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Markov Chain Analysis of Land-use Changes in India and Maharashtra

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Dynamics of Agriculture resembles the history of agriculture in India which examines the emphasizing significance to the nation's legacy, culture and civilization. India's agriculture changed after independence from a food-scarce nation to one that exports food this comes true primarily due to the result of scientific advancements. The present study is based on secondary data with the use of Markov Chain analysis to ascertain land-use changes in India and Maharashtra state. Changes in land use brought on by agriculture, urbanization and environmental factors significantly

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impact resource management and sustainability. We build a Markov Chain model with secondary land utilization data from government reports to measure the transition probabilities between various land use categories over time. The Markov chain model is easy to understand and communicate. It effectively captures transitions between land-use changes over time. The model works with limited data as compared to other complex models, making it accessible for studies. The results of the study emphasize dynamic interactions between various land-use patterns in India and Maharashtra. There we have concluded a stable land-use changing pattern. A trend towards intensive cropping has been observed during this study. This study reveals important trends in land conversion, most notably the growth of urban areas at the expense of forested and agricultural areas. The predictive abilities of model highlight the significance of well-informed policy-making for sustainable land management by offering insights into potential future land use scenarios.

Keywords: Land-use changes; Markov chain analysis; stochastic model; transition probability matrix.

1. INTRODUCTION

One of the most important components of environmental and economic changes in any region is the dynamic shifting of land cover and use over time, also known as land-use changes (Patel, 2019). For sustainable development and efficient land management in India, a country known for its wide range of landscapes, particularly in Maharashtra, a notable state with sizable agricultural and urban sectors, an understanding of these transitions is essential. Geographic and temporal social approaches are widely used in environmental research across various fields. Therefore, the primary causes of environmental changes are changes in land type and human land use (Basommi, 2016). The rapid urbanization, industrialization, and agricultural transformation that both Maharashtra and India are experiencing calls for a more accurate analysis and prediction of land use changes. While traditional land use analysis methods are often inadequate in capturing the probabilistic nature of these transitions, Markov Chain analysis proves to be invaluable in this regard (Mirkatouli, 2015). The Markov Chain model, grounded in probability theory, provides a strong framework for examining and projecting the likelihood of transitions between various land use states over time (Anonymous, 2022, 2011-2022, 2021-22).

The study has focused on land changes in India and Maharashtra as important factors of sustainable development. An effective technique for resource management and urbanization is Markov Chain analysis. It is a tool for making decisions. Research also examines the connection between sustainable environmental practices and agricultural practices (Kale, 2016, Kumar, 2023, Moghadam, 2013, Pathak, 2022). It also provides effective guidelines for current practices in the field. This study examines land-use changes in India and Maharashtra using Markov Chain analysis. This study attempts to provide a thorough understanding of how land use categories evolve, the probabilities associated with these changes, and their implications for future land management by using past land use data and applying Markov Chain models. By using Markov Chain models, this study greatly advances our understanding of land-use dynamics (Maurya, 2023). It provides localized results by concentrating on particular areas, crucial for creating policies that effectively promote sustainable land-use practices (Areendran, 2013, Chavhan, 2023, Jagtap, 2024). Furthermore, various data sources used during the study enhance the analysis and highlight the value of advanced statistical methods in geography. This research contributes to ongoing conservation efforts by educating policymakers about the ecological and socioeconomic implications of land-use changes by highlighting the potential impact on local biodiversity and ecosystems (Reddy, 2017, Saritha, 2023, Singh, 2012, Ubale, 2023, Vinayak, 2021). The findings of this study are anticipated to make a substantial contribution to the areas of urbanization and land management, providing valuable information to researchers, planners, and policymakers who are interested in the sustainable development of Maharashtra and India.

2. DATA SOURCES AND METHODOLOGY

The annual secondary data on Land Utilization for the period from 2011 to 2022 for India and Maharashtra were used for Markov Chain Analysis.

The steps involved in conducting a Markov Chain analysis, such as creating transition

matrices and estimating state probabilities, are explained in detail in the following sections. The study will also go over the findings, emphasizing significant trends and patterns in land use transitions.

2.1 Markov Chain Analysis

According to Russian mathematician Andrey Markov, A Markov chain or Markov process is a stochastic model describing a sequence of possible events in which the probability of each event depends only on the state attained in the previous event.

P_{ij}= P [X_{m+1}= j | X_m = i]

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P_{ij}^{n} = P [X_{n+m} = j | X_m = i]

This will give us the Transition Probability Matrix as a result.

2.2 Transition Probability Matrix

A matrix is said to be a Transition Probability Matrix if it satisfies the following two conditions:

1) All elements of the matrix must lie between 0 to 1.
2) Each row sum of the matrix must be 1.

