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A conceptual framework to assess ecological quality of urban green space: a case study in Mashhad city, Iran

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Abstract This study evaluates the green space ecological quality with regard to its spatial properties. It investigates how the spatial properties of green space patches affect ecological aspects of municipal green spaces of Mashhad in Iran. The importance and necessity of this investigation is to develop a concept to evaluate the quality of urban green patches based on the perspective and method of landscape ecology. In accordance with our objectives, the quality concept is defined by quantitative (size, area, density) and qualitative (shape, complexity, connectivity) factors as referred to spatial configuration and composition of landscape structure. However, to have a better understanding of the quality concept, we explored the relationship between landscape variables and ecological quality by spatial analysis and correlation tests. We (1) drew the urban green space map by images processing, (2) quantified landscape metrics for the green space patches, (3) analyzed and represented the metric value spatially, (4) calculated ecological quality and drew the grade map, (5) measured the Pearson correlation coefficients and linear regression between ecological quality and each landscape metric. Results of this study provided the evidence to study ecological quality by integrating metrics map and analyzing spatial heterogeneity in Mashhad city. Results showed that the extent and continuity of the green spaces were too low to effectively support some key ecological services. Additionally, the Pearson's correlation coefficients and linear regression revealed strong relationships between ecological quality and most landscape metrics except LSI. Although it was expected that the qualitative variables of green space had higher influence on the ecological quality, quantitative variables had the highest effect due to the origin and nature of the green patches.

Keywords Ecological quality · Quantitative variable · Qualitative variables · Landscape metrics · Mashhad

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1 Introduction

Urbanization considerably affects ecosystems and their services to human beings and other living things. Urban development isolates, fragments, and degrades natural habitats and disrupts hydrological systems. It also makes the composition of species simple and uniform and modifies energy flow and nutrient cycling (Alberti et al. 2003). According to the United Nations (UN) report, more than 54% is related to lives of people in cities, a proportion expected to increase by 66% by 2050 (United Nations 2014). In recent decades, overcrowding and unplanned growth of cities have received considerable attention and increased the need to achieve sustainable cities (Rostami et al. 2015). As the world continues its urbanization process, sustainable development challenges will be increasingly concentrated in cities (SDSN Thematic Group 2015; Nilsson et al. 2014; United Nations Human Settlements 2009; United Nations 2014). Development of cities influences structure of landscape through the shape, size, composition, and interconnectivity of natural patches. It also generates different, unique and severe disturbances via physical changes in urban areas (Alberti 2005). Therefore, integrated approaches to enhance the lives of urban quality dwellers are needed (Nilsson et al. 2014).

In urban systems, urban green spaces are an important natural and semi-natural part of city that can be a significant contributor in urban sustainable development (Ahern 2013; Haq 2011; Li et al. 2015; Tian et al. 2014). They are the most important ecological entities for urban dwellers by enhancing sustainability and livability of cities and improving the quality of urban life with a wide range of benefits, including health (De Vries et al. 2003; Maas et al. 2006; Mitchell and Popham 2008; Takano et al. 2002; Wolch et al. 2014), social aspects (Grove et al. 2006; Hope et al. 2003; Martin et al. 2004; Troy et al. 2007), ecological dimensions (Gómez et al. 2004; Gómez-Baggethun and Barton 2013; Jim 2013; Tian et al. 2011) and economic advantages (Kong et al. 2007; Morancho 2003; Tyrväinen and Miettinen 2000). However, in recent decades, human activities and urbanization have had strong effects on scales and structures of urban green spaces. As a result, it has profoundly affected biodiversity, ecosystem processes, ecosystem services, climate, and environmental quality on scales ranging from the local city to the entire globe (Costanza et al. 1997; Costanza and Daly 2003; De Groot et al. 2002; Tian et al. 2012; Wu 2014; Wu et al. 2013; Xu 2014). Therefore, studying and analyzing ecological quality of urban structure, especially urban green space, can be an effective response to rapid urbanization and maintain a sustainable living urban environment (Li et al. 2015). As a definition, in this study, green space ecological quality (GSEQ) is a concept that spatially measures and evaluates the ecological quality of green space by quantities metrics according to the landscape ecology approach. Evaluation of urban GSEQ is helpful to understand the landscape structure and current status of sustainable development. These are the key issues required to be resolved by urban ecologists and landscape planners. In this research, valuation of the GSEQ with regard to its spatial properties has become considerable. This investigates how the spatial properties of green space patches would affect ecological quality of green spaces. It also aims to measure the ecological quality with spatially explicit methods considering both ecosystem properties and landscape structural attributes such as landscape ecology approach and metrics (Ahern 2013). Although, in recent studies, ecologists have endeavored to present the quality concept and how it affects ecological function and processes (Engen et al. 2002), it is not easy to determine the causality between process and pattern. To conceptualize quality, it is necessary to develop a conceptual framework to evaluate the ecological quality of urban green patches. This conceptual framework, through quality, considers the factors trying to fill the gap between patterns, processes, and functions relationship and landscape structure properties. Although various conceptual and analytical approaches exist in measurement of the ecological quality (Forman 1995; Forman and Godron 1986), in this study, the spatial analysis and the landscape ecology index method were used to find the ecological quality. In this paper, the main objectives are as follows:

1. To propose a conceptual framework to evaluate the ecological features of urban green spaces performed using the landscape ecology approach.
2. To analyze ecological values of patches and represent them spatially via landscape metrics.
3. To analyze the spatial quality providing a comprehensive understanding of the current green areas of cities that may be considered an appropriate basis for efficiency and planning.
4. To evaluate the efficiency and effectiveness of the metrics of landscape by calculating the correlation between metrics value and the spatial quality of green space patches. This analysis, by measuring and integrating the landscape indices, would determine the quality of urban green space spatially and indicate which landscape metrics has the highest impact on the landscape quality.
5. To examine a framework for possible application of urban planning that was tested and explored through calculating landscape metrics and correlation analysis. The ecological quality that can be spatially determined in an integrated map is used to describe and understand landscape heterogeneity better and is applied in landscape urban planning.

1.1 Theoretical foundations and research background

This part proposes a theoretical framework by which the ecological quality of urban green spaces can be evaluated according to its spatial properties. The quality concept has been compiled by reviewing other literature sources and developed in an integrated approach. In environment literature sources, the ecological benefits of green space are not limited to only absorption CO_2 and producing O_2 (McDonald et al. 2007; Nowak et al. 2006; Zhao et al. 2010), purifying air pollution (Liu and Shen 2014; Nowak et al. 2006), decreasing noise (Aylor 1972; Fang and Ling 2003; Van Renterghem et al. 2012) improving soil condition and groundwater recharge (Jim 2001; Pinfield 1992; Rijsberman and Van De Ven 2000), and moderating microclimates and reducing the heat island effect in cities (Chen et al. 2006; Lee et al. 2009; Li et al. 2011; Onishi et al. 2010; Weng et al. 2004). However, creating a living and dynamic system has improved the urban ecological structure and function and promoted the quality of the urban environment (Escobedo and Nowak 2009; Maimaitiyiming et al. 2014). In addition to multiple economic and social advantages (Chiesura 2004; Zhou and Wang 2011), ecological value of urban green space can improve through synergies with the urban spatial structure and function (Maimaitiyiming et al. 2014). Spatial structure of landscapes is assessed; this concept integrates complex aspects of the environment (Uuemaa et al. 2013). Structure of space is the main subcategory of spatial heterogeneity, commonly assuming the spatial configuration of the system property. Ecological processes and the relationship between them can be identified by determining spatial configuration and urban green spaces composition (Johst et al. 2015; Peng et al. 2016). However, the literature shows that the quality concept was carried out by ecological and environmental variables. In particular, the quality of urban green space is specified through qualitative and quantitative factors, that if understood and analyzed properly, it can achieve the concept of quality. With an emphasis on structural aspects of landscape and urban green spaces, landscape ecology approach has provided a powerful tool to assess changing green patches and landscape (Forman and Godron 1986).

