The Study of Land Use Changes in the Tehran Metropolitan Area by Using MOLAND Model

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1. Introduction

Increasingly, in urban areas land is too scarce a commodity to allow it to be taken up in unplanned growth. However, any action – or lack of it – to influence land use has significant consequences both for people, businesses, and organizations in the area, and, more generally, for the urban morphology itself. According to the FAO's definition of land use planning, estimating the socio-economic conditions of human society and the land potential for development, is necessary to select the best land-use options. So "Planning involves anticipation of the need for change as well as reactions to it" (FAO, 1993). Forecasting the effectiveness as well as the indirect consequences of policies are two main focal points of planning studies. Modeling urban land use changes is helpful to understanding urban dynamics and can be used as an important tool for planners, capable of producing insights about the possible consequences of decisions made by them. Land use modeling can provide a dynamic information base that can inform the policy process at the local, national, and transnational levels. Urban planning and urban models have to be discussed jointly. Couclelis has argued that connecting these two spheres could "amplify the positive synergies between the two domains and enhance the ability of spatial planning to prepare for the future" (Couclelis 2005: 1353).

Land use transformation models can therefore generate data of meaningful representations of the region's characteristics and allow the processing of different data sets. The models contribute to understand the landscape changes and drivers of the dynamics in the development conditions of each study area. It is also helpful to answer where and at which intensity land-take for urbanization occurs and how spatial growth patterns alter over time; how urbanization (e.g. sprawl) affects large areas overruling local and regional decision.

Land use change models are tools that can support the analysis of the causes and consequences of land use dynamics. Scenario analysis with land use models can support land use planning and policy. Numerous land use models with various technical bases are available. Markov Chain model (e.g. López, 2001), Spatial logistic regression, economical models (e.g. Irwin, 2001), statistical models (e.g. Veldkamp, 2001), optimization techniques (e.g. Pijanowski, 2002), rule based models (e.g. Klosterman, 2005), CA based models such as CLUE (e.g. Verburg, 1999) and SLEUTH (e.g. Clarke and Hoppen, 1997) multi agent models (e.g. Torrens, 2006), developed from different disciplinary backgrounds.

The MOLAND model is a constrained cellular automata (Constrained CA) model that can be used to simulate future urban development. The basic idea of MOLAND model is to simulate the land use scenario demands based on socio-economic data at first, and then allocate the land use scenario patterns at the local scale with the considerations of land use suitability, zoning, accessibility and neighborhood effect by using cellular automata (CA) model to satisfy the balance between land use scenario demands and supply.

Tehran Metropolitan Area include Tehran city and its surrounding urbanized areas, covers an area about 12000 km^2 and approximately has a population of 14 million that about 7.8 million of this population lives in Tehran, experienced a rapid growth in population and an enormous spatial development. In this research, future urban growth scenarios created, based on data and storylines for the Tehran metropolitan area, Iran and the scenarios are carried out using the MOLAND model.

2. Tehran Metropolitan Area Land Use Changes

In this study, Tehran metropolitan area was picked as an ideal case for this research, whereas it had a lot of changes within last decades. Tehran is the capital and the largest city of Iran and the Middle East and also the administrative center of Tehran province with more than 13 million inhabitants (Fardi, 2010). The center of study area is located at latitude and longitude of 35.6962°N, 51.423°E.

