Urban sprawl trend analysis using statistical and remote sensing approach

Case Study: Mashhad City

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Abstract

Urban sprawl is a significant challenge in urban areas and considered as the most influential drivers of land use and land cover change associated with growth of populations and economy. Iran's cities have been faced with the urban sprawl phenomenon, especially since the 1970s. More recently, scientific studies have been proved negative impacts of urban sprawl in Iran's cities including the destruction of landscapes and natural resources around the city and coastal areas. Mashhad is a metropolis which has faced urban sprawl in recent decades. The present study aims to generate an urban sprawl model using statistical and remote sensing approach by the integration of geographic information system (GIS) in Mashhad city, northeastern Iran. For this purpose, various temporal LANDSAT satellite datasets were used to map land use/land cover characteristics and to evaluate built-up growth in Mashhad in 1996, 2006 and 2016. Maximum likelihood classification method (MLC) mapped the land cover for the Mashhad using Landsat TM datasets. The ability of MLC in minimizing misclassification errors by allowing variable weight specifications during the classification process and use of training data made it a suitable method for this study. After MLC proses, Shannon's Entropy based on the land use classification result is used to measure urban sprawl. Results indicated a significant increase of urban built-up area during the last two decades. During the two time periods of this study the Shannon entropy increased in all of the two time periods that showing the City of Mashhad continue to have a problem with urban sprawl.

Key words: Urban sprawl, Shannon's entropy, Remote Sensing, Landsat TM, Maximum likelihood classification

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1. Introduction

Urban growth has been accelerating in the past few decades with the massive immigration of population to cities (Kumar and Pandey, 2016). The rapid urban growth is becoming a serious problem in most developing countries (Tong et al., 2017). The pattern and pace of land development in which the rate of land consumed for urban purposes exceeds the rate of population growth, and which results in an inefficient and consumptive use of land and its associated resources, is termed sprawl (Liu et al., 2018). According to the complex activities which take place in the urban area, the issue of urban sprawl has been paid especial attention by local decision makers, urban planners, policymakers, climatologists, ecologists and sociologists. Moreover, the urban sprawl plays an important role in sustainable urban development (Gao et al., 2016). Unsustainable land use and land cover changes through the urban sprawl have dire consequences for land use and cause serious damage to the natural ecosystem (Arsanjani et al., 2013). Since urban sprawl is an unavoidable process, efforts can be made to direct it in the most proper way by urban land use planning so as to protect the natural resources and the needs and rights of the people (Bwanika, 2016). Hence, accurate mapping of urban environments and monitoring urban growth is becoming increasingly important at the global level (Hegazy& Kaloop, 2015). According to literature, statistical techniques along with remote sensing and GIS have been increasingly used in many urban sprawl studies. Statistical techniques have also been used to determine the relationship between the impervious area and various urban development parameters (saxena et al. 2016). In the recent years, different analysts have made considerable progress in quantifying the urban sprawl. A common approach is to consider the built up area and population density over the spatial and temporal changes (Effat and El Shobaky 2015). The built-up is generally considered as the key parameter for quantifying urban sprawl (Yang et al, 2018). Characterizing urban sprawl involves appropriate quantification and statistical summarization like as Shannon entropy, patchiness, landscape metrics, regression analysis, etc. Rabbani et al., 2017) Shannon's entropy acts as an indicator of spatial concentration or dispersion and can be applied to investigate any geographical units. It is metric calculations are taken into account statistically to measures urban sprawl patterns (Cegielska et al., 2018). It can also specify the degree of urban expansion by examining whether the land development is dispersed or compact (Aduah and Baffoe, 2013). The goal of this study is to exhibit the integrated use of remote sensing and GIS together with Shannon's entropy in addressing a basic environmental issues of the developing countries at a local level. Precise objectives are to evaluate urban growth patterns in the studied area in the last 20 years through Shannon's entropy approach. This measurement of physical growth in Mashhad city is essential to urban planners and decision-makers who immediately need updated database for planning and management purposes.

