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Landscape Metrics for Urbanization and Urban Land-Use Change Monitoring from Remote Sensing Images: A case of Shiraz Metropolis, Iran

Mohammadreza Elmi[1] Abdulmannan Rouhani[2]* Ehsan Keshavarz[1]

[1] *School of Natural Resources and Desert Studies, Department of Environmental Science, Yazd University, Yazd, Iran*
[2] *Environmental science, Graduate of School of Natural Resources and Desert Studies, Department of Environmental Science, Yazd University, Yazd, Iran*

INFORMATION

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Contact
*Abdulmannan Rouhani
a.rohani70@gmail.com

ABSTRACT

Urban development causes fundamental changes in the ecological structure and functioning of landscape and gradual change in the spatial structure and landscape pattern. Landscape ecology concepts can be used in landscape planning to reduce the negative impacts of urbanization. Landscape ecology, based on landscape metrics, is an appropriate tool for mapping and quantifying spatial land use characteristics. The aim of the current study is to quantify the spatial pattern of Shiraz metropolitan area using landscape metrics over a 36-year period. The metrics used for the analysis were Number of points (NP), Point density (PD), Edge density (ED), The edge effect (TE), Largest point index (LPI), Landscape index (LSI), Shannon diversity index (SHDI) and Shannon equality index (SHEI). These metrics were produced for the years 1982, 1996, 2006, and 2018. The classes of urban area, agriculture, tree cover, bare land, and street/road were the subjects for analysis. Results of the study reveal fragmentation of agricultural land and tree cover over the third period of the study (2006-2018). Increase in suburban area between 1982 and 2006, due to the increasing growth of urbanization, has taken place in different directions, which shows disorientated and disorderly trend; however, the trend has declined between 2006 and 2016, indicating orientation of outskirt development as a result of building ring roads within the study area. Economic growth and increased urbanization have been identified as the most important factors affecting land use in the area.

1. Introduction

The population concentrations and socioeconomic activities in urban areas have resulted in fast urban sprawl worldwide over the last decades (Li et al., 2017; Zhang and Su, 2016). If this growth continues, urbanization will nearly triple by the end of 2030 (Luederitz et al., 2013). At the same time, other land-use types particularly forest and agricultural lands surrounding the urban areas will be embezzled over the rapid growth of cities. These enormous changes in land use and drastic human activities reported major problems to human and natural environment (Sahana et al., 2018; Dadashpoor et al., 2019), for instance the biodiversity loss (Bihamta et al., 2014), an enhance of the urban heat island impact (Min et al., 2019; Zhou and Cao, 2020), continuous degradation of environmental (Dadashpoor and Salarian, 2018; Simwanda and Murayama, 2018), reduced watershed runoff and enhanced flood potential in urban areas (He et al., 2019), and increased CO_2 emissions (Ali et al., 2019). These problems have been broadly investigated in term of landscape patterns (Li et al., 2017; Zhang and Su, 2016) and are commonly reported using landscape metrics (Jiao et al., 2019; Shen et al., 2019; Yang et al., 2019).

Currently, urban sprawl is accelerating globally (Liu and Li, 2017). Urban spatial sprawl, as a crucial aspect of the urban expansion process, has always been a trending topic globally in the fields of urban geography, urban planning and urban land use survey (Wen et al., 2016; Liu et al., 2016; Feng et al., 2018). Tremendous efforts have already been made to use quantitative factors and more objective methods to evaluate the environmental influences of urban development. With the emergence of the modern science of landscape ecology, novel insights appeared regarding the study of urban ecology and its impacts (Xiao et al., 2003). With advanced developing in the Remote Sensing (RS) and Geographic Information Science (GIS) techniques it becomes easier to describe a landscape and quantify its structural changes. Over the last few decades, a set of indices has been introduced to evaluate landscape patterns in term of area, shape, aggregation and diversity (O'Neill et al., 1988; Feng et al., 2018). In most of the studies on urban landscape and its structural model analysis, a combination of gradient analysis and landscape metrics has been used (Wang et al., 2008). Luck and Wu (2002) were the first to use a combination of gradient method and metrics analysis to study the Arizona city pattern (Lausch and Herzog, 2002).

