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Landscape change assessment of reservation areas using remote sensing and landscape metrics (case study: Jajroud reservation, Iran)

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Abstract Understanding and analyzing the dynamics of reservation areas, as one of the most valuable ecological resources, is of great importance for effective management of these environments. Monitoring the process of land-use/land-cover (LULC) transformations in these areas and knowing their driving forces would contribute to an informed decision making. In this study, an integrated application of satellite imagery interpretation and landscape ecology approach is implemented to quantify and analyze the landscape dynamics of Jajroud reservation area, Iran. The digital images collected by satellite at 1986, 2000, and 2010 were classified following an ensemble classification method. The resultant LULC maps included six categories of orchard, healthy rangeland, degraded rangeland, afforest, water, and urban. Landscape metrics-based analysis of temporal patterns of LULCs indicated that Jajroud reservation area has been undergoing rapid and drastic changes over the past 25 years. Based on class area metric at landscape level, changes were mostly due to the conversion of degraded rangeland and orchard to urban category. The impervious area expanded approximately fivefold from 1986 to 2010. Based on Largest Patch Index metric, the dominant land-cover class across the study time frame was degraded rangeland that decreased from 1986 to 2010. The main driving forces of

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urban growth in the area were willingness of local residents to sell their orchard lands and having financial interests. Because of rapid economic development and expansion of human-constructed elements, the landscape of the area experienced a fragmentation process during the last three decades. The study demonstrated that integrated application of satellite imagery and landscape metrics can be a useful and easy-to-implement tool for environmental impact assessment of an ongoing urbanization process.

1 Introduction

The world's urban population expanded from 30 % of the global population in 1950 to 50 % in 2000 and is expected to increase to 60 % by 2025 (United Nations 2000). Increasing populations and extensive economic development have increasingly altered the structure of land parameters worldwide. More and more productive lands and forests have been transformed into urban areas and impervious surfaces. These land-use/land-cover (LULC) conversions have attracted increasing attention due to their impact on degradation of local and regional ecosystems. Reservation areas are among the most valuable environments for wildlife conservation, providing habitats and creating opportunities for aesthetic and recreational experiences as well as cultural and artistic inspiration. Also, the current concerns on environmental changes at a global scale are all bound up with landscape structure (Whyte 2002). Understanding, analyzing, and modeling of the process of LULC transformations have been an important area of research for scholars in the professional community of spatial sciences (e.g., Antrop 2000; Herold et al. 2002; Li et al. 2004; Gong et al. 2011, 2013a, b, c; Gong and Wu 2014; Dezhkam et al. 2014; Asgarian et al. 2014; Hasani Sangani et al. 2014; Sakieh et al. 2014a, b, 2015). Since landscape patterns and landscape functions are mutually influenced, applying landscape indices to analyze landscape functions has been a common methodology in such studies (Bartel 2000; Corry and Nassauer 2004). Quantifying and analyzing landscape pattern change provide additional level of knowledge on landscape baseline and its possible future dynamics. This approach can also provide monitoring indicators and managing strategies with regard to environmental change (Gulinck et al. 2001). Landscape analysis can also assist understating of the relationships between human activities and landscape changes, especially in ecologically valuable areas that guide policy makers to make appropriate decisions toward sustainable development.

Applying landscape metrics for analyzing LULC change patterns has been discussed as a tool for environmental impact assessment (EIA) and change detection studies (Herold et al. 2002; Southworth et al. 2002; Chang 2003; Wang et al. 2013; Zhang et al. 2013; Wang et al. 2012). Empirical studies have also been conducted in landscape assessment (Aspinall and Pearson 2000), landscape monitoring (Dramstad et al. 2001; Herzog and Lausch 2001), and landscape design and planning (Leitao and Ahern 2002).

Since remote sensing technology provides cost-effective, multispectral, and multitemporal data, it has become a popular data source for comparative studies of environmental change assessments (Kepner et al. 2000; Southworth et al. 2002; Liu and Yang 2015; Sano et al. 2009; Ji et al. 2006). These researches mainly concentrated on the analysis of landscape patterns, while a simultaneous assessment of landscape change and economic development can shed new insights into the current processes of LULC transformations.

Iran, as a developing country, has been experiencing rapid transformation of LULCs during its social and economic development periods (Fanni 2006). However, detailed assessments of land-use change in urban or suburban areas from a landscape perspective are rare in Iran. These changes are characterized by rapid conversion from woodlands, rangelands, and natural cover to agricultural lands (orchards) and from agricultural lands to urban areas. There are only a limited number of publications that have addressed landscape monitoring and landscape assessment in Iran (Rafiee et al. 2009a, b; Asgarian et al. 2014; Sakieh et al. 2015). At Jajroud reservation area, one of the most rapidly developing districts in Iran, this paper will quantify landscape change with respect to its temporal characteristics using remote sensing and landscape metrics. Accordingly, the objectives of the present study are as follows: (1) landscape metrics-based change detection in a highly developing reservation area (Jajroud), (2) linking the ongoing change processes with their socioeconomic causes, (3) identifying the most dynamic land categories of the area based on composition- and configuration-based attributes.

2 Materials and methods

2.1 Study area

The study site, Jajroud reservation area (51.30–51.57 longitude and 35.48–35.30 latitude), is located in Tehran Province, central north of Iran (Fig. 1). It spans over an area of 55,118 ha, including two national parks (Khojir and Sorkhe-Hesar) that cover an extent of 19,351 ha. In 1982, this area was entrusted to the Iranian Department of Environment (DOE). Annual precipitation varies from 500 to 1100 mm, with a mean of 711 mm. Precipitation is maximum in November (69.8 mm) and minimum in July (11.2 mm). Annual mean temperature is 26 °C, with extreme values of −8 and 32 °C registered in January and July, respectively. Regarding biodiversity, the area has a collection of 512 plant species (*Tamarix aphylla*, *Haloxylon ammodendron*, *Zygophyllum eurypterum*, *Calligonum comosum*, *Atriplex hymenelytra*, etc.). Jajroud reservation area is an essential refuge for 192 animal species including Alborz red sheep, leopard, wild goat, goitred gazelle, hyena, wild boar, caracal, cape hare, chukar partridge, see–see partridge, sand grouse, green-headed duck, teal and hoopoe (Ziaiee 2002).

Some parts of the study area are occupied by lands regulated as excluded zones. These locations are possessed by local residents, and they are less protected against development. These lands are main the cause of recent area increase in human-made surfaces in the study site, since residents face no legal constraints for conducting development in these regions. In addition, due to the lack of functional preventive and prohibitive legal measures in the area, temporal and gradual encroachment of built-up areas into ecologically valuable lands has been occurring during the last decades. Therefore, due to the existence of such inconsistencies in the management of the area, the importance of LULC planning studies in the region is highlighted more than ever before (Jaafari 2013).

