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Monitoring and modeling the urban growth of mid-size cities in Iran by Markov model: the case study of Zanjan City

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Abstract

Rapid land use change has taken place in many mid-sized cities of Iran such as *Zanjan* over the past three decades. This research analyzed the land use/cover change *Zanjan* from 1965 to 2005; identified the patterns of urban growth and the fragmentation of the urban space by applying GIS and remote sensing tools. The main driving forces of the urban changes were analyzed and the model to predict the land use/cover changes was applied. Our results show the importance of monitoring and modeling of rapid urban growth for attaining sustainable mid-sized cities in developing countries that are strongly dependent on export of natural resources. The results indicated that there had been a notable and uneven urban growth and a major loss of cropland loss between 1965 and 2005. Most of the urban growth and loss of agriculture land occurred in inner and outer suburbs. This research analyzed the land use/cover change *Zanjan* from 1965 to 2005, identified the patterns of urban growth and the fragmentation of the urban space, applying GIS and remote sensing tools. We believe that in urban growth modeling process there has been multi social-economical and physical elements in which have key rules in it, and we attempted to use some of them.

Keywords: Land Use Change; Satellite Remote Sensing; GIS; Markov Chain; Urban Growth; Zanjan.

Introduction

The intensity of land use change in response to world population growth and its consequences for the environment warrant in-depth studies of these transformations. Several international interdisciplinary research projects have been initiated during the past two decades for this purpose. These include the International Geosphere-Biosphere Project (1988) and the Land Use and Cover Change program (Messerli, 1997). Both of these projects indicated the need to construct an updated and accurate database concerning these changes, their meaning, their pace and the explanatory factors prompting their appearance (Mather, 1999). The phenomenon of urban development is one of the major forces driving land use change. In the Iran, urban and built-up areas increased by 27% between 1975 and 1985, and this increase mainly came from the conversion of croplands (Bygdelly, 2004). In Iran, the rapid urbanization process caused an unprecedented scale and rate of urban expansion over the last two decades (Mahdavi *et al.,* 2004). Urban land will continue to expand at a rapid rate in Iran because more than 80% of its population will be urban by 2030 according to a statistic bureau of I.R of Iran (2001, www.stit.org). The issue of land use change in Iran is of great significance because Iran per-capita land resource is near the world's average. Prior to 1965, the government had relatively strict control on land use planning. Since 1965, when Iran initiated its Active economic Program based on oil incomes, rapid urbanization and economic expansion has brought about massive land developments all over the country leading to the loss of a significant amount of agriculture land (Taherkhani *et al.,* 2002). Traditionally managed agricultural landscapes play a vital role in sustaining local biodiversity and ecosystems (Turner, 1990). Local land-use and land-cover change can influence environmental and ecological changes and furthermore contribute to global changes (Meyer & Turner, 1991). Fragmentation of farms in the urban fringe caused by urban sprawl has come with a loss of the traditional farming economic base and a change in the character and visual quality of rural communities (Brabec & Smith, 2002). All of these changes, especially the loss of agricultural land, have the potential to undermine the long-term harmony of humans and their environment and threaten the food security of urban area in Iran. There is a pressing need for knowledge about the magnitude, pattern and type of land use and land cover changes and for projecting future land development.

Materials and methods

Modeling land use change as a spatial analysis tool

The ability to model and simulate varied urban growth scenarios constitutes an important advance for land use change research. The only way to exactly evaluate environmental and social consequences of landscape fragmentation is with a projection model that spatially represents land use change patterns (Brown *et al.,* 2002).

Most recent studies in the field have been carried out in the United States, Europe, and Asia. The modeling parameters used to simulate urban spatial growth include the present extension of urban areas, principal transport infrastructure, distance to labor, goods, and input markets, topographic conditions, and special situation land (protected areas, drainage areas, etc.). The models attempt to identify the physical and socioeconomic factors that determine or condition the pressure applied on previous land uses and the shift to urban use.

