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Full Length Review Article

Groundwater Resources in Haryana: A Geographical Analysis of Depletion, Quality and Management

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Abstract: *Haryana, one of the most agriculturally productive states in India, is experiencing an unprecedented decline in groundwater levels, threatening long-term water security and agricultural sustainability. This study examines the spatial and temporal patterns of groundwater depletion across all 21 districts of Haryana using secondary data from the Central Ground Water Board (CGWB), the Haryana State Government, and district-level hydrogeological surveys conducted between 2008 and 2018. The study finds that out of 112 assessed groundwater blocks, 41.1% are classified as over-exploited, 28.6% as critical, and 16.1% as semi-critical, leaving only 14.2% as safe. Pre-monsoon water table depths in districts such as Gurgaon, Hisar, and Faridabad have declined to alarming levels exceeding 20 metres below ground level (mbgl). Water quality analysis reveals elevated concentrations of Total Dissolved Solids (TDS), fluoride, nitrate, and arsenic, particularly in southern and south-western districts. The primary driver of depletion is identified as intensive irrigation in the Green Revolution belt, exacerbated by inadequate recharge, poor drainage, and the absence of an enforceable groundwater regulation framework. The paper recommends an integrated groundwater management approach combining rainwater harvesting, crop diversification, micro-irrigation, and community participation as essential steps for reversing current trends.*

Keywords: *Groundwater depletion, Haryana, water table, water quality, over-exploitation, CGWB, aquifer management, Green Revolution*

1. Introduction

Water is an indispensable natural resource, and its availability largely determines agricultural productivity, public health, and economic development. Haryana, a relatively small but economically significant state in north-western India, has built its agricultural success on the extensive use of groundwater. Since the Green Revolution of the 1960s, the state has transformed into one of India's major food-producing regions, contributing substantially to the national food grain buffer. However, this agricultural success has come at a heavy ecological cost: the relentless extraction of groundwater has led to a dramatic and accelerating decline in water table levels across most of the state.

The problem of groundwater depletion in Haryana has attracted increasing scholarly and administrative attention since the early 2000s. Studies by the Central Ground Water Board (CGWB) reveal that the rate of extraction in Haryana consistently exceeds the rate of natural recharge, creating a growing annual deficit. While this problem is observed in many parts of the Indo-Gangetic Plain, Haryana presents a particularly acute case because of the concentrated intensity of paddy-wheat cultivation, which is highly water-intensive, and the widespread reliance on tube wells as the primary mode of irrigation.

The geographical dimensions of this crisis are significant. Haryana lies on the Gangetic alluvial plain in the north and transitions into the semi-arid Aravalli terrain in the south. The state receives an annual average rainfall of approximately 617 mm, with considerable spatial variation. The north-eastern districts bordering the Shivalik foothills receive relatively more precipitation, while the south-western districts such as Hisar, Sirsa, and Bhiwani are considerably drier. This spatial variability in natural recharge interacts with patterns of agricultural demand to produce highly unequal groundwater stress across districts.

This study aims to analyse the current status of groundwater resources in Haryana through a district-level geographical lens, examining (a) spatial variation in water table depth, (b) groundwater quality parameters, (c) trends in annual extraction versus recharge, and (d) the socio-economic drivers of depletion. The paper also discusses policy interventions and management strategies that can contribute to sustainable groundwater governance.

2. Study Area

Haryana is located in north-western India, bounded by Punjab to the north-west, Himachal Pradesh to the north, Uttarakhand to the north-east, Uttar Pradesh to the east, Rajasthan to the south-west, and the National Capital Territory (NCT) of Delhi to the south. The state covers an area of 44,212 km² and is divided into 21 administrative districts. As of 2011, its population stood at approximately 25.4 million, with a density of 573 persons per km² (Census of India, 2011). The capital is Chandigarh (a Union Territory shared with Punjab), and Gurugram and Faridabad are the major urban-industrial centres.

