Tsukuba Geoenvironmental Sciences, Vol. 12, pp. 11-15, Dec. 25, 2016

Urban growth monitoring and prediction with remote sensing and GIS in Wuhan region, China

Xinmin ZHANG* and Yuji MURAYAMA**

Abstract

This study investigated the land use/cover changes and urban growth in Wuhan region by employing remote sensing and GIS techniques. Wuhan region has experienced rapid urban expansion in the past few years. The area of urban land has increased by 160.29% from 2000 to 2014. The simulation was conducted to predict the future expansion of urban land by using Multi-layer Perceptron neural network and Markov model. The predicted map in 2030 shows 41.27% increase of urban land from 2014, indicating that urban growth will continue in the future.

Key words: land use/cover changes, remote sensing, urban growth simulation, Wuhan region

1. Introduction

Study of land use/cover changes (LUCC) with satellite images has been one of the main branches of urban geography. This approach plays an important role to the local transformation of the earth's climate system (Mahmood *et al*. 2014). LUCC has largely affected the global warming and heat island (Muñoz-Rojas *et al*. 2015). It is necessary to monitor actual LUCC for sustainable urban planning.

Urban growth has been the main subject in various urban studies (Lv *et al*. 2012; Tan *et al*. 2014; Zhou *et al*. 2014). Urban growth is the most important social and economic phenomenon that influences urban planning in the 21st century (United Nations 2015). The challenge of monitoring urban growth is to obtain accurate and timely data on LUCC in different periods using geospatial techniques of remote sensing and GIS.

Few geographical studies were carried out in Wuhan based on different scales (Tan *et al*. 2014; Zhou *et al*. 2014). The urban land of Wuhan urban agglomeration increased with an annual growth rate of 46.75% from 1988 to 2011 (Tan *et al*. 2014). Wuhan is currently in a stage of rapid urbanization (Zhou *et al*. 2014). This study attempts to clarify the LUCC and urban growth from the spatial perspective of natural and spontaneous changes.

Maximum Likelihood Classification (MLC), a widely used pixel-based method for classifying LUCC maps, is a stable and robust classifier with high precision and accuracy (Sun *et al*. 2013). In this study, MLC is used to map the land use/cover of Wuhan for the years 2000, 2009 and 2014 and detect the spatiotemporal changes. The flowchart of urban growth monitoring and prediction is shown in Fig. 1.

The final goal of this study is to predict the future urban growth in Wuhan region (2014-2030) by employing Multi-layer Perceptron Neural Network (MLPNN) and Markov chains.

2. Methodology

2.1. Study area

In order to examine the urban growth in Wuhan region, we used a 100 km × 100 km study area covering the capital city of Hubei Province, China. The location of study area is shown in Fig. 2. The aggregated high-elevation area is distributed in the northern part of the study area which is named Mulan Mountain. Yangtze River and its longest branch namely Han River are located in the region. In 2014, Wuhan (prefectural-level city) had an urban population of 5.59 million, which is over 67.6% of the total population. Meanwhile, the gross domestic product (GDP) increased from 120.7 billion yuan in 2000 to 1,006.9 billion yuan in 2014 (Wuhan Municipal Bureau of Statistics 2014). Wuhan indicated unprecedented pace of urbanization from 1988 to 2013 (Zhou et al. 2014).

2.2. Land use/cover mapping

Landsat images in 2000, 2009 and 2014, with a spatial resolution of 30 m, were obtained from the United States Geological Survey (http://earthexplorer.usgs.gov/). The images were classified to produce accurate land use/cover maps using the MLC tool in ArcGIS. Six land use/cover types were classified, namely urban, cropland, grassland, bareland, forest, and water.

The accuracy of each of the classified LUCC maps was assessed using 600 reference points. These points were selected using stratified random sampling technique and verified from Google Earth.

* Graduate School of Life and Environmental Sciences, University of Tsukuba, Japan
** Faculty of Life and Environmental Sciences, University of Tsukuba, Japan

2.3. LUCC modeling

MLPNN was used for transition potential mapping. Then Markov module in TerrSet - Land Change Modeler was employed for simulation and prediction. The actual change simulation is done by Land Change Modeler, which uses an internal module to allocate the quantity of change (predicted using 2000 and 2009 maps and Markov model) based on the transition potential maps (modeled using 2000 and 2009 maps, the driving factors, and MLPNN). The driving factors we used for LUCC modeling include: (1) City center; (2) Roads; (3) Elevation: Digital Elevation Model (DEM); (4) Slope: Extracted from DEM; and (5) Euclidean distance from land categories. Concerning the urban land and water, some rules were taken into account as follows: (1) the transformation from urban land into other categories is unlikely to happen; (2) water is also considered stable and unlikely to change into other categories. These two corresponding transitions were excluded from the transitions.

