a more temporal analysis of groundwater availability and integrating base flow and lateral flow components more accurately into the water balance equation.<sup>1</sup> This would allow for a more precise understanding of the interactions between groundwater and surface water, a key element of conjunctive water use.<sup>4</sup>

### 3.3 Strategic Recommendations for a Water-Resilient Future

Based on the synthesis of the 2024 assessment and the methodological framework, the following strategic recommendations are proposed to ensure the long-term sustainability of India's groundwater resources:

1. **Prioritize Demand-Side Management in Agriculture:** Given that 87% of groundwater is used for irrigation, this is the most critical area for intervention.<sup>1</sup> Policies must be implemented to reform the perverse incentives that drive over-extraction. This includes re-evaluating agricultural power subsidies, promoting water-efficient micro-irrigation technologies, and encouraging crop diversification away from water-intensive crops in water-stressed areas.<sup>5</sup>
2. **Strengthen Data Collection and Institutional Frameworks:** The principle that "we can

only manage what we can measure" is paramount.<sup>1</sup> The national network of observation wells should be expanded and the use of direct, metered measurement of groundwater withdrawals should be made mandatory, especially in over-exploited and critical areas.<sup>3</sup> Institutional reforms, such as the proposal for a National Water Commission to integrate the functions of the CWC and CGWB, would help create a more cohesive and effective water management framework.<sup>7</sup>

3. **Implement Region-Specific Management Strategies:** The data clearly shows that groundwater challenges are not uniform across the country.<sup>1</sup> Management strategies must be tailored to the specific hydrogeological reality of each region. This means different solutions for the alluvial plains (demand-side management), arid zones (conservation and judicious use), and hard rock terrains (local recharge and community-led management).<sup>1</sup>
4. **Promote Community Empowerment and Participatory Governance:** Programs like the Atal Bhujal Yojana have demonstrated that community participation is vital for successful groundwater management.<sup>8</sup> Empowering local bodies, including village councils and water user associations, to create water budgets, monitor usage, and implement local conservation schemes is an effective way to address the issue at the grassroots level.<sup>8</sup> The participation of women in these decision-making roles is particularly important, as highlighted in the ATAL JAL scheme.<sup>8</sup>

## Conclusion

The 2024 National Compilation on Dynamic Ground Water Resources of India offers a detailed, data-rich assessment of the nation's most precious freshwater resource. The report's findings present a complex and multi-faceted picture: a long-term trend of improvement is being challenged by a short-term reversal, signaling that the system remains under intense pressure. This pressure is not uniform but varies dramatically across the country, influenced by a combination of climate, geology, and human activity.

The report reinforces the fact that India's groundwater crisis is inseparable from its agricultural sector, which accounts for the vast majority of water consumption. Therefore, sustainable groundwater management must be an integral part of India's broader strategies for food security and rural development. The analysis also confirms that while national programs have successfully boosted recharge from conservation structures, these gains are being outpaced by extraction in many regions.

The GEC-2015 methodology has provided a consistent and scientific basis for this assessment. However, the path forward requires continuous refinement of this methodology, including more rigorous field studies to validate empirical norms and a transition to a more

hydrologically coherent, aquifer-based management approach. Ultimately, securing a water-resilient future for India will depend on a decisive shift toward a holistic strategy that combines supply-side augmentation with bold, demand-side reforms, all supported by robust data and empowered community participation. A concerted effort, guided by the granular data and strategic insights of reports like the GWRA-2024, is an essential step towards safeguarding this invaluable resource for generations to come.