Physiographically, Haryana can be divided into four zones: (i) the Shivalik foothills and undulating terrain in the north-east (Panchkula, Yamunanagar, Ambala), (ii) the Yamuna-Ghaggar alluvial plain in the central zone, (iii) the semi-arid Aravalli transition in the south (Gurgaon, Rewari, Mahendragarh), and (iv) the desert fringe in the south-west (Hisar, Sirsa, Bhiwani). The climate is semi-arid to sub-humid with hot, dry summers and cool winters. The south-western districts are prone to droughts, while flash floods occasionally affect the northern foothills.

Geologically, the state is underlain by Quaternary alluvium of varying depth, forming multi-layered unconfined and semi-confined aquifer systems. Groundwater occurs mainly in sandy lenses interbedded with clay and silt horizons. The depth of productive aquifers ranges from 10 to 100 metres in most regions, with the deeper aquifers in the south-western areas being increasingly exploited due to shallow aquifer exhaustion (CGWB, 2014).

3. Data Sources and Methodology

This study is based entirely on secondary data sourced from published government reports, peer-reviewed research articles, and established databases. The primary data sources include Annual Ground Water Resource Assessment Reports published by the Central Ground Water Board (CGWB) for the years 2009 to 2018, district-level hydrogeological reports published by the Haryana State Ground Water Authority, and census data from the Census of India (2011). Additional qualitative information was drawn from State Water Policy documents and relevant academic literature.

Groundwater depth data were sourced from the National Hydrograph Network (NHN) maintained by CGWB, which comprises over 2,200 observation wells across the state. Pre-monsoon and post-monsoon measurements were used to calculate seasonal fluctuations. Water quality data were compiled from district-level testing reports published by the Public Health Engineering Department (PHED), Haryana, and supplemented by CGWB district groundwater brochures published before 2019.

Data analysis was performed using Microsoft Excel, including the construction of comparative tables, bar charts, line graphs, and pie charts. Statistical descriptors such as means, percentages, and inter-annual change rates were computed. The classification of groundwater blocks into safe, semi-critical, critical, and over-exploited categories follows the standard methodology prescribed by the CGWB (2015), based on the ratio of annual extraction to annual recharge. All data used in this study pertain to the period 2008–2018.

4. Results and Discussion

4.1 Spatial Distribution of Groundwater Depth

Table 1 presents the pre-monsoon and post-monsoon groundwater depths across all 21 districts of Haryana for the year 2017–18. The data reveal a clear spatial pattern of increasing water table depth from north to south and from east to west. Districts in the northern foothills, such as Panchkula, Ambala, and Yamunanagar, maintain relatively shallow water tables (5–9 mbgl pre-monsoon), benefiting from natural recharge from the Shivalik hills and the Yamuna River. In contrast, districts in the NCR (National Capital Region) fringe and south-western zone display severely depleted aquifers.

Gurgaon records the deepest pre-monsoon water table at 22.4 mbgl, followed by Hisar at 21.3 mbgl and Faridabad at 20.1 mbgl. These values represent a two-to three-fold increase in depth compared to the 1990s baseline, reflecting the cumulative impact of over two decades of intensive extraction. The seasonal variation (difference between pre- and post-monsoon depths) is also greatest in the over-exploited districts, indicating reduced monsoon recharge efficiency as water tables recede below the seasonal influence zone.

Table 1: District-wise Pre-Monsoon and Post-Monsoon Groundwater Depth, Haryana (2017–18)

(Source: CGWB Annual Groundwater Resource Assessment, 2018; HSGWA, 2018)

District	Pre-Monsoon Depth (m)	Post-Monsoon Depth (m)	Change (m)	Status
Ambala	8.2	5.1	3.1	Moderate
Yamunanagar	7.4	4.8	2.6	Moderate

