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Dynamics of Land Use Patterns and Agricultural Instability in Haryana: A Temporal Analysis

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ABSTRACT

Background: Haryana, India, is a major foodgrain producing state since the Green Revolution, faces growing challenges of land and water degradation. Intensive rice-wheat cropping patterns have resulted in groundwater depletion, waterlogging, salinity, alkalinity and declining soil health. Despite these concerns, limited research has comprehensively examined the temporal dynamics of land use and agricultural instability in the region. The present study aimed to analyze land use changes and instability in Haryana's agricultural landscape from 2002 to 2022. The study utilized secondary data from Statistical Abstract of Haryana and land use statistics (Ministry of Agriculture).

Methods: Analytical techniques such as compound annual growth rate (CAGR) analysis and cuddy-della valle instability index (CDVI) were employed to assess trends and volatility across different land categories.

Result: Findings revealed critical paradox: while India demonstrated marginal forest expansion (0.10% CAGR) and moderate intensification, Haryana experienced alarming environmental degradation with forest cover declining sharply (-7.30% CAGR) and barren lands surging (22.00% CAGR). Agricultural intensification was evident through 2.60% CAGR in area sown multiple times, yet offset by rising instability in culturable wasteland (CDVI: 32.97%) and non-agricultural land use (CDVI: 40.05%). These findings underscore urgent need for sustainable land management and policy interventions to balance agricultural productivity with environmental conservation in Haryana.

Key words: Growth rate, Instability index, Land degradation, Land use change, Sustainability.

INTRODUCTION

Agriculture, which depends heavily on natural resources such as soil, water, biodiversity and sunlight, faces severe stress due to increasing biotic and abiotic pressures (Gawande, 2000). Given the finite nature of these resources, enhancing agricultural output must come from improved productivity on existing farmland rather than expansion into new areas. However, demographic growth, socio-economic pressures, erratic monsoons and frequent floods and droughts are rapidly degrading soil and water quality, posing significant threats to future food security. Globally, land degradation affects approximately 430 million ha, with Asia accounting for 18 per cent of this degraded land (Barrow, 1991). In India, land degradation varies regionally, Jammu and Kashmir (69.24%) and Himachal Pradesh (50.90%) face degradation due to snow cover and forest loss, while states like Rajasthan (29.64%) suffer from sandy terrain and desertification (MoRD and NRSA, 2005). Additionally, nearly 9.4 per cent of India's geographical area is affected by acidic soils, particularly in states like Assam, West Bengal, Kerala and Karnataka (Maji, 2008).

Haryana, a key agricultural state in India, has faced severe land and water degradation due to intensive farming practices adopted during the Green Revolution. The state contributes significantly to India's food grain production but suffers from declining soil health, waterlogging, salinity and alkalinity. Approximately 60 per cent of Haryana's geographical area is affected by soil degradation, particularly in districts like Karnal, Kaithal, Rohtak and Gurugram (Planning Commission, 2009).

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The shift from traditional crops like millets to water-intensive rice and wheat cultivation has worsened groundwater depletion. In regions like Faridabad, Gurugram and Bhiwani, water tables are declining by nearly one meter annually due to excessive groundwater extraction (Sunita, 2023). Conversely, areas like Rohtak and Sonipat face waterlogging due to poor drainage and over-reliance on canal irrigation.

While extensive research exists on land use changes at the national level, comprehensive temporal analyses examining both trends and instability at the state level remain limited, particularly for agriculturally intensive states like Haryana. This study addresses this gap by:

- ❖ Examining temporal trends in land use patterns across different land categories in India and Haryana from 2002 to 2022.
- ❖ Assessing instability in land use categories using the CDVI methodology.
- ❖ Comparing national and state-level patterns to identify regional vulnerabilities.

MATERIALS AND METHODS

An attempt has been made to describe briefly the basic approach of the sources of data and analytical techniques adopted for the present study.

