GROUND WATER DEVELOPMENT FOR PORTABLE WATER SUPPLY IN RAJASTHAN: A CASE STUDY

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Abstract:
Groundwater is a highly essential source of drinking water and cultivation for crops in low-income countries such as India. Rajasthan, an arid state in northwestern India, grapples with severe water scarcity. It is crucial for the realization of the human right to water. However, the percentage of households using groundwater in comparison to other sources is infrequently measured because national and international data are more concerned with the facilities than the resources that are used. This is a serious information vacuum, particularly in light of attempts to expand water services in line goals of the sustainable development. Understanding the incidence of groundwater dependency for drinking is crucial for individuals involved in water services planning and management so they can better monitor and advocate for the management of water resources that supports sustainable services for families. This study investigates emerging groundwater resource concerns in Rajasthan and assesses groundwater resource issues that influence the likelihood of people. The study involves analyzing hydrological conditions, water availability, quality assessment, and management strategies for sustainable groundwater development. Findings highlight the case for governments and development agencies to improve their involvement with groundwater resource management as a basic requirement for attaining affordable water services for everyone.

Keywords: Sustainable Development Goals, Ground Water, Ground Water Management, Portable Water

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1. Introduction

Around the world, groundwater offers a significan t contribution to the continuous attainment of the human right to water. In still developing nation contexts where 2.1 billion people still lack access to safely treated water and 844 million lack even basic water (WHO, 2017). The sources of water on the earth which is available to people are groundwater, surface water (rivers, streams, and ponds), atmospheric water (rain, snow, and hail), and springs. The quality of these water bodies depends on their location, surrounding atmospheric conditions, and area of development. As per the hydrological cycle precipitation infiltration from lakes and streams, recharge ponds, and waste-water treatment systems are separate sources. Groundwater moves through soil, sediment, and rocks due to those impurities such as bacteriological, biological, suspended, and colloidal presence in water filtered out. With management and policy yet to appropriately respond in many circumstances, ground water remains inadequately understood and insufficiently protected (Foster et al. 2013). The result is extensive stress on groundwater resources, with an approximately 1.7 billion people living in areas affected by excessive consumption (Gleeson et al. 2012). Rajasthan faces one of the greatest scarcities of water resources in the country. It has 13.88% of India's cultivable area, 5.67% of the population, and about 11% of the country's livestock but has only 1.16% of surface water and 1.70% of groundwater (RajRAS 2019). In Rajasthan, groundwater contains many harmful substances due to the geological condition of the state. The availability of hygienic and safe drinking water for all is one of the most important challenges facing municipal authorities and the government of Rajasthan. During the year 2020, there was a wide variation of rainfall in North West and South Eastern parts of the State between 240.25 mm. and 1067.60 mm in Ganganagar and Pratapgarh respectively. The Normal monsoon rainfall of the state (1901-2019) is 526.44 mm and the Normal non-monsoon (1901-2019) is 48.03 mm. The annual normal rainfall (1901-2019) of the state is 574.47 mm. 75% to 95 % of the total rainfall mostly precipitates in the monsoon period i.e. from June to September. The average annual Rainfall (2020) of the state is 583.13 mm (GRGWD, 2020). Rajasthan's vulnerability to droughts is one of the highest in the country, more so in the western parts, with the probability of occurrence as high as 25 percent (Sinha and Wale 2006). This makes irrigation development imperative, to prove against droughts. While the renewable freshwater resources available from the state's river basins are extremely limited, there is a high level of development of available water resources for irrigation, municipal and industrial uses. Instead of the limited surface water resources, the dependence has been extremely high on groundwater. Heavily subsidized electricity for the agricultural sector, and massive rural electrification has led to over-exploitation of groundwater in most parts of the state.

1.1. Study Objectives

The study of groundwater development for Portable water supply in Rajasthan, with an investigation framed by the following objectives,

- To access the potential of groundwater as a source of portable water supply in the arid state of Rajasthan.
- To evaluate the hydro-geological conditions, water availability, water quality, and existing management strategies, and propose sustainable development.