## Appendices

### Appendix A: Key Tables from the GWRA-2024 Report

Table 1: All-India Groundwater Resources and Extraction Scenario (2024)

Category	Value (bcm)	Percentage
Total Annual Ground Water Recharge	446.90	N/A
Annual Extractable Ground Water Resources	406.19	N/A
Total Annual Ground Water Extraction	245.64	N/A
Stage of Ground Water Extraction	N/A	60.47%
Extraction by Use		
For Irrigation	213.29	87%
For Domestic Use	28.07	11%

For Industrial Use	4.28	2%
<b>Recharge by Source</b>		
From Rainfall	270.91	61%
From Other Sources	175.68	39%

**Table 2: State-wise Groundwater Status Overview (Selected States, 2024)**

State	Total Assessment Units	Safe	Semi-critical	Critical	Over-exploited
Andhra Pradesh	679	591 (87.03%)	38 (5.59%)	2 (0.29%)	9 (1.32%)
Bihar	535	473 (88.41%)	49 (9.16%)	9 (1.68%)	4 (0.75%)
Haryana	143	36 (25.17%)	8 (5.59%)	11 (7.69%)	88 (61.54%)
Punjab	153	22 (14.38%)	12 (7.84%)	4 (2.61%)	115 (75.16%)
Rajasthan	302	37 (12.25%)	21 (6.95%)	27 (8.94%)	214 (70.86%)
Tamil Nadu	313	127 (40.3%)	55 (17.6%)	20 (6.4%)	106 (33.87%)
Telangana	620	490 (79.03%)	85 (13.71%)	13 (2.10%)	32 (5.16%)
Uttar Pradesh	836	566 (67.7%)	165 (19.74%)	46 (5.50%)	59 (7.06%)

## Appendix B: Glossary of Technical Terms and Abbreviations

- **ATAL JAL:** Atal Bhujal Yojana
- **bcm:** Billion Cubic Meters
- **CGWB:** Central Ground Water Board
- **CLEG:** Central Level Expert Group
- **GEC-2015:** Ground Water Estimation Methodology - 2015
- **GWRA-2024:** Dynamic Ground Water Resource Assessment of India, 2024
- **IN-GRES:** India Groundwater Estimation System
- **JSA:** Jal Shakti Abhiyan
- **NAQUIM:** National Aquifer Mapping & Management Programme
- **RIFM:** Rainfall Infiltration Factor Method
- **SLC:** State Level Committees
- **WTFM:** Water Table Fluctuation Method

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## Potential Chatbot Queries

- What is the total annual groundwater recharge in India for 2024?
- What is the total annual groundwater extraction for all uses in 2024?
- What is the national average stage of groundwater extraction?
- How many assessment units are categorized as 'Over-exploited' in the 2024 report?
- Which state has the highest stage of groundwater extraction?
- What percentage of India's groundwater extraction is used for agriculture?
- What are the main components of the GEC-2015 water balance equation?
- How is a 'Watershed' different from a 'Block' as an assessment unit?
- What are the different categories for groundwater assessment units?
- What is the purpose of the Atal Bhujal Yojana?
- How has the percentage of 'Safe' assessment units changed since 2017?
- Can you provide a definition for a 'Semi-critical' groundwater unit?
- What are the primary methods for calculating groundwater recharge from rainfall?
- What is the purpose of the validation framework in the GEC-2015 methodology?
- What are the key findings of the 2024 report regarding groundwater quality?
- Which government initiatives focus on community participation for water management?
- How is groundwater extraction estimated when direct measurements are not available?
- In which regions of India is over-exploitation of groundwater most concentrated?
- What does the acronym CGWB stand for?
- What is the significance of the "water-food-energy nexus" in India's water management?
- Can you provide groundwater data for the state of Haryana?
- What are the components of recharge from "other sources"?

## Frequently Asked Questions (FAQs)

**Q: What are the primary findings of the 2024 National Compilation on Dynamic Ground Water Resources of India? A:** The report provides a comprehensive overview of the nation's groundwater. The key findings for 2024 are:

- Total annual groundwater recharge is estimated at **446.90 billion cubic meters (bcm)**. After accounting for natural discharge, the total annual extractable groundwater resource is **406.19 bcm**.
- Total annual groundwater extraction for all uses is **245.64 bcm**, resulting in an average national stage of extraction of **60.47%**.
- Groundwater extraction for agriculture accounts for **87%** of the total, while

domestic use accounts for 11% and industrial use for 2%.