In this study, the conceptualized framework of quality is based on the landscape ecology approach and method, which can facilitate the representation and analysis of changes and environmental processes. Therefore, it addresses the environmental quality and specifies the requirements. By landscape ecology approach, we can interpret the impacts of the above-mentioned processes for environment ecological features and achieve a primarily classification of green space quality and function (Leitao and Ahern 2002). According to this, the quality concept depends on the ecological process nature (Alberti 2005) occurred at a different level of scale (Wu 2004), measured in the plot context (Forman and Godron 1986), analyzed at several times (Riitters et al. 1995; Turner 1990; Turner and Romme 1994), and displayed and represented in spatial patterns (Gustafson and Parker 1992; McGarigal et al. 2002; McGarigal and Marks 1995). Conceptually, landscape structure is referred to spatial configuration and composition of environmental and ecological units and relationships among them (Dunning et al. 1995; McGarigal and Marks 1995). Due to independent and interactive effects on ecological processes, GSEQ can be characterized by configuration and composition features. Figure 1 shows the conceptual framework and dependent variables of the ecological quality. At scale level, in fact, urban environments, described as a heterotrophic ecosystem, have interacted spatially with context and its survival greatly dependent on energy and materials in large amounts. In this ecosystem, the

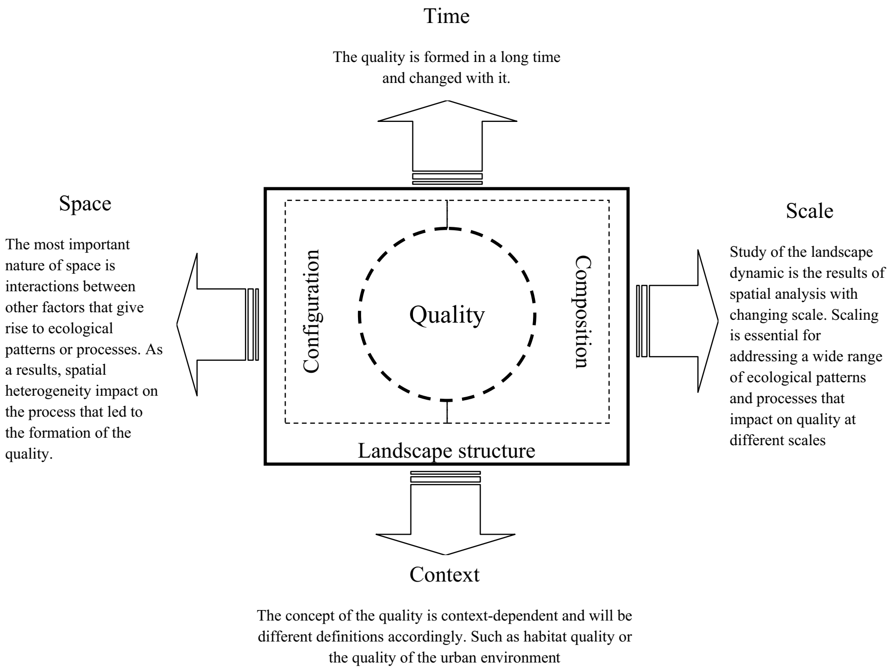


Fig. 1 Schematic representations of the ecological quality conceptual framework. *Source*: Authors

green patches are described as ecological units by the spatial distribution, resource, function and utilization among other units (Wiens 1989). As dynamic units, they have been influenced widely on spatial properties and have indirectly impacted ecological quality and different spatial and temporal scales through urban development patterns. As a result, spatial heterogeneity of urban green space is present in nature on all scales. Its establishment and interactions with ecological operations can affect ecological quality of the landscape structure. Ecologists often describe spatial heterogeneity as patches of discrete areas that are different in composition, structure and function (Cadenasso et al. 2006; Pickett and Cadenasso 2006; Zhou et al. 2011). In the urban landscape structure, the spatial incongruity of green spaces maybe described by patches based on such varied attributes such as shape, density, size, connectivity, and complexity. Spatially, various configurations and composition of the urban structure cause heterogeneity and show other results regarding the quality of green patches mosaic (Alberti 2005).

Composition is quantified simply and is related to properties correlated with the excess and variety of patch types in the landscape. Configuration is more troublesome to quantify and is related to the spatial arrangement and character, position, or patches orientation in the landscape or class (Gustafson 1998; Li and Wu 2004; McGarigal and Marks 1995). Green patches as a unit in the structure of landscape can reflect succession, disturbance, ecosystem function, and conservation (Pickett and Rogers 1997) specified by patchiness on broader scales, thus, ignoring the basis to define patchiness, quality of green spaces depends on spatial heterogeneity. Although it is not easy to determine the causality between quality, process, pattern, and function, the result regarding ecological processes and landscape metrics is often inconsistent. Quality through differences in the structure of landscape can affect patterns, processes, and functions of green patches that are also constrained by environmental conditions varying in time and space and by the local interaction (Wagner and Fortin 2005). From landscape ecology point of view, there is always an association between spatial heterogeneity and landscape structure redefined by quantitative and qualitative variables. Figure 2 presents the GSEQ's conceptual framework.

Owing to their nature and origin, these variables provide a new description of configuration and composition of the ecological structure characteristics of landscape. Quantitative variables include measurable landscape elements characteristics, which are

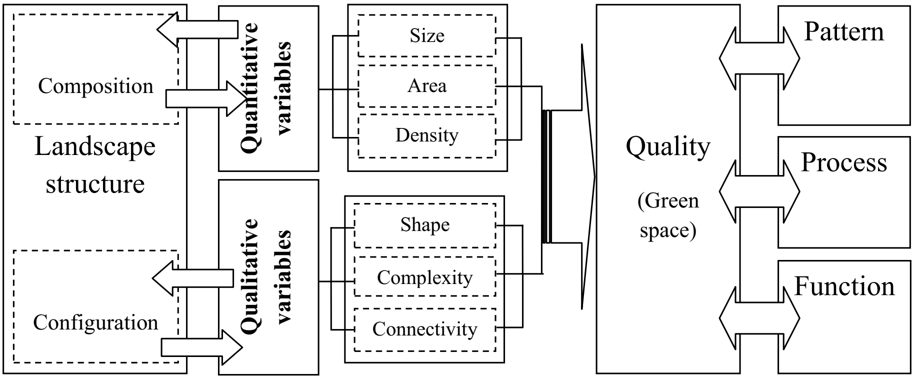


Fig. 2 Relationship between landscape structure, the quality of green space, and pattern, process and function. *Source*: Authors

numerical and often calculated by simple and linear mathematical equations, and have ordinal, interval and ratio quantitative scales (e.g., area, size, and length). Qualitative variables cannot consider with respect to any natural ordering, and therefore they are measured according to a nominal scale that may be coded to seem numeric; however, their numbers have no meaning (e.g., shape, complexity, and continuance). These variables are calculated mostly by complex and nonlinear mathematical equations. Since the functions of green patches are dependent on their structure, and therefore metrics of landscape are suitable means to explain the mosaic pattern and its urbanization changes and is influenced by human beings (Borrelli et al. 2013; del Castillo et al. 2015; Liu and Zhang 2011). The use of landscape indexes to examine the connections between ecological processes and the quality of green space, functions, and patterns constitutes a crucial tool to plan and manage the environment regardless of the conceptual constraints. The utility of the patch characteristic information will ultimately depend on the objectives of the investigation. According to the study objectives, this applies spatial data (patches) of landscape elements to evaluate the green space quality. Specifically, in this study, quantitative variables, including size, area, and density are used to indicate the green space composition. For instance, the metrics used to describe these variables measure percent of land, mean proximity and total edge of patches. On the contrary, complexity, shape, and continuity are the variables that can provide qualitative characteristics based on configuration of landscape. The equivalent metrics indicate complexity of patch and landscape shape and effective area and size distribution, respectively.

Theoretically, the first planned green city is proposed in the garden city concept by Howard, an ideal of urban temporal, spatial, and cultural, (Duany 2011; Hestmark 2000), form and structure presented by the association between planning and ecology (Leitao and Ahern 2002). Despite continuance of promoting green spaces in cities in 1950, the urban planners mainly focused on urban sprawl development and the necessity to preserve natural resources due to more physical aspects of green spaces needed to be assumed with respect to their ecological characteristics. There are numerous researches on the subjective or objective green spaces characteristics. Subjective studies include the evaluation between esthetic value and landscape quality (Acar et al. 2006; Bulut and Yilmaz 2008; Chen et al. 2009; Li et al. 2005) or objective referring to significant functions of them in urban life (Miller et al. 1998; Uy and Nakagoshi 2008). Recent literature attempted to relate quality concept and ecological properties to each other. These studies applied various spatial indices usually applied in the research of the ecology of landscape and evaluated ecological quality (Tian et al. 2014) regarding some indices such as proximity relationship, patch shape, patch size, and edge configuration (Tian 2002; Tian et al. 2014). In addition, most of these studies have evaluated patterns of urban green spaces and its changes using satellite images and GIS (Rafiee et al. 2009; Wu 2004; Wu et al. 2002). However, few studies have considered the spatial representation and ecological quality (Saura 2004; Uuemaa et al. 2011, 2013; Wu et al. 2002). These studies specifically assessed the urban green space quality in a compact city such as Hong Kong by landscape ecology (Jim 2013), or have focused on subset of urban green space ecological properties and impacts such as greenway (Baschak and Brown 1995) and green network (Kong et al. 2010). This research has analyzed the landscape patterns composition and configuration spatially (size, area, percent coverage edge, interconnectivity and shape) and examined the impact of variables on ecological quality using correlation test. It is widely used in determining the effectiveness of urban green space used by urban ecologists, planners, and designers.

