



Environmental Impact on Spatial and Temporal Variation in Groundwater Depth: A Case Study of Mahendergarh District, Haryana

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KEYWORDS

Environment, Rainfall, Degradation of land, Groundwater depth, water level fluctuation, spatial variation, temporal analysis

ABSTRACT:

Groundwater serves as a lifeline for agriculture and household use in semi-arid areas like Mahendergarh district in Haryana. Temporal and spatial analysis reveals a consistent decline in groundwater levels, particularly in intensively cultivated blocks, driven by erratic rainfall patterns, and excessive groundwater extraction for agriculture. This study takes a close look at how groundwater levels have changed both across space and over time across eight administrative blocks between 1991 and 2023. Relying on the latest secondary data from CGWB, the analysis points to a severe decline in water levels, as the district average reached to 50.93 meters below ground level by 2023. Notably, over 81% of the area now falls into the "extremely deep" zone (greater than 30 meters), reflecting over-extraction and limited natural recharge especially by rainfall. The worst-affected blocks Ateli, Satnali and Mahendergarh have seen water level drops of more than 30 meters over the study period. On the other hand, Narnaul and Sihma showed some signs of recovery in the most recent decade. These findings highlight the need for urgent, long-term strategies focused on sustainable groundwater management, especially for districts that are already under stress.

Introduction: Groundwater continues to be a vital resource for human survival and development, especially in countries like India, where it supports a large share of both domestic and agricultural needs (Kumar and Kumar, 2020). It contributes to more than 60% of irrigation and fulfills around 85% of rural drinking water requirements. As demands have increased due to agriculture, industrial growth, and population expansion, India is now among the world's leading consumers of groundwater. Over time, unregulated extraction and limited recharge have led to noticeable declines in groundwater levels, particularly in semi-arid and northwestern parts of the country. If this pattern persists, it may lead to serious social and economic impacts, especially in rural areas (Gaur et al., 2024).

Haryana presents a clear example of this broader national issue. Although geographically smaller in size, the state ranks among the top groundwater-consuming regions in India. Many areas in Haryana are historically water-stressed, and droughts are common, especially in its southern and western districts: Mahendergarh, Rewari, Bhiwani, Hisar, and Sirsa (Sharma, 2020).

Objectives:

To analyze the spatial and temporal (1919 – 2023) distribution of groundwater depth across the eight blocks of Mahendergarh.

To study the relationship between rainfall variability and groundwater table change over the selected period.

Methods: This study relies on secondary data from the Dynamic Groundwater Resources of Haryana report (March 2024) published by the Groundwater Cell under the Irrigation and Water Resources Department, Haryana. Groundwater levels in the state are monitored twice a year—once before the monsoon (June) and once after (October). For the purpose of this analysis, data collected



during the pre-monsoon period in June has been used, as it provides a more accurate reflection of the stress on groundwater resources. While the rainfall data is used as mean annual rainfall (m.m.).

The study takes the administrative block as the basic unit of analysis. The collected data has been organized on a block-wise basis under two key parameters:

Depth and fluctuation in ground water table (in meters).

Temporal and spatial change in rainfall (in m.m.).

Results: This analysis shows the total rechargeable area and how much of it falls into different groundwater depth ranges across the block in the district. The district is dominated by deep water tables as 81.66% of the total rechargeable area (4,68,108.36) falls under 30m and above depth zone. Only 13.36% of the area of the district has water tables between 20 to 30m in depth and 4.25% area is under relatively shallower water table between 5 to 20m. A negligible area of 0.73% is under 5 to 10m water depth and nil area between 0 to 5m depth shows that the entire district lacks in shallow water table depth, confirming the deepening of this valuable resource. **Conclusions:** Over the past five decades (1991–2023), the district has experienced a significant and consistent decline in groundwater levels across nearly all blocks. The average depth reached up to 50.93 meters by June 2023.

More than 81% of the district's area now falls under the extremely deep category (> 30 meters), leaving only a negligible portion under shallow or moderately deep groundwater zones. Three blocks have more than 90% of their area under 30m and above depth zone.

