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Mapping and Analyzing Urban Expansion Using Remotely Sensed Imagery in Isfahan, Iran

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Abstract: Urban expansion is one of the key factors in changing land cover/use which has caused major problems like agricultural lands loss, water pollution, soil erosion and some social and economic disadvantages. Isfahan is a metropolis which has faced fast growth in recent decades. The main purpose of this paper is to use remote sensing imagery for detecting changes occurred in residential areas of Isfahan during 1956-2006; this is the maximum period for measuring changes in this region using aerial photos and satellite images. Two series of aerial photos and Landsat MSS, TM, ETM+ and IRS LISS-III images were used. The study area was classified into three main categories (residential areas, non-residential areas and green spaces) using visual interpretation of aerial photos and processing of satellite images. Finally, change process of Isfahan residential areas over 1956-2006 was determined using overlay analysis and its relation with population growth was studied. In this period, residential areas have expanded about 9 times and population increased by about 6 times. Isfahan was surrounded by agricultural lands and gardens, so the growth of this city during 5 decades has caused some changes in some agricultural fields and gardens and transformed them into residential areas.

Key words: Urban expansion · Population growth · Residential areas · Satellite images · Aerial photos · Urban planning

INTRODUCTION

Nowadays urban areas experience fast growth due to enormous population growth, rapid industrialization, economic development and specific economic policies adopted by governments and immigration of people from villages to cities. Accelerated urban growth is usually associated with and driven by the population concentration in an area. The extent of urbanization or its growth drives the change in land use/cover pattern [1].

Globally, the world's population is becoming more urbanized. In 1995, over 51 percent of the world's population lived in settlements [2] and it is estimated that by 2025 more than 65% of world population will live in cities [3]. More than 66% of Iran's population lives in cities and for Isfahan it is 79.5%. Physical expansion of cities could have some effects on environment, economy and social issues [4].

Accurate information on the extent of urban growth is of great interest for the municipalities of growing urban and suburban areas for diverse purposes such as urban planning, water and land resource allocation, etc. Urban authorities and municipal management, marketing analysis, service corporations are required to devote more time, attention and effort to manage the use of land and other resources in order to accommodate the expanding population or other urban land uses.

Land use, land cover and agricultural fields' changes in urban areas are the most environmental effects of expansion which may cause major problems like loss of agricultural areas, water pollution, soil erosion, torment increasing and decreasing quality of environment.

As urbanization is an inevitable process it can be directed in the most appropriate way by urban land use planning so that the needs and rights of people, natural resources, lands around cities and agricultural fields could

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be protected. So, in urban planning process from land planning view, exploring the changes occurred in the past and detecting and describing the change trend in urban areas have significant importance.

Remote sensing is cost effective and technologically sound, so it is increasingly used for the analysis of urban expansion [5-7]. Remote sensing provides spatially consistent data sets that cover large areas with both high spatial detail and high temporal frequency. Dating back to 1960, remote sensing can also provide consistent historical time series data. The importance of remote sensing has been emphasized as a "unique view" of the spatial and temporal dynamics of the processes in urban growth and land use change. Satellite remote sensing techniques have, therefore, been widely used in detecting and monitoring urban changes on various scales with useful results [8].

Interpreting aerial photos from different time periods can be used for monitoring and controlling land use changes and providing a useful tool for recognizing and studying land features. Using aerial photos for identifying current situations of geographical areas and human-made landscapes and making advantage of existing facilities are completely obvious. From a historical view point, interpreting satellite images is fundamental in land use mapping for a region. The advantage of satellite image with high spatial resolution is its accuracy for interpreting features in complex landscapes and its ability for recognizing different types of land use and land cover, but one of the main issues is that interpreting satellite images is very expensive and time-consuming.

Nowadays because of remote sensing development and the ability of getting different satellite images with different resolutions, researchers can study urban and natural environment on various scales.

One of the advantages of Satellite images is the opportunity to get image so many times than aerial photograph and collect data in frequent time periods. Another main advantage of satellite imagery is that it can show a large area. One of limitations of using satellite images is that with sub-pixel complexity in urban area in spatial resolution of most existing satellite data (10-90M pixel), correct classifications of land use by simple methods is difficult [9].

