

Assessing the effect of green cover spatial patterns on urban land surface temperature using landscape metrics approach

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Abstract The present study was aimed to investigate how and to what extent urban land surface temperature (ULST) is affected by spatial pattern of green cover patch in an urban ambient in Isfahan, Iran. To materialize the effects of spatial pattern of green cover on ULST, Landsat ETM+image data on May 5, 2002 was acquired to be processed for ULST estimation and to generate Land Use/Land Cover (LULC) classes. Given to five percent of total available cells with a randomized distribution across the built-up areas, the linkage between ULST and composition, configuration and structure of green cover class was quantified. Five patch level landscape metrics including nearest distance (ND), patch area (AREA), perimeter to area (PARA), shape index (SHAPE) and core area index (CAI) were chosen and applied as explaining variables in statistical analyses due to their potential effects on ULST. Results of the present study have revealed that all the landscape metrics values of the green cover class were significantly correlated to their nearest ULST sample points, amongst which a stronger linkage was observed between ND ($r=0.611$, $p < 0.05$) and ULST compared to others. Stepwise generalized additive modeling method-based multiple linear regression model was then fitted to dataset and resulted in developing the model ($r^2=0.41$, $p < 0.05$), explaining the relationship between spatial pattern of green cover and ULST. Finally, we concluded that the present study could provide additional level of knowledge through which urban planners can optimize composition, configuration and structure of green cover patches to mitigate the adverse impacts of LST phenomenon especially where urbanization is still ongoing.

Keywords Urban Heat Island · Land surface temperature · Green cover patches · Landscape ecology · Landscape design

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Introduction

Population growth-induced urbanization is considered as the most drastic LULC transformation, substantially affecting interconnected components of ecosystems (Mondal and Southworth 2010). In the process of their evolution, urban areas impose noticeable impacts on their adjacent environment including wide exploitation of abandoned lands (Xiao et al. 2006; Deng et al. 2009), wildlife habitats degradation and isolation (McKinney 2002), hydrological cycles disruption (Weng 2001), air pollution (Nafstad et al. 2004), water contamination (Shao et al. 2006) and lifestyle quality of urban dwellers (Barnes et al. 2001). Urban heat island (UHI) is also taken into account as a well-documented consequence of LULC conversion (Kalnay and Cai 2003).

UHI is a phenomenon representing how urban temperature differs from its non-urban ambient. UHI occurs mainly due to land surface manipulations brought about by buildings construction and impervious surfaces such as asphalt, sidewalks and pavement and bare soils (Voogt and Oke 2003). This phenomenon was first introduced by Luke Howard in 1833 (Kolokotroni et al. 2006) and since then this research area has attracted considerable interest among researchers. Some of these studies have reported that UHI had revealed a close relationship with meteorological parameters and characteristics of earth surface such as climate change (Arnfield 2003), change in pattern of local wind direction (Cui and Shi 2012), increased level of energy use in the cities (White et al. 2002), air pollution through production of ground level ozone (Akbari et al. 2001) and ultimately influencing comfort and physical health of citizens (Kim and Zhou 2012). On the contrary, landscapes in urban environments serve several ecological functions, alleviating adverse UHI outcomes. There are several studies in the literature dealing with mitigating effects of UHI using green cover (Zhou et al. 2011; Weng et al. 2007) and green roof technology (Teemusk and Mander 2009; Takebayashi and Moriyama 2007).

There are two types of UHI which including air temperature UHI and surface UHI. The former represents stronger and spatial variation during the nighttime, whereas the later occurs at daytime (Zhou et al. 2011). Recent advances in remotely sensed LST have paved new insights for scientific understanding of LST effects so that several algorithms for LST detection from space-borne thermal sensors have been developed (Sobrino et al. 1996; Gillespie et al. 1998; Qin et al. 2001). With the same spirit, landscape metrics as a tool of explicitly quantifying the landscape pattern, indicate noticeable tract of studies in the field of outlying the relationship between ecological processes and spatial patterns including composition, structure and configuration of a landscape (Rutledge 2003).