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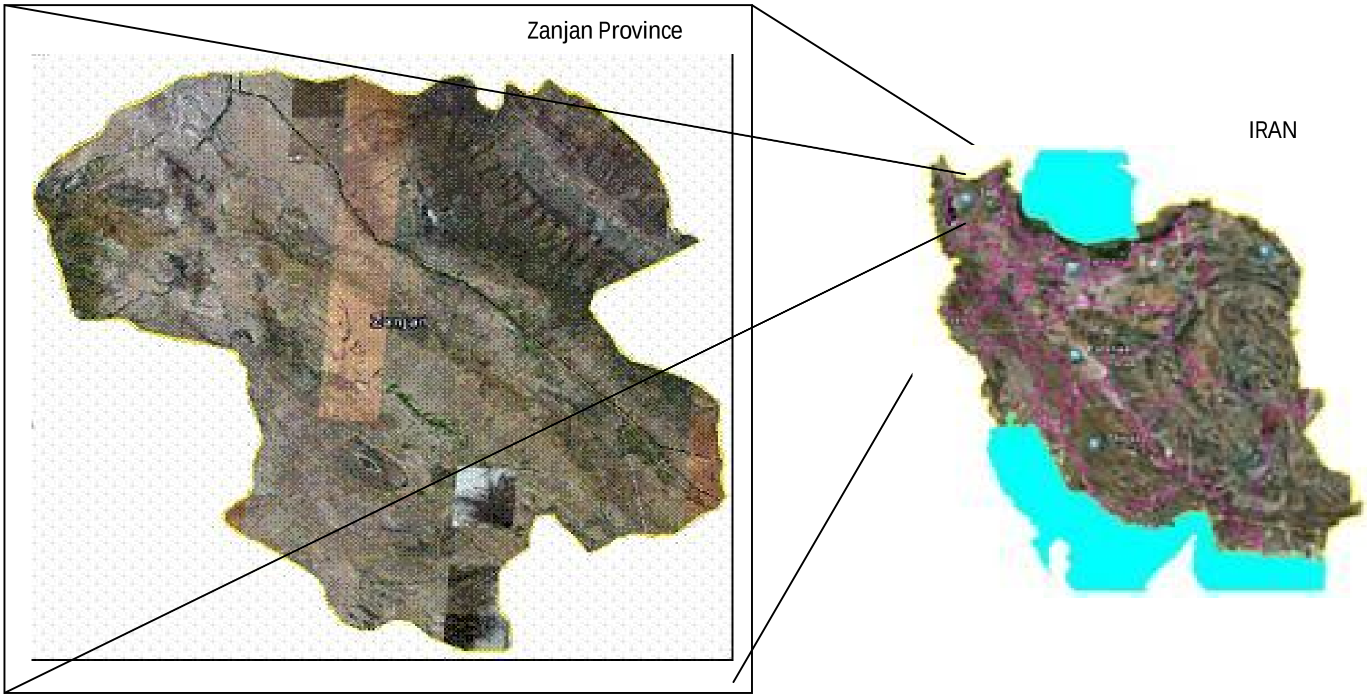
Fig. 1. Location of Zanjan city in Zanjan Province



A particular urban modeling method known as Cellular Automata (CA) was used for the present research. This model created by von Neumann (1966) and first used by Tobler (1979). CA is a heuristic model for simulating complex spatial processes that is capable of demonstrating non-linear growth dynamics like the spatial segregation of socio-economic groups (Barredo *et al.,* 2003). Numerous studies have since used CA to model rural settlement patterns (Deadman & Brown, 1993) and urban growth (White & Engelen, 1993; Couclelis, 1997; Clarke & Gaydos, 1998; Li & Yeh, 2000; White *et al.,* 1997). In general, there are two ways to apply a GIS-based CA model: with or without limiting factors (Sui & Zeng, 2001). The first method does not consider geographic restrictions to urban growth, affording all the grid's units the same likelihood of changing their status according to a statistical probability. In the second method, unit conversion probabilities are not permitted.

Another method for predicting the land use change is the Markov chains, which is derived from applied mathematics. Markov chains assume that land use change is a stochastic process in which the change of distinct land use categories depends on the status immediately prior to change. Markov analysis has concentrated on the study of vegetation types (Balzter, 2000) and more recently on urban and non-urban coverage change. Although, criticized for its lack of spatial expression, numerous investigations have successfully predicted and simulated land use change with Markov matrix (Lo´ pez *et al.,* 2001; Weng, 2002). Recently, Pontius & Malanson (2005) have integrated the Markov chains with the CA and Multi-Criteria Evaluation (MCE) in a CA_Markov model to predict land change in united state, central Massachusetts (Fig.1).

