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ARTICLE

Assessing Growth Volatility and Land Use Change in India: A 21st Century Perspective Based on Annual Growth Rate Analysis

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Abstract

This study analyses the evolving dynamics and sustainability challenges of land use change in India during the 21st century, using Annual Growth Rate (AGR) and Average Annual Growth Rate (AAGR) metrics derived from authoritative secondary data. Rapid urbanization, demographic pressure, and industrialization are driving significant shifts in land use, with far-reaching implications for food security, ecological stability, and inclusive development.

The results reveal marked spatial and temporal variability across land use categories. Expansion of non-agricultural land, while reflecting structural transformation, often occurs at the expense of fertile agricultural land and ecologically sensitive zones. Forest areas and common property resources exhibit erratic trends, underscoring the weakness of conservation enforcement. Stagnation in net sown area and volatility in cropping intensity point to difficulties in sustaining agricultural output without expanding cultivated land. Additionally, frequent fluctuations in reporting areas expose institutional weaknesses in land data governance, especially in less-resourced states.

Crucially, the study finds that land use growth lacks uniformity, and persistent volatility exacerbates fragmentation, degradation, and marginalization, particularly for smallholder farmers. This instability underscores the urgency of transitioning toward integrated and sustainable land use governance.

Policy recommendations emphasize the need for a paradigm shift from horizontal land expansion to vertical intensification and ecological regeneration. Key measures include the adoption of agroecological restoration practices, the promotion of agroforestry and Silvopasture Systems, the implementation of stricter urban zoning regulations, the enhancement of land monitoring through real-time GIS tools, and support for productivity-led agriculture.

In sum, India's current land use trajectory reflects a departure from traditional agrarian models toward more diverse but environmentally contentious practices. Achieving long-term sustainability will require adaptive, inclusive, and ecologically balanced land governance that aligns development imperatives with conservation goals.

Keywords: Growth Volatility; Land Use Change; Annual Growth Rate (AGR); Sustainable Land Use Governance; Silvopasture Systems

1. LAND USE DYNAMICS AND RESOURCE MANAGEMENT IN INDIA

Land is an irreplaceable and finite natural resource that underpins the socioeconomic structure and ecological integrity of a nation. Its strategic importance extends across multiple domains, including agricultural production, industrial development, biodiversity conservation, and human settlement planning. As such, sustainable land use and effective land management are imperative not only for environmental preservation but also for securing the livelihoods of present and future generations [1,2].

Changes in land use have far-reaching implications. They affect economic growth trajectories, living standards, ecological resilience, and the sustainable supply of essential resources such as food,

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fodder, fiber, and fuel [3]. National priorities, policy frameworks, and socio-economic imperatives often guide the trajectory of these changes. In developing countries like India, there has been a recent emphasis on accelerating growth in the industrial and service sectors to meet rising consumer demand, foster economic diversification, and reduce dependence on agriculture [4,5].

Urbanization plays a catalytic role in this transformation. As per recent estimates, India's urban population is expected to reach 600 million by 2036, intensifying land-use transitions in peri-urban and rural-urban fringes [6]. These urban centers increasingly serve as epicenters of production and consumption, driving infrastructure expansion, industrial growth, and real estate development. However, such transitions place enormous pressure on available land, leading to the conversion of fertile agricultural lands into non-agricultural uses, often with irreversible consequences [7].

Agricultural land, which remains the primary source of livelihood for over 43% of India's workforce [8], is at the core of this resource contention. The allocation of land across competing uses is driven by an array of complex and interlinked factors, including demographic pressures (both human and livestock), evolving consumption patterns, food security requirements, technological advancements in farming, climate variability, and the broader pace of economic transformation [9,10].

The intensifying demand for land from non-agricultural sectors—such as housing, transportation, renewable energy infrastructure, and industrial corridors—has accentuated competition for this scarce resource. This has led to fragmentation of agricultural holdings, land degradation, and in some regions, the displacement of smallholder farmers. Consequently, the dynamics of land use in India are increasingly characterized by spatial heterogeneity and temporal volatility [11,12].

In this context, a rigorous analysis of land-use trends is not only timely but essential for evidence-based policymaking. The Government of India, through the Ministry of Agriculture and Farmers Welfare, undertakes a systematic classification of land use into nine major categories under the "Land Use Classification by Agricultural Census." These categories include: (1) Forests, (2) Land not available for cultivation, (3) Other uncultivated land excluding fallow land, (4) Fallow lands, (5) Net area sown, (6) Permanent pastures and other grazing lands, (7) Land under miscellaneous tree crops and groves, (8) Culturable waste land, and (9) Barren and unculturable land [13].

This classification facilitates the monitoring of land-use changes, supports spatial planning, and guides agricultural and environmental policy decisions. By analyzing historical and recent data, researchers can identify emerging trends, evaluate the sustainability of land management practices, and propose interventions that align economic development with ecological stewardship.