Selection of study area

The secondary data for this study were collected from various published sources to analyze the dynamics of land use in Haryana. For land resources, data on land use patterns, including categories such as forest area, net sown area, culturable wasteland and fallow land, were obtained from the statistical abstract of Haryana, land use statistics published by the Ministry of Agriculture and reports from the Department of Agriculture and Cooperation (DACNET). These datasets provided annual trends from 2002 to 2022, enabling an assessment of changes in land utilization over time.

Rationale for time period selection

The period 2002-2022 was chosen as it represents two decades of significant agricultural transformation in Haryana, capturing the post-Green Revolution intensification period and recent environmental degradation trends. Quinquennial grouping of data (five-year averages) was employed to reduce year-to-year fluctuations and reveal long-term structural trends.

Analytical tools

For the purpose of analysis to meet the objective of the study, appropriate analytical techniques were employed to draw valid inferences from the study.

Compound annual growth rate

Compound annual growth rate (CAGR) was used to study trends in agricultural use by land for the period 2002-03 to 2021-22 in Haryana. Compound growth rates for various land use categories were worked out on the basis of the following log-linear regression equations:

$$Y = AB^t u$$

Where,

Y= The dependent variable (land use categories, irrigation sources, water level depth).

A= The constant.

B= The regression coefficient.

t= The time variable.

u= Error term.

Taking natural logarithms of both sides yields the log-linear regression equation:

$$\ln (Y_t) = \ln (A) + t \times \ln (B) + \ln (u_t)$$

This equation was estimated using ordinary least squares (OLS) regression. The CAGR was then calculated as:

$$\text{CAGR} = [\text{Antilog} (\ln (B - 1)] * 100$$

Cuddy and della valle index (CDVI)

The agricultural instability can be measured by different methods, such as the coefficient of variation (CV), dispersion, Cuddy Della Valle Index (CDI), Coppock Instability index, *etc*. The present study applies the Cuddy Della Valle Index for measuring the instability. Cuddy Della Valle index first de-trends the given series and gives a clear direction about the instability. The use of coefficient of variation as a measure to show the instability in any time series data has some limitation. If the time series data exhibit any trend, the variation measured by CV can be over-estimated (for example if the region which has growing production are at constant rate will score high in instability of production if CV is applied for measuring instability). As against that, Cuddy-Della Valle index attempts to de-trend the CV by using coefficient of determination (r^2). Thus it is a better measure to capture instability in agricultural production (Anjum and Madhulika, 2018).

CDVI was proposed by John D. Cuddy and Peter A. Della Valle in 1978 for measuring the instability in time series data that is characterized by trend. The estimable form of the equation is as follows:

$$\text{CDVI} = \text{CV} \sqrt{1 - r^2}$$

Where,

CV= Coefficient of variation.

r^2= Coefficients of determination.

$$\text{CV} = \frac{\text{S.D.}}{\text{Mean}} \times 100$$

Where,

S.D.= Standard deviation.

r^2= The coefficient of determination from the log-linear trend regression equation used for CAGR estimation.

The instability index values ranging from 0 to 15 per cent indicates low instability, 15 per cent to 30 per cent indicates medium instability and greater than 30 per cent denotes high instability.

RESULTS AND DISCUSSION

National land use dynamics (2002-2022)

The land use pattern in India, as presennted in Table 1 from 2002-03 to 2021-22 revealed significant shifts in land allocation across different categories, reflecting broader socio-economic and environmental changes. The reporting area, which constituted the surveyed land, remained relatively stable at around 93.12 per cent to 93.64 per cent of the total geographical area (3,28,726 thousand ha), indicating minimal variation in land documentation over the two decades. The forest area exhibited a marginal but consistent increase, growing from 70,529 thousand ha (21.45%) in 2002-07 to 72,072 thousand ha (21.92%) in 2017-22, with a compound annual growth rate (CAGR) of 0.10 per cent. This gradual expansion aligned with afforestation initiatives and stricter conservation policies, though the rate remained modest compared to ecological demands (Khan, 2022 and Gowda *et al.,* 2021).