Acquisition of land use data

The study area is composed of one 14×10 km^2 square. The land use/cover change in Zanjan and its surrounding areas are determined through the digital interpretation of aerial photographs from 1965 (scale 1:10,000), 1975 (1:10,000), 1985 (1:15,000), 2000 (1:10000) and 2005 (1:10,000). These photographs were scanned and geo-referenced in a common Universal Transverse Mercator (UTM) coordinate system. Topographical maps (1:50,000) for Zanjan Province were attained from the Military Geographic Institute of I.R. of Iran. These maps and digital aerophotogrametric information (CAD format) were used as references. The types of land use/cover were based on an adaptation of Anderson's classification scheme (Anderson, Hardy, Roach, & Witmer, 1976), which includes: (1) urban (residential, commercial, services, industrial, and mixed), (2) transport, (3) crops and pasture, (4) shrubs, (5) forests, (6) wetlands, (7) water (watercourses), and (8) barren lands. Land use/cover polygons were interpreted and digitalized with Arc GIS-Arc Info 9.0 and interpretations were verified with field visits. The Arc GIS-Arc Info 9.0 coverage was converted to GRID format (10-m cell size) for subsequent processing in GIS IDRISI Kilimanjaro. The minimum mapping area was derived from the spatial resolution of the aerial photographs and reference maps. Additionally, the current urban limits of Zanjan were digitalized in order to identify urban advances outside of the zone established by present planning instruments.

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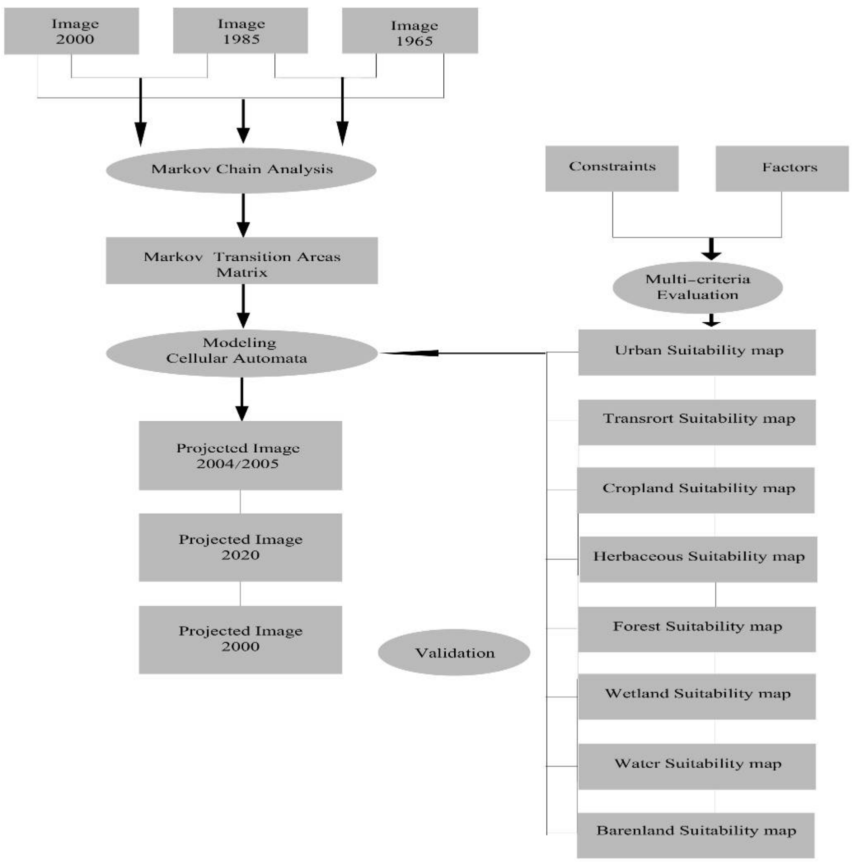
Fig. 2. Sismocluc scheme



The driving forces of urbanization

The most important urbanization driving forces in Zanjan were identified; these are the independent variables. These variables were selected according to the availability and comparability of census data over time and include: (a) total population from population and housing censuses in 1965, 1975, 1985,1995,2005 (b) annual demographic growth rates for 1965- 1975, 1975-1985,1985-1995,1995-2005; and (c) provincial land use. The urban surface was estimated for 1965, 1975, 1985, 1995, and 2005 with a geometric projection, using the aforementioned aerial photographs and other aerial photographs from 1965 (1:10,000) as references. Changes in urban land use/cover were associated with the independent variables through simple correlation analyses.