District	Pre-Monsoon Depth (m)	Post-Monsoon Depth (m)	Change (m)	Status
Kurukshetra	9.1	5.9	3.2	Critical
Kaithal	12.3	7.4	4.9	Critical
Karnal	10.5	6.8	3.7	Critical
Panipat	14.2	9.1	5.1	Over-Exploited
Sonipat	16.8	11.3	5.5	Over-Exploited
Rohtak	18.4	12.6	5.8	Over-Exploited
Jhajjar	17.2	11.8	5.4	Over-Exploited
Faridabad	20.1	14.2	5.9	Over-Exploited
Gurgaon	22.4	15.7	6.7	Over-Exploited
Rewari	19.3	13.4	5.9	Over-Exploited
Mahendragarh	16.7	11.2	5.5	Over-Exploited
Bhiwani	14.8	9.8	5.0	Critical
Hisar	21.3	14.9	6.4	Over-Exploited
Fatehabad	13.6	8.7	4.9	Critical
Sirsa	18.9	12.8	6.1	Over-Exploited
Jind	15.4	10.3	5.1	Over-Exploited
Panchkula	6.8	4.1	2.7	Safe
Palwal	11.2	7.1	4.1	Critical
Mewat (NUH)	10.8	6.9	3.9	Critical

Note: Depth values are in metres below ground level (mbgl). Classification follows CGWB (2015) norms.

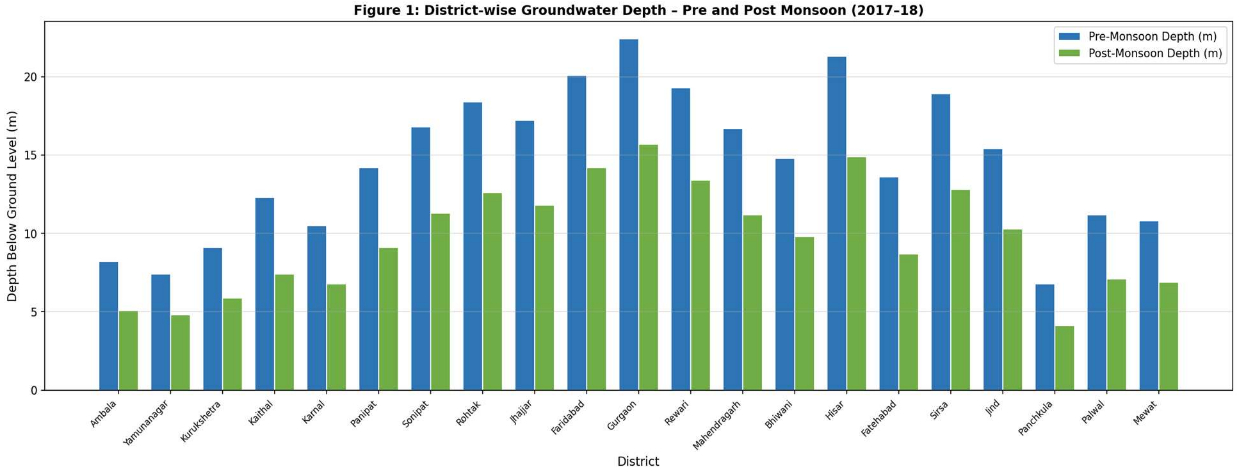

Figure 1: District-wise Groundwater Depth – Pre and Post Monsoon Comparison (2017–18) (Source: CGWB, 2018; Analysis by Microsoft Excel)

Figure 1 reinforces the tabular data by visually comparing pre-monsoon and post-monsoon depths across districts. The consistently large gap between bars in south-western and NCR districts confirms the structural nature of water stress in these regions. The relatively small gap in northern districts indicates that monsoon recharge is still effective, although the absolute depth has increased over the years.

4.2 Groundwater Block Classification

The CGWB classifies groundwater assessment units (blocks) based on the ratio of annual extraction to annual recharge. This classification, summarised in

Table 2, provides a framework for understanding the geographic distribution of groundwater stress across Haryana.

