

Status of Groundwater Table in Haryana State of India and its Implications for Sustainability of Agriculture

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ABSTRACT

The rapid depletion of groundwater in Haryana, driven by intensive agricultural practices and over-reliance on irrigation, poses a significant threat to the state's agrarian economy. This study examines the correlation between multiple cropping patterns and groundwater depletion, highlighting how the rice-wheat cropping system has exacerbated water stress. Analysis of district-wise data reveals that over 44% of the total cropped area is cultivated more than once annually, leading to excessive groundwater extraction. The study further links these findings with a historical decline in the water table between 1990 and 2020, demonstrating the unsustainability of current agricultural practices. The environmental consequences include soil degradation, loss of biodiversity, and increased risks of desertification, while the social implications involve rising irriga-

tion costs and economic distress for farmers. Urgent policy interventions promoting crop diversification, water-efficient irrigation technologies, and groundwater recharge initiatives are essential for ensuring long-term agricultural sustainability in Haryana.

Keywords Groundwater depletion, Haryana, Multiple cropping, Sustainable agriculture, Water-intensive crops.

INTRODUCTION

Haryana, a pivotal state in India's agrarian economy, is confronting an escalating water crisis that threatens its agricultural sustainability and economic stability. The state has a total geographical area of 4.4 million hectares, of which 3.9 million hectares is arable. Agriculture in the state engages about 3/4th of the state's population and consumes about 85% of water. The state's total water resources are estimated at approximately 20.5 billion cubic meters, with 53.7 and 46.3% contribution from surface and groundwater sources, respectively (HWRA 2025). However, as per the Haryana Water Resource Authority's (HWRA) report, the net water requirement in 2023 was 32.5 BCM, resulting in a supply-demand gap of 12.0 BCM, which is projected to widen to 12.9 BCM by 2027. This highlights the importance of considerate water use in the area.

Contrarily, Pal *et al.* (2022) reported that about 38.80% of the irrigated area is served by surface water, while about 61% of the irrigated land is served

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by groundwater. The gross water requirement of the state was about 20 million acre-feet (MAF). At the same time, the Yamuna River and Bhakra irrigation system cumulatively supplies about 2.3 MAF of water to the state, and an additional 12 MAF was extracted from groundwater using tube wells. However, the state still remains water deficit by about 5.7 MAF (Khedwal and Chaudhary 2021), and the annual groundwater consumption in the surpasses the recharge rate, leading to a persistent water deficit. In paddy-growing districts, the groundwater table is declining by an average of 0.5 to 1 meter each year (Khedwal and Chaudhary 2021). About >60% of the state's geographical area has reached the red zone in groundwater availability due to overexploitation and injudicious use of water resources (Pal *et al.* 2022). Agriculture in Haryana has traditionally been dominated by water-intensive crops, notably rice and wheat. The Green Revolution of the 1960s and 1970s, while significantly enhancing food production, led to the widespread adoption of these crops, resulting in substantial groundwater extraction. The groundwater level in districts such as Kurukshetra, Kaithal, Bhiwani, and Mahendragarh has declined by more than one meter annually since 2013, reaching depths exceeding 40 meters below ground level by 2020 (Khedwal and Chaudhary 2021).

The Central Ground Water Board (CGWB 2023) has classified 85 out of Haryana's 141 administrative blocks as "over-exploited," signalling a critical imbalance between groundwater extraction and natural recharge rates (Gupta 2021). This over-extraction is primarily driven by the cultivation of water-intensive crops, which consume significantly more water compared to alternatives like pulses or oilseeds (Choudhary 2025).

The implications of this depletion are profound. Lowering water tables increases the energy costs for

pumping, reduces water availability for irrigation, and can lead to the abandonment of agricultural land. Moreover, the deterioration of groundwater quality, including salinity intrusion, poses additional challenges to crop productivity, soil health and health risks to humans and livestock (Zhang *et al.* 2023). Groundwater depletion is a threat to the sustainability of agricultural practices and the overall water security of the region (Kapoor and Anand 2024) and it leads to declining productivity of agricultural land, which may lead to increased incidences of financial distress (Verma 2019). The declining groundwater is associated with reduced water availability for the ecosystem, which may exacerbate the destruction of natural habitats and, thereby, lead to a loss of biodiversity (Dangar *et al.* 2021). Additionally, the depletion of groundwater resources has had a negative impact on the environment, reducing water availability for ecosystems and leading to the loss of biodiversity and degradation of natural habitats. These factors collectively contribute to a disturbing imbalance in the subsurface hydrological regime, accelerating groundwater depletion in the region. This study focuses on the spatio-temporal dynamics of groundwater status in Haryana state.