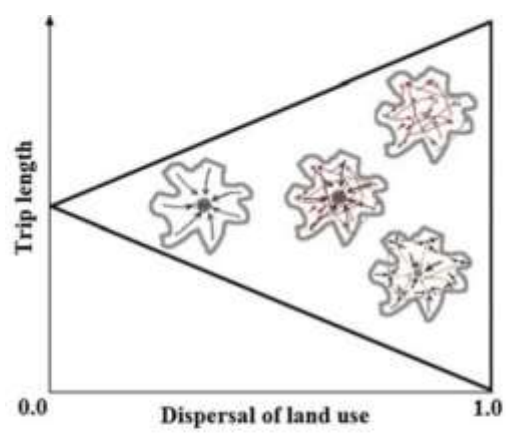
2. Literature review

2.1. The Urban sprawl phenomenon

The term "urban sprawl" has been widely used in spatial planning discipline. Despite the widespread adoption of the term and spatial identification of the phenomenon, there has not been a commonly accepted definition. Initial efforts to determine "urban sprawl" date back to the 1970s, and till now numerous definitions have been attempted by several research institutions, universities and organizations (Pozoukidou & Ntriankos, 2017).

Urbanization process is the complex phenomenon of transforming rural areas into urban lands, resulting in various effects on environmental structures. Rapid urbanization leads to dispersed urban development surrounding existing urban areas causing the urban sprawl phenomenon (Adolphson 2010). Exponential growth in urban population requires more facilities, houses, and so on, thus forcing the expansion at the boundary of existing urban areas to the rural environment. Hence, urban sprawl is supported by piecemeal extensions of essential urban infrastructures, such as sewers, roads, water, and power (Paulsen, 2014). Historically, the escape of the middle class affluent of the population after industrialization period from the high-density central parts, with congestion, pollution, and so on, to the low-density suburban areas with better neighborhoods was the main reason of suburban expansion. Currently, economic issues force the low-income population to acquire and construct undeveloped and cheap lands for more affordable residential buildings, especially in developing countries. Minimum regulation for construction, maximum tax incentives, low commuting costs, and the role of individual choices are some other factors that promote fringe development (Brandful & Nsomah, 2017). The term "urban sprawl" can be used both as a verb (process) and as a noun (condition), but it still requires a clearer definition despite many researchers claiming to "know it when they see it". However, a general agreement exists that urban sprawl is the combined effect of growing affluence, changing life style, and increase in private mobility. Thus, a concern toward the interaction between transportation and urban form is important to understand sprawl development (Abdullahi et al, 2018) (Fig.1)

Fig.1.The relationship between trip length, dispersal and urban form (Abdullahi et al, 2018)



The complexity of urban sprawl is also caused by the micro and macro perspectives of this phenomenon. At the micro level, changes in geography, climate, local public policy, and so on may all influence the expansion patterns of cities. At the macro level, urban sprawl reflects interregional migration, population growth, changes in transport systems of commuting, and increasing income among others. Unfortunately, no clear and distinguishable classification of sprawl development with significant regional and temporal variations exists. Consequently, sufficient data with detailed information on the micro spatial causes of sprawl are required to study and analyze urban sprawl accurately (Banister, 2012).

2.2. Characteristics of urban sprawl

Urban sprawl development has several characteristics, such as leapfrog or scattered, commercial strip, low density, and large expanses of single land use developments. Leapfrog or scattered development increases the growth of isolated built-up areas along the city borders. Similar to satellite towns, this kind of urban pattern is the most land resources-consuming form, with the highest car dependency and requirements of transportation network and other utilities. Commercial strip development is characterized by huge major roads lined with fast food restaurants, gas stations, shopping centers, drive-through banks, office complexes, and many other structures (Ewing and Hamidi, 2015). This kind of urban pattern has low density and high car dependency, with long and low box configurations of retails surrounded by parking spaces. The development characterized by widespread, single story buildings with separate parking spaces and roadways in low density is the most obvious format of sprawl urban development. Finally, developing urban areas of single land use pattern with separation of different land use categories and urban activities is another important characteristic of sprawl development. Single land use development absolutely increases daily car dependency because of the separation of living, working, and recreational facilities locations. (Karakayaci, 2016)