A notable trend was the expansion of non-agricultural land use, which grew from 24,767 thousand ha (7.53%) to 27,645 thousand ha (8.41%), registering a CAGR of 0.70 per cent. This rise underscored rapid urbanization, industrialization and infrastructural development, leading to the conversion of agricultural and fallow lands into residential, commercial and industrial zones. Concurrently, barren and uncultivable land declined from 17,414 thousand ha (5.30%) to 16,589 thousand ha (5.05%), with a negative CAGR of -0.30 per cent, suggesting land reclamation efforts or shifts toward alternative uses (Bhattacharyya *et al.,* 2015; Pandey and Ranganathan, 2018).

Agricultural land dynamics present a mixed pattern as noted from the Table 1. The net area sown remained relatively stable at around 42 per cent of the total geographical area, with a negligible CAGR of 0.10 per cent, indicating stagnation in the expansion of primary agricultural land. However, the total cropped area exhibited a more pronounced increase, rising from 1,87,954 thousand ha (57.18%) to 2,09,558 thousand ha (63.73%), with a CAGR of 0.70 per cent, driven by multiple cropping and intensification. This is further corroborated by the area sown more than once, which nearly doubled from 14.94 per cent to 21.15 per cent, growing at a CAGR of 2.30 per cent, reflecting enhanced irrigation, better cropping patterns and higher agricultural productivity.

Conversely, marginal declines were observed in permanent pastures (-0.10% CAGR), culturable wasteland (-0.70% CAGR) and fallow lands (-0.50% CAGR), indicating pressure on grazing lands and the conversion of underutilized lands into productive uses. The reduction in land under miscellaneous tree crops (-0.60% CAGR) further signaled a shift towards more intensive land-use practices, possibly at the expense of traditional agroforestry systems.

The instability index values presented in Table 2 revealed critical insights into the volatility of land use patterns across different categories in India during 2002-2022. This index measures the degree of instability in land use patterns, with higher values indicating greater variability over time. The instability index values ranging from 0 to 15 per cent indicates low instability, 15 per cent to 30 per cent indicates medium instability and greater than 30 per cent denotes high instability.

The reporting area exhibited relatively low instability, with the index values ranging from 0.03 to 0.11 across the periods, reflecting consistent land accounting practices. The forest category showed fluctuations, with the index peaking at 0.54 in the first period and decreasing to 0.26 by the last period, suggesting relative stabilization in forest areas over time.

Table 2 demonstrated moderate instability in areas under non-agricultural use, with the index varying between 0.25 and 0.71, influenced by urbanization and infrastructure expansion. Barren land showed notable instability, especially in the last period, with an index of 0.89, possibly due to reclamation and land use conversion efforts. Pastures and grazing areas recorded minimal variability

Table 1: Land use pattern in India (2002-2022). (in '000 ha)

Classification	Time period				CAGR (in %)
	2002-03 to 2006-07	2007-08 to 2011-12	2012-13 to 2016-17	2017-18 to 2021-22	
Reporting area	3,06,097 (93.12)	3,07,318 (93.48)	3,07,827 (93.64)	3,07,068 (93.40)	0.00*
Forest area	70,529 (21.45)	71,568 (21.77)	71,808 (21.84)	72,072 (21.92)	0.10*
Area under non-agricultural use	24,767 (7.53)	26,206 (7.97)	27,054 (8.23)	27,645 (8.41)	0.70*
Barren land	17,414 (5.30)	17,004 (5.17)	16,987 (5.17)	16,589 (5.05)	-0.30*
Permanent pastures and other grazing	10,450 (3.18)	10,333 (3.14)	10,278 (3.13)	10,351 (3.15)	-0.10*
Land under misc. trees crops and groves	3,383 (1.03)	3,264 (0.99)	3,137 (0.95)	3,096 (0.94)	-0.60*
Culturable waste land	13,332 (4.06)	12,802 (3.89)	12,394 (3.77)	12,044 (3.66)	-0.70*
Total fallow land	27,367 (8.33)	25,217 (7.67)	26,087 (7.94)	25,257 (7.68)	-0.50*
Net area sown	1,38,856 (42.24)	1,40,926 (42.87)	1,40,082 (42.61)	1,40,014 (42.58)	0.10*
Total cropped area	1,87,954 (57.18)	1,94,644 (59.21)	1,98,161 (60.27)	2,09,558 (63.73)	0.70*
Area sown more than once	49,099 (14.94)	53,718 (16.34)	58,079 (17.67)	69,544 (21.15)	2.30*
Total geographical area	3,28,726 (100.0)	3,28,726 (100.0)	3,28,726 (100.0)	3,28,738.6 (100.0)	0.00*