The temporal analysis indicates a worsening trend post-2001, with the average groundwater level falling by 27.57 meters since 1991. A possible reason for this could be intensify agricultural practices and low recharge rate.

The last decade alone (2011–2023) witnessed a decadal decline of 5.78 meters across the district. However, the modest water table recovery in Narnaul and Sihma during this period offers a ray of hope. It suggests that targeted water management interventions may yield positive outcomes.

If fast-depleting water depth and no one pay attention regarding rainwater harvesting practices, it could lead to complete groundwater exhaustion in several blocks within the next few decades.

1. Introduction

Groundwater continues to be a vital resource for human survival and development, especially in countries like India, where it supports a large share of both domestic and agricultural needs (Kumar and Kumar, 2020). It contributes to more than 60% of irrigation and fulfills around 85% of rural drinking water requirements. As demands have increased due to agriculture, industrial growth, and population expansion, India is now among the world's leading consumers of groundwater. Over time, unregulated extraction and limited recharge have led to noticeable declines in groundwater levels, particularly in semi-arid and northwestern parts of the country. If this pattern persists, it may lead to serious

social and economic impacts, especially in rural areas (Gaur et al., 2024).

Haryana presents a clear example of this broader national issue. Although geographically smaller in size, the state ranks among the top groundwater-consuming regions in India. Many areas in Haryana are historically water-stressed, and droughts are common, especially in its southern and western districts: Mahendergarh, Rewari, Bhiwani, Hisar, and Sirsa (Sharma, 2020). Most blocks are now classified as “overexploited,” meaning that the rate of extraction exceeds the natural recharge. This type of declining trend raises major concerns for long-term water sustainability (Dharampal, 2022). One of the main contributors to the falling water table is the



introduction and spread of water-intensive crops (rice, wheat and sugarcane). Additionally, the rapid increase in tube well irrigation has led to the widespread overuse of groundwater across the state (Aneja, 2017; Sharma, 2020).

The situation is particularly severe in the southern belt of Haryana, including Bhiwani, Rewari and Mahendergarh districts. These areas lie in a semi-arid climatic zone and suffer from very limited surface water availability, making them heavily reliant on underground water reserves (Gaur et al., 2024). In some blocks, the water table has dropped below 60 meters, making extraction both technically challenging and economically unviable.

Experts in Geography, Hydrology and water resource management have raised growing concerns about excessive groundwater withdrawal in such regions (Gahlawat, 2022). Mahendergarh, in particular, has been classified as entirely overexploited (Singh and Amrita, 2015). While groundwater trends have been widely discussed at the state and national levels, there remains a noticeable gap in block-level studies.

Over exploitation of groundwater by using wet crop cultivation and modern techniques of irrigation are major causes for drop of groundwater table. On the other hand, the source of groundwater recharge also affected the groundwater table on a particular area like Mahendergarh district. The environmental impact specially amounts of rainfall and its temporal and spatial variability are also affect the groundwater table.

Even though long-term groundwater and rainfall data exists, few efforts have focused on examining spatial and temporal patterns in depth in relation to rainfall across Mahendergarh. This study addresses that gap by analyzing block-wise groundwater trends over several decades in relation to environmental impact.

Study Area:

This research is focused Mahendergarh district, situated in the south-western region of Haryana, India. Geographically, the district lies between 27°47' to 28°26' North latitude and 75°56' to 76°51' East longitude. It shares boundaries with Rewari and Bhiwani districts of Haryana and Alwar and Jhunjhunu districts of neighboring Rajasthan. Spanning across an area of approximately 1,899 square kilometers, the study area is

administratively divided into eight blocks: Ateli, Mahendergarh, Narnaul, Kanina, Nangal Chaudhary, Satnali, Sihma, and Nizampur (Fig no. 1).