2.2 Assessing method

Landsat 4 and 5 images of the TM sensor were selected for LULC classification of the study area during a period when change in land cover by human activities has been recognized as an important driver of global environmental changes (Lepers et al. 2005).
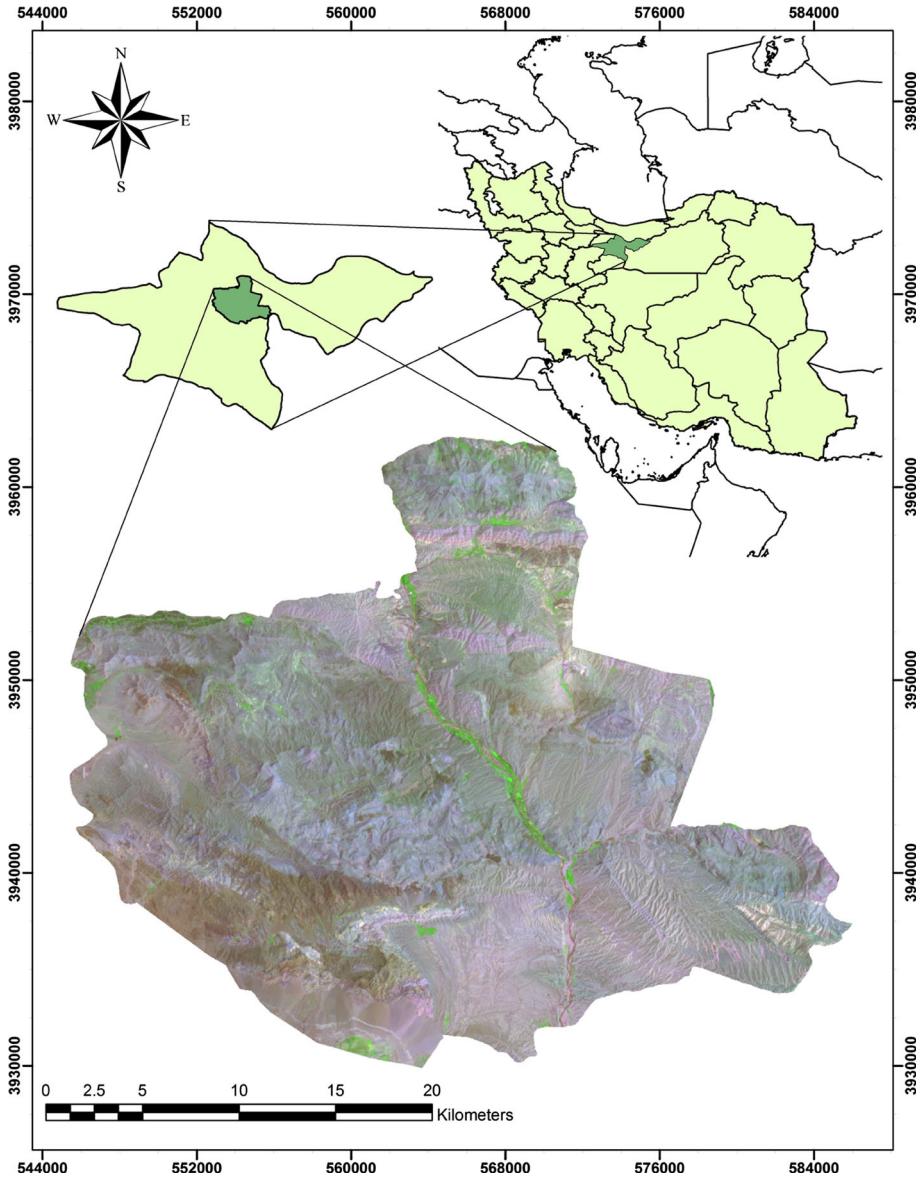
Fig. 1 Location of the study area in the Tehran province, Iran

Satellite images were obtained on June 18 (1986), July 26 (2000), and June 4 (2010) for path/rows of 35/165. Selection of this imagery was based on minimal cloud cover, time of the year, and the time frame in which land-cover change could be monitored since the designation of the location as a reservation area. Image preprocessing, classification, change detection, and GIS analysis were applied using ENVI 4.5 and Arc GIS Info 9.3 (ESRI) softwares. Ground control points, collected in the field, were used to rectify the 2010 image. Images were controlled from the standpoint of radiometric quality, and no

significant distortions such as striping, banding, sweep error, duplicate pixels, atmospheric error or existing clouds were found. The 2000 and 1986 images were rectified to the 2010 image via image-to-image registration. Images were resampled using the nearest-neighbor algorithm with RMS (root mean square) error less than 0.5 pixels. Atmospheric corrections were not undertaken to the satellite data as the datasets were classified separately (Song et al. 2001).

The LULC categories were decided based on the first level of Anderson classification schema (Anderson et al. 1976). Six land-cover types were selected for mapping at medium spatial resolution using the 30-m Landsat imageries. After co-registration of the imagery, the hybrid method including supervised, unsupervised, and on-screen visual classification was employed. In this process, in addition to the original bands, synthetic bands consisting of Normalized Difference Vegetation Index (NDVI) and principal component analysis (PCA)-derived data were calculated to further improve in classification accuracy. The supervised classifier was the conventional maximum likelihood, and ISODATA clustering algorithm was used for unsupervised classification. Afterward, the images were entered in a very time-consuming process for which classification errors were detected and modified through pixel-by-pixel image control, using ancillary data such as field survey information, aerial photography, and GPS information. The layers acquired from the hybrid method were merged and cross-tabulated across different node years for accuracy and consistency. Thus, the 1986 and 2000 maps were cross-tabulated and revised, and then, the revised 2000 map was used for cross-tabulation with the 2010 map. After the forward cross-tabulation and revision, a backward revision was also conducted, such that in the end, no apparent inconsistency was present in the maps. Visual accuracy assessment of the outputs (through pixel-by-pixel comparisons) was also undertaken, and the resultant layers indicated a high level of accuracy (Messina et al. 2000; Mahiny and Clarke 2012). The LULC categories consisted of healthy rangeland (healthy grazing land), degraded rangeland (degraded grazing land), orchard (historical private properties of the local residents with green covers), afforest (lands planted with coniferous trees), water, and urban.

An attempt was made to quantify the landscape structure of the study area using FRAGSTATS 3.3 (McGarigal and Marks 1995). In the literature, there are hundreds of landscape metrics available, although few key metrics are derived from the original metrics. It is often necessary to use several metrics to characterize a specific landscape (Neel et al. 2004), but a misinterpretation of the results could occur by the use of less interpretative indices (e.g., Li and Reynolds 1995; McGarigal and McComb 1995; Ritters et al. 1995; Li and Wu 2004). Although these studies indicate that the patterns of a landscape can be quantified by a series of metrics, there is no general agreement on which metrics are the best set.