Source: Land Use Statistics: 2002-22.

Note: CAGR means compound annual growth rate, figures in paranthesis indicate percentage of the total.

*Means significant at 1 per cent.

initially, but instability surged significantly to 2.37 in the final period, reflecting changes in grazing practices or reclassification of such lands. Miscellaneous tree crops and groves exhibited high instability in earlier periods, with the index reaching 0.91 in 2012-17, followed by stabilization at 0.25 in the last period.

Also, culturable wasteland displayed high variability initially, with an index of 0.99 in the first period, declining to 0.28 by the final period, likely due to improved land management practices. Total fallow land showed substantial instability in the first period with an index of 10.28, which drastically reduced to 0.45 by the last period, indicating significant stabilization. The net sown area and cropped area demonstrated moderate instability over the years, with indices declining steadily, reflecting better consistency in agricultural practices. The area sown more than once experienced higher instability compared to other agricultural categories, with the index peaking at 4.21 in the second period but decreasing to 2.19 in the last period.

State-level analysis: Haryana land use dynamics

The analysis of land use patterns in Haryana from 2002-03 to 2021-22 as presented in Table 3 revealed a complex interplay of agricultural intensification, ecological degradation and socio-economic transformations, with significant implications for the state's sustainable

Table 2: Instability Index of different land use categories in India. (in per cent)

Classification	Time period 2002-03 to 2006-07	2007-08 to 2011-12	2012-13 to 2016-17	2017-18 to 2021-22
Reporting area	0.11	0.03	0.05	0.10
Forest area	0.54	0.01	0.10	0.26
Area under non-agricultural use	0.25	0.39	0.71	0.34
Barren land	0.18	0.68	0.26	0.89
Permanent pastures and other grazing	0.16	0.09	0.24	2.37
Land under misc. trees crops and groves	0.59	0.89	0.91	0.25
Culturable waste land	0.99	0.90	0.50	0.28
Total fallow land	10.28	3.77	2.50	0.45
Net area sown	2.11	0.75	0.47	0.33
Total cropped area	2.56	1.62	1.19	2.89
Area sown more than once	3.85	4.21	2.98	2.19

Source: Computed by author.

Table 3: Land use pattern in Haryana (2002-2022). (in '000 ha)