The district is within Haryana's semi-arid zone, which is marked by low and erratic rainfall patterns. On average, Mahendergarh receives between 40 to 50 centimeters of rainfall annually, with its concentration in the monsoon months from July to September. This region experiences extremely hot summers and cool winters, along with high evapotranspiration rates. All these factors limit the potential of this area for effective natural recharge of groundwater. Topographically, the district has undulating landforms, rocky hills, and sandy plains. Due to the unreliable surface water sources, the population in the area relies heavily on groundwater for both domestic and irrigation needs. Agriculture is the primary occupation, and it heavily relies on tube wells and submersible pumps, which fetch even deeper aquifers to meet irrigation demands.

In most parts of Mahendergarh, the groundwater table is found at considerable depths. According to findings by Singh and Inderjeet (2016), the annual groundwater recharge in the district is far lower than the total volume being extracted. Reports from the Central Ground Water Board (CGWB) and the Ground Water Cell of Haryana also confirm that many blocks in the district are classified as "over-exploited," with groundwater depths in some areas dropping below 70 meters. This makes Mahendergarh a critical area for examining long-term patterns in groundwater usage.

2. Objectives

The primary goal of this study is to assess how groundwater depth has changed across the district over the last fifty years. The specific objectives are:

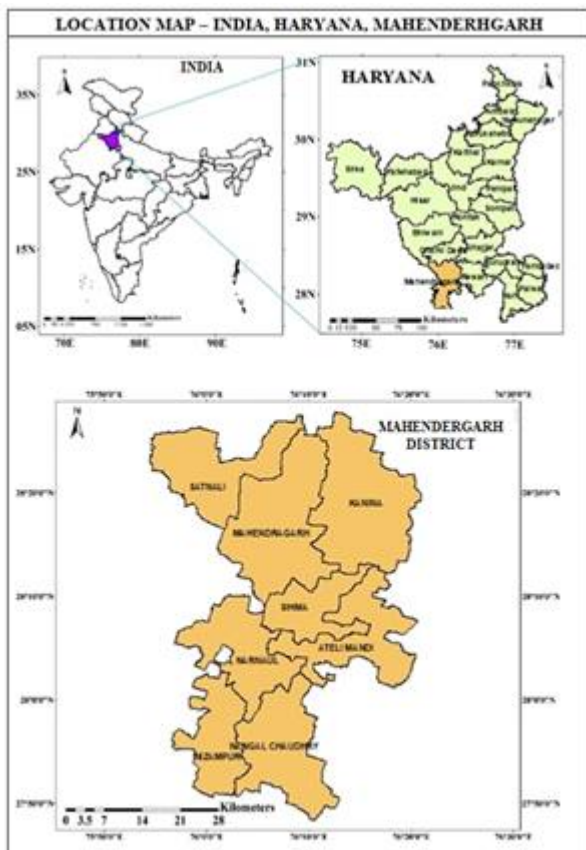


Fig no. 1

Source: (<https://www.mapsofindia.com>) District Census Handbook Mahendergarh, Haryana

- To analyze the spatial and temporal (1919 – 2023) distribution of groundwater depth across the eight

Safe = < 70%, Semi-critical = 70-90%, Critical = 90-100%, Over-exploited = >100%

blocks of Mahendergarh.

- To study the relationship between rainfall variability and groundwater table change over the selected period.

3. Methods

This study relies on secondary data from the Dynamic Groundwater Resources of Haryana report (March 2024) published by the Groundwater Cell under the Irrigation and Water Resources Department, Haryana. Groundwater levels in the state are monitored twice a year—once before the monsoon (June) and once after (October). For the purpose of this analysis, data collected during the pre-monsoon period in June has been

used, as it provides a more accurate reflection of the stress on groundwater resources. While the rainfall data is used as mean annual rainfall (m.m.).

The study takes the administrative block as the basic unit of analysis. The collected data has been organized on a block-wise basis under two key parameters:

- Depth and fluctuation in ground water table (in meters).
- Temporal and spatial change in rainfall (in m.m.).