In accordance with the purpose of this study (landscape structure), six metrics were used for their potential to interpret the composition- and configuration-based attributes, which quantify various characteristics of the landscape (Table 1). For selecting this set of the metrics, at the first step several shape, connectivity, and area metrics were calculated, and the correlations between them were measured. In this case, majority of the metrics were highly correlated. Therefore, however correlated (Table 2), based on our local knowledge on growth patterns in the study area, a collection of most interpretative metrics was decided based on the following reasons (Gustafson and Parker 1992; Hargis et al. 1998; Jaeger 2000; Botequila et al. 2006; Cushman et al. 2008; Sakieh et al. 2015):

1. These measures quantify fundamental settings of a landscape structure (area, size and distance, and connectivity of the patches);

Table 1 Landscape metrics used in this study

Landscape metric	Units	Category	Equation	Range
Total class area (CA)	ha	Area metrics	$CA = \sum_{j=1}^{n} a_{ij}\left(\frac{1}{10,000}\right)$	CA > 0
Largest Patch Index (LPI)	%	Area metrics	$LPI = \frac{\max\limits_{j=1}^{a}(a_{ij})}{A}(100)$	0 < LPI ≤ 100
Number of patches (NP)	Number	Patch density, patch size and variability metrics	NP = ni	NP ≥ 1
Mean patch size (MPS)	ha	Patch density, patch size, and variability metrics	$MPS = \frac{A}{N}\left(\frac{1}{10,000}\right)$	MPS > 0
Effective mesh size (MESH)	ha	Contagion/ interspersion metrics	$MESH = \frac{\sum_{j=1}^{n} a_{ij}^2}{A}\left(\frac{1}{10,000}\right)$	Ratio of cell size to landscape area ≤ MESH ≤ total landscape area (A)
Mean Euclidean nearest-neighbor distance (ENN_MN)	m	Isolation/ proximity metrics	$MNN = \frac{\sum_{j=1}^{n} h_{ij}}{n_i}$	ENN_MN > 0

Source: McGarigal et al. (2002)

2. They are simple to interpret and easy to understand; and
3. They would yield robust results when implemented together to measure the spatial complexity of a landscape in terms of patches, patch spatial distribution, and connectivity.

The metrics included class area (CA), Largest Patch Index (LPI), number of patches (NP), mean patch size (MPS), mean Euclidean nearest-neighbor distance (ENN_MN), and effective mesh size (MESH). CA equals the sum of the areas of all patches belonging to a given class, in map units; LPI quantifies the percentage of total landscape area comprised by the largest patch. MPS metric determines the average patch size within a particular class. ENN_MN metric equals the average distance (m) to the nearest-neighboring patch within a particular class, based on shortest edge-to-edge distance. MESH metric indicates the possibility of a connection between two points in the landscape that are not separated by a barrier showing the disruption of the continuity of the desired class area (Jaeger 2000; Girvetz et al. 2008).

3 Results

3.1 Landscape composition

Figure 2 illustrates the resultant LULC maps with six different classes. Detailed description on landscape metrics are provided in Table 3.

Table 2 Spearman correlation analysis results for implemented metrics in this study

LULC category	Metric	CA	NP	MPS	LPI	MESH	ENN_MN
Urban	CA	1.000	0.500	1.000**	1.000**	1.000**	−1.000**
	NP		1.000	0.500	0.500	0.500	−0.500
	MPS			1.000	1.000**	1.000**	−1.000**
	LPI				1.000	1.000**	−1.000**
	MESH					1.000	−1.000**
	ENN_MN						1.000
Healthy rangeland	CA	1.000	1.000**	−1.000**	0.500	0.500	−1.000**
	NP		1.000	−1.000**	0.500	0.500	−1.000**
	MPS			1.000	−0.500	−0.500	1.000**
	LPI				1.000	1.000**	−0.500
	MESH					1.000	0.500
	ENN_MN						1.000
Poor rangeland	CA	1.000	0.500	0.500	1.000**	1.000**	−0.500
	NP		1.000	−1.000**	−0.500	−0.500	−0.500
	MPS			1.000	0.500	0.500	0.500
	LPI				1.000	1.000**	−0.500
	MESH					1.000	−0.500
	ENN_MN						1.000
Orchard	CA	1.000	0.500	−0.500	−0.500	−0.500	−0.500
	NP		1.000	−1.000**	−1.000**	−1.000**	−1.000**
	MPS			1.000	1.000**	1.000**	1.000**
	LPI				1.000	1.000**	1.000**
	MESH					1.000	1.000**
	ENN_MN						1.000

Since afforest category has witnessed inconsiderable change during the studied time period, calculated metrics for this category cannot be implemented for correlation analysis. In addition, water bodies only existed in the year 2010. Therefore, this category was also excluded from correlation analysis

** Correlation is significant at the 0.01 level (two-tailed)

3.2 Landscape metrics

The CA is the sum of the area of all patches of the corresponding class (ha). CA is useful when comparing different study areas with the same extents. In 1986, degraded rangeland and healthy rangeland were dominant land features in Jajroud reservation area in which together accounted for 96 % of the total area, as shown in the Table 3. On the contrary, urbanized lands covered only 1049.67 ha, a mere 0.01 % of the total area. This depicted that Jajroud reservation area was still a rangeland-dominated landscape, and urban growth had just triggered at the time. The healthy rangeland category increased from 1986 to 2000 and then decreased slightly in 2010. The degraded rangeland dramatically declined from 1986 up to 2000 and decreased until 2010. Orchard increased slightly since 1986 until 2000 and the reduction intensified with a noticeable rate (252 ha of conversion). Many orchard areas were transformed into manmade structures. Urbanized regions sharply expanded from 1986 to 2000 (614.97 ha) and from 2000 to 2010. Urban sprawl was continually occurring with a noticeable increase, and a total of 4912.29 ha was added. Urban category
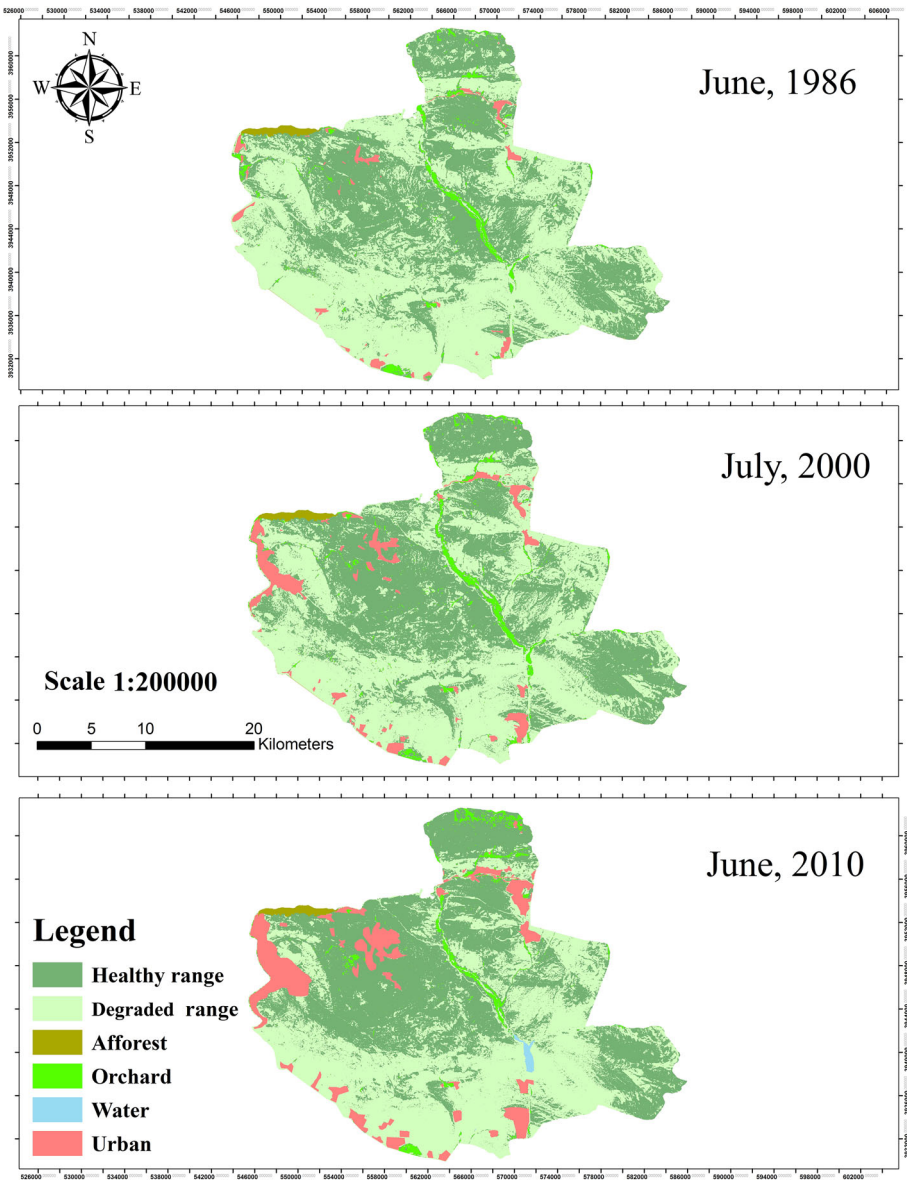
Fig. 2 Land-cover/land-use maps of Jajroud reservation area (1986, 2000, and 2010)

