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Parameter Sensitivity Analyses in Agent-Based Urban Growth Models

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Land use activity is a major issue and challenge for town and country planners. Modelling and managing urban growth is a complex problem. Cities are now recognised as complex, non-linear and dynamic process systems. The design of a system that can handle these complexities is a challenging prospect. Local governments that implement urban growth models need to estimate the amount of urban land required in the future given anticipated growth of housing, business, recreation and other urban uses within the boundary. There are so many negative implications related to the type of inappropriate urban development, such as increased traffic and demand for mobility, reduced landscape attractiveness, land use fragmentation, loss of biodiversity and alterations of the hydrological cycle. The aim of this study was to use an agent-based model as a powerful tool for simulating urban growth patterns. Our study area was Sanandaj city located in the west of Iran. Landsat imageries acquired in 2000 and 2006 were used. The dataset used included distance to principle roads, distance to residential areas, elevation, slope, distance to green spaces and distance to region centres, land price and distance to fault. In this study, an appropriate methodology for urban growth modelling using satellite remotely sensed data was presented and evaluated. Percent correct match (PCM), figure of merit and kappa statistics were used to evaluate the simulation results.

Keywords: *agent based, urban growth, modelling, sensitivity analysis.*

1 Introduction

Rapid urbanisation and population growth have been a common worldwide phenomenon, especially in the developing countries (Li *et al.*, 2009). In recent years, urban development in developing countries has been faster than in developed countries (Youssef *et al.*, 2011). Nowadays, 70% of the world's largest cities are found in the developing world (Cohen, 2006). Urbanisation is a dramatic form of irreversible land transformation (Luck and Wu, 2002; Seto and Fragkias, 2005), involving massive immigration of rural and peri-urban population to urban areas. Thus, controlling and monitoring the urbanisation and urban expansion process require accurate and reliable information about urban growth patterns (Jiang and Yao 2010). This rapid expansion has resulted in so many negative impacts, such as negative socioeconomic and environmental effects (Lambin *et al.*, 2001), decaying infrastructure, global warming, climate and ecosystem changes (López *et al.*, 2001), uncontrollable growth (sprawl) of informal settlements (Angotti, 1993; Sudhira *et al.*, 2004) and consumption of agricultural land (Huang *et al.* 2009). In fact, land and resources have been greatly challenged by this uncontrolled growth and because of that planning, policy decisions and decision making have become ineffective. In addition, haphazard planning, poor statistical and urban data collection over the years have also made planning projection ineffective (Al-Qubati, 2002; Al-Haj, 2001). This phenomenon has played an important role in air pollution, too. It has been estimated that approximately 80% of all CO_2 emissions are from world cities (Churkina, 2008; Svirejeva-Hopkins and Schellnhuber, 2008; Zhao *et al.*, 2009). Sprawl is another result of poor planning. Urban sprawl, which is caused by irrational development, has exerted a huge stress on surrounding natural and semi-natural ecosystems (Yeh *et al.*, 1996; Ewing, 1997; Brueckner, 2000; Conway and Lathrop, 2005; Lin *et al.*, 2007; Yu *et al.*, 2007; Lin *et al.*, 2008; Gong *et al.*, 2009).

There are a number of methods in modelling urban growth, the focus of which is to understand the basic characteristics of land use change trends over time. Urban growth as an unavoidable phenomenon affects regional, social and economic development and global environmental changes (Turner *et al.*, 1993). Thus, monitoring, modelling and forecasting urban growth using remote sensing (RS) data and geospatial information systems (GIS) tools seem to be needed. The availability of free to less expensive remote sensing data and their temporal frequency has greatly enhanced the potential for monitoring urban growth (Masser, 2001, Im *et al.*, 2008). In fact, integration of RS data and GIS tools have been recognised as powerful and effective tools in monitoring environmental change, such as land use/land cover change and urban growth modelling (Güler *et al.*, 2007; Long *et al.*, 2008).