Landscape metrics are between the ways broadly used for evaluating (Wu et al., 2017), monitoring and landscape patterns planning (Peng et al., 2010). Studies have shown that most landscape metrics are calculated on land cover/land use classified maps (Buyantuyev et al., 2009). Using landscape metrics, one can study the spatial patterns of the considered area and its changes in relation to urbanization processes, and can interpret the effects of these processes on environmental characteristics. Moreover, these metrics can be used in making decisions concerning urban growth, distribution of land uses and planning sustainable urban development (Ji, 2008). Landscape metrics are appropriate indicators for the evaluation of land use changes within a specific period; hence, the most efficient ones must be selected and applied (Pelorosso et al., 2009; Buyantuyev et al., 2009).

Landscape metrics are regarded to be crucial indicator of landscape heterogeneity and its impacts on many kinds of ecological processes (Hao et al., 2017). These metrics can provide environmental conditions or vulnerabilities in the studied area in quantitative terms (Turner and Gardner, 1994). Projects and programs that are more environmentally efficient often require the quantification of spatial patterns. In recent years, various studies have been conducted on the benefits of terrestrial land metrics for land planning and management around the world, the most important of which include Xu et al. (2020), Tong et al. (2019), He et al. (2020) and Dadashpoor et al. (2019).

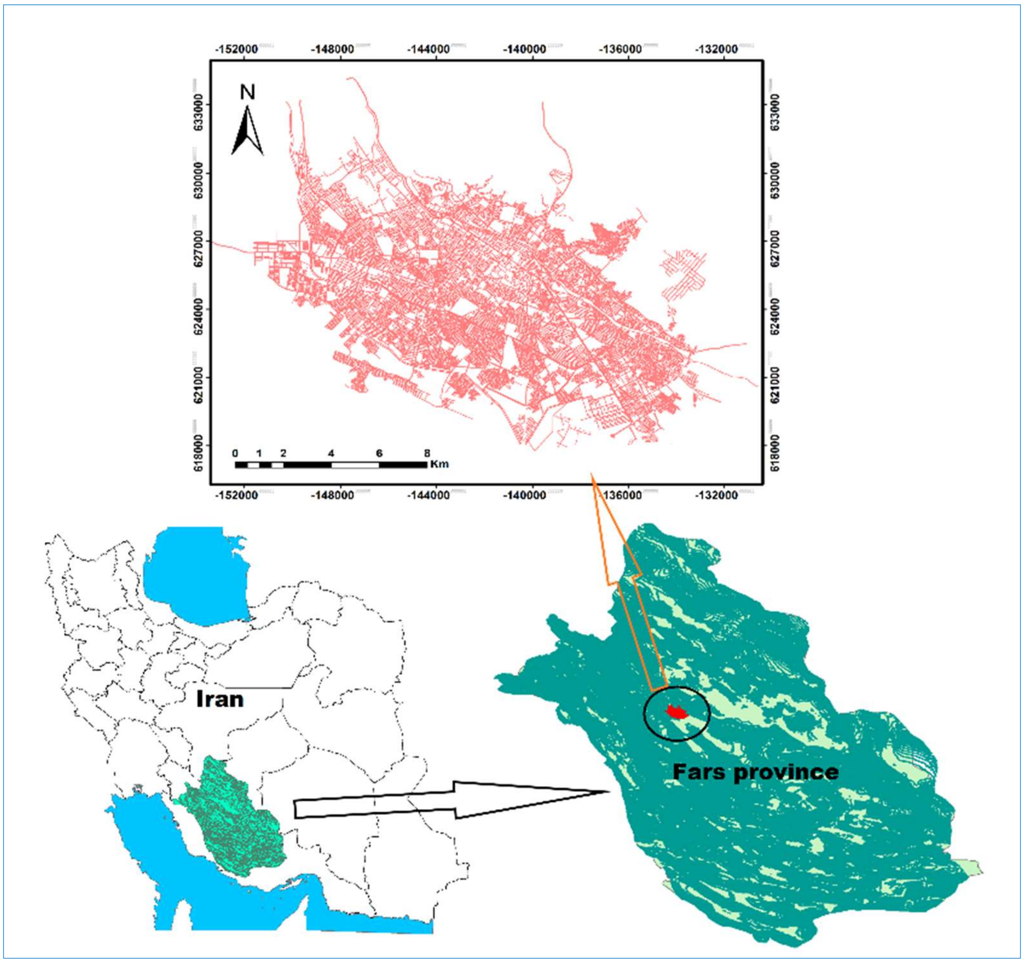

Fig.1. The location of the study area

The aim of the current study is to quantify the spatial pattern of Shiraz metropolitan area using landscape metrics over a 36-year period. The Shiraz is an area which requires comprehensive, integrated urban management due to rapid urbanization and its industrial and agricultural applications as well as cultural, historical and natural values. Investigation of spatial-temporal changes in the urban pattern and quantifying it via landscape metrics can be a significant step in the study of urban pattern of Shiraz, and can help decision-makers and policy makers with better management of the city. The current study is aimed at primary recognition of structure and function of Shiraz landscape. To perceive the mechanisms of landscape pattern, a comprehensive framework is required based on geography and ecological sciences and socio-economic considerations.

2. Materials and Methods

2.1. Location of the area under study

As the center of Fars Province, Shiraz is the most populated area in the southern part of Iran and is located on a wide plain with a length of 120 km and width of 15 km. Its latitude and longitude specifications are (29°53'N, 52°58'E). Its latitude varies between 1448 m in the eastern part and 1700 m in the western part. Shiraz city is situated in the central part of Shiraz Township and takes 71.1% of its area and 15% of the area of the whole Fars Province (Fig. 1).

