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Impact of climate change on cropping and land use pattern in Ramanathapuram district: A Markov chain analysis

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Abstract

Examining shifts in cropping and land use patterns is crucial for gaining better insights into agricultural development strategies. The present study was undertaken to investigate the dynamics of cropping patterns and land use patterns in the Ramanathapuram district of Tamil Nadu from 2004 to 2023, using Transitional Probability Matrices (TPM) to analyze changes across two distinct periods: 2004-2013 (Period I) and 2014-2023 (Period II). The results revealed significant changes in both land use patterns and crop stability. Forest retention dropped sharply from 89% in Period I to 18% in Period II, with substantial transitions to non-agricultural uses, while barren land retention decreased from 96% to 11%. Pasture retention declined from 91% to 28%, reflecting reduced grazing areas. Conversely, the retention of culturable wasteland increased to 100% and land under tree crops showed improved stability. Regarding cropping patterns, paddy remained the most stable crop, with 72% and 76% retention rates in Periods I and II, respectively. Sorghum and green gram showed instability during the first period, though sorghum's stability improved in the second period, while green gram remained unstable. These findings indicate a trend toward diversification in cropping patterns and land use. The study highlights the influence of urbanization pressures, intensified agricultural activities and shifts in crop choice, offering valuable insights into land management strategies and developmental trends within the district.

Keywords

climate change; cropping pattern; land use pattern; markov chain

Introduction

Agriculture is a crucial sector of India's Tamil Nadu state economy, contributing approximately 13% of the total state income. About 56% of the total population of this state is dependent on agriculture (1). In India, the agriculture sector contributes approximately 16% to the nation's GDP. It employs more than half its population, making it a significant factor in socioeconomic sustenance, job creation and national food security (2). With the advancements from the Green Revolution, drastic changes have occurred in our country's agricultural sector. The total geographical area of the Ramanathapuram district is 408,957.035 hectares, with a cropped area of 189,088 hectares. The net sown area constitutes 44.62% of the total area, highlighting the district's significant agricultural activity (3). Technological developments in crop varieties and other yield-increasing factors have influenced farmers' choices, leading to shifts from cultivating low-value crops to high-value crops in many regions.

Agriculture plays a pivotal role in Ramanathapuram's economy, with a large portion of the population dependent on the agricultural sector for employment and income. About 65% of the population of Tamil Nadu lives in rural areas, relying on agriculture and the rural non-farm sector (4). A cropping pattern combines crops grown in a particular geographical area. Changes in cropping patterns and land use reflect shifts in the proportion of area allocated to different crops. Long-term changes in cropping patterns within a region may result from irrigation infrastructure development. At the same time, short-term fluctuations in cropped area and productivity are often influenced by natural factors, such as rainfall, and various institutional factors (5). These fluctuations have a significant effect on the economic returns for farmers as well as on the environment. Assessing shifts in cropping and land use patterns across different regions is crucial for understanding agricultural development. In this context, the present study attempts to analyze the cropping and land use pattern in Ramanathapuram district, Tamil Nadu, using Markov chain analysis for both crop seasons.

Materials and Methods

The study was conducted in the Ramanathapuram district, which comprises eleven administrative blocks. Four blocks - Thiruvadanai, Mandapam, Muthukulathur and Kamuthi were selected for the study. Time series data on the area under different crops grown in these districts from 2004-2013 and 2014-23 was collected from publications of the Directorate of Economics and Statistics, Ramanathapuram. The transition probability matrix was constructed using Lingo 18.0 software for the districts and analyzed using Markov chain analysis (6).