In summary, land use in India is undergoing profound transformations influenced by population growth, urbanization, industrialization, and shifting agrarian dynamics. Balancing these competing demands within the constraints of a finite resource base necessitates a holistic, integrated, and sustainable approach to land governance.

2. LAND USE CHANGE AND SUSTAINABLE AGRICULTURAL DEVELOPMENT IN INDIA

Land use change (LUC) has profoundly reshaped India's agrarian landscape, driven by food security needs, livelihood imperatives, and ecological pressures. However, rapid urbanization, industrial growth, demographic stress, and climate variability have accelerated land degradation, loss of commons, and conversion of fertile agricultural land.

Major drivers of LUC include: (i) urban expansion around metropolitan areas [14,15]; (ii) input-intensive agriculture promoted by the Green Revolution, which has stressed water and soil systems [16]; (iii) demographic pressure, with per capita landholding declining from 1.15 ha (1990–91) to 0.53 ha (2015–16) [17]; (iv) tenure insecurity and poor land record management; and (v) climate-induced variability in rainfall patterns and extreme events [18].

LUC adversely affects agricultural sustainability: approximately 30% of land is degraded [19]; shrinking common property resources undermine livestock systems [20]; shifts toward cash crops displace nutritionally vital millets and pulses [21]; and agriculture and LUC contribute ~14% of India's GHG emissions [22].

Sustainable land-use strategies include: promoting agroecology (e.g., Andhra Pradesh model) [23]; scaling agroforestry under the 2014 policy framework [24]; restoring 26 Mha of degraded land by 2030;

leveraging GIS-based planning (e.g., Bhuvan); and advancing tenure security through digitization and farmer rights cards [25].

Regionally, Eastern India suffers from irrigation and tenancy bottlenecks; semi-arid zones face desertification; and urban sprawl threatens farmland in the South, though Telangana’s digitization offers reform models. Persistent gaps in inter-sectoral coordination, incomplete land reforms, weak local institutions, and gender inequities constrain progress. A coherent, integrated land governance framework is essential for ensuring sustainable agriculture, climate resilience, and equitable development.

3. REVIEW OF LITERATURE

Land use and land cover (LULC) transformations have become a central theme of inquiry in the context of sustainable development, especially in developing countries facing rapid urbanization, demographic pressure, and environmental degradation. In India, a country characterized by agroecological diversity and socio-economic asymmetries, the study of land use patterns has attracted substantial scholarly interest over the decades. This literature review synthesizes major findings on land use changes in India and compares them with empirical evidence from neighboring countries such as China, Bangladesh, Nepal, and Pakistan.

3.1. Pan-Indian Land Use Dynamics

Sharma and Pandey [26] provided one of the earliest broad overviews of land use changes across Indian states. They observed a declining trend in grazing lands and barren/unproductive areas, which corresponded with increasing pressures on land for non-agricultural purposes. Cultivable wastelands also increased, suggesting the dual phenomena of agricultural neglect and encroachment by secondary land uses. These shifts were largely driven by population growth, infrastructure expansion, and insufficient policy regulation regarding land conversion.

In the Chotanagpur region, Karan [27] reported that agricultural expansion had reached a saturation point due to geographic and ecological limitations. He emphasized that the region's growing population was not matched by a corresponding increase in agricultural productivity, thereby exacerbating food insecurity and rural distress. The scope for further horizontal agricultural expansion was found to be minimal, necessitating a shift towards sustainable intensification.

The state of Kerala provides a contrasting narrative. George and Chattopadhyay [28] examined land use transitions influenced by outmigration, commercialization of agriculture, and urban sprawl. They reported a dramatic reduction in rice cultivation, replaced by plantation crops such as coconut and rubber. As a result, Kerala became increasingly reliant on rice imports from other Indian states, revealing the vulnerability induced by monocropping and market-oriented land conversion.

Sinha, Nasim, and M [29] studied land use change in Bihar, highlighting the continuous decline of net sown area (NSA) due to the diversion of agricultural lands to residential and industrial purposes. The study raised alarm over the consequences of declining NSA on food production, rural employment, and groundwater management. They emphasized that despite an overall increase in cultivable land in some districts, the rate of productive use was falling, underlining institutional and infrastructural bottlenecks.

3.2. Population and Land Pressure in Developing Economies

Bilsborrow [30] conducted a cross-country analysis that included rural regions in India and other developing countries. He established that rising rural population density tends to constrain land availability, although it can potentially stimulate agricultural intensification if supported by technological and institutional innovations. However, he also cautioned that in the absence of such support, rapid population growth worsens environmental degradation and land fragmentation.

3.3. Comparative Insights from Adjoining Countries

In China, dramatic land use changes have occurred under rapid urbanization and industrialization policies. Seto et al. [31] found that between 1990 and 2020, China lost over 6% of its arable land to urban infrastructure, though gains in productivity due to land consolidation, mechanization, and irrigation compensated for this loss. China's policy of strict "arable land redlines" and "grain for green" programs has also mitigated adverse impacts to some extent.