MATERIALS AND METHODS

The study has focused on the groundwater table in the major districts of Haryana. The current study is based on secondary data on groundwater for the major districts of Haryana from 1990 to 2022. The Groundwater Cell, Department of Agriculture, Haryana, records the depth of groundwater (both pre- and post-monsoon) in all districts of Haryana. Together this data, the Department of Agriculture has been monitoring a network of 2021 observation wells, distributed throughout Haryana. Additionally, some other data sources referred to are presented in Table 1. The study employed basic statistical methods, growth

Table 1. Data sources of different variables.

Sl. No.	Variables	Data sources
1	Area under different crops (in thousand hectare)	DAFW, 2025 (https://agriharyana.gov.in/)
2	District-wise land use statistics	Statistical Abstract of Haryana, Various Issues
3	Groundwater table in Haryana	Groundwater Yearbook of Haryana State, various issues and Dynamic ground water resources of Haryana state, CGWB, GoI

rate analysis, and descriptive statistics. Growth estimates have been made using the compound annual growth rate (CAGR), which is calculated using the given equation (1).

$$\text{Growth (\%)} = \left[\left\{ \frac{\text{Ending value}}{\text{Beginning value}} \right\}^{1/t} - 1 \right] * 100 \quad (1)$$

RESULTS AND DISCUSSION

District-wise area under water-intensive and non-water-intensive crops

The district-wise analysis of changes in the area under water-intensive and non-water-intensive crops in Haryana between 1998–2000 and 2011–21 reveals significant shifts in cropping patterns. Water-intensive crops, including rice, wheat, and sugarcane, have expanded in most districts, while the area under non-water-intensive crops, such as bajra, jowar, maize, barley, gram, rapeseed, mustard, and cotton, has generally declined. The Compound Annual Growth Rate (CAGR) values further highlight these trends.

At the state level, the total area under water-intensive crops has increased from 3,496.27 thousand hectares in 1998–2000 to 3,990.38 thousand hectares in 2011–21, with a CAGR of 0.69% (Table 1). Several districts, including Fatehabad (1.30%), Hisar (1.64%), Jind (0.84%), Kaithal (0.47%), Karnal (0.55%), and Sirsa (1.62%), have exhibited a positive growth trend, with Sirsa experiencing the most sig-

nificant expansion, increasing from 279.22 to 381.92 thousand hectares. Additionally, some districts, such as Mewat, Palwal, and Charkhi Dadri, which had little to no cultivation of water-intensive crops between 1998 and 2000, have seen substantial increases. Palwal, for instance, expanded from zero to 126.52 thousand hectares, reflecting a shift toward intensive irrigation-based agriculture. However, some regions have experienced a decline in the cultivation of these crops, including Gurgaon (-4.61%), Faridabad (-5.43%), and Mahendragarh (-1.14%), suggesting a possible shift towards alternative cropping patterns or constraints related to water availability.

In contrast, the total area under non-water-intensive crops has declined from 1,981.34 thousand hectares in 1998–2000 to 1,786.46 thousand hectares in 2011–21, with a negative CAGR of -0.43%. Several districts, such as Bhiwani (-1.99%), Fatehabad (-2.30%), Gurgaon (-2.96%), Hisar (-1.05%), Jind (-8.20%), Rohtak (-2.61%), and Sonapat (-0.59%), have witnessed a significant reduction in the cultivation of these crops, with Jind showing the steepest decline from 90.22 to 79.02 thousand hectares. Conversely, some districts, including Mahendragarh (0.70%), Kurukshetra (6.94%), and Panipat (3.06%), have shown positive growth in non-water-intensive crops (Table 2). Kurukshetra, in particular, has increased its area under these crops from 0.96 to 3.12 thousand hectares, indicating efforts toward crop diversification or the adoption of more sustainable agricultural practices.