2 Methods

2.1 Study area

Mashhad (Capital of Khorasan Razavi) is in the northeast of Iran at latitude: 36°18′N59°36′E (Fig. 3). With an area of 382 km^2 and current population 2.9 million, Mashhad is the second most populous city in Iran (Municipality of Mashhad 2014). With high (35 °C) and low (− 8 °C) temperatures, Mashhad have a steppe climate with hot summers and cool winters. In recent decades, it has witnessed rapid growth, mostly due to its economic, social, and religious attractions (Rafiee et al. 2009).

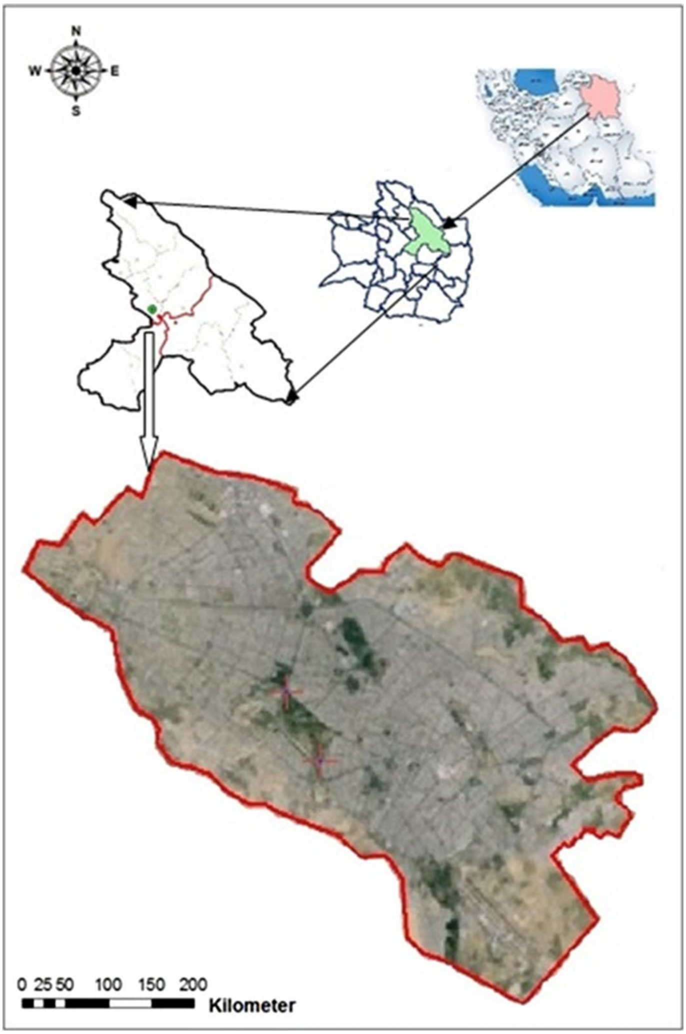
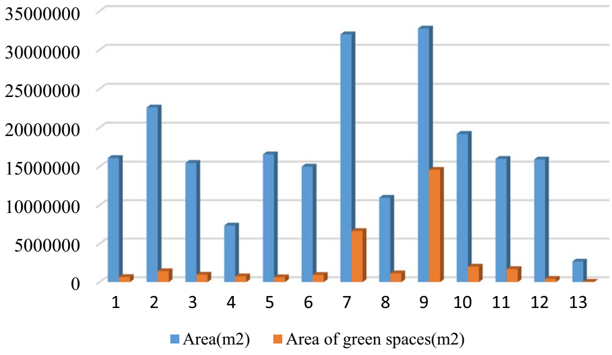


Fig. 3 Location of the study area in the northeast of Iran

Table 1 Regions, population and green space classification in Mashhad urban area. *Source*: Mashhad parks and green space organization, 2012. www.parks.mashhad.ir

Regions	Area (ha)	Populations	Area of green spaces (m^2)
1	1611	195,577	667,683
2	2260	458,464	1,433,622.4
3	1547	344,972	971,963.7
4	734	246,871	760,444.3
5	1658	162,960	634,012.6
6	1500	200,175	936,265.5
7	3200	223,691	6,627,101.3
8	1097	117,021	1,139,925.1
9	3275	329,760	14,588,271.2
10	1918	256,380	2,024,991
11	1600	213,621	1,712,828
12	1592	34,198	429,440.9
13	268	32,851	54,325.7

Fig. 4 Comparison between the population and green space area



Due to the physical expansion of Mashhad, urban green areas have been replaced with different buildings, and therefore, it is required to study urban green spaces in term of quality. Based on the divisions of Mashhad Municipality, it has 13 regions that each one has different area, population, and green spaces types and conditions. Table 1 quantitatively shows distribution of green space and urban parks. A comparison between population and area indicates that Region 9 has a higher share and a better condition than other regions and Regions 7 and 2 are in the following category. Figure 4 shows the comparison between the population and green space area.

2.2 Data processing and green space distribution map

Satellite images were utilized to derive urban green space maps. The details of satellite image data (Landsat 8 ETM +) used in this study were obtained from the US Geological Survey (USGS) on June 21, 2013. Classification, image processing, and GIS analyses were performed by ENVI 4.7 software and ArcGIS 10. To provide a green space map, the unsupervised classification method was used to a generate patch layer map (i.e., a polygon layer) in ENVI 4.7 software setting. Types and features were created based on the integrated land use map as well as calculating and extracting the normalized difference

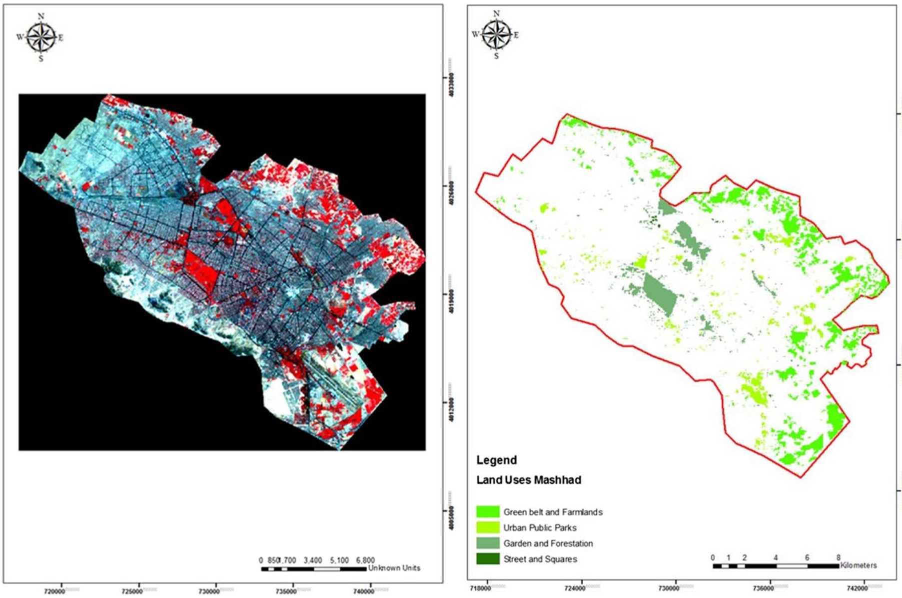


Fig. 5 Unsupervised classifications of the original Landsat 8 NDVI (left) and Green space distribution and type map in study area (right)

Table 2 Green space types and area classification. *Source*: Authors

Green spaces types	Area (m^2)	Percentage (%)
Green belt and farmlands	21,751,664.91	56.92
Garden and forestation	9,242,517.00	24.18
Public urban parks	6,849,211.85	17.92
Street and squares	370,374.73	0.96
Total	38,213,768.49	100

of vegetation cover index (NDVI). To obtain a distribution map of the green spaces, the NDVI map was rectified and geo-referenced by the ArcGIS 10 (Fig. 5).

As a final map, urban green space was categorized into four types: green belt and farmlands, garden and forestation, public urban park, and street and squares. Estimates show that a large part of the totality of Mashhad green space area is allocated to the green belt and farmlands (56.92%). In this classification, public urban parks, garden, and forestation and street and squares are in the next category (Table 2).