In Iran, the first aerial photos were taken in 1956 and we are able to study regional changes in the last 50 years with the aid of existing remote sensing data.

The rapid urban expansion in Iran from 1956 to 2006 has come along with population growth and immigration to mega cities. Also, a lot of remote sensing data (aerial photos and satellite images) have been taken from urban areas. The data provides an opportunity to study urban changes especially physical expansion and land use changes in urban ranges.

For a better future urban development and infrastructure planning, municipal authorities need to understand urban sprawl phenomenon and be aware of this point that in what way it is likely to move in the years to come.

During recent decades, lots of researches have been done on urban growth using aerial photos and satellite images. Some of them are mentioned below:

Collins and Bike (1971) used aerial photos to provide land use map and noted that it is difficult to generate land use map of urban areas because of complexity of human processes and high density of buildings.

Lopez *et al*. (2001) predicted land use and cover changes in the coast of Mexico over a 30-year period by using aerial photos and GIS (Geographical Information Systems) technique. They investigated relation between urban growth and landscape changes and identified that grassland and shrub lands are the most inconsistent classes which turned to urban areas quickly [10].

Harris and Ventura (1995) compared land use and land cover data derived from aerial photos and TM image and PAN image of Spot in Beqrerdam Winson and found that visual interpretation of photos resulted in findings with more than 86% accuracy and utilizing satellite images led to identifying less classes of land use compared with aerial photos. Identifying commercial and industrial areas was more difficult in comparison with other features in satellite images [11].

Kemper *et al*. (2001) reviewed land use changes in Istanbul in a 50 year period. They chose 60 classes of land use and analyzed them for 4 years which was based on IRS and IKONOS and visual interpretation. They estimated existing changes between these utilizations for 5 decades [3].

Alphan (2003) explored land use change and urbanization of Adana, Turkey between 1984 and 2000. He used Landsat TM and ETM+ images and classified them using supervised classification. The post-classification comparison method was employed to detect changes and the results showed that urban area increased by a factor of 2.07 during the 16 years [12].

Weber & Puissant (2003) investigated urbanization process in Tunis Metropolitan Area from 1986 to 1996. To identify urbanization processes, they employed SPOT images acquired in 1986 and 1996 and used supervised

classification by stepwise discriminant analysis to classify them [13]. Al Rawashdeh & Saleh (2006) attempted for measuring and modeling Amman growth using RS and GIS techniques. They tried to measure future urban growth using existing data and land use maps. Moreover, they reviewed both aerial photos and satellite images to determine land use and urban growth process for Amman. The obtained data from this research includes 6 land use maps of 1960, 1970, 1980, 1990, 2000 and 2003. The results showed that Amman faced a 20% growth rate each year which was reached 650% for 1970-2003 [14].

Doygun *et al*. (2007) investigated changes in urban area of the city of Kahramanmaraº (K.Maraº) between 1948 and 2006. They used two black-white monoscopic aerial photographs and IKONOS and the QuickBird images acquired in 1948, 1985, 2000 and 2006 to extract urban change information. The aerial photographs and the images were visually interpreted on screen and urban areas were extracted [15].

Isfahan is the third most populated province in Iran. This province has faced an unpredicted growth rate. Having a special place among other metropolises of Iran and regarding the fast population growth of Isfahan, there is a significant need for planning for economic development and appropriate allocation of regions for different urban, industrial and agricultural uses. For this purpose, there should be complete knowledge of land and resources conditions and changes that they encounter.

The objective of this study is to quantify physical expansion of Isfahan using aerial photos and satellite images and exploring the relationship between physical expansion and population growth in Isfahan from 1956 to 2006.

MATERIALS AND METHODS

Study Area: Isfahan is located in 32°38' 30" N latitude and 51°38' 40" E longitude (Fig. 1). The minimum height is 1550 meters around Zayandeh Rood and maximum is 2232 meters in Sofeh Mountains. Annual average precipitation and temperature is 121.1 mm and 16.2°C, respectively [4]. Isfahan is the capital city of Isfahan province and the third biggest city in population in Iran and one of Iran metropolises. In recent decades, it has been the center of attention and population because of economic, industrial, tourism and cultural development which have increased requests for different industrial, residential, transport, business, cultural, educational and entertainment uses. Isfahan population has increased from 254708 in 1956 to 1602110 in 2006.