2. Literature Review

With the rapid development of society and the economy, people’s living standards are increasing, and water resources are becoming increasingly scarce. The problem of ecological environment deterioration is becoming increasingly prominent, which seriously affects people’s survival. People's attention gradually turned to the exploitation of groundwater and the protection of the water environment, and then carried out in-depth research on the development, utilization, and protection of water resources. India's water resources include ground water, which is crucial. It is vital to India economy and society, especially in areas with sparse surface water supplies and dry or semi-arid climate like the Rajasthan Sand Basins in the north-west. Similar the arid resign in china studied by (Hao, 2018) a thorough analysis of the hydrogeological conditions, ground water quality, improvement, and consumption in the area. Along with this, the author discussed how ground water is distributed both temporally and spatially. The main tenets of ground water exploitation control, protection, and management in the future were also put out in order to address the environmental issues brought on by the excessive exploitation of water resources and fulfil the growing demands on China's water resources. (Huang, 2021) carried out the Yangtze River hydrogeological survey project under the direction of the earth structure and water cycle theory in order to further our understanding of the hydrogeology and groundwater reserves in the Ya ngtze River region and challenge the conventional view of surface water or ground water. The changing law of groundwater must be understood in order to carry out appropriate planning and sustainable exploitation of current water resources. Pradhan (2021) examined the Ganges River's lower reaches' groundwater cycle. A collaborative neural fuzzy inference system based on fuzzy cooperation. The author proposed fuzzy logic and radial basis function networks with a comparative analysis of soft computing technologies. Nair et al. (2006) evaluated the quality of North-East Libya's ground water by adopting a water index. Authors identifying their physicochemical properties and water quality index parameters, the acceptability of ground water for drinking was assessed in various areas. Previous study focus on different domain of research assessment of water quality using different model. However ground water development in Indian condition need to studied. Further this study examine Rajasthan's water shortage scenario with a focus on its socioeconomic effects. Study concentrate about the importance of groundwater as a supply of water, as well as its accessibility and sustainability. The assessment of ground water management ideas and practices as well as the hydrogeological conditions in Rajasthan. To guide Rajasthan, it will also look at successful groundwater development programs in other areas.

3. Methods

The Study area selection criteria and data collection methods will be outlined. This section will discuss hydrogeological data collection, water quality sampling and analysis, and socio-economic data collection. Data analysis techniques, such as statistical analysis and water quality assessment methods, will be described.

1) The methodology is the systematic, theoretical analysis of the methods applied to a field of study.
2) It comprises the theoretical analysis of the body of methods and principles associated with a branch of knowledge.
3) Typically, it encompasses concepts such as paradigms, theoretical models, phases, and quantitative or qualitative techniques.
4) The current study is descriptive in nature and is based on secondary data gathered from a variety of sources, including books, education, and development, journals, scholarly articles, government publications, and printed and online reference materials.

3.1. Analysis of the Hydrogeology

The hydrogeological investigation conducted in Rajasthan is essential for comprehending the features and availability of groundwater resources. The region's geological features, aquifer characteristics, and groundwater potential will all be examined as part of this examination.

Rajasthan has a variety of geological features, including fractured rock systems, alluvial plains, and sedimentary rock formations. The varieties of aquifers and their characteristics, like porosity, permeability, and storage capacity, are determined by these geological formations. Alluvial, sedimentary, and fractured rock aquifers can all be found in Rajasthan.

To locate possible aquifer zones and evaluate their qualities, groundwater research techniques like geophysical surveys and remote sensing methods are used. The depth, thickness, and lithological properties of aquifers can be determined using geophysical techniques such as electromagnetic techniques, seismic surveys, and electrical resistivity imaging.

3.2. Water Availability Assessment

Analyzing rainfall patterns, surface runoff, and the interactions between surface water resources and groundwater are all part of the assessment of water availability in Rajasthan. To assess the sustainability of water resources, it is also crucial to measure the availability and recharge rates of groundwater. Rajasthan's water availability is greatly influenced by rainfall patterns. To comprehend the annual water supply to the region, historical rainfall data, including seasonal fluctuations and long-term trends, are analyzed. Estimating the overall water potential for recharge and groundwater replenishment is made easier with the aid of this information. The contribution of surface water resources, such as rivers, lakes, and reservoirs, to water availability is analyzed. To comprehend the interaction between these sources and their effects on overall water quality, the relationship between surface water and groundwater is investigated.