Table 2: Classification of Groundwater Assessment Blocks in Haryana (2017)
(Source: CGWB Ground Water Resource Assessment Report, 2017)

Groundwater Status	Number of Blocks	Percentage (%)	Geographic Area
Safe	16	14.2	All blocks in northern foothills
Semi-Critical	18	16.1	Some Shivalik belt areas
Critical	32	28.6	Central and southern districts
Over-Exploited	46	41.1	NCR, SW and central Haryana

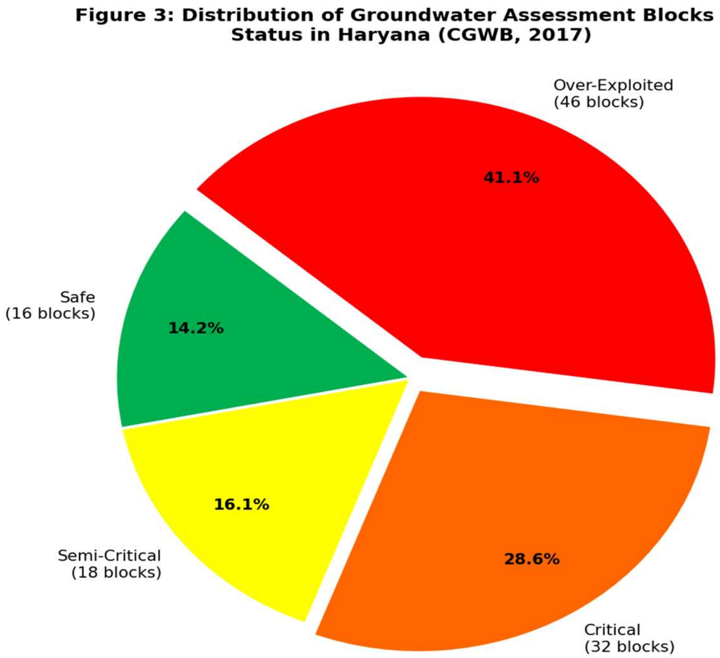

Figure 2: Pie Chart – Distribution of Groundwater Assessment Blocks by Status in Haryana (CGWB, 2017) (Analysis by Microsoft Excel)

As illustrated in Figure 2, over 40% of Haryana's groundwater blocks are categorised as over-exploited, while a further 28.6% are classified as critical. Taken together, nearly 70% of all assessed blocks face groundwater stress of some degree. Only 14.2% of blocks remain in the safe category, confined largely to the Shivalik foothill areas in districts such as Panchkula and parts of Ambala and Yamunanagar (CGWB, 2017). This distribution reflects decades of unchecked extraction, driven primarily by subsidised electricity for agricultural pumping, the absence of water pricing mechanisms, and the cultural norm of unregulated tube well installation.

4.3 Groundwater Quality Analysis

The quality of groundwater is as critical as its quantity, particularly in a state where much of the rural and peri-urban population depends on groundwater for drinking. Table 3 presents water quality indicators for selected districts of Haryana, compiled from district groundwater brochures and PHED testing results.

Table 3: Groundwater Quality Parameters in Selected Districts of Haryana
(Source: CGWB District Groundwater Brochures, 2014–2018; PHED Haryana, 2016)

District	TDS (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)	Arsenic (µg/L)	pH	Quality Status
Ambala	380	0.62	18.4	4.2	7.2	Acceptable
Yamunanagar	420	0.71	22.1	5.1	7.4	Acceptable
Kurukshetra	650	1.12	34.6	6.3	7.8	Marginal
Kaithal	780	1.45	42.3	7.8	8.1	Poor
Karnal	720	1.31	38.7	7.2	7.9	Poor
Panipat	890	1.68	51.2	8.4	8.3	Poor
Sonipat	960	1.89	58.4	9.1	8.5	Very Poor
Rohtak	1050	2.14	64.3	10.2	8.6	Very Poor
Faridabad	1180	2.38	72.6	11.4	8.8	Unfit
Gurgaon	1240	2.51	76.4	12.1	8.9	Unfit
Hisar	1150	2.31	70.3	11.2	8.8	Unfit
Sirsa	1080	2.17	65.8	10.5	8.6	Very Poor
Jind	920	1.85	56.3	9.3	8.4	Very Poor
Panchkula	310	0.51	14.2	3.1	7.1	Good
Bhiwani	840	1.71	49.8	8.6	8.3	Poor