was the most dynamic land parameter and demonstrated the highest increase rate compared to others (5.67 times) from 1986 to 2010. Figure 3 demonstrates spatial distribution of changed areas from different LULCs categories to urban land use. Water category was not existed in 1986 and 2000 and emerged in 2005 because of dam construction. Afforest class was characterized with no considerable change across the studied time frame.

The NP metric has limited interpretive value by itself; however, it can provide useful information when compared with other metrics such as PD or MPS. The PD metric has the

Table 3 Landscape metrics change through the examined study period

Year	Land-cover class	CA	NP	MPS	LPI	MESH	ENN_MN
1986	Good rangeland	31,727.43	4310	7.36	8.97	1513.2	88.2
	Poor rangeland	41,094.09	3741	10.98	22.99	729,036	84.46
	Afforest	432.18	1	432.18	0.32	1.4	N/A
	Orchard	1515.51	810	1.87	0.32	1.7	217.85
	Water	–	–	–	–	–	–
	Urban	1049.67	39	26.91	0.1	0.63	926.32
2000	Good rangeland	33,783.03	6148	5.49	10.9	1872.26	81.76
	Poor rangeland	35,999.37	6014	5.98	21.02	5893.21	81.52
	Afforest	432.18	1	432.18	0.32	1.4	N/A
	Orchard	1754.01	1474	1.19	0.2	1.09	187.64
	Water	–	–	–	–	–	–
	Urban	3040.29	46	66.01	0.79	11.44	793.6
2010	Good rangeland	33,306.03	4757	7	12.51	2469.74	83.91
	Poor rangeland	33,701.76	4690	7.18	19.38	5013.11	88.34
	Afforest	432.18	1	432.18	0.32	1.4	N/A
	Orchard	1502.01	936	1.55	0.24	1.15	192.65
	Water	262.26	359	0.73	0.16	0.34	187.8
	Urban	5961.96	40	149.04	1.53	44.43	596.6

same basic utility as the NP measure except that it facilitates comparisons among landscapes of varying sizes. Based on the principles of landscape ecology, the increasing number of patches is indicative of ecosystem degradation (Gerger and Turner 2002). The healthy rangeland increased from 1986 to 2000 and then slightly decreased up to 2010. From 1986 to 2010, the NP metric depicted a constant increasing trend for healthy rangeland category. This denotes fragmentation of the healthy rangeland during last three decades. A similar conversion pattern was also detected for degraded rangeland and orchard categories. The NP metric for both categories increased from 1986 to 2000 and decreased from 2000 to 2010 (Table 3). Orchard increased from 1986 to 2000 and then decreased until 2010, which indicates that urban expansion led to numerous separated edges grow together to form more homogenous urban landscape. The afforest class indicated unnoticeable variations from the standpoint of the NP metric.

The MPS metric determines the average size of the patches. Changes in the metric are proportional to the area and number of patches in the class or landscape (McGarigal and Marks 1995). The most increase in the MPS metric belongs to the urban class (5.53 times from 1986 to 2010). However, MPS of urban areas increased constantly, which mirrors the process of aggregation during urban growth mechanism. This is the result of rapid economic development, which led to an increasing demand for land construction and housing. Urban areas and many newly built environments were established and then extended to the former degraded rangeland and orchard that resulted in increasing of the MPS metric value. A similar trend was also detected in terms of healthy rangeland and orchard. These categories decreased from 1986 up to 2000 and then increased in 2010. The value of the metric in the degraded range land depicted a decreasing trend from 1986 to 2010. This denotes fragmentation of degraded rangeland. There is no noticeable change for afforest during 1986–2010 time period.
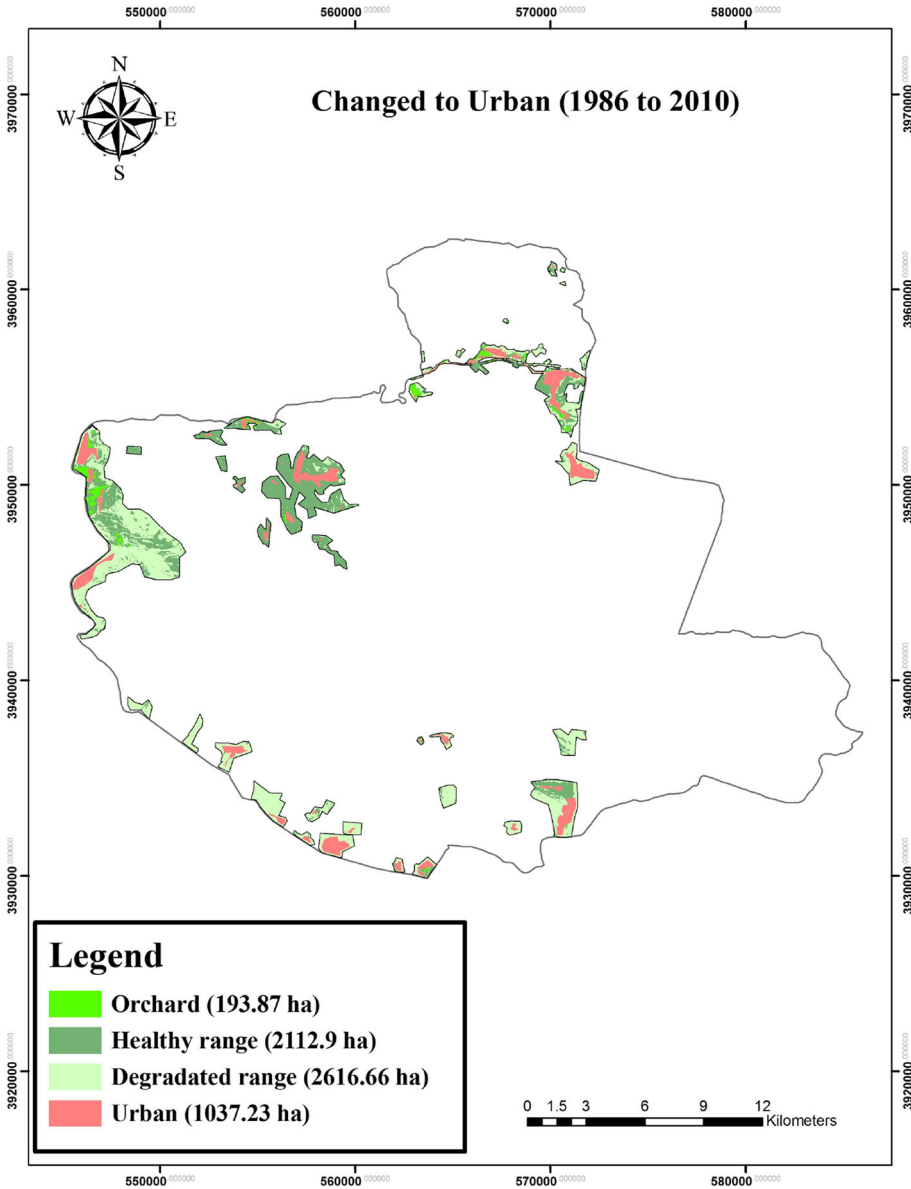
Fig. 3 Spatial distribution changed areas from different LULCs to urban land use