2.3. Effects of urban sprawl

Sprawl development has several environmental, social, and economic effects on human life and natural environment because of its pattern and characteristics, it has some positive aspects as well. In the quality of life perspective, sprawl development provides single-family homes on large parcels with high movement freedom and green environment out of the city center with high density, traffic congestion, and high crime and poverty rates. Large house in a green and low-density neighborhood and multiple car ownership indicate affluence and wealth in most the cultures (Chen et al, 2014). Suburban and urban fringes are more attractive for living purposes than inner cities because of such advantages. The negative effects of sprawl development on human life and natural environment should not be forgotten because of these few personal benefits. Urban sprawl has become a major problem in rapidly growing and developing countries (Dadi et al, 2016). The negative impacts were highlighted further since the emergence of the sustainable urban development concept (Ren et al, 2013). Therefore, this topic has gained considerable amount of attention among public and urban researchers because of various unsustainability characteristics. Public concern about this topic and its effects increased significantly after the 1990s (Verbeek et al, 2014). The dispersion of urban structures and separation of human activities in sprawl development in addition to higher land consumption increase fuel consumption, traffic congestion, and commuting time. This also leads to the increased concern on air quality and the associated costs from human and environmental health issues (Emadodin et al, 2017). Specifically, concern on the global warming issue causes more attention to be focused on the air pollution and carbon emission from the automobile dependency of the sprawl development pattern. Although the carbon emission of current automobiles has been significantly reduced compared with older models (made before 1970) because of technological advancement, the spatial dispersion of urban patterns (which increase vehicle miles traveled—VMT) has still caused the emission of huge amounts of carbon into the air in the recent decades. Thus, considering that sprawl urban development increases VMT substantially is very important (Gu et al, 2014).

2.4. Theoretical framework

Studying urban growth has been an intense subject of research especially with the availability of spatial data and geospatial tools. Typically, the degree of urban growth or sprawl is attempted by quantifying for the amount of paved surface or the built-up area in a given region obtained from the classification of remotely sensed data or other geospatial data.

Characterizing the pattern of urban sprawl would then rest on noting the extent of built-up areas and its associated measures that depict sprawl based on the notion of built-up or paved area. A key aspect in the expansion of built-up area is its engulfing of surrounding open spaces. Hence an attempt is made to assess the extent and pattern of such expanse while answering whether urban sprawl leading to loss of open spaces comprising water bodies, vegetation, etc. So in this study, for studying urban sprawl from the indicators in built up area including buildings, weathered roads and human settlements of any size and non-built up area including Open/Bare Land and Agriculture/Green space is used.

3. Materials and Methods

3.1. Study area

Mashhad as the capital city of Khorasan-e-Razavi province has about 3057679 populations (Statistical center of Iran, 2016) which located in the northeastern Iran (36°37′–36°58′N, 59°26′–59°44′E) (Fig. 2). This city is located in semi-arid region with sensitive climate that experiences mean annual temperature of 14 °C and annual precipitation of 260 mm based on a long-term time-period of 1966–2016. The spatial analysis of urban topography in GIS indicated that the highest part of the city in the southwest has an altitude of 1340 m above sea level and the lowest part in the northeast has an altitude of 920 m above sea level.

The surface area of urban restriction of Mashhad is recorded as 292 km2. Hence the population density of Mashhad is 87 p/ha in 2016.

Fig.2. General Position and geographical location of the study area

3.2. Datasets

In the present study, various temporal LANDSAT satellite datasets were used to map land use/land cover (LULC) characteristics and to evaluate built-up growth in Mashhad in 1996, 2006 and 2016 (Table1). The LANDSAT satellite images downloaded from the USGS website (http://earthexplorer.usgs.gov) for the year 1996, 2006 and 2016. These satellite images were geometrically corrected and acquired in the standard projection system (UTM 40N, WGS84 datum). All these satellite images were acquired in the month of November due to which the impact of seasonal variations was very insignificant on these images.

Table1. Details of Satellite data used in the study

LANDSAT Sensors	Date of Acquisition	Data source	True color composite (TCC)
TM	23th Nov. 1996	US Geological Survey (USGS)	BAND 7, 4, 1
TM	16rd Nov.2006	US Geological Survey (USGS)	BAND 7, 4, 1
TM	7th Nov. 2016	US Geological Survey (USGS)	BAND 7, 4, 1

3.3. Image pre-processing and classification

The atmospheric correction is a necessary step to accurately extract quantitative information from the Landsat (Liang et al., 2001). To image pre-processing, Landsat TM image rescaled to the Top of Atmosphere (TOA) reflectance and/or radiance using the standard Landsat equations and scaling factors. The reference data include aerial photographs; land use maps were used to assist in supervised training site selection for Land use/cover change features of interest. Based on different bands of the Landsat images a composite image was created that helps us to clear distinguish the different Land use/cover change in images. Land cover classification was performed using supervised Maximum likelihood classification method (MLC). MLC is a probability approach, which makes use of training sites (sample areas) to determine classes of each cell in the image. Theoretical statistical distribution allows the uses of the MLC, which produces lowest probability of misclassifications.

The MLC used both variance and covariance of the class signature derived from training sites when allocating each cell to one of the classes in the signature file. MLC was used for spectral classification of the land sat images based on the training sites, at a 30 m resolution and a projection system (UTM-WGS 1984 Zone 40 N). The three land cover classes were identified in the study area, namely, built-up areas, Open/Bare Land and Agriculture/Green space (Table 2).