Simple Percentage Change: To assess the change in amount of rainfall and ground water table between two specific time periods (e.g., baseline vs. future):

$$\text{Change(\%)} = \left(\frac{x_{\text{future}} - x_{\text{baseline}}}{x_{\text{baseline}}} \right) \times 100$$

Status of Groundwater Development (SOD): It refers to the ratio between net annual recharge and groundwater draft expressed as a percentage. Annual recharge includes recharge from rainfall and all other sources (tanks, ponds, and water conservation structures) for the year. Groundwater draft includes groundwater extraction for all uses, i.e., irrigation, domestic, and industrial uses.

S. O. D. (%)

$$= \frac{\text{Existing gross groundwater draft for all uses}}{\text{Net annual groundwater availability}} \times 100$$

The degree of development of groundwater is categorized as below:

Annual Rate of Change –

$$\text{Annual Rate of Change} = \frac{V_2 - V_1}{n}$$

Where:
 V_1 =

value in the initial (base) year,

V_2 = value in the final (terminal) year

n = total number of years

Karl Pearson's Correlation Coefficient and t-value in the significance t- test to find out the Correlation Coefficient and significant level between rainfall and ground water depth.

**Table 1:** Block-wise Area under Range of Depth to Water Table (June 2023)

Blocks	TOTAL Rechargeable Area	Area under different zone of Depth to Water Table (in meters bgl)								
		0-5.0	5.0-10.0		10.0-20.0		20.0-30.0		30.0 Above	
			Area	%	Area	%	Area	%	Area	%
Ateli	52,893.48		614.72	1.16	1539.63	3.01	1180.13	2.23	49505	93.59
Kanina	87,385.94		1465.4	1.68	6813.28	7.8	14973.5	17.13	64133.8	73.39
Mahendergarh	86,152.97		-	-	405.2	0.47	2954.35	3.43	82793.4	96.1
Nangal Chaudhary	60962.78		-	-	346	0.57	9075.42	14.89	51541.4	84.55
Narnaul	52145.48		394	0.76	4876.34	9.35	12970.62	24.87	33904.5	65.02
Nizampur	38880.17		910	2.34	4036	10.38	13566.23	34.89	20367.9	52.39
Sihma	34162.79		-	-	1843	5.39	7806.54	22.85	24513.3	71.75
Satnali	55,524.84		-	-	-	-	-	-	55524.8	100
Total	468108.36		3384.12	0.73	20013.45	4.25	62526.79	13.36	382284	81.66

Sources: Department of soil sciences, CCSHAU, Hisar

As per the Central Ground Water Board (CGWB), groundwater levels between 5 and 10 meters are generally considered safe for extraction. For this research, a slightly broader classification is being used to suit regional conditions: depths between 10 and 30 meters are labeled as “moderately deep,” while levels exceeding 30 meters are categorized as “extremely deep.” This adjustment is based on observed patterns, as groundwater in several blocks has reached depths beyond 70 meters, posing significant challenges for access and increasing the cost and energy required for extraction.

Rainfall variability in the study area also characterised at block level. The rainfall variability (CV) is further classified on the basis of fluctuation that is very high more than 60%, high 60 to 45%, moderate 45 to 30%, low 30 to 15% and very low is less than 15%.

4. Results

Variation in Area Under Range of Depth (June 2023)

This analysis shows the total rechargeable area and how much of it falls into different groundwater depth ranges across the block in the district. The district is dominated by deep water tables as 81.66% of the total rechargeable area (4,68,108.36) falls under 30m and above depth zone. Only 13.36% of the area of the district has water tables between 20 to 30m in depth and 4.25% area is under relatively shallower water table between 5 to 20m. A negligible area of 0.73% is under 5 to

10m water depth and nil area between 0 to 5m depth shows that the entire district lacks in shallow water table depth, confirming the deepening of this valuable resource.

All the blocks have significant large areas under deep water table depth zones with some variations in percent area. Blocks with extensive

areas under the extremely deep category include the block which have more than 90% of its area under 30m and above depth. Satnali is the worst affected block with 100% of its area under this category, followed by Mahendergarh with 96.10% and Ateli with 93.59%. Blocks with a majority of their land (70-90%) under extremely deep-water level include Nangal Choudhary 84.55% Kanina 73.3.1% and Sihma 71.75%. Blocks with moderate area (less than 70 %) under the extremely deep category include Nizampur 52.39% and Sihma 65.02% which shows that

Temporal and spatial Variation and Fluctuation in Water Table Depths

This section examines how groundwater levels have changed from 1991 to 2023 across different blocks. All blocks in the district have shown a continuous deepening of the water table over the three-decade period.