2.3 Metrics calculation and analysis

To evaluate the green space ecological quality, the landscape ecology approach and metric measurements were used to analyze landscape configuration and composition patterns. Landscape pattern indices promote landscape pattern analysis from a qualitative analysis to a quantitative one, and they are widely used to analyze characteristics of landscape patterns (Zhang et al. 2004). To select and apply the metrics of landscape, previous studies have introduced landscape metrics according to objectives and methodology of research. Landscape metrics characterize spatial patterns of the landscapes and compare ecological quality across the landscapes (Liu and Weng 2008; McGarigal 2002; Riitters et al. 1995, 2009). Nevertheless, landscape metrics cannot be simply categorized as representation of composition or configuration of landscape. For instance, patch density and mean patch size of a patch show the amount of the patch (composition) and its distribution of space (configuration). However, all metrics should not be categorized based on the configuration dichotomy versus simple composition. In addition, landscape structure involves composition and configuration; different metrics show these landscape structure aspects in combination or in isolation (McGarigal and Marks 1995). Additionally, the landscape metrics usages are constrained via their sensitivities, capabilities, and methods of derivation (Gustafson 1998; McGarigal 2002; McGarigal and Marks 1995), easy calculation, and interpretation. The most frequently used configuration and composition metrics were selected to quantify ecological quality of the green spaces. All selected landscape metrics were measured by the analysis program FRAGSTATS 4 for landscape structure. Table 3 lists the used landscape metrics, their definitions, and formula, which were classified in two categories including:

(a) *Composition metrics* (quantitative variables) percentage of landscape (PLAND), mean patch size (MPS), total edge (TE), class area (CA), and mean proximity index (MPI).

    The landscape metrics have been chosen to quantify landscape composition and measure specific features of green patches. The PLAND index calculates the size ratio of each green patch within the total area. The MPS index indicates the average size of various types of green patches. The TE index measures the edge length of green space patches and demonstrates degree of landscape fragmentation. The CA index shows the total area of a green patch, and the MPI index calculates the degree of green patches isolation by measuring size and distance of each patch to all neighboring patches in the same type.

(b) *Configuration metrics* (qualitative variables) mean patch fractal dimension (MPFD), mean shape index (MSI), landscape shape index (LSI), and effective mesh size (MESH).

    In term of configuration metrics, the MPFD index measures the complexity of patch shape to a standard shape of the same size. The MSI index as a shape index represents the ratio between the perimeter of a patch and the perimeter of the simple patch. The LSI index indicates the normalized ratio of edge to area. Finally, the MESH index measures the ratio between square of the sum of patches and the total area of landscape.

None of landscape metrics alone could not indicate the appropriate and inappropriate status of landscape; therefore, the metrics are evaluated with each other and all metrics must be assumed in analyzing ecological status.

2.4 Representing of metric value

To represent the numerical value of each metric, it is necessary to attach amount of the calculated metrics to the related patches. This stage is performed in the GIS setting by spatial analysis process and thus will be represented as quantities value per metric. GIS setting usually provides spatial analysis tools to calculate feature statistics and conduct geoprocessing activities as data interpolation. In this study, interpolation techniques were used to represent the metric value and spatial analysis. Spatial interpolation is the process of

Table 3 List of landscape metrics used in this study. *Source:* McGarigal (2002)

Metric types	Metrics	Definitions	Formula	Descriptive	Range
Composition	TE	Total edge	$\mathrm{ED} = \frac{\sum_{k=1}^{m} e_{ik}}{A}(10,000)$	Edge calculations include all the edge on the landscape including boundary edge	$\mathrm{TE} \geq 0$
	MPS	Mean patch size	$\mathrm{MPS} = \frac{\sum_{i=1}^{m} [a_i]}{m}$	The average area of all patches in the landscape	$\mathrm{MPS} > 0$
	MPI	Mean Proximity Index	$\mathrm{MPI} = \frac{\sum_{s=1}^{n} \frac{aijs}{hijs^2}}{A}$	Mean proximity index is a measure of the degree of isolation and fragmentation of a patch	$\mathrm{MPI} \leq 0$
	CA	Class area	$\mathrm{CA} = \sum_{j=1}^{n} a_{ij}\left(\frac{1}{1000}\right)$	Sum of areas of all patches belonging to a given class	$\mathrm{CA} > 0$
	PLAND	Percentage of landscape	$\mathrm{PLAND} = \frac{\sum_{j=1}^{n} aij}{A}$	Percentage of area occupied by certain land cover class	$0 > \mathrm{PLAND} < 100$
Configuration	MPFD	Mean patch fractal dimension	$\mathrm{MPFD} = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} \left(\frac{.2\mathrm{In}(.25Pij)}{\mathrm{In}\, aij}\right)}{N}$	Mean fractal dimension approaches one for shapes with simple perimeters and approaches two when shapes are more complex	$1 \leq \mathrm{MPFD} \leq 2$
	LSI	Landscape Shape Index	$\mathrm{LSI} = \frac{ei}{\min\, ei}$	Ratio of the total edge to the minimum total edge	$\mathrm{LSI} \geq 1$
	MSI	Mean Shape Index	$\mathrm{MSI} = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} \left(\frac{0.25pij}{\sqrt{aij}}\right)}{N}$	Sum of each patch's perimeter divided by the square root of patch area for each class	$\mathrm{MSI} \geq 1$
	MESH	Effective mesh size	$\mathrm{MESH} = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij}^2}{A}$	Mesh is based on the cumulative patch area distribution and is interpreted as the size of the patches	Cell size $\leqq$ MESH $\leqq$ total landscape area A

using points with known values to estimate values at other unknown points. They are a set of deterministic methods based on mathematical formulas. Estimates are on based on the averages of the measured values at unknown points. Inverse distance weighting (IDW) is an interpolation method according to values in close locations weighted only through the distance from the position of interpolation. Equation 1 shows the used formula for the IDW (Shepard 1968):

$$\text{Zest}_j = \sum \left[z_i / \left(h_{ij} + s\right)^{\rho}\right] / \sum \left[1 / \left(h_{ij} + s\right)^{\rho}\right] \tag{1}$$

where Zest_j, estimated value for location j; z_i, measured sample value at point i; h_{ij}, distance between Zest_j and z_i; S, smoothing factor; ρ, weighting power.

This expression can be used as a spatial dimension per metric and be added to each patch in GIS setting. Therefore, a data layer will be obtained per metric representing the patch spatial features. The entire process is performed by using the spatial analyst tools in GIS setting and can help to provide a better representation of ecological quality of the green spaces.

2.5 Determining weights of criteria through AHP

At this stage, indicating the weight of each metric to integrate layers into an ecological quality map is the most important issue. Since the share of each metric in the ecological quality of green space is not clear, it is necessary to determine and standardize effective criteria of assessment. Thus, ecological quality of the green spaces was simulated by multiplication summary of the weight of each metric through the loading values (S) of the related indexes (Tian et al. 2014). The analytic hierarchy process (AHP) was used along with GIS to study the ecological quality. AHP includes the following steps:

(a) Production of pair-wise comparison matrices: It uses a primary scale with quantities of 1–9 to indicate the relative priorities regarding two criteria.
(b) Calculation of criterion by weight.
(c) Estimation of according ratio (Saaty and Vargas 2012).

AHP is also a common means of eco-environment quality evaluation at present, and with respect to ecological environment, it is a large and multilayer system (Ying et al. 2007). It has the privilege of qualitatively and quantitatively solving the problems and combining decision makers' judgment and experience into the model via quantitative treatment. This method, as a highly common multiple criteria decision making (MCDM) technique (Chen et al. 2010; Kordi and Brandt 2012; Mosadeghi et al. 2015), is a multicriteria decision making that uses the pair-wise comparison method (PCM) (Saaty 2008), where factors are organized in hierarchy (Saaty 1990). To compute the ratios for each pair of composition and configuration metrics, it required to establish a matrix of pair-wise comparison. According to the specified decision rules, the expert committee made the pair-wise comparisons for the set of the nine corresponding metrics, after debate and thorough analysis of the set of the quality criteria. Table 4 shows a sample of the pair-wise comparison matrix.

Experts with landscape ecology and urban sustainable development backgrounds were invited to give the proportional significance of every metric. The all metrics weights calculated by the pair-wise comparison matrix are entered in the Expert choice

Table 4 Preference matrix and pair-wise comparison of criteria

Criteria	MESH	MPFD	LPI	PLAND	MSI	TE	MPS	MPI	LSI
MESH	*1*	5	6	2	7	5	9	9	7
MPFD	1/5	*1*	1/3	1/3	4	5	7	7	7
LPI	1/6	3	*1*	1/3	7	6	6	7	7
PLAND	1/2	3	3	*1*	9	9	9	9	9
MSI	1/7	1/4	1/7	1/9	*1*	3	5	3	3
TE	1/5	1/5	1/6	1/9	1/3	*1*	5	5	5
MPS	1/9	1/7	1/6	1/9	1/5	1/5	*1*	3	3
MPI	1/9	1/7	1/7	1/9	1/3	1/5	1/3	*1*	3
LSI	1/7	1/7	1/7	1/9	1/3	1/5	1/3	1/3	*1*

1, Equal; 3, Moderate; 5, Strong; 7, Very Strong; 9, Extreme

11 software (Fig. 6). Finally, the rank of the relative importance for each factor is obtained. Conclusions were:

- MESH as a connectivity factor is the most important metric to indicate ecological quality of the green patches. Therefore, weight of MESH was the highest.
- MPFD had relatively high weight. In the expert committee's view, it implies that the complexity with connectivity, as a configuration metric in the landscape structure, is considered the most important factor in evaluating ecological quality of urban green spaces.
- In this evaluation, a relative comparison indicates that CA and PLAND are less important. However, it could not be ignored for the assessments directly related to ecological quality, planning issue, and urban sustainable development.