In Rajasthan, rainfall is the main primary source of groundwater recharge and development, which is supplemented by recharge from canals, irrigated fields, and surface water bodies. Dams, rivers, and canals are also the source of supply of poTable water. The central groundwater board report says around 10.82 billion cubic meters of groundwater is available in Rajasthan every year after recharge but around 13.13 billion cubic meters is exploited for irrigation and 1.70 billion cubic meters for domestic and industrial purposes. (Hindustan Times, 2017). The Rajasthan groundwater department prepared a report in 2014 taking 1984 as the baseline year. According to the report, the groundwater level has dipped 15 meters in Nagaur, Jhunjunu, Jalore, Jaipur, and Sikar districts because of overexploitation in the last 30 years. Alwar and Dausa districts registered a 10-15 meters decline in groundwater level. The level is under five meters in Ajmer, Baswara, Baran, Bharatpur, Bhilwara, Bundi, Dholpur, Dungarpur, Kota, Sawai Madhopur, Tonk, and Udaipur districts (Hindustan Times, 2017). According to experts, Rajasthan has to rely on groundwater because of a shortage of surface water. Groundwater recharging is low in western Rajasthan except in areas adjoining canals. A jump in the number of tube wells has also pushed down the groundwater level (CGWB, 2017).

The State's water resources are categorized in the following terms:

3.2.1. Surface Water (SW):

Surface water generated within Rajasthan Boundaries are tabulated in table 1 below:

- The surface water potential of the state from internal sources comprising 14 rainfed river basins is estimated at 15.86-million-acre feet.

Table 1 Status of available surface water and storage created in Rajasthan (2010)

S.No.	River Basin	Available Yield (in MCM)	Storage created (in MCM)
1.	Shekhawati	104.7	89.72
2.	Ruparail	179.5	101.64
3.	Banganga	449.2	412.26
4.	Gambhiri	353.3	231.56
5.	Parvati	138.1	157.28
6.	Sabi	168.3	107.65
7.	Banas	4039.3	3639.76
8.	Chambal	5203	2906.77
9.	Mahi	3149	2726.59
10.	Sabarmati	799.9	200.09
11.	Luni	451.8	1136.66
12.	West Banas	406.1	79
13.	Sukli	111.7	44.29
14.	Other Nallah of Jalore	31.6	0
15.	Outside Basin	468	9

(**Source:** based on Water Resource of Rajasthan-Geology RajRAS 2019).

- Surface water source: Rivers, Lakes & Dams of Rajasthan depicted in following figure-1.

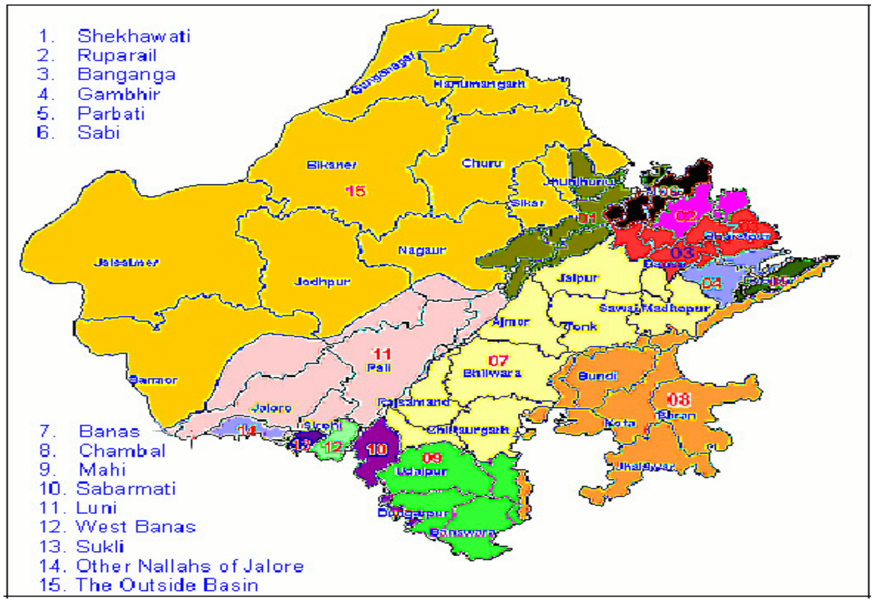

Figure 1 Water basin Map

(Source: based on Groundwater Management in India – Rajasthan State Report August2022)