Markov Chain Analysis applies dynamic programming to solving a random process. A finite Markov process is a model in which the result of a given trial at a time ‘t’ (t = 1, 2, …. T) depends only on the outcome of a preceding trial (t-1) and this dependence is the same at all stages of the sequence of trials (7). Consistent with this definition, let the S_i represent i^{th} state or possible outcomes; i = 1, 2,...,r and let W_{it} represent the probability that state S_i occurs on trial t or proportion observed in trial 't', in alternative outcome state i of a multinomial population based on sample size n, i.e. Pr (S_{it}). P_{ij} represents the transitional probability of moving from state S_i to state S_j at time t.

i.e. $Pr(S_j , t+1 / S_{it},) = P_{ij}$

The probability matrix Pr = (P_{ij}) represents the shift chance for each try of states (i, j = 1, 2, ..., r) and has the following properties;

$0 \leq P_{ij} \leq 1$ …..(Eqn.1)

$å^{n}_{j-1} P_{ij} = 1$ …..(Eqn.2)

Given this set of notations and definitions for a first-order Markov chain, the probability of particular sequence S_i at trial t and S_j at trial t + 1 may be represented by

$Pr (S_{it}, S_{j\ t+1} = Pr (S_{it},) Pr (S_{j\ t+1} / S_{it}) = W_{it} P_{ij}$ .....(Eqn.3)

and the probability of being in state j at trial t + 1 may be represented by

$Pr (S_{j\ t-1}) = å\ i\ W_{it} P_j$ or, $W_{j, t+1} = å\ i\ W_{it} P_{ij}$ …..(Eqn.4)

The data representing the proportion of the area under crop was collected for selected crops, including Paddy, Maize, Sorghum, Green gram, Black gram, Ragi, Cotton, Chillies and Groundnut. For Land Use Patterns, data was categorized into Forests, Areas under Non-Agricultural Uses, Barren and Unculturable Land, Permanent Pasture and Other Grazing Land, Land Under Misc. Tree Crops and Groves, Culturable Waste Land, Fallow Lands Other Than Current Fallows, Current Fallows and Net Area Sown. The proportions change yearly due to weather, technology, price institutional changes, etc. It is reasonable to assume that the combined influence of these individual systemic forces approximates a stochastic process and the propensity of farmers to move from one crop to another differs according to the crop state involved.

A matrix P of first-order transition probabilities can represent the process of cropping pattern changes. The element P_{ij} indicates the probability that a cropped state i in one period will move to crop state j during the following period. The diagonal element P_{ij} measures the probability that the proportion share of i^{th} category of the crop will be retained. Equation (4) can be used to estimate the Transitional Probability Matrix as a basis for specifying the statistical model for estimating transitional probabilities. When errors are included, Equation (4) becomes:

$W_{it} = å_i W_{it} W_{i, t-1} P_{ij} + U_{jt}$ …..(Eqn.5)

Or in matrix form, this can be written as,

$Y_j = X_j P_j + U_j$ …..(Eqn.6)

Where Y_j represents a (T * 1) vector of proportions in cropping pattern j at time t, X_j represents a (T * r) matrix of proportions in cropping pattern in time t - 1, P_j represents an (r * 1) vectors of unknown transition parameters to be estimated and U_j represents a vector of random disturbances.

Data from 2004-13 and 2014-23 were collected and compiled from the various reports published by the Bureau of Economics and Statistics, Directorates of Economics and Statistics, Government of Tamil Nadu. Using the Markov chain analysis technique, these were analyzed separately for Period I (2004 - 2013) and Period II (2014 - 2023). The rationale behind dividing the study period into blocks of ten years was to know the crop change from 2004 - 2013 to 2014 - 2023.

Results and Discussion

Impact of climate change on Cropping Pattern in Ramanathapuram district

The Markov chain analysis revealed shifts in crop patterns across the Ramanathapuram district, presented in a transition probability matrix. As the diagonal elements approach zero, the crops become less and less stable, and as they approach one, they become more stable over time.

The transition probability matrix rows showed the previous acreage of the corresponding crop lost to the other crops in the current period. Columns indicate the area gained from the different crops (8). Diagonal elements nearing one indicate excellent crop stability, while those approaching zero suggest instability. This analysis sheds light on the shifts in crop acreage and their relative stability throughout the study period, emphasizing crop stability's crucial role in supporting the local agricultural economy and food security. A steady crop acreage ensures consistent farmer income, minimizes market fluctuations and maintains a reliable food supply. These factors are vital for meeting regional demand and strengthening economic resilience, especially in the face of climate or economic challenges (9). The Transitional Probability Matrix (TPM) in Table 1 shows these shifts in the area of different crops in the Ramanathapuram district from 2004 to 2013 (Period I).