Data: Aerial photographs from 1955, 1956, 1967, 1969, 1975 and 1991 at a scale of 1:50000, 1: 6000, 1:25000, 1:10000, 1:5000 and 1:40000 were employed for producing urban area maps. Landsat Multi spectral Scanner (MSS), Landsat TM, Landsat Enhanced Thematic Mapper Plus (ETM+) and IRS-P6 LISS III images for the years 1975, 1990, 2001 and 2006 were also used in this study.

A time series of remotely sensed imagery were used for this study as follows:

- Aerial photos of 1955 at the scale of 1:50000
- Aerial photos of 1956 at the scale of 1:6000
- Aerial photos of 1967 at the scale of 1:25000
- Aerial photos of 1969 at the scale of 1:10000
- Aerial photos of 1975 at the scale of 1:5000
- Aerial photos of 1991 at the scale of 1:40000
- Landsat Multi spectral Scanner (MSS) image of 1975
- Landsat Thematic Mapper (TM) image of 1990
- Landsat Enhanced Thematic Mapper Plus (ETM+) image of 2001
- IRS- P6 LISS-III image of 2006
- Isfahan topographic map of 2003 at the scales of 1:4000
- Isfahan population census data

The following items were taken into account to select aerial photos and satellite images

- The chance for investigating time changes should be maximum.
- Image qualities should be appropriate.
- There should be a chance to use a more accurate resource for measuring accuracy of produced maps while taking photos.
- Population census data should be available while taking aerial photo or satellite image.

Data Preprocessing and Processing: All aerial photos and satellite images were rectified and georeferenced to UTM coordinate system based upon well distributed ground control points on topographic maps. Finally, a first-order polynomial model was applied and all data were resampled using the Nearest Neighbor method. Geometric correction was resulted in RMSE between 0.5 and 0.8. In the next step, Georeferenced aerial photographs were mosaicked together.

Then current urban area of Isfahan was extracted from mosaic aerial photos and satellite images.

Fig. 1: Location of the study area

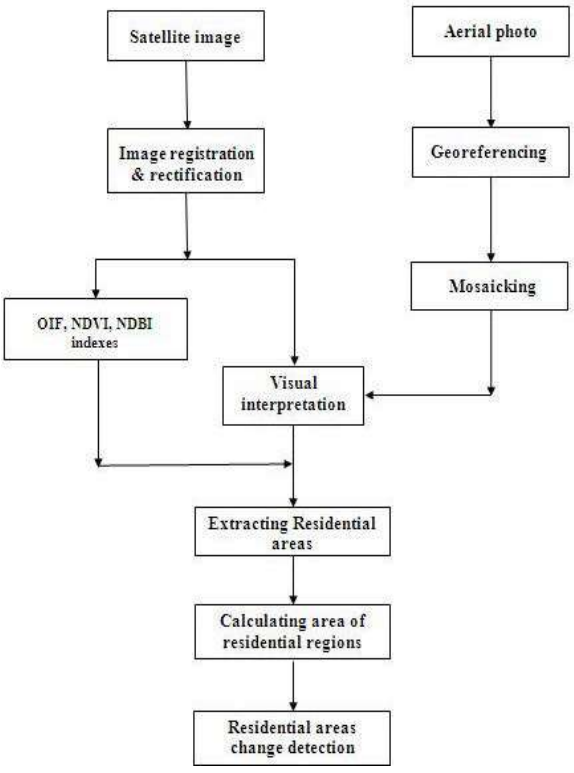

Fig. 2: Flowchart of methodology

The standard image processing techniques, such as image extraction, rectification, restoration and classification have been used for the analysis of four satellite images. After that, visual interpretation was done and residential, nonresidential and agricultural areas were digitized. Identifying features was based on color, tone, shape, texture and size. Stereoscope was used for better interpretation while visual interpreting of aerial photos was being done. PAN image was used for digitizing ETM+ and LISS III images and false color composite (FCC) images were used for MSS and TM images interpretation. The best band composites was detected for making false color composite images based on OIF (Optimum Index Factor) on TM and MSS images. Besides that, using computer processing and introducing two NDBI (Normalized Difference Built-up Index) and NDVI (Normalized Difference Vegetation Index) indexes, residential and agricultural areas were separated from satellite images.

