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Assessment and Challenges of Groundwater Resources of India: A Comprehensive Study of Current Status and Sustainability Measures

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Abstract: India's groundwater resources are critical to its agricultural, industrial, and domestic needs, yet their sustainability is increasingly in jeopardy due to over-extraction and pollution. Through a review of various government reports and existing literature, the current status of groundwater resources in India has been provided in this study. This study also provides a historical background of groundwater assessment in India. The study highlights the key challenges India is currently facing in groundwater management, including overexploitation of groundwater resulting in the lowering of the water table, contamination from agricultural runoff and industrial activities, and the impacts of climate change on groundwater resources. The research further evaluates ongoing sustainability measures, such as government policies, community-based management practices, and technological innovations in groundwater monitoring and recharge. By analysing the effectiveness of these measures and identifying gaps, the study proposes a framework for improved groundwater management that integrates scientific research, policy reform, and community engagement.

Keywords: Groundwater • Groundwater Challenges • Sustainability measures

Introduction

Water is considered an elixir of life, without it, it isn't easy to imagine life on Earth. Rainfall is the primary source of water on the earth's surface. After the earth's surface receives rainfall, either it is deported to water bodies through surface runoff or it seeps into the ground. Based on these specialties of water movement, water can be broadly divided into two types. The first one is surface water, which includes streams of different sizes whether they are big or small, and the second one is groundwater. After water seeps into the ground, it flows through unsaturated zones and ultimately reaches the water table. A water table is an imaginary surface from where the ground beneath is saturated Suhag, R. (2016). The most important source of replenishable underground water is rainfall. If we exclude the polar ice caps, 95% of the freshwater available on Earth is groundwater. Rivers and lakes make up only 3 % of our surface water. Types of rock formation, their capacity to hold water, and their power to transfer water to other rocks also have a significant influence on groundwater recharge. Based on hydraulic properties geological formations can be divided into four parts namely, Aquifer, Aquitard, Aquiclude, and Aquifuge. Aquifers have high porosity that makes them more permeable than any other three geological formations mentioned above. Due to its high porosity, it also has the highest capacity to store groundwater making it most useful for human beings Siebert et al (2010). Aquitard has low to medium permeability rates and usually consists of silt and clay. Aquiclude and Aquifuge both have very low permeability and do not transfer any amount of groundwater. The hydrogeological setting of any region is also important in the water retention and replenishment capacity of the aquifer system Pandey et al (2022). Based on the hardness or softness of the rocks, Indian rock formation can be broadly divided into two parts, Hard rock formation, and soft rock formation. In the soft rock formations, there are ample number of pores through which water percolates easily into the ground thus making this type of formation a good repository of groundwater. In India, Indo-Ganga-Brahmaputra plains come under this type of formation. Most of the peninsular India especially the central peninsula comes under the hard rock formation category. In these formations, rainwater does not percolate underground easily resulting in low groundwater recharge. In this study, this study focuses on different problems arising due to unsustainable management of groundwater resources and provides solutions for effective management of groundwater through reviewing different groundwater management programs and policies of national and international level.

Background of Groundwater Assessment in India

India's water resource assessment history dates back to 1901 when the surface water resources of India were calculated to be around 144 million hectares meters by the first irrigation commission NABARD (2006). For the systematic groundwater assessment, in 1979, the agriculture Refinance and Development Corporation formulated the Groundwater Over-exploitation Committee. According to the report submitted by this committee, India's gross groundwater recharge was 47 million-hectare meters at that time. The net recharge was assessed at 32 million hectare meters Central Ground Water Board (1995). In 1982, the 'Ground Water Estimation Committee' was formed by the Indian government, usually known as GEC. The committee submitted its report in 1984. It was the result of this report that state governments constituted working groups that later on tried to assess the groundwater potentials of various areas within the state. In 1995, all the collected data from every state and union territory was compiled together, and finally, a report was published. According to that report, the total replenishable groundwater in India was 432 billion cubic meters (bcm) at that time Central Ground Water Board (1995). This report is considered a landmark event in the history of groundwater assessment because the publication of this report motivated the government to formulate another committee, that reviewed the existing methodology of groundwater resource assessment and suggested some revisions to their report. This report is known as GEC 1997. To study how to estimate groundwater in hard rock terrains and what the problems are in assessing the groundwater resources in these areas, a committee named 'Ground Water Estimation Methodology' was formed in 2001. This committee suggested that for groundwater estimation, terrain conditions should not be given that much importance, instead the categorization of blocks should be done based on some criteria. Based on the methodology provided in the report of GEC 1997, groundwater estimation for the entire country was carried out, taking 2004, 2009, 2011, and 2013 as base years. Groundwater estimated during the past years has been shown in Table 01, given below.