Afterward, post-classification refinements were used to reduce classification errors created by the similarities in spectral responses of individual classes. Additionally, a normalized spectral mixture analysis was applied to address the problem of mixed pixels. After image classification, mode filter (5 * 5) was used to each classification to generalize the supervised classified land cover class maps and remove the isolated pixels. Finally, the generalized images are reclassified to create the final version of land cover class maps for 1996, 2006 and 2016.

3.4. Urban sprawl measurement

One of the measures commonly used due to its toughness in urban sprawl measurement is Shannon's entropy (Mashagbah, 2016). It measures the patterns of built-up area either dispersed or concentrated over time. Entropy calculation is based on computation of area. It is measured with the help of a combination of remote sensing (RS) and geographic information system (GIS). (Sarvestani et al. 2011). In this study Shannon's entropy used to measure the degree of urban sprawl. Land cover maps for 1996 in addition to 2006 and 2016 were used in the Shannon's entropy computation in order to determine the degree of sprawl. Shannon's entropy spatial-based algorithm uses entropy values ranging from 0 to 1; with 0 indicating maximal concentration of built-up areas and the value 1 indicating uneven dispersion of the built-up areas (urban sprawl).

Table2. Classes used in the land cover classification

S/N	Land cover class	Description
1	Built-up Areas	Buildings, weathered roads and human settlements of any size
2	Open/Bare Land	Bare soil, barren land, rock cover and cleared construction sites
3	Agriculture/Green space	Cropped land, fields, range-land, pasture land and agro-forestry systems falling below the thresholds used for the Tree cover

4. Results and Discussion

4.1. Land cover changes in Mashhad

The classified images obtained after supervised classification which are showing the land use and land cover of the study area are given in Figs. 3–5. These images provide the information about the land use pattern of the study area.

Fig.3. Land cover maps from the supervised classification of Landsat TM image of 1996.

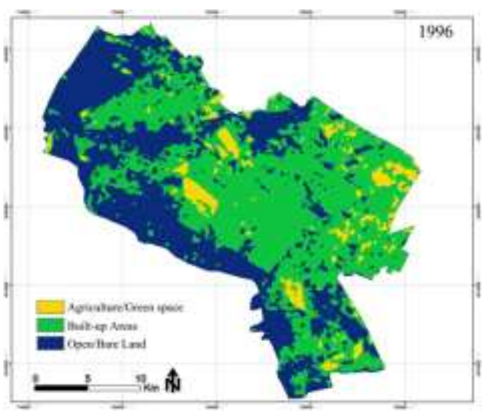


Fig.4. Land cover maps from the supervised classification of Landsat TM image of 2006.

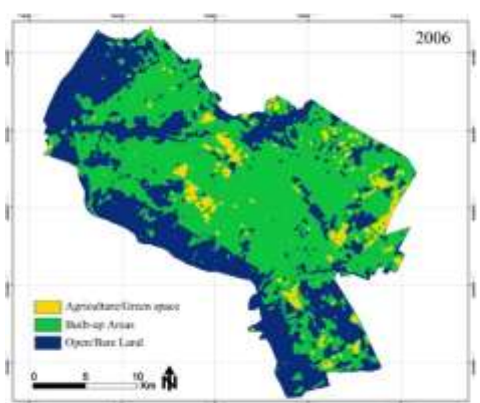
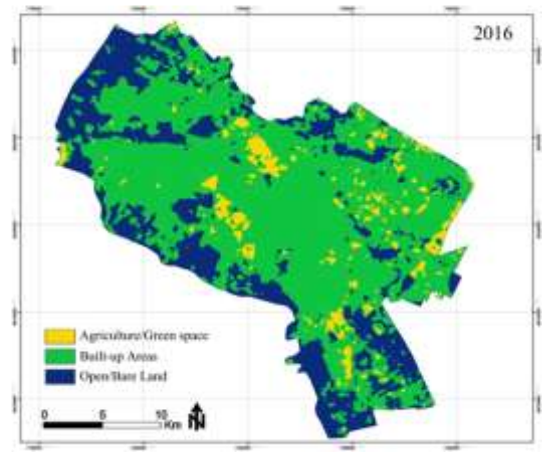


Fig.5. Land cover maps from the supervised classification of Landsat TM image of 2016.