Initially, in 1991, the water table was relatively shallow in most of the blocks. Except Satnali 39.56 m and Narnaul 26.54 m, all the blocks have a water table depth of around 20 m. Progressive depletion started in 2001 from where the



water level crossed the depth of 25 m in all the blocks except Kanina at 17.63 m. A sharp decline in water table depth started after 2001 and there was a drastic fall up to 2011. Except for two blocks, Kanina 26.75 m and Nizampur 27.24 m, the depth of all the blocks crossed 40 m depth with Ateli and Satnali crossed the depth of 63m. The alarming depletion continues up to the recent decade, i.e., 2023, with a slight recovery for the Narnaul and Sihma blocks. The district average reached a depth of 50.9 m, with Ateli at 74.80 m and Satnali at 68.17 m at the deepest water level.

these blocks have slightly better availability of groundwater. A very significant large area under extremely deep-water level means that groundwater extraction in these areas is becoming increasingly difficult and expensive, requiring deeper wells and more energy for pumping. Under moderately Deep (10-30m) water level blocks like Nizampur 45.27%, Narnaul 34.22% and Sihma 28.24%, have a notable portion of their land in this depth zone.

Table 2: Block-wise Temporal and spatial Variation and Fluctuation in Depth to Water Table (bgl in mts)

Blocks	Depth to Water Table (bgl in meters)				Water Level Fluctuation	
	June 1991	June 2001	June 2011	June 2023	Fluctuation 1971-2023	Decadal Fluctuation 2011-2023
Ateli	22.49	28.54	63.65	74.8	-52.31	-11.15
Kanina	18.37	17.63	26.75	36.91	-18.54	-10.16
Mahendergarh	21.29	25.54	41.65	55.84	-34.55	-14.19
Narnaul	26.54	34.84	57.24	44.6	-18.06	12.64
Nangal Chaudhary	16.36	24.75	40.46	53.58	-37.22	-13.12
Sihma	21.31	27.21	41.06	40	-18.69	1.06
Nizampur	20.94	27.84	27.24	33.56	-12.62	-6.32
Satnali	39.56	43.8	63.17	68.17	-28.16	-5
Average	23.36	28.77	45.15	50.93	27.57	5.78

Sources: CGWB and GWC Haryana, 2024

These areas might still be suitable for sustainable groundwater extraction with proper management. Shallow water table (0-10m) is almost absent in the district. Only a few pockets of Nizampur 2.34%, Kanina 1.68%, Ateli 1.16% and Narnaul 0.76% have water tables between 5 to 10m. The nil area under 0 to 5m depth zone suggests that there is no area in this district with easily accessible groundwater (Table 1).

Although the water level in all the blocks goes deeper, according to the rate of decline, the blocks can be

identified into three categories. Firstly, the sharpest declining blocks include Mahendergarh, Ateli and Nangal Choudhary due to over extraction for irrigation and low recharge rate. Second, gradual declining blocks, including Kanina and Satnali. Third, relatively stable blocks have seen a slower decline compared to other blocks. It includes the Sihma, Narnaul and Nizampur blocks. Narnaul even showed a slight recovery in 2023 compared to 2011 (Table 2).

Table 3: Block-wise Temporal and spatial Variation of mean annual rainfall (in m.m.) and rainfall variability (CV) in percentage

Blocks	Years				Raifall Variability - CV (%) 2001-2023	Variation Level
	1991	2001	2011	2023		
Ateli	1104.6	373	371	380.9	65.46	Very High
Kanina	171	270.2	268	233.5	19.64	Low



Mahendergarh	548.4	370.8	195.5	203.3	50.63	High
Narnaul	690.6	628.1	591.5	595.2	7.33	Very Low
Nangal Choudhary	258.8	344	243.5	256.2	16.72	Low
Sihma	650.5	605.3	581.5	570.8	5.88	Very Low
Nizampur	270.4	372.2	196.5	245.3	27.35	Moderate
Satnali	649.3	457.5	264.6	302.2	41.85	High
Rainfall variability	56.28	29.8	47.85	44.32	44.56	High

Sources: Department of land records, Haryana

Variations in Groundwater Fluctuation

Groundwater fluctuation indicates how water levels have changed over the long term (1991-2023) and the short term (2011–2023).