Landscape metrics have effectively been applied in different areas of environmental researches, consisting water resources management and assessment (Amiri and Nakane 2009), delineation of protected areas (McGarigal et al. 2005), environmental impact assessment of urban growth mechanism (Mitsova et al. 2009; Tang et al. 2008) and landscape rehabilitation plans (Herzog et al. 2001). Given that, some studies have substantiated relationship between spatial characteristics of LULCs and LST (Zhou et al. 2011; Weng et al. 2007; Liu and Weng 2009) among others. These studies indicated that landscape metrics maintain significant potential in exploring spatial pattern of LST. However, most of these studies have examined the effects of spatial pattern of LULC features, especially green cover and built-up areas (Cao et al. 2010; Zhang et al. 2009; Weng et al. 2007), on LST and there are fewer number of works taking the effects of spatial distribution of landscapes on surface temperature of other LULC classes into account.

Therefore, the present study is aimed to find answer to the following questions as our main objectives namely: 1) could spatial pattern of green cover significantly affect their nearest

ULST and; 2) could landscape metrics of green cover be introduced in regression models whereby variations in ULST could be explained by change in measure of the landscape metrics of green cover; and 3) to specify whether allocation approaches of green cover patches can be applied to mitigate the ULST.

Materials and methods

Study area

Isfahan is, as the capital of Isfahan province, the third populated city in Iran. The study area spans over $32^{\circ} 32' 38''$ – $32^{\circ} 40' 49''$ N longitude and $52^{\circ} 26' 27''$ – $51^{\circ} 49' 58''$ E latitude with the area of 340 Km^2 (Iranian Bureau of Statistics 2010). This city is characterized with its seasonal river, Zayandeh-Roud, passing through the middle of the city and indicates minimum elevation of the study site (1550 m), whereas maximum elevation is recorded on Sofah Mountain (2,332 m) in the south (Soffianian et al. 2010). This city has experienced a considerable increase in the number of population (over 1,350,000) due to its significant population growth rate (2.1) during last five decades (Iranian Bureau of Statistics 2010), so that total area of the city has expanded to up to 16,000 ha between 1956 to 2006 (Soffianian et al. 2010). Besides, it has generally experienced a rapid industrial growth mainly due to its historical, cultural and industrial attractions, resulting in a high rate of immigration into the city. According to De Martonne index, Isfahan is located in a hot dry desert region (Shafagi 2001). Annual mean temperature and precipitation of the study area in year 2000 are 16.5°C and 125 mm, respectively (Shafagi 2001). Fig. 1 illustrates the study area across the Isfahan province.

Data collection

Landsat ETM+ image data on May 5, 2002 (path 37 and row 146) and digital topographical map of the study area (1:25000) in 2001 (obtained from National Cartographic Center) were applied to generate LST and LULC maps of the study area. Based on the data acquired from Isfahan meteorological station ($32^{\circ} 37' \text{ N}$ - $51^{\circ} 40' \text{ E}$), weather of the study area on May 5, 2002 was sunny with no amount of cloud, daily mean air temperature was 20.7°C with relative humidity of 3.1 % and evaporation of 10.1 mm.

Preparation of LULC Map

To geometric correction, the satellite image was co-registered with acceptable RMSE using the first-order polynomial model and nearest neighbor algorithm. Radiometric distortion was corrected according to Chander et al. (2009) and image header files. Having been corrected geometrically and radio-metrically, hybrid method including unsupervised, supervised and on-screen image classification (Aronoff 2004) was employed to classify the image according to first level of Anderson (1976) classification schema (table 1).

Normalized Difference Vegetation Index (NDVI) was, as a common index in vegetation detection, applied to extract green cover class. This index has formulated using red (X_{red}) and near infra-red (X_{nir}) bands of Landsat image as equation 1 (Mcfeeters 1996).