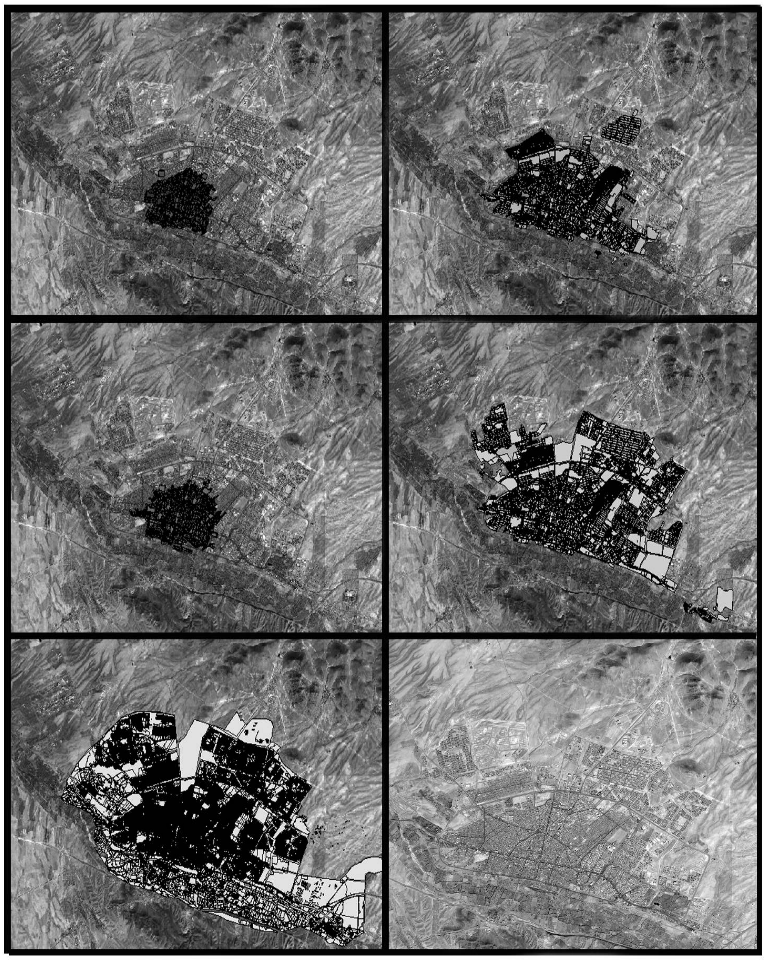
The spatial analysis of urbanization patterns

The spatial patterns of urbanization that occurred from 1965 to 2000 were examined by considering the distance decay from the city's geometric center and the distance decay from the principal city access routes, using a 500m buffer. This two distance decay curves have been based on the concept of critical isochrone of the Getis's model (Wheeler *et al.,* 1998). The number of urban patches determined the degree of fragmentation in the new urban patterns. This indicator was related to important socio-cultural variables in the city's socio-spatial differentiation process, including: (a) wealth, (b) power, (c) status, (d) knowledge, and (e) territory. Each of these variables was operationalized using indicators obtained from the population censuses of 1975, 1985, and 1995. Wealth was measured as the non-poor percentage of the population according to the Integrated Poverty Method (MIP) proposed by ILPES; MIP considers physical housing deficiencies and the head of household's vulnerability. Power was quantified by the percentage of homes with private cars; status by the percentage of managers and professionals with respect to the total population through the International Uniform Occupation Classification (IUOC); knowledge by the percentage of the population with higher education (university and technical); and territory by the number of persons per household.

Urban growth simulation

In order to monitor the spatial growth patterns of urban land use, a simultaneous simulation model of changes in land use/cover (SISMOCLUC) were developed (Fig. 2). This high-resolution model was developed in GIS IDRISI Kilimanjaro and included three stages. In the first stage, the transition probabilities of the distinct land covers were determined in order to simulate the situation in year x, based on a period x_1, using the Markov matrix method. In the second stage, a MCE was performed in order to determine suitable land use, including factors and constraints for each type of land coverage. Finally, land use/cover, especially urban, was simulated by combining the reference map to be projected, the Markov transition matrix, MCE coverage, and CA, which included the number of iterations and a contiguity filter. MCE was used to evaluate suitability of land use/cover by category. Particular attention was paid to urban suitability, since its change dynamic is more accelerated. The MCE considered two spatial constraints affecting urban growth and three previously determined urban growth factors. The spatial constraints included already constructed areas (urban and transportation) and watercourses (50m buffer), whereas the urban growth factors were closeness to principal access routes, closeness to urban center, and the uses most likely to become urban. The first two factors were adjusted with distance decay curves and the third with the Markov matrix. The importance between factors was determined by assigning a relative weight to pairs of factors through the Analytical Hierarchy Process known as IDRISI. Afterwards, the MCE model was executed, incorporating the above limits and weighted factors into the analysis.

Fig.3. Overlaid maps of urban growth process and land use/Cover changes in Zanjan between1965-2005 based on satellite image in 2005



The result was a final image aggregated urban suitability with a range of 0-255, where 0 is no suitability and 255 is maximum suitability. Suitability maps for crop/pasture, shrub, and forest land considered already urbanized areas (urban and transportation) as constraints and land use/cover susceptible to change was considered as a growth factor; this also applied to the actual land use, which was assigned a greater value. Transportation, wetland, and water cover were considered to be constraints for all other uses/covers, and growth factors for their own uses. In other words, for this type of land use, the only change possible is the expansion of the present use. All suitability maps were grouped into a single transition file for running the spatial simulation (Fig. 2).

