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Assessing Urban Land-Use Expansion in Regional Scale by Developing a Multi-Agent System

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Abstract

Expansion of urban area is a well-known phenomenon in developing countries with population growth and the migration from villages to cities being two major factors. Those factors reduce the influence of efforts to limit the cities boundaries. Thus, spatial planners always look for the models that simulate the expansion of urban land-uses, and enable them to prevent unbalanced expansions of cities, and guide the developments to the desired areas. Several models have been developed and evaluated for simulating urban land-use expansions. Although these models are numerous, most of them have focused to simulate urban land-use expansions in sub-urban areas. The regional models that cover wider area are equally important.

In this study, a new agent-based model has been developed and implemented to simulate urban land-use expansion in Qazvin and Alborz regions of Qazvin province, which cover 1620 square kilometres. In this model, land-use developers have been treated as computer agents that move in the landscape explicitly, and assess the state of parcels for development. The environment of the model is raster. The agents are categorized based on two scenarios. In the first scenario, all agents are of similar category and in the second scenario the agents are divided into five categories with different objectives. Then, the results of the two scenarios are compared. Due to the spatial essence of the problem, Geographical Information Systems (GIS) were used to prepare the environment of agents' movement and search, and to aggregate and analyze the results.

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To evaluate the model, data of year 2005 were used as the input and data of year 2010 were used for checking the results. By calibrating the parameters, the most desired configuration of the model was found in the second scenario, since the results were close to the reality as the Kappa index raised up to 78.17 percent. These results showed that the precision of the model to simulate land-use developments are of considerable quality. Thus, the model is able to detect the area that faced rapid urban expansions. Moreover, a comparison between the results of the two scenarios revealed that dividing the agents into categories with different aims and parameters will improve the outcome of the model. However, it is vitally important to determine the number of the agents in each category as well as their parameters precisely.

Keywords: Land-use Development, GIS, Agent-Based Modeling, Qazvin, Kappa Index.

1. Introduction

This paper presents the concepts and specifications of a newly developed agent-based model (ABM) for simulating urban land-use sprawl in Geographical Information Systems (GIS) environment. Using GIS is an appropriate way for representing model input and output of a geospatial nature (Vahidnia et al., 2009). Currently, there are an increasing number of efforts to explore the potential of agent-based system tools for modelling human decisions and subsequent changes in land-use/cover. Assessment of Land-Use/Cover Change (LUCC) is one of the most profound human-induced alterations of the earth's system (Vitousek et al., 1997; Le et al., 2008). LUCC is a complex process caused by the interaction between natural and social systems at different spatial scales (Rindfuss et al., 2004; Valbuena et al., 2008).

The LUCC models, which have been developed to explain and simulate land-use dynamics and, further on, to serve as planning tools are based on various objectives, paradigms and methodologies. There is no simple, uniform way to analyze and explain the dynamics of land-use changes. Traditionally, two approaches have been proposed to characterize LUCC: (1) a bottom-up, anthropological, process-oriented approach based on household surveys and resource base inventory, and (2) a top-down, land evaluation, pattern oriented approach based on remote sensing and census data (Geoghegan et al., 1998). Despite their differences, they have some features in common: they are usually interdisciplinary, problem-oriented and empiric-inductive (Castella and Verburg, 2007). Their common constraint for scenario development and exploration of future land-use is that they are not dynamic. In contrast, in the local, anthropologic approach, another group of models has been recently emerged and gained popularity among land change modelers. These models use the real actors of land-use change (individual or institutions) as objects of analysis and of simulations, and pay explicit attention to interactions between these ‘agents’ of changes. Therefore, they are commonly referred to as agent-based models (Castella and Verburg, 2007).

A number of definitions describe the concept of agent. In this research we adopt the definition of Maes (1994): “*An agent is a system that tries to fulfill a set of goals in a complex, dynamic environment. An agent is situated in the environment: it can sense the environment through its sensors and act upon the environment using its actuators*”. Agents can represent individuals, groups of individuals and if appropriate, inanimate objects such as houses or cars (Malleson et al., 2010). In principle, ABM is a bottom-up dynamic structure (Ligmann-Zielinska and Jankowski, 2010). Agent-based models usually deal with systems that are complex, open-ended, hence, emergent and thus exhibit novelty and surprise (Crooks et al., 2008). The main concept of ABM is capturing the observed behavior of a system by agents that represent the main drivers of changes in the state of the system. All agents are structurally deal with an environment and with each other by a set of rules. Each agent behaves autonomously (Brown et al, 2005, Ligtenberg et al., 2010).

In this research, we developed and implemented an agent-based model equipped with new methods for searching landscapes, for selecting parcels to develop and for allowing competitions among agents. Modeling land-use development is inherently important for future planning. It can also be performed as a sub-model for exploring other aspects of human behaviors in the landscape such as urban segregation (Feitosa et al., 2011). In the following, some studies of agent-based modeling in

LUCC and land-use development are briefly analyzed.