Classification	Time period 2002-03 to 2006-07	2007-08 to 2011-12	2012-13 to 2016-17	2017-18 to 2021-22	CAGR (in %)
Reporting area	4373.06 (98.92)	4371.32 (98.88)	4371.48 (98.88)	4367.99 (98.80)	0.00*
Forest area	43.72 (0.99)	39.34 (0.89)	38.56 (0.87)	34.29 (0.78)	-7.30*
Area under non-agricultural use	434.90 (9.84)	483.77 (10.94)	467.66 (10.58)	216.10 (4.89)	-19.20**
Barren land	98.49 (2.23)	103.84 (2.35)	120.18 (2.72)	182.92 (4.14)	22.00
Permanent pastures and other grazing	25.35 (0.57)	27.89 (0.63)	24.88 (0.56)	101.48 (2.30)	49.00
Land under misc. trees crops and groves	8.42 (0.19)	11.61 (0.26)	7.64 (0.17)	26.92 (0.61)	35.90**
Culturable waste land	40.37 (0.91)	27.97 (0.63)	32.68 (0.74)	70.62 (1.60)	20.00**
Total fallow land	193.64 (4.38)	126.77 (2.87)	168.41 (3.81)	162.95 (3.69)	-2.30
Net area sown	3528.19 (79.81)	3550.13 (80.30)	3511.48 (79.43)	3572.82 (80.81)	0.30*
Total cropped area	6348.53 (143.60)	6457.41 (146.06)	6503.60 (147.11)	6612.14 (149.56)	1.00*
Area sown more than once	2820.34 (63.79)	2907.28 (65.76)	2992.12 (67.68)	3039.32 (68.75)	2.60*
Total geographical area	4.421 (100.0)	4.421 (100.0)	4.421 (100.0)	4.421 (100.0)	0.00*

Source: Land use statistics: 2002-22.

Note: CAGR means compound annual growth rate, figures in paranthesis indicate perctange of the total; *Means significant at 1 per cent, **Means significant at 5 per cent.

development. The data demonstrated a paradoxical coexistence of agricultural expansion and environmental stress, as evidenced by the stable reporting area (98.80-98.92% of geographical area) alongside dramatic changes in specific land categories. Forest cover experienced a concerning decline at 7.30 per cent CAGR (significant at 1 per cent level), shrinking from 43,720 to 34,290 ha, reflecting persistent deforestation pressures in this predominantly agrarian state. Simultaneously, non-agricultural land use showed a statistically significant decrease from 434.90 thousand ha to 216.10 thousand ha (-19.20% CAGR, significant at 5 per cent level), reflecting changes in land categorization and urbanization trends, coincided with the findings of Meenu (2014) who highlighted that the area in Haryana under non-agricultural use increased due to more and more land was being used for industrial sites, housing, transport systems, recreational purposes, irrigation systems *etc.*

The most alarming trends emerge in land degradation indicators, with barren lands expanding at 22 per cent CAGR to 182,920 ha (4.14% of geographical area) by 2021-22, likely due to unsustainable agricultural practices and poor land management (Rani, 2019 and Sharma *et al.,* 2015) and culturable wasteland increasing at 20 per cent CAGR (significant at 5 per cent level), suggesting growing land quality deterioration. These negative developments are partially offset by the significant expansion of permanent pastures (49% CAGR) and land under miscellaneous trees (35.90% CAGR, significant at 5 per cent level), possibly reflecting government afforestation initiatives or changing farming practices. Agricultural land use patterns revealed intensification, with net sown area maintaining stable coverage (79.43-80.81%) but showing minimal growth (0.30% CAGR, significant at 1 per cent level), while total cropped area expanded at 1 per cent CAGR through increased multiple cropping (area sown more than once growing at 2.60% CAGR, significant at 1 per cent level). This intensification, however, occured against a backdrop of declining fallow lands (2.30% CAGR), indicating reduced opportunities for land recovery and raises sustainability concerns given Haryana's severely over-exploited groundwater resources (135.79% development stage).

Instability index for various land use categories in Haryana across four quinquennial periods from 2002-03 to 2021-22 is presented in Table 4. The reporting area demonstrated minimal variability, with index values ranging from 0.00 to 0.13, reflecting stable land accounting practices. The forest category showed moderate to high instability throughout the period, with an increasing trend, peaking at 3.92 in the final period, indicating fluctuations in forest coverage.

The area under non-agricultural use exhibited significant instability, particularly in the last period, with an index value of 40.05, highlighting dynamic changes possibly due to urbanization. Similarly, barren land showed increasing instability, with the index reaching 36.08 in the final period, suggesting variations in land degradation. Permanent pastures and grazing areas experienced the highest instability among all categories in the final period, with an index of 52.90, reflecting notable changes in land allocation for grazing purposes.