The decreasing value of LPI metric reflects that larger patches were fragmented into smaller ones. Patchiness in an integrated landscape has an intense effect on ecological processes (Veldcamp and Lambin 2001). LPI metric value increases in urban and healthy rangeland over the study time span. Increase in LPI metric of urban areas indicates the development of urban patches, and this is not a favorable trend in a reservation area. The LPI metric has a decreasing trend for degraded rangeland and orchard over the studied

node years. The LPI metric of the degraded rangeland decreased through the entire study time frame, which was the consequence of gradual encroachment of degraded rangeland by urbanization.

The MESH metric is based on the probability that two randomly chosen points can be connected (Jaeger 2000; Girvetz et al. 2008). Conceptually, MESH metric also gives the area-weighted mean patch size of patches of the corresponding patch size, but the proportional area of each patch is based on the total landscape area, not the class area. In this way, MESH takes into account the patch size distribution of the corresponding class as well as the total landscape area comprised of that class, providing a relative measure of patch structure. The value of MESH metric was decreased for degraded rangeland and orchard from 1986 to 2000 and then again increased. The value of the metric in degraded rangeland and urban had a surging trend from 1986 to 2010 and for degraded rangeland, and orchard illustrated an inverse pattern for the corresponding years. The ENN_MN metric is the shortest straight-line distance between the focal patch and its nearest neighbor of the same class (in meters). The metric has a decreasing trend in terms of urbanized lands. The ENN_MN value for healthy rangeland, degraded rangeland, and orchard categories declined from 1986 to 2000 and increased from 2000 to 2010. Referring to Table 3, ENN_MN value is undefined for afforest land category.

4 Discussion

4.1 Temporal change patterns in Jajroud reservation area

This paper demonstrates the applicability of remote sensing and GIS analysis for evaluating landscape change in Jajroud, a rapidly developing area in Iran. In a similar study conducted by Uuemaa et al. (2013), it has been shown that LULC change detection using remote sensing, GIS, and landscape metrics may provide valuable insights on ecosystem functions and services as well as species richness and diversity. Their results also highlight the importance of monitoring of landscape structure change caused by LULC transformations.

The landscape matrix was dominated by degraded rangeland before 1986. Then, urban areas gradually dominated the landscape in the subsequent years. Similarly, other studies (Rahdary et al. 2008; Young et al. 2006; Wang et al. 2009) reported the same pattern in terms of urban areas and natural covers. Generally, the witnessed pattern of urban evolution in our study area is consistent with the theory formulated by Dietzel et al. (2005) that suggests how diffusion and coalescence of urban areas take place in the process of their expansion. The present study highlighted that the ENN_MN metric values were indicative of structural changes in the landscape. Regarding the ENN_MN decrease in urban patches, it was depicted that urban patches tend to aggregate together and form bigger clusters. Similar to our study, Abdullah and Nakagoshi (2006), Matsushita et al. (2006), Weng (2007), and Lausch and Herzog (2002) concluded that application of CA, NP, and MPS metrics effectively contributes to the understanding and detailed analysis of LULC changes in the landscape patterns.

The reservation area is surrounded by main roads, highways, and is close to Tehran, one of the most developed and populated regions in Iran. Adjacency to Tehran is a reason for overloaded visitor centers especially in peak seasons. For this reason, there is an urgent need to establish recreational centers located in specific zones in the area. Asphalt

development plans created islands of natural areas within the developed surrounding environment (Azcárate et al. 2013). Due to urbanization, urban and built-up areas have significantly increased at the expense of degraded rangeland and orchard decrease. In 1986, urban class was only 0.01 % of total area, and this category increased by more than 5.67 times during the study time frame. On the other hand, degraded rangeland reduced by more than 7393 ha during this period. The main driving force for residential area increase was the willingness of local people to sell their orchards and agricultural lands, so as rich Tehranian people can avoid from air and noise pollution of the capital and immigrate to a natural area. Specifically, proximity to Tehran has a noticeable contribution in forming the ongoing urbanization process in the area. Attractions such as transportation supplies, affordable general facilities, and educational benefits have made an increasing rate of immigration to Tehran from rural environments and other small cities (including our study area) such that migrants usually sell their farmlands to rich Tehranian people who are looking for natural areas for building weekend houses. This phenomenon has brought about the culture of "Villa Building" and might be considered as the main cause of urban expansion in the targeted area. These buildings are characterized as individual households with low-density dispersion across the landscape.

In conclusion, the loss of degraded rangeland was the result of urban sprawl. Similar findings are reported in the study of Wang and Li (2010). They concluded that temporal dynamic changes can be satisfactory expressed by landscape metrics. In addition, they showed that human activities have exerted great impacts on LULC changes. This characteristic confirms the effect of the orchard class reduction in 25 years (Abelairas-Etxebarria and Astorkiza 2012). Meanwhile, the landscape has been undergoing homogenization along with urbanization. However, whether this trend would continue through time will require further investigation based on the latest remote sensing images. If this trend continues, the lack of proper land-use planning and management strategies can cause irreversible damage to the ecosystem structure. The result shows that controlling the urban sprawl in the area is necessary for conservational goals. Findings also demonstrate that landscape metrics can be used to determine the landscape matrix where land-use statistics cannot identify it properly.

