MODELLING URBAN DYNAMICS VIA CELLULAR AUTOMATA

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ABSTRACT:

Modelling urban dynamics is mostly pronounced in metropolitan areas, where spatial information science could contribute to efforts of understanding the pattern and future characteristics. This paper discusses the past, current and future trend of land-use dynamics of European part of the Istanbul Metropolitan. Studies on urban growth modelling state that, there is no consensus on the selection method of appropriate urban growth parameters and transition rules, since they depend mainly on the examined urban structures, dynamics and environmental conditions. Hence, the main objective of this study is to define a framework and methodology for the urban growth model simulation of the Istanbul Metropolitan Area. Current methods available and applied were discussed. Landsat images retrieved 1984, 1995 and 2006 were used to determine the land-use information. The year 2017 was predicted using cellular automata. Cellular Automata has been used in many applications and is a dynamic spatial modelling method, which can be easily used to simulate the future development urban plans having 'what if' cases by decision makers. This study clearly shows that spatial information sciences served quite well in understanding about the dynamics of the urban development process and modelling the interaction between non-urban and urban land units for sustainable urbanization in a region.

1. INTRODUCTION

The complexity and variety of different components making up the urban environment, and the interactions among them, are the most pronounced in the mega cities. In this context, it is important to develop integrated frameworks and systems in order to detect changes and monitor dynamics, where looking at one component of change in isolation could lead to decisions being taken on the basis of insufficient information. The integration will certainly be facilitated be new technologies, tools, and expertise as land-use/cover changes are quite difficult to grasp as they occur incrementally (Musaoglu, 2006). Additionally, the simulation of taken decisions and modeling urban dynamics attracts many attentions from the decision maker's side, where spatial information science could provide adequate solutions. As a result, extensive researches and the developments in spatial modelling based GIS lead to a better understanding of the spatial and temporal processes of urban growth and its applications (Meaille, R., Wald, L., 1990; Batty, M., Xie, Y., 1994), where spatial agent-based modelling, Cellular Automata (CA) and the fractal growth of cities attracts a lot of interest (Brown, D.G., Xie, Y., 2006; Liu, X.P., et al., 2008; Al-kheder, S., et al., 2008) Most of the developed models are cell-based methods that can be categorized as models that use cellular automata (Batty, M., et al., 1999; White, R., Engelen,

G., 1997), models that use transition probabilities in a class transition matrix (Turner, M.G., 1987; Veldkamp, A., Fresco, L.O., 1996) and GIS weighted overlay models (Pijanowski, B.C., et al, 1997) Studies on urban growth modelling state that, the selection method of appropriate urban growth parameters and transition rules, depend mainly on the examined urban structures, dynamics and environmental conditions. Hence, the main objective of this study is to define a framework and methodology for the urban growth model simulation of the Istanbul Metropolitan Area. This study focuses on using Cellular Automata method for presenting the land-use dynamics of European side of Istanbul and predicting the land-use characteristics for the year 2017.

2. DATA AND METHODOLOGY

Several research projects have been conducted to quantify the urban growth of Istanbul. According to the studies the European side of the metropolitan area is increasing rapidly, when compared to Asian side. Istanbul metropolitan area now covers around 2238.6 km^2 and the area with the most rapid rate of urban expansion is on the European side of the city. (Kaya and Curran, 2006) In 2000, around 65% of the population were living on the European side of the city with its large

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Figure1. The Istanbul Metropolitan Area

industrial/commercial and trade centres. The population is increasing as a result of both births exceeding deaths and mass immigration. Consequently, planned and unplanned housing are increasing while green areas are decreasing. The Istanbul Metropolitan area, shown in Figure 1, covers an area of 2000 km^2, while the metropolitan area occupies 5700 km^2. The Istanbul Metropolitan area had a population about 4.7 Million according to 1980 census data which has more than doubled and reached about 10 millions in only two decades. For monitoring urban dynamics, the importance of remote sensing technology is now widely recognized. Remotely sensed data were used to monitor urban growth for two periods: 1984–1995 and 1995–2006. From the obtained trend, the land-use values for the year 2017 were predicted via Cellular Automata. The methodology was designed explicitly for simplicity in order to facilitate its future uptake by the Municipality of Istanbul.

