Spatial modeling of urban dynamics in the Kathmandu valley, Nepal

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Abstract: The metropolitan region of Kathmandu valley, surrounded by complex mountainous terrain, has very limited land resources for new developments. As similar to many cities of the developing world, it has been facing rapid population expansion and daunting environmental problems. This research aims to model urban dynamics and extrapolate future urban growth in the valley. Time series land cover maps were prepared from satellite imaging techniques. A spatial model is developed in cellular automata framework and calibrated using the Bayesian probability function. The model extrapolated the urban growth patterns for 2010 and 2020 based on historical landscape transition and underlying driving factors. Furthermore, this study reveals that due to the topographical constraint, the existing urban space is already saturated in terms of resources, lands, green space, water, and other public facilities.

Keywords: Urban Growth, Land Use Change, Bayesian Approach, Dynamica, Cellular Automata

1. Introduction

Rapid urbanization is an ongoing dynamic process, and is the most dominant phenomenon in all developing countries. Agglomeration of isolated population centers into metropolitan cities with the expense of natural landscape to urban landscape has become major trend in recent years. Persistent dynamic urban change processes, especially the remarkable worldwide expansion of urban populations and urbanized areas, affect natural and human systems at all geographic scales, and are expected to accelerate in the next several decades. Worsening conditions of crowding, housing shortages, insufficient infrastructure, and increasing urban climatological and ecological problems require consistent monitoring of urban growth (Thapa et al., 2008).

While new urban models have provided insights into urban dynamics, a deeper understanding of the physical and socioeconomic patterns and processes associated with urbanization is still limited by the available data and related empirical studies, especially in developing countries in South Asia (Thapa and Murayama, 2010a). This research aims to model urban dynamics in the Kathmandu valley using Bayesian probability function and cellular automata. As the result of population growth and migration from rural to urban areas, urbanization has been recognized as a critical process in metropolitan areas of Nepal. The Kathmandu metropolitan region, capital and major tourist gateway, has been facing rapid urbanization over the last three decades. Recently, it has an estimated population of 2.18 million with an annual growth rate of 5.2% (Thapa and Murayama, 2010b). Such urbanization pressure results rapid changes in the urban landscape pattern of the region adding more constructions and the loss of natural lands.

2. Database and methodology

In this paper, the land cover maps are created using satellite images at different time points. Two land use

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maps of the Kathmandu valley at 30 meters spatial resolution for the years 1991 and 2000 are acquired from Thapa (2009), which are created using remote sensing techniques. A hybrid method with series of processing steps for creating the land use maps can be found in Thapa and Murayama (2009). These two land use maps are further modified to land cover maps with five categories, i.e., urban built-up, agriculture, forest, shrubs, and excluded areas. Elevation, slope, population growth, and proximity to urban centers, roads, rivers, and industries are investigated as major drivers of land change in the valley. A land change model is calibrated using the Bayesian approach (weight of evidence) integrating with cellular automata framework. Further details in this integrated approach can be found in Thapa and Murayama (2010a). The conceptual framework excluding Input Data part shown in Figure 1 was programmed in DYNAMICA software environment.

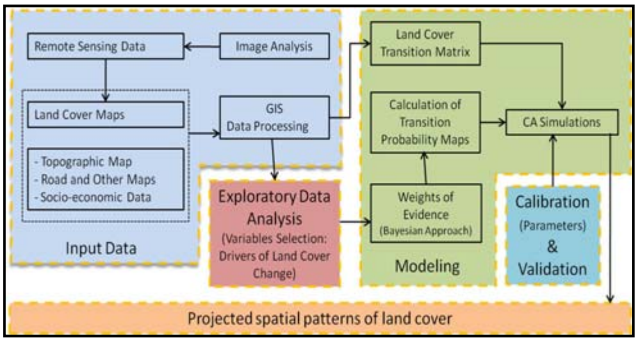

Figure 1. Modeling framework.