Among the crops analyzed, paddy has the highest retention probability at 72%, underscoring its role as a principal crop in the Ramanathapuram district. Paddy lost its minor share of 1% to sorghum, 6% to the black gram, 9% to green gram and 12% to chillies but gained substantial area from other crops, especially 74% from chillies, 65% from maize and 41% from sorghum. Ragi retained 68% of its area, transitioning 31% to groundnut and 1% to green gram while gaining from cotton and groundnut. Groundnut had a retention rate of 65%, with 34% of its previous acreage shifting to chillies and 1% to ragi. However, groundnuts gained area from other crops, including 31% from ragi, 14% from sorghum and 2% from cotton. Chili retained only 26% of its previous area. Meanwhile, it has lost 74% of its area to paddy. On the other hand, it grabbed an area of 78% from black gram, 34% from groundnut and 12% from paddy.

Cotton retained 24% of its original area while losing 35% to ragi, 21% to sorghum and 20% to groundnut. However, cotton grabbed 45% of its area from sorghum. Maize had retained to an extent of 23%. It lost 65% to paddy and 12% to the green gram, though it gained 44% of its area from the green gram. This aligns with observations in which farmers switched to maize crops from pulses, which proved remunerative (10). Black gram retained 21% of its area, losing 78% to chili and 1% to sorghum. Black gram grabbed 56% of its area from green gram and 6% from paddy. Sorghum and green gram were the most unstable crops. Sorghum lost mainly to 3 crops, i.e., 45% to cotton, 41% to paddy and 14% to groundnut. Green gram lost mainly to 2 crops, i.e., 56% to the black gram and 44% to maize. This observation aligns with findings from the Ramanathapuram district in Tamil Nadu, where environmental stressors, such as frequent droughts and limited water availability, contribute to the instability of crops like sorghum and green gram. While somewhat drought-tolerant, these crops are still sensitive to the intensity and duration of water scarcity. High input costs and fluctuating market prices can further destabilize production and profitability, making these crops more vulnerable in this region compared to other areas with more consistent rainfall or better irrigation infrastructure (11).

The Transitional Probability Matrix (TPM) in Table 2 shows the shifts in crop area in the Ramanathapuram district from 2014 to 2023 (Period II). Among all crops, paddy had the highest retention probability at 76%, indicating its significance in the Ramanathapuram district. Paddy lost a minor share of its area to other crops, including 10.0% to sorghum, 10% to chillies and 4% to maize. However, paddy gained 34% from cotton, 18% from groundnut and 14% from sorghum. Cotton retained 66% of its area and lost 34% to paddy. Cotton grabbed 21% of its area from sorghum and 19% from the black gram. Similar results were observed in shifting the cotton area to the red gram in Arvi tehsil of Wardha district in Maharashtra (12). Chili retained only 57% of its previous area. Meanwhile, it lost 15% of its area to maize, 12% to sorghum, 9% to groundnut and 7% to black gram. On the other hand, it grabbed an area of 45% from

Table 1. Transitional Probability Matrix (TPM) for Shifts in Cropping Pattern in Ramanathapuram district (2004-2013)

Crops	Paddy	Maize	Sorghum	Green gram	Black gram	Ragi	Cotton	Chillies	Groundnut
Paddy	0.72	0	0.01	0.09	0.06	0	0	0.12	0
Maize	0.65	0.23	0	0.12	0	0	0	0	0
Sorghum	0.41	0	0	0	0	0	0.45	0	0.14
Green gram	0	0.44	0	0	0.56	0	0	0	0
Black gram	0	0	0.01	0	0.21	0	0	0.78	0
Ragi	0	0	0	0.01	0	0.68	0	0	0.31
Cotton	0	0	0.21	0	0	0.35	0.24	0	0.20
Chillies	0.74	0	0	0	0	0	0	0.26	0
Groundnut	0	0	0	0	0	0.01	0	0.34	0.65