Table 2. Average area under water-intensive and non-intensive crops (in 000' ha) and growth (%) between 1998-2021.

Districts	Water intensive crops				Non-water intensive crops			
	1998–2000	2001-10	2011-21	Growth	1998–2000	2001-10	2011-21	Growth
Ambala	164.20	172.96	184.04	0.97%	6.75	4.23	5.29	7.14%
Bhiwani	138.23	153.45	176.10	0.99%	474.32	465.88	353.42	-1.99%
Charki Dadri	0.00	0.00	20.73	-	0.00	0.00	56.73	-
Faridabad	167.81	120.22	42.75	-5.43%	43.11	23.91	12.31	2.09%
Fatehabad	236.92	251.95	298.96	1.30%	140.52	120.60	93.63	-2.30%
Gurgaon	141.34	82.48	51.26	-4.61%	124.45	81.91	49.23	-2.96%
Hisar	234.61	248.28	291.09	1.64%	276.13	279.71	253.31	-1.05%
Jhajjar	121.71	116.03	142.73	0.83%	95.43	99.40	84.54	-0.30%
Jind	316.01	312.69	347.75	0.84%	90.22	102.59	79.02	-8.20%
Kaithal	329.90	332.45	347.71	0.47%	8.32	14.98	11.94	0.00%
Karnal	332.73	346.32	362.15	0.55%	5.26	2.91	2.40	-0.01%
Kurukshetra	234.61	240.39	242.15	0.20%	0.96	1.04	3.12	6.94%
Mahendragarh	47.56	42.85	44.51	-1.14%	196.66	203.04	213.24	0.70%
Mewat	0.00	53.81	84.55	-	0.00	42.12	64.89	-

Table 2. Continued.

Districts	Water intensive crops				Non-water intensive crops			
	1998–2000	2001-10	2011-21	Growth	1998–2000	2001-10	2011-21	Growth
Palwal	0.00	38.84	126.52	-	0.00	6.26	31.04	-
Panchkula	24.06	24.60	28.77	1.49%	11.72	11.23	6.91	-2.84%
Panipat	159.90	162.82	167.10	0.71%	1.58	1.70	1.49	3.06%
Rewari	54.29	49.17	47.15	-1.27%	121.46	129.77	134.37	-0.77%
Rohtak	129.51	129.95	155.56	-0.25%	72.94	72.15	53.76	-2.61%
Sirsa	279.22	310.69	381.92	1.62%	282.59	269.09	253.16	-0.57%
Sonipat	222.70	222.63	257.61	0.81%	24.36	27.17	19.49	-0.59%
Yamunanagar	160.95	173.62	189.25	0.98%	4.57	4.69	3.17	-1.19%
Total	3496.27	3586.20	3990.38	0.69%	1981.34	1964.40	1786.46	-0.43%

Source: Based on <https://agriharyana.gov.in/>

The expansion of water-intensive crops at the expense of non-water-intensive crops suggests an increasing reliance on groundwater for irrigation. The Green Revolution, along with government policies that promote rice and wheat cultivation through Minimum Support Prices (MSP) and procurement programs, has incentivized farmers to prioritize water-intensive crops. This trend has placed significant stress on the groundwater table, as evidenced by severe depletion in several districts of Haryana. To ensure sustainable agricultural practices, it is essential to encourage diversification towards less water-intensive crops, implement efficient irrigation techniques, and strengthen groundwater conservation policies. Future agricultural planning should focus on promoting water-efficient farming methods to mitigate the adverse effects of excessive groundwater extraction and ensure long-term water security.

Areas sown more than once under different crops

The data on multiple cropping across Haryana's districts highlights the state's intensive agricultural practices and their impact on groundwater sustainability. The total area under multiple cropping stands at 2,783.62 thousand hectares, demonstrating a strong dependency on high-intensity farming. Districts like Bhiwani (321.69), Hisar (286.59), Sirsa (304.22), and Jind (211.07) have the most significant areas under multiple cropping, primarily due to the dominance of water-intensive crops such as wheat and rice. Other significant contributors include Fatehabad (199.87), Karnal (182.05), Kaithal (174.95), and Sonipat (131.17), all of which rely heavily on groundwater

for irrigation (Table 3).