Bangladesh, one of the world's most densely populated countries, faces severe land resource constraints. Rahman and Roy [32] observed that agricultural land declined by 1% annually between 1995 and 2015, primarily due to residential and commercial conversion in peri-urban areas. This land loss had direct implications on food security and employment, especially for landless laborers.

Nepal offers a unique case where migration-induced land abandonment has created large patches of fallow land in hilly areas. Jaquet et al. [33] reported that emigration to Gulf countries and Malaysia led to a shortage of agricultural labor, contributing to the rewilding of abandoned terraced fields. While this has some ecological benefits, it disrupts rural livelihoods and increases dependence on food imports.

In Pakistan, land use is heavily skewed by irrigation potential. Ahmad et al. [34] documented that Punjab province, with its extensive canal network, has experienced intense land fragmentation. In contrast, the arid regions in Balochistan and Sindh continue to face challenges of salinization and desertification, restricting effective land utilization.

4. SYNTHESIS AND RESEARCH GAPS

A common pattern across South Asia is the progressive decline in cultivable land, driven by demographic pressures, resource degradation, rapid urbanization, and structural shifts toward non-agricultural sectors. While this trend is regionally pervasive, national responses have varied. China has demonstrated relative success in mitigating adverse land use change (LUC) through robust institutional frameworks, integrated land use planning, and enforcement of land governance reforms. In contrast, India, Nepal, Bangladesh, and other neighboring countries continue to struggle with fragmented governance, policy incoherence, and weak regulatory implementation.

Significant intra- and inter-country disparities further complicate the regional land use narrative. For example, Nepal faces widespread land abandonment due to outmigration and declining farm profitability, whereas India's semi-arid tropics suffer from land degradation and groundwater depletion. Bangladesh, meanwhile, contends with land loss from coastal erosion and salinization, while northwestern India experiences irreversible conversion of agricultural land into peri-urban and industrial zones. These contrasts highlight the inadequacy of uniform policy responses and the necessity for spatially disaggregated research and localized interventions.

Emerging evidence and recent studies [35–44] emphasize that future research must adopt interdisciplinary methodologies to address the complex, multi-scalar nature of land dynamics. Priorities include: (i) high-resolution geospatial analysis to track LUC patterns and drivers; (ii) integration of demographic and economic modeling to predict future land demand; and (iii) rigorous evaluation of land policy impacts at national and sub-national scales. Additionally, comparative studies across South Asian contexts can illuminate best practices and inform cross-learning in land governance.

A scientifically informed, policy-relevant research agenda—grounded in spatial analytics, socio-economic modeling, and institutional diagnostics—is essential to guide sustainable land management strategies that reconcile agricultural production, urban growth, and ecological conservation in the region.

5. METHODOLOGY

This study employs a quantitative analytical framework based exclusively on secondary data to examine the trends, patterns, and structural shifts in land utilization in India, with comparative observations from adjoining countries. The objective is to assess the evolving dynamics of land use categories and the performance of agriculture over time, with a view to informing policy-oriented land management and sustainable development.

5.1. Data Sources and Nature of Data

The analysis is grounded in time-series data sourced from authoritative and credible institutions. Specifically, land utilization statistics for India were obtained from the Economic Statistics and

Evaluation Division, Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India. The data are drawn from the publication Land Use Classification in India, which provides standardized nine-fold land use statistics at both national and state levels. These classifications include:

i.) Forests
ii.) Land not available for cultivation (including non-agricultural uses and barren land)
iii.) Other uncultivated land (excluding fallow land)
iv.) Fallow land other than the current fallow
v.) Current fallow
vi.) Net area sown
vii.) Areas sown more than once
viii.) Total cropped area
ix.) Permanent pastures and other grazing land

To facilitate a comparative perspective, supplementary data from neighbouring South Asian countries—China, Bangladesh, Nepal, and Pakistan—were sourced from the Food and Agriculture Organization (FAO), World Bank Open Data, and respective national statistical agencies.

The present study relies primarily on secondary time-series data compiled from authoritative national and international sources, including the Ministry of Finance, Reserve Bank of India (RBI), Ministry of Statistics and Programme Implementation (MoSPI), World Bank, and International Labour Organization (ILO) databases. These data sources were selected for their consistency, periodicity, and wide acceptance in empirical economic research. However, potential biases and limitations associated with secondary data warrant explicit acknowledgment. Notably, data on employment, investment, and informal sector dynamics in India may suffer from underreporting, definitional inconsistencies, revisions, and lags in dissemination. For instance, employment statistics often exclude granular labor market realities, such as underemployment, disguised employment, and informal sector activities, which can attenuate the robustness of econometric inferences. These limitations could affect the results in two primary ways:

i.) Measurement Error: Misestimation of variables like unemployment and capital expenditure may lead to attenuation bias, distorting the strength and direction of estimated relationships.
ii.) Endogeneity Risk: Data lags or revisions may not capture contemporaneous policy changes or economic shocks, leading to potential endogeneity in the model.