MLPNN is a module of TerrSet software that can accurately simulate LUCC in urban areas (Shooshtari and Gholamalifard 2015). The advantage of using MLPNN is that it can deal with nonlinear relationships among variables. It is the most robust method for the transition potential modeling (Eastman 2009).

Using the transition probability matrix and their corresponding transition potential maps as inputs to the TerrSet - Land Change Model, we simulated 2014 and 2030 land use/cover maps. In this study, we ran the iteration of 16 times and selected the simulation with the best results. Fi-

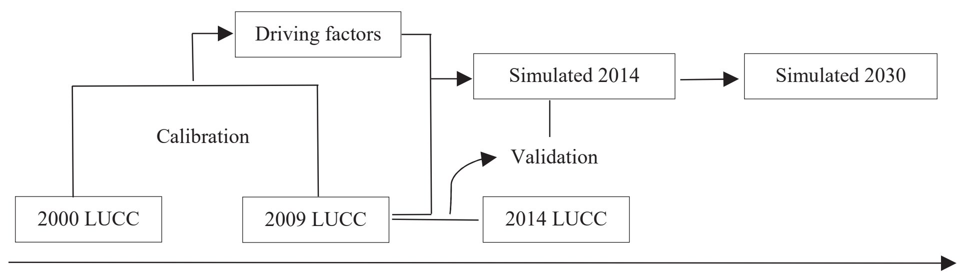

Fig. 1 Flowchart of the urban growth monitoring and prediction.

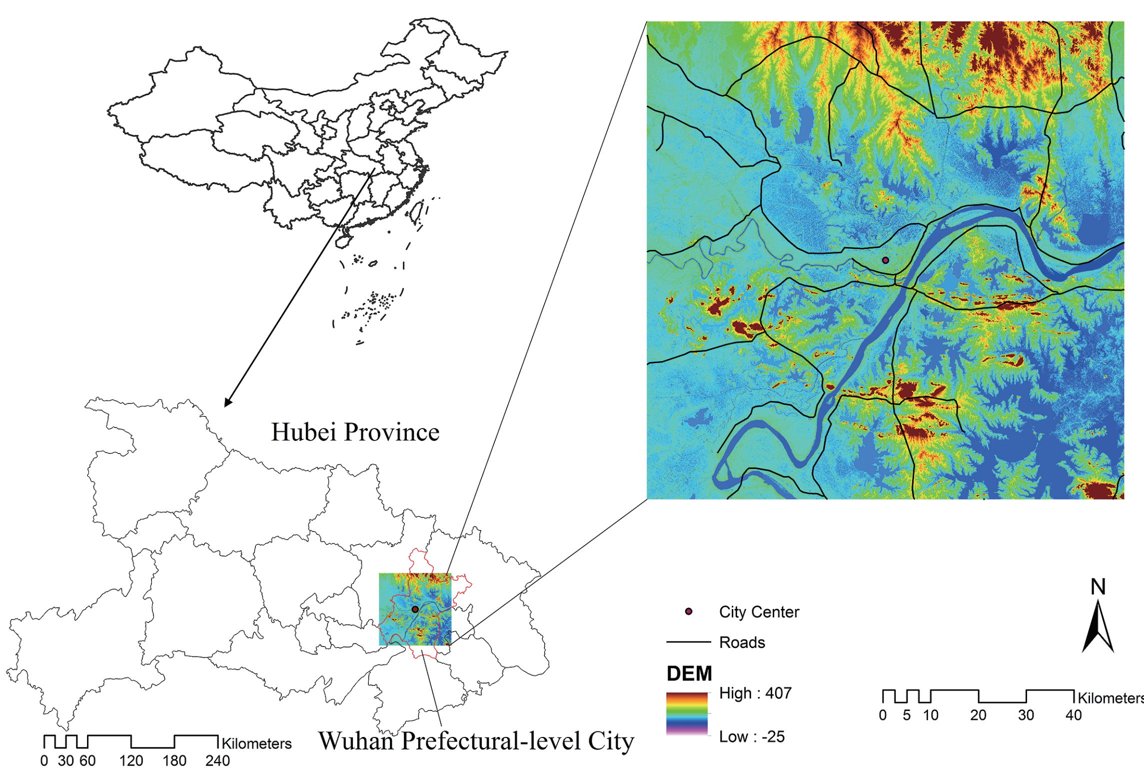

Fig. 2 Location of Wuhan region, China.

nally, the simulation results were reclassified into urban/non-urban land.