This city is located in a mountainous area and has moderate weather. A seasonal river runs amid the city, known as Khoshk (dry) River, which contains water only in winter and spring. This river runs into Moharlou Lake in the southeast of the city. With an area of 348 km^2 and a population of 1547129, Shiraz is the third big city in Iran in terms of area and the sixth one in terms of population. Shiraz is restricted with Drak Mount in the west and Bamo, Sabzpooshan, Chehelmagham and Babakouhi Mounts in the north. Based on the latest divisions, Shiraz Township consists of nine urban districts and has an area of over 178 km^2. Reduced agricultural activity and green space, along with the establishment of industries and increased construction activities, especially road and street construction, have changed the city's image in recent years, leading to an imbalance in the ecosystems. Landscape metrics are appropriate tools to describe spatial patterns and variety of the landscape in the area under study.

2.2. Methodology

In the current study, Landsat satellite images from MSS, TM and ETM sensors during the years 1982, 1996, 2006 and 2018 were used together with 1:50000 map obtained from the geographical organization of the Armed Forces and the Mapping Organization. For the purpose of geometric correction, firstly, geometric correction of OLI sensor images for 2018 was carried out using 1:50000 topographic maps of the area. To do so, 38 points with proper distribution on the image and map were selected and geometric correction was made using the first-order equation and the sampling was performed using the nearest neighbor method. In the next phase, ETM Landsat images for 1982 were recorded on 2018 images. Table 1 shows the RMSE of each image.

Land cover maps of the area under study were prepared using a supervised classification method. Land cover maps were categorized into 5 classes; agriculture, urban area, bare land, tree cover and street (Table 2). Pixel size of land cover maps is an effective factor in calculation of the metrics; hence a pixel size of 30 m was considered for the evaluation and comparison of the metrics.

The most common and standard method for determining the accuracy of classified maps is to use an error matrix. Another method is using general accuracy which is one of the indicators used to express the accuracy of the results obtained from different classification methods. The Kappa coefficient can also be used to compare the classification results (Park et al., 1925).

Table 1. RMSE of each class of image

Image	No. of land-control spots	RMSE
Landsat OLI sensor (2018)	38	0.43
Landsat ETM sensor (2006)	35	0.54
Landsat TM sensor (1996)	32	0.44
Landsat MSS sensor (1982)	35	0.41

Table 2. categorization of land cover map

Category	Description
Agriculture	Agricultural land and fallow land
Tree cover	Gardens and orchards, green space and parkes
Bare land	Bare land, solon chalk, weak pastures, mounts and lands without any construction
Street	Street and road
Urban	Residential and trade area and industrial districts

For this purpose, 70 spots were selected via random sampling, and the accuracy of the classification was examined based on relative recognition of the area under study and Google earth software as well as GPS application in field studies; accuracy matrix of each map was prepared accordingly (Table 3).