Current Status of Ground Water Resources in India

In recent times, groundwater has become a vital resource to fulfill the water demands of the country. With this rising demand, the extraction of groundwater has also increased. To understand the current status of groundwater in India. A study of annual groundwater recharge and groundwater extraction is necessary to understand the current status.

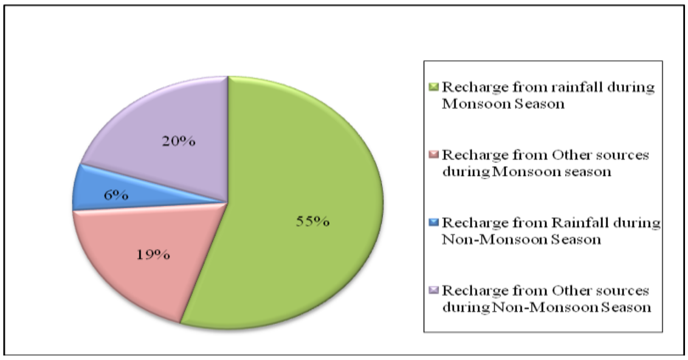
Table 1. Ground Water Resource Assessment from 2004 to 2023

SN	Ground Water Resources Assessment	2004	2009	2011	2013	2017	2020	2022	2023
1	Annual Ground Water Recharge (bcm)	433	431	433	447	432	436	438	449
2	Annual Extractable Ground Water Resource (bcm)	399	396	398	411	393	398	398	407
3	Annual Ground Water Extraction for Irrigation, Domestic & Industrial uses(bcm)	231	243	245	253	249	245	239	241
4	Stage of Ground Water Extraction (%)	58 %	61 %	62 %	62 %	63 %	62 %	60%	59%

Source: National Compilation on Dynamic Ground Water Resources of India, 2023

Annual Ground Water Recharge

The annual groundwater recharge is also known as dynamic groundwater resources because rainfall and other secondary sources, like water conservation structures surface water bodies like lakes, ponds, applied irrigation water, etc. recharge it every year. The total annual groundwater recharge of India in 2023 was 449.08 bcm, out of which 407.21 bcm was available to be extracted annually. In India recharge from rainfall is the main contributor to the estimated groundwater recharge annually. The total amount of groundwater recharge through monsoon and non-monsoon season is 270.78 bcm, which is approximately 60%. The rest of the groundwater recharge, which is 178.31 bcm, is from different sources, like canal seepage and irrigation return flow. Recharge from tanks, ponds and other water conservation techniques like recharge pits, trenches, etc. also play a huge role in groundwater recharging. Annual groundwater recharge in the states like West Bengal, Bihar, Uttar Pradesh, Punjab, Haryana, and the northeastern states is high. The reason for this high amount of groundwater recharge is that the soil of this area is mostly made up of unconsolidated alluvium, which is helpful in the percolation of surface water to the underground. Annual groundwater recharge in these areas is between 0.25 to more than 0.5 m. The coastal plains, especially the eastern coastal plain have relatively high annual groundwater recharge, in the range of 0.25 to more than 0.5 m. In most of the peninsular part of India, annual groundwater recharge ranges from 0.10 to 0.15 m.



Source: National Compilation on Dynamic Ground Water Resources of India, 2023

Figure 1. Groundwater Recharge Scenario in India, 2023

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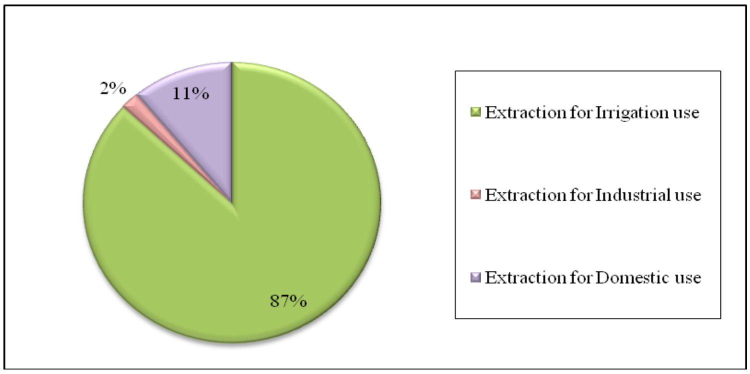
The reason for this low amount of annual water recharge is that this area is mostly covered with hard rocks. These hard rock formations have a very low storage capacity to hold water and an even lower capacity to infiltrate water underground. Western parts of India, including Rajasthan and parts of northern Gujrat have the lowest groundwater recharge which is up to 0.025 m. This area represents the arid type of climate in India receiving a very low amount of rainfall, resulting in the lowest amount of groundwater recharge annually.