2.4. Validation: Figure of Merit (FoM)

The FoM is the ratio of the intersection of the observed change and simulated change to the union of the observed change and simulated change (Pontius et al. 2008; Thapa and Murayama 2011). The FoM has been widely used as a validation measure in urban growth simulation (Pontius et al. 2008; Thapa and Murayama 2011). We derived FoM by employing a three-map comparison analysis, involving the observed 2009 and 2014 urban/non-urban maps and the simulated 2014 urban/non-urban map. Based on the three-map comparison, we derived the four components of correctness and error (null successes, hits, misses and false alarms), which were then used to calculate FoM (Eq. (1)).

$$FoM = [H / (H+M+F)] \times 100\% \quad (1)$$

where H is the area due to observed change simulated as change, M is area due to observed change simulated as persistence, and F is area due to observed persistence simulated as change.

3. Results and discussion

3.1. Land use/cover changes

The classified land use/cover maps (Fig. 3) had an overall accuracy of at least 80%. Spatially, it can be observed that urban land had expanded outward from the city core and along two sides of Yangtze River. Table 1 shows the detected LUCC in Wuhan region. In the past 14 years (2000-2014), the total area of urban land increased from 27.30 thousand ha to 71.06 thousand ha, resulting in a net increase of 160.29%. It can be observed that majority of the landscape was covered with cropland, bareland and water. Grasslands were limitedly distributed in the study area. The cropland and other lands near the urban land in 2000 had been replaced by urban land in 2014.

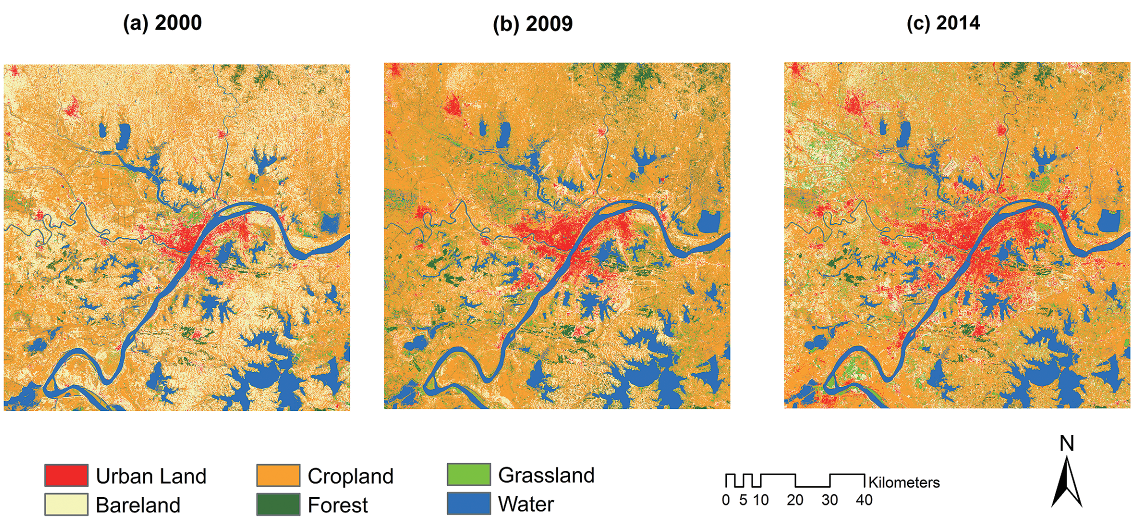

Fig. 3 LUCC maps in Wuhan region in 2000, 2009, and 2014.

Table 1. Land use/cover changes in Wuhan region.