Model validation can be done through accuracy assessment which is defined as the task of comparing two maps: one generated by the model (data to be assessed), and the other based on the ground truth (the reference data). The reference data are assumed to be accurate and forms the standard for comparison. The assessment of accuracy is conducted by preparing an error matrix where producer's, user's, overall accuracies, and Kappa coefficients are computed. In addition, a neighborhood context is also considered for validating the simulation results because even maps that do not match exactly cell by cell could still present similar spatial patterns. Considering this fact, we used fuzzy similarity method (Hagen, 2003) with exponential decay function that accounts the fuzziness of location and category within a cell neighborhood. This method uses three maps (i.e., initial landscape, final landscape, and simulated landscape) comparison approach.

3. Results and discussion

The Figure 2 shows the land cover maps of 1991 and 2000 derived from the remote sensing and GIS techniques, and simulated land cover maps of 2000, 2010, and 2020 derived from the modeling.

Table 1. Land cover transition area matrix (in hectare)

	2000			
1991	Shrubs	Forest	Urban built-up	Agricultural
Shrubs	**7107**	92	95	821
Forest	54	**13263**	149	386
Urban built-up	0	0	**5706**	0
Agricultural	8	45	2715	**36342**

Land cover transition matrix (Table 1) provided an important basis to analyze the temporal and spatial changes of land cover and examine the driving forces behind those changes in the valley. In the matrix, the diagonal values shown in bold represent the area of unchanged. During the period of 1991-2000, a large amount of agricultural land (2715 ha) was transformed into urban built-up area. The forest (149 ha) and shrubs (95 ha) lands were also changed to built-up areas due to the expansion of rural roads in the 1990s. Agricultural land gained its area from Shrubs (821 ha) and Forest (386 ha). However, a small portion of agricultural land in rural areas is also converted to shrubs and forest lands in the period. After the establishment of democracy in 1990, Kathmandu became the center of political power and hub of business activities (Thapa et al., 2008). The business and economic opportunities led to a population influx in the valley putting housing demands that eventually increased the urban built-up surfaces.

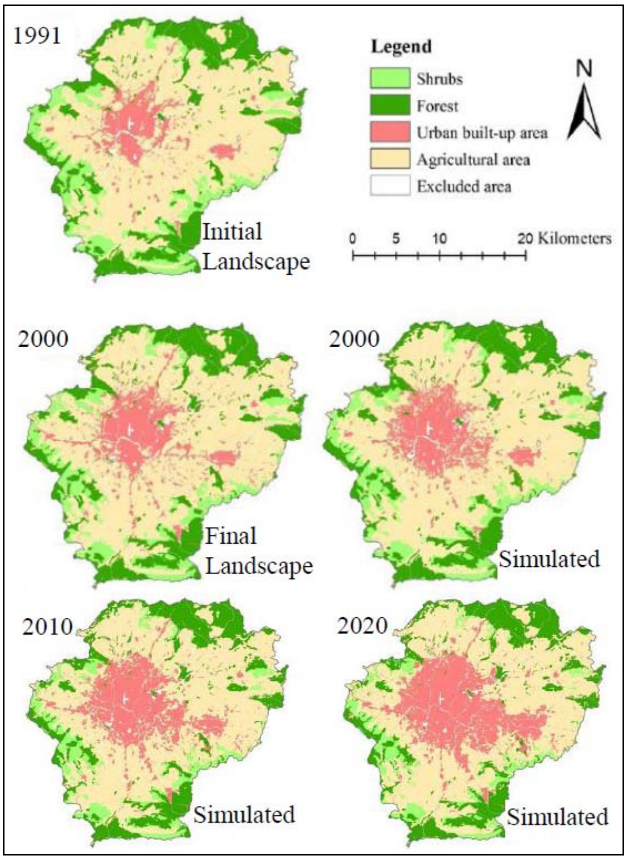

Figure 2. Real and simulated land cover maps (1991-2020).