2 Materials and methods

In the recent decades, a number of methods have been used to present and understand the mechanism of urban expansion (Chong and Jianquan, 2007). Multi-agent systems (MAS) in the last 2 decades have been used significantly for modelling urban growth and land use change. Multi-agent systems can be defined as a set of agents interacting in a common environment, able to modify themselves and their environment (Ferrand, 1996). MAS explicitly represent actor behaviour (Robinson *et al.*, 2007). Linear multi-nominal models are always applied to getting the value of utility (Equation 1) (Cheng and Masser, 2003). Furthermore, based on the theoretical and practical analysis of location utility and household's actions (Raju *et al.*, 1998), traffic accessibility, land price and residential environment are chief contributors to residential location choice. Then, the utility U_{ik} of land parcel k chosen by household i is expressed in Equation 1:

$$U_{ik} = P_{p_i} \times V_{p_k} + P_{t_i} \times V_{t_k} + P_{e_i} \times V_{e_k} \quad (1)$$

where P_{p_i}, P_{t_i} and P_{e_i} stand for the preferences to land price, traffic accessibility and environment conditions by household i, respectively; V_{p_k}, V_{t_k} and V_{e_k} are the values of land price, traffic accessibility and environment conditions of land parcel k, respectively.

2.1 Case Study

The study area in this research is Sanandaj city, in the west of Iran. In the past few decades, Sanandaj has shown remarkable urban growth. One of the reasons for the rapid population growth in this city is migration from neighbouring cities and even from neighbouring provinces to the city because of the economic and social potential of this city.

2.2 Data Preparation

Remote sensing techniques and the availability of free to less expensive data sources of satellite imagery and their temporal frequency have greatly enhanced the potential for monitoring urban growth (Im, 2008; Goodchild, 2000). The data used in our research came from 2 satellite imageries related to years 2000 and 2006 from Landsat satellite and are from TM & ETM^+ sensors, which have Earth pixel size of 28.5 meters. The data were projected to the World Geodetic System (WGS) 1984, Universal Transverse Mercator (UTM) Zone 38N coordinate system. The 2000 and 2006 Landsat imageries were classified according to Anderson level 1 with ENVI 4.7. Figures 1 and 2 show the satellite and the classified imageries.

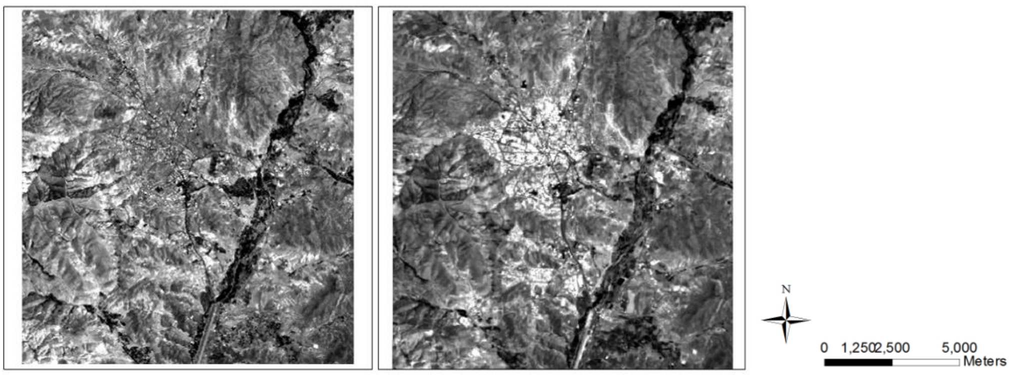

Figure 1. Satellite imageries of Sanandaj, 2000 and 2006, respectively.

