Postprint of Multi-temporal Land Use Change Simulation Based on CA-Markov Model

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Date: 2019-11-15T00:00:00+00:00

Abstract

Land Use and Cover Change (LUCC) simulation constitutes a primary component and important methodology of LUCC research. Time interval represents a crucial parameter in the simulation process, and its impact on simulation accuracy warrants further in-depth investigation. Taking Sidaohezi Town in the typical oasis area of the Manas River Basin, Xinjiang as a case study, land use data for 1975, 1985, 1995, 2000, 2005, 2010, and 2015 were extracted from remote sensing imagery. CA-Markov models were constructed using time intervals of 20 a, 15 a, 10 a, and 5 a to simulate the 2015 land use structure, thereby quantitatively exploring the influence of time interval on CA-Markov model accuracy. Results indicate that from 1975 to 2015, LUCC in Sidaohezi Town was dominated by cropland and grassland. During this period, cropland and construction land expanded rapidly, while forestland, grassland, and unused land decreased substantially. Water bodies exhibited a slight increase from 1985 to 2000. The increase in cropland and the decrease in grassland and forestland represent the most prominent characteristics of LUCC in the study area over the past 40 years. Comparison of simulated and actual results reveals that TFOM values for time intervals of 20 a, 15 a, 10 a, and 5 a were 70.35%, 69.18%, 76.32%, and 88.00%, respectively. The simulation based on transition probabilities from 2005–2010 was closer to the actual 2015 results and is suitable for simulating future land use changes in Sidaohezi Town. Land use simulation should determine the optimal time interval based on regional LUCC characteristics to improve simulation accuracy.

Full Text

Simulation of Land Use Change at Different Time Spans Based on CA-Markov Model

DOI: 10.12118/j.issn.1000-6060.2019.06.21
Journal: Arid Land Geography (ChinaXiv Partner Journal)

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Abstract

The study of Land Use/Cover Change (LUCC) and its dynamics is crucial for human existence and sustainable development. LUCC simulation represents the main content and an effective method in LUCC research, where time span constitutes one of the most important parameters in the simulation process, and its effect on simulation accuracy requires further investigation. To explore LUCC simulation accuracy at different time spans, we selected Sidaohazi Town in the Manas River Basin of Xinjiang, China as our study area. Seven land use maps were created from remote sensing images (MSS images for 1975, TM images for 1985 and 1995, ETM images for 2000, 2005, and 2010, and OLI images for 2015), with land surfaces classified into six cover categories: cultivated land, woodland, grassland, water area, construction land, and unused land. The land use transition probabilities during four distinct periods (1975–1995, 1985–2000, 1995–2005, and 2005–2010) were then used to establish a CA-Markov model to simulate land use in 2015 using long-term (20-year), medium-term (15-year and 10-year), and short-term (5-year) intervals respectively. The simulation process was completed using the CA-Markov module in IDRISI software. Finally, four simulated land use maps for 2015 (R , R , R , R) were compared with the actual land use map for 2015 (R), and the Total Figure of Merit (TFOM) index was employed to evaluate model accuracy.

Results showed that from 1975 to 2015, cultivated land and grassland were the dominant land use types in Sidaohazi Town. During the study period, cultivated land and construction land expanded rapidly, whereas forest land, grassland, and unused land were substantially reduced, and the water area experienced a slight increase from 1985 to 2000. Throughout the study period, the increase in cultivated land and decrease in grassland and woodland represented the most significant features of LUCC. Comparing the simulated results with the actual 2015 land use map revealed five components of agreement and disagreement as S , S , S , S , and S . The TFOM indices for 20-year, 15-year, 10-year, and 5-year intervals were 70.35%, 69.18%, 76.32%, and 88.00% respectively, indicating that smaller time intervals produced higher accuracy. The 5-year time span represented the optimum interval for simulating land use change in Sidaohazi Town from 1975 to 2015. This study provides a scientific basis for selecting time intervals in land use change simulation. Moreover, simulation accuracy depends not merely on land use transition probability within a certain period, but also requires consideration of local land policies and social development

characteristics.

Keywords: Manas River Basin; land use and cover change; CA-Markov; time span

1. Introduction

Land Use and Cover Change (LUCC) constitutes a critical research area with significant implications for human survival and sustainable development. Simulation modeling represents the primary methodological approach in contemporary LUCC research, with time span serving as a fundamental parameter that directly influences simulation accuracy. The CA-Markov model has emerged as a widely applied integrated approach, combining Markov chain analysis with Cellular Automata (CA) to simulate spatial-temporal land use dynamics. Previous studies have demonstrated that model performance varies considerably across different temporal intervals, yet systematic investigation of the relationship between time span and simulation accuracy remains limited.