Accuracy Assessment: Knowing that there is not any possibility to gather data from past years, accuracy of produced maps for the years 1967, 1975, 1990 and 2001 was determined using visual interpretation.

To determine accuracy for the observed control points of aerial photos with 1:6000 of the same year was used. Also, to get accuracy of produced maps for 1975, 1990 and 2001, 1:10000 aerial photos of 2006, 1:5000 aerial photos of 1975, 1:40000 aerial photos of 1991, 1:4000 topographic maps of 2003 were used, respectively. Field inspection was used to control the maps derived from LISS IIII satellite images. The overall accuracy of generated maps was calculated using error matrices. Fig. 2 shows the steps involved in the present study.

RESULTS AND DISCUSSION

In this section we discuss the results of different sections of the study.

Geometric Correction of Aerial Photos and Satellite Images: Topographic maps were used for Geometric Correction of aerial photos and satellite images. RMS Error of aerial photos and satellite images were under one pixel which was acceptable regarding the scale and resolution of photos and images (Table 1). Table 1 shows that the most error was occurred for aerial photos of 1956 due to low scale of aerial photos. The lowest error was related to LISS III Panchromatic image due to its high resolution and also because the images were new and there was ability to field effect inspection for accuracy control was possible. Rees *et al*. (2003) and Yuan *et al*. (2005) described in similar studies that RMSe with less than one pixel will give good results [16, 17].

Accuracy Assessment: To determine accuracy of produced maps in each year, available data of the same year was used to determine valid control points. Results were presented in Table 2 and Table 3. The results show that the most accurate result relates to LISS III image with 90.4% accuracy and the least one relates to MSS image with 75.6% accuracy. This is because of this fact that MSS image is old and its spatial resolution is lower compared with other images.

In most studies, aerial photos and satellite images are used to provide land use maps. In this study, aerial photos (with visual interpretation method) and satellite images (with both visual interpretation method and NDVI, OIF and NDBI indexes) were used to provide urban maps. More significant data will lead to more information about existing composite band. The best color composite image of MSS was made when OIF index was used with 1-2-4 bands and TM photo with 3-4-7 bands.

Table 1: RMSe (in pixels) in aerial photos and satellite images

Urban map	Source of definition	Scale/ spatial resolution	Number of control points	ZRMSe
1956	Aerial photo	1:50000 scale	17	0.74
1967	Aerial photo	1:25000 scale	15	0.45
1975	MSS image	59 meters	24	0.68
1990	TM image	30 meters	23	0.53
2001	ETM+ PAN image	15 meters	24	0.42
2006	LISS-III PAN image	5.8 meters	21	0.40

Table 2: Accuracy of urban map for different years

Year	Accuracy	Number of control points	Source of accuracy/scale
1956	89.7	140	Aerial photo / 1:6000
1967	90	115	Aerial photo / 1:10 000
1975	75.6	164	Aerial photo /1:5000
1990	86.5	155	Aerial photo / 1:40000
2001	89.2	128	Topographic map/1:4000
2006	90.4	106	Field inspection

Table 3: Error matrix of urban map for 2006

Land cover class	Urban area	Non-urban area	Total pixels	Commission error
Urban area	12410	1092	13507	0.0812
Non urban area	709	4779	5488	0.1292
Total	13119	5876	18995	
Omission error	0.0540	0.1876		0.0951

Sum of pixels: 18995 Overall accuracy: 90.4% overall kappa: 77.4%

In this study, NDVI values were between -0.11 and 0.73. Green and Non-green classes were separated based on determining appropriate threshold. Results of NDVI and NDBI indexes showed that NDVI index divided agricultural and green lands from other land uses accurately while NDBI did not extract residential areas properly. There is not any good result in arid areas with NDBI index because of similar reflection of bare lands and urban areas. Thus, visual interpretation was used and all urban region maps was produced by this method. All generated maps had acceptable accuracy of 75% to 90%, the least one being one that was taken from MSS image. Accuracy of urban area map for 2006 by field inspection was 90.4%.