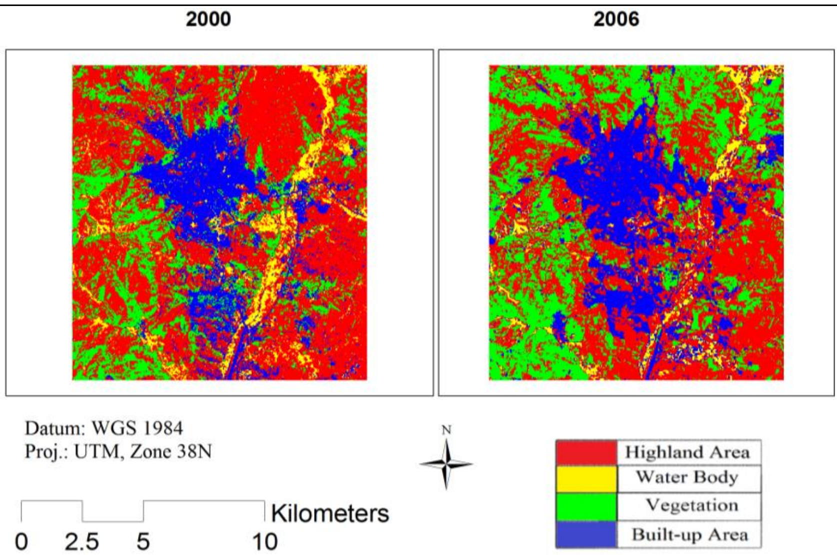

Figure 2. Classified imageries.

The main road map, attractive areas (such as parks), faults, slope, elevation, land use maps and others also are formatted in the Shape file, using software Arc GIS 9.3 ESRI. In this research, 8 parameters including distance to main road, distance to park, distance to faults, slope, elevation, distance to district centre, distance to developed region and land price were used. According to Pijanowski et al. (2002), these numbers were normalised between 0 and 1 before using them. This normalising process has a lot of benefits, e.g. the programme needs less memory because smaller values need less space for storage and the programme deals with the numbers of the same value range (0 to 1). The maximum likelihood method as a supervised classification method was used to classify the imageries. The kappa coefficient and overall accuracy of these imageries were 89.17% and 92.57% for 2000 and 92.68% and 94.71% for 2006, respectively. Tables 1 and 2 present classification accuracies.

Table 1. Accuracy totals (2000).

Class Name	Referenced Totals	Classified Totals	Number Correct	Producer's Accuracy	User's Accuracy
Water Body	123	120	120	97.56	100
Built-up Area	177	219	173	97.74	79
Highland Area	505	483	455	90.10	94.2
Vegetation	286	269	262	91.61	97.4
Total	1091	1091	1010		

Table 2. Accuracy totals (2006).

Class Name	Referenced Totals	Classified Totals	Number Correct	Producer's Accuracy	User's Accuracy
Water Body	118	147	117	99.15	79.59
Built-up Area	176	177	175	99.43	98.87
Highland Area	243	214	213	87.65	99.53
Vegetation	87	86	86	98.85	100
Total	624	624	591		

2.3 Accuracy Assessment

Figure of merit (Equation 2) is a method to evaluate resemblance between actual and simulated maps as suggested by Pontius, 2008. If a simulated map has a high goodness of fit to an actual map, the figure of merit will be high, and vice versa.

$$Figure\ of\ Merit = \frac{b}{a+b+c+d} \qquad (2)$$

where, a is an error due to observed change predicted as persistence, b is correct due to observed change predicted as change, c is an error due to observed change predicted as wrong gaining category, and d is an error due to observed persistence predicted as change.

Percent correct match (PCM) is another method to compare maps (imageries). This method compares only the parameters of the original diameter of A and D in the confusion matrix using Equation 3 (Table 3).

$$PCM = \frac{A+D}{A+B+C+D} \qquad (3)$$

Table 3. Confusion matrix.