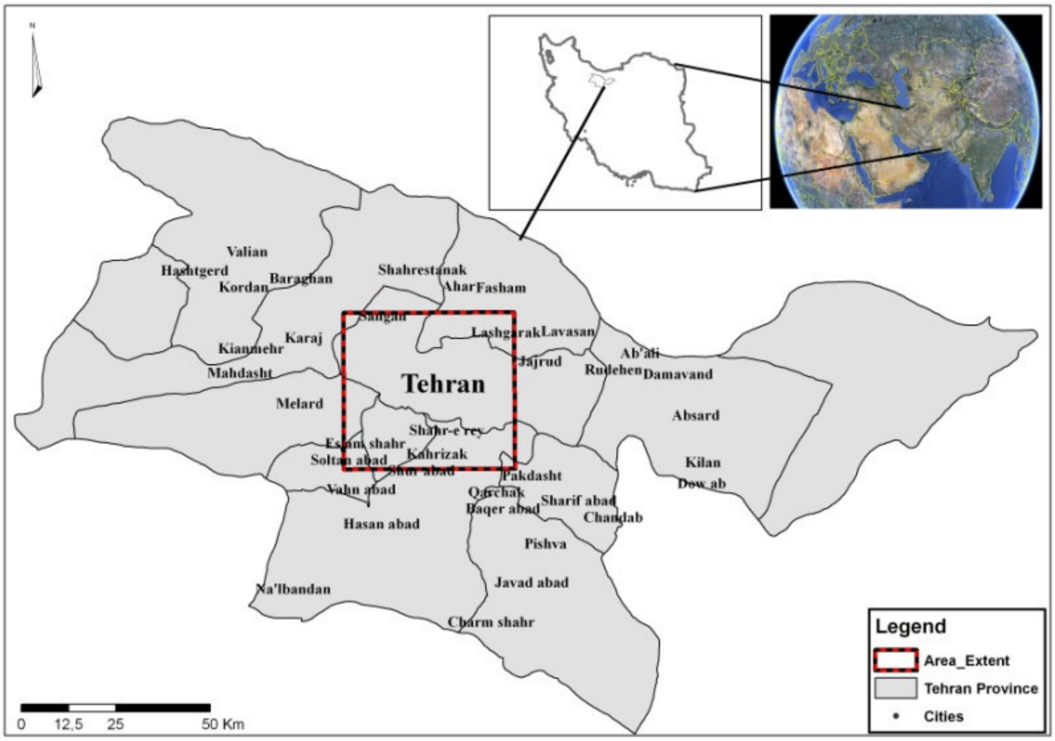
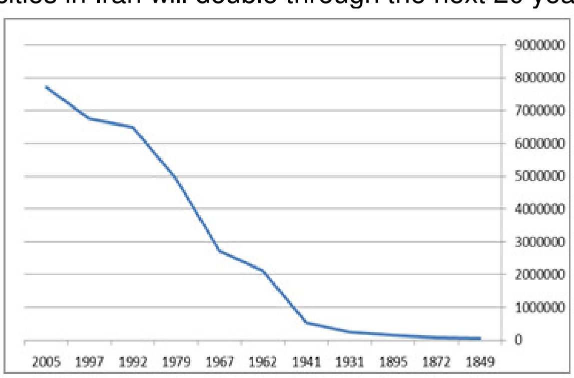


Figure 1: Location of Tehran Metropolitan Area, Tehran Province, Iran

During the early years after the Islamic revolution of Iran (1979) and occurrence of the imposed war against Iran (1989-1981), extensive migrations started all over the country. Many farmers came to cities progressively because of economic stagnation in villages resulted from land reform and waning of seasonal economy. In addition to farmers' migrations, there were widespread migrations from towns to large cities, mainly to the center of provinces. During this period and even to present, Tehran is the first destination of all migrants. Configuration of the city's population was changed by these migrations which led to fast growth of urbanization in the Tehran and its neighbor cities. From 1980 to 2000, resident population in Tehran nearly doubled and the city extended itd edges. According to these conditions and upon evaluating the trends, demographers predicted that the population of cities in Iran will double through the next 20 years.