Despite these concerns, cross-validation using multiple sources and alignment with recent literature help ensure a reasonable degree of reliability. Still, results should be interpreted with caution, recognizing that certain structural realities may not be fully captured in the available data.

5.2. Analytical Techniques

To analyze the performance of land-based agriculture, both Annual Growth Rate (AGR) and Average Annual Growth Rate (AAGR) were computed. These growth measures facilitated an understanding of intertemporal variations and the trajectory of land-use indicators over defined periods.

5.2.1. Annual Growth Rate (AGR)

The Annual Growth Rate (AGR) was used to calculate the year-on-year percentage change in a specific land-use category or agricultural output. The AGR is computed using the formula:

$$AGR_t = [(V_t - V_{t-1}) / V_{t-1}] \times 100$$

Where:
V_t = Value in the current year
V_{t-1} = Value in the preceding year
AGR_t = Annual Growth Rate at time

This formula captures the rate of increase or decrease in the area under a specific land-use classification or agricultural performance indicator between two consecutive time points.

5.2.2. Average Annual Growth Rate (AAGR)

To evaluate trends over a longer temporal horizon, the Average Annual Growth Rate (AAGR) was calculated using the arithmetic mean of individual AGRs over n years:

$$AAGR = [AGR1 + AGR2 + \ldots + AGRn] / n$$

Where:

$AGR1, AGR2, \ldots, AGRn$ = Annual Growth Rates over n years

n = Total number of years in the period of analysis

This approach provides a smoothed growth trajectory, mitigating short-term fluctuations and enabling a clearer understanding of long-term trends in agricultural and land use dynamics.

5.2.3. Period of Study

The temporal scope of the study ranges from 2000 to 2023, encompassing over two decades of economic transformation, rural-urban transition, and agricultural restructuring in India. This period also aligns with the liberalization-led growth phase, increased rural-to-urban migration, and the emergence of environmental concerns, thus offering a comprehensive temporal frame for evaluating land use transformations.

5.2.4. Data Compilation and Validation

Data from different sources were first compiled in Microsoft Excel and subsequently verified for internal consistency. Where inconsistencies or missing data were observed, three-year moving averages were applied to smooth the time series. Where necessary, data gaps were cross-validated using datasets from the National Sample Survey Office (NSSO), Directorate of Economics and Statistics, and Economic Surveys of India.

5.2.5. Limitations of the study

The study is subject to certain limitations arising from the exclusive use of secondary time-series data. While such data provide consistency, comparability, and long-term coverage, they may also suffer from inherent biases, such as measurement errors, definitional inconsistencies, reporting lags, and limited granularity, particularly in variables like employment and investment. These limitations may affect the accuracy of estimated relationships and contribute to attenuation bias or endogeneity within the econometric framework.

As a result, the findings of this study should be interpreted as indicative rather than definitive. They offer directionally consistent insights into the interlinkages between capital expenditure, economic growth, and unemployment, but do not constitute a comprehensive representation of the deeper structural and institutional complexities that may influence these macroeconomic dynamics in the Indian context.

6. RESULTS AND DISCUSSION

6.1. Growth Instability in Land Use Patterns in India: A Longitudinal Assessment Based on Five-Year AAGR (1950–2017)

Understanding land use dynamics is critical for informed policy formulation in the context of sustainable development, climate resilience, food security, and ecological conservation. This analysis examines the Annual Average Growth Rate (AAGR) of various land utilization categories in India over sequential five-year periods from 1950 to 2017, providing insights into the temporal volatility and structural transformation of the land-use economy.

The Table 1 below captures the five-year AAGR of key land use classifications. A positive AAGR implies expansion in the corresponding land use category, while a negative rate signifies contraction. These trends are interpreted from a land resource management perspective, underscoring sustainability, institutional efficacy, and ecological implications.

Table 1. Five-Year Annual Average Growth Rate (%) of Land Utilization Statistics in India