Land use/cover for the year 2020 Zanjan, based on information from 1965 to 2000, was simulated with SISMOCLUC. For Zanjan, simulations for 2004 and 2005 were made based on data from 1965 to 1985 and 1985 to 2000, respectively. Finally, a simulation of 2000, based on 1965-1985 (Zanjan) was used to validate the results by comparing them with maps from 2000; the Kappa Index of agreement (KIA) was used. This is one of the most widely used statistical indexes for measuring he differences in map-reality agreement. The KIA evaluates whether the classification has appropriately discriminated the categories more precisely than a random assignment could have.
Thus, kappa is 1 when observed agreement is perfect; kappa is 0 when observed agreement is equal to the expected agreement due to chance (Pontius, 2002).

The changes of land use/cover in 1965-2000 include considerable urban growth in Zanjan (Fig. 3). The data indicates that Zanjan has seen a 60.4% increase in urbanization over the last 35 years (from 396.04 to 4785.9 ha). A comparison of spatial growth (1965-2000) with the urban limits set by urban planning instruments reveals 9.3% of zanjan new urban areas developing outside the limits of the Master Plan.

The main changes in land use/cover in zanjan are increased urban use, followed by increased agricultural use. Most of the new urban areas have taken over crop and pasture lands (27% in Zanjan). The other uses have remained fairly constant.

Analysis

Table 1.Urban expansion and demographic growth for Zanjan

Year	Urban expansion rate (%)	Demographic growth rate (%)
1965-1975	2.04	5.51
1975-1985	10.9	7.49
1985-1995	7.7	3.35
1995-2005	5.2	2.65

The driving forces of urbanization

Urban growth and population growth are positively correlated in Zanjan (r = +0.98) from 1965 to 2005.However, since the growth rates of these two variables are inversely related (Table 1), demographic growth is not significantly related to spatial growth in Zanjan. In the case of Zanjan, the strongest relationship is that between urban growth and vegetable and flowers production (Table 2).

Analysis of spatial urbanization patterns

Figs. 4(a) and (b) show the urban diffusion process across space and time. Section 1 shows that distance decay from the city center has not limited urban growth in

Table 2. Urban expansion rate in Zanjan and expansion of planted areas rate

Zanjan 1965-1995	Expansion of planted areas							
	Rate (%)	Cereals & horticulture farms	Industrial Cropland	Vegetables and flowers	Forage plants	Fruit	Vineyards	Forestry
	1.73	-0.60	-0.42	1.71	-0.46	2.64	-2.1	2.35

Table 3.Driving forces of urban fragmentation in Zanjan

Year	No of urban Patch[a]	Wealth (%)	Power (%)	Status (%)	Knowledge (%)	Territory (persons/ household)
1965	5	44.5	9.7	3.4	4.6	3.5
1975	6	53.1	11.6	3.9	7.3	4.2
1985	9	58.3	8.4	4.1	9.4	4.6
1995	17	61.2	14.9	4.3	13.4	4.4
2000	32	63.1	15.7	5.1	16.7	5.1

Note: [a]Values based on aerial photographs of year 1975, 85, 95, and 2000.

Zanjan from 1975 to 2000. Half of the urban land use change was concentrated between 1500 and 3500m from the center of the city; fewer cells changed to urban use between 3500 and 5000m from downtown, reaching a new spatial concentration maximum, 15-24% of the total, at distances between 4500 and 5500m from downtown. Beyond 5500 m, the curve of urban land use change finally falls. Distance decay curves from principal access routes (Fig. 4(b)) are similar in this city: the first 500m concentrate 52% of urban change; at 1000 m, change is over 80%; and almost 100% of urban growth is concentrated within a distance of 2000m from the routes.

Our results show new growth patterns in the form of a horizontal expansion, ever more distant from the city center (leap-frog), and in which the gravitational effect of access routes on urban land use change is noteworthy. From 1978 to 1998, the number of urban patches increased in both Zanjan went from five patches in 1975 to 32 in 2000 (increase of 550%).

The physical fragmentation of the urban landscape is closely connected with the social fragmentation of the corresponding city, since higher income groups in both cities tend to be located at increasing distances from the city center in urban patches of private condominiums and pleasure parcels.