$$NDVI = (X_{nir} - X_{red}) / (X_{nir} + X_{red}) \quad (1)$$

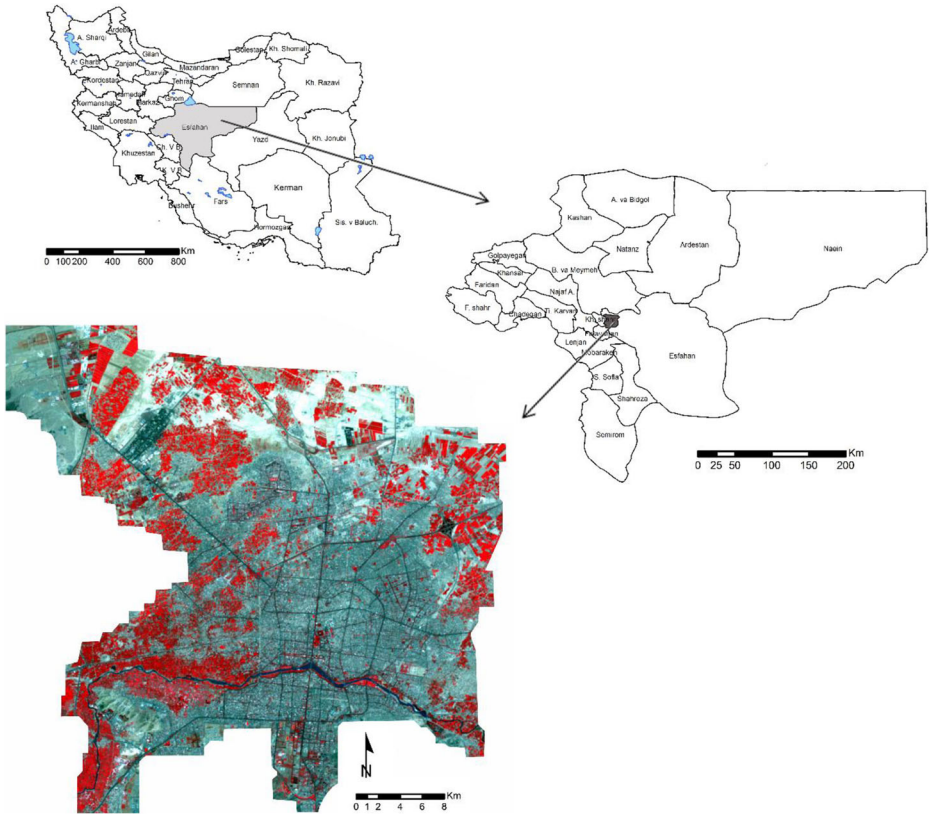


Fig. 1 False colour composite of the study area

Hence, NDWI was applied to extract water bodies by equation 2, where X_{green} is the green band and X_{nir} denotes to near infra-red band (Mcfeeters 1996).

$$NDWI = (X_{green} - X_{nir}) / (X_{green} + X_{nir}) \tag{2}$$

Finally, maximum likelihood classifier was employed to divide remaining area into built-up and barren areas. It is noteworthy that digital topographical map of the study area (1:25000) of the year 2001, accuracy of the generated maps based on contingency-derived indices (Kappa and overall accuracy) were quantified.

Table 1 Description of LULC classes

LULC classes	Description
Build-up area	Residential, commercial, industrial, mixed urban, transportation and roads
Vegetated land	Agriculture and vegetation
Bare land	Exposed soils and mountains
Water	Zayanhah-road river

Estimating the land surface temperature

For LST estimation, the procedure suggested by Weng et al. (2004) was applied. In this case, the digital numbers of Landsat ETM+thermal band were first converted into spectral radiance using following equation:

$$L_{\lambda} = G_{rescale}(Q_{cat}) + B_{rescale} \quad (3)$$

Where L_{λ} is spectral radiance for each cell; Q_{cat} represents the digital number of cell; and $G_{rescale}$ and $B_{rescale}$ are the band-specific rescaling gain and bias factor, respectively. The spectral radiance was then modified for at-satellite brightness temperature (i.e. blackbody temperature). Finally, according to equation 5, at-satellite temperature was corrected under the assumption of different emissivity of various LULC classes.

$$T_B = K_2 / \ln((K_1 / L_{\lambda}) + 1) \quad (4)$$

$$S_t = T_B / [1 + (\lambda \times T_B / (h \times c / \alpha)) \ln \varepsilon] \quad (5)$$

Where; T_B is the blackbody temperature; S_t is land surface temperature; L_{λ} is spectral radiance; K_1 and K_2 are calibration coefficients for ETM+sensor thermal band, λ represents emitted wavelength equal to $11.5 \mu\text{m}$, α denotes Boltzman constant ($1.38 \times 10^{-23} \text{ k/J}$), h indicates Plank constant ($6.626 \times 10^{-34} \text{ J/s}$); c is the light velocity ($2.998 \times 10^8 \text{ m/s}$); and ε stands for emissivity of land surface. To calculate the land surface emissivity, NDVI Thresholds Method as a reliable, applicable and easy to work procedure was implemented (Sobrino and M, Jiménez CJ, Paolinib 2004). Based on it, $\text{NDVI} < 0.2$ is regarded as bare soil with emissivity equal to 0.97 and $\text{NDVI} > 0.5$ is considered as fully vegetated with emissivity equal to 0.99. Emissivity between NDVI 0.2 and 0.5 is estimated by applying equation 6, where ε_v is the vegetation emissivity and ε_s is the soil emissivity, d_{ε} is the effect of geometrical distribution and internal reflections of natural surfaces and P_v (equation 7) is the vegetation proportion.