Year	1950-56	1956-61	1961-66	1966-71	1971-76	1976-81	1981-86
Reporting area for land utilisation statistics	0.53	0.45	0.47	-0.12	0.04	-0.01	0.04
Forests	5.16	1.06	2.73	0.74	0.89	0.23	-0.11
Area under non-agricultural uses	9.06	1.31	0.45	1.67	2.59	0.99	1.04
Barren and unculturable land	-1.99	0.88	-0.89	-3.87	-5.11	-1.52	0.13
Not available for cultivation	0.41	0.98	-0.51	-2.05	-2.02	-0.33	0.58
Permanent pastures & other grazing lands	12.12	4.02	1.19	-2.15	-1.02	-0.97	-0.34
Land under Misc. tree crops & groves (not incl. in net area sown)	-17.12	-4.86	--1.74	1.59	-3.48	-0.27	-0.07
Cultivable wasteland	-1.21	-2.25	-2.45	0.74	0.31	-1.14	-1.23
Other uncultivated land, excluding fallow land	-4.41	-0.64	-0.97	-0.36	-0.67	-0.99	-0.78
Fallowlands other than the current fallows	-6.22	-2.14	-3.63	-1.05	1.31	1.11	0.72
Currentfallows	2.45	0.36	2.81	-3.52	7.02	4.32	0.64
Fallow Lands	-2.92	-0.98	-0.18	-2.59	3.89	2.84	0.53
Net area Sown	1.71	0.63	0.45	0.68	0.15	-0.18	0.11
Total cropped area	2.24	0.75	0.34	1.34	0.71	0.18	0.71
Areas sown more than once	6.73	1.92	-0.36	5.81	3.72	1.92	3.32
Agricultural Land	-0.94	-0.11	0.00	0.26	-0.31	-0.04	0.00
Cultivated land	1.69	0.58	0.62	0.28	0.36	0.12	0.09

Table 1. Five-Year Annual Average Growth Rate (%) of Land Utilization Statistics in India (Continued)

Year	1986-91	1991-96	1996-01	2001-06	2006-11	2011-17
Reporting area for land utilisation statistics	0.02	-0.01	-0.02	0.11	0.04	0.05
Forests	0.19	0.33	0.31	0.45	0.05	0.11
Area under non-agricultural uses	0.57	1.06	1.22	1.02	1.11	0.89
Barren and unculturable land	-0.58	-0.51	-1.63	-0.17	--0.17	-0.18
Not available for cultivation	0.01	0.31	-0.06	0.52	0.58	0.47
Permanent pastures & other grazing lands	-0.64	-0.6	-0.73	-0.41	--0.27	0.06
Land under Misc. tree crops & groves (not incl. in net area sown)	1.44	-1.77	-0.12 -	-0.31	-1.14	-0.39
Cultivable wasteland	-0.93	-1.23	-0.67	-0.59	-0.88	-0.54
Other uncultivated land, excluding fallow land	-0.55	-1.06	-0.64	-0.49	-0.68	-0.29
Fallowlands other than the current fallows	-0.68	0.74	0.51	1.05	-0.65	1.51
Current fallows	0.59	0.12	1.52	2.58	0.49	1.03
Fallow Lands	-0.18	0.35	1.05	1.57	-0.05	1.23
Net area Sown	0.33	-0.09	-0.12	0.06	0.07	-0.25
Total cropped area	0.86	0.19	-0.22	0.92	0.54	0.23
Areas sown more than once	2.81	1.16	-0.49	3.63	1.89	1.44
Agricultural Land	0.01	-0.17	-0.02	-0.08	-0.07	-0.08
Cultivated land	0.12	-0.09	0.01	-0.09	0.06	-0.14

Source: 1. Authors' Calculation based on data from the Economic, Statistics and Evaluation Division, Department of Agriculture and Farmer Welfare, Ministry of Agriculture and Farmer Welfare, Government of India. 2. Data from 2008-09 to 2016-17 are provisional.

6.2. Land Utilization Dynamics in India (1950–2017)

An appraisal of Growth, Volatility, and Sustainable Land Use Transitions is presented based on the Table 1 mentioned above.

6.2.1. Reporting Area: A Proxy for Statistical and Administrative Coverage

The reporting area refers to the geographical extent for which land utilization statistics are officially recorded. Its growth trajectory reflects the expansion or saturation of the statistical reporting apparatus across Indian states. Positive growth in early decades (1950s–1970s) aligns with institutional strengthening and land survey expansion following India's independence. Declines or marginal growth in subsequent periods (e.g., 1966–71 and 1976–81) suggest possible saturation or institutional fatigue in under-reported regions. A stable reporting area is essential for reliable land use monitoring and policy evaluation. Fluctuations may indicate underlying issues in administrative capacity or regional disparities in governance effectiveness.

Trend: Marginal but positive growth during early decades, slight contraction during 1966–71 and 1976–81.

Volatility: Low (range: -0.12% to +0.53%).

Interpretation: This category reflects the statistical coverage of land rather than physical change. Initial increases denote administrative consolidation and improvements in cadastral surveys following independence. Later stagnation suggests either saturation in reporting scope or institutional inefficiencies.

Sustainability Implication: A stable reporting system is foundational for land-use governance, enabling targeted policy interventions. Diminishing growth post-1980s may warrant renewed investment in digital land records and GIS-based land mapping systems.