The category of land under miscellaneous tree crops and groves also displayed considerable instability, with the index fluctuating across periods and peaking at 23.11, before declining and rising again to 21.39 in 2017-22. Culturable wasteland showed consistently high variability, with the index reaching 32.97 in 2012-17, before slightly stabilizing to 22.83 in the last period, indicating inconsistent utilization patterns. Total fallow land exhibited significant fluctuations, with the index peaking at 21.28 in 2012-17, before decreasing slightly to 19.67 in the final period.

In contrast, agricultural categories displayed relatively lower instability as noted from the Table 4. The net sown

Table 4: Instability index of different land use categories in Haryana. (in per cent)

Classification	Time period			
	2002-03 to 2006-07	2007-08 to 2011-12	2012-13 to 2016-17	2017-18 to 2021-22
Reporting area	0.01	0.01	0.00	0.13
Forest area	3.25	1.04	3.01	3.92
Area under non-agricultural use	2.53	3.18	8.12	40.05
Barren land	3.43	1.39	7.07	36.08
Permanent pastures and other grazing	2.91	5.81	1.56	52.90
Land under misc. trees crops and groves	23.11	6.88	15.52	21.39
Culturable waste land	26.56	3.80	32.97	22.83
Total fallow land	6.75	7.21	21.28	19.67
Net area sown	0.63	0.18	0.34	0.86
Total cropped area	2.00	0.93	0.83	0.72
Area sown more than once	3.76	2.11	1.66	2.11

Source: Computed by author.

area remained highly stable, with index values ranging from 0.18 to 0.86, reflecting consistent agricultural practices. The cropped area exhibited minimal variability, with the index declining from 2.00 to 0.72 over the periods, indicating improved stability in cropping practices. The area sown more than once displayed moderate variability, with the index peaking at 3.76 in the first period and stabilizing at 2.11 in the subsequent periods, showing increased consistency in intensified agricultural practices.

Paradox of agricultural intensification and environmental stress

The analysis reveals critical paradox in Haryana's land use trajectory: agricultural intensification coexists with severe environmental degradation. While the state has successfully increased area sown multiple times (2.60% CAGR, approaching 69% of net sown area), this intensification occurs within shrinking, degraded resource base characterized by:

- ❖ 21.6% reduction in forest cover (-7.30% CAGR).
- ❖ 85.8% expansion in barren lands (22.00% CAGR).
- ❖ Over-exploitation of groundwater (135.79% development stage).
- ❖ Rising salinity and alkalinity affecting approximately 60% of state's geographical area.

This paradox reflects development model that prioritizes short-term productivity gains over long-term resource sustainability (Bhattacharyya *et al.*, 2015). The findings align with critical analyses suggesting that Green Revolution technologies, while transformative in increasing food grain production, have externalized substantial environmental costs (Sharma *et al.*, 2015). Research on Indian agriculture confirms that land degradation results in productivity losses per hectare annually, with substantial state-level variations (Bansal *et al.*, 2024 and Gorain *et al.*, 2023).

The Green Revolution technologies, while transformative in increasing food grain production, have externalized substantial environmental costs in states like Haryana (Barrow, 1991). The water-intensive rice-wheat cropping system, consuming over 70% of groundwater resources, has created an unsustainable trajectory. Climate projections indicating 15-17% yield losses in irrigated rice and wheat by mid-century further compound these sustainability challenges (Meenu, 2014).