Annual Ground Water Extraction

In 2023, the estimated value of the total annual groundwater extraction in India was 241.34 bcm, which accounts for 59.26%. Dadra & Nagar Haveli, Haryana, Daman & Diu, Rajasthan, and Punjab are some states where groundwater extraction is above 100%. The agricultural sector uses 209.74 bcm of groundwater, which is 87% of the total groundwater extraction. Karnataka, Tamil Nadu, Delhi, UTs of Chandigarh, Uttar Pradesh, Puducherry, and Lakshadweep, groundwater extraction is between 60-100 %. In the other states/UTs, extraction of groundwater is less than 60 %. In states like Jammu & Kashmir, Assam, Sikkim, Himachal Pradesh, Mizoram, Uttarakhand, most of West Bengal, Arunachal Pradesh, etc. groundwater extraction is low. There is little need to extract groundwater in these places because they are heavily dependent on natural springs for their daily water needs. Springs are the most conspicuous forms of natural return of groundwater to the surface. They come in all sizes, from small trickles to large streams. When ground water oozes from the ground surface, it is called a spring. The largest consumer of groundwater is the agriculture sector, which uses 209.74 bcm groundwater of the total extractable groundwater. It accounts for almost 87%. Groundwater for domestic use accounts for 27.57 bcm which is 11% of the total extractable groundwater. The industrial sector uses only 2% (4.01 bcm) of groundwater.



Source: National Compilation on Dynamic Ground Water Resources of India, 2023

Figure 2. Groundwater Extraction Scenario in India, 2023

Challenges Related to Ground Water in India

Groundwater is essential for agriculture but over-exploitation of groundwater for intensive agriculture in major agricultural regions of India has led to many groundwater-related challenges. Lowering of the water table is the most common problem due to overexploitation of the groundwater. When the water table gets very low, it may take several years to get fully recharged again, resulting in a long-term shortage of groundwater. Depletion of the water table is also associated with loss of base flow; it affects those water bodies that get their water from base flow, like wetlands and lakes, etc. For irrigation purposes, Groundwater is a critical source but it is depleting at an alarming rate across the globe. In India, over 80 % of groundwater is used for irrigation. Due to the over-exploitation of groundwater for irrigational purposes, water tables have dropped by more than 8 m on average since the 1980s Rodell et al (2009), resulting in the depletion of groundwater reserves in many regions across the country. Over the years, groundwater depletion has impacted crop production significantly. During the winter season, when there is little rainfall available, groundwater plays an important role in crop production. The problem of groundwater depletion is consistent in the agriculture sector because the farmers have increased investment in high-capacity pumps to extract groundwater Bhattarai et al (2021).

Ensuring a safe drinking water supply in a vast country like India is an uphill task. In India, groundwater nearly fulfills 85% of rural and 50% of urban drinking water requirements Saha and Ray (2018). Groundwater pollution is one of the issues, India is dealing with. Groundwater pollution is caused by waste generated in agricultural fields. Liquid waste or sewage discharged from industrial areas, and urban and rural waste disposal. All this waste is mixed with surface water, which slowly percolates underground and pollutes the groundwater. Uranium concentration is beyond the permissible limits in 12 states of the country with Punjab leading the states with the highest percentage of uranium concentration wells, followed by Haryana. Groundwater in Uttara Pradesh, Rajasthan, and Delhi also has a toxic concentration of Uranium Central Ground Water Board (2021). The problem of fluoride is found across 27 states of India. Arsenic is found in 230 districts in 25 states of India. Arsenic occurs in groundwater due to fly ash from thermal power plants and waste discharge from mining areas. Chronic exposure to arsenic can cause black foot disease. West Bengal state is the worst affected state due to arsenic contamination in groundwater. Assam is heavily affected by iron pollution in groundwater. Iron concentration greater than 1.0 mg/l has been found in more than 1.1 lakh settlements of India. Nitrate concentration beyond permissible limits has been found in almost all hydrological formations across the country. Excessive nitrate concentration in drinking water can lead to diseases like blue baby syndrome Overview of Ground Water Quality (Cgwb).