The intensification of agriculture has directly contributed to the decline in the groundwater table in Haryana. Districts with high multiple cropping areas, particularly Kaithal, Karnal, and Kurukshetra, are experiencing severe groundwater depletion due to excessive water extraction. The rice-wheat mono-

Table 3. District with multiple cropping systems.

District	Total cropped area (000' Ha)	Area sown more than once (000'Ha)	% of TCA sown more than once
Ambala	207.16	83.16	40.14%
Bhiwani	698.95	321.69	46.02%
Charki Dadri	36.83	17.00	46.16%
Faridabad	146.88	67.27	45.80%
Fatehabad	422.25	199.87	47.34%
Gurgaon	154.39	52.47	33.99%
Hisar	600.66	286.59	47.71%
Jhajjar	226.42	83.86	37.04%
Jind	442.71	211.07	47.68%
Kaithal	366.45	174.95	47.74%
Karnal	370.69	182.05	49.11%
Kurukshetra	262.66	120.76	45.97%
Mahendragarh	262.53	118.39	45.10%
Mewat	130.38	50.86	39.01%
Palwal	105.42	46.28	43.90%
Panchkula	41.90	18.61	44.42%
Panipat	177.64	87.52	49.27%
Rewari	184.39	65.11	35.31%
Rohtak	213.23	78.39	36.76%
Sirsa	677.61	304.22	44.90%
Sonipat	279.95	131.17	46.86%
Yamunanagar	198.72	82.33	41.43%
Grand total	6207.81	2783.62	44.84%

culture prevalent in these regions has exacerbated the crisis, as rice cultivation requires continuous flooding. Additionally, government policies, including the Minimum Support Price (MSP) and assured procurement of wheat and rice, have incentivized farmers to maximize production through multiple cropping cycles, further straining water resources.

Analysis of the proportion of Total Cropped Area (TCA) sown more than once reinforces this concern. On average, 44.84% of Haryana's TCA undergoes multiple cropping, with districts like Karnal (49.11%), Panipat (49.27%), Kaithal (47.74%), and Hisar (47.71%) exceeding this average significantly. Other districts, including Fatehabad (47.34%), Jind (47.68%), and Bhiwani (46.02%), also exhibit intensive cultivation. Limited canal irrigation has further encouraged farmers to rely on excessive groundwater withdrawal through tube wells and bore wells, thereby accelerating depletion.

Trends in groundwater table

The analysis of groundwater table data in Haryana from 1990 to 2023 reveals a long-term declining trend, with fluctuations across different periods. The average groundwater depth in 1990 was approximately 8.65 meters, which increased to 14.14 meters in 2020 before marginally decreasing to 12.49 meters in 2023. The 1990s witnessed a relative stability, with some years showing recovery (e.g., 1996–1998, with the water table rising to around 7.05 meters) (Fig. 1). This trend strongly correlates with the expansion of

water-intensive cropping systems, particularly paddy cultivation in semi-arid zones of Haryana. Studies have documented that groundwater extraction in the state accelerated post-Green Revolution due to assured procurement of rice and wheat, subsidized electricity for pumping, and proliferation of tube wells (Asoka *et al.* 2017). The CGWB (2020) has classified 61% of Haryana's blocks as "overexploited," underscoring unsustainable withdrawal levels. Economically, declining groundwater tables impose multiple costs. First, deeper pumping raises energy requirements, thereby increasing irrigation costs. Rodell *et al.* (2009) estimated that groundwater depletion in northwestern India, including Haryana, is among the highest globally, reducing long-term agricultural competitiveness. Farmers often respond by shifting to high-capacity submersible pumps, which raises entry barriers for smallholders, exacerbating rural inequality (Shah 2010). Second, declining tables increase the risk of aquifer depletion and deterioration in water quality. Tiwari *et al.* (2009) highlight salinity intrusion and fluoride contamination risks as water levels fall. Such externalities are not factored into farm-level decision-making, leading to a "tragedy of the commons."