Table 3. Kappa coefficient and general accuracy of land use maps

Land use map	Kappa coefficient	General accuracy
OLI 2018	0.78	90.5
ETM 2006	0.79	91.5
TM 1996	0.78	91
MSS 1982	0.80	92.2

Table 4. Landscape metrics

Metrics	Symbol	Unit	Range of changes
Number of points	NP	-	NP>0
Point density	PD	Meter per hectare	PD>0
Edge density	ED	Meter per hectare	ED>0
The edge effect	TE	Meter per hectare	TE>0
Largest point index	LPI	Percent	0<LPI<100
Landscape index	LSI	-	LSI>0
Cohesion			
Shannon diversity index	SHDI	-	SHDI>0
Shannon equality index	SHEI	-	SHEI>0

2.3. The studied metrics

To carry out the analyses, a number of metrics were selected at the level of class and landscape. Both combination and distribution metrics were used to show the changes in the landscape of the area. Metrics with high correlation coefficients were eliminated through Pearson's correlation test and correlation matrix of the landscape metrics. The metrics were calculated on the FRAGSTATS and ArcGIS at the class and landscape levels (Turner and Gardner, 1994). Table 4 presents a list of the metrics used in the study.

3. Results and Discussion

3.1. Quantification of landscape spatial pattern

Landscape indicators were used in the present study, including landscape percentage, NP, LPI, environment density index, LSI, and the TE index, so that the changes in the landscape pattern can well be manifested via investigating the changes in these indicators. The NP for the tree cover has increased during the first period, decreased during the second period and increased in the third period, indicating the fragmentation of this usage in the studied area in the first and third periods. Reduced NP in the second period is also due to the destruction of smaller spots in the area, as a result of the destruction of the tree cover and its transformation into urban construction areas. The NP for the road and street has increased, indicating the development of the road network in the region.

However, the reduction in the NP for urban areas indicates an increase in continuity due to the increasing number of urban areas in the studied area. Agricultural use shows a decrease in the total of three study periods. Due to the transformation of agricultural use to construction, a large part of agricultural use and farm points have been destroyed, which indicates a decrease in the NP (Table 5). Due to temporal difference in the comparisons, one of the best indicators that can show the changes in the NP is the PD. The PD in urban areas ranges from 36 points per 100 hectares to 19 points per 100 hectares, which shows a significant change.

Also, in case with agriculture, the index varies from 39 points per 100 hectares in 1982 to 17 points per 100 hectares in 1996. It is estimated that there is a significant reduction in the number of agricultural points. The increase in the NP for tree cover from 17 points per 100 hectares in 1982 to 32 points per 100 hectares in 2018 indicates the fragmentation of this usage, which is clearly evident with this indicator. Also, due to the inherent continuity, Road and street cover has increased from 3 points per 100 hectares to 5 points per 100 hectares, which is one of the major causes of fragmentation of uses such as tree cover and bare land cover.

Fig. 2 shows the rate and pattern of changes in PD for different land uses in the studied area. Due to the increase in the urban areas, point density, which is a function of the NP per hectare area, has dramatically decreased. Also, the increased PD for tree cover indicates the fragmentation of this usage in the studied area.

Table 5. Changes in landscape metrics between 1982 and 2018 in the area

Land cover and use	PD				NP			
	1982	1996	2006	2018	1982	1996	2006	2018
Agriculture	0.39	0.24	0.17	0.25	149	93	66	95
Bare land	0.12	0.31	0.32	0.35	47	117	122	134
Tree cover	0.17	0.24	0.21	0.32	65	91	79	123
Road and street	0.03	0.29	0.01	0.05	11	11	6	20
Urban area	0.36	0.34	0.25	0.19	139	128	96	74