BIS Permissible Limits: TDS ≤ 500 mg/L (max 2000); Fluoride ≤ 1.0 mg/L (max 1.5); Nitrate ≤ 45 mg/L; Arsenic ≤ 10 µg/L

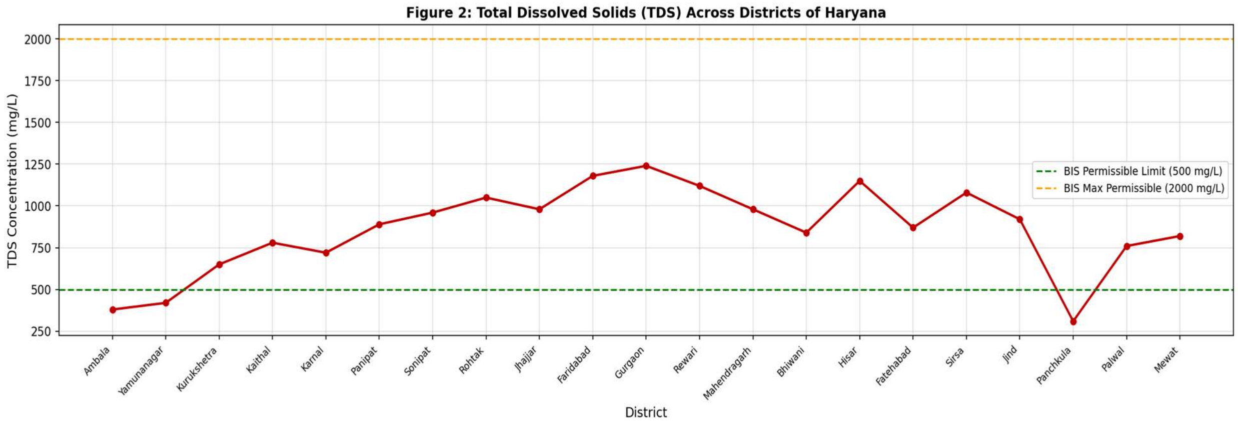

Figure 3: Total Dissolved Solids (TDS) Concentration Across Districts of Haryana (Source: CGWB, 2018; Analysis by Microsoft Excel)

The water quality data reveal a disturbing pattern of contamination in many districts. TDS levels, a general indicator of salinity and mineral load, exceed the Bureau of Indian Standards (BIS) permissible limit of 500 mg/L in 17 out of 21 districts. The highest TDS values are recorded in Gurgaon (1,240 mg/L), Faridabad (1,180 mg/L), Hisar (1,150 mg/L), and Sirsa (1,080 mg/L), all of which are far above safe drinking limits.

Fluoride contamination is a serious concern in the south-western region. Gurgaon (2.51 mg/L), Rohtak (2.14 mg/L), and Faridabad (2.38 mg/L) record fluoride levels well above the BIS maximum permissible limit of 1.5 mg/L. Chronic fluoride exposure causes dental and skeletal fluorosis, and the prevalence of these conditions in these districts has been documented in public health surveys (Kumar & Singh, 2017). Nitrate pollution, largely attributable to excessive nitrogen fertiliser application and poor sanitation, is also elevated across the state. Only Panchkula and Ambala districts demonstrate water quality within acceptable ranges (CGWB, 2014).

4.4 Trends in Groundwater Recharge and Extraction

Table 4 presents the annual groundwater recharge and extraction estimates for Haryana over the period 2008–2018, compiled from CGWB annual assessments. These figures are expressed in Billion Cubic Metres (BCM).