$$\varepsilon = \varepsilon_v P_v + \varepsilon_s (1 - P_v) + d_{\varepsilon} \quad (6)$$

$$P_v = [(NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min})]^2 \quad (7)$$

The only available data for validating the accuracy of LST generated map on May 5, 2002 was in situ land surface temperature. Hence, in situ land surface temperature of three weather stations (Daneshgah, Isfahan and Sharq stations) at 9.00 AM local standard time, distributed within the study area, were chosen and then compared to the ETM+LST generated map.

Landscape metrics calculation

Five percent out of the total available built-up cells ca. 7,500 pixel with unstratified scheme across the entire the study area were re-sampled applying Hawth's analysis tools (Beyer 2004) (Fig. 2).

LST was then extracted in the location of sample points. Following on from that, based on our empirical knowledge of inherent features of landscape metrics and also the nature of the designed study, a set of landscape metrics at patch level were selected to investigate how

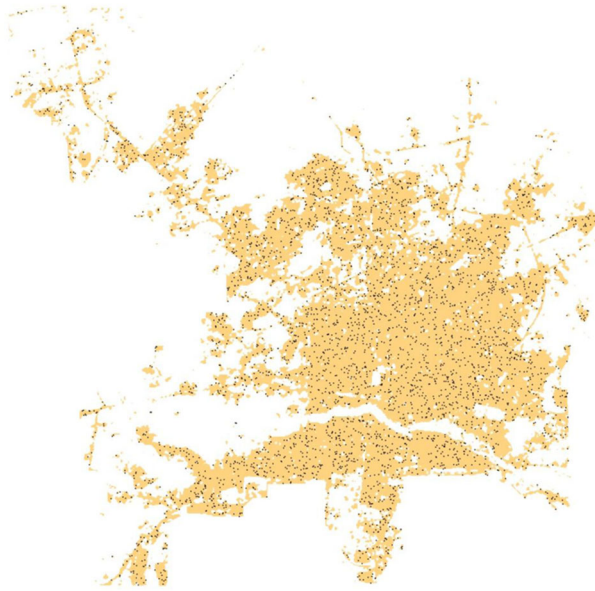


Fig. 2 ULST sampling point locations

spatial pattern of green cover could affect on their nearest ULST sample points. Out of them, based on obtained correlation coefficients between the landscape metrics values and ULST, five landscape metrics based on McGarigal and Marks (1995) include nearest distance (ND), patch area (AREA), perimeter to area (PARA), shape index (SHAPE) and core area index (CAI) were chosen and applied for each green cover patches in the entire study area (table 2).

The effect of the green cover patches configuration was examined by applying ND metric, applying near tools in ArcGISTM 10 package which was undertaken to calculate the distance from each sample point to their nearest green patches. This metric shows us how green cover patches could affect ULST in their neighbourhood. AREA is kind of composition-related metrics and equals to the area of each patch. Hence, SHAPE, PARA and CIA were chosen to quantify the effect of each green cover structure on their ULST neighbour. PARA is the ratio of

Table 2 Description of the selected landscape variables

Variable	Landscape characteristic	Abbreviation	Range	Unit	Description
Nearest distance	configuration	ND	$ND > 0$	Meter	distance of each LST sample points to the nearest green patch
area	composition	AREA	$AREA > 0$	Hectares	the area of the patch, divided by 10,000
Shape index	structure	SHAPE	$SHAPE \geq 1$	None	Patch perimeter divided by the minimum perimeter possible for a maximally compact patch of the corresponding patch area.
perimeter to area	structure	PARA	$PARA > 0$	None	The ratio of the patch perimeter to area.
Core area index	structure	CAI	$0 \leq CAI < 100$	Percent	the patch core area divided by total patch area, multiplied by 100

the patch perimeter to its area. SHAPE calculates the geometrical complexity of patch shape and CAI quantifies the percentage of a patch that is comprised of core area (McGarigal and Marks 1995). Finally, a database was prepared for statistical analyses based on joining of each patch ID that includes ULST in the sample points and all values of their nearest green cover patches metric.