4.2 Policy implications

Comparing the detected pattern of urban growth in our study area (as the most dynamic category) with the results of other studies conducted in Iranian urban contexts (Mahiny and Gholamalifard 2007; Rafiee et al. 2009a, b; Mahiny and Clarke 2012, 2013; Dezhkam et al. 2014; Bihamta et al. 2014; Sakieh et al. 2014a, b, 2015; Jafarnezhad et al. 2015) reveals some important findings. Considering urbanization as the most drastic form of LULC conversion in our study area, there is a crucial need for adopting an appropriate strategy for future urban land-use planning in Jajroud reservation area. In this case, there are a series of strategies in the literature, which emphasize the management of urbanized land from different perspectives. The first planning strategy concerns centralization of urban patches. Under this pattern, urban clusters experience a compact and infill form of expansion. In other words, lands with adjacency to current urban boundaries and available areas in interior urban environments have higher priorities for development. As a consequence, natural and productive lands can be protected from encroachment of urbanized lands and distribution of man-made structures, which are the main causes of fragmentation in Jajroud reservation area. On the other hand, this pattern prevents coalescence of separated urban patches, since it prohibits linear and dispersed urban growth. As a consequence, landscape

of the area will be occupied by a disconnected net of urban blobs, which is a challenging pattern from an urban planner's perspective. It should be noted that centralization of urban patches can be an appropriate strategy in locations where there is an adequate level of technology, which maximizes the efficiency of LULC transformation process into man-made structures (Sakieh et al. 2015).

On the contrary, decentralized urban land-use planning is another alternative (Sakieh et al. 2015). Decentralization of urban patches indicates that urban areas with very large physical size that are beyond their carrying capacity in terms of the number of residents and ecological footprint should minimize their growth cycles, and instead, small-scale urban centers are allowed to grow. Under such pattern, the landscape of the area will be occupied by dispersed and low-density distribution of small urban cores. These growing urban centers have lower levels of ecological footprint and environmental consequences. Therefore, they can grow linearly, and disconnected urban cores are more likely to grow together and form bigger patches. This pattern of growth is more preferable in terms of its connectivity in which more connected areas are provided for city planners to establish urban facilities. On the other hand, the landscape of the area will heavily be permeated by human-made parameters that are the main cause of fragmentation in natural lands. Accordingly, ecologically valuable lands will be downsized with modified ecosystem functions, which reduce their supporting ability for biodiversity and wildlife (Wu 2014).

An appropriate strategy for Jajroud reservation area is a compromised solution between centralized and decentralized urban planning paradigms. As a developing region, the efficiency of LULC transformations into urban structures in Jajroud area is not adequate enough to adopt the centralization strategy. In addition, a highly fragmented landscape is more potential for habitat loss and biodiversity decrease and will cause many negative environmental consequences (Wu 2014). The compromised solution indicates that major urban cores with very large physical size should largely decrease (not totally) their growth cycles, and instead, small-scale and growing urban centers are allowed to grow. These small urban centers should be allocated with adjacency to each other and are allowed to sprawl linearly to grow together, which is a more probable pattern to be witnessed in the future. Under such spatial arrangement, adverse effects of the ongoing urbanization might be alleviated, while urban growth is still occurring.

5 Conclusions

The current study has an important ecological implication. The landscape metrics-based approach for LULC change detection not only quantifies composition- and configuration-based attributes of a landscape, but also identifies the most dynamic categories with mutual exchanges by other land features. This is an important parameter in land-use planning studies. Because dynamic categories are the main cause of complexity, they are potential elements to have several conflicts with other land parameters. Therefore, conflict resolution programs are necessary to solve issues between categories such as urban and orchard. Finally, functional changes in the landscape, especially in a human-dominated and rapidly developing area, can also be revealed via analyzing landscape pattern changes. Future studies must focus on current knowledge of LULC changes and landscape pattern of this reservation area and analyze in-depth management issues. In fragile areas such as those featured in this paper, it will always be a challenge to balance the promotion of social and

economic development with ecologically grounded planning and management of the land's natural resource to achieve sustainable development.

According to national development plans in Iran, non-spatial planning efforts such as economic development plans are now being regulated in terms of regional and national considerations for each province in Iran. But enrichment of spatial planning practices with informed data at regional and national scales necessitates consideration of several environmental variables which are very time-consuming to be periodically collected and processed. Therefore, spatial regional planning efforts in Iran are mostly undertaken within the administrative boundary of a province, and provincial authorities are the main decision makers on the future conditions of the province in Iran. Finally, it can be stated that success of regional spatial policies in Iran depends largely on directing the urban growth boundaries in trajectories that support the sustainability of urban complex environments.

References

Abdullah, S. A., & Nakagoshi, N. (2006). Changes in landscape spatial pattern in the highly developing state of Selangor, peninsular Malaysia. *Landscape and Urban Planning, 77*, 263–275.

Abelairas-Etxebarria, P., & Astorkiza, I. (2012). Farmland prices and land-use changes in periurban protected natural areas. *Land Use Policy, 29*(3), 674–683.

Anderson, J. R., Hady, E., Roach, E. J., Wetter, T., & Richard, E. (1976). *Lands cover classification system for use with remote sensor data*. Washington: United States Government Printing Office.

Antrop, M. (2000). Changing patterns in the urbanized countryside of Western Europe. *Landscape Ecology, 15*(3), 257–270.

Asgarian, A., Amiri, B. J., & Sakieh, Y. (2014). Assessing the effect of green cover spatial patterns on urban land surface temperature using landscape metrics approach. *Urban Ecosystems*. doi:10.1007/s11252-014-0387-7.

Aspinall, R., & Pearson, D. (2000). Integrated geographical assessment of environmental condition in water catchments: Linking landscape ecology environmental modeling and GIS. *Journal of Environmental Management, 59*, 299–319.

Azcárate, F. M., Robleño, I., Seoane, J., Manzano, P., & Peco, B. (2013). Drove roads as local biodiversity reservoirs: Effects on landscape pattern and plant communities in a Mediterranean region. *Applied Vegetation Science, 16*(3), 480–490.

Bartel, A. (2000). Analysis of landscape pattern: Towards a 'top down' indicator for evaluation of landscape. *Ecological Modeling, 130*(1–3), 87–94.

Bihamta, N., Soffianian, A., Fakheran, S., & Gholamalifard, M. (2014). Using the SLEUTH urban growth model to simulate future urban expansion of the Isfahan Metropolitan Area, Iran. *Journal of the Indian Society of Remote Sensing*. doi:10.1007/s12524-014-0402-8.

Botequila, A., Miller, J., Ahem, J., & Mcgarical, K. (2006). *Measuring landscapes: A planner's handbook*. Washington: Island Press.