Land cover transition rate was computed using Markov's approach which is used for model simulation. By varying parameters in each model run, various simulation results were produced, and their accuracies against the actual land cover for the year 2000 were computed using error matrix approach and fuzzy similarity metrics. Through vigorous calibrations of the model, the best results that the model has generated are illustrated in the Figure 2 (see simulated 2000). The landscape patterns in the simulated map are almost similar to the actual map (see final landscape 2000) in visual comparison. Table 2 shows the simulation accuracy results at quantitative level. An overall accuracy of 91% and Kappa coefficient of 86% is achieved. No significant discrepancies between the producer's and user's accuracies of each category are observed. The producer's and user's accuracies are found very high (over 90%), except in the urban built-up category. As compared to other land cover types, the urban built-up area has low producer's and user's accuracies, i.e., 76.78% and 76.56%, respectively. This means that 23.22% of the actual urban built-up areas are omitted from being selected for development, and 23.44% of the simulated urban built-up areas are committed to the category by the model incorrectly. This may be due to ribbon and leap frog types of urban development in some part of the valley, which is very difficult to predict in the urban growth modeling.

Table 2. Simulation accuracies in percentages

Land cover	2000	
	Producer's Accuracies	User's Accuracies
Shrubs	90.44	90.43
Forest	95.87	95.91
Urban built-up area	76.78	76.56
Agricultural area	92.82	92.87
Overall Accuracies	91.09	
Kappa Statistics	85.53	
Fuzzy similarity method		
1st	44.40	
2nd	50.89	

In order to make the simulation accuracies more realistic to reflect performance of the model, the areas (water and open space) excluded from the modeling are also removed while computing the simulation accuracies and model calibration process. However, in some cases, the accuracies assessment in the pixel by pixel comparison (error matrix) approach may not be enough because the simulated results may not produce exact mirror of the real situation. In urban growth simulation, similarity in the spatial patterns between the simulated and reference maps are very important (Hagen, 2003; Thapa and Murayama, 2010a). Hence, to justify the model further, we used fuzzy similarity method with an exponential decay function for checking the similarity of spatial patterns between the simulated and reference maps. The average adjustment of the simulated map achieved 50% in comparison with the score of 44% obtained when comparing the input map of 1991 and the reference map of 2000 (Table 2). According to Hagen (2003), the selected model is validated when a simulation result shows an increase in the fuzzy similarity metrics. Therefore, in both accuracy assessments, the simulated results of the model can be validated and regarded as appropriate to forecast the future urban dynamics in the Kathmandu valley. The Table 3 evidences the results by land cover type at quantitative level, i.e., actual vs. simulated with minor differences.

Table 3. Actual vs. simulated land cover in 2000 (in ha)

Land cover	Actual	Simulated
Shrubs	7169.76	7170.03
Forest	13408.83	13402.08
Urban built-up area	8664.48	8690.4
Agricultural area	37568.97	37549.53

Using the same configuration of the 1991-2000 simulation model and input map of 2000 and road network of 2000, we performed a simulation aiming to project the spatial patterns of urban growth in the valley for the year 2010 and 2020. Figure 2 (see simulated landscape for 2010 and 2020) shows the urban growth consistently expanding eastwards agglomerating the sub-urban villages and the two urban centers, i.e., Madhayapur Thimi and Bhaktapur. The built-up surface of villages in the southeastern part also starts agglomeration by 2010. Current agricultural area between the Madhayapur Thimi and Kathmandu-Lalitpur urban centers will be converted into urban built-up area in the 2010s. By 2020, all the urban centers will be aggregated into a greater metropolitan region in the valley. The observed spatial patterns suggest that most vulnerable land cover seems to be shrubs land which may change likely to agricultural area. The changing spatial patterns over the study period show that the agricultural area will be converted mostly to the urban built-up area.

4. Conclusion

This study confirms that overall agricultural encroachment in rural hills and mountain peripheries was occurred during the 1990s where the shrubs and forest landscape in rural areas of the valley mostly changed to agricultural areas. While in the valley floor, conversion of agricultural lands into built-up surface was observed. Integrating these landscape change knowledge with biophysical and social variables, the spatial model simulated the almost similar patterns of land cover change. The simulated result was validated by two techniques, i.e., pixel by pixel and fuzzy similarity metrics, which show the robustness of the predictive model. The simulation estimates, however, are based on extrapolation from historic processes which are not guaranteed to continue in the future but it mirrors spatial patterns of land cover in the valley if the historic process continues. In this case, the model has generated maps to show where and how the urban development in Kathmandu is heading in the next two decades from 2000, which may be a critical reference to make decisions for guiding future urban development and sustainable land management in the valley.

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