The CA-Markov model integrates the advantages of Markov chains in predicting quantity changes with CA' s capability for spatial allocation, making it particularly suitable for simulating complex land use transitions. However, the selection of temporal intervals for establishing transition probability matrices significantly affects model outcomes. While longer intervals may capture macro-scale trends, they risk obscuring short-term fluctuations and policy impacts. Conversely, shorter intervals offer higher temporal sensitivity but may introduce noise from transient changes. This study systematically evaluates simulation accuracy across 20-year, 15-year, 10-year, and 5-year intervals to identify the optimal temporal resolution for LUCC modeling in arid region oasis environments.

2. Methodology

2.1 Study Area and Data Sources The study focused on Sidaohazi Town within the Manas River Basin, Xinjiang. Remote sensing imagery spanning four decades was acquired, including MSS imagery for 1975, TM imagery for 1985 and 1995, ETM imagery for 2000, 2005, and 2010, and OLI imagery for 2015. These datasets provided the foundation for constructing seven temporal land use maps.

2.2 Land Use Classification Land surfaces were classified into six categories: cultivated land, woodland, grassland, water area, construction land, and unused land. This classification scheme captured the major land use types characteristic of oasis agricultural systems in arid regions.

2.3 CA-Markov Model Implementation Transition probability matrices were calculated for four distinct periods: 1975–1995 (20-year), 1985–2000 (15-year), 1995–2005 (10-year), and 2005–2010 (5-year). These matrices served as inputs for the CA-Markov module in IDRISI software to simulate land use patterns for 2015. The model employed a 30m×30m cell size for primary simulations, with additional validation at 5m×5m resolution for precision assessment.

2.4 Accuracy Assessment The Total Figure of Merit (TFOM) index was applied to evaluate simulation accuracy across different temporal intervals. TFOM is calculated as:

$$TFOM = \frac{S_1 + S_2}{S_1 + S_2 + S_3 + S_4 + S_5}$$

where S through S represent components of agreement and disagreement between simulated and actual land use maps. The index ranges from 0% (no agreement) to 100% (perfect agreement), providing a comprehensive measure of model performance that accounts for both spatial allocation and quantity accuracy.

3. Results

3.1 Land Use Change Dynamics (1975-2015) Analysis revealed that cultivated land and grassland dominated the landscape throughout the study period. However, significant structural changes occurred: cultivated land and construction land expanded rapidly, while woodland, grassland, and unused land experienced substantial contraction. The water area showed a slight increase between 1985 and 2000, likely reflecting irrigation expansion and water management policies. The conversion of grassland and woodland to cultivated land represented the most prominent transformation process.

3.2 Simulation Accuracy Across Time Intervals Comparative analysis of simulated versus actual 2015 land use maps yielded TFOM values of 70.35% for the 20-year interval, 69.18% for the 15-year interval, 76.32% for the 10-year interval, and 88.00% for the 5-year interval. The monotonic increase in accuracy with decreasing interval length demonstrates that shorter temporal spans better capture the underlying drivers of land use change, including policy shifts and socioeconomic dynamics.

The 5-year interval emerged as the optimal temporal resolution, achieving the highest TFOM value of 88.00%. This finding suggests that in rapidly evolving oasis landscapes, transition probability matrices derived from shorter intervals more effectively represent the complex interplay between natural constraints and anthropogenic drivers.

4. Discussion

The superior performance of short-interval simulations highlights the importance of capturing recent land use trajectories and policy implementations.

While long-term intervals may smooth inter-annual variability, they fail to account for critical transition points such as land reclamation policies, urbanization accelerations, and water resource reallocations that characterize arid region development. The results indicate that simulation accuracy depends not only on the statistical properties of transition matrices but also on the degree to which temporal intervals align with actual planning cycles and policy implementation periods in the study region.

5. Conclusion

This study demonstrates that time span selection significantly impacts CA-Markov simulation accuracy in LUCC modeling. For Sidaohazi Town in the Manas River Basin, the 5-year interval provided optimal results, achieving a TFOM of 88.00%. The research provides a methodological reference for temporal interval selection in LUCC simulations within arid oasis contexts and underscores the necessity of considering local policy frameworks and development characteristics alongside statistical model parameters.

References

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Note: Figure translations are in progress. See original paper for figures.