1.2 Imported Surface Water:

- Imported water delivered to Rajasthan from other states by means of several projects under relevant inter-state agreements tabulated in following Table-2.

Table 2 Rajasthan in out of state rivers as per various inter-state agreements

S.No.	Resource	Allotted Water in MAF (Million Acre Feet)
1.	Gang Canal	1.11
2.	Bhakra Canal	1.41
3.	Narmada	0.5
4.	Ravi-Beas	8.6
5.	Yamuna Water	0.91
6.	Mahi Water	0.37
7.	Chambal/Kota Barrage	1.6
Total		**14.5**

(Source: based on Water Resource of Rajasthan-Geology Raj RAS 2019).

3.2.2. Ground Water (GW):

- Groundwater availability in Rajasthan is highly variable, depending on hydrological conditions with demonstrate in figure 2 below.
- The limited groundwater resources in Rajasthan are increasingly being exploited for irrigation, Industrial, and domestic uses.
- In 2011, out of 243 Block.

Table 3 the ground water status

S. No.	Parameter	No. of Blocks
1.	Over Exploited (greater than 100%)	172
2.	Critical (90% - 100%)	25
3.	Semi – critical (70% - 90%)	20
4.	Safe (Less than 70%)	24
5.	Saline Water Blocks	2
Total		**243**

(Source: based on Water Resource of Rajasthan-Geology Raj RAS 2019).