There are some errors in using remote sensing method which decreases accuracy of results:

- Error of geometric correction of aerial photos and satellite images because low error amount doesn't describe correct geometric correction.

Table 4: Area and population of Isfahan in different years

Year	Density	Population	Area (hectares)
1956	129.08	254708	1973
1967	116.6	424045	3637
1975	89.04	661510	7429
1990	81.3	1127030	13856
2006	87.9	1602110	18228

- Error of visual interpretation of aerial photos and satellite images. This error from satellite images interpretation is more than aerial photos because of no use stereoscope. In spite of ETM+, photos have multi spectral bands but they cannot be compared with aerial photos in size of land division and describe them in details.
- Error of difference between scale of aerial photos and spatial resolution of satellite images.

It is notable that sometimes the mentioned error sources could act vice versa and break errors. Sometimes they join together and increase the size of error in final maps more than expected.

Urban area of Isfahan during 6 different periods in current area was estimated by analyzing satellite images and aerial photos. The population rate is mentioned for comparison with given areas.

As it can be seen in Table 4, physical area of Isfahan is 18228 hectares in 2006 which have expanded about 9 times than1956. Also, studying population growth rate showed that population is 7.8 times bigger in the last 5 decades (Fig. 3). Fig.4 shows Isfahan growth in consecutive 6 periods of time. Reasons for this growth include immigration from villages to cities, regional industrialization and old areas joining the city. It is a major environmental, economical and social concern which could lead to significant problems like increasing unemployment and crime rate, environmental, health problems and lack of social and wealthy services.

By concentrating on population and urban areas, we can say that Isfahan had horizontal growth during 1956-1990 and since 1991 it has vertical growth despite higher population growth compared with urban growth. Therefore horizontal expansion and destruction of suburb lands have been less. Regarding the historical, cultural and tourism importance of this city vertical, growth means that the perspective of the historical are being alerted and it should be considered in urban planning.

As it is shown in Fig. 4, the highest population density in the city of Isfahan has occurred over the period of 1956–1975, whereas during the years of 1975 to 2001, the lowest density is observed.