Increase in urban areas shown with the increase in the impervious surfaces (built-up areas), which was apparent on the land cover maps. These land cover maps visually reveal urban sprawl in the Mashhad and its clear built-up areas are expanding outwards into non-built-up environments. Based on the results from 1996 to 2016, there was a notable change in urban areas as it increased from 17793.39 (1996) to 23170.8 ha (2016) (Table 3). This increase in built-up area primarily attributed to the increase in population and infrastructure developments in the study area.

Table3. Built- up and non-built-up areas in hectares of each year from 1996 to 2016.

Year	1996	2006	2016
Built-up Areas	17793.39	18829.98	23170.8
Non Built-up	10931.3	9894.71	5553.89
Total Area in Area	28724.69	28724.69	28724.69
Percentage (%) Built-up Areas	61.94	65.55	80.67
Percentage (%) Non Built-up Areas	38.06	34.45	19.33

4.2. Measurement of the urban sprawl

The results of applying Shannon's Entropy spatial-based algorithm on the land cover maps of 1996, 2006 and 2016 are 0.2, 0.3 and 0.5 respectively (Table 4).

The maps were reclassified into two classes (Built-up and non-built up), then concentric buffer zones of 500 m drawn from the municipality's center in order to calculate the amount of built-up areas for use in the Shannon's entropy (H_k) formula (Eqs. (1) and (2)).

$$P_i = \frac{x_i}{\sum_{i=1}^{n} x_i} \quad (1)$$

$$H_k = [\sum_{i=1}^{k} P_i * log_e P_i] / log_e(k) \quad (2)$$

Where; pi: Probability value , x_i: [(Quantity of built-up area in i th of k buffer zones) / (total quantity of land)].

Table4. Mashhad City: Shannon's Entropy Value

Year	Value of Shannon's entropy
1996	0.21
2006	0.34
2016	0.58

The entropy values obtained in the study were 0.21 in 1996 and 0.58 in 2016. Entropy value confirmed a gently increasing rate in the study period, meaning that study area grew toward a dispersed development. The result show that the distribution of built-up in the region in 1996 was more or less dispersed, the degrees of which had further increased in 2016.

4.3. Factors responsible for urban sprawl development in Mashhad

Migration, population and economic growth as prominent factors causing urban sprawl. (Kantakumar et al., 2016). Examining the population data from 1996 to 2016 (Table 5), a consistent population rise is observed. This increment is attributed to natural factors such as fertility as well as refugee influx. Additionally, Fig. 2-4 shows that as much as built-up areas increased from 2006 to 2016, there are observably spotted built up areas across the study area such as in the North West. These spotted, unplanned built-up areas lead to urban sprawl as residents follow new infrastructures such as new roads, schools, water and the opportunities it provides.

Table5. Population changes of Mashhad 1996–2016.

Year	Population
1996 census	1887400
2006 census	2427300
2016 census	3057679

5. Conclusions

Rapid urban sprawl calls for sound urban planning strategies hence the need to assess and quantify the uncontrolled or controlled encroachment of urban environments into the urban fringe. To ensure sustainable management of urban areas, remote sensing and GIS technologies provide the adequate and relevant information that is required in informing decision-makers. The study further shows that remotely sensed data coupled with Shannon entropy approach acts a good indicator to recognize and measure the spatial extends of land development both at regional and local level. Again, in order to maintain a systematic urban growth pattern at regional or global level, effective management planning has to be prepared initially at local level. This paper demonstrated the capability of Remote Sensing techniques and Shannon's Entropy in assessing urban sprawl developments. The land cover change analysis revealed that the built up area has shown a constant increase (from 1996 to 2016) and Open/Bare Land and Agriculture/Green space have decreased over the last two decades. The obtained Shannon's entropy values indicated that spatial expansion of Mashhad city is sprawling and at the time of 1996 the city was more compact compared to 2006 and 2016. It is noted that although the extent of built-up area increase was around 20 percent, it did not reveal any pattern of the built-up spread or suggested the characteristic of sprawl. However, by computing the Shannon's Entropy it revealed the growth of sprawl over the two periods. It may be noted that the reliance on the metrics is dependent on the accuracy of classification, the discussion of which, is beyond the scope of this paper. Further from studying the built- up and non-built-up areas this result was obtained that the most changes were occurred in the regions of Northwest and Southwest in Mashhad. The rate of growth is quite high and needs proper management to attain sustainable development. Else large numbers of driving forces such as population increase, economic growth and ineffective implementation of land use planning will lead to possible considerable impacts on surrounding environment. Hence it is imperative that with reliable data, planning and managements, urban expansion into other land use/land cover should be monitored and managed in a sustainable way to protect the natural land covers of the biosphere.

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