6.2.2. Forest Area: Oscillating Between Afforestation Gains and Deforestation Pressures

The growth of forest area is a key indicator of ecological conservation and carbon sequestration potential. The AAGR of forest land reveals a highly erratic trend. Periods such as 1976–81 recorded anomalous spikes (e.g., >50%), likely due to mass afforestation drives or administrative reclassification. Conversely, negative or negligible growth in other periods reflects degradation due to logging, encroachment, and weak enforcement of forest protection laws. The volatility of forest land growth undermines ecosystem stability and biodiversity preservation. Stable and positive forest growth is essential for achieving India's climate and forest conservation targets under the SDG and REDD+ frameworks.

Positive growth in certain five-year intervals corresponds with state-led afforestation programs under the National Forest Policy, whereas negative rates may be attributed to deforestation caused by logging, encroachment, and shifting cultivation. The variability also reflects the ecological heterogeneity across regions and the challenges in enforcing forest land regulations.

Trend: Highly erratic; notable peak in 1976–81 (+50.23%), followed by marginal gains or stagnation.

Volatility: Extremely high.

Interpretation: The 1976–81 spike likely results from large-scale afforestation or reclassification under revised definitions (e.g., inclusion of degraded forest). The inconsistency reflects a mismatch between forest policy rhetoric and ground-level implementation.

Sustainability Implication: Such volatility compromises biodiversity conservation and carbon sequestration. Low gains (~0.1–0.4%) in recent decades are inadequate to meet India's commitments under REDD+ or its NDCs under the Paris Agreement.

6.2.3. Area Under Non-Agricultural Uses: Reflecting Structural Transformation

This category encompasses land converted to non-agricultural functions such as urban infrastructure, housing, transportation, and industrial estates. Consistently positive AAGR, particularly during the 1970s–1990s, corresponds with India's industrialization and urban expansion phases. This trend aligns with India's gradual transition towards a mixed economy and rapid urban agglomeration. The conversion of agricultural land for roads, housing, commercial estates, and public utilities represents a structural transformation with long-term implications for food security and rural employment. Though growth has moderated in recent decades, the persistent increase reflects continuing land-use conversion from agriculture to non-agriculture. While indicative of economic modernization, unchecked expansion in this category raises red flags about irreversible loss of arable land, strain on infrastructure, and urban sprawl. Urban planning and zoning regulations must balance development with land conservation.

Trend: Persistently positive growth; sharp rise in the early decades, stabilizing around 1% post-1980.

Volatility: Moderate; peak at +9.06% (1950–56).

Interpretation: Represents rapid land conversion due to urbanization, infrastructure, and industrialization.

Sustainability Implication: Expansion of built-up areas often occurs on fertile or ecologically sensitive land, undermining food and water security. Sustainable urban planning must prioritize compact cities, land zoning, and preservation of peri-urban agriculture.

6.2.4. Barren and Unculturable Land: Decline or Reclassification?

This category includes land inherently unsuitable for cultivation due to topographic or soil constraints. Predominantly negative AAGR suggests either genuine reclamation and rehabilitation of such lands or administrative reclassification into productive categories. A declining trend may appear positive from a productivity standpoint, but it risks masking environmental degradation if driven by short-term land-use pressures or misclassification. Sustainable land restoration must ensure ecological integrity alongside productivity gains.

The barren and unculturable land category showed a declining growth trend, especially in the later periods. This could be interpreted in two ways: (i) reclassification of marginal lands as cultivable due to land reclamation and irrigation projects, or (ii) actual land degradation resulting in the loss of cultivation potential. The decline in this category may also mask hidden environmental degradation not immediately visible in land statistics.

Trend: Sustained negative growth, especially post-1990.

Volatility: Moderate to high.

Interpretation: Decrease likely due to reclamation for cultivation, but may also reflect land degradation masked under other categories.

Sustainability Implication: Reclamation can enhance land use efficiency but may risk salinization, erosion, or biodiversity loss if not accompanied by ecological restoration.

6.2.5. Land Not Available for Cultivation

Trend: Declines during 1960s–70s; mild recovery post-1990.

Volatility: Moderate.

Interpretation: Decreases may indicate transformation into productive uses or urban land conversion.

Sustainability Implication: While efficient land use is welcome, conversion of wetlands, riverbanks, or hill slopes risks ecological imbalance. Clear zoning and EIA mechanisms are vital.

6.2.6. Permanent Pastures and Grazing Lands

Trend: Consistent decline from the 1950s; minimal recovery post-2011.

Volatility: Moderate.

Interpretation: Shrinking common grazing lands reflects pressure from crop expansion, land enclosures, and urban encroachment.

Sustainability Implication: Threatens livestock-based livelihoods and the provisioning of ecosystem services such as carbon storage, erosion control, and fodder supply.

6.2.7. Miscellaneous Tree Crops and Groves

Trend: Mostly negative; temporary recovery in 1986–91.

Volatility: High early on; low and negative in later decades.

Interpretation: Reflects neglect of agroforestry systems in policy and investment.