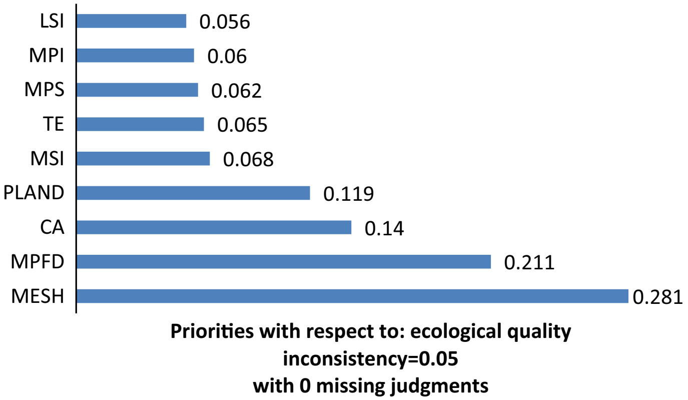


Fig. 6 Relative weight of the parameters calculated by Expert Choice software

2.6 Calculating ecological quality and drawing the grade map

Based on the research method, values of all metrics were overlaid to determine the green space ecological quality. The ArcGIS ver.10 software was used in the representation of the layers value as well as gradation and creation of the grade map in the ecological quality. It uses the layers, variables, and numerical values with the method of multilayer weighted sum after standardization and quantization of the thematic data. Automatically, the quantification evaluation of ecological quality was carried out by the overlay of data layers by aster calculator tool. The output is a quantities map represented into spatial data through overlaying analysis. Therefore, the final evaluated map is the whole weight values of all related metrics by using Eq. 2.

$$\mathrm{GSEQ} = \sum_{i=1}^{n} M_i W_i \tag{2}$$

where GSEQ is the synthetic map of the green space ecological quality, M is the representative of each metric, W is the weight of each metric, and n is the whole metric, $i = 1, 2, 3\ldots n$.

3 Results

To assess ecological quality of the green spaces according to the landscape metrics, spatial pattern of the green spaces was depicted via the value of all landscape metrics. The findings of this research are presented in three sections: In the first section, the findings related to the landscape composition and spatial pattern; in the second section, the findings related to the landscape configuration and spatial pattern, and in the third section, final quality map was presented.

3.1 Landscape composition and spatial pattern

Figure 7 shows the spatial distribution of PLAND, MPS, TE, MPI, and CA, and the changes of composition metrics in the whole study area. All composition metrics have the highest amount in the east and southeastern of Mashhad city, and this high value is due to the Torogh Park, one of the largest parks in Mashhad. By district, it has the largest patch with the highest PLAND (31.1), MPS (0.26), CA (10.05), TE (1785.82), and MPI (0.0011). Ecological status improving through increasing patch size and the environmental conditions would be more stable. Enhancement of MPS metric demonstrates reduction in fragmentation, and reduction in MPS metric increases the fragmentation (McGarigal and Marks 1995). North, west, and central regions have the lowest CA, MPS, and PLAND, resulting in low ecological quality of green spaces. MPI measures the fragmentation and isolation of a patch and applies to the closest neighbor statistic (McGarigal and Marks 1995).

Low amount of MPI shows less proximity among patches, and therefore, there would be much fragmentation. In the whole study area, the lowest MPI (0.00031) areas are present in the western and southern regions of the city, and thus, fragmentation would be reduced by enhancing the MPI value. As a result, their low TE is associated with less complications

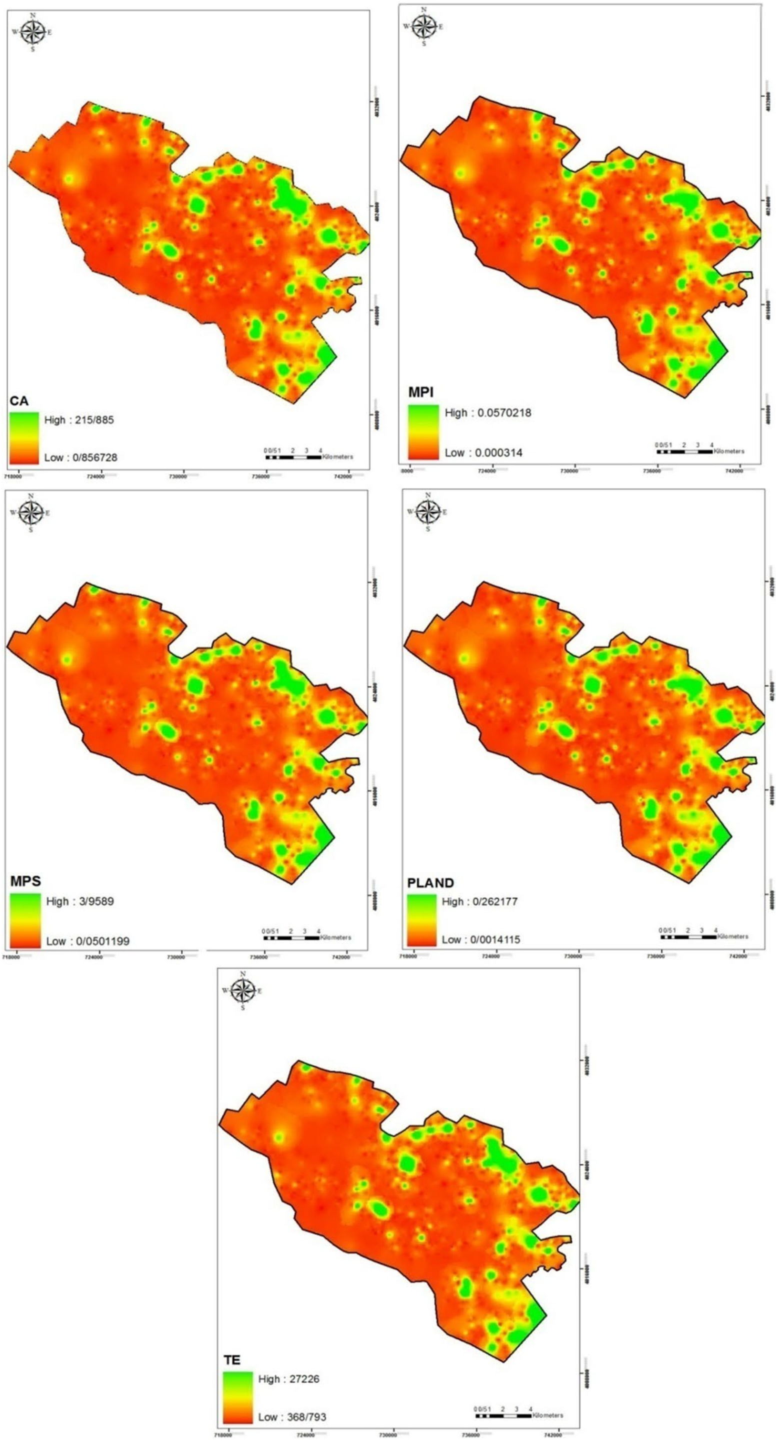


Fig. 7 Spatial representation of composition metrics

(mainly straight) and total edges, showing that the green patches are smaller, more fragmented, and heterogeneous with lower ecological quality. Since the eastern and north-eastern regions of Mashhad have the highest area and coverage, therefore, it is expected that these regions have high TE. In this region, amount of TE is the highest (27,226) in comparison with the whole study area. CA metric determines the largest patch area in the northeast and east of the city (215.885). It can be an effective factor to determine stability in the region. The more area and the larger patch, the more stable it would be (McGarigal and Marks 1995). In addition, this study was performed at class level. In line with the research objectives, all landscape metrics were standardized according to the model of standard deviation (Fig. 8). The green space fragmentation metrics yield high values, in particular, for areas surrounding the central urban area and northern part of the city. Center of the study area is specified using lower values since the green space is confined to some small compact patches. The fragmentation of green space decreases near the rural/urban interface, reflecting the more natural character and higher ecological value of these areas.