Mountain area of Vietnam as a pilot study area of an international program is a case study for several models of studying LUCC (Castella et al., 2005; Castella et al., 2007; Castella and Verburg, 2007; Le et al., 2008). For instance, Castella et al., (2005) developed SAMBA agent-based model to assess the effects of government politics on LUCC especially agricultural area. In yet another study, Castella and Verburg (2007) combined process-oriented and pattern-oriented models of land-use changes in the same area. In that study, agent-based model was regarded as the bottom-up model and a logistic regression-based model was exercised as the pattern-oriented top-down model. For implementing the actual activities in the agent-based model, the game theory was used. In the study of Le et al., (2008) in the same area, a multi-agent was used in which the agents represent four components, namely: human population, land patches, policy factors and decision making procedures. There were some parameters in the models which were determined empirically. The study framework has been programmed on Netlogo 3.0. These studies approved the capabilities of ABM in assessment of LUCC. Also, they represent that there are many aspects in LUCC that can be modeled with various ABMs. Some other related researches are briefly explained in the followings.

Ligtenberg et al (2001) developed a spatial planning model combining a multi-agent simulation approach with cellular automata to simulate the urban development in mid-east of the Netherlands. They implemented a pilot model using JAVA and Swarm agent modeling toolkit. In that model, two categories of actors were defined: the reconnaissance actors who had the voting power during a planning process and the planning actors who had also the authority to change the spatial organization. The simulation ran for 30 time steps (each time step represents 1 year) and each agent was allowed to develop 300 hectares per year. In that study, two scenarios have been defined and compared, although no validation method had been used.

Loibl and Toetzer (2003) developed and agent-based model for urban sprawl in Vienna, Austria. In that model, agents were people looking for settlements (land-development for several activities like commercial, industrial or residential). Agents were classified into six categories based on their behaviors. The agents started the site selection among municipal districts looking for the best sites within the districts. Finally, the best settlement point was selected within a neighborhood. A user interface was developed in that study which claimed to have basic GIS functionality, cellular automata functionality and agent functionality. The data of year 1969 entered into the model and the state of year 1999 was predicted successfully. Based on 1999 data, the model forecasted the state of 2011.

Pijanowski et al., (2009) established an Artificial Neural Network (ANN) for urban expansion simulation in Tehran, Iran. The results showed 78% of agreement between the predicted results and observed maps based on Kappa coefficient. ANN was trained with the existing samples. They showed their study resembles a pattern prediction methodology and is usually comparable with regression methods.

Rafiee et al., (2009) calibrated SLEUTH (Slope, Land Use, Exclusion, Urban Extent, Transportation, and Hillshade) model for simulating future urban growth in Mashhad, Iran. The calibration was done by the historical data and then a 50 year prediction of urban growth was carried out. However, the calibration was evaluated with the inner parameters of SLEUTH (Rafiee, et al., 2009). SLEUTH is a modified Cellular Automata (CA)-based model for urban growth modeling. The main advantage of ABMs over CA-based model in urban growth simulation is that the ABMs are able to handle the decisions of individuals. Moreover, the software packages for LUCC modeling consider some aspects of LUCC. Thus, they suffer from lack of flexibility.

In this research, the agents are assumed as land-use developers that traverse the landscape seeking for land parcels to develop. Also, two scenarios are defined. In the first scenario all agents are of the same category, and in the second scenario the agents are categorized into five categories with various objectives. The categorization is performed through different weights that the agents assign to the criteria maps. The model is executed with data of year 2005 and the data of year 2010 are used for evaluating the results. In addition, GIS is used for representing model inputs and outputs and analyzing the results (Tian et al., 2011).

2. Proposed Methodology

Our model is presented in details in the following.

A workflow of the stages is represented in Figure 1.

- The second category includes the high income developers seeking for valuable lands that have also admissible attractions.

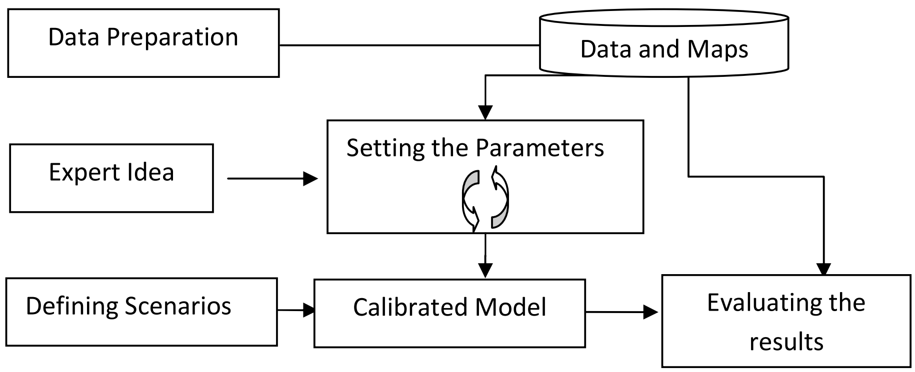


Fig 1. Workflow of Implementation Strategy

2.1 Agent Classes and Their Characteristics

The categorization of agents takes place by considering the characteristics and goals of land-use developers. This categorization is similar to what was performed by Loibl and Toetzer (2003) to some extents, but has been modified to match the conditions of the executing environment in Iran. Thus, the five categories of agents are:

- The first category contains young persons with moderate income who look for rather cheap parcels with good accessibility.
- The third category consists of rich people who need high attractive parcels for recreational residence.
- The forth category includes low income people that search for the cheapest parcels.
- The fifth category contains moderate to high income people who consider three criteria of land-value, accessibility and attractiveness with the same importance.