Table 6. Changes in landscape metrics between 1982 and 2018 in the area

Land cover and use	TE (x10^4 m)				ED			
	1982	1996	2006	2018	1982	1996	2006	2018
Agriculture	13.08	6.32	4.83	5.45	149	24.05	18.43	20.85
Bare land	20.67	24.84	23.47	24.01	47	94.46	89.61	91.81
Tree cover	6.44	9.94	9.50	10.03	65	37.81	36.26	38.38
Road and street	2.70	15.39	23.04	27.56	11	58.51	87.99	105.41
Urban area	16.33	39.93	43.53	42.41	139	151.95	166.21	162.20

The TE index is an edge indicator which decreases the length and distance of various land uses. In the current study, this index is used to show the edge of land uses including agriculture and tree cover to yield an understanding of the effectivity of the land use. Despite the decrease in tree cover in the studied area, the TE index has increased in this case, which indicates that with the passage of time and the destruction of a large part of the tree cover, the impressibility of this land cover from marginal (edge) areas has increased. Urban areas will be followed by a significant increase in the TE due to the increased area and road and street cover has also experienced a ten-fold increase in the studied area (Table 6). Reduced TE for agriculture has been due to the destruction of this land cover, and the TE for bare land has increased due to the segmentation of this land cover as a result of urban development and road network in the studied area. To better illustrate the TE and standardize the comparison of edge (marginal) variations in this study, the ED index has been used and the edge of land use and land cover per hectare has been shown in Table 6.

The graph in Fig. 3 shows the TE index in the area under study. The increase in urban edge between 1982 and 2006 is due to the increasing growth of the city in different directions in a disordered manner; however, the decrease in the urban edge between 2006 and 2018 shows the directed and ordered manner due to the establishment of ring roads. Moreover, the dramatic increase in TE for road and street cover has been attributed to the development of road networks (Fig. 4).

The ED index, shown with meter per hectare, is depicted in Fig. 5. This standardized index is used to compare two regions with the same area or for the comparison of the same area in different periods.

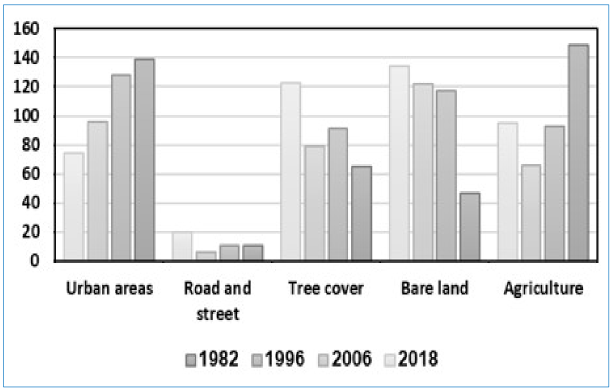

Fig. 2. Changes in the NP for various land uses (covers) in the area

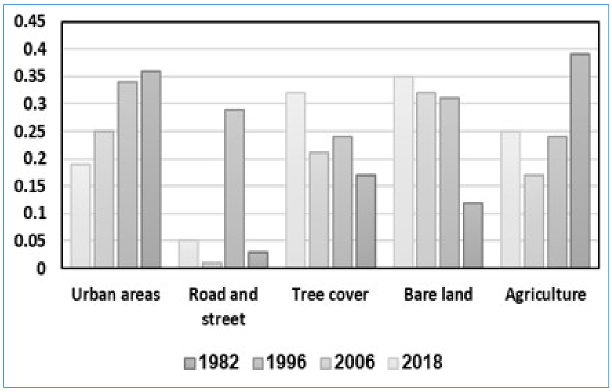

Fig. 3. Changes in the PD for various land uses (covers) in the area

The LPI is used at landscape and class level, and shows the percentage of the whole landscape covered by the largest point regarding the considered land use. Values of this index were calculated for all the land uses in the area and are shown in Table 7. In this study, an increase was observed in the LPI for all land uses in all the three periods. In fact, in 1982, the largest point for urban area covered only 7.53% of the whole area while it increases to 36.07% in 1996 (Table 7). This growth indicates high integration of this land use in the area.