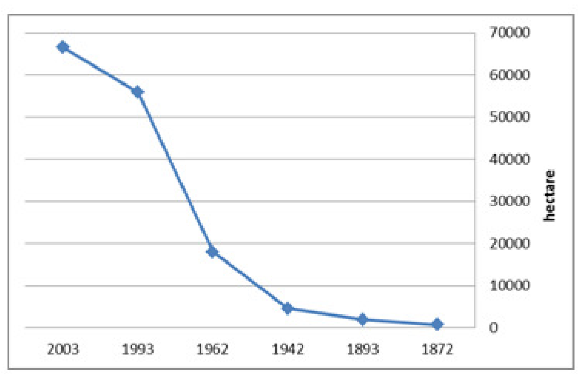


Figure 2: a) Growth of the City Population b) Growth of the City Area
(Source: Tehran Master Plan, 2006)

The fast physical and demographical expansion of Tehran in the recent decades has had many unpleasant impacts on the environment. This rapid urbanization caused by population growth, transforms agricultural lands and natural bodies to industrial sites and urban built up areas. To meet the aim of sustainable development, it is very necessary to protect the land resources during the process of urbanization and planners need to know the specific land demands under different scenarios and their spatio-temporal dynamics.

3. Methodology

The spatial decision support system used here, the MOLAND model, was developed as part of an initiative of the Joint Research Centre1 (JRC) of the European Commission as a response to the challenge of providing a means for assessing and analyzing urban and regional development trends across European member states (Engelen et al. 2007). It was intended to be a generic tool that could be used in a wide variety of contexts, both geographic and institutional, to enhance the spatial planning process. It has been applied, for example, in the Friuli-Venezia Giulia region of Italy to explore possible future flood losses consequent on urban expansion in the region (Petrov et al., 2005) and in Lagos, Nigeria to explore the future growth of the city
(Barredo et al. 2004, Williams 2012).
The aim of MOLAND is to provide a spatial planning tool that can be used for assessing, monitoring and modeling the development of urban and regional environments. The MOLAND model comprises two sub-models working at different scales: a spatial interaction-based model of activity location and migration (the macro model), and a CA-based land use model (the micro-model) with which the macro model is linked dynamically, so that the two components run as a single model (Williams, 2012: 230).
In standard CA the fundamental idea is that the state of a cell at any time depends on the states of the cells within its neighborhood based on the predefined transition rules. The attractiveness of CA to model real-world phenomena is manifold, and is highly connected to their characteristics. They are simple, although not simplistic, and highly adoptable and intuitive in their making. They can produce highly complex and realistic dynamics with properties such as phase transition and bifurcation in continuous dynamic systems. In the last years cellular automata (CA) have gained popularity as modeling tools for urban process simulation. Several approaches have been proposed for modifying standard CA in order to make it suitable for urban simulation. The results of the previous applications are promising and have shown realistic results in several cities in different parts of the world.
A spatial dynamics model, that has been developed as part of MOLAND, takes as input the land use and transport databases for the study areas, as well as the socio-economic data, and simulates the future land use development under alternative urban and regional planning and policy scenarios. The model takes as input five types of digital maps, for the geographical area of interest: (a) actual land use types present in the area; (b) inherent suitability of the area for different land uses; (c) zoning status (i.e. legal constraints) of the area for different land uses; (d) accessibility of the area to the transport network; (e) socio-economic characteristics (e.g. population, income, production, employment) of the area (Lavalle 2002: 9). Then, at the regional scale the model calculates land use demands for each land use type by using socio-economic data. At the local scale, model calculates a a vector transition potential for each land use type in each cell and then allocate land uses to cells with highest potential (Figure 3) according to CA transition rules until the number of cells that have a certain land use, become equal to land use demands. The result is a dynamic land use map, on which the land use pattern changes year by year in a realistic manner as validated by land use maps for past periods as well as the present (Williams 2012: 231).