The framework considers the landscape as a raster space on which agents act for developing the parcels. Besides their category, each agent has a location in a cell of landscape, a limited movement, a minimum required location change (jump) in a district, and a number of districts to search. Furthermore, the weights of criteria maps vary for different agent categories, and every agent also has a degree of Frustration. Each run of the model corresponds to one year and the model is executed for five consecutive years.

2.2 Criteria for Selecting Target Location

Many researchers have taken into account various factors as decision making criteria for agents to select the targets for development (Parker et al, 2003; Matthews et al, 2007). Nevertheless, residential decision criteria such as household stage in a life cycle, the price of property, the demographic structure of neighborhood, or public transport do not count more than 20% to 30% of development choice (Benenson and Torrens, 2004). Consequently, it has been stated that traditional micro-simulation modeling, which extensively uses such databases, does not account for the interdependences among the decision factors (Benenson and Torrens 2004; Waddell 2001). Thus, three criteria maps, namely; attractiveness, accessibility and land-price were used in our research. In this study, the landscape is treated as raster maps and each cell can be developed or not-developed. Therefore, each agent should assess the undeveloped area and decide where to develop.

2.3 Distribution of Agents in the Landscape

First, the agents must be located in the landscape. Undoubtedly, the landscape is not a homogeneous area and different districts can often be detected. Thus, the agents primarily choose a district for search. Districts certainly have different chance of selection by different categories of agents based on their overall characteristics. The decision, which district to be selected, is performed randomly referring to the chosen probability distribution P_i^k for each agent. Where k is the category of the agent and i is the district.

Neighborhoods of initially developed area are disposed for development. So, in each district, the agents first start from the neighborhoods of initially developed area. Each agent moves around and after a limited movement, changes its location to another position in the same district. The agents only traverse the undeveloped cells.

The agents might also change their district and do the same activities in the new one.

2.4 Agent Movement

Wherever the agent starts, it assesses the state of current (standing) cell and also its eight adjacent cells. State means the value of three criteria maps in the given position. Then, the agent moves to its best neighboring cell or if more than one cell achieves the same score, chooses one of them randomly. The agent records the position and the state of all its traversed cells, and their undeveloped neighbors. Traversed cells and their undeveloped neighbors are called visited cells. Finally, when the agents finished their search in the landscape, they have lists of the states and positions of their visited cells. This list can be assumed as the agent's investment list.

2.5 Decision to Develop

Once an agent finishes its search, it should decide which cells to develop. To do this task, the agent sorts its investment list in a descending order. Thus, the most suitable cell lies at the top of the sorted investment list. Then, the agent selects top scoring cell from the top of its sorted investment list and develops it if there is no competitor.

2.6 Competition

It is highly probable that one cell is required by more than one agent for development. Such a cell will certainly be developed. In such conditions, the conflict is dissolved by competition. The issue is to determine the dominant agent. The winner of the competition is determined by the scores that competing agents gain. Score is a unitless value which depends on the category of the agent and the number of times the agent loses a parcel in the previous competitions. The score is calculated with the following formula:

$$\text{Score} = W_{\text{Type}} \times \text{Score}_{\text{Type}} + W_{\text{Frustration}} \times \text{Frustration}$$

where $\text{Score}_{\text{Type}}$ is the score assigned to each category of agent, frustration is a digit that shows how many times an agent has lost a parcel, and W_{Type} and $W_{\text{Frustration}}$ are the weights considered for $\text{Score}_{\text{Type}}$ and frustration, respectively. The value of frustration is equal to zero for all agents at the beginning. However, whenever an agent loses a parcel in a competition, its frustration value increases by one. This increase means that the agent in the next competition will have higher propensity to develop a parcel. W_{Type}, $W_{\text{Frustration}}$ and $\text{Score}_{\text{Type}}$ are determined by the experts via considering pair by pair conditions of the competitions among the agents. Setting the parameters is explained in details in Section 3.2.

3. Study Area

The study area is a part of Qazvin province in Iran with 45 kilometers length and 36 kilometers width (Fig 2). The landscape is composed of 162,000 cells of 100×100 meters. This area contains Qazvin as the central city and five nearby cities. Moreover, the area includes several towns, villages and industrial regions. The study area is an exposure to the rapid urban development. For example the urban population of Qazvin has increased from 552,928 persons in 1996 to 777,975 persons in 2006 (Statistical Centre of Iran, 1996, 2006)). All of the cities and towns around Qazvin have been created or developed in the past 50 years.

3.1. Data Preparation

Various criteria have been used as the effective parameters on land-use development. Nevertheless, Benenson and Torrens (2004) clarify that taking numerous parameters into consideration not only do not improve the results but also make the problem more complicated. Waddell (2001) also indicated that using more criteria maps results in involving dependent data which causes biased results. Three criteria maps (layers), namely land-value, attractiveness and accessibility, are used (Figure 4) in this study. Also, the map of initially developed sections is used (Figure 3). Each of the criteria maps has been produced by a combination of other maps. This means the three criteria maps involve many other sub-criteria (Ligmann-Zielinska and Jankowski, 2010). For land-value map, the primary maps are land-price, disposing of land for development, slope and the quality of soil. For accessibility map, the shortest time of reaching to the central city centre (Qazvin city) from each cell was calculated. For this task, all roads and maximum velocity moving on them and also the velocity of walking outside the roads were taken into consideration. To produce the attractiveness map, in lack of lakes and wetlands, proximity to the parks and forests, the visibility of the central city and the coolness of the weather were considered.