Land categories	2000	2009	2014	Net change (2000-2009)	Net change (2009-2014)
	’000 ha	’000 ha	’000 ha	%	%
Urban	27.30	40.11	71.06	46.92	77.16
Cropland	473.83	623.32	576.88	31.55	-7.45
Grassland	15.70	38.85	52.39	147.45	34.85
Bareland	353.14	131.71	172.68	-62.70	31.11
Forest	16.06	49.19	15.75	206.29	-67.98
Water	114.37	117.22	111.64	2.49	-4.76
Total	1000.40	1000.40	1000.40		

3.2. Simulation of urban land in 2014

Fig. 4 shows the (a) actual map and (b) simulated map of urban and non-urban land in 2014. Our simulation has a FoM of 6.37%. The simulation has highly accumulative urban areas in the center of Wuhan, and the driving factor has strong impact on the urbanization. Other urban areas are distributed with quite dispersed conditions spatially different from the actual urban land map.

3.3. Prediction of urban land in 2030

Fig. 5 presents the predicted urban land of Wuhan region in 2030. It can be found that the new growth area would extend in the northwestern and southwestern directions. The new growth area would be 41.27% larger

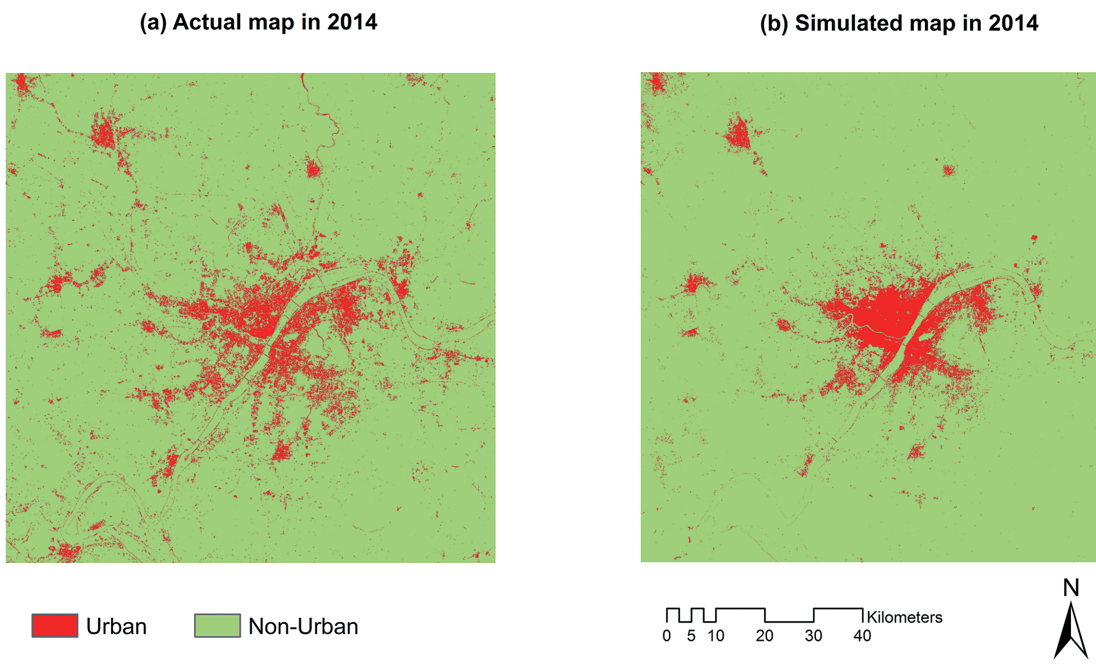

Fig. 4 The urban/non-urban land map in Wuhan region in 2014.

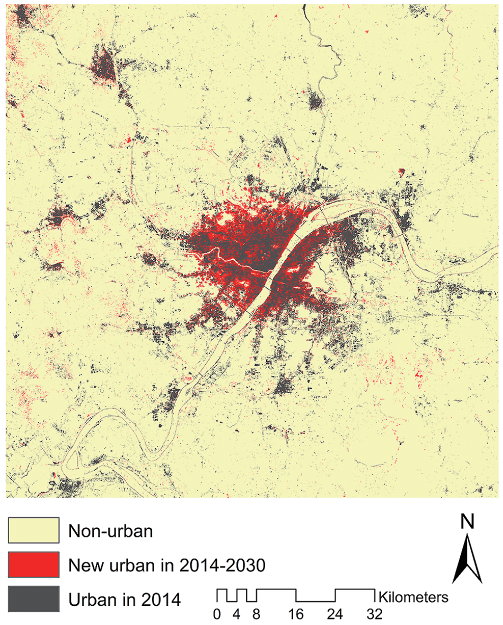

Fig. 5 Predicted urban land in 2030 with the actual urban land in 2014.

than that in 2014. The study area is characterized by its low altitudes. It has small lakes which are located in the west side of Yangtze River. These areas need to be considered in the future development and economic growth in the local district, and will get more chances to increase economic development and propel urban transformation. Wuhan region has obviously gotten strong influences from the city center because of the new expansion from the previous accumulative urban areas transitionally to the outskirts.