The results show that each of the classes has unique characteristics. Accordingly, the green belt and farmlands mostly developed in the eastern and northern of Mashhad have the maximum amount of PLAND, CA, TE, MPI, and MPS. In this comparison, urban public parks, gardens and forests, and street and squares are in next categories, respectively. Spatially, the results indicate that the farmland and green belt have high cohesion

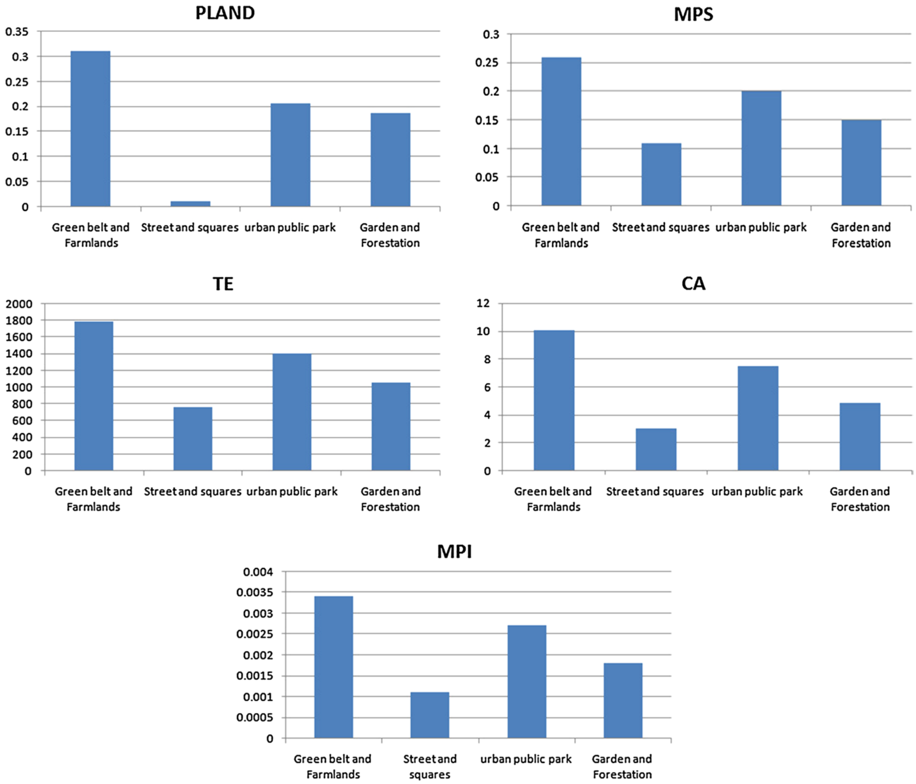


Fig. 8 Landscape composition metrics for existing green space in class level

and homogeneity in comparison with other classes. This has the highest amount of TE, and this feature can significantly affect ecological and environmental interactions. Broad and contiguous emergence of the green patches have enhanced ecological potential and caused to decrease the spatial heterogeneity. However, other green space types have high spatial heterogeneity due to scattering and low area. MPS and MPI indices are appropriate measures to assess the degree of heterogeneity. It can be argued that the landscape composition of agricultural land and green belt are in a better ecological condition, and therefore it is expected to have an effective role in ecological functions and processes.

3.2 Landscape configuration and spatial pattern

Figure 9 shows that the variations of MESH, MPFD, LSI, and MSI in the whole study area. Spatial analysis of each metric indicates that the districts in central and northwest regions have lower LSI, MPFD, MSI, and MESH than most others. The highest MESH (215.88) and MPFD (1.23) areas are ascribed to the east and southeast regions of the city. MESH shows the size of green patches when the landscape is classified into areas with the same landscape division as achieved for the obtained cumulative area distribution. Hence, the contiguous patch area may be obtained from a randomly selected cell with leaving no patches (McGarigal et al. 2002). Calculating MPFD according to fractal dimension of each patch that shows the patch complexity and provides morphological properties of green patches is an alternative to the regression approach (McGarigal and Marks 1995). The highest MPFD is found in forests and gardens (1.24). Therefore, enhancing fractal dimension values may elevate the interaction with the environment and enhance the ecological quality. LSI is a choice based on the “average” patch features at landscape and class levels. This index examines the ratio of perimeter to area as a whole for the landscape; however, the index is also applied at the class level. LSI and MESH are highly effective metrics in characterizing landscape fragmentation (Fan and Myint 2014). In this study, spatial analysis shows green space heterogeneity in the west and south of the city. The average patch shape is measured by MSI, like most other metrics; eastern and southeastern regions have the highest amount. To analyze based on the level of the class, like the previous section, all selected landscape metrics were standardized based on the standard deviation model (Fig. 10). The comparison shows that the green belt and farmlands are also in the lead due to their configuration properties. Spatially, the patches containing a high amount of MESH are crucial in connectivity and continuity, and therefore, it implies the high ecological value. Shape and complexity are other factors that determine ecological quality of the green spaces and play a primary role in spatial configuration. What should be considered is the same treatment of different classes of green space by taking landscape metrics into account. Although all classes have a man-made nature, the complexity, shape, and continuity of the greenbelt and farmland are closer to natural green patches. Thus, this class of green spaces in Mashhad may have higher ecological quality than other classes.

3.3 Quality of urban green space

The evaluation results in Fig. 11 are the sum of weighted metrics based on green patches, and the selected landscape metrics are presented in the Methods. All urban green spaces of Mashhad are determined in this map based on the metrics of landscape so that green parts are the most appropriate and red parts are the most inappropriate in terms of ecological quality. The grade map in a determined area is presented as Eq. 3:

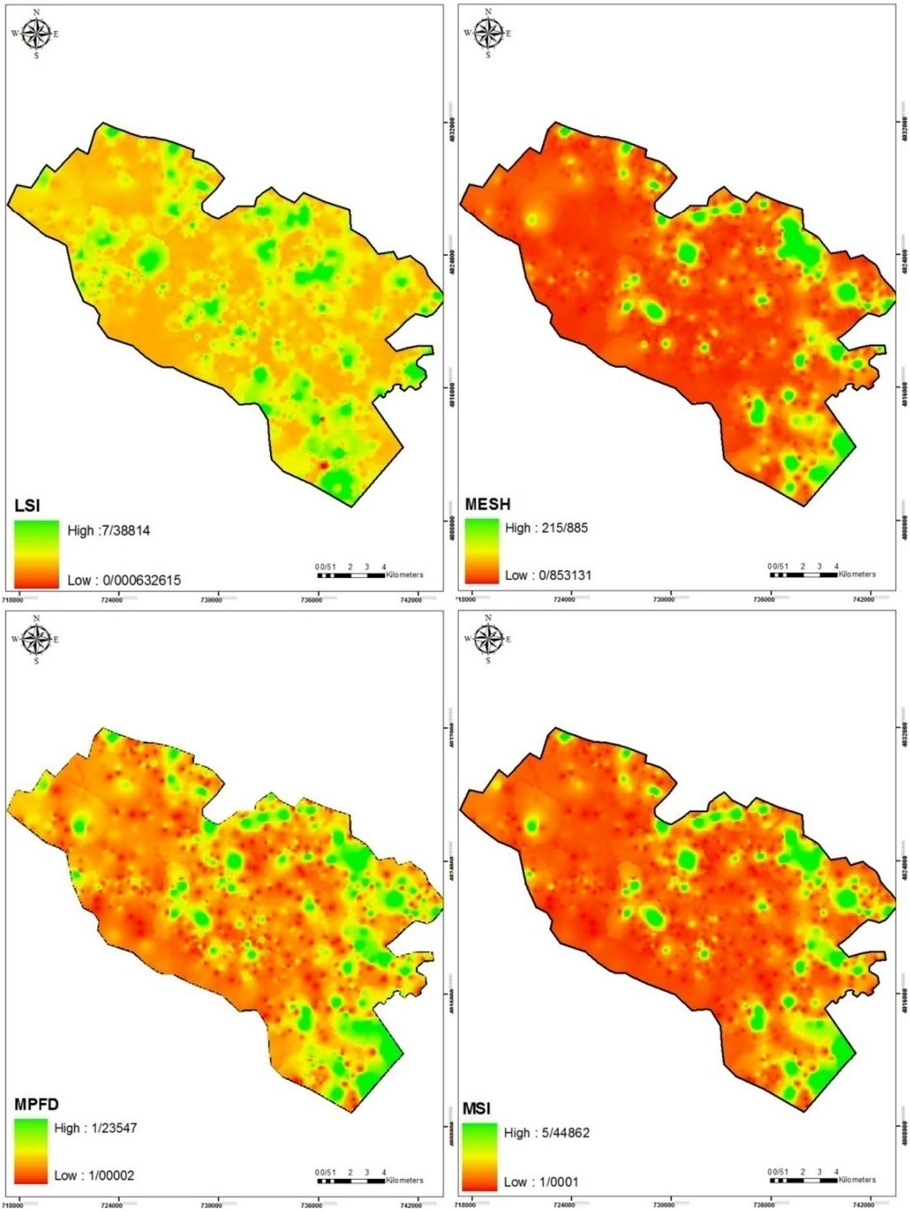


Fig. 9 Spatial representation of configuration metrics

$$\begin{aligned}\mathrm{GSEQ} = {} & (\mathrm{MESH} * 0.281) + (\mathrm{MPFD} * 0.211) + (\mathrm{CA} * 0.14) \\ & + (\mathrm{PLAND} * 0.199) + (\mathrm{MSI} * 0.068) + (\mathrm{MPS} * 0.062) \\ & + (\mathrm{TE} * 0.065) + (\mathrm{MPI} * 0.06) + (\mathrm{LSI} * 0.056)\end{aligned} \tag{3}$$