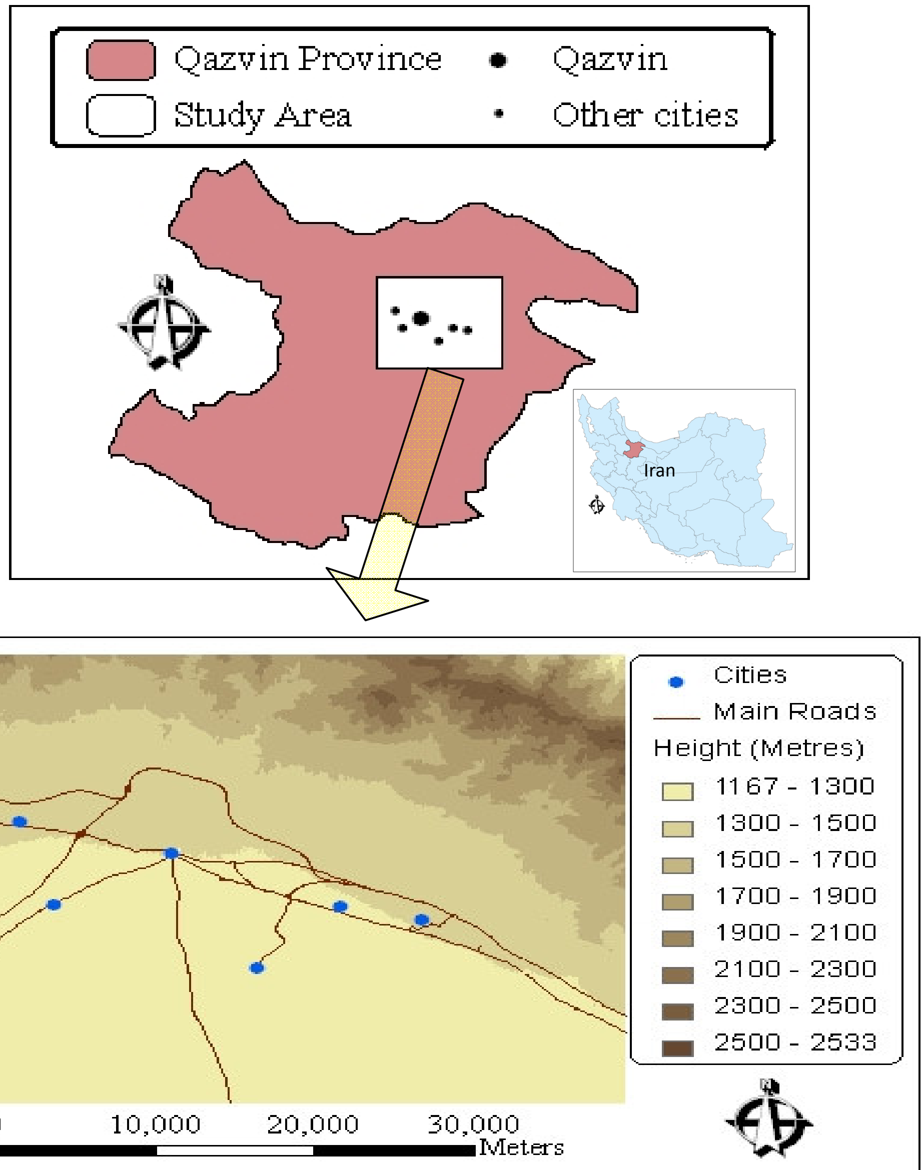


Fig 2. The Study Area

Also, all maps were normalized to have the values between 0 and 1. The other map that is used in this study is the map of districts. To produce this map, first 12 districts were recognized in the landscape. Then, the probability of each district was calculated by dividing the developments of that district (between 2005 and 2010) to the total development of the study area (Table 1).

Table 1. The Probability of Districts

District	1	2	3	4	5	6	7	8	9	10	11	12
Probability (Percent)	38.2	8.5	19.9	10.5	8.1	6.9	1.1	1.5	2.1	1.3	0.7	1.2

By getting the map of land-use/land cover in two years of 2005 and 2010 from National Cartography Center of Iran, the development maps were produced. In development maps there are four classes, namely: undeveloped, developed, un-developable and industrial or not absorbable for urban development.