However, it is essential to note that recent years (2021–2023) show modest improvement compared to 2019–2020. This could be linked to increased rainfall variability, implementation of water-saving programs such as "Mera Pani Meri Virasat" scheme in Haryana (Government of Haryana 2020), and greater awareness about sustainable practices. Yet,

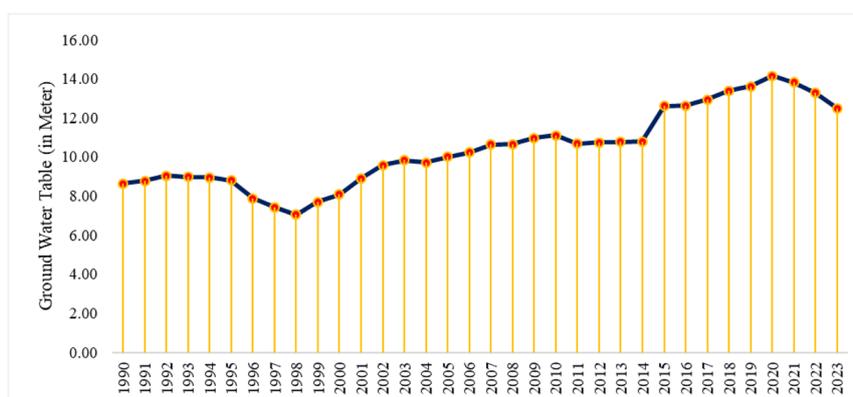


Fig. 1. Changing groundwater table in Haryana from 1990 to 2023 (Source: Groundwater annual report of Haryana, various years).

Asoka *et al.* (2017) argue that monsoon variability contributes significantly to short-term fluctuations, suggesting that the recovery may not represent structural improvements but rather temporal hydrological responses.

From a policy perspective, the results highlight both challenges and opportunities. On one hand, continued paddy-centric production threatens the sustainability of groundwater, undermining long-term food security (Choudhary 2025). On the other hand, technological interventions like direct-seeded rice, laser land levelling, and micro-irrigation could reduce water intensity. Moreover, market and policy reforms such as incentivizing crop diversification toward millets and pulses could alleviate pressure on aquifers while aligning with national nutrition goals.

Spatio-temporal dynamics of groundwater status across Haryana

The district-wise time series analysis of groundwater

levels in Haryana between 1990 and 2023 reveals substantial spatial and temporal heterogeneity (Table 4), reflecting the combined effects of hydrogeology, land use, irrigation intensity, and urban expansion. The Compound Annual Growth Rate (CAGR) estimates highlight both stress-prone and relatively stable regions, offering insights into the differentiated nature of groundwater dynamics across the state. Notably, a negative growth rate in groundwater depth indicates aquifer recovery, whereas a positive rate signifies continued depletion.

During the first decade (1990–2000), several districts such as Ambala, Hisar, Jhajjar, Panipat, and Rohtak displayed negative growth rates, suggesting modest improvements in groundwater conditions. These outcomes may be linked to relatively lower irrigation intensity and the presence of recharge-prone alluvial aquifers in parts of northern and western Haryana (Shah 2010). However, districts including Gurugram, Faridabad, Kaithal, and Kurukshetra reported positive growth rates, pointing towards emerg-

Table 4. Spatio-temporal dynamics of groundwater (in meter) across Haryana state. GR¹, GR², GR³ and GR⁴: Decadal growth rates, while overall, GR: Growth rate between 1990-2023.