Table 2. Transitional Probability Matrix (TPM) for Shifts in Cropping Pattern in Ramanathapuram district (2014-2023)

Crops	Paddy	Maize	Sorghum	Green gram	Black gram	Ragi	Cotton	Chillies	Groundnut
Paddy	0.76	0.04	0.10	0	0	0	0	0.10	0
Maize	0	0.20	0.53	0	0	0.27	0	0	0
Sorghum	0.14	0	0.40	0	0.13	0	0.21	0.12	0
Greengram	0	0.44	0	0	0.56	0	0	0	0
Black gram	0	0	0.16	0	0.49	0.16	0.19	0	0
Ragi	0	0	0.70	0	0	0.30	0	0	0
Cotton	0.34	0	0	0	0	0	0.66	0	0
Chillies	0	0.15	0.12	0	0.07	0	0	0.57	0.09
Groundnut	0.18	0	0	0.14	0	0	0	0.45	0.23

groundnut, 12% from sorghum and 1% from paddy. Black gram retained 49% of its area and experienced losses to other crops, including 19% cotton and 16% ragi and sorghum. However, it also gained area, with 56% from green gram, 13% of its area from sorghum and 7% from chili.

Groundnut had a retention capacity of 23%, transitioning 45% of its previous acreage to chillies, 18% to paddy, and 14% to the green gram, while gaining 9% from chilli. Similar findings were observed in a shift in area from groundnut to paddy in the Northern transitional zone from 1991-92 to 2006-07 in Karnataka (13). Sorghum retained 40% but lost 21% to cotton, 14% to paddy, 13% to black gram and 12% to chili. It gained a significant proportion of its area from multiple crops, including 53% from maize,16% from black gram, 12% from chili,70% from ragi and 10% from paddy. Ragi had retained 30% of its area and primarily lost 70% to sorghum. Ragi gained 27% from maize and 16% from black gram. Conversely, Maize lost most of its area to sorghum (57%) and ragi (27%), retaining only 20% of its original area. Green gram is lost mainly to a single crop, i.e., 100% to paddy only. Green gram is the most unstable crop from 2014 to 2023. This aligns with observations in which the green gram showed instability in the Ramanathapuram district of Tamil Nadu during the study period. Compared to Period I, sorghum becomes a more stable crop than maize, meaning it shows less variability in the area under cultivation or retention across seasons, while maize has more significant fluctuations. In contrast, green gram remains an unstable crop, consistently showing high variability in its cultivation area due to fluctuating demand or adaptability challenges.

During the period I (2004-2013), paddy had the highest stability with a 72% retention rate, transitioning minor areas to sorghum, black gram, green gram and chillies while gaining substantial area from chillies and maize. Sorghum and green gram were the most unstable crops, transitioning significant acreage to other crops. The fall in the area may be attributed to a lack of irrigation water and increased production costs (14). In Period II (2014-2023), paddy's retention increased to 76%, reflecting continued dominance, but it faced increased losses to sorghum and chillies. Cotton and black gram improved their retention rates, while green gram became the most unstable crop, transitioning its entire area to paddy. This aligns with similar results, which reported a complete shift from green gram to paddy for better profitability (15). Overall, crop stability slightly increased for crucial crops like paddy and cotton, while green gram's instability intensified over time.

Impact of climate change on Land Use Pattern in Ramanathapuram district

The Markov chain analysis of land use transitions highlights the impact of climate change on land use patterns by quantifying shifts across land categories. Each row sums to 1, indicating a total probability of 100% for each land use category transitioning to all possible categories, including itself. The Transitional Probability Matrix (TPM) for land use categories in Ramanathapuram district from 2014 to 2023 reveals significant shifts and retention in various land categories in Table 3.