Statistical analysis

Kolmogorov-Smirnov test ($p < 0.01$) was firstly applied to assure whether our sampled dataset follows normal distribution. Afterward, Pearson correlation test ($p < 0.05$) was used to examine whether there are statistically significant relationship between ULST sample points and the spatial pattern of their nearest green cover patches. Moreover, stepwise multiple-linear regression was developed to model the linkage between LST and landscape metrics. The most fitted model was selected based on regression statistics (r^2 , p -value) and keeping in mind that the coefficients of the model were statistically significant and residuals of the model were normally distributed, as well. Collinearity between the independent variables was finally evaluated in terms of variance inflation factor (VIF). Fig. 3 shows steps of the methodology used in this study.

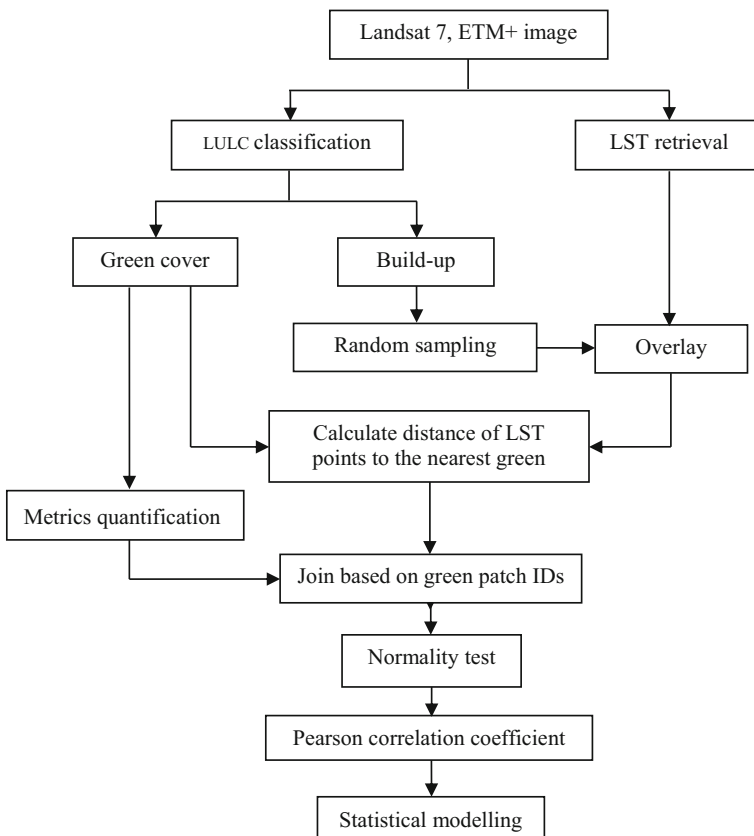


Fig. 3 Flowchart of the methodology

ULST Gradient

Additionally, a temperature gradient has been included for better interpretation of interactions between ULST and spatial pattern of green cover. To figure out this matter, a series of buffer zones were extended from the green cover edges into built-up areas and the mean of ULST was then examined in the buffer zones.

Results and discussion

The satellite images were co-registered in UTM coordinate system (WGS 84, Zone 39) with acceptable RMSE of 0.3. Having geometrically and radiometrically been corrected, the ETM+ image was further processed and LULC map was generated applying hybrid method whose total accuracy and kappa coefficient were 93 and 89, respectively (Fig. 4).

For LST estimation, the data were derived from thermal infrared (TIR) band of a Landsat ETM+ image. For this, applying original rescaling factor, DN values (Q_{cal}) of pixels were converted into spectral radiance and then into at-satellite temperature. Relying on equation 5 and in respect to various emissivity of LULC classes, the at-satellite temperature was finally converted to LST for different emissivity of the LULC cover types. NDVI Thresholds Method (Sobrino and M, Jiménez CJ, Paolinib 2004) was then applied to assign the emissivity