- **Long-term or total fluctuation (1991–2023):** All the blocks in the district show a continuous deepening of the water table over five decades. Ateli has seen the most extreme drop with -52.3 m. An alarming drop is seen in Nangal Choudhary -37.22, followed by Mahendergarh -34.5m and Satnali -28.16m. Nizampur -12.62m, Sihma -18.69m, Narnaul -18.06m, and Kanina -18.54m show smaller fluctuation as compared to other blocks.
- **Short-term or decadal fluctuation (2011–2023):** Decadal fluctuation for the district is -5.78m with a rate of 0.578m per year. There is variation in decadal fluctuation across the blocks. A rapid decline (more than 10m) is observed in Mahendergarh (-14.19, which experienced the steepest drop), followed by Nangal Choudhary -13.12m, Ateli -11.15m and Kanina -10.16m. Moderate fluctuation is observed for Nizampur -6.32m and Satnali -5.00m in the past decade. Positive fluctuation which is a sign of recovery is shown by Narnaul +12.64m and Sihma +1.06m. The rise in water level is likely due to a reduced extraction rate and the linking of ponds with nearby canals which gave a rise to the water table.

Temporal and spatial Variation of mean annual rainfall and rainfall variability (CV)

Block-wise Interpretation of rainfall (1991–2023):

The table presents block-wise variation over the period 1991 to 2023, revealing marked spatial and temporal differences across the study area. Ateli shows high values in 1991, followed by a sharp decline in 2001 and remain

stabilization thereafter, indicating a major structural change during the 1991–2023. Kanina shows a rise from 1991 to 2001, followed by a gradual decline up to 2023, suggesting moderate fluctuations. Mahendergarh exhibits a continuous decreasing trend from 1991 to 2011 with a slight recovery in 2023, reflecting long-term reduction with marginal recent improvement. Narnaul and Sihma maintain consistently high values, though both display a gradual decline, indicating relative stability despite mild temporal variations. Nangal Choudhary and Nizampur show noticeable fluctuations, with peaks around 2001 followed by declines and partial recovery by 2023. Satnali demonstrates a sharp decline from 1991 to 2011 and a moderate increase in 2023. Overall, the data indicate declining trends in most blocks with varying degrees of recovery, highlighting spatial inequality and differentiated temporal dynamics across the region (Table 3).

Block-wise Interpretation of rainfall variability (CV) (1991–2023):

Coefficient of Variation (CV) of Rainfall reveals significant spatial and temporal variability among the blocks of the study area. Year-wise analysis shows high spatial disparity in 1991, 2011, and 2023, indicating unequal distribution across blocks, while 2001 exhibits moderate variability, reflecting comparatively balanced conditions. Block-wise classification highlights Ateli, Mahendergarh, and Satnali as zones of high temporal variability, suggesting pronounced fluctuations over time. In contrast, Sihma, Narnaul, Kanina, and Nangal Choudhary fall under the low variability category, indicating relative stability. Nizampur represents a moderate variability zone, acting as a transitional block. Overall, the map clearly delineates stable and unstable regions, useful for regional planning and resource management (Table 3).



Assessment of annual average rain fall and ground water table depth:

Correlation and *t*-Test results shows strong (+ 0.768 in 2023) to very weak (+ 0.151 in 2001) positive relationship between declining ground water table depth and rainfall variability across the blocks indifferent study periods (1991-2023). The calculated *t*-value ranges from (2.94 in 2023 to 0.37 in 2001) at 5 % significance level (± 2.447 for $df = 6$) shows statistically significant relationship in 2023 to no meaningful association in 2001 in the study area (Table 4). The above statistical analysis between rainfall and ground water table are more or less positively correlated since the study period (1991 to 2023) except the year 2001.