3. RESULTS AND DISCUSSION

3.1 Land-use Changes in India

Table 1 shows that cultivated land shows 100 per cent of area retention in Land-use changes in India, indicating that all cultivated land remains within its category with no changes in its area share. The total cropped area has 95 per cent of area retention showing stability in its proportion and lost 5 per cent share of the area to sown more than once area, reflecting a shift towards more intensive cropping practices. The area sown more than once retained 83 per cent share of the area means this category holds a significant share and lost 17 per cent to the total cropped area, suggesting that while multiple cropping areas are significant, there's also a substantial integration or overlap with the total cropped area.

Forest land retained 57 per cent of the share of an area even though it lost 21 per cent share of the area to Uncultivable land and 22 per cent of the share of the area to Fallow land. Also, it gains 14 per cent of the share of area from uncultivable land and 12 per cent each from area excluding fallow land and cultivable land. This reflects a complex interaction where forest land loses a considerable portion to other land categories but also sees gains from various sources, indicating a dynamic equilibrium.

Uncultivable land retained 57 per cent share of the area and lost 14 per cent and 29 per cent share of the area to Forest and Net sown area respectively. Suggesting that while a significant portion remains uncultivable, some of it transitions to other uses, particularly net sown area. Net sown area retained 76 per cent share of the area and lost 24 per cent to cultivable land. This indicates that a significant portion of the land previously categorized as net sown is being reallocated or reassigned to cultivable land.

We can see from Fig. 1 the gains and losses occurred during land-use changes in India. It can be clearly noticed that the losses to some categories of land-use have been dynamically balanced by the gains from other land-use categories.

3.2 Land-use Changes in Maharashtra

From Table 2 we can see that, Cultivable land has 95 per cent of area retention indicating a high degree of stability in land classified as cultivable in Land-use changes in Maharashtra. Cultivable land retention shows that most of the land classified as cropped remains stable while it lost a 4 per cent share of the area to cultivated land and a 1 per cent share of the area to forest land, indicating that some cultivable land is reclassified or repurposed, but the majority remains in this category. The total cropped area retained a 91 per cent share of the area and it lost 6 per cent, 2 per cent and 1 per cent share of the area to forest land, area excluding fallow land and uncultivable land respectively. Area sown more than once retained 87 per cent share of the area meaning a substantial portion of this land remains as multiple cropping zones while it lost 13 per cent share of the area to total cropped area reflecting a significant overlap or transition between these categories.

Forest land retained 71 per cent of the share of the area even though it lost 29 per cent of the

Table 1. Transition probability matrix of land-use changes in India

	Forest	Uncultivable	Fallow	Excluding Fallow	Net Sown	Sown more than once	Total Cropped	Cultivable	Cultivated
Forest	0.57	0.21	0.22	0	0	0	0	0	0
Uncultivable	0.14	0.57	0	0	0.29	0	0	0	0
Fallow	0	0	0	0	0	0	0	1	0
Excluding Fallow	0.12	0.7	0	0.8	0	0.03	0	0	0
Net Sown	0	0	0	0	0.76	0	0	0.24	0
Sown more than once	0	0	0	0	0	0.83	0.17	0	0
Total Cropped	0	0	0	0	0	0.05	0.95	0	0
Cultivable	0.12	0	0.05	0.05	0.11	0	0	0.67	0
Cultivated	0	0	0	0	0	0	0	0	1

Table 2. Transition probability matrix of land-use changes in Maharashtra

	Forest	Uncultivable	Fallow	Excluding Fallow	Net Sown	Sown more than once	Total Cropped	Cultivable	Cultivated
Forest	0.71	0	0.29	0	0	0	0	0	0
Uncultivable	0	0.74	0	0	0	0.26	0	0	0
Fallow	0	0.18	0.42	0.40	0	0	0	0	0
Excluding Fallow	0	0.11	0	0.36	0	0	0.53	0	0
Net Sown	0	0	0	0	0	0	0	0.06	0.94
Sown more than once	0	0	0	0	0	0.87	0.13	0	0
Total Cropped	0.06	0.01	0	0.02	0	0	0.91	0	0
Cultivable	0.01	0	0	0	0	0	0	0.95	0.04
Cultivated	0	0	0	0	0.92	0	0	0	0.08