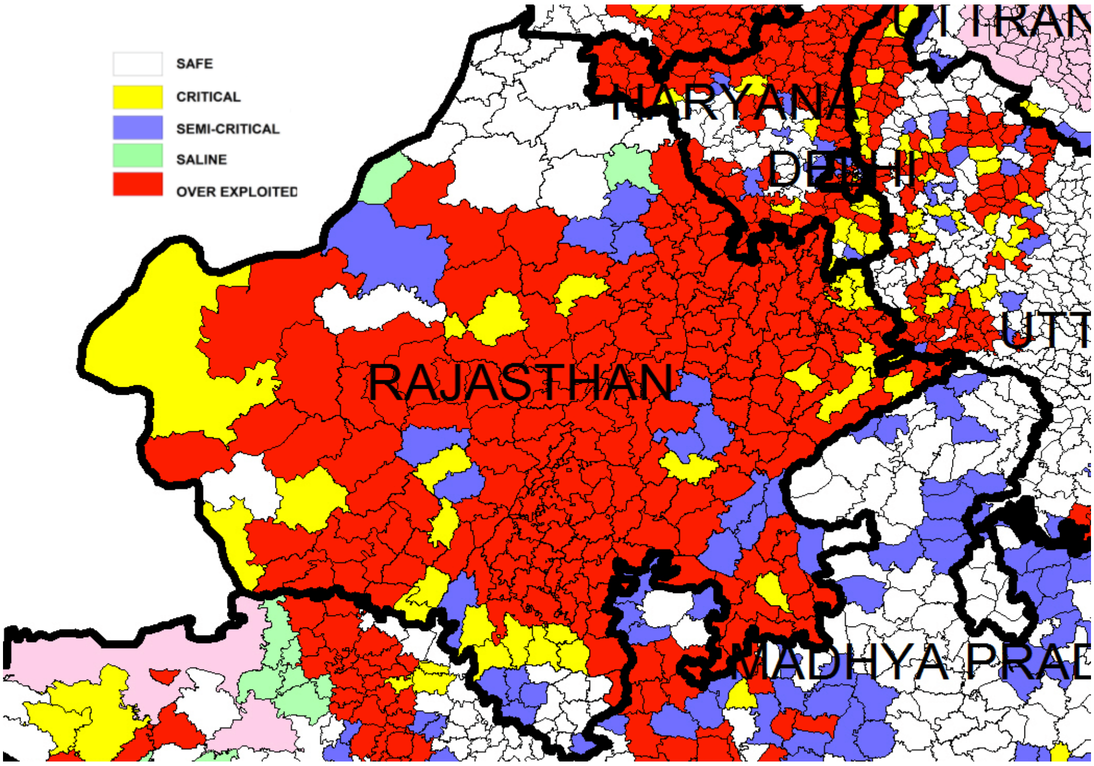

Figure 2 Ground Water Availability in Rajasthan
(Source: based on Groundwater Management in India – Rajasthan State Report August 2022)

3.2.3. Rainfall

The state's primary source of groundwater recharge is rainfall. From June through September, the southwest monsoon brings 90% of the state's rainfall. It doesn't rain much in the winter. The following figure 3 depicted the average yearly rainfall in Rajasthan distribution for the year 2020.

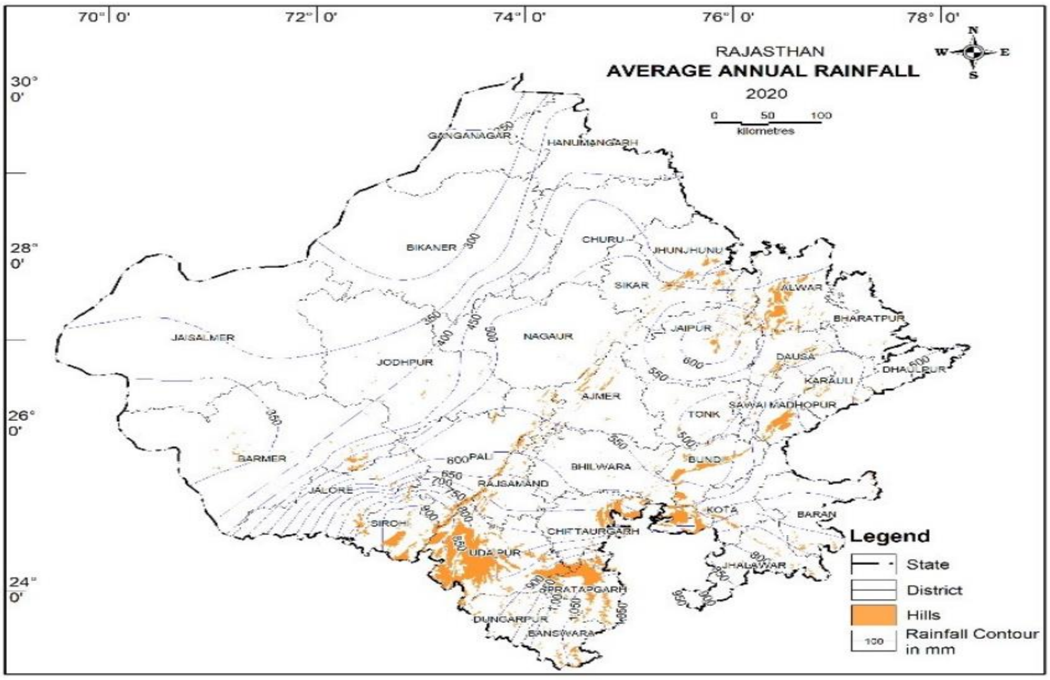

Figure 3 State's average yearly rainfall distribution for the year 2020
(Source: based on Central Ground Water Board-Ground Water Year Book 2020-2021 Rajasthan)

In the state, there are 349 stations with rain gauges. To determine the average rainfall for each district in the corresponding years, 10 years' worth of yearly rainfall data from 2011 to 2020 were evaluated. The state will receive 583.13 mm of rain on average annually from 2020 to 2025. Figure 3 displays the state's average yearly rainfall and deviations (%) from the average annual rainfall. The average yearly rainfall percentage deviations from the norm (1901–1970) have been calculated. The isohyets of annual rainfall for 2020 (Figure 4) indicate that the rainfall in the east of Aravalli is significantly higher as compared to the western part.