Model	Reality		
	Change	Non Change	Total
Change	A	B	213
Non Change	C	D	86
Total	A+C	B+D	591

Kappa statistic is a statistical method for evaluating similarity between 2 maps (imageries), which is widely used in spatial issues. This coefficient shows the rate of compatibility between simulation and reality (Monserud *et al.*, 1992). In other words, this factor can be used to measure the spatial distribution of the amount of similarities between 2 maps (Mohammady, 2013). It is generally considered that kappa values for map agreement are as follows: >0.8 is excellent; 0.6-0.8 is very good; 0.4-0.6 is good; 0.2-0.4 is poor; and <0.2 is very poor (Pijanowski *et al.*, 2005). The calculation of kappa is based on a contingency table (Monserud *et al.*, 1992) (Table 4).

$$P(A) = \sum_{i=1}^{c} P_{ii} \quad (4)$$

$$P(E) = \sum_{i=1}^{c} P_{iT} \times P_{Ti} \quad (5)$$

$$KS = \frac{P(A) - P(E)}{1 - P(E)} \quad (6)$$

Table 4. Contingency table.

	Model					Total
Reality	**Class**	**1**	**2**	**…**	**C**	
	1	P_{11}	P_{12}	…	P_{1C}	P_{1T}
	2	P_{21}	P_{22}	…	P_{2C}	P_{2T}
	…	…	…	…	…	…
	C	P_{C1}	P_{C2}	…	P_{CC}	P_{CT}
Total		P_{T1}	P_{T2}	…		*1*

3 Results and discussion

We analysed the sensitivity of the implemented MAS to their properties. Agents in each position search for pre-defined neighbourhoods. In this study, Moore neighbourhood was used as the space where agents interact. The size of this neighbourhood should be defined properly, too. Thus, the neighbourhood size ranged from 3×3, 5×5, …, to 17×17. Figure 3 shows the assessment result of changing the size of windows. The number of agents is another critical issue in agent-based modelling. Thus, finding the proper number of agents seems to be important. In this study, the agent numbers used to evaluate the results ranged from 25 to 1000 (Figure 4). The third parameter is the *L* value. This value shows the number of times that a certain pixel is selected by the agents to change from a non-urban to urban situation. The *L* value in this research ranged from 2 to 50. Figure 5 shows the assessment results.