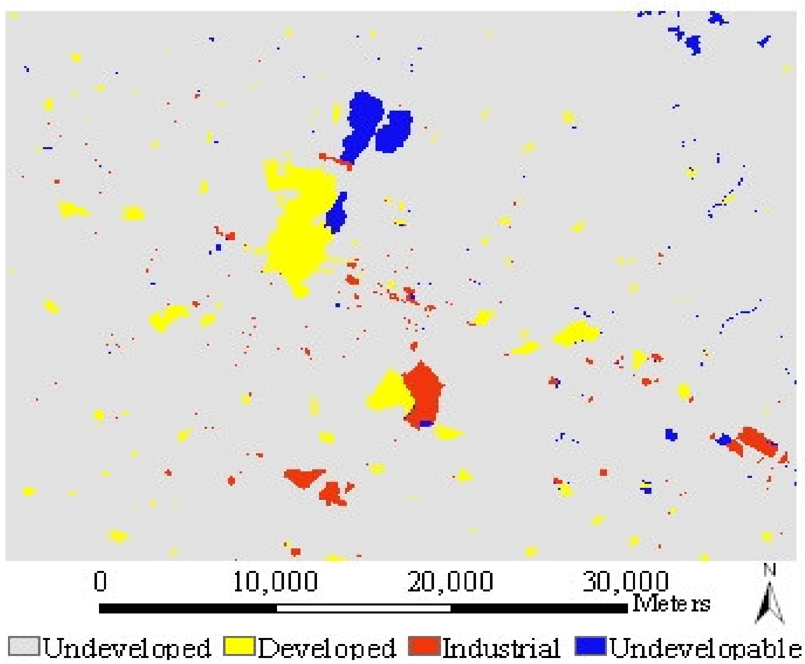


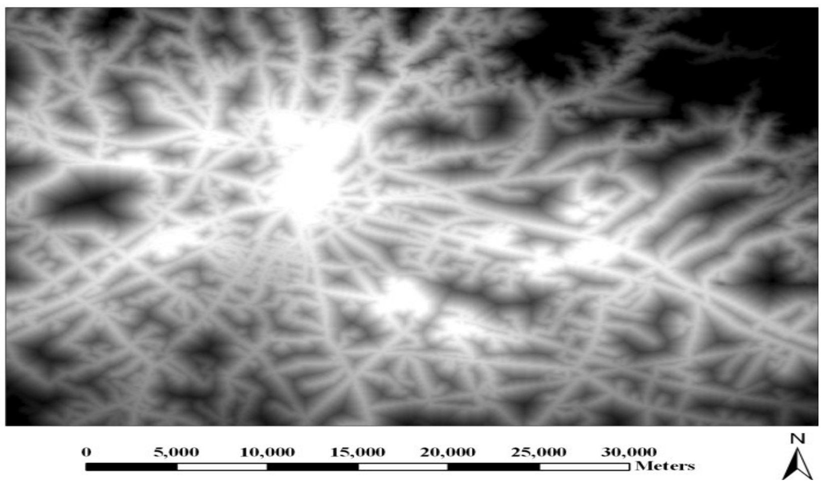
Fig 3. Development Maps: Top: Development 2005, Bottom: Development 2010

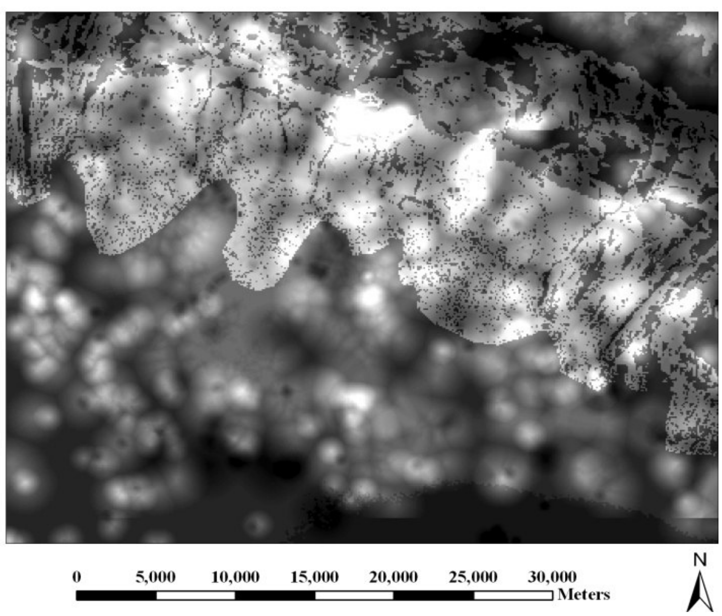
We used AutoCAD 2009 and ArcGIS 9.3 for preparing maps and statistical analyzes. Also, NetLogo 4.1 with its GIS extension was used in this research for implementing the proposed agent-based model.

3.2. Setting the Parameters

There are several parameters in the model which have to be set before running the model. These parameters and their values are presented in Table 2. Three approaches were used to set the parameters: using the idea of experts, determining by existing data, and setting by establishing various configurations of the model.

The weights of the districts were specified by experts. The experts were also asked to determine the scores of the agents (Equation 1). To do that, the experts considered all of the dual conditions of competition among various categories of agents. Consequently, W_{Type} and $W_{Frustration}$ were determined 9 and 10 respectively.