Urban landscape fragmentation is closely related with the behavior of the evaluated socioeconomic indicators (Table 3), especially knowledge: increase of 259% in Zanjan between 1965 and 2000. The population's education structure changed noticeably, especially between 1985 and 2005 when the percentage of the population with higher education (university or technical) has been very increased. This tendency indicates an interesting relationship between the population's educational level and the arrival of higher income groups in the insular sectors of the city.

The results of the SISMOCLUC for 2010 and 2020 are presented in Fig. 5. The slight sprinkling of patches of urban and other uses at the top of each simulation is due to noise phenomenon. This derives from both unsystematic trivial change on the landscape and error in the maps (Pontius & Malanson, 2005).

Compared with 2000, 2010 Zanjan's projected urban use grows by 34.16% (from 2294.1 to 3077.9 ha) and by 70.62% (from 2294.1 to 3914.3 ha) in 2020.The Zanjan simulation (a) shows new urban areas along the northwestern access route that disappear in simulation (b); this effect is due to different time interval and the stochastic nature of the spatial simulation model, which allows urban agglomeration in any suitable urban area.

The projected spatial patterns of urban growth reaffirm similar processes in Zanjan. The principal structuring axis of urban growth is made up by means of communication. Urban patches near the city center fuse and new patches appear farther from the center, resulting in an extremely fragmented landscape. The benefits of agricultural lands diminish dramatically in the face of urban advance, increasing the number of ''agricultural islands''.

The evaluation of the city used in this study show much more fragmented urban growth in Zanjan. The projected scenarios for Zanjan, especially for 2020, confirm linear expansion along the south highway and main road of city. Furthermore, enormous urban pressure will be experienced by the agricultural land located to the south and northeast of the city. Model validation, which compared the 2000 land use/cover (a reference image) with a simulation for the same year, is presented in Table 4. The KIA for these two images shows greater agreement with urban use in Zanjan (0.88). The value obtained represent an agreement strong for Zanjan (K>0.80), with reference data (Congalton & Green, 1999), for which our errors are considered acceptable. Sui and Zeng (2001) reported location errors between 17% and 29%.

Nevertheless, the error level for estimated urban area is moderate for Zanjan (28%), warranting a later adjustment to the model. Considering the overall accuracy among all land use/cover, a greater agreement was achieved in Zanjan (0.79), through the index KIA (Kstandard).

Discussion and conclusions

This research has proven its original hypothesis: over the last 20 years (1975-2000), the growth of the mid-sized city studied has been clearly fragmented, as is often the case of Iranian cities. The projected spatial patterns of urban growth reaffirm similar processes in Zanjan. The principal structuring axis of urban growth is made up by

Table 4.Estimated and observed land use/cover for 2000 for Zanjan

	Urban	Transport	Cropland	Herbaceous	Forest	Wetland	Water	Barenland
Zanjan 2000								
Observed(ha)2000	2293.2	133.4	9113.8	1195.8	328.6	184.1	448.6	711.7
Simulated (ha)	2946.5	240.7	8347.7	1202.8	440.5	277.6	426.9	617.1
Difference(ha)	-652.3	-117.3	865.1	-6.9	-112.9	-93.5	23.7	93.6
Percentage (%)	28.5	95.1	9.6	0.6	34.1	50.8	6.1	13.2
KIA[1]	0.880	0.991	0.713	0.815	0.727	0.874	0.926	0.861

[1] *Kappa Index of agreement (KIA)*

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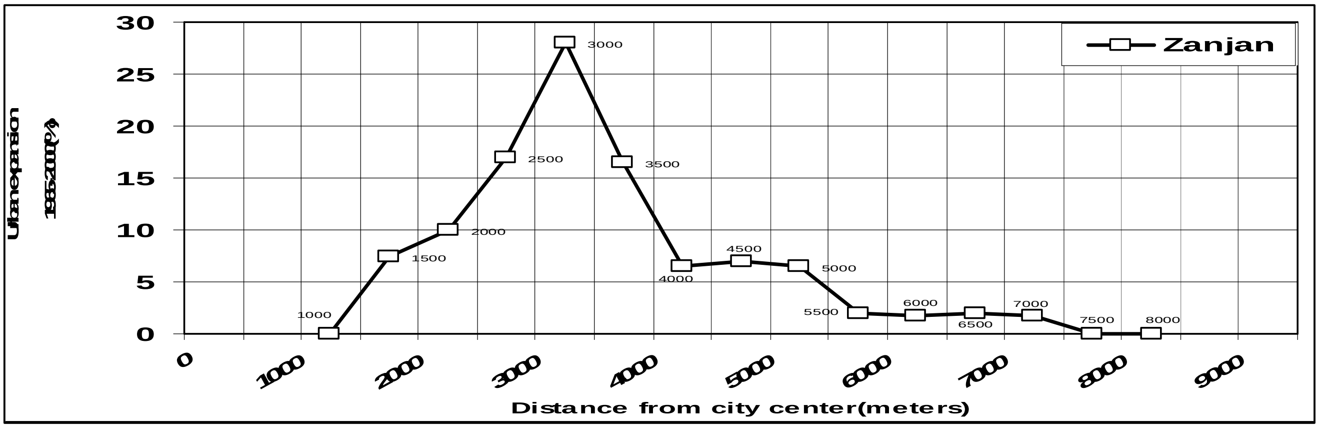
Fig.4. Types of urban expansion pattern in Zanjan 1965-2000: (a) distance decay from city center and (b) distance decay from principal city access routes.