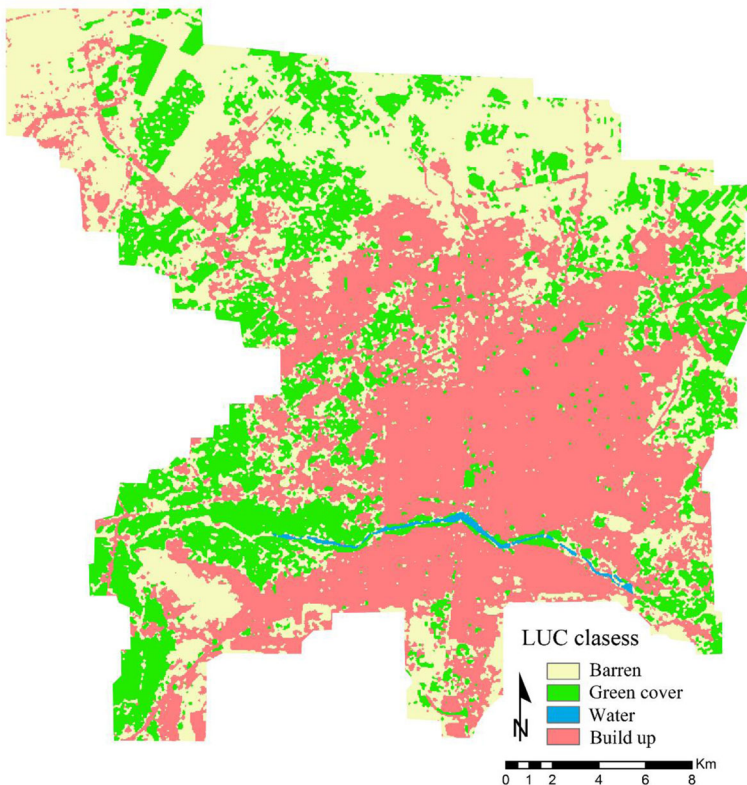


Fig. 4 LULC map of Isfahan city

measures of different NDVI classes to each pixel including bare soil (NDVI 0.2, $\epsilon=0.97$), fully vegetated pixels (NDVI 0.5, $\epsilon=0.97$) and mixture of bare soil and vegetation pixels (0.2 NDVI 0.5, $\epsilon=\text{equation 6}$). In order to evaluate the accuracy of the LST generated map, Landsat ETM+LST have been compared with in situ land surface temperature measurements of the weather stations data on May 5, 2002. The accuracy of the LST derived from Landsat ETM+was less than ± 2.5 °C with the in situ measurements of the three weather stations. Figure 5 illustrates the LST generated map.

Figure 6 depicts the ULST measures versus distance from the green cover patch edges (buffer zones). Based on Fig. 6, mean value of the ULST decreases if distance from the green cover patch edges into the urban areas increases by applying buffer zones.

Result of Pearson correlation test (Table 3) indicated that ND ($r=0.611$, $p < 0.05$) and CAI ($r=-0.141$, $p < 0.05$) metrics exhibited the strongest and weakest correlation to their nearest ULST, respectively. Out of five landscape metrics, only ND and PARA represented the positive correlation with their nearest ULST, while others showed negative correlation.

Multiple-linear regression through stepwise approach was then applied to develop the model, which explains how change in landscape metrics would be able to describe change in ULST. In this model, CAI metric was removed from the model and determination coefficient of the model was scored at 0.41, which is significant at probability level of 0.05 (Table 4). Moreover, AREA and ND metrics were determined with the best predictive performance, while indicating negative and positive correlation to LST, respectively.