Forests had the highest retention probability at 89%, with only 11% of their area transitioning to non-agricultural uses, such as urban development, industrial growth and infrastructure expansion. The land under non-agricultural uses retained 65% of its previous area, with 35% shifting to areas under cultivation. Barren and unculturable land showed a high % retention rate of 96%, transitioning just 4% to net area sown. Permanent pasture and other grazing land retained 91% of its area, with a 9% transition to forests. Land under miscellaneous tree crops and groves retained 50% of its area, transitioning 40% to net area sown and 10% to fallow lands other than current fallows. Culturable wasteland had a retention rate of 37%, transitioning 63% to net area sown. Fallow lands other than current fallows retained 48% of their area, transitioning 39% to land under miscellaneous tree crops and groves and 13% to culturable wasteland. Current fallow retained 69% of its area, with a 31% transition to non-agricultural uses.

Table 3 Transitional Probability Matrix (TPM) for Shifts in Land Use Pattern in Ramanathapuram district (2004-2013)

	Forests	**Area Under Non-Agricultural Uses**	**Barren and Unculturable Land**	**Permanent Pasture and Other Grazing Land**	**Land Under Misc. Tree Crops and Groves**	**Culturable Waste Land**	**Fallow Lands Other Than Current Fallows**	**Current Fallow**	**Net Area Sown**
Forests	0.89	0.11	0	0	0	0	0	0	0
Area Under Non-Agricultural Uses	0	0.65	0	0	0	0	0	0	0.35
Barren and Unculturable Land	0	0	0.96	0	0	0	0	0	0.04
Permanent Pasture and Other Grazing Land	0.09	0	0	0.91	0	0	0	0	0
Land Under Misc. Tree Crops and Groves	0	0	0	0	0	0.1	0.5	0	0.4
Culturable Waste Land	0	0	0	0	0	0.37	0	0	0.63
Fallow Lands Other Than Current Fallows	0	0	0	0	0.39	0.13	0.48	0	0
Current Fallow	0	0.31	0	0	0	0	0	0.69	0
Net Area Sown	0	0.05	0	0	0.39	0.12	0.11	0.07	0.26

Net area sown retained 26% of its previous area, with 39% transitioning to non-current fallow lands, 12% to culturable wasteland, 11% to other fallow lands and 7% to current fallows. This analysis highlights that forests and barren land categories had notably high retention rates. At the same time, areas under non-agricultural uses currently fallow and the net area has experienced significant transitions to other categories (16). These shifts reflect changes in land use priorities, emphasising agricultural and non-agricultural developments in the district. Markov chain analysis revealed that the retention capacity for land under non-agricultural uses and current fallow land increased after economic reforms, indicating that non-farming activities may gradually absorb farmlands, creating a vulnerability for the agriculture and allied sectors (17). This analysis provides a comprehensive view of how land use categories interact and change over time, offering valuable insights for land management and policy-making in Ramanathapuram district during the period I.

The Markov chain analysis for Ramanathapuram district from 2014 to 2023 illustrates the probabilities of transitions among various land use categories in Table 4. Forests exhibit a relatively low retention probability of 18%, transitioning 82% of their area to non-agricultural uses. The area under non-agricultural uses retained 46% of its area, transitioning 24% to forests, 16% to barren and unculturable land, 7% to permanent pasture and other grazing land and 7% to net area sown. Barren and unculturable land had a low retention rate of 11%, with the majority (89%) transitioning to net area sown. Permanent pasture and other grazing land retained only 28% of its area, transitioning 72% to non-agricultural uses. Land under miscellaneous tree crops and groves retained 48% of its area, with the remaining 52% transitioning to fallow lands other than current fallows. Culturable wasteland showed a 100% retention rate, with no transitions to other categories. Fallow lands other than current fallows retained 51% of their area, transitioning 36% to forests, 11% to non-agricultural uses and 2% to permanent pasture and other grazing land. Current fallow retained 31% of its area, transitioning 12% to forests, 13% to non-agricultural uses, 8% to barren and unculturable land, 1% to permanent pasture and other grazing land, 11% to land under miscellaneous tree crops and groves and 24% to net area sown.