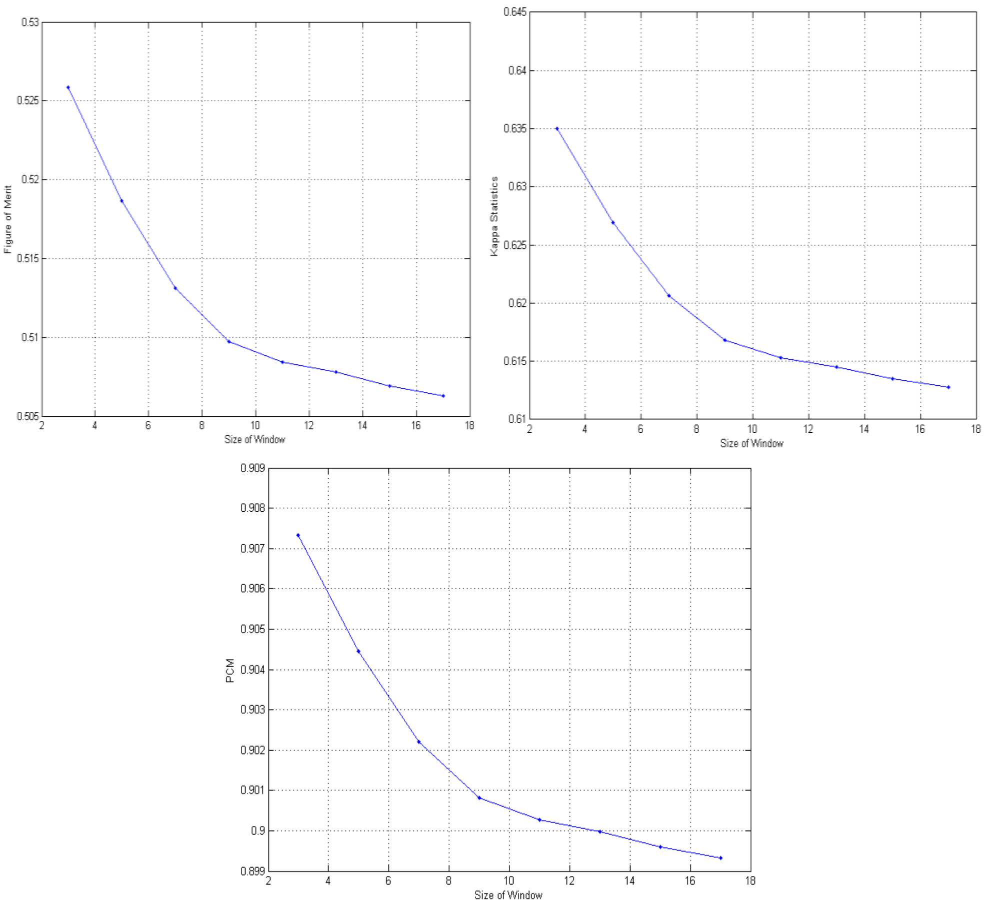

Figure 3. Sensitivity of the size of window in figure of merit, kappa statistics and PCM.

According to Figure 3, the simulation was obtained by changing the window sizes. The window size changed from 3×3, 5×5, … to 17×17. This figure shows that there is a meaningful difference between the accuracies obtained using the 3×3 window size and the 17×17 window size. This difference in the figure of merit factor is 3%, which seems to be a noticeable value. In fact, the size of the selected window is an important task. Thus, finding the optimum value of the window size must be done carefully, because, as shown in Figure 3, finding the non-precise value as the size of window decreases the accuracy of the results.