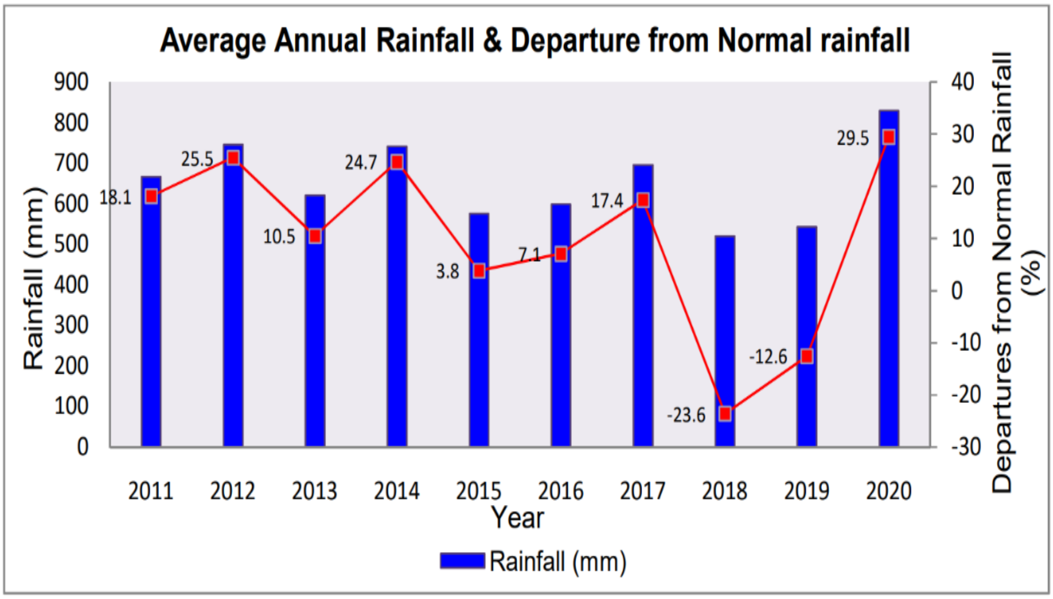

Figure 4 Annual Rainfall and Departure from Normal
(Source: based on Central Ground Water Board-Ground Water Year Book 2020-2021 Rajasthan)

3.3. Water Quality Assessment

We are going to assess the principal ions and physicochemical properties of the groundwater. We will determine the sources of the contaminants and the potential effects on human health. We'll talk about water quality standards and how they apply to groundwater quality.

By examining 640 samples taken from National Hydrograph Stations or nearby NHS, the chemical quality of the groundwater has been assessed. The

Bureau of Indian Standards (BIS) was taken into consideration when analyzing the water quality indicators that affect human health. Where Summary of water samples is as follows in Table-4.:

Table 4 Summary of water samples is as follows

Limit	Constituents (Percentage)								
	TDS	**Cl**	**SO_4**	**F**	**NO_3**	**TH**	**Ca**	**Mg**	**EC**
Accep Table limit	19.23	57.50	59.14	59.88	61.12	26.70	71.71	32.65	52.58
Permissible limit	52.60	29.26	20.94	13.84		54.43	23.87	50.31	24.07
Beyond Permissible	28.17	13.24	19.92	26.28	38.88	18.87	4.42	17.03	28.50

(Source: based on Central Ground Water Board-Ground Water Year Book 2020-2021 Rajasthan)

The main indication of groundwater salinity is electrical conductivity (EC). Gadi Sawairam in the Alwar district has an EC of less than 250, whereas Kuri in the Barmer district has an EC of 47670 S/cm. A solution's EC provides information on the number of ions or dissolved solids.

Higher EC values of water (>3000 S/cm) have been found in the state's western, central, and eastern regions, rendering the groundwater saline and unusable. As long as the EC values are within 1500 S/cm, the water is fresh in the southern and some eastern parts of the state.