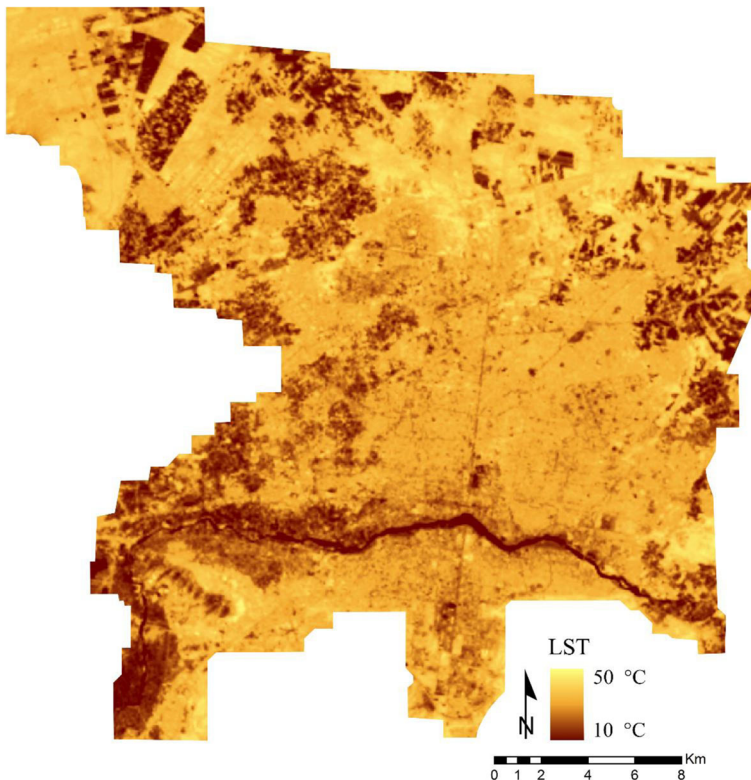


Fig. 5 LST map of Isfahan city

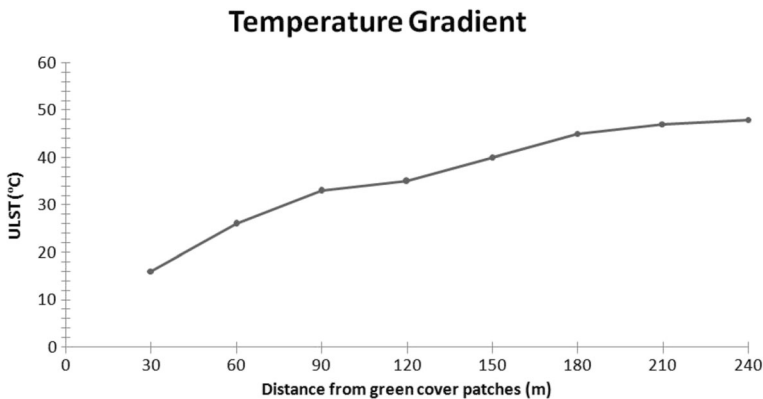


Fig. 6 LST measures along urban gradient

Discussion

Thanks to progressive advancement of remote sensing and landscape ecology, many studies have been designed and aimed to investigate the relationship between spatial pattern of LULC classes and their LST. For example, based on the pervious study which is carried out in this area (Asgarian et al. 2013), the LST of different LULC classes such as built-up and green cover patches are significantly related to their spatial distribution. Moreover, Zhou et al. (2011), Weng et al. (2007) and Xie et al. (2013) demonstrated that all three aspects of landscape including configuration, composition and structure of LULC classes could affect significantly their LST. On the other hand, ULST gradient displayed in Fig. 3 and findings of other works such as (Hun and Xu 2012) and Zhang et al. (2004) have indicated that the LST of a specific LULC could have a significant effect on LST of other LULC classes. Hence, the present study, regardless of the effect of the spatial pattern of a specific patch on its LST, was designed and aimed to investigate the effects of composition, configuration and structure of green cover patches on their nearest ULST.

Effects of green cover patches on their nearest ULST

Five landscape metrics of ND, SHAPE, AREA, PARA and CAI were employed to satisfy the effects of green cover patches on their nearest ULST. The results indicate if ND metric value decreases, ULST will decrease. Strictly speaking, more homogeneous dispersed pattern of

Table 3 Descriptive statistics of the selected landscape variables

Variable	Descriptive statistics				Normality (kolmogorov-smirnov)	Correlation (pearson)
	Min	Max	Mean	Std.		
Nd	15	776.14	239.56	121.44	0.163	0.611
Area	0.09	1311.93	4.29	38.25	0.165	-0.501
Shape	1	14.08	3.29	0.75	0.201	-0.159
Para	0.13	1333.33	848.86	363.26	0.189	0.173
Cai	0	66.74	53.72	47.14	0.197	-0.141

Table 4 Quantified multiple linear regression parameters

Variable		Coefficient	Statistics						
Dependent	Independent		S.E.	r ²	F	sig.	t	sig.	VIF
LST	constant	35.37	0.081	0.409	916.6	0.00	370.26	0.00	
	ND	3.012	0.127				35.16	0.00	1.76
	AREA	-2.286	0.10				-12.51	0.00	1.74
	PARA	0.051	0.19				8.01	0.00	1.08
	SHAPE	-0.009	0.06				-2.64	0.00	1.09

green cover patches around built-up areas, stronger mitigating function of ULST. Hence, it will result in decrease in UHI adverse effects. In contrast to ND metric, the AREA was negatively correlated to ULST. Hence, increasing in area of the green space patches within the built-up area will result in decreasing ULST. More specifically it should be noted that area, as the composition feature of green space patches is another contributing factor, which significantly affects ULST.