District	1990	2000	GR ¹ (%)	2010	GR ² (%)	2020	GR ³ (%)	2023	GR ⁴ (%)	Overall GR (%)
Ambala	5.56	3.82	-0.04	4.80	0.02	4.59	0.00	5.56	0.07	0.00
Bhiwani	12.13	10.40	-0.02	10.19	0.00	9.87	0.00	9.55	-0.01	-0.01
Charkhi Dadri	10.10	8.35	-0.02	8.03	0.00	13.46	0.05	5.66	-0.25	-0.02
Faridabad	7.67	11.12	0.04	20.52	0.06	32.94	0.05	25.30	-0.08	0.04
Fatehabad	5.69	5.38	-0.01	6.22	0.01	10.12	0.05	9.59	-0.02	0.02
Gurugram	8.47	15.14	0.06	27.22	0.06	27.76	0.00	25.71	-0.03	0.03
Hisar	9.77	6.61	-0.04	8.45	0.02	8.36	0.00	8.59	0.01	0.00
Jhajjar	5.43	4.46	-0.02	3.65	-0.02	3.18	-0.01	2.32	-0.10	-0.03
Jind	6.98	6.07	-0.01	9.72	0.05	11.94	0.02	11.17	-0.02	0.01
Kaithal	4.90	6.25	0.02	12.16	0.07	17.41	0.04	15.18	-0.04	0.03
Karnal	7.64	6.64	-0.01	15.99	0.09	22.46	0.03	22.32	0.00	0.03
Kurukshetra	10.67	13.37	0.02	27.84	0.08	38.90	0.03	40.49	0.01	0.04
Mahendragarh	19.02	18.45	0.00	19.94	0.01	24.86	0.02	22.89	-0.03	0.01
Mewat	5.61	2.99	-0.06	2.73	-0.01	4.23	0.04	5.51	0.09	0.00
Palwal	5.54	4.01	-0.03	7.49	0.06	7.77	0.00	6.75	-0.05	0.01
Panchkula	13.32	11.87	-0.01	13.28	0.01	13.29	0.00	11.78	-0.04	0.00
Panipat	7.28	4.93	-0.04	5.58	0.01	14.51	0.10	11.17	-0.08	0.01
Rewari	15.34	12.98	-0.02	15.99	0.02	19.67	0.02	11.39	-0.17	-0.01
Rohtak	4.86	3.76	-0.03	2.70	-0.03	2.85	0.01	2.20	-0.08	-0.02
Sirsa	14.03	10.08	-0.03	10.62	0.01	11.18	0.01	10.66	-0.02	-0.01
Sonipat	3.44	4.44	0.03	4.30	0.00	4.85	0.01	4.44	-0.03	0.01
Yamunanagar	6.81	6.27	-0.01	6.69	0.01	6.84	0.00	6.54	-0.01	0.00
Grand total	8.82	7.22	-0.02	8.45	0.02	10.33	0.02	9.05	-0.04	0.00

ing over-exploitation due to accelerated urbanization and paddy-dominated agriculture. Similar patterns of urban and peri-urban groundwater stress in Haryana and the National Capital Region (NCR) have been noted by MacDonald *et al.* (2016).

The second decade (2000–2010) marked a sharper intensification of depletion. Districts such as Karnal, Kaithal, and Kurukshetra recorded some of the highest depletion rates, underscoring the heavy pressure from water-intensive paddy cultivation supported by subsidized electricity and assured procurement (Rodell *et al.* 2009, CGWB 2019). This trend aligns with broader regional findings that northwestern India is among the most rapidly depleting aquifer systems globally (Tiwari *et al.* 2009).

Between 2010 and 2020, the situation further worsened in central and southern Haryana. Districts like Kaithal, Fatehabad, and Gurugram continued to face sustained depletion, reflecting entrenched dependence on groundwater for irrigation and urban supply (Sachdev and Panigrahi 2023). By contrast, districts such as Jhajjar and Mewat exhibited relative stability or marginal improvements. These local recoveries may be attributable to cropping pattern shifts, community-led water management, or recharge interventions under state and national programs such as the Atal Bhujal Yojana. The short-term trend for 2020–2023 reveals mixed outcomes. Districts like Rewari and Charkhi Dadri registered sharp declines in groundwater depth, suggesting improved recharge, whereas Faridabad, Panipat, and Rohtak showed continued depletion, largely driven by urban-industrial expansion and irrigation demand. These observations are consistent with findings by Ahamad *et al.* (2023), who noted that rainfall variability and targeted recharge projects in semi-arid Haryana have produced localized improvements but failed to offset wider regional depletion.

At the aggregate level, Haryana's overall groundwater growth rate (0.00) across three decades indicates near stagnation. However, this masks critical inter-district disparities. Water-stressed districts such as Gurugram, Karnal, Kaithal, and Kurukshetra exhibit deepening depletion trends, while Jhajjar, Rohtak, and Sirsa report stabilization or recovery.

Such divergence underscores the strong influence of local hydrological settings, cropping intensity, and policy frameworks on groundwater trajectories (Mukherjee *et al.* 2015).

Overall, the findings emphasize that while some districts have succeeded in stabilizing aquifer conditions, many agriculturally intensive and urbanizing regions continue to face acute depletion. This pattern underscores the need for differentiated groundwater governance strategies—including crop diversification away from paddy, scaling up micro-irrigation technologies, rationalizing energy subsidies, and expanding recharge infrastructure to safeguard long-term water security and sustainability in Haryana.