4. Conclusions

In Wuhan region the urban land increased from 27.30 thousand ha in 2000 to 71.06 thousand ha in 2014. The urbanization progressed along the two sides of Yangtze River. In each side, the urban growth expanded spatially from the city center to the outskirts.

The future urban growth in Wuhan region was predicted by the MLPNN and Markov model. The simulation result shows that the newly urbanized areas will be extended in the northwestern and southwestern parts in Wuhan region by 2030. These areas will be in the surrounding of urban core with low altitudes.The findings can help the local government to understand which areas should be considered in the urban planning and policy.

However we could not clarify the driving forces of the future urban development in this paper. This remains for our further study.

Acknowledgement:

This study was supported by the Japan Society for the Promotion of Science through Grant-in-Aid for Scientific Research B (No. 26284129, 2014-16, Representative: Yuji Murayama). We express our gratitudes to Dr. Ronald C. Estoque for his valuable comments and suggestions.

References

Eastman, J.R., 2009: *IDRISI Taiga, Guide to GIS and Image Processing*. Clark Labs, Clark University, Worcester, MA.

Lv, Z. Q., Dai, F. Q., & Sun, C. (2012): Evaluation of urban sprawl and urban landscape pattern in a rapidly developing region. *Environmental Monitoring and Assessment*, **184**(10), 6437-6448.

Mahmood, R., Pielke, R. A., Hubbard, K. G., Niyogi, D., Dirmeyer, P. A., McAlpine, C., ... & Baker, B. (2014): Land cover changes and their biogeophysical effects on climate. *International Journal of Climatology*, **34**(4), 929-953.

Muñoz-Rojas, M., Jordán, A., Zavala, L. M., De la Rosa, D., Abd-Elmabod, S. K., & Anaya-Romero, M. (2015): Impact of land use and land cover changes on organic carbon stocks in Mediterranean soils (1956–2007). *Land Degradation & Development*, **26**(2), 168-179.

Pontius Jr, R. G., Boersma, W., Castella, J. C., Clarke, K., de Nijs, T., Dietzel, C., Duan, Z., Fotsing, E., Goldstein, N., Kok, K., Koomen, E., Lippitt, C. D., McConnell, W., Sood, A. M., Pijanowski, B., Pithadia, S., Sweeney, S., Trung, T. N., Veldkamp, A. T., & Verburg, P. H. (2008): Comparing the input, output, and validation maps for several models of land change. *The Annals of Regional Science*, **42**(1), 11-37.

Shooshtari, S. J., & Gholamalifard, M. (2015): Scenario-based land cover change modeling and its implications for landscape pattern analysis in the Neka Watershed, Iran. *Remote Sensing Applications: Society and Environment*, **1**, 1-19.

Sun, J., Yang, J., Zhang, C., Yun, W., & Qu, J. (2013): Automatic remotely sensed image classification in a grid environment based on the maximum likelihood method. *Mathematical and Computer Modelling*, **58**(3), 573-581.

Tan, R., Liu, Y., Liu, Y., He, Q., Ming, L., & Tang, S. (2014): Urban growth and its determinants across the Wuhan urban agglomeration, central China. *Habitat International*, **44**, 268-281.

Thapa, R. B., & Murayama, Y. (2011): Urban growth modeling of Kathmandu metropolitan region, Nepal. *Computers, Environment and Urban Systems*, **35**(1), 25-34.

United Nations, Department of Economic and Social Affairs, Population Division (2015): *World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352).*

Wuhan Municipal Bureau of Statistics (2014): *National economic and social development statistical bulletin in 2014 of Wuhan city.*

Zhou, K., Liu, Y., Tan, R., & Song, Y. (2014): Urban dynamics, landscape ecological security, and policy implications: A case study from the Wuhan area of central China. *Cities*, **41**, 141-153.

Received 15 September 2016
Accepted 5 October 2016