In India, groundwater's natural recharge mechanism has been directly affected by climate change because rainfall and evapotranspiration are mainly controlled by the climate. In semi-arid areas, rainfall is the only contributor to recharging of groundwater but sometimes heavy rainfall also leads to microbial pollution Swain et al (2022). In the recent past, climate change has affected the rainfall pattern in India. Now there is a higher amount of precipitation in a short period. This type of rainfall pattern, where a higher amount of rainfall happens in a shorter period, increases the chances of a high amount of surface runoff, resulting in less amount of water infiltration to the underground Aadhar and Mishra (2020). These changes reveal that due to this type of rainfall pattern in the future, Kharif crops will face more risks of droughts and floods. Even Rabi crops during the summer season will face excessive evapotranspiration. To curb this increased water demand for crops, the extraction of groundwater will also increase at a much larger scale in the future. Climate change's indirect impact on groundwater is mostly changes in the use of groundwater, which is mostly governed by anthropogenic activities. Uses of fertilizers to increase the production of crops has led to the deterioration of groundwater quality.

Several bodies are responsible for managing groundwater in the country. Over the years, this type of fragmented regulation has resulted in unsustainable and unregulated

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groundwater resource management. There is also a lack of legal provisions related to how much groundwater a person or a family can extract. In India, groundwater extraction is directly associated with the land ownership rights of the owner of the land. It allows the landowners to extract groundwater at any level they want. One of the major problems in monitoring and sustainable planning of groundwater resources is the lack of comprehensive data related to groundwater. This makes it difficult for policymakers to formulate any kind of policy related to groundwater management in India.

Sustainability measures

If we talk about how to sustainably manage groundwater, we can use a two-way approach. One is an action-based approach, and the second is a technology-driven approach. In an action-based approach, changes in the cropping pattern, sowing those crops that demand less water, improving irrigation water use efficiency, and rainwater harvesting can be the options. At the technology level, information related to the aquifer's characteristics, recharge zone identification, and accurate prediction of the upcoming monsoon are some ways.

Policy intervention can be an area that needs attention Danger et al (2021). The agriculture sector uses the most amount of groundwater in the country. India is one of the most important producers of various crops, like wheat, rice, maize, soybean, etc. To fulfill the food demand, the current level of crop production must be sustained. However, meeting these crops water demand is a big challenge in water-stressed regions of India. That's why focusing on crops that take less water to grow, like rice and different kinds of pulses, can be an option to reduce the dependence of the agriculture sector on groundwater Russo et al (2015). It has been seen that due to government subsidy on electricity, even in areas where there is less shortage of water for different purposes, the withdrawal of groundwater has increased. The rapid increase in groundwater extraction in states like Haryana, Punjab, etc. is not suitable for sustainable groundwater management in the country Lenton (2014).

For long-term groundwater sustainability, enhancing groundwater recharge is very important. In the 21st century, Managed aquifer recharge (MAR) is a technology that can help restore groundwater recharge Dillon et al (2019). MAR is useful in the groundwater's vulnerability caused due to climate change. It is also useful in aquifer recharging, improving groundwater quality, controlling saltwater intrusion, and preventing subsidence of land.

Watershed development should be done at the local level. Watershed development initiatives can help increase groundwater recharge. The most important thing to be taken care of in the case of watershed development is the continuous monitoring and collection of data. Impact assessments regarding drought resilience should also be done at regular intervals. This knowledge regarding watershed development, dos and Don'ts in the management of developed watersheds, and other necessary knowledge should be imparted to the community people. So that they can collect the data at regular intervals.

In the past, there have been many initiatives regarding water resources management. *Pani Panchayat* model in the state of Orrisa has been a successful initiative. Since 2015, The Pani Panchayat's have strengthened 6 major irrigation projects in Orrisa Boruah and Naz (2020). *Atal Bhujal Yojna* is a joint initiative by the World Bank and the Government of India, for sustainable management of groundwater. The main goal is to improve groundwater levels in water-stressed areas of Haryana, Madhya Pradesh, Rajasthan, and Gujrat. This initiative also focuses on community development through workshops and hands-on training programs. "*(PMKSY)-*

Har Khet ko Pani (HKKP)” scheme envisages improving the aquifer recharge. At present, central and state governments are responsible for groundwater management, the focus needs to be shifted from a top-bottom approach to a bottom-up approach, where the community should have the full authority to manage groundwater resources.

Further, India also needs to adopt successful groundwater management practices from other countries. Like Mexico, India can also declare groundwater as national property. Like the US, India can also treat river water and then add it to the groundwater basin. India can also learn from Canada, where management of groundwater is done through aquifer classification. In this classification, aquifers are classified according to their uses, vulnerability, and contamination level Chevalking et al (2008).

Water harvesting is an option to sustainably manage rainfall. In the southern part of India, where there are semi-arid watersheds, water harvesting systems account for 50% of aquifer recharge. Water harvesting in India is an ancient, indigenous knowledge. In the modern era, where the whole world is relying on recharge zone identification and aquifer mapping using remote sensing and Geographical Information Systems, rainwater harvesting still holds a significant amount of value. It is very important to impart this indigenous knowledge to the younger generation so that they can integrate the technological knowledge with the indigenous knowledge to manage the groundwater sustainably.