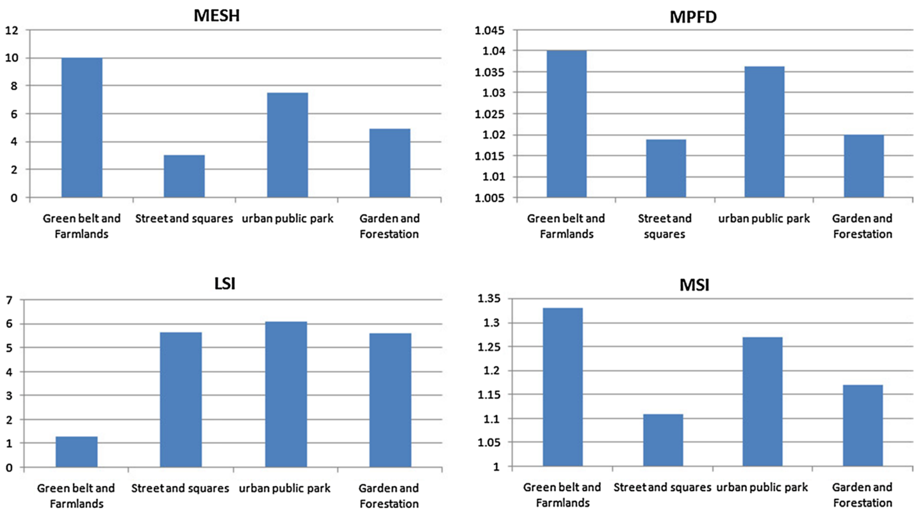
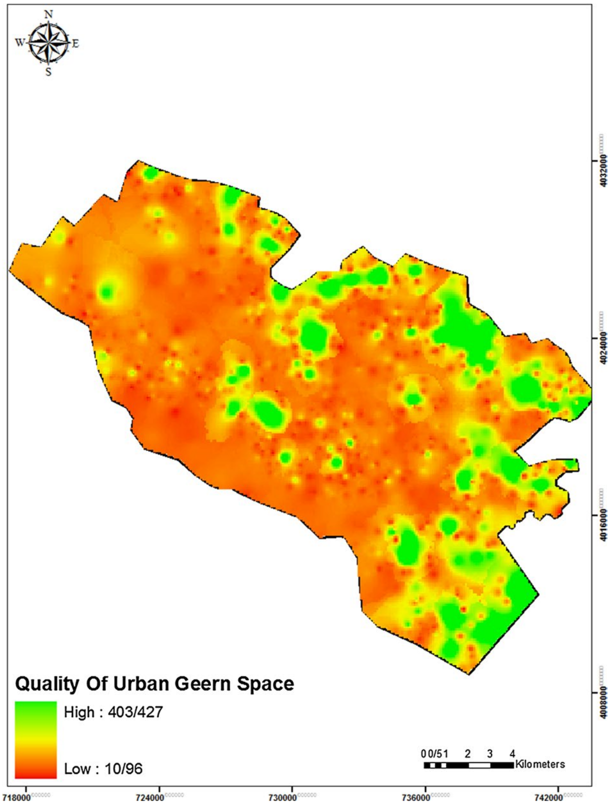


Fig. 10 Landscape composition metrics for existing green space in class level

Fig. 11 Spatial quality of urban green space



According to this, each landscape metric is associated with its weight to make the polygon of green patches and their characteristics identical. Concerning the spatial distribution of green space in the study area, the ecological quality represented green space status of Mashhad urban areas. Most of the areas with high quality were located in the east, northeastern, and southeastern regions, where there were plenty of aggregated farmlands and large areas and tracts greenbelt. In contrast, the west and inner regions had lower quality grade where there were mainly new development of cities and compact urban fabric leading to lack of green spaces. In this region, the green spaces are lower and more fragmented and heterogeneous with lower MPS, PLAND, and CA than those in most regions. At class level, the green space in the greenbelt and farmlands has usually higher values than other levels like MPS, PLAND, CA, and MESH. However, streets and squares of green space with the lowest CA, PLAND, MPS, and MESH spatially have higher heterogeneity than other classes. Table 5 shows the quality comparison between the classes.

Although most class indexes are described as fragmentation indexes since they examine the fragmentation of a specific patch, most of the landscape indices can be interpreted more broadly as landscape heterogeneity indices because they measure the overall landscape structure (McGarigal and Marks 1995). For instance, mean patch size (MPS) is assumed as an index to analyze fragmentation. Hence, a patch with a smaller mean patch size compared to other patches can be more fragmented within a single landscape. Moreover, in a landscape, the total amount of edge is needed for many ecological phenomena. In fact, the crucial importance of spatial pattern is associated with edge effects in many landscape ecological studies (McGarigal 2002). Additionally, continuity, shape characteristics, and complexity may be described as fragmentation indexes since they consider the fragmentation and the whole landscape structure of a special patch type. Because of these factors, eastern, northeastern, and southeastern regions with the largest CA, PLAND, ED, MPS, MPFD, and MESH have higher spatial homogeneity or lower fragmentation of green spaces than other regions. Thus, spatially, this region has the highest quality in the whole study area.

4 Conclusion

Urban green space has widespread usage and many benefits for quality of human life. However, climate restriction and urban development features and policies have influenced the urban green space ecological quality in Mashhad city. In this study, we also used and examined a conceptual framework to measure green space ecological quality in Mashhad by landscape metrics and spatial analysis. The proposed patch metrics in terms of composition and configuration have informed us about function of urban green patches separately. However, when the analytic hierarchy process (AHP) was used and integrated landscape metrics map along with GIS, we were able to study the quality of green space patches. In

Table 5 Quality comparison between classes in the study area

Class	NumP	Average quality	Max	Min
Green belt and farmlands	568	91.7455	403.427	11.99
Urban public park	291	79.715	395.699	11.334
Garden and forestation	399	57.201	361.440	10.96
Street and squares	87	25.854	150.787	11.375

fact, the green space ecological quality has provided evidence for the green space quality by spatial analysis of heterogeneity in Mashhad. Therefore, the results reveal that green spaces of Mashhad have low relative frequency, and patches of green spaces have undesirable conditions in terms of spatial composition and configuration. Statistically, the results of quality analysis demonstrate a significant difference between the minimum (10.96) and maximum (403.427) values in the spatial map. This means that there is a notable difference between the points with low and high ecological quality in the study area. In addition, average of quality values equal to 109.268 and standard deviation (SD) equal to 80.9125. Average and standard deviation are two closely related concepts measuring how "spread out" of a distribution or a data set value is. According to the descriptive statistics, we can imply that heterogeneity exists in distribution ecological quality values. Inappropriate distribution of green patches in the study area increases spatial heterogeneity and negatively influences the urban green space ecological quality. Based on the statistic point of view, landscape ecology approach has proposed many landscape metrics that can be applied to assess the quality of green patches. In this study, size, shape, and distance incidences are considered in terms of quantity and quality variables. According to the theoretical framework, green patches with the highest area and the largest patch size can have the highest potential to change microclimate, absorb spices and extend biodiversity in the urban area. In addition, shape and distance can influence the relationship between green patches and their environment, enhance the complexity of patch edge according to edge and shape effect, and may have better ecological quality. Thus, it has no sufficient extension and continuity to provide ecological services and improve ecological quality. Appropriate distributions of patches are recognized in these areas, proximity of patches is extremely uniform, and there is heterogeneous distribution of patches. There is no appropriate distribution of green space patches in other regions of the city; green spaces patches have been distributed non-uniformly and heterogeneously. Most patches are small, fragmentation is recognized, and there are no appropriate ecological conditions. Therefore, there would be no appropriate ecological quality. To identify which factors have the major effect on quality of urban green spaces', it is necessary to analyze the correlation between ecological quality and landscape metrics. Regression analyses evaluated the association between spatial quality and metrics. Correlation and regression analysis are used to quantify the association between landscape composition, configuration variables, and urban green space ecological quality.