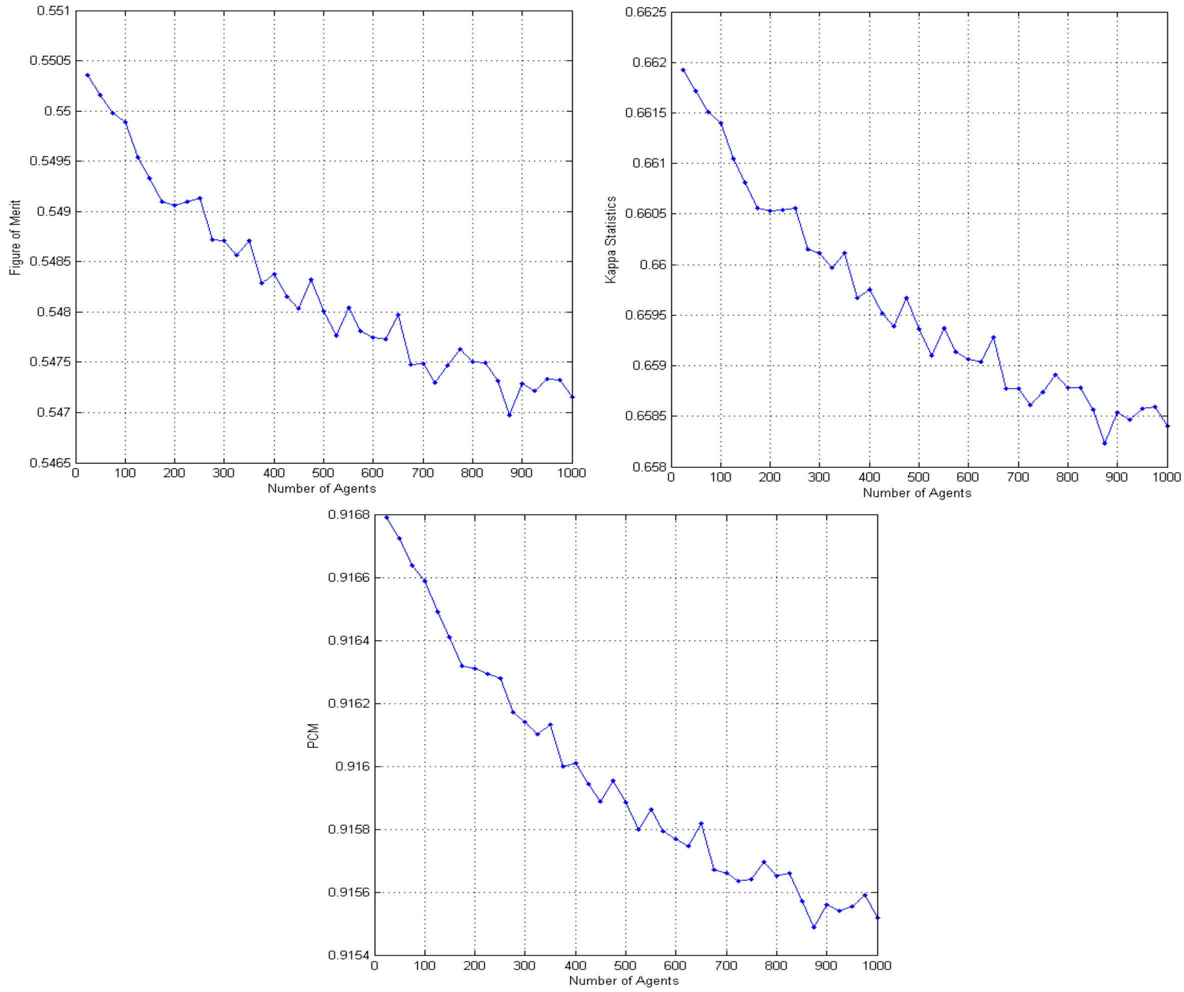

Figure 4. Sensitivity of the number of agents in figure of merit, kappa statistics and PCM.

According to Figure 4, the second important factor is the number of agents. The difference between the resulted accuracies from 25 agents to 1000 agents in the 3 accuracy assessment factors is shown in Figure 4. This difference in the figure of merit factor is about 0.35%. It seems that 25 agents had the best accuracies.

According to Figure 5, the *L* value ranges from 2 to 50. This factor had the least importance. The difference between the obtained accuracies from the *L* value 2 to 50 was about 0.08% in the figure of merit. Thus, it seems that the simulation had the least sensitivity to this factor.

The best values of the parameters were selected to be 25 agents, the *L* value equal 2 and 3×3 as the size of window. Figure 6 shows the simulation result using the proposed properties.