(a)



(b)

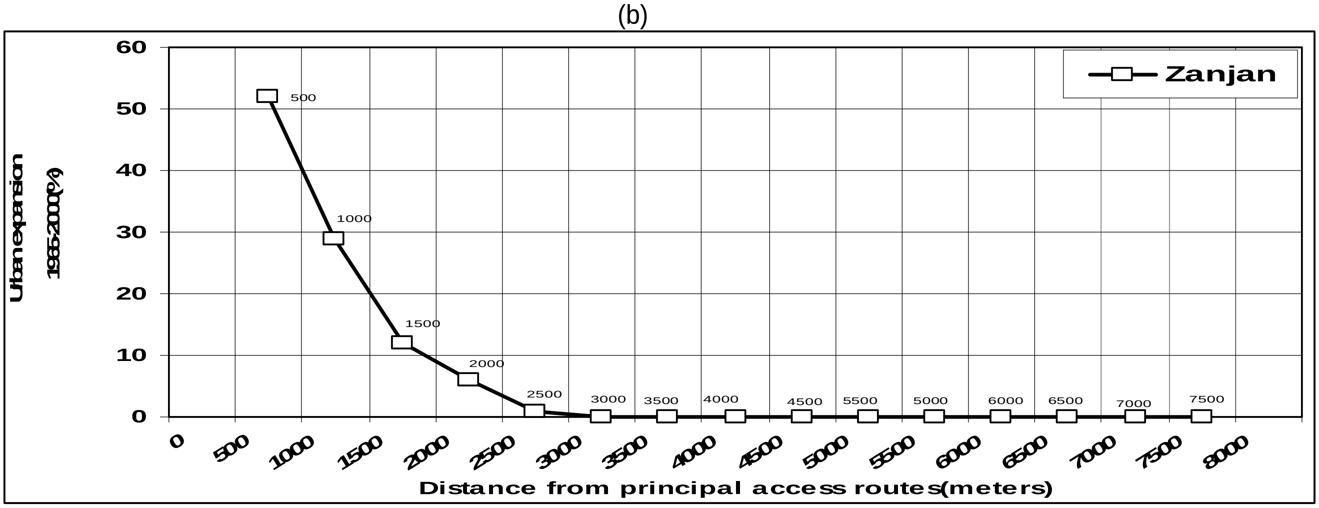
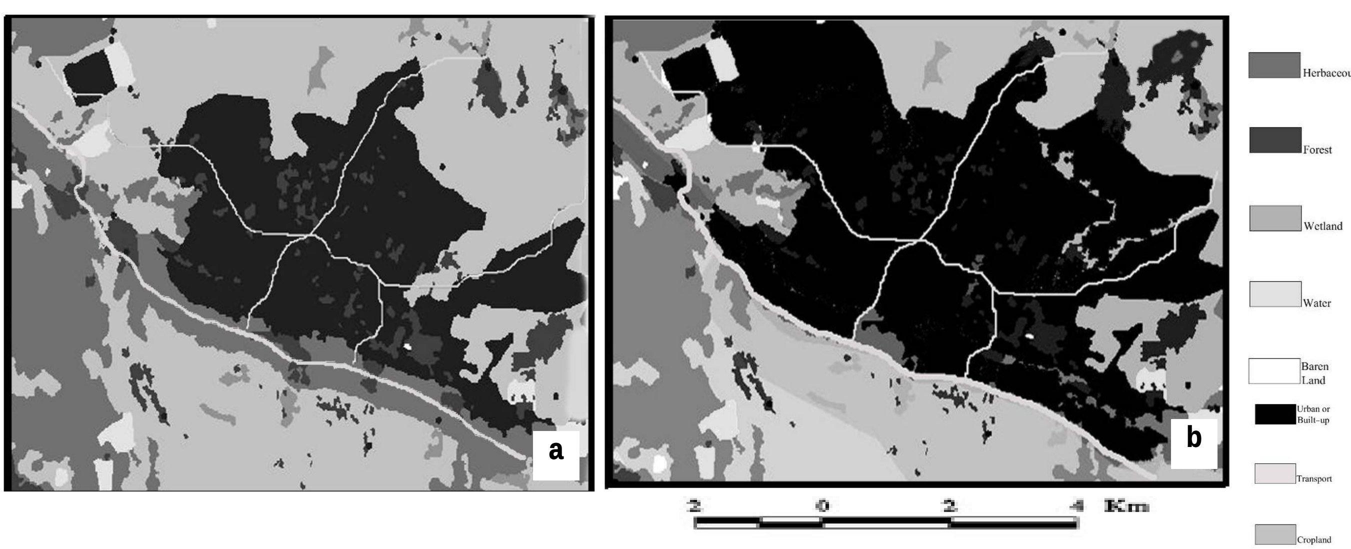