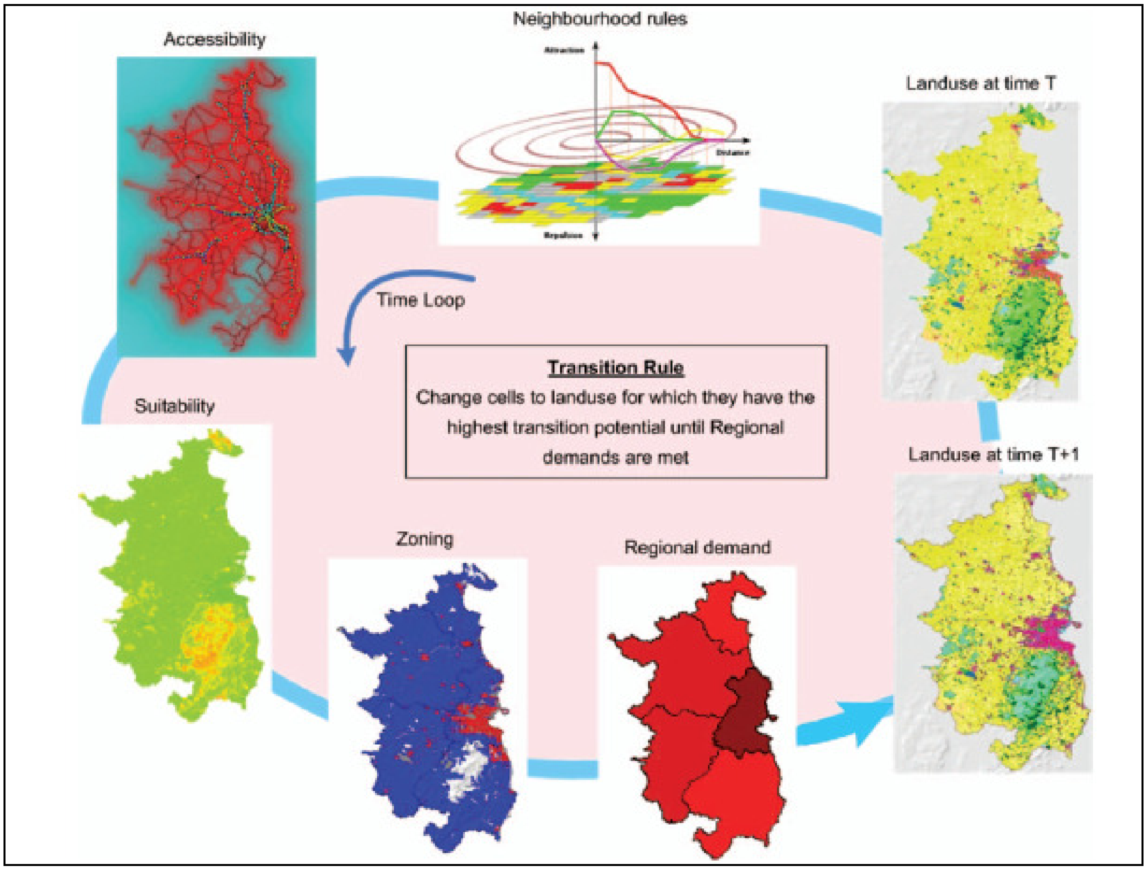


Figure 3: Land Use Transition in MOLAND Model
(Source: RIKS b.v. 195)

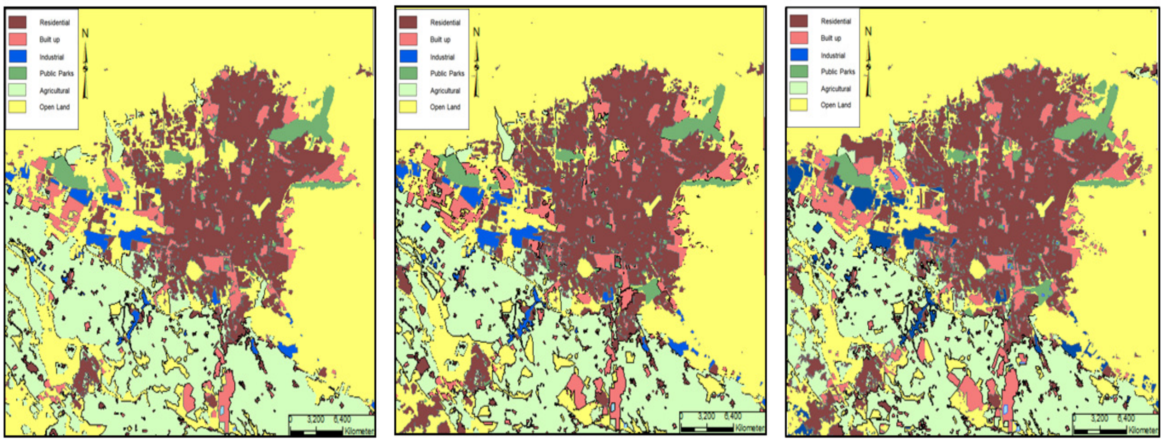
Vector of transition potentials is calculated for each cell from the suitabilities, accessibilities, zoning, and neighborhood space effect, and the deterministic value is then given a stochastic perturbation using a modified extreme value distribution, such that most values are changed very little but a few are changed significantly. The probabilistic function is thus obtained by the equation:

$$Pij = Aij\ Sij\ Zij\ Nij\ v$$

Where
Pij is the transition potential of the cell i for land use j;
Aij is accessibility of the cell i to the transportation network for land use j;
Sij is the intrinsic suitability of the cell i for land use j;
Zij is the zoning status of the cell i for land use j;
Nij is the neighbourhood space effect on the cell i for land use j;
v is a scalable random perturbation term defined as: $v = 1 + [- \ln (rand)] J$, where ($0 < rand < 1$) is an uniform random variable, and J is a parameter that allows the size of the perturbation to be adjusted (Barredo et al. 2002: 3).

4. Modeling Tehran Land Use Change

In this investigation, various sorts of data such as multi-spectral and temporal satellite images, a set of environmental and terrestrial attributes, as well as, socio-economic data were gathered. The satellite images were employed to extract land use maps. Also, the other collected data included demographic data of Tehran metropolitan area extracted through the last accomplished census statistics. Besides, a geodatabase of environmental and urban features such as topography, hydrology, building blocks, transport network, farming land and prepared land use maps was gathered. ESRI Shapefile was chosen as the base file format and all the data were converted to this format. Topographic data after preparation and missing data correction were converted to Digital Elevation Model. A set of topographic characteristics such as slope, aspect, and hillshade was produced. All provided data were converted into raster format at 100 meter resolution and UTM geodetic reference system. A regular set of 10-year step images of 1986, 1996, 2006 was chosen. The accuracy assessment process was done through Kappa index calculation. The accuracy of these maps was significant (i.e. 0.91, 0.88, and 0.90, respectively). These maps were classified into 6 categories such as open land, agricultural land, Industrial area, residential, built-up area and public parks. These maps are the source maps of this research which each map have 189772 cells are shown in figures 4.a, 4.b, and 4.c.



4.a *4.b* *4.c*

Figure 4: Extracted Land Use Maps of a) 1986, b) 1996, c) 2006

Then, suitability maps for each land use produced, by combining different environmental maps (such as soil erosion). By using road and train maps and other transportation maps and using appropriate weighting, accessibility maps for each land use created. Due to the fact that there is no zoning map available for the Tehran metropolitan area, zoning maps were created by using official planning documents about Tehran (such as Tehran master plan 2008, and Tehran metropolitan plan 1999).
During a 20-year period (1986–2006), land uses with the greatest increase constituted residential land, urban built up areal and industrial lands.