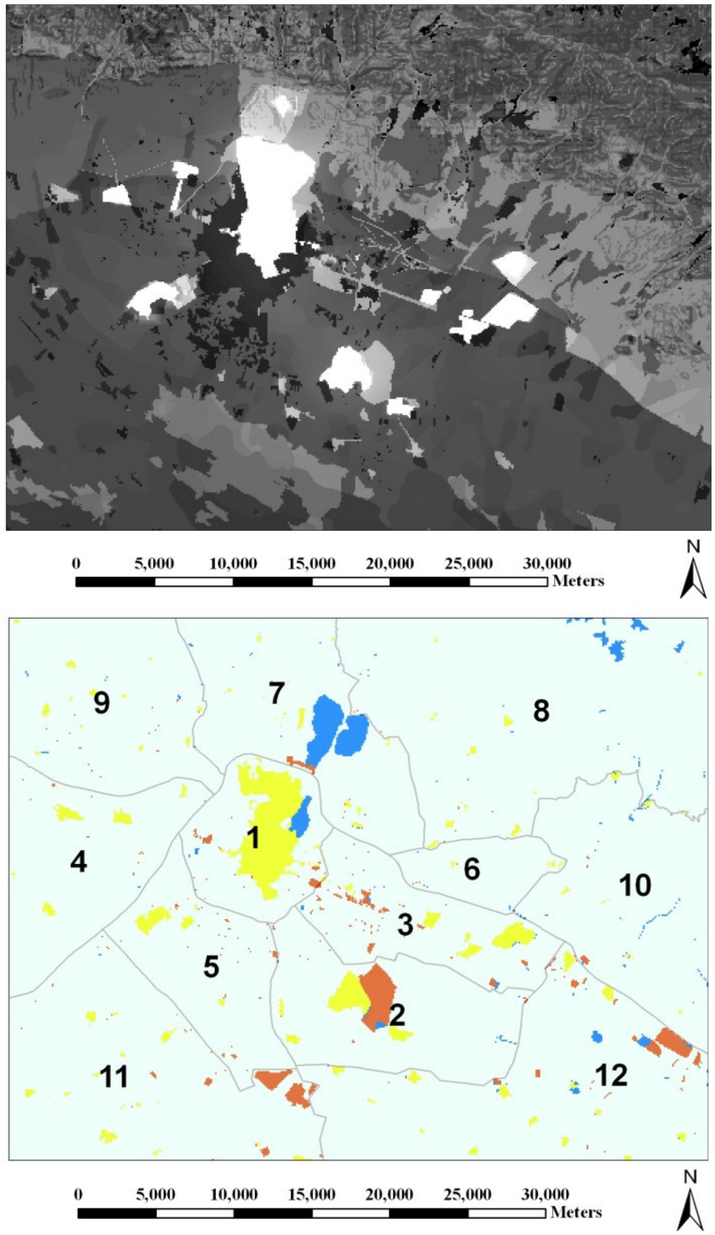


Fig 4. Maps of A: Accessibility, B: Attractiveness, C: Land-Value and D: Districts. (Brighter Color in A, B and C Means Higher Corresponding Criteria)

In this study, each agent develops a cell per year. Then, the number of agents in each category must be determined. For this task, 1200 ha developed area between 2005 and

2010 were analyzed. Then, based on land-value, accessibility and attractiveness of development, 110 ha were verified as developments of category 1, 90 ha for category 2, 10 ha for category 3, 20 ha for category 4 and 10 ha for category 5 in each year. To determine the remaining parameters, category 5 was set as a reference. So, we supposed that agents search 50%, 70%, 80% or 90% of districts and this search would be one district more for other categories. Furthermore, the number of cells that each agent traverses per year; examined to be 10 or 15 times of the number of cells each agent develops per year. This amount would be a little more for other categories (Table 2). Finally, the number of jumps assumed to be equal to the parcels that each agent develops per year. This parameter is one more for the other categories except category 5. Totally, all of the configurations of the model using aforementioned parameters were run 10 times. To compare the results, Kappa coefficient was used (Tian et al, 2011). The observation showed that when we consider the number of cells each agent traverses per year 15 times of the number of cells each agent develops per year, the values of Kappa are greater. Also, the highest kappa is realized when the agents search 70 percent of districts. In consequence, the parameters listed in Table 2 were set for the model.

Table 2. The Parameters of the Model

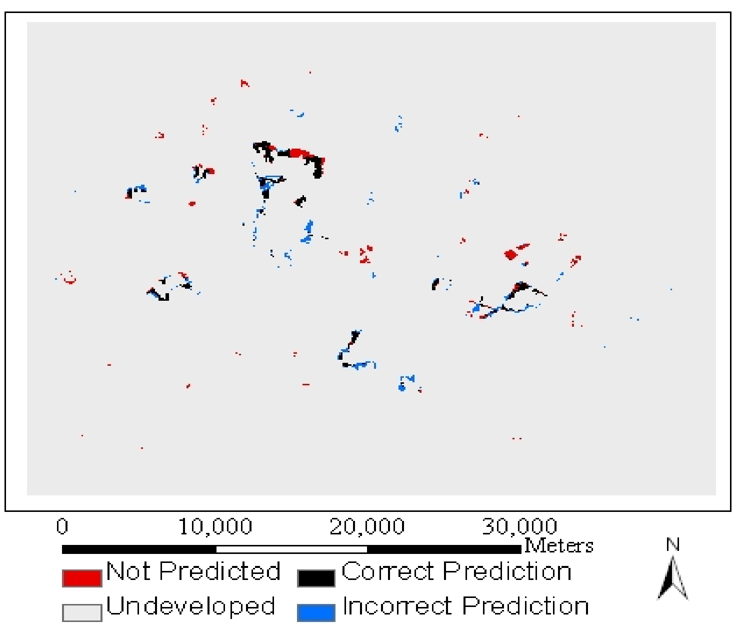
Categories of Agent	1	2	3	4	5
Count	110	90	10	20	10
Parcels to develop each year	1	1	1	1	1
Weight of Accessibility	3	1	1	2	1
Weight of Attractiveness	1	2	2	1	1
Weight of Land-Value	2	3	1	1	1
Number of searching districts	9	9	9	9	8
Number of traverse parcels	17	16	16	18	15
Number of jumps in each district	2	2	2	2	1
$Score_{Type}$	2	5	5	1	3