Images for the years 1984, 1995 and 2006 were retrieved from Landsat. Additionally, aerial photographs and orthophoto maps were used for ancillary information. For image rectification, 1:25000 scaled topographic maps were used, where the achieved accuracy was about 0.5 pixel root mean square (RMS). The first degree polynomial transformation and nearest neighbourhood method were used. In this study, the Iterative Self Organizing Data Analysis Technique (ISODATA) unsupervised classification algorithm was used. For land cover classes were identified being water (sea and lake), forest (involving natural and semi-natural vegetation, brushes etc.), open/cropland (barren land, pastures, arable and harvested agricultural land, mining areas), urban (involving impervious surfaces). The classification accuracy for years 1984, 1995 and 2006 are 82%, 85% and 87% respectively, where the results were achieved with 50 training samples of each land cover collected in the field measurements and from land use maps. The main transportation networks of Istanbul were obtained using the screen digitizing technique from satellite images. For industrial areas, analyses were performed from the GIS base-maps of Istanbul Metropolitan Municipality. Finally, the urban and industrial spatial information integrated with the classified images to examine their affect on urban growth process.

The flow-chart of the followed steps were presented in Figure 2, where classified images were used to detect transition areas. The Cellular Automata(CA) method is widely used for simulating urban dynamics, since the approach is straight forward. The urban CA model uses the neighbourhood transition rules (e.g., what is the state of cell? such as urban or non-urban, how close is the cell to the centre of the city or protected zones such as watershed or forest?) to simulate the land use change from one cell's state to another such as the developments from a non-urban to urban cell during the urban growth. This transition rule is working as a local function of what is going on in a specified neighbourhood of the cell for each pixel of the spatial data at a time related to urban theories (Liu, X.P., et al., 2008). Due to the dynamic self-organizing structure, this transition rules provide the most important advantage to CA models. In this study, the Moore neighbourhood, having 24 pixels in a 5 x 5 window, was used to run the transition rules according to the transition probability of land conversion which were covered in Markov analysis. The future urban land pattern was also estimated based on Markov transition matrix. It predicts the number of new pixels to be urbanized at a specified time period depending upon the existing urban space. Finally, the transition rules were applied on a cell-by-cell basis and repeated on annual basis to reach the urban growth rate during the time period.
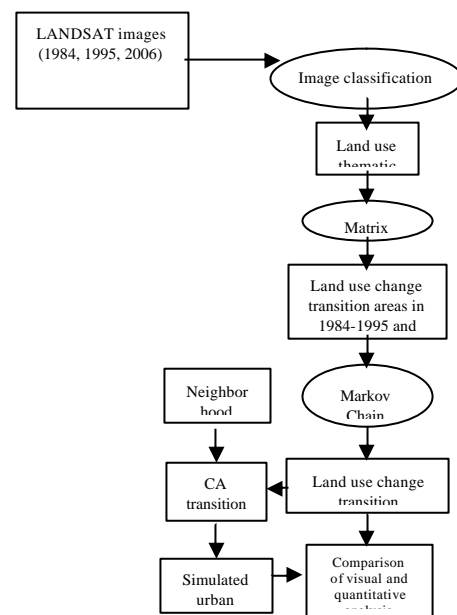

Figure 2. The flowchart of the urban growth simulation

3. RESULTS AND CONCLUSION

For each discrete time periods being from 1984 to 1995 and from 1995 to 2006, spatial and temporal land use changes at the European side of the Istanbul metropolitan area were explored and future urban growth for 2017 was simulated. The classification results of the years 1984, 1995 and 2006, were illustrated in Figure 3, where red spots represents the urban settlement. The results showed that the most striking land use change was among forest, open/crop and urban land, where transition was from forest to open/crop land and from that into urban land. Urban and industrial areas greatly increased and open/crop land and forest areas significantly decreased during

the study periods in 1984, 1995 and 2006. Industrial sites were distributed irregularly, and industrial and residential growths occurred in the region close to the transportation network. Industrial sides were easily recognized, where within the years 1984-1995, industrial areas had been increased 142%. This trend slows down with the years 1995- 2006, however still the industrial areas with the region increased %20, where figures were illustrated in Table 1.