4.1 Landscape composition and urban green space spatial quality

Scatter plots show the associations between landscape composition metrics and urban green space ecological quality (Fig. 12). Our analysis found a similar strong linear relationship between ecological quality and composition metrics in the whole study area. All metrics have almost complete correlation with ecological quality. Results showed that ecological quality increases were significantly enhanced due to green space increasing. Spearman's rank correlation analysis was applied to identify the relationship between composition metrics and green space ecological quality. Pearson *r* correlation is widely used in statistics to examine the relationship between linear-related variables. Table 6 presents the correlation coefficients between ecological quality and metrics of landscape composition. Ecological quality was highly correlated with landscape composition metrics. For green space, the mean ecological quality was positively correlated with PLAND, class area CA, MPS, TE, and MPI. The Spearman's correlation between TE and ecological quality is the highest amount of correlation (0.943). These relationships indicate a significant effect of landscape composition on ecological quality of urban green spaces. Thus, we expect

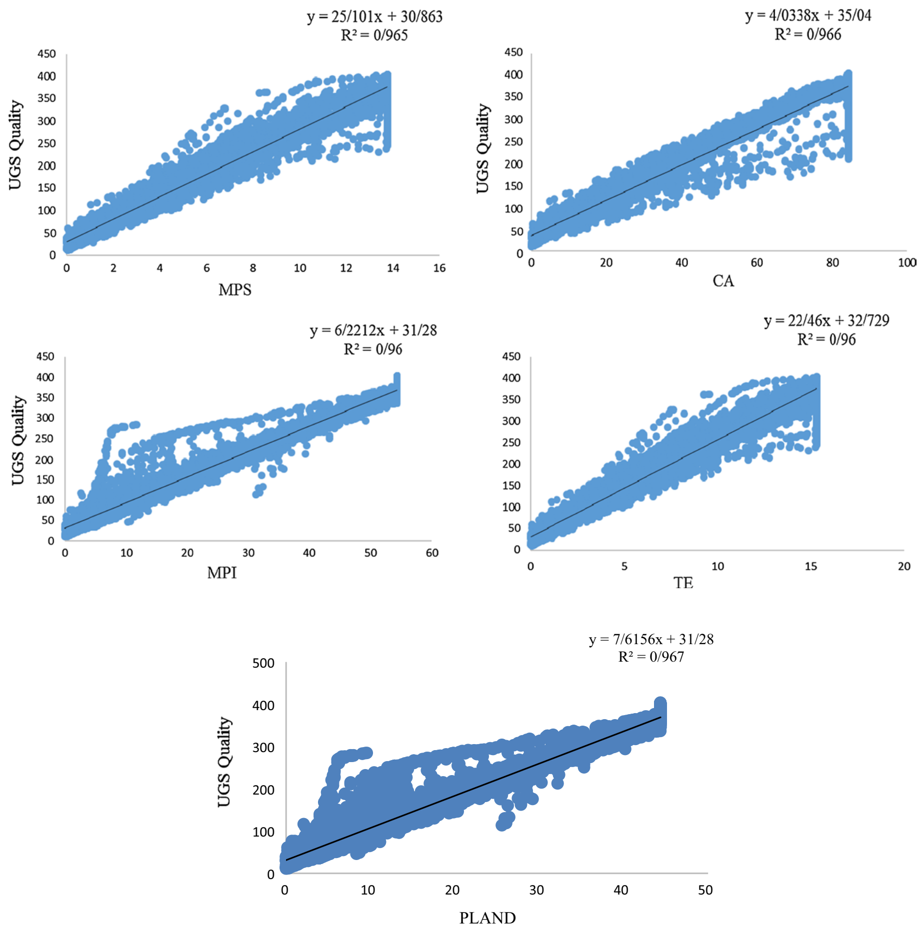


Fig. 12 Scatter plots of landscape composition metrics versus urban green space quality (UGS)

Table 6 Correlation and regression statistics (*n* ~ 35,000)

	PLAND	MPS	TE	MPI	CA
R^2 coefficient	0.967	0.965	0.966	0.967	0.966
Spearman's rank correlation coefficient	0.932**	0.942**	0.943**	0.932**	0.937**
Sig	0.000	0.000	0.000	0.000	0.000

** Correlation is significant at the 0.01 level (2-tailed)

ecological quality of green spaces will improve when quantitative variables are subsequently enhanced. The trend of variation is increasing, especially the length of the greatest impact on quality. By green edge enhancement in the patch, increased environmental and ecological interactions are caused, thereby increasing the ecological quality. Increasing the size and area are factors that directly affect ecological quality of the green spaces.

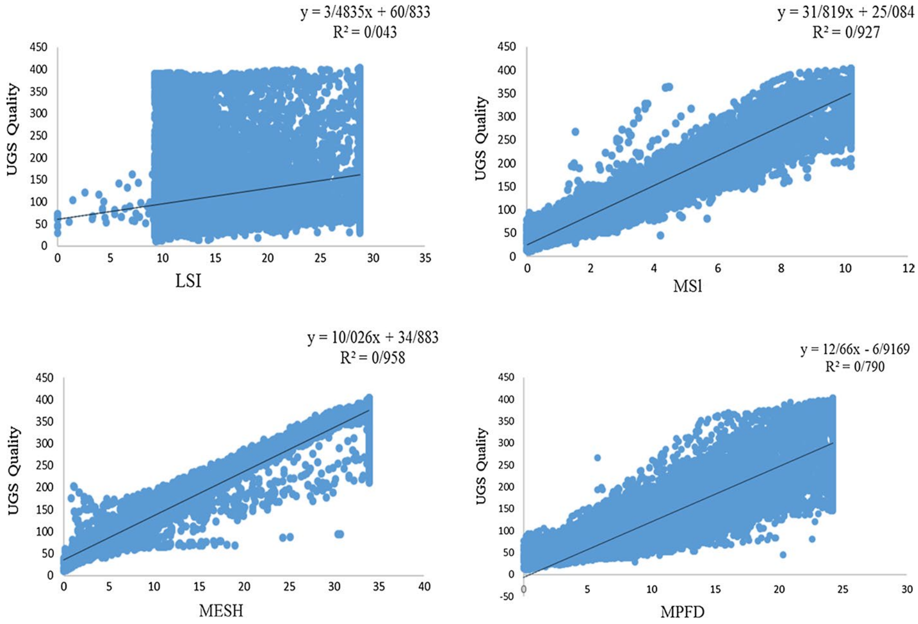


Fig. 13 Scatter plots of landscape configuration metrics versus urban green space quality (UGS)

4.2 Landscape configuration and urban green space spatial quality

Scatter plots examined the bivariate association between each of the landscape configuration metrics and ecological quality. Figure 13 shows two dimensional scatter plots between ecological quality and landscape configuration metrics. There seems to be a linear relationship between landscape metrics and ecological quality of green spaces. Although the relationships among the variables are positive and increasing, unlike composition variables representing to be highly correlated with the quality, the configuration variables show a different behavior. Spearman's rank correlation analysis was applied to identify the relationship between configuration metrics and ecological quality of green spaces. Table 7 presenting the correlation coefficients between the variables. In this group of variables, except LSI that has the low linear correlation (0.043) and Spearman's rank correlation coefficient (0.305), there is relative high correlation between quality and each other metrics relatively. In this study, analysis of the association between variables implies that there is a weak association between the shape and quality. The relationship analysis depends on

Table 7 Correlation and regression statistics (*n* ~ 35,000)

	MPFD	LSI	MESH	MSI
R^2 coefficient	0.790	0.043	0.958	0.927
Spearman's rank correlation coefficient	0.824**	0.305**	0.927**	0.896**
Sig	0.000	0.000	0.000	0.000

** Correlation is significant at the 0.01 level (two tailed) the important relationship between complexity and ecological quality. Although it was expected that the complexity of green space patches considerably affects the ecological quality; however, origin and nature of the green patches are one of the main factors have been generally made by human activities and transformed under the effect of human activities. Thus, the landscape structure has less complex and therefore low impact on the ecological quality of green spaces Due to a close relationship between the complexity and LSI, it can be implied that green patches shape makes low ecological quality by nature and origin. Finally, continuity is a crucial variable that has the greatest impact on the ecological quality. The highest correlation shows that the ecological quality increases unrestrictedly if the continuity of the green patches increases. Results indicate that metrics of landscape composition significantly are more effective than metrics of landscape configuration so that the ecological quality in the study area depends on the quantitative properties of landscape and green spaces more than the qualitative properties. Therefore, to achieve high-quality urban green space and improve urban life, it is required to prevent fragmentation of patches, increasing green space area, and percentage of land cover, and to create maximum continuity between the green space patches. More connection and ecological network communication increases ecological stability, which can enhance stability of urban environment quality and protect and revive structural elements of landscapes.

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