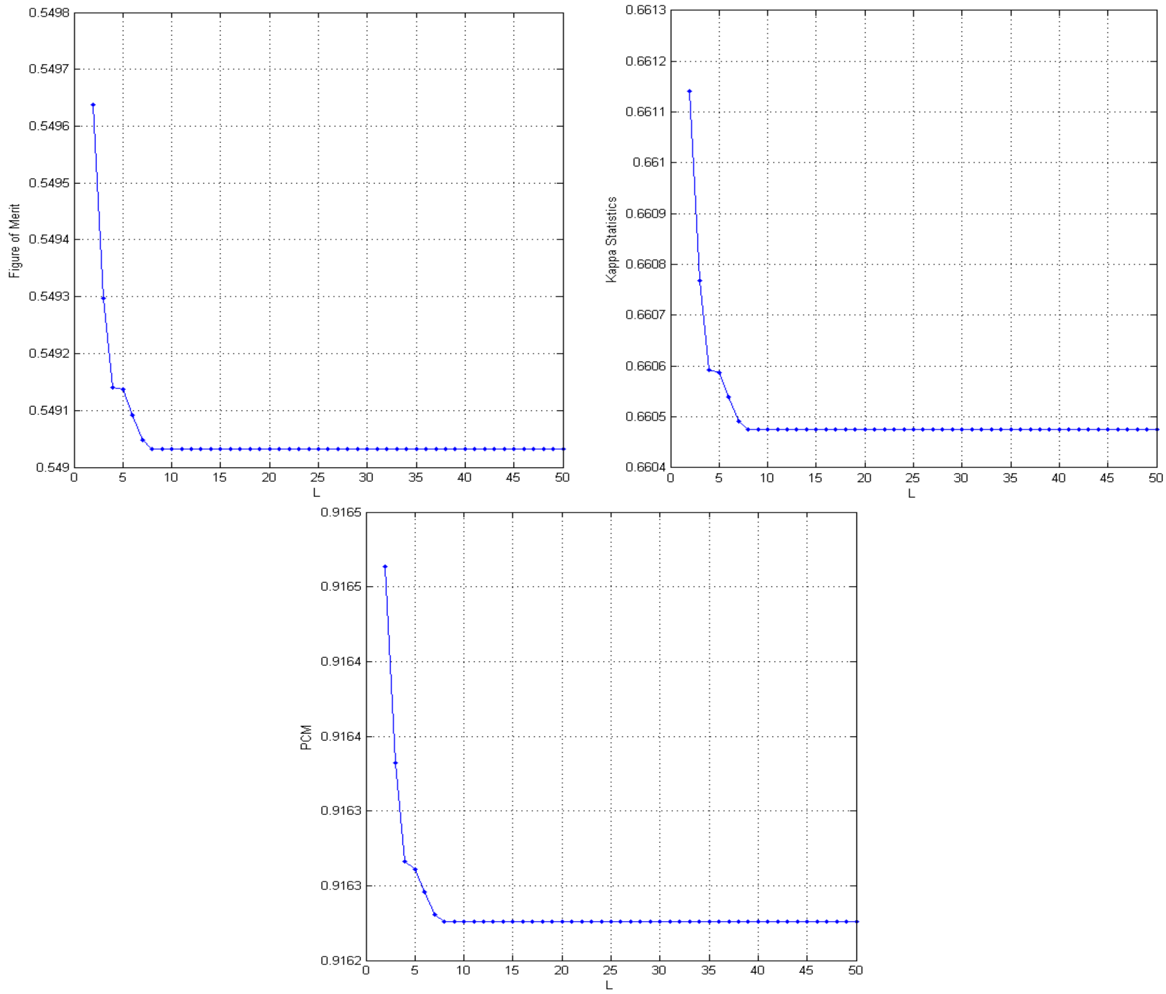

Figure 5. *Sensitivity of the L value in figure of merit, kappa statistics and PCM.*