Chang, C. Y. (2003). Landscape structure and bird's diversity in the rural areas of Taiwan. *Journal of Environmental Sciences, 15*(2), 241–248.

Corry, R. C., & Nassauer, J. I. (2004). Limitations of using landscape pattern indices to evaluate the ecological consequences of alternative plans and designs. *Landscape and Urban Planning, 72*(4), 265–280.

Cushman, S. A., McGarigal, K., & Neel, M. C. (2008). Parsimony in landscape metrics: Strength, universality, and consistency. *Ecological Indicators, 8*(5), 691–703.

Dezhkam, S., Amiri, B. J., Darvishsefat, A. A., & Sakieh, Y. (2014). Simulating urban growth dimensions and scenario prediction through sleuth model: A case study of Rasht County, Guilan, Iran. *GeoJournal, 79*(5), 591–604.

Dietzel, C., Oguz, H., Hemphill, J. J., Clarke, K. C., & Gazulis, N. (2005). Diffusion and coalescence of the Houston Metropolitan Area: Evidence supporting a new urban theory. *Environment and Planning B, 32*(2), 231–246.

Dramstad, W. E., Fry, G., Fjellstad, W. J., Skar, B., Helliksen, W., Sollund, M. L. B., et al. (2001). Integrating landscapebased values—Norwegian monitoring of agricultural landscapes. *Landscape and Urban Planning, 57*, 257–268.

Fanni, Z. (2006). Cities and urbanization in Iran after the Islamic revolution. *Cities, 23*(6), 407–411.

Gerger, S. E., & Turner, M. G. (2002). *Learning landscape ecology: A practical guide to concepts and techniques*. New York: Springer.

Girvetz, E. H., Thorne, J. H., Berry, A. M., & Jaeger, J. A. G. (2008). Integration of landscape fragmentation analysis into regional planning: A statewide multi-scale case study from California, USA. *Landscape and Urban Planning, 86*(3), 205–218.

Gong, C., Chen, J., Wu, J., & Yu, S. (2013a). The influence of socioeconomic and topographic factors on nocturnal urban heat islands: A case study in Shenzhen, China. *International Journal of Remote Sensing, 33*(12), 3834–3849.

Gong, C., Chen, J., & Yu, S. (2011). Spatiotemporal dynamics of urban forest conversion through model urbanization in Shenzhen, China. *International Journal of Remote Sensing, 32*(24), 9071–9092.

Gong, C., Chen, J., & Yu, S. (2013b). Biotic homogenization and differentiation of the flora in artificial and near-natural habitats across urban green spaces. *Landscape and Urban Planning, 120*, 158–169.

Gong, C., & Wu, W. (2014). Comparisons of regression tree models for sub-pixel imperviousness estimation in a Gulf Coast city of Mississippi, USA. *International Journal of Remote Sensing, 35*(10), 3722–3740.

Gong, C., Yu, S., Joesting, H., & Chen, J. (2013c). Determining socioeconomic drivers of urban forest fragmentation with historical remote sensing images. *Landscape and Urban Planning, 117*, 57–65.

Gulinck, H., Múgica, M., Delucioj, V., & Atauri, J. A. (2001). A framework for comparative landscape analysis and evaluation based on land cover data, with an application in the Madrid region (Spain). *Landscape and Urban Planning, 55*(4), 257–270.

Gustafson, E. J., & Parker, G. R. (1992). Relationships between landcover proportion and indices of landscape spatial pattern. *Landscape Ecology, 7*(2), 101–110.

Hargis, C. D., Bissonette, J. A., & David, J. L. (1998). The behavior of landscape metrics commonly used in the study of habitat fragmentation. *Landscape Ecology, 13*(3), 167–186.

Hasani Sangani, M., Amiri, B. J., AlizadehShabani, A., Sakieh, Y., & Ashrafi, S. (2014). Modeling relationships between catchment attributes and river water quality in southern catchments of the Caspian Sea. *Environmental Science and Pollution Research*. doi:10.1007/s11356-014-3727-5.

Herold, M., Scepan, L., & Clarke, K. C. (2002). The use of remote sensing and landscape metrics to describe structures and changes in urban land uses. *Environment and Planning A, 34*(8), 1443–1458.

Herzog, F., & Lausch, A. (2001). supplementing land-use statistics with landscape metrics: Some methodological considerations. *Environmental Monitoring and Assessment, 72*(1), 37–50.

Jaafari, S. (2013). *Landscape metrics application in investigation of land use change detection trend and its impact on protected areas* (*Study Case: Jajrud and Varjin Protected Areas*). M. Sc. Thesis. University of Tehran.

Jaeger, J. (2000). Landscape division, splitting index, and effective mesh size: New measures of landscape fragmentation. *Landscape Ecology, 15*(2), 115–130.

Jafarnezhad, J., Salmanmahiny, A., & Sakieh, Y. (2015). Subjectivity vs. objectivity—A comparative study between Brute Force method and Genetic Algorithm for calibrating the SLEUTH urban growth model. *Urban Planning and Development*. doi:10.1061/(ASCE)UP.1943-5444.0000307.

Ji, W., Ma, J., Twibell, R. W., & Underhill, K. (2006). Characterizing urban sprawl using multi-stage remote sensing images and landscape metrics. *Computers, Environment and Urban Systems, 30*, 861–879.

Kepner, W. G., Watts, C. J., Edmonds, C. M., Maingi, J. K., Marsh, S. E., & Gonzaloluna, G. (2000). A landscape approach for detecting and evaluating change in a semiarid environment. *Environmental Monitoring and Assessment, 64*, 179–195.

Lausch, A., & Herzog, F. (2002). Applicability of landscape metrics for the monitoring of landscape change: Issues of scale, resolution and interpretability. *Ecological Indicators, 2*(1), 3–15.

Leitao, A. B., & Ahern, J. (2002). Applying landscape ecological concepts and metrics in sustainable landscape planning. *Landscape and Urban Planning, 59*(3), 65–93.

Lepers, E., Lambin, E. F., Janetos, A. C., DeFries, R., Achard, F., Ramankutty, N., & Scholes, R. J. (2005). A synthesis of information on rapid land-cover change for the period 1981–2000. *BioScience, 55*(2), 115–124.

Li, Z., Li, X., Wang, Y., Ma, A., & Wang, J. (2004). Land-use change analysis in Yulin prefecture, northwestern China using remote sensing and GIS. *International Journal of Remote Sensing, 25*(24), 5691–5703.

Li, H., & Reynolds, J. F. (1995). On definition and quantification of heterogeneity. *Oikos, 73*(2), 280–284.

Li, H. B., & Wu, J. G. (2004). Use and misuse of landscape indices. *Landscape Ecology, 19*(4), 389–399.

Liu, T., & Yang, X. (2015). Monitoring land changes in an urban area using satellite imagery, GIS and landscape metrics. *Applied Geography, 56*, 42–54.

Mahiny, A. S., & Clarke, K. C. (2012). Guiding SLEUTH land-use/land-cover change modeling using multicriteria evaluation: Towards dynamic sustainable land-use planning. *Environment and Planning B, 39*(5), 925–944.