Table 1.Observed characteristics at the European side, 1984, 1995, 2006 (Unit:ha)

	Water	Forest	Open/Crop Land	Urban	Industry
1984	285564	159642	167078	21006	1585
1995	286112	148374	155224	41321	3844
2006	287721	143979	149803	48757	4615

As a result, the total amount of urban land has increased 96%, where it continues to increase 17% within the second phase of observation. Classification of images revealed rapid land cover change on the European side of Istanbul. The big grow of residential and business area forced a loss in agricultural surface. Istanbul reacts similar to all big metropolitans worldwide.
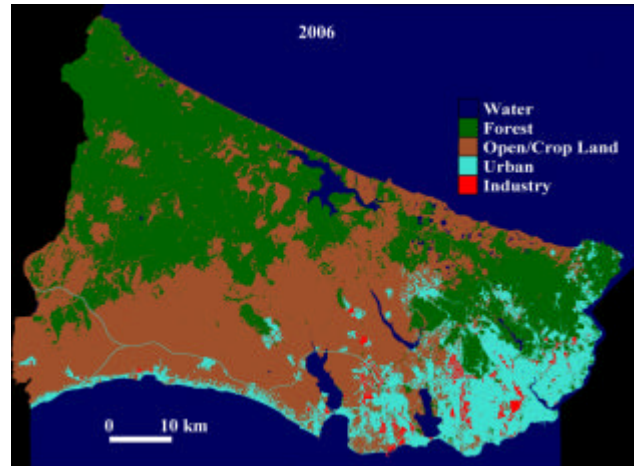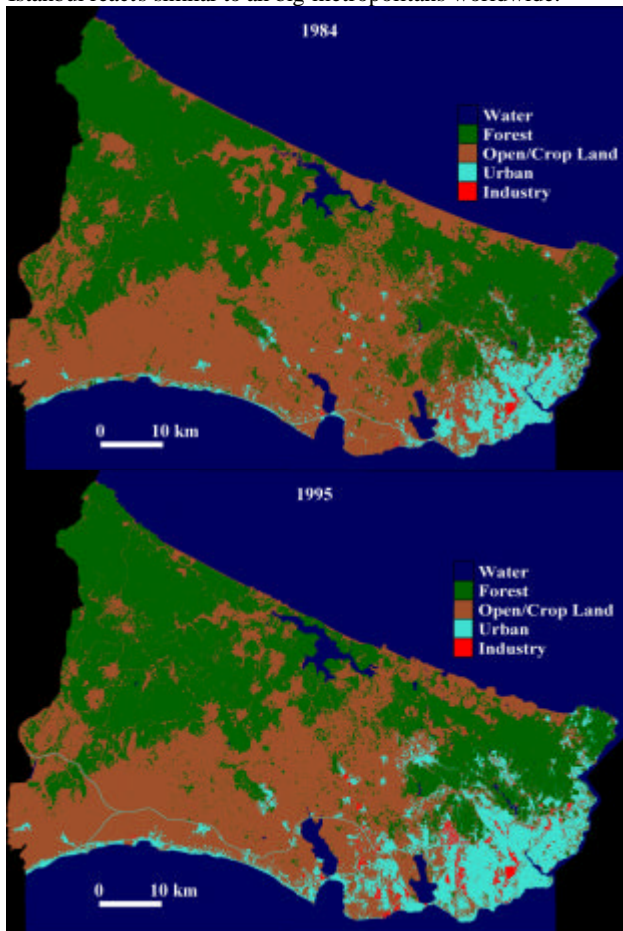

Figure 3. Land use results for 1984, 1995 and 2006

For prediction and simulating the urban pattern at 2017, Cellular Automata (CA) model were introduced. The generic development principle fits well with the way systems in general and city systems in particular appear to develop, or might be developed. In essence, the state of a cell changes if something does or does not happen in its neighborhood, however that be defined. (Batty, 1997) The principle can be stated in its most general form as

IF *something* happens in the *neighborhood* of a *cell*

   THEN

   some-other-thing happens to the *cell*

For both models, firstly simulation between 1995 and 2006 was conducted and major findings were used for the years 2006 to 2017. The Markov transition probabilities of the observed landscape changes from 1984 to 1995 and from 1995 to 2006 were illustrated in Table 2. By examining the land-use transition probabilities of both time periods, it can be recognized that the urbanization of open/crop land was one of the driving forces and it had great impact on the resulting general trends.