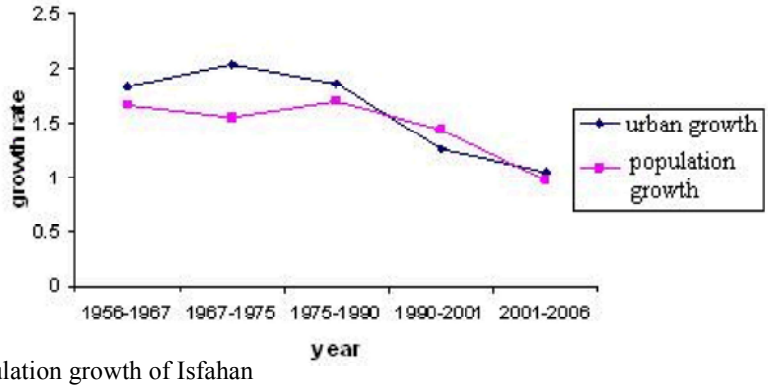

Fig. 3: Area and population growth of Isfahan

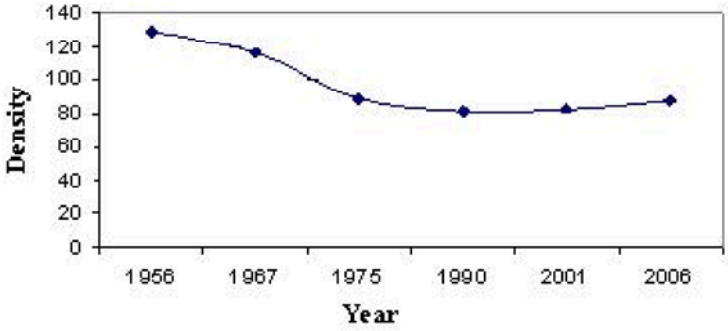

Fig. 4: Isfahan population density over five decades

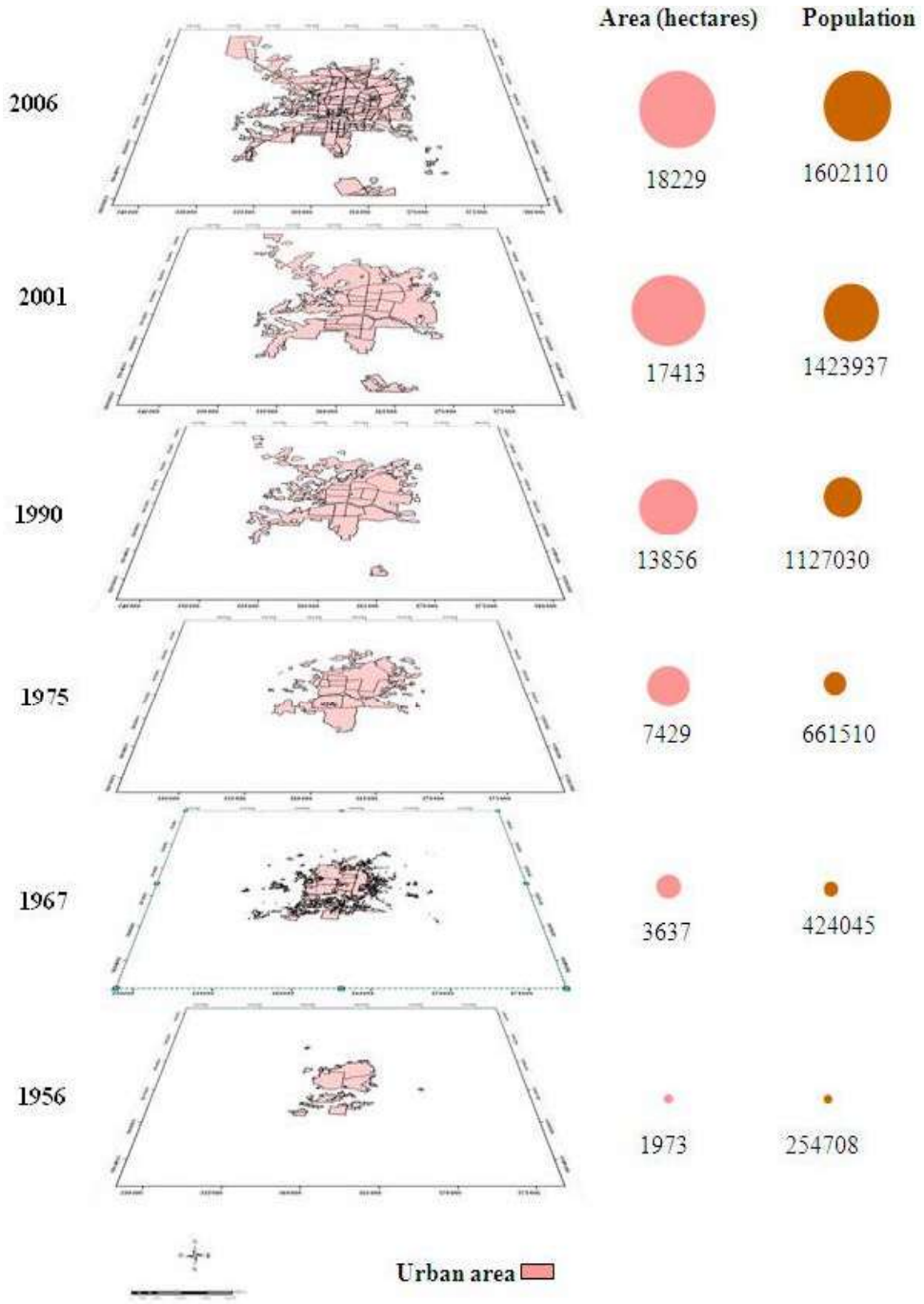

Fig. 5: Change trend of Isfahan population and urban area during 1956-2006

The major reason for high density during the decades of 1956 to 1975 was the traditional urbanization which exhibits a concentration of human activities in bazaars and settlements of families close together and around the downtown area. The factors like transportation, security and the life style supported this level of population density.