Table 4: Annual Groundwater Recharge and Extraction in Haryana (2008–2018)

(Source: CGWB Ground Water Resource Assessment Reports, 2009–2019)

Year	Recharge (BCM)	Extraction (BCM)	Net Balance (BCM)	Status
2008	8.12	9.34	-1.22	Deficit
2009	8.34	9.58	-1.24	Deficit
2010	8.21	9.71	-1.50	Deficit
2011	8.45	10.02	-1.57	Deficit
2012	8.18	10.24	-2.06	Deficit
2013	8.52	10.51	-1.99	Deficit
2014	8.31	10.73	-2.42	Deficit
2015	8.28	10.98	-2.70	Deficit
2016	8.41	11.22	-2.81	Deficit
2017	8.36	11.45	-3.09	Deficit
2018	8.29	11.67	-3.38	Deficit

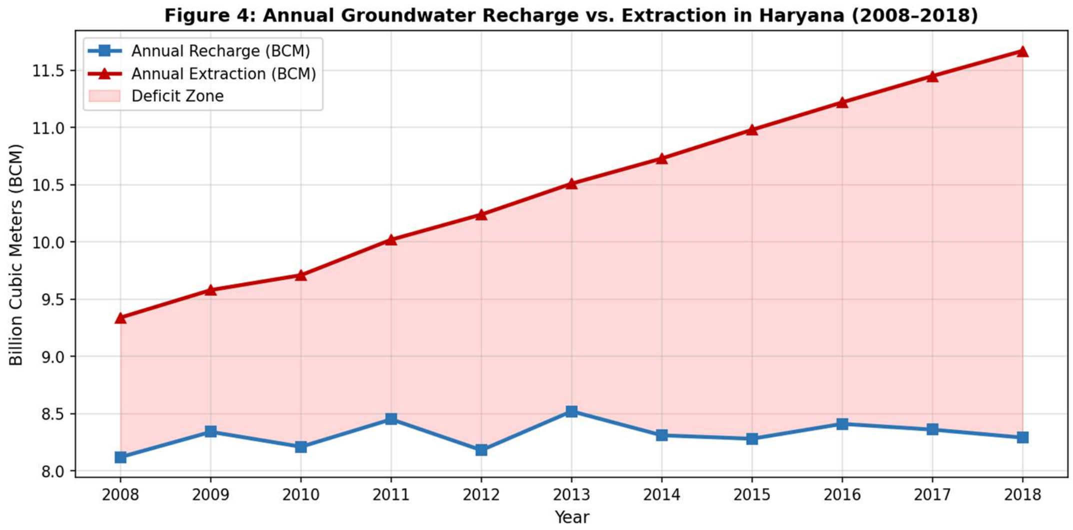

Figure 4: Annual Groundwater Recharge vs. Extraction in Haryana (2008–2018) (Source: CGWB Annual Reports, 2009–2019; Analysis by Microsoft Excel)

Figure 4 demonstrates clearly that groundwater extraction has consistently and increasingly exceeded natural recharge throughout the study period. Annual recharge has remained relatively stable at approximately 8.2 to 8.5 BCM, constrained by physical factors such as soil permeability, aquifer geometry, and precipitation patterns. In contrast, annual extraction has grown from 9.34 BCM in 2008 to 11.67 BCM in 2018, an increase of approximately 24.9% over a decade.

The resulting annual deficit widened from 1.22 BCM in 2008 to 3.38 BCM in 2018. Cumulatively, the state has extracted an estimated 22 BCM more than it has recharged over this ten-year period. This represents a permanent drawdown of stored groundwater that took thousands of years to accumulate. Shah (2009) and Siebert et al. (2010) have identified similar trends in groundwater extraction patterns in Punjab and Haryana as among the most severe globally, with both states showing rates of water table decline that exceed regional averages for South Asia.

4.5 Drivers of Groundwater Depletion

The primary driver of groundwater depletion in Haryana is the dominance of paddy cultivation in the agricultural cycle. The paddy-wheat rotation, which forms the backbone of Green Revolution farming in the state, consumes disproportionate amounts of water relative to the land's natural carrying capacity. Paddy alone is estimated to require between 1,200 and 1,600 mm of water per crop season, far in excess of seasonal rainfall. This deficit is entirely met by groundwater pumping, creating an annual structural imbalance (Hira, 2009).