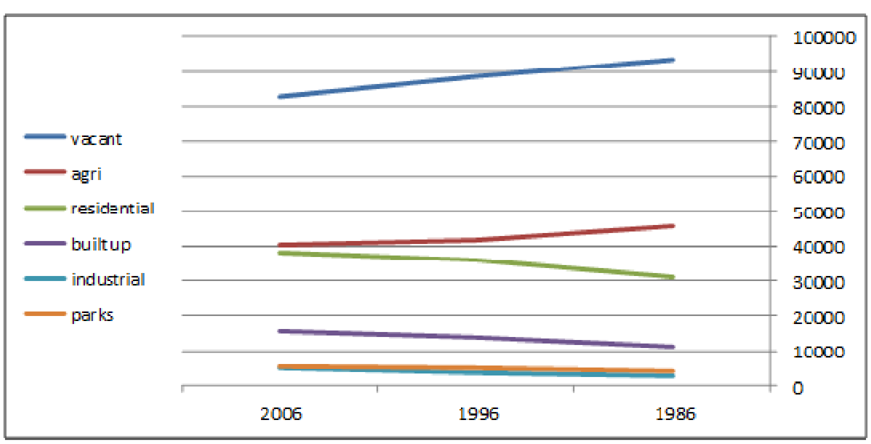


Figure 5: Land use change in the study area

As we can see in this chart, the the number of residential areas and built up land use increased annually and in this period, we have a decrease in vacant and arable land. So, we can say that we have a urbanization process in the study area. With a look at land use maps we can conclude that this process occur in the city edges.
To generate realistic scenarios of how the landscape would appear in the year 2020 “if”, we incorporated our understandings of the existing conditions regarding population, un/employment and economically active population, business activities, labour productivity, urbanized areas and constructions, tourism and services, transportation networks, and communication (Petrov et al.2009: 15). Pattern developments differ between scenarios not only by urbanization strength but also because of different spatial policies (e.g. preserving the seashore, policies aiming at compact urbanization) and suitability. The growth of built-up areas was calculated proportionally with changes in population, GDP and growth in industrial, commercial, and services sectors, by the macroeconomic model.

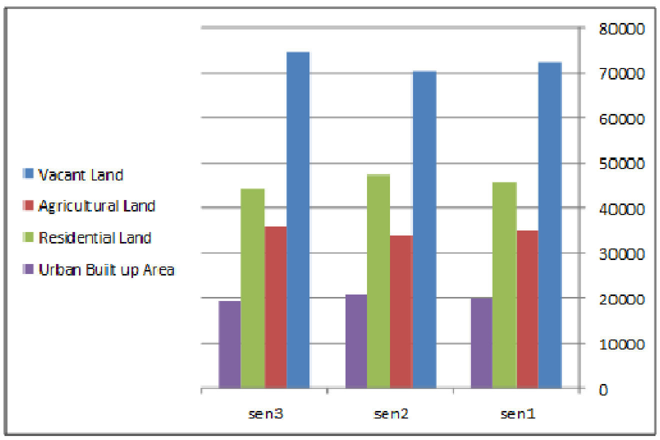
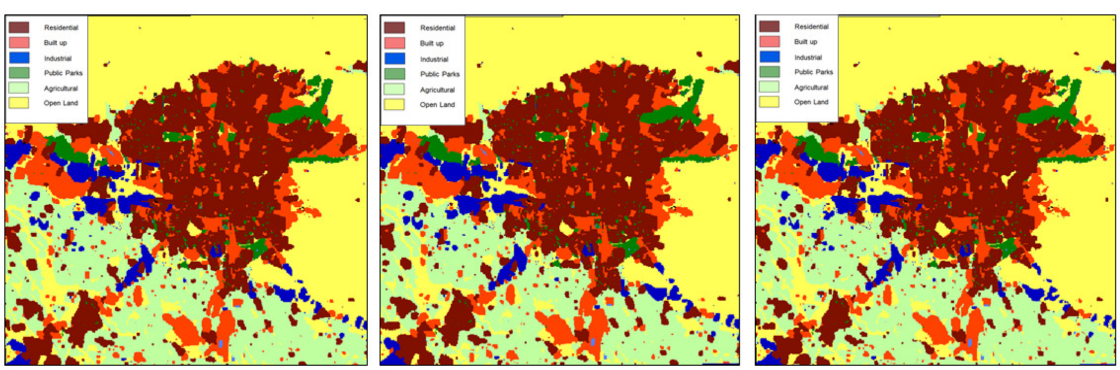


Figure 6: Evolution of urban land use classes for scenario 1, 2, and 3

Three different scenarios have been simulated using different population projections. They represent medium, high and low population growth which we will name Scenarios 1, 2, and 3 hereafter. All scenarios are based on the population forecast for the year 2026. According to this and other socio-economic factors we estimate a land use demand for each scenario, and then model land use changes. Land use maps for each scenario in year 2026 seen in figure 7.