Between 1990 and 2001, on the other hand increasing the industrial areas around the city caused a basis of reducing the population density. Building roads and streets provided the possibility of using private vehicles and create the auto-oriented culture of the city. The life style began to changed and young people preferred to live independently. As a result Isfahan city was faced to

horizontal development and urban sprawl because the lower land prices in the suburbs and lack of city regulations drive developers farther out.

In the recent years (2001 to 2006) the city of Isfahan has attempted to move toward more "sustainable" compact cities by encouraging increases in population density in built up areas. This change has been occurring in the distribution of population in Isfahan city as a result of changes in policy and encouraging developers toward multi-storied buildings. Additionally, an increase in land prices and a huge decrease in the purchasing power compelled developers to build more efficient and smaller affordable apartments instead of large single-use houses.

In the process of industrialization and modernization in the city of Isfahan, the evolution of this settlement pattern and distribution was an inevitable result of socio-economic development which required rapid urban growth to improve living standards.

CONCLUSION

By comparing maps derived from aerial photos and satellite images, it can be seen that agricultural lands in Isfahan have the least stability to convert to urban areas among other lands and for this reason most of agricultural lands in Isfahan have been converted to residential and urban regions. Physical expansion of the city during 1956-2006 regarding directions is that there has been the biggest urban expansion during 1975-1977 and it was more in south and southern western direction (Fig. 5). Geographical direction of expansion of the whole city is toward North and North West. Lands located in southern bank of Zayandeh Rood River and northern parts of city and also western parts of the city have undergone the most changes among other agricultural lands of Isfahan. All of these lands were under cultivation in 1956 and were used as agricultural lands, but today they are part of the urban infrastructures. There are some reasons for this matter like road network expansion, establishing lots of industrial factories, establishing different universities, schools, lots of offices and building.

Saleh &Al Rawashdeh (2007) investigated urban expansion in three cities of Jordan using GIS and RS techniques. They used Landsat ETM+ and TM images and aerial photos to extract urban areas and monitor urban expansion in their study. Results showed a fast urban growth which mainly occurred along main roads and productive lands and. Our results are the same as this study [18].

Regarding basic logistics rules of land use planning, the first and second grade agricultural lands shouldn't be used for other purposes [19]. Results show that physical expansion in this city is against rules of land use planning, urban planning and sustainable development and it seems that it will continue in the same way in future. According to land use planning rules, there should be a frame for urban land use which can prevent inappropriate use of lands and economic and social aims, physical limitations and environmental policies should be considered. Protection rule should be considered as well. This rule insists on preventing demolition of lands, connection between urban and nature, conserving consistent, conserving cultural heritage and green space and the best land use site selection.

In expansion of Isfahan, the rule of land use planning was not obeyed, especially in agricultural lands which are categorized as consistent natural resources and expansion of Isfahan has been occurring mostly on these types of lands. Knowing that these lands are natural investments of country and there has been a lot of hard work behind them for many years we should protect and prevent them from being converted to industry and residential regions and use non agricultural lands for building and gathering population at least. Specialists think that establishing urban management unit in big cities, keeping environment clean, reaching space equivalence and controlling population growth in Isfahan, protecting, restoration and appropriate use of natural sources, management of tourism industry, increasing efficiency in economical sections are some of long term goals which can be reached just by having a view from past to now and predicting future urban growth process.

Apart from limitations and restrictions and other problems of Isfahan, this city has potential for establishment of big industries, cultural concentration, tourist attraction, etc. but it needs strong management and appropriate planning for expansion. Due to urban growth, conversion of agricultural lands, buildings construction and immigration to big cities especially Mashhad, Tabriz etc, there should be similar planning to be performed in the cities. Results of this kind of research could have major impact on urban and regional planning.

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