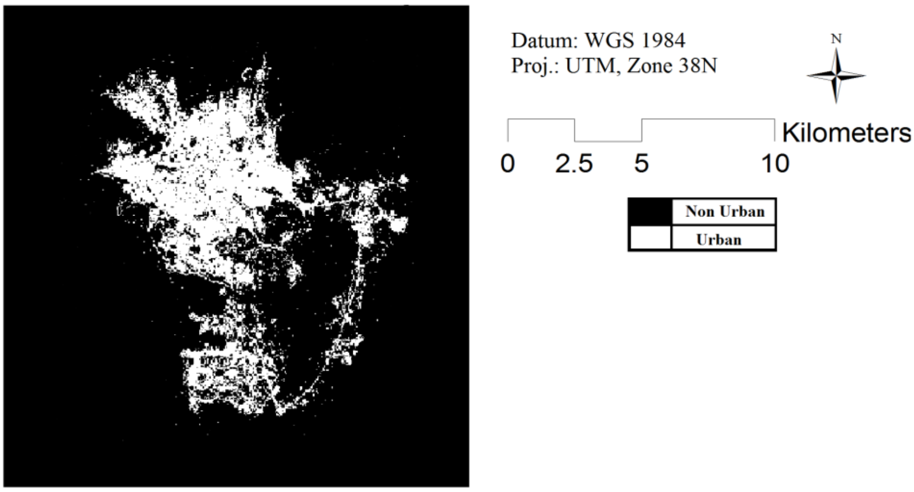

Figure 6. *The simulation result using proposed properties.*

4 Conclusions

According to Figures 2 and 3, urban growth in this city during 2000 to 2006 occurred inclemently in the southern area of the city. Although in other regions of the city urban growth also occurred, in the southern areas the growth was much greater. According to Figure 4, the slope and elevation maps indicate exiting of high elevation area in the west, southwest, north and northeast of the city, which limits the growth of the city in these directions. Integration of GIS, remote sensing data and MAS as a computational method, provide a strong method in environmental modelling such as urban growth modelling. MAS as a rule-based method is a powerful method in environmental modelling such as modelling urban growth. In this paper, we implemented a MAS structure for modelling urban growth in Sanandaj city between 2000 and 2006 (Figure 6). According to Figures 3, 4 and 5, the proposed model had the most sensitivity to the size of window. The number of agents was another important factor in modelling urban growth during 2000 to 2006. Figure 6 presents the 2006 map of the city according to the selected properties. This map presents the area of the city in 2006, which could be used for prediction of future. The southern area of the city seems to have faster growth than other areas. Appropriate slope conditions and good road infrastructure could be the reason behind the fast growth. The implementation of RS and GIS data and tools enables urban planners and managers to monitor, check and predict urban area growth. Also, it gives them an appropriate and reliable source of data and knowledge for location allocation of services and emergency centres according to the needs of the city and the growth rate of the city. Besides, in so many areas of many countries, RS data could be the only source of data for monitoring and checking the urban area. Needless to say, another important benefit of RS data is that in many cases they are free or inexpensive data, which makes them accessible anywhere. Thus, scientific research like this, which uses free to less expensive satellite data and GIS tools, can be acceptable and practicable in many urban areas.

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Miesto augimo modelių parametrų jautrumo analizė

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Žemės panaudojimas yra didelė problema ir iššūkis miestų ir šalies planuotojams. Miesto augimo modeliavimas ir valdymas yra kompleksinė problema. Didmiesčiai šiuo metu yra pripažinti kaip sudėtingos, nelinijinės ir dinaminės procesų sistemos. Sistemos, kuri pajėgtų susitvarkyti su šiais iššūkiais, sukūrimas yra sudėtingas uždavinys. Vietos valdžios, įgyvendinančios miesto augimo modelius, turi įvertinti miesto žemės kiekį, reikalingą ateičiai, įvertinant gyvenamųjų namų, verslo, poilsio ir kitus miesto poreikius nustatytose ribose. Yra labai daug neigiamų pavyzdžių, susijusių su netinkamu miesto vystymusi, kaip padidėjęs transportas ir mobilumo poreikis, sumažėjęs patrauklus kraštovaizdis, žemės naudojimo fragmentacija, biologinės įvairovės nykimas ir hidrologinio ciklo pokyčiai. Šio tyrimo tikslas buvo panaudoti agentu pagrįstą modelį kaip galingą įrankį imituojant miesto plėtros tendencijas. Šio tyrimo vieta yra Sanandai miestas, įsikūręs Irano vakaruose. Buvo panaudoti 2000 m. ir 2006 m. vaizdai, gauti iš palydovo „Landsat“. Duomenų rinkinį sudarė atstumas iki pagrindinių kelių, atstumas iki gyvenamųjų vietų, paviršiaus pakilimas (aukštis), nuolydis, atstumas iki žaliųjų zonų bei regioninių centrų, žemės kaina ir atstumas iki sprūdžio. Šiame tyrime buvo pateikta ir įvertinta tinkama miesto augimo modeliavimo metodologija, kuri remiasi iš palydovų nuotoliniu būdu gauta informacija. Teisingas procentinis sutapimas (*angl.* Percent Correct Match, PCM), Merit ir Kappa statistikos skaičius buvo panaudoti siekiant įvertinti imitavimo rezultatus.

Raktiniai žodžiai: *agentu pagrįstas, miesto plėtra, modeliavimas, jautrumo analizė.*