Fig. 5. Simulation of Land Use/cover in Zanjan city :(a) 2015; (b) 2025.



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means of communication. Urban patches near the city center fuse and new patches appear farther from the center, resulting in an extremely fragmented landscape. The benefits of agricultural lands diminish dramatically in the face of urban advance, increasing the number of ‘‘agricultural islands’’.

The evaluation of the city used in this study show much more fragmented urban growth in Zanjan. The projected scenarios for Zanjan, especially for 2025, confirm linear expansion along the south highway and main road of city. Furthermore, enormous urban pressure will be experienced by the agricultural land located to the south and northeast of the city. Model validation, which compared the 2000 land use/cover (a reference image) with a simulation for the same year, is presented in Table 4. The KIA for these two images shows greater agreement with urban use in Zanjan (0.88). The value obtained represent an agreement strong for Zanjan (K>0.80), with reference data (Congalton & Green, 1999), for which our errors are considered acceptable. Sui & Zeng (2001) reported location errors between 17% and 29%.

Nevertheless, the error level for estimated urban area is moderate for Zanjan (28%), warranting a later adjustment to the model. Considering the overall accuracy among all land use/cover, a greater agreement was achieved in Zanjan (0.79), through the index KIA (Standard).

This new growth pattern is characterized by peripheral urban patches that are largely made up of high-income populations and consisting of private condominiums and ‘‘pleasure parcels’’. On the other hand, illegal settlements and low-class neighborhoods reproduce these functional, socio-spatial processes in large cities like Tehran, Tabriz, Esfahan and Mashhad. As in nature, where fragmentation into patches adversely affects living species, the sustainability of the human urban world is also tightly linked with its spatial disintegration. Some influences affecting this process are: the increased use of automobiles for going downtown, resulting in vehicular congestion and air pollution; greater isolation of social groups favoring residential segregation; and elevated costs of supplying basic services (sewage, potable water, and electricity) to areas outside of the coverage range. Furthermore, the agricultural and natural landscape is fragmented.

The specific conclusions drawn from the results for Zanjan can be summarized as follows: In Zanjan, the most important land use/cover changes (1975-2000) were new urban areas that emerged on land once used for agriculture and pastures. The most important factors explaining this growth are advancing agricultural and industrial activities in Zanjan. Demographic growth, however, are also explain urban growth in these city.

The analysis of urbanization patterns in Zanjan suggested that distance from the city center is not as important as distance from main transportation routes. Nevertheless, new urban growth patterns in this city include leap-forging as a central element, so growth in space is diffused and fragmented.

An analysis of the socio-economic indicators shows an improvement in general city conditions, but a more detailed revision is necessary to evaluate the degree of socio-spatial differentiation and segregation between the diverse socio-economic strata.

Future urban growth modeling (2000-2025) of spatial growth tendencies projects a much more disintegrated city, spreading out around its access routes. The SISMOCLUC proposal can be improved by including more recent data and considering other significant urban growth variables such as increased ground rent, property ownership, productivity of agricultural soils, the social status of the residents, physical restrictions (geophysical risks), normative restrictions (regulating plans), and topographic characteristics, amongst others.

The economic changes Iran has experienced as a consequence of its commercial internationalization and economic deregulation are regionally expressed in land use/cover changes that can explain the high urbanization indexes. This is especially important now that Iran want to be a party to numerous free trade agreements with distinct economic powers. These agreements favor natural resource and industrial goods exports and, consequently, urban growth in cities like Zanjan. It is, therefore, imperative that different urban growth scenarios are evaluated in order to increase the sustainability of mid-sized cities.

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