Implications of declining groundwater table on sustainability of agriculture

The rapid depletion of Haryana's groundwater table due to intensive agricultural practices has significant long-term implications for the sustainability of agriculture, as well as broader environmental and social consequences. The continued over-extraction of groundwater to support multiple cropping cycles, particularly the rice-wheat monoculture, poses a severe threat to the viability of farming in the state. If current trends persist, Haryana's farmers will face declining water availability, reduced crop yields, and increased production costs due to the need for deeper bore wells and more energy-intensive irrigation methods. This unsustainable water consumption pattern could ultimately lead to an agricultural crisis, threatening food security and rural livelihoods.

One of the most pressing environmental implications of groundwater depletion is land degradation. As water tables fall, soil moisture decreases, leading to declining soil fertility and increased vulnerability to drought. Excessive withdrawal also causes land subsidence, making certain areas unsuitable for cultivation in the long run. Additionally, over-extraction of groundwater accelerates salinization and water contamination, reducing soil productivity and affecting crop health. The dependence on chemical fertilizers and pesticides to maintain yields further depletes soil quality, leading to long-term desertification risks in some regions. Declining groundwater levels also

reduce the availability of surface water, affecting wetlands, rivers, and biodiversity. As natural water bodies dry up, ecosystems suffer, leading to loss of aquatic life and biodiversity, further exacerbating the environmental crisis.

From a social perspective, the depletion of groundwater exacerbates economic distress among farmers. As water sources become scarcer, farmers are forced to dig deeper bore wells, which require substantial financial investment. Small and marginal farmers, who lack the resources for expensive irrigation infrastructure, are particularly vulnerable. Many are driven into debt, leading to increased farmer suicides and rural distress. The inequitable access to water resources also intensifies social disparities, as wealthy farmers can afford deep wells, while poorer farmers struggle with water scarcity. In the long run, declining agricultural productivity may force many farmers to abandon agriculture altogether, leading to increased rural-to-urban migration and unemployment.

Addressing these challenges requires urgent policy interventions to promote sustainable water use. Crop diversification toward less water-intensive crops, adoption of efficient irrigation techniques like drip and sprinkler systems, and large-scale groundwater recharge initiatives are essential. Government policies should incentivize sustainable practices through subsidies and support for rainwater harvesting and afforestation. Without immediate action, Haryana's groundwater crisis could lead to an irreversible decline in agricultural sustainability, posing severe consequences for food security, the environment, and rural communities.

CONCLUSION

The study highlights the grave challenge of groundwater depletion in Haryana, primarily caused by the dominance of the rice–wheat cropping system and excessive reliance on irrigation. With more than 44% of the cropped area cultivated multiple times annually, groundwater tables have fallen at alarming rates, with some districts experiencing depletion levels exceeding 200% between 1990 and 2020. This unsustainable trajectory jeopardizes agricultural

sustainability, food security, and rural livelihoods. The consequences are severe and multifaceted. Environmentally, groundwater decline has led to reduced soil fertility, desertification risks, and the drying of wetlands and rivers. Socio-economically, small and marginal farmers face escalating irrigation costs, indebtedness, and migration pressures. While policies such as MSP and subsidized electricity helped secure food supplies in the past, they have also fueled unsustainable water use, highlighting the urgent need for structural reforms.

POLICY IMPLICATIONS

To address the groundwater crisis, Haryana must urgently promote crop diversification from water-intensive rice to less water-demanding crops such as maize, pulses, and oilseeds, supported through MSP, procurement, and assured markets. Equally important is the widespread adoption of water-saving technologies like drip and sprinkler irrigation, direct-seeded rice, and conservation agriculture to improve water-use efficiency. Groundwater recharge initiatives—including farm ponds, check dams, and watershed development—need to be scaled up alongside stricter regulation of extraction. At the same time, subsidy regimes should be restructured by rationalizing electricity support and linking incentives to efficient water use. Finally, farmer awareness and capacity-building programs on sustainable cropping patterns and climate-smart practices are essential to ensure long-term ecological balance, agricultural sustainability, and livelihood security.

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