This index decreased for agriculture in all three periods, showing the reduction of this land cover in the area. In fact, the largest point for agriculture in 1982 was 2.89% of the whole area, decreasing to 1.15% and 1.05% in 1996 and 2006, respectively, and even further decreased to 0.45% in 2018 (Table 7). Transformation of agriculture to construction in the recent years is a major factor in this regard. Similarly, the index has decreased for tree cover. In 1982, the largest point has been 5.23% of the whole area, decreasing to 3.92% in 1996. Although the index increased to 4.43% in 2006, it decreased to 2.33% in 2018 (Table 7). The temporary increase has been due to the establishment of parks and temporal consideration of the importance of green space in those years. The LPI for bare land has decreased from 61% in 1982 to 11% in 2018. This shows segmentation of this land cover into smaller pieces. Urban development and road development are among the major factors in this regard. Finally, economic growth and increased urbanization in the area have led to the increase in the LPI for street and road cover.

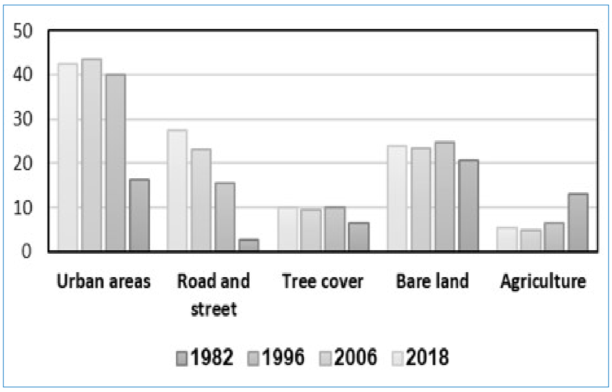

Fig. 4. Changes in the TE for various land covers in the area

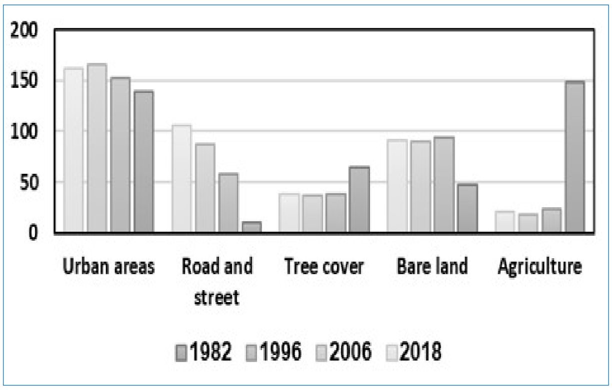

Fig. 5. Changes in ED for various land covers in the area

The landscape shape index, which is calculated as the ratio of the environment to the area in the landscape, is the same indicator as the habitat diversity in ecological studies. Although this index has been calculated at the class level in this study, it can also be used at landscape level. In this study, the index was calculated for agricultural use, which showed that the index decreased from 20 units in 1982 to 13.55 in 2006 (Table 7), which is due to the isolation and reduction of diversity in this land use.

This index has increased in case with bare land area due to segmentation and increased diversity in this edge. The increase in this index for tree cover from 10 units in 1982 to 18 units in 2018 shows the increased diversity in this land use. However, tree cover will be affected by human activities due to its sensitivity. This may lead to complete destruction of this land cover in future. This index has also increased for street and road from 25 units in 1982 to 79 units in 2018 (Table 7).

Finally, this index has increased for urban area during the first two periods due to the development of cities and distribution of residential centers in the area; however, the objective development during the recent years has resulted in more order and integration in the area and as a result, this index has decreased in the third period.

Table 7. Changes in landscape metrics in the area between 1982 and 2018

Land cover and use	LSI				LPI			
	1982	1996	2006	2018	1982	1996	2006	2018
Agriculture	20.07	16.43	13.45	16.86	2.89	1.15	1.05	0.45
Bare land	15.06	20.69	20.77	21.28	61.01	12.77	10.56	11.02
Tree cover	10.35	16.17	16.32	18.44	5.23	3.92	4.43	2.33
Road and street	25.81	59.21	72	79.72	0.20	1.58	2.44	2.82
Urban area	19.45	31.16	31.77	30.50	7.53	36.07	40.43	41.03

The graph in Fig. 7 shows the changes in landscape shape index for various land uses in different years. This index also shows significant changes during the studied years. This index has increased for all land uses in the first period, showing dramatic disorder in these land uses in the area. The SHDI is another index used in the study to investigate the diversity of points and the corresponding changes in the area, the results of which are presented in Table 8.