Table 2 Land use change transition probability in European side for 1984, 1995 and 2006

		1995				
		Water	Forest	Open/Crop land	Urban	Industry
1984	Water	0.9935	0.0003	0.0047	0.0013	0.0001
	Forest	0.0025	0.8337	0.1331	0.0288	0.0019
	Open/Crop Land	0.0118	0.0909	0.7920	0.0938	0.0116
	Urban	0.0017	0.0011	0.0135	0.9801	0.0037
	Industry	0.0006	0.0000	0.0095	0.0524	0.9375
		2006				
1995	Water	0.9967	0.0009	0.0017	0.0007	0.0001
	Forest	0.0017	0.8850	0.1076	0.0056	0.0002
	Open/Crop Land	0.0135	0.0798	0.8590	0.0430	0.0047
	Urban	0.0054	0.0008	0.0004	0.9933	0.0001
	Industry	0.0005	0.0002	0.0003	0.0021	0.9969

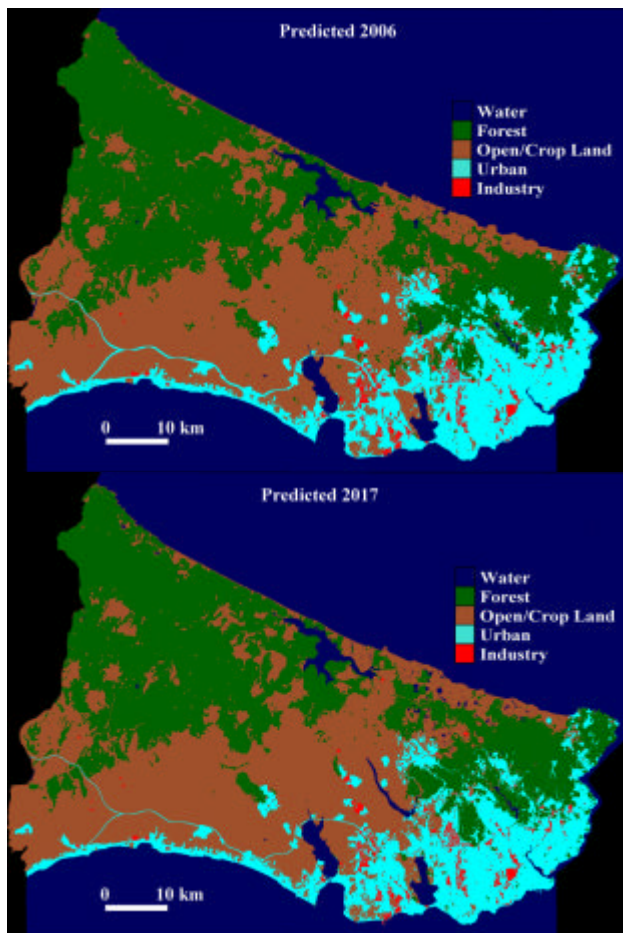The simulation of Istanbul Metropolitan Area for 2017 was presented in Figure 4 and 5.

Figure 4 and Figure 5. Simulated land use change using CA-Markov model in 2006 and 2017.

According to the analyses, the urban growth rate for second study period (1995-2006) is less than first period (1984-1995). Urban areas at Istanbul were increased (about 117%) within the period (1984 – 1995), however the urbanization rate was slowed down to 19% at 2006. Land use distribution values, which were simulated from Markov model for the year 2017, represent more realistic states compared to logistic regression.(Cetin and Demirel, 2010) Land-use distribution simulated using CA-Markov model for 2017 shows a consistent pattern of urban and industrial areas gradually increasing at the open/crop land (Figure 5). Also, the results indicate that the selected time intervals greatly affect the prediction rate of the land use changes, since the simulation by stochastic models depend on previous discrete time.

This study clearly shows that spatial information sciences served quite well in understanding dynamics of the urban development process and modelling the interaction between non-urban and urban land units for sustainable urbanization in the region. Monitoring the urban growth will enable the Municipality of Istanbul to better manage this complex urban area, where scenarios might help to visualize and simulate the problems. The results indicate that generic algorithms such as cellular automata could aid managers, decision-makers and urban planners by informing them of the past, current and future land-

use/cover changes, that will contribute to sustainable resource use and management.

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