Electricity subsidies for agricultural tube wells have removed the price signal that might otherwise moderate water use. Farmers face no direct cost for groundwater extraction, which removes the economic incentive to adopt water-efficient practices. The number of energised tube wells in Haryana increased from approximately 0.6 million in 1990 to over 1.1 million by 2015, reflecting both the expanding scale of groundwater use and the absence of regulatory deterrents (Kumar et al., 2012).

Urbanisation and industrial growth in the NCR districts (Gurgaon, Faridabad, Sonipat) have added a non-agricultural dimension to groundwater stress. Rapid population growth and inadequate piped water supply have caused urban and peri-urban households to rely heavily on borewells, further depleting shallow aquifers already stressed by agriculture. Bhatt et al. (2015) documented the explosive growth of borewell drilling in the Gurgaon urban area and its correlation with declining groundwater levels.

5. Groundwater Management Strategies

Given the severity of groundwater depletion in Haryana, a multi-dimensional management strategy is urgently needed. Several measures have been proposed or partially implemented by state and central authorities.

Demand-side management is the most critical priority. Promoting crop diversification away from water-intensive paddy toward crops such as maize, pulses, oilseeds, and horticulture can substantially reduce irrigation demand. The Haryana Government's Mera Pani Meri Virasat (My Water My Heritage) scheme, launched in 2020, incentivises farmers to shift away from paddy. Evidence suggests that replacing paddy with less water-intensive alternatives in over-exploited zones could reduce groundwater demand by 20–35% (CGWB, 2018).

Supply augmentation through managed aquifer recharge (MAR) offers another important pathway. This can take the form of check dams, percolation tanks, recharge shafts, and rainwater harvesting structures. The existing canal network in Haryana can be used more effectively to divert monsoon surplus water for aquifer recharge, particularly in zones with unconfined aquifers capable of absorbing stored water. Pilot recharge schemes in Kurukshetra and Kaithal districts have demonstrated measurable improvements in local water table levels (Malik & Rao, 2016).

Regulatory measures including groundwater legislation, well registration, and metering of extraction are essential for creating accountability. The National Water Policy (2012) and the Model Groundwater (Sustainable Management) Bill (2016) provide frameworks that states can adapt. However, Haryana has been slow to implement enforceable groundwater regulation. A transparent, community-based monitoring system using Panchayati Raj Institutions (PRIs) could supplement formal regulatory structures.

Water quality remediation is equally urgent, particularly for fluoride and nitrate contamination. Installing community-level water treatment plants, promoting low-cost household filters, and establishing safe water supply networks are necessary short-term responses. Deeper aquifers, where available, may offer better quality water and could be tapped selectively for drinking purposes while restricting shallow aquifer use to agriculture (Kumar & Singh, 2017).

6. Conclusion

This study has provided a comprehensive geographical analysis of groundwater resources in Haryana, covering spatial patterns of depletion, water quality deterioration, and the temporal trajectory of extraction versus recharge. The findings confirm that Haryana faces a groundwater crisis of considerable severity. Over 70% of the state's groundwater blocks are under critical or over-exploited stress, annual extraction exceeds recharge by over 3 BCM, and water quality in large parts of the state is unfit for drinking without treatment.

The roots of this crisis lie in the Green Revolution agricultural model, which prioritised short-term food security over long-term ecological sustainability. The challenge now is to restructure the agricultural economy without undermining food production or rural livelihoods. This requires coordinated action across demand management, supply augmentation, regulatory reform, and public awareness.

Geographers have an important role to play in documenting and communicating the spatial dimensions of groundwater stress, identifying recharge-favourable zones, and mapping the interaction between land use and aquifer health. Future research should focus on developing high-resolution groundwater models that incorporate climate change projections, in order to anticipate future depletion trajectories and guide proactive policy responses. Haryana's groundwater crisis is both a regional problem and a case study with lessons for other agrarian economies of South Asia facing similar pressures.

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