The major problem associated with groundwater quality is fluoride, nitrate, and salinity. The worst affected districts with 50% or more concentrations are:

Fluoride:

1. Tonk, Jaipur, Nagaur, Ajmer, Bhilwara, Sirohi, Bundi and Pali
2. Causes of high Fluoride:

a. Presence of rocks like Pegmatite, Gabbros, etc. containing minerals like Fluorspar, Fluorite, Lepidolite, and Tremolite.
b. Presence of calcite and dolomite which accelerate the leaching of fluoride to the groundwater.
c. The arid climate with high evaporation and insignificant natural recharge increases fluoride concentration in the groundwater.

Nitrate > 100 ppm:

1. Churu, Nagaur, Jhunjhunu

Total Dissolved Solids (TDS) > 2000 ppm:

1. Churu, Barmer, Bharatpur

Iron > 1ppm:

1. Bhilwara, Jodhpur, Baran, Jaipur

3.4. Management Strategies for Sustainable Groundwater Development

To ensure a sustainable water supply in Rajasthan, groundwater resources must be managed. To balance water demand, encourage conservation, and avoid overexploitation, effective management measures are necessary. The many management techniques for regional groundwater development that are sustainable are covered in this section.

Demand Management and Water Conservation: Water conservation practices are essential for lowering total water demand and fostering sustainable ground water development. Agriculture, the greatest consumer of ground water, may dramatically reduce water waste by implementing effective irrigation techniques like drip irrigation and sprinkler systems. The use of modern farming techniques and encouraging farmers to adopt water-efficient cropping patterns can both help to maximize water consumption. Promoting awareness campaigns and educational initiatives to increase public knowledge of water conservation and promote water-saving behaviors.

4. Results and Discussion

Nowadays due to the increase in population, industrialization, agricultural activities, and urbanization, large quantities of sewage and industrial wastewater discharged into water bodies have significantly contributed to the pollution of the surface and groundwater. For the assessment of the water pollution status of the water bodies, the following water quality parameters were analyzed: (1) pH (2) Conductivity (3) Temperature (4) Total dissolved solids (TDS) (5) Total Alkalinity (6) Hardness (7) Cations and Anions (8) Carbonates and Bicarbonates (9) Sulphate. Physicochemical Characteristics of Water in India are showing in Table 5 below.

Table 5 Physicochemical Characteristics of Water in India

S. No.	Parameter	BIS Specification
1.	pH	6.5 – 8.5
2.	Conductivity	600 Ms/cm
3.	Alkalinity	200 Mg/l
4.	TDS	500 Mg/l
5.	Hardness	300 Mg/l
6.	Chlorides	250 Mg/l
7.	Turbidity	5 NTU
8.	Temperatures	23^0C
9.	Ca	75 Mg/l
10.	Mg	30 Mg/l
11.	Na	200 Mg/l
12.	K	200 Mg/l
13.	Carbonates and bicarbonates	-
14.	Sulphate	150 Mg/l

Table 6 List of substances found naturally in some ground waters which can cause problems in operating wells

S.No.	Substance	Types of problems
1.	Iron (Fe^{+2}, Fe^{+3})	Encrustation, staining of laundry and toilet fixtures
2.	Manganese (Mn^{-2})	Encrustation, staining of laundry and toilet fixtures
3.	Silica (SiO_2)	Encrustation
4.	Chloride (Cl^-)	Portability, Corrosiveness
5.	Fluoride (F^-)	Fluorosis
6.	Nitrate (NO3	Methemoglobenemia
7.	Sulphate (So_4^{-2})	Portability
8.	Dissolved Gases	Corrosiveness
9.	Dissolved Oxygen	Corrosiveness
10.	Hydrogen Sulphate (H_2S)	Corrosiveness
11.	Carbon dioxide (CO_2)	Corrosiveness
12.	Radio Nuclides	Portability
13.	Miner Constituents	Portability, Encrustation
14.	Calcium and Magnesium (Ca^{2+}, $Mg^{2+)}$	Encrustation

From the above Table-6, depicted the list of substances found naturally in some ground waters which can cause problems in operating wells.