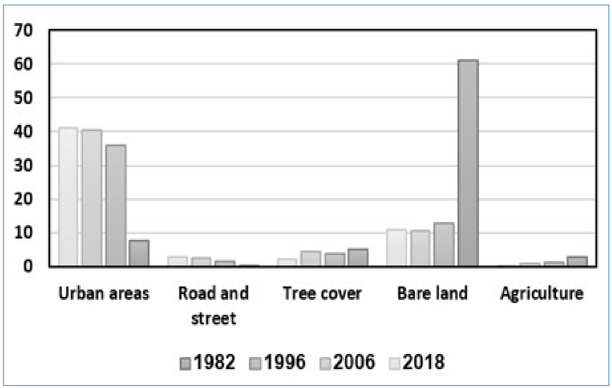

Fig. 6. Changes in the LPI of various land covers in the area

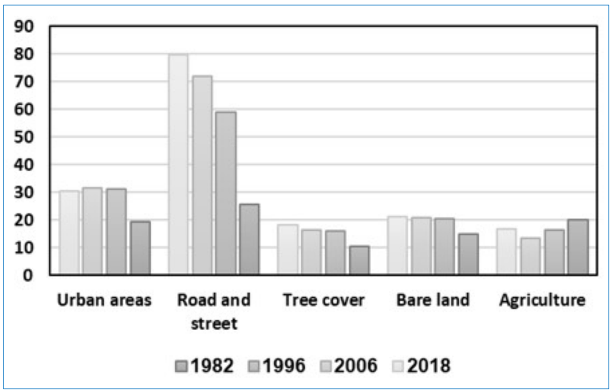

Fig. 7. Changes in LSI for various land uses and land covers in the area

The numerical value of this index gives information about the points. This index is used for the comparison of various landscapes or the same landscape in different times. This index is calculated at landscape level, and in the present study, it is calculated as 1.07 for 1982, 1.13 for 1996, 1.14 for 2006 and 1.11 for 2018. It can be concluded from the comparison that this index has increased over the first two periods while it decreased in the third period (2006-2018). The reason for the initial increase is the integration and increase in diversity while the final decrease is due to the separation and lack of integration, leading to decreased diversity in the area.

Another index which is calculated in this study is the SHEI (Table 8). This index varies between zero and one. When the landscape consists only of one point, this index is equal to zero and when all points are equally distributed in the area, it approaches one. This index was calculated as 0.67 in 1982, 0.70 in 1996, 0.71 in 2006 and 0.68 in 2018. The final decrease indicates isolation over the final period. The increase in urban area is significant and has affected this index.

Table 8. Changes in SHDI and SHEI in the area between 1982 and 2018

Sampling Years	SHDI	SHEI
1982	1.07	0.67
1996	1.13	0.70
2006	1.14	0.71
2018	1.11	0.68

4. Conclusion

The extent and patterns of land use changes were investigated in the area and the effective factors were identified. Five types of land cover and land use were identified in the area, among which, urban area was determined to be the most significant with considerable growth. Economic growth and increased urbanization were identified as the most important factors in land use changes in the area. Migration from villages to city and population growth were two other important reasons.

Tree cover has significantly decreased in the area and has transformed to urban areas in most cases. This trend is still continuing and, in absence of effective management, will lead to complete destruction of this land use in the future. Hence, effective planting and expanding the green space are strongly recommended in this area.

Land transformation is one of the most important causes of farmland degradation in the world, which was also observable in this area. In fact, huge areas have transformed into urban area, affecting agriculture and food production in the area. Hence, prevention of agriculture destruction and efforts to restore this land cover are strongly recommended in the area.

It seems that vertical construction, instead of horizontal construction, can solve much of housing problem and can prevent farmland and tree cover degradation. Also, economic growth and entrepreneurship in small townships can prevent migration to large cities, and are regarded as a managerial strategy in such areas, which seem to be effective in the area under study.

What already mentioned in the study reveals that the area is threatened from different aspects. However, effective management can turn the threats into opportunities and, subsequently, can solve the crises ahead.

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