Table 4: Block-wise assessment of temporal and spatial relationship between amount of annual average rain fall (mm) and Depth to Water Table (bgl in meters) in Mahendergarh district

Year	1991	2001	2011	2023
Correlation (<i>r</i>)	0.222	0.151	0.417	0.768
<i>t</i> - test (<i>t</i>)	0.56	0.37	1.12	2.94
<i>p</i> - value (<i>p</i>)	0.596	0.721	0.304	0.026

Discussion

The groundwater scenario and rainfall in the Mahendergarh district presents a deeply concerning picture. It is characterized by both spatial inequality and temporal degradation of water table levels are associated with rainfall variability.

- Over the past five decades (1991–2023), the district has experienced a significant and consistent decline in groundwater levels across nearly all blocks. The average depth reached up to 50.93 meters by June 2023.
- More than 81% of the district's area now falls under the extremely deep category (> 30 meters), leaving only a negligible portion under shallow or moderately deep groundwater zones. Three blocks have more than 90% of their area under 30m and above depth zone.
- The temporal analysis indicates a worsening trend post-2001, with the average groundwater level falling by 27.57 meters since 1991. A possible reason for this could be intensify agricultural practices and low recharge rate.

- The last decade alone (2011–2023) witnessed a decadal decline of 5.78 meters across the district. However, the modest water table recovery in Narnaul and Sihma during this period offers a ray of hope. It suggests that targeted water management interventions may yield positive outcomes.
- If fast-depleting water depth and no one pay attention regarding rainwater harvesting practices, it could lead to complete groundwater exhaustion in several blocks within the next few decades.

Causes of Groundwater Depletion:

Besides the historically deep water levels due to natural factors (erratic rainfall and topography) in the study area compared to the rest of Haryana, there are many man-made causes for the depletion. Several studies have pointed out that the sharp drop in groundwater levels in Southern Haryana, including Mahendergarh, is mainly due to the heavy use of submersible tube wells, particularly for irrigation. Additionally, researchers have linked the problem to free or subsidized electricity, which reduces the cost of pumping and leads to excessive extraction. Further increased area under wheat cultivation also considered as a main reason of depleted water. These factors, combined with low rainfall and high water demand, have accelerated the depletion of groundwater across the region.

These findings indicate that with the right policies and active participation from local communities, it is possible to slow down or even reverse the ongoing decline in groundwater levels. Tackling the issue of water security requires effective and adaptive groundwater management practices (Kumar and Kumar, 2020). For this to happen, prompt and coordinated efforts are needed across all levels, involving government agencies, nongovernmental organizations, social groups, and local stakeholders. Their collaboration will be key in designing and implementing sustainable groundwater strategies that are both practical and locally responsive (Sangwan & Gautam, 2019).

Limitations and Future Scope of The Study

Since this research focuses on block-level analysis, it's important to acknowledge that variations may be there within individual blocks. Some areas within a block may be facing much worse conditions than others. Due to this, future research should consider using village-level or any



other level data, so that critically affected zones may be identified. This could help in designing location-specific groundwater management plans.

- The analysis highlights a worrying pattern of groundwater depletion across the Mahendergarh district. Several blocks, most notably Ateli, Satnali, and Mahendergarh have reached near-critical conditions, with water tables sinking to extreme depths. This trend not only increases the financial burden of extraction but also raises concerns about long-term sustainability. Over the past fifty years, particularly since the mid-1990s, the pace and severity of groundwater decline have intensified. If the current trajectory continues, the semi-arid region could face serious ecological and economic consequences shortly.
- At its core, this study brings attention to the urgent nature of the groundwater crisis in the district. It is also a clear appeal to policymakers, researchers, and local communities to take proactive steps. Conservation-oriented agricultural practices must be promoted to attain sustainability and to protect the groundwater resources of Mahendergarh for the future generation.

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