Table 7 Ground Water Resources Availability and Status of its Utilization in India

S. N.	Regions	Annual Replenishable Ground Water Resource (bcm)	Natural Discharge during non-monsoon season (bcm)	Net Annual Ground Available (bcm)	Annual Ground Water Draft (bcm)	Stage of Water Development (%)	Categorization of Assessment Units (Blocks/Mandals)		
							Total Assessment Units	Over Exploited Nos/%	Critical Nos/%
1	2	3	4	5	6	7	8	9	10
1	Northen Himalayan states	5.4	.48	4.92	1.84	37	30	2/6.67	0
2	North Eastern Hilly States	33.99	3.02	30.98	5.63	18	118	0/0	0
3	Eastern Plain States	111.63	9.03	102.5	43.97	43	1895	1/.05	2/.11
4	North Western Plain States	80.78	6.92	73.85	72.17	98	277	201/72.56	28/10.11
5	Western arid Region	27.38	1.97	25.4	24.48	96	462	172/37.23	62/13.42
6	Central Plateau States	90.723	5.19	85.53	36.11	42	985	31/3.15	6/.61
7	Southern Peninsular States	82.78	7.14	75.65	46.4	61	1946	432/22.2	128/6.58
8	Islands	0.34	0.01	0.32	0.01	4	10	0	0
	Country Total	**433.02**	**33.77**	**399.26**	**230.63**	**58**	**5723**	**839**	**226**

Salient details of groundwater resource availability, utilization, stage of development, and categorization of Assessment units for the above Regions of the country are given in above Table.7.

5. Conclusions

In conclusion, this study demonstrate the difficulties, solutions, and sustainability of groundwater development for portable water supply in Rajasthan, India. Due to acute water shortage, both urban and rural residents now rely heavily on groundwater as a source of drinking water. But excessive use of groundwater resources has brought about several issues, including dwindling water tables, diminishing water quality, and environmental deterioration. Further study emphasizes the significance of comprehending Rajasthan's intricate dynamics of water supply, demand, and management. To guarantee long-term water security and sustainability, it highlights the requirement for efficient groundwater management strategies. The following summary of findings highlights the implications and key recommendations for policymakers, water resource managers, and stakeholders:

5.1. Implications of findings:

- Rajasthan faces severe water scarcity, and groundwater serves as the primary source of potable water supply.
- Excessive groundwater extraction has led to declining water levels and quality issues.
- The Hydrogeological analysis revealed diverse geological features and aquifer characteristics across the region.
- Water availability assessment emphasized the importance of rainfall patterns, surface runoff, and the interlinkage between surface water and groundwater.

5.2. Recommendations

- Implement water conservation and demand management strategies, such as promoting efficient irrigation techniques and raising public awareness about water-saving practices.
- Emphasize artificial recharge techniques, including constructing check dams, percolation tanks, and recharge wells to replenish groundwater levels during periods of high rainfall.
- Promote the conjunctive use of surface water and groundwater by interlinking rivers and canals and integrating managed aquifer recharge practices.
- Establish robust groundwater regulations and monitoring mechanisms to control excessive pumping, prevent unauthorized abstraction, and make informed management decisions.

5.3. Future Research Directions:

- Further research is needed to assess the impact of climate change on groundwater availability and recharge patterns in Rajasthan.
- Conduct studies on the socio-economic implications of sustainable groundwater development including the livelihoods of farmers and the economic viability of alternative water sources.
- Explore innovative technologies and practices for efficient water use and recharge, such as smart water meters, precision irrigation systems, and nature-based solutions.
- Investigate the potential of decentralized groundwater management approaches, including community-driven initiatives and participatory groundwater governance models.
- Assess the long-term sustainability of artificial recharge techniques and their effectiveness in replenishing groundwater resources.

List of abbreviations: Not applicable

6 Declarations

Availability of data and material: The data that support the findings of this study are available from the corresponding author,[Dungar Singh], upon reasonable request.

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Authors contribution: The authors confirm contribution to the paper as follows: study conception and design Rakesh Kumar, Dungar Singh; data collection: Rakesh Kumar; analysis and interpretation of results: Rakesh Kumar; draft manuscript preparation Rakesh Kumar, Dungar Singh, and Monu Kumar. All authors reviewed the results and approved the final version of the manuscript.

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