Net area sown retained 36% of its area, with 18% transitioning to forests, 10% to non-agricultural uses, 11% to barren and unculturable land, 12% to permanent pasture and other grazing land, 1% to fallow lands other than current fallows and 12% to current fallow. Forests and permanent pastures exhibit the lowest retention rates, with significant transitions to non-agricultural uses and other categories (18). In contrast, culturable wasteland had the highest retention rate, indicating its limited transition to different categories, which emphasizes the significance of this finding. These shifts reflect changing land use priorities and pressures on agricultural and non-agricultural land in the district (19). The observed probabilities highlight the dynamic land use changes in Ramanathapuram district, providing insights for effective land management and policy -making during period II (2014-2023).

The Transitional Probability Matrices for Ramanathapuram district (2004-2023) highlight significant changes in land use over time. Forest retention dropped sharply from 89% in Period I to 18% in Period II, with substantial transitions to non-agricultural uses. Non-agricultural land retention decreased from 65% to 46%, indicating more diversified land reallocation n of land (20). Barren land retention fell significantly from 96% to 11%, with most converted to cultivable land. Permanent pasture retention dropped from 91% to 28%, indicating reduced grazing areas. Tree crop retention improved from 10% to 48%, showing increased stability. Culturable wasteland retention rose to 100%, while fallow land retention remained similar at around 50%. Current fallow retention decreased from 69% to 31%, and net area sown retention increased from 26% to 36%.

Table 4 Transitional Probability Matrix (TPM) for Shifts in Land Use Pattern in Ramanathapuram district (2014-2023)

	Forests	Area Under Non-Agricultural Uses	Barren and Unculturable Land	Permanent Pasture and Other Grazing Land	Land Under Misc. Tree Crops and Groves	Culturable Waste Land	Fallow Lands Other Than Current Fallows	Current Fallow	Net Area Sown
Forests	0.18	0.82	0	0	0	0	0	0	0
Area Under Non-Agricultural Uses	0.24	0.46	0.16	0.07	0	0	0	0	0.07
Barren and Unculturable Land	0	0	0.11	0	0	0	0	0	0.89
Permanent Pasture and Other Grazing Land	0	0.72	0	0.28	0	0	0	0	0
Land Under Misc. Tree Crops and Groves	0	0	0	0	0.48	0	0	0.52	0
Culturable Waste Land	0	0	0	0	0	1	0	0	0
Fallow Lands Other Than Current Fallows	0.36	0.11	0	0.02	0	0	0.51	0	0
Current Fallow	0.12	0.13	0.08	0.01	0.11	0	0	0.31	0.24
Net Area Sown	0.18	0.1	0.11	0.12	0	0	0.01	0.12	0.36

The observed changes in land use patterns highlight a significant shift towards non-agricultural uses and increased cultivation (21). The sharp decline in forest and pasture retention and the increased conversion of barren land to cultivable land reflect expanding urbanization and intensified agricultural activities. Improved stability in tree crops and culturable waste land retention suggests implementing targeted land management strategies. These trends indicate a dynamic reallocation of land resources driven by increasing agricultural demands and developmental pressures.

Conclusion

The Markov chain analysis of Ramanathapuram district illustrates that paddy remains the most stable crop, while green gram and sorghum have experienced significant acreage losses. Forests and barren lands are increasingly being converted to non-agricultural uses, whereas the retention of culturable wasteland has improved. These shifts highlight the need for policies promoting crop diversification with resilient crops like black gram and cotton. Additionally, land use regulations should focus on protecting forests and sustainable practices must support small and marginal farmers in adapting to these changes. Future research should assess the impact of climate change on crop productivity, water availability and soil health in the Ramanathapuram district, as these factors are likely to alter agricultural outputs significantly and land use sustainability in the region, influencing both long-term productivity and land management frameworks.

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Authors' contributions

KP[1] designed the study framework, conducted the economic analysis and drafted the manuscript. AM participated in the data collection, contributed to the analysis of the results and assisted in drafting the manuscript. SPR provided insights into the climate impact assessments and helped with the literature review. KP[3] performed the statistical analysis and contributed to refining the methodology. RB conceived the overall research idea, supervised the study and prepared the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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