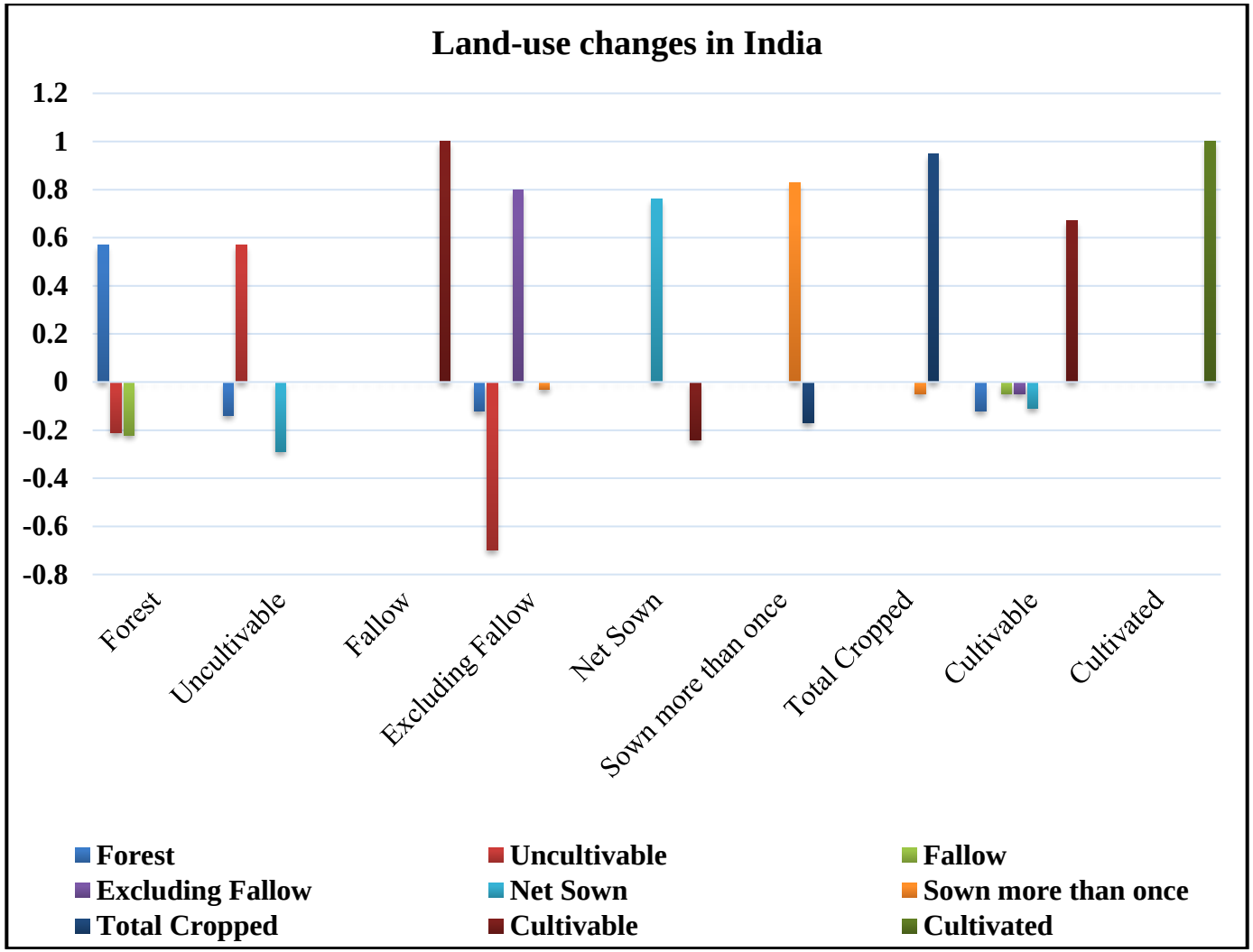

Fig. 1. Land-use changes in India

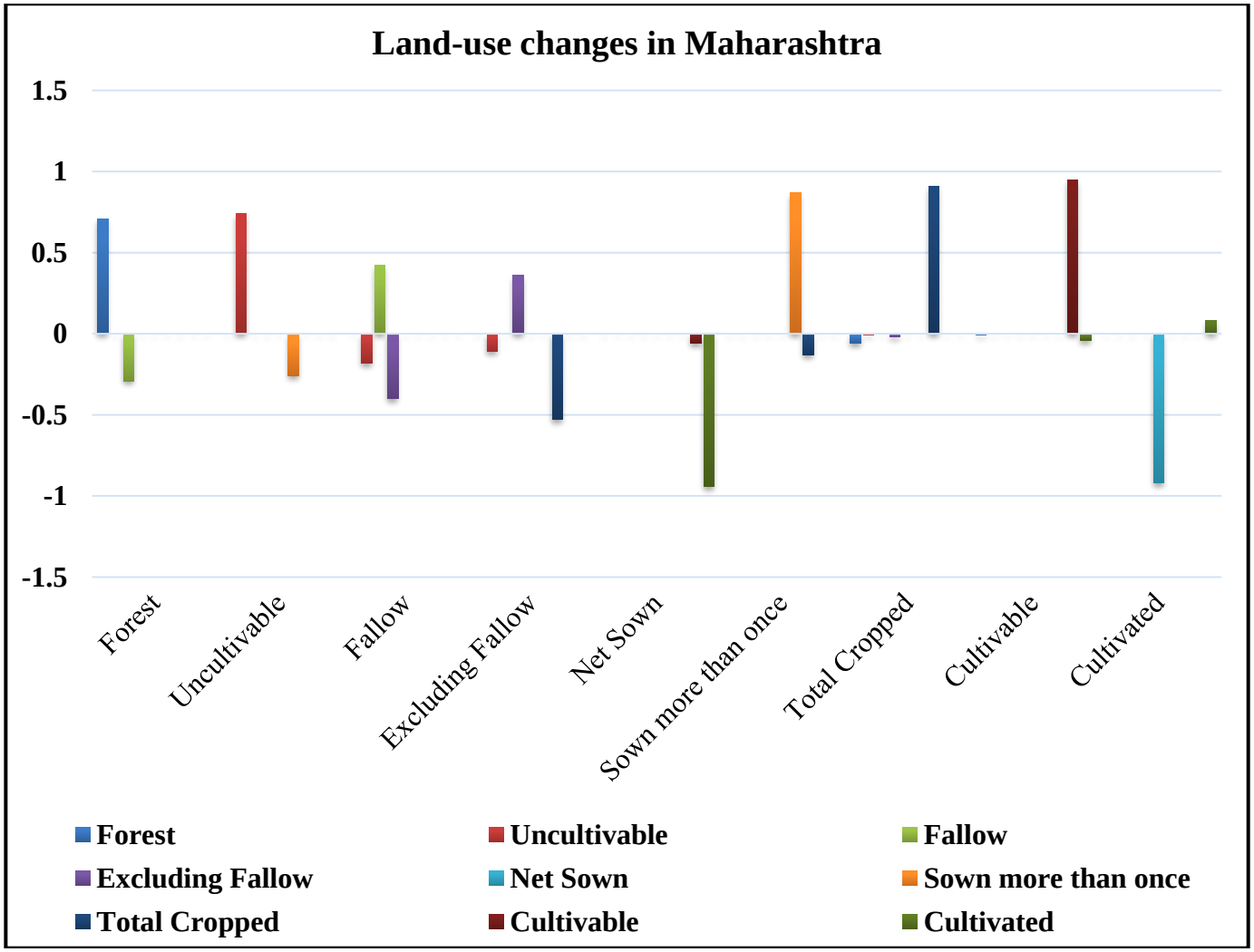

Fig. 2. Land-use changes in Maharashtra

area to Fallow land, suggesting that a significant portion of forest land is being converted or reclassified as fallow land, which might reflect a change in land use or natural processes affecting forest cover.

Uncultivable land retained 74 per cent share of the area and lost 26 per cent share of the area to Sown more than once area indicating that some land previously categorized as uncultivable is now being utilized for multiple cropping, reflecting a shift in land use or improved land management practices.

From Fig. 2 it can be observed that there was a significant equilibrium in land-use changes of Maharashtra. Some land-use categories have diverse losses in land-shifting while they also gain land under use from other land categories. This showing a stable land-use changes in Maharashtra.

4. CONCLUSION

The analysis of land-use changes in India and Maharashtra reveals notable stability across various land categories. In India, cultivated land retains 100 per cent of its area share in land-use changes, while the total cropped area has 95 per cent retention indicating a trend towards more intensive cropping practices. The area sown more than once suggesting a significant overlap with the total cropped area. Forest land shows a complex interaction in which forest land experiences gains from multiple sources while also losing a significant amount to other land categories, pointing to a dynamic equilibrium. Some uncultivable land transitions to other uses, particularly net sown areas. The net sown area indicates a significant portion of land being reallocated to cultivable land. In Maharashtra, cultivable land has high stability. Most cropped land remains stable with a 4 per cent share lost to cultivated land and 1 per cent to forest land. Some cultivable land is reclassified but the majority remains in this category. The total cropped area retained 91 per cent. Area sown more than once with a significant portion remaining as multiple cropping zones. Forest land retained 71 per cent of the area, while a 29 per cent share was lost to fallow land. Uncultivable land indicates a shift in land use or improved management practices.

Overall, the findings reflect a stable agricultural environment in both India and Maharashtra with high retention rates and a trend toward more intensive cropping practices, with a noticeable ability for proper land use management. However, the dynamic interactions between forest land and agricultural areas require ongoing monitoring to balance agricultural development with environmental sustainability.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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