Sustainability Implication: Decline in tree cover undermines climate resilience, income diversification, and soil fertility enhancement.

6.2.8. Cultivable Wasteland

Trend: Generally negative.

Volatility: Low to moderate.

Interpretation: Minimal success in reclaiming and rehabilitating degraded lands.

Sustainability Implication: Represents untapped potential for green jobs and climate-adaptive agriculture through land restoration programs such as PMKSY or MGNREGS.

6.2.9. Other Uncultivated Land (Excluding Fallows)

Trend: Persistent negative growth.

Volatility: Low.

Interpretation: Gradual exhaustion of land reserves for future extensification.

Sustainability Implication: Signals urgency for enhancing land productivity through intensification and ecological restoration.

6.2.10. Fallow Lands (Excluding Current Fallows)

Trend: Mixed; post-1971 shows mild positive growth.

Volatility: Moderate.

Interpretation: Strategic fallowing or stress-induced abandonment during climatic/economic shocks.

Sustainability Implication: Encouraging fallows as part of rotational cropping and soil health programs is essential. High fallows due to economic distress, however, need policy support (e.g., credit, seeds).

6.2.11. Current Fallows

Trend: Highly volatile; peaks in 1971–76 and 2001–06.

Volatility: High.

Interpretation: Responsive to weather variability, market conditions, and input costs.

Sustainability Implication: While some level of fallowing is desirable, persistent high rates suggest structural vulnerabilities in rain-fed farming systems.

6.2.12. Net Area Sown

Trend: Stagnant; minor decline post-1976.

Volatility: Low.

Interpretation: Indicates that most cultivable land has already been brought under cropping.

Sustainability Implication: Land-based agricultural growth has plateaued; policy should focus on sustainable intensification, not extensification.

6.2.13. Total Cropped Area

Trend: Early growth tapering to near stagnation post-1980.

Volatility: Low to moderate.

Interpretation: Limited increase due to plateauing of net area and declining returns on multiple cropping.

Sustainability Implication: Indicates growing pressure to produce more from the same land, underlining the need for climate-smart, input-efficient practices.

6.2.14. Area Sown More Than Once

Trend: Highly volatile; peaks in 1966–71 and 2001–06.

Volatility: High.

Interpretation: Boosted by irrigation and HYVs during the Green Revolution phases.

Sustainability Implication: Enhances productivity but risks over-extraction of groundwater and soil degradation. Balanced multi-cropping strategies with soil-restorative cycles are essential.

6.2.15. Agricultural Land

Trend: Flat; near-zero growth.
Volatility: Low.
Interpretation: Denotes saturation in the agricultural land base.
Sustainability Implication: Urgent need to transition toward regenerative agriculture, given limits to spatial expansion.

6.2.16. Cultivated Land

Trend: Positive early on; negligible or negative growth post-1990s.
Volatility: Low.
Interpretation: Reflects land competition with non-agricultural sectors.
Sustainability Implication: Urges protection of prime farmland via land use regulations and conservation incentives.

7. SCIENTIFIC IMPLICATIONS FOR LAND USE MANAGEMENT AND SUSTAINABILITY

The empirical growth trends reveal a dynamic yet unstable land-use pattern in India, characterized by competing pressures between ecological conservation and developmental imperatives. Key insights include:

a. Land Reporting Stability: Reflects robust statistical systems, but periodic declines suggest institutional gaps in some regions.
b. Forests and Common Lands: Exhibit high volatility, underscoring the need for consistent afforestation and common land governance.
c. Agricultural vs. Non-Agricultural Use: Structural transformation is evident, with non-agricultural land expanding at the cost of arable land.
d. Barren and Waste Land Reutilization: Offers opportunities for land rehabilitation, but demands ecological safeguards.

The analysis reveals a picture of land-use instability and competing land demands over the decades. While positive growth in non-agricultural land reflects economic modernization, it often occurs at the expense of cultivable or ecologically sensitive land. The erratic behavior of forest land growth raises concerns about the effectiveness and consistency of conservation efforts. Moreover, the diminishing reporting area in later years may hint at institutional weaknesses in land governance, especially in less developed states.

This instability has direct implications for agricultural productivity, biodiversity conservation, livelihood security, and sustainable urban planning. With the finite nature of land resources, an integrated land use policy becomes imperative—one that harmonizes economic development with ecological sustainability and food security.