Regional divergence: National vs. state patterns

National-level data masks significant regional vulnerabilities. While India demonstrates modest environmental progress (marginal forest expansion, declining barren lands), Haryana exhibits pronounced environmental stress. This divergence reflects:

- ❖ **Differential agroecological contexts:** Haryana's semi-arid climate, limited precipitation and groundwater-dependent irrigation systems create inherent vulnerability to degradation (Gowda *et al.*, 2021).
- ❖ **Regional heterogeneity in policy implementation:** Afforestation initiatives and soil conservation programs show uneven implementation across states, with Haryana lagging in forest cover restoration (Khan, 2022).
- ❖ **Comparative competitive pressure:** Haryana's position as major food grain producer creates incentives for intensive cultivation, potentially at expense of environmental conservation compared to states with more diversified economies.

Instability as indicator of policy inconsistency

High instability values in non-agricultural use (40.05%), barren land (36.08%) and permanent pastures (52.90%) suggest policy inconsistency or uncertain land governance frameworks. The pattern of declining instability in agricultural categories (from 3.85% to 2.19% in area sown multiple times) contrasts sharply with increasing volatility in degradation indicators, suggesting:

- ➢ Established agricultural practices provide stable land use framework.
- ➢ Land degradation and conservation efforts lack clear, consistent policy direction.
- ➢ Urbanization pressures create unpredictable land reclassification patterns.

This interpretation aligns with recent research emphasizing that effective land governance requires integrated, place-based and adaptive management approaches rather than top-down uniform policies (Lousada, 2025; Pandey and Ranganathan, 2018).

Policy implications and recommendations

Findings suggest urgent need for:

- ❖ **Integrated land resource management:** Harmonize agricultural production objectives with environmental conservation through comprehensive land use planning at district level.
- ❖ **Groundwater sustainability programs:** Shift from extraction-focused policy to recharge-focused strategy; promote water-efficient crops (pulses, oilseeds) reducing groundwater pressure (Meenu, 2014).
- ❖ **Land restoration initiatives:** Target culturable wasteland (70.62 thousand ha) and barren lands (182.92 thousand ha) for active restoration through afforestation, soil amendment programs.
- ❖ **Crop diversification:** Current rice-wheat duopoly should transition toward climate-resilient, water-efficient alternatives to reduce resource pressure. Recent farmer surveys identify lack of market access and price uncertainty as primary barriers to diversification (Bansal *et al.*, 2025).
- ❖ **Institutional strengthening:** Establish consistent land use governance with clear, transparent classification systems to reduce instability in environmental and urban land categories.

❖ **Farmer support systems:** Transition support mechanisms from input subsidies to outcome-based incentives for sustainable practice adoption.

Recommendations prioritize

✧ Groundwater recharge over continued extraction-focused development.
✧ Crop diversification away from water-intensive rice-wheat system.
✧ Active land restoration targeting many hectares of degraded/ underutilized land.
✧ Institutional reform to ensure consistency in land governance and conservation policies.

Future research should examine: (i) economic costs of land degradation in Haryana; (ii) district-level variations in sustainability; (iii) adoption barriers for alternative crops; (iv) groundwater scenario modeling under climate change conditions; (v) farmer willingness-to-adopt sustainable practices. These investigations will provide critical evidence base for designing effective, farmer-responsive policies balancing productivity and sustainability imperatives in India's most agriculturally intensive states.

CONCLUSION

This 20-year analysis of land use dynamics in Haryana reveals state at critical juncture. Agricultural intensification achievements, demonstrated through 2.60% CAGR in area sown multiple times and stable cropped area have been purchased at substantial environmental cost. Sharp forest cover decline (-7.30% CAGR), barren land explosion (22.00% CAGR) and culturable wasteland accumulation (20.00% CAGR) indicate unsustainable resource depletion trajectories. High instability in environmental and urban land categories (36-53%) suggests policy inconsistency in addressing land degradation.

Comparative analysis reveals that national-level optimism about agricultural sustainability masks serious regional vulnerabilities specific to states like Haryana that have specialized in water-intensive production. The state's 135.79% groundwater development stage, combined with findings of declining forest cover and expanding degradation, creates urgent imperative for policy reorientation.

Conflict of interest

The authors declare that they have no conflict of interest.

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