Coordination between surface water agencies like the Central Water and Power Research Station (CWPRS), Department of Drinking Water and Sanitation, Central Water Commission (CWC), and groundwater monitoring agencies like the National Institute of Hydrology (NIH) and Central Ground Water Board (CGWB) is also important for long-term quantification and groundwater resource assessment in India Srinivasan and Kulkarni (2014). The interaction between the environment and social practices should be understood to make better policies for sustainable management of groundwater resources Giuliani et al (2016).

References

Aadhar S and Mishra V (2020). Increased Droug ht Risk in South Asia Under Warming Climate: Implications of Uncertainty in Potential Evapotranspiration Estimates. *Journal of Hydrometeorology (Online)*, *21*(12), 2979–2996.

Bhattarai N, Pollack A, Lobell D B, Fishman R, Singh B, Dar A and Jain M (2021). The impact of groundwater depletion on agricultural production in India. *Environmental Research Letters*, *16*(8), 085003.

Boruah J and Naz F (2020). Groundwater Management under Indian Legal Framework. *SSRN Electronic Journal*.

Central Ground Water Board (1995) Ground Water Resource of India. Ministry of Water Resources, Govt. of India, Faridabad.

Central Ground Water Board. *Ground Water Year Book - India - 2021 -22*.

Chevalking S, Knoop L and Van Steenbergen F (2008). *Ideas for groundwater management*. https://portals.iucn.org/library/node/9237

Dangar S, Asoka A and Mishra V (2021). Causes and implications of groundwater depletion in India: A review. *Journal of Hydrology*, *596*, 126103.

Dillon P, Stuyfzand P, Grischek T, Lluria M, Pyne RDG, Jain RC, Bear J, Schwarz J, Wang W, Fernandez E, Stefan C, Pettenati M, van der Gun J, Sprenger C, Massmann G, Scanlon B.R, Xanke J, Jokela P, Zheng Y, Rossetto R, Shamrukh M, Pavelic P, Murray E, Ross A, Bonilla Valverde JP, Palma Nava A, Ansems N, Posavec K, Ha K, Martin R, Sapiano M, (2019). Sixty years of global progress in managed aquifer recharge. Hydrogeol. J. 27, 1–30. .

Giuliani Matteo, Li Y, Castalletti and Gandolphi C. A Coupled Human-natural Systems Analysis of Irrigated Agriculture Under Changing Climate. *Water Resources Research*, vol. 52, no. 9, Sept. 2016, pp. 6928–47. .

Lenton Roberto (2014). "Irrigation In The Twenty-First Century: Reflections On Science, Policy And Society." *Irrigation and Drainage (Online)*, vol. 63, no. 2, Apr. 2014, pp. 154–57.

NABARD (2006) Review of methodologies for estimation of ground water resources of India. Technical Services Department, NABARD, Mumbai.

Overview of ground water quality | cgwb. https://cgwb.gov.in/overview-ground-water-quality

Pandey, Vagish Vandana, et al. "Challenges and Issues of Groundwater Management in India." *Current Science (Bangalore)*, vol. 123, no. 7, Oct. 2022, p. 856. .

Rodell M, Velicogna I and Famiglietti J S (2009). Satellite-based estimates of groundwater depletion in India. *Nature*, *460*(7258), 999–1002.

Russo, T. A., et al. "Assessment of Agricultural Water Management in Punjab, India, Using Bayesian Methods." *Springer eBooks*, 2015, pp. 147–62. https://doi.org/10.1007/978-3-319-12194-9_9.

Saha, Dipankar, and Ray R K (2018). "Groundwater Resources of India: Potential, Challenges and Management." *Springer eBooks*, 2018, pp. 19–42. ttps://doi.org/10.1007/978-3-319-75115-3_2.

Siebert S, Burke J S, Faurès J, Frenken K, Hoogeveen J, Döll P and Portmann F T (2010). Groundwater Use for Irrigation – a Global Inventory. *Hydrology and Earth System Sciences*, *14*(10), 1863–1880.

Srinivasan Veena and Seema Kulkarni (2014) "Examining the Emerging Role of Groundwater in Water Inequity in India." *Water International*, vol. 39, no. 2, Feb. 2014, pp. 172–86. .

Suhag R (2016). Overview of ground water in India. *RePEc: Research Papers in Economics*. https://econpapers.repec.org/RePEc:ess:wpaper:id:9504