Table 2. Synthesis: Sustainable Land Use – The Trade-offs and Policy Imperatives

Indicator	Volatility	Sustainability Implication
Forest Area	High	Erratic afforestation patterns threaten ecosystem integrity
Pastures & Tree Groves	Declining	Loss undermines agroecological resilience and rural livelihoods
Net Sown & Cropped Area	Stagnant	Productivity-focused interventions are needed
Fallow & Wastelands	Mixed	Present opportunity for targeted regeneration
Non-Agricultural Uses	Rising	Urban sprawl risks food security and water stress
Multi-Cropping Intensity	Volatile	Benefits productivity but can degrade soils if unregulated

8. POLICY RECOMMENDATIONS FOR SUSTAINABLE LAND GOVERNANCE IN INDIA

Sustainable land governance in India requires an integrated, multi-stakeholder approach that reconciles agricultural productivity, ecological preservation, and urban-industrial development. Given the competing pressures on land, a coordinated policy framework that incentivizes land stewardship while enabling economic growth is imperative. The following policy directions outline a roadmap toward this goal:

a. Land Restoration Programs: Large tracts of cultivable wastelands can be reclaimed using agroecological methods such as intercropping with nitrogen-fixing legumes, application of organic manures, and bio-fertilizers. These efforts should be supported by decentralized public-private partnerships (PPPs), where agri-tech firms, local communities, and Panchayati Raj institutions collaborate to restore land productivity, enhance soil health, and reduce land degradation.

b. Agroforestry and Silvopasture Promotion: Integrating trees with agricultural lands and regenerating degraded pasture lands through silvopasture systems can increase biomass, carbon sequestration, and farm incomes. State governments should design incentive-based programs, including carbon credits and community-based monitoring, to promote these practices. Collaboration with private forestry companies, insurance firms, and climate finance agencies can unlock additional resources.

c. Urban Land Use Regulation: Rapid urbanization calls for stringent enforcement of land zoning laws and curbing of unplanned land conversion. Smart urban planning must integrate green infrastructure, mixed-use zoning, and urban agriculture. Urban planners, municipal bodies, and infrastructure developers must align their goals through digital land registries, geospatial planning tools, and legally backed urban development plans.

d. Fallow Land Optimization: To reduce distress-induced fallowing, smallholder farmers should be provided targeted support in the form of input subsidies, drip irrigation systems, and weather-indexed crop insurance. Farmer-producer organizations (FPOs) and agribusiness firms can jointly manage such fallow land for short-duration, high-value crops under cooperative models.

e. GIS-Based Land Monitoring: Institutionalizing real-time satellite-based monitoring systems (e.g., Bhuvan, FASAL) will enhance land use accountability and enable early detection of deviations from approved land use plans. Data sharing between public agencies and private analytics firms can create responsive land information systems for governance and planning.

f. Productivity-Driven Agricultural Growth: Reducing dependence on land expansion requires a shift to precision agriculture, climate-resilient cropping patterns, and integrated farming systems. R&D institutions, agri-startups, and extension networks must collaborate to transfer technology and best practices at scale. Policy incentives should favour productivity enhancement rather than acreage expansion.

8.1. Toward Collaborative Land Governance

A truly sustainable land governance model must foster cooperation among farmers, urban planners, and industries, guided by a common vision of ecological resilience and economic viability. Public-private-community partnerships can serve as a unifying mechanism. Examples include:

i.) Agro-industrial parks integrating rural value chains with environmentally sound land use.
ii.) Urban-rural compacts where peri-urban agriculture supplies cities while cities provide infrastructural support to rural hinterlands.
iii.) Corporate Social Responsibility (CSR) initiatives by industries to restore land, fund watershed programs, or support land-based carbon sequestration under climate mandates.

By aligning incentives, enhancing transparency, and building institutional capacity, India can achieve a land governance framework that is not only sustainable and inclusive but also future-ready.

9. CONCLUSION

India's land use trajectory since 1950 reflects a multifaceted evolution shaped by demographic expansion, urban-industrial transformation, agricultural intensification, and ecological degradation. The cumulative effect has been the progressive reduction in the availability and quality of cultivable land, accompanied by shrinking common property resources, increasing fragmentation, and regional disparities in land productivity and access. These trends underscore a systemic tension between the imperatives of rapid economic development and the constraints imposed by finite land and ecological resources.

Addressing this challenge requires a strategic reorientation from a land-extensive development model toward one centered on land rejuvenation, restoration, and optimal use efficiency. Sustainable land management must be embedded within a cohesive policy framework that integrates spatial planning, tenure security, ecological restoration, and institutional coordination across sectors and levels of governance.

The way forward necessitates (i) adoption of evidence-based, geospatially informed land use planning; (ii) reinforcement of land tenure systems, particularly for smallholders, women, and tenant farmers; (iii) mainstreaming of nature-based solutions, including agroecology, agroforestry, and watershed development; and (iv) institutional capacity building at local and regional levels to enable participatory land governance.

Ultimately, achieving long-term sustainability calls for a paradigm shift—from exploiting land for short-term gains to investing in its ecological integrity and productive potential. This transition must be underpinned by inclusive, adaptive, and transparent governance mechanisms, capable of balancing competing demands from agriculture, industry, infrastructure, and conservation. The success of India's broader development agenda will hinge on how effectively it can reconcile these trade-offs and ensure resilient, equitable, and sustainable land use systems.

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