4. Defining the Scenarios

The hypothesis of the study is that defining the various categories for the agents significantly increases the quality of the results. So, by defining the various categories for the agents the model would be a better simulator of residential development. To test this hypothesis two scenarios were considered. In the first scenario, all agents are of the same category and in the second scenario the agents are categorized into the five aforementioned categories. Since in the first scenario we do not consider the specifics of the land-use developers, the agents would have a moderate behavior. Thus, in the first scenario the weights of all criteria maps would be the same.

5. Results and Discussions

The results of the model in two scenarios are shown in Figure 5. The results are classified into four categories. Correctly predicted developments are desired area where the results of the model match the observed developments. Undeveloped cells are also regarded as the correct responses because the model has not considered any development there. However, the incorrect results are the cells that have been predicted to be developed but have not been developed in the reality, and the cells that have been developed in the reality but those developments have not been predicted by the model.



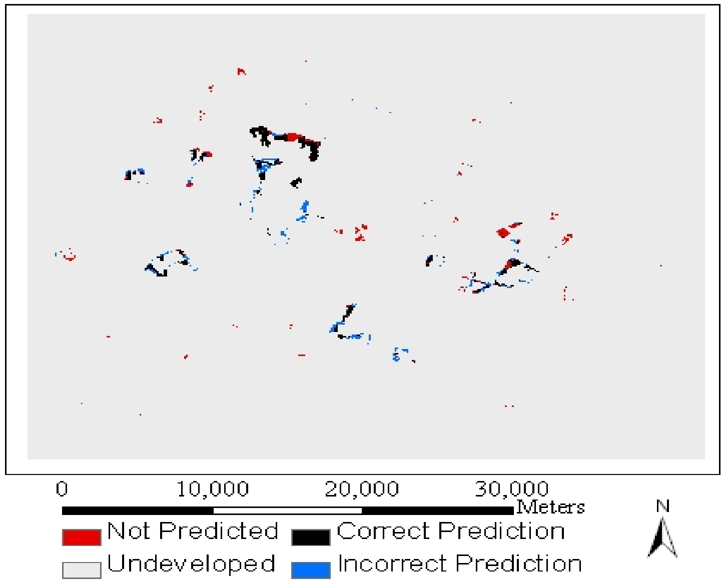


Fig 5. Simulation Results: Top: Scenario 1 and Bottom: Scenario 2

The quantitative results are illustrated by two indices, namely: the Kappa coefficient and the Number of Correctly Predicted Developed Cells (NCPDC). Kappa is a popular index that shows how much a classification matches the other basic one (Pijanowski et al, 2005, Tian et al, 2011). Kappa is calculated based on the predicted and observed values over the entire area by the following formula (Pijanowski et al, 2005, Tian et al, 2011):

$$\text{Kappa} = \frac{P_0 - P_C}{1 - P_C} \quad (2)$$

where P_0 is the percent correct for the model output, and P_C is the expected percent correct due merely to chance. The quantitative results of the model are illustrated in Table 3.

Table 3. Values of Kappa and NCPDC

	Kappa (Percent)	NCPDC
Scenario 1	73.36%	716
Scenario 2	78.17%	762

It needs to be mentioned that because of the stochastic nature of the model, the results of the model varies a little in each run of the model. So, the model was run 10 times in each scenario. Because the variations were too low (less than 0.8%) the values in Table 3 are corresponding to the maps of Figure 5.

Based on the researches of Sousa et al., (2002), Pontius (2002) and Pijanowski (2005) in evaluating urban growth, if the value of Kappa is lower than 40%, the model is absolutely weak. If it lies between 40% and 60%, the model is moderately weak. The values between 60% and 80% represent a good agreement between the predicted and observed maps. Finally, the values higher than 80% mean that the model is excellent.

Therefore, overall result of the model is satisfactory. In both scenarios, the model is almost successful in predicting the developments. The results of the second Scenario are near to touch the borders of excellence. Nevertheless, the developments located far from the cities and in the towns are less predicted. This means that the factors of development around the cities are more influential than the ones around the towns and villages. A look at the criteria maps (Figure 4) shows that accessibility and land-value in the suburbs of the cities are much better than accessibility and land-value near the towns and the villages. So, it is logical to assume that the agents prefer suburbs of the cities for development. It seems that other reasons may cause the developments observed far from the cities. For instance, rumors, birthplaces of the developers and some other unknown factors which make land-use change a complex system.

Table 3 obviously shows that Scenario 2 is a better case than Scenario 1. Therefore, categorizing the developer agents into five classes significantly increase the quality of prediction. However, a dipper exploration of the results is necessary. In Scenario 1 the importance of all criteria maps are the same. Thus, anywhere that sum of the values of three criteria maps is greater, is a suitable position for investment of the agents. Because the accessibility and land-value are almost higher around the cities, it is only the attractiveness that may scatter the agents from the suburbs of the cities. So, it causes scattered developments far from the cities where those developments are mostly incorrect. On the other hand, in Scenario 2 most of the agents are in categories 1 and 2. Agents of categories 1 and 2 assign greater importance to the accessibility and land-value. Consequently, most of the agents are absorbed to the suburbs of the cities where the accessibility and land-value are high. Only the agents of category 4 prefer more attractiveness and therefore may be located far form the suburbia and exurbia. Some developments of agents of category 4 may locate exactly in the observed developed area and some developments may not.