Mahiny, A. S., & Clarke, K. C. (2013). Simulating hydrologic impacts of urban growth using SLEUTH, multi Criteria evaluation and runoff modeling. *Journal of Environmental Informatics, 22*(1), 27–38.

Mahiny, A. S., & Gholamalifard, M. (2007). Dynamic spatial modeling of urban growth through cellular automata in a GIS environment. *International Journal of Environmental Research, 1*(3), 368–377.

Matsushita, B., Xu, M., & Fukushima, T. (2006). Characterizing the changes in landscape structure in the lake Kasumigaura Basin, Japan using a high-quality GIS dataset. *Landscape and Urban Planning, 78*(3), 241–250.

McGarigal, K., Cushman, S. A., Neel, M. C., & Ene, E. (2002). *FRAGSTATS: Spatial pattern analysis program for categorical maps*. Amherst College: Computer software program produced by the authors at the University of Massachusetts.

McGarigal, K., & Marks, B. J. (1995). *FRAGSTATS: Spatial analysis program for quantifying landscape structure*. USDA Forest Service General Technical Report PNW-GTR-351.

McGarigal, K., & McComb, W. C. (1995). Relationships between landscape structure and breeding birds in the Oregon Coast Range. *Ecological Monographs, 65*(3), 235–260.

Messina, J. P., Crews-Meyer, K. A., & Walsh, S. J. (2000). Scale dependent pattern metrics and panel data analysis as applied in a multiphase hybrid land cover classification scheme. In *Proceedings of the 2000ASPRS conference*, Washington.

Neel, M. C., McGarigal, K., & Cushman, S. A. (2004). Behavior of class-level landscape metrics across gradients of class aggregation and area. *Landscape Ecology, 19*(4), 435–455.

Rafiee, R., Mahiny, A. S., Khorasani, N., Darvishsefat, A. A., & Danekar, A. (2009a). a). Assessment of changes in urban green spaces of Mashad city using satellite data. *International Journal of Applied Earth Observation and Geoinformation, 11*(6), 19–26.

Rafiee, R., Mahiny, A. S., Khorasani, N., Darvishsefat, A. A., & Danekar, A. (2009b). Simulating urban growth in Mashad City, Iran through the SLEUTH model (UGM). *Cities, 26*, 19–26.

Rahdary, V., Soffianian, A., MalekiNajfabdai, S., Khajeddin, S. J., & Pahlavanravi, D. (2008). Land use and land cover change detection of Mouteh wildlife refuge using remotely sensed data and geographic information system. *World Applied Sciences Journal, 18*(8), 1124–1132.

Ritters, K. H., O'Neill, R. V., Hunsaker, C. T., Wickham, J. D., Yankee, D. H., Timmins, S. P., et al. (1995). A factor analysis of landscape pattern and structure metrics. *Landscape Ecology, 10*, 23–40.

Sakieh, Y., Amiri, B. J., Danekar, A., Feghhi, J., & Dezhkam, S. (2014a). Scenario-based evaluation of urban development sustainability: An integrative modeling approach to compromise between urbanization suitability index and landscape pattern. *Environment, Development and Sustainability*. doi:10.1007/s10668-014-9609-7.

Sakieh, Y., Amiri, B. J., Danekar, A., Feghhi, J., & Dezhkam, S. (2014b). Simulating urban expansion and scenario prediction using a cellular automata urban growth model, SLEUTH, through a case study of Karaj City, Iran. *Housing and the Built Environment*. doi:10.1007/s10901-014-9432-3.

Sakieh, Y., Salmanmahiny, A., Jafarnezhad, J., Mehri, A., Kamyab, H., & Galdavi, S. (2015). Evaluating the strategy of decentralized urban land-use planning in a developing region. *Land Use Policy, 48*, 534–551.

Sano, M., Miyamoto, A., Furuya, N., & Kogi, K. (2009). Using landscape metrics and topographic analysis to examine forest management in a mixed forest, Hokkaido, Japan: Guidelines for management interventions and evaluation of cover changes. *Forest Ecology and Management, 257*, 1208–1218.

Song, C., Woodcock, C. E., Seto, K. C., Lenney, M. P., & Macomber, S. A. (2001). Classification and change detection using Landsat TM data: When and how to correct atmospheric effects? *Remote Sensing of Environment, 75*(2), 230–244.

Southworth, J., Nagendra, H., & Tucker, C. (2002). Fragmentation of a landscape: Incorporating landscape metrics into satellite analyses of land-cover change. *Landscape Research, 27*(3), 253–269.

United Nations. (2000). *World urbanization prospects: The 1999 revision*. New York.

Uuemaa, E., Mander, Ü., & Marja, R. (2013). Trends in the use of landscape spatial metrics as landscape indicators: A review. *Ecological Indicators, 28*, 100–106.

Veldcamp, A., & Lambin, E. F. (2001). Predicting land use change. *Agriculture, Ecosystems & Environment, 85*(1–3), 1–6.

Wang, D., Gong, J., Chen, L., Zhang, L., Song, Y., & Yue, Y. (2012). Spatio-temporal pattern analysis of land use/cover change trajectories in Xihe Watershed. *International Journal of Applied Earth Observation and Geoinformation, 14*, 12–21.

Wang, D., Gong, J., Chen, L., Zhang, L., Song, Y., & Yue, Y. (2013). Comparative analysis of land use/cover change trajectories and their driving forces in two small watersheds in the western Loess

Plateau of China. *International Journal of Applied Earth Observation and Geoinformation, 21*, 241–252.

Wang, Y., & Li, S. (2010). Simulating multiple class urban land-use/cover changes by RBFN-based CA model. *Computers & Geosciences, 37*(2), 111–121.

Wang, Y., Mitchell, B. R., Nugranad-Marzilli, J., Bonynge, G., Zhou, Y., & Shriver, G. (2009). Remote sensing of land-cover change and landscape context of the National Parks: A case study of the Northeast Temperate Network. *Remote Sensing of Environment, 113*(7), 1453–1461.

Weng, Y. C. (2007). Spatiotemporal changes of landscape pattern in response to urbanization. *Landscape and Urban Planning, 81*(4), 341–353.

Whyte, I. D. (2002). *Landscape and History since*. London: Reaktion.

Wu, J. G. (2014). Urban ecology and sustainability: The state-of-the-science and future directions. *Landscape and Urban Planning, 125*, 209–221.

Young, J. E., Sánchez-Azofeifa, G. A., Hannon, S. J., & Chapman, R. (2006). Trends in land cover change and isolation of protected areas at the interface of the southern boreal mixedwood and aspen parkland in Alberta. *Canada. Forest Ecology and Management, 230*(1–3), 151–161.

Zhang, Z., Van, C. F., De Clercq, E. M., Ou, X., & De Wulf, R. (2013). Mountain vegetation change quantification using surface landscape metrics in Lancang watershed, China. *Ecological Indicators, 31*, 49–58.

Ziaiee, H. (2002). *Jajroud protected complex action plan*. Tehran: Iran Department of Environment.