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ORIGINAL ARTICLE

Forecasting the Growth of Ilam City Using Satellite Images and the CA-MARKOV Model

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EXTENDED A B S T R A C T

Introduction
This research addresses the critical issue of rapid urban expansion and its impact on the environmental sustainability of Ilam, Iran. As urban populations increase due to demographic shifts and physical development, the pressure on surrounding natural landscapes becomes immense. The study focuses on the transformation of land use classes—specifically residential/built-up areas, agriculture, forests, barren lands, and gardens—from 1976 (1355 SH) to 2021 (1400 SH). The central problem is that unplanned horizontal growth leads to the degradation of biodiversity, loss of agricultural productivity, and increased environmental costs, such as higher surface temperatures and ecological imbalance. The primary objective of this study is to analyze historical land-use changes and utilize spatial forecasting models to predict future urban footprints, thereby providing a scientific basis for sustainable urban planning and land-use management.

Mothodology
The study employs a multi-temporal remote sensing approach combined with advanced spatial modeling. Four Landsat satellite images (MSS, TM, ETM+, and OLI) covering the period from 1355 to 1400 SH were used. The methodology involved several key stages:
- **Image Processing:** Geometric and radiometric corrections were applied to ensure consistency across the time series, using ground control points and dark-object subtraction.
- **Classification:** A supervised classification using the Maximum-Likelihood method was performed via ENVI and ArcGIS software. Training samples were selected based on field knowledge and Google Earth imagery to ensure high accuracy.
- **Accuracy Assessment:** The classification reliability was verified using the Kappa coefficient and overall accuracy metrics, which showed high performance across all years.
- **Predictive Modeling:** To simulate future scenarios, the research integrated **Markov Chain** models with **Cellular Automata (CA)**. The Markov model was used to calculate the probability and magnitude of land-use transitions, while the CA component handled the spatial allocation of these changes based on neighborhood rules and suitability filters. This hybrid **CA-Markov** approach allowed for the simulation of land-use maps for the years 1410

Findings
The results indicate a profound shift in the landscape of Ilam over the past four decades. Historical analysis reveals that residential/built-up land increased by approximately 1,905.73 hectares, largely at the expense of forest cover, which declined by 2,066.16 hectares, and barren lands, which decreased by 1,110.78 hectares. While agricultural land saw an increase of 1,403.46 hectares, the overall trend highlights a significant conversion of natural ecosystems into anthropogenic

landscapes.

The CA-Markov simulation for the future periods (1410 and 1420) confirms that these trends are set to persist. The model predicts that the proportion of residential land will rise from 35.11% in 1400 to 41.34% in 1410, reaching 42.00% by 1420. Concurrently, forest cover is projected to undergo a severe decline, dropping from 16.13% in 1400 to roughly 12.32% by 1420. The discussion of these findings suggests that the current trajectory of Ilam's urban growth is highly extractive, treating forests and barren lands as primary sources for urban expansion. This spatial pattern indicates a lack of containment in urban boundaries, suggesting that without intervention, the city will continue to sprawl into ecologically sensitive zones, potentially leading to permanent loss of regional biodiversity and ecosystem services.

Discussion and Conclusion

This study concludes that the historical growth pattern of Ilam City is unsustainable under current management paradigms. The CA-Markov model effectively demonstrates that continued horizontal expansion will lead to the critical depletion of forest and agricultural resources. To mitigate these impacts, the research offers several strategic recommendations:

- Urban Intensification: Planners should prioritize vertical growth and densification within existing urban limits to reduce the footprint of sprawl.
- Regulatory Oversight: Strict enforcement of urban growth boundaries and the limitation of construction permits in high-sensitivity ecological zones (especially forests) are essential.
- Strategic Land-Use Policy: Development projects should be directed toward barren or less ecologically valuable lands to protect the city's natural buffers.
- Integrated Planning: Future urban governance must integrate spatial forecasting models into the decision-making process to balance economic development with environmental sustainability and climate resilience.

K E Y W O R D S

Satellite Images, Land Use Change, Forecasting Urban Growth, CA-Markov, Ilam City

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