One another strong point of the results is related to the industrial area. Industrial cells have grown during the simulation time. However, the residential developments predicted by the model in both scenarios have not been converted to the industrial land-use. So, even incorrect predictions do not seem to be unreasonable.

Altogether, the construction of the proposed agent-based model and three considered criteria maps led us to an appropriate simulation of urban land-used development in a regional scale. However, categorizing the developers and considering special behaviors for them increased the quality of the results. Alongside the ABM, GIS analysis and spatial relations empowered us to model the behaviors of land-use developers and to produce necessary maps which were used to run the ABM and evaluate the results. Extracting the criteria that causes the developments in the towns and villages may increase the quality of simulation.

6. Conclusion and Recommendations

Simulating the urban land-use expansion helps urban planners for better decisions. This paper demonstrated a new agent-based model to simulate urban land-use expansion in Qazvin and Alborz regions of Qazvin province with 1620 squared kilometers area. In this model, agents represented mobile land-use developers which assessed the state of parcels for development. The agents were considered in two scenarios. In the first scenario, all agents were of the same category and in another scenario the agents were divided into five categories which have different aims. GIS were also used to prepare the environment of agents' search and to aggregate and analyze the results.

To evaluate the results of the model, data of year 2005 were used as the input and data of year 2010 were used for checking the results. By calibrating the parameters, the most desired configuration of the model was found in the second scenario, and the results were closer to the observed development as the Kappa index raised up to 78.17 percent. Thus, the model is successful in simulating the patterns of land-use development. Moreover, comparison between the results of two scenarios revealed that categorizing the agents improves the results.

Heterogeneity and contiguity of space make spatial models of the residential development intractable. While the application of simulation to study the urban growth and land-use development is burgeoning, developing a comprehensive and empirically based framework for linking the social geographic disciplines across space and time remains for further research. Also, further research is needed to detect and model more details in the process of land-use development.

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بررسی گسترش کاربری اراضی شهری در مقیاس منطقه‌ای با توسعۀ یک مدل چندعامله

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گسترش شهرها، پدیده‌ای آشنا در کشورهای در حال توسعه است. مهاجرت و رشد جمعیت موجب کاهش اثربخشی تلاشهایی شده است که سعی در محدود نگه داشتن کران شهرها داشته‌اند. بنابراین، برنامه‌ریزان شهری همواره به دنبال راهکارهایی بوده‌اند که با مدلسازی توسعه، آنان را قادر سازد تا از توسعه‌های نامطلوب شهری جلوگیری نماید. از آنجا که تا کنون بیشتر مدلهای ارائه شده بر شبیه‌سازی گسترش کاربری اراضی شهری در اطراف شهرها متمرکز بوده‌اند، مدلهایی که در یک مقیاس منطقه‌ای عمل نمایند اهمیت زیادتری می یابند.

در این تحقیق، مدلی عامل-بنیان برای شبیه‌سازی گسترش کاربری اراضی شهری در منطقه‌ای از استان قزوین با مساحت ۱۶۲۰ کیلومتر مربع، طراحی و پیاده‌سازی شده است. در این مدل، توسعه‌دهندگان زمین به عنوان عاملهایی در نظر گرفته شده‌اند که در سطح منطقه حرکت کرده، شرایط زمینها را برای توسعه می‌سنجند. دو سناریو در این پژوهش بررسی می‌شود. در سناریوی نخست تمام عاملها مشابه هستند و در سناریوی دوم عاملها به پنج دسته با خصوصیات متفاوت تقسیم می‌شوند. همچنین با توجه به ماهیت مکانی مسأله، از GIS به منظور آماده کردن محیط عمل عاملها و نیز برای جمع‌بندی و تحلیل نتایج استفاده شده است.

جهت ارزیابی مدل، داده‌های سال ۲۰۰۵ به مدل وارد و از داده‌های سال ۲۰۱۰ برای مقایسۀ نتایج استفاده گشت. پس از تنظیم و کالیبره نمودن مدل، بهترین پاسخ مدل در سناریوی دوم به دست آمد که حاکی از تطابق ۷۸/۱۸ درصدی پاسخهای مدل با شرایط واقعی بر حسب شاخص کاپا بود. این نتایج نشانگر توانایی مدل در شناسایی مناطقی است که دچار توسعۀ سریع شهری می‌شوند. همچنین مشخص شد که تقسیم‌بندی عاملها در دسته‌های مختلف سبب بهبود نتایج شبیه‌سازی می‌گردد.

واژگان کلیدی: توسعۀ کاربری اراضی، GIS، مدلسازی عامل بنیان، قزوین، شاخص کاپا.

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۱. دانشجوی سیستم اطلاعات مکانی داشگاه صنعتی خواجه نصیرالدین طوسی

۲. دانشیار سیستم اطلاعات مکانی دانشگاه صنعتی خواجه نصیرالدین طوسی