In the case of configuration effect of green cover patches on ULST, negative correlation between PARA and ULST denotes that in a green cover patch with a specific area if the perimeter to area ratio decreases, the ULST and consequently the adverse effects of UHI will decrease. In addition, negative relationship has been observed between CAI and ULST, which indicates that if CAI of the green cover patches increases, LST reduces in the urban environment. CAI varies between 0–100. The former indicates that patch contains no core area and greater value than zero (up to 100) suggests that patch contains mostly core area in terms of size, shape, and edge width, (McGarigal and Marks 1995). Accordingly, the green cover patch with more core area has a more mitigating effect on ULST. Given to SHAPE metric as an index of shape complexity of landscape, this metric exhibited negative relationship to ULST. Accordingly, if SHAPE metric of the green space patches increases, it will result in reducing LST in built-up areas. Noting that SHAPE metric equals one, it suggests that the patch maintains the regular shape (rectangle or circle) with highest level of compactness and inversely as the metric value increases, the patch become more irregular as well (McGarigal and Marks 1995). Therefore, referring to study area, lower LST can be witnessed in response to following configuration modifications of green cover clusters: i) the more homogeneously dispersed patches, the lower LST in urban area; ii) maximum allocated area of green cover patches around built-up areas with more irregular shape, which contains more core area; and iii) the more perimeter to area ratio, the lower LST in urban environment.

Hence, multiple-linear regression model was developed as per stepwise approach to model ULST in relation to green cover. In respect to VIF values for all variables (less than 1.74), there was no colinearity between independent variables (Chatterjee et al. 2000). Additionally, all predictive variables were significant in explaining the variation of ULST at probability level of 0.05.

Urban landscape design implications

Urban landscapes can be characterized by spatial patterns of different LULC classes and ecological processes occurring throughout them. The results of the present study enhance our scientific knowledge on UHI phenomenon, which indicate that spatial arrangement of green space patches can affect their nearest ULST. As results revealed, ULST is considerably affected by composition, configuration and structure of green space patches. Several studies

demonstrated that landscape composition parameters, specially the size of LULC classes could significantly affect their LST (Zhou et al. 2011). Additionally, based on obtained results, we showed that landscape composition properties also could affect their nearby LULC classes, especially in this case of built-up areas but further studies should be carried out to prove this effect in the real-world processes. According to this and keeping in mind that the nearest built-up sample points to the green cover patches had less LST, it could be suggested that establishing urban landscape in where, green space clusters have got shortest distance from each other and larger size might alleviate LST phenomenon. These two urban design factors are the landscape composition and configuration settings that can be applied together in the first step in urban designing. After allocation of green cover clusters in the urban area based on minimum distance from each other and maximum area, the next question would be which structure of green cover has the strongest mitigating effect on ULST. According to the findings, three landscape features of each green cover patch have a significant effect on their nearest ULST. The first feature is the perimeter to area ratio that must be in the minimum. The highest ratio of this factor could easily be found across the entire of pavements and roads. The second factor is the core area. The core area maintains environmental conditions in the patch interior context compared to patch edge (McGarigal and Marks 1995). A green cover patch with no core area certainly has highest edge effect and consequently, the ecological processes of the patch may not function properly to mitigate their nearest ULST. The third landscape structure factor is shape complexity of green cover patch. . Our results showed that patch shape is a significant factor in determining how green cover patches affect their nearest ULST and complex patch shape with highly convoluted edge has stronger implication for urban designing and ULST mitigation than simple patch shapes.

This concern, for our study area, has great deal of importance where barren lands surrounded the city and availability of land provide the opportunity to conduct multiple land use programs without conflicting objectives. At the same time, correlations between spatial patterns of green cover patches to ULST, leads urban planners and landscape designers to invent proper green cover patches in response to urban growth mechanism.

Concluding remarks

UHI phenomenon is considered as one of the most obvious negative consequences of urbanization affecting human welfare in urban contexts directly. Well-documented factors in intensifying UHI effects are referred to impervious surfaces and energy use. In the present paper, the effects of spatial pattern of LULC classes on LST were outlined, by which the variation in LST was explained through landscape metrics as predictive variables in developed regression model.

Lastly but not the least, the result of this study can practically be applied by city and urban planners to optimize the location of green space clusters in order to strengthen their mitigating function against LST. Future comparison studies in different study sites may receive further interest for expanding the scientific comprehension on how LST is affected by spatial configuration of various LULC classes.

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