a) Scenario 1 *b) Scenario 2* *c) Scenario 3*

Figure 7: The land use maps of Tehran metropolitan area for year 2026 for scenario 1, 2 and 3

Figure 8 shows the distribution of the residential urban category of 1 vs. 2, 1 vs. 3, and 2 vs. 3 scenarios. Many possible combinations of land use scenarios can be analyzed according to spatial plans and policies needed for understanding future urban development.

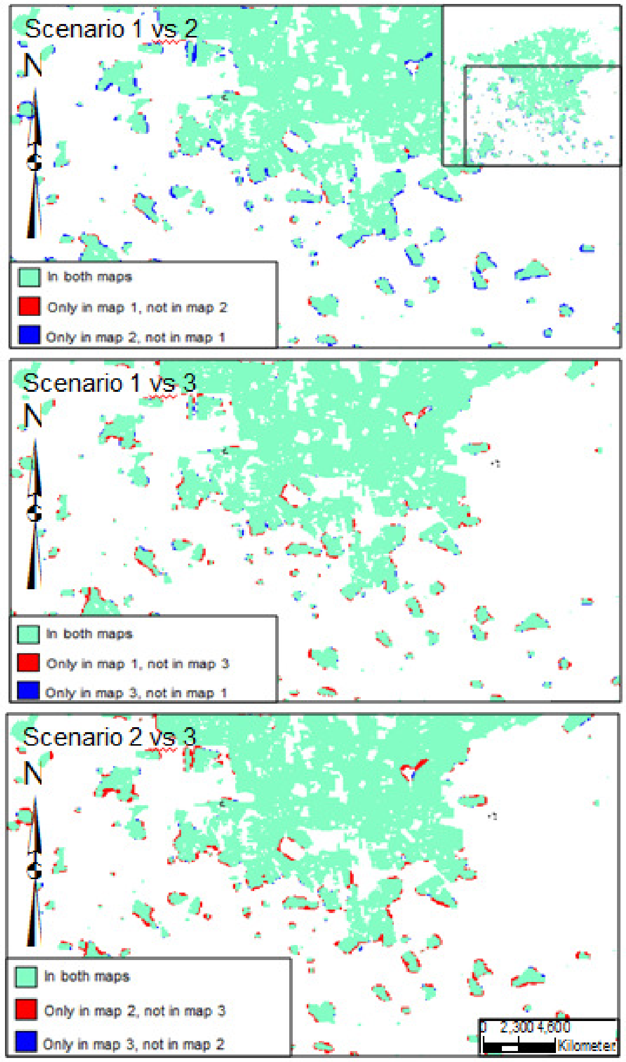


Figure 8: Comparing residential land use in different scenarios

5. Conclusion

Modeling of urban growth and optimizing the future growth allocation have been the objective of urban planning research for many years. To understand the past growth process and project future patterns, this research established an constrained CA based urban land use modeling framework that provides alternative future growth allocations in the Tehran metropolitan area. The model is able to capture most of the elements from qualitative storylines. However, there are elements that cannot be easily translated in the model such as human decision making or climate change.

The expansion of construction and decrease of arable land are still the main changes in local land use. Most of the increasing construction is due to expansion from the existing urban area through occupation of the surrounding arable land, garden plots, forest, and unused land. It occurs mainly at the urban–rural fringe and around major roads. From the spatial allocations for the three scenarios, we conclude that the main difference among them

is the amount of expanding or decreasing land which is dependent on the different land use demands under different social and economic conditions.
By using the results of land use scenario analysis and impact assessment based on this coupled model, local planners and decision-makers could grasp the different local land use demands under different developing scenarios, the dynamics of their spatiotemporal changes, and the growth and decline in urban land and farm land. In other words, they can get the needed knowledge to assist plan-making(Zheng et al. 2009: 59).

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