- Of the 6,746 assessment units, 751 (11.13%) are categorized as 'Over-exploited,' where extraction exceeds annual recharge. An additional 206 units (3.05%) are classified as 'Critical'.

**Q: How does the 2024 groundwater assessment compare to the 2023**

**assessment?** **A:** The 2024 report shows a marginal increase in the national stage of extraction from 59.21% in 2023 to 60.47% in 2024. This change is attributed to a slight decrease in annual recharge and an increase in extraction. The decrease in recharge is primarily due to a reduction in return flow from irrigation. Despite this year-on-year change, the long-term trend since 2017 shows an overall improvement, with the percentage of 'Over-exploited' units declining from 17.24% to 11.13% and 'Safe' units increasing from 62.6% to 73.4%.

**Q: What is the GEC-2015 methodology for groundwater assessment?** **A:** The Ground Water Estimation Methodology - 2015 (GEC-2015) is the technical framework used for the assessment. It is based on the fundamental water balance equation: Inflow - Outflow = Change in Storage. The methodology quantifies inflows, such as recharge from rainfall and other sources, and outflows, such as groundwater extraction and natural discharge. It also defines a standardized "groundwater year" and categorizes assessment units based on the stage of extraction.

**Q: What are the two main methods for calculating recharge from rainfall?** **A:** The GEC-2015 methodology uses two primary methods for calculating rainfall recharge :

1. **Water Table Fluctuation Method (WTFM):** This method is preferred when sufficient water level data is available. It calculates the change in storage by measuring the rise in the water table during the monsoon season and multiplying it by the aquifer's specific yield and area.
2. **Rainfall Infiltration Factor Method (RIFM):** This is an empirical method used when water level data is inadequate. It applies a predefined Rainfall Infiltration Factor to the volume of net rainfall over a given area.

**Q: How is groundwater extraction for different uses estimated?** **A:** Since direct metering of groundwater is often not feasible, the GEC-2015 methodology recommends using multiple indirect methods to obtain a more reliable figure. These methods include:

- **Unit Draft Method:** Estimating the average water withdrawn per well per day and multiplying it by the number of active wells in an area.
- **Crop Water Requirement Method:** Calculating the water needed for specific crops in an area and assuming a portion of this demand is met by groundwater.
- **Power Consumption Method:** Estimating the volume of water extracted per

unit of electricity consumed and using total power consumption data from agricultural feeders.

- **Consumptive Use Method:** For domestic and industrial use, this method relies on per-capita water needs or industrial water consumption norms multiplied by population or number of units.

**Q: How are assessment units categorized and what do the categories mean? A:** Assessment units are classified based on the 'Stage of Groundwater Extraction', which is the ratio of annual extraction to annual extractable resources. The categories are:

- **Safe:** Stage of extraction is less than 70%.
- **Semi-critical:** Stage of extraction is between 70% and 90%.
- **Critical:** Stage of extraction is between 90% and 100%.
- **Over-exploited:** Stage of extraction is greater than 100%.
- **Saline:** A distinct category for units where the water in the shallow aquifer is brackish or saline.

**Q: What government initiatives are in place for groundwater management? A:** The Indian government has launched several initiatives to promote sustainable groundwater management.

- **Atal Bhujal Yojana (ATAL JAL):** A community-led, data-driven scheme focusing on demand-side management in water-stressed areas across seven states. It encourages communities to prepare water budgets and monitor usage.
- **Jal Shakti Abhiyan (JSA):** A campaign focused on water conservation, rainwater harvesting, and the rejuvenation of water bodies.
- **Pradhan Mantri Krishi Sinchayee Yojana (PMKSY):** A scheme that aims to create irrigation potential through groundwater development in 'Safe' assessment units where there is sufficient resource available for development.
- **National Aquifer Mapping & Management Programme (NAQUIM):** This program maps major aquifers and formulates management plans, prioritizing over-exploited, critical, and semi-critical areas.<sup>1</sup>