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The Effects of Spatial Patterns of Urban Green Structure on the Thermal Changes of Urban Heat Islands: The Case Study of Tehran

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Abstract
This paper aimed to demonstrate the detailed relationship between the surface temperature of urban heat islands (UHI) and spatial patterns of urban green spaces, an issue that has been much debated in recent years. Tehran city, as the case study has faced the impacts of uneven built development and changes in spatial patterns of green spaces, and at the same time experiencing the increase of average temperature. The method of research is based on classification of Local Climate Zone (LCZ), correlation and partial correlation. The results of the analysis of the spatial composition of these classes showed that tree canopy greenspaces in both cases of high / low density with low plants has a reducing effect on temperature. This is also true for dense tree areas with low plants, because of the mean patch size. The result for the low-density grasslands and scattered shrubs with soil cover showed that there is a positive and significant relationship with temperature in relation to their surface area and edge density metrics. Thus, paying attention to spatial patterns of urban green space, through determining the type, composition, and configuration effect on the reduction of surface temperature and will help to decrease urban heat island impacts.

Keywords: Heat islands, Spatial pattern, Structure of urban greenspace, Tehran

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Expanded Abstract

Introduction

Urbanization, especially in big cities of developing and developed countries, has major impacts on climate change by producing greenhouse gas and increasing average temperature, and thus creating urban heat islands (UHI).

Rising temperature and global warming intensify a wide range of negative environmental and social consequences, including social welfare, public health, and natural sustainability. Urban heat islands describe the phenomenon of higher temperatures in urban areas than in rural and suburban areas, so that as urbanization increases, the effects of urban heat islands are intensified.

One of the contemporary approaches to reduce the effects of urban heat islands is to increase air quality through green infrastructure. The term urban green infrastructure (GI) refers to the planned networks of natural and semi-natural environments with a wide range of ecosystem services in urban areas at different spatial. In addition to reducing the effects of urban heat islands by the quality and quantity of green spaces, it is stated that green infraturture can be helpful to manage runoff water controlling flood, also improving urban beauty, and protecting biodiversity.

The unplanned urban development and even planned ones with the least attention given to green land uses (both natural and built) are the main factors responsible for destruction of natural ecosystems and thus increasing warming conditions especially in metropolitan areas, where the growing the built areas destroy the landscape pattern of natural and green areas. Lack of enough attention to preserving natural and green infrastructure is one of the factors causes city warming. Urban heat islands challenges are important issues in urban environmental planning nowadays. Urban heat island consists of air temperature and surface temperature. Studies show that land cover planning and management can control surface temperature. The relationship between increasing the green spaces as an important element of the green infrastructure and decreasing surface temperature is already has been studied. Regarding the literature has been reviewed in this paper, the purpose of this study is to investigate and clarify the detailed relationship between the characteristics of spatial patterns of urban green spaces and their influences on surface temperature. Spatial composition and spatial configuration are two main elements of spatial patterns of urban green areas. Classification of green land cover based on Local Climate Zone (LCZ) helps to discover the detailed relationship between each patterns' components and the classified green spaces. The case under study is the city of Tehran, which has witnessed certain changes in relation to the development of built-up areas (both in form of planned and unplanned developments), reduction of green spaces and their spatial patterns, as well as rising average temperature.

Materials and Methods

Although different methods have been applied in the research to classify the green land uses, they have mostly used the same classification for urban green space. However, these types of green space have not been considered as a means of reducing the surface temperature. Due to ability of measuring different green landscape patterns in a period of time, this study based on a conceptual model of the relationship between green spaces criteria of spatial composition (surface area and proportion of green space) and spatial configuration (sequence or physical distribution of different types of green spaces) to find their relation to urban heat island.

Tehran, the case under study, is located in the southern hills of the Alborz Mountains and the northern edge of the central desert of Iran, which covers an area of about 730 km^2. Its ecological landscape shows a long-term shaping influencing by climate, geology and other natural factors and therefore different landscape pattern from north to south exists in the city. Uneven urban developments cause damages to the natural ecosystem and terminate the structure and function of landscape patterns, intensifying conservative policies in protecting natural conditions and preventing the process of land

degradation (vegetation, natural corridors and open natural spaces, etc.) are essential for the city natural and built environments.

In the process of investigating the relationship between urban spatial patterns of greenspaces in city of Tehran and land surface temperature, different methods and techniques are applied. The greenspace classification map of the city of Tehran was produced with the help of Landsat 8 satellite (2019) and LCZ method of land use classification, which divides green areas into four classes as follows:

A) heavily wooded landscape of deciduous and/or evergreen trees, land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.

B) Lightly wooded landscape of deciduous and/or evergreen trees, land cover mostly pervious(low plants). Zone function is natural forest, tree cultivation, or urban park.

C) Open arrangement of bushes, shrubs, and short, woody trees, land cover mostly pervious (bare soil or sand). Zone function is natural scrubland or agriculture.

D) Featureless landscape of grass or herbaceous plants/crops, few or no trees. Zone function is natural grassland, agriculture, or urban park.

Kappa coefficient and overall accuracy of this map was 0.8706%, 88.172%, which confirms its accuracy. The next step was selecting landscape metrics. Based on the aim of the study and the reviewed literature, spatial composition and spatial configuration are selected as two main elements of spatial patterns of urban green areas. The relationship between land cover patterns and surface temperature is analyzed and discussed by using Pearson and Pearson Partial correlation method.

Discussion of results

The result of Pearson correlation analysis showed that there is a significant and negative correlation between spatial composition of A, B and D land cover classes with surface temperature. The highest negative correlation belongs to class B (scattered trees) and the lowest belongs to class A (dense trees). In contrast to these negative correlations, the correlation coefficient of class C with surface temperature is positive and significant.

The result of Pearson correlation analysis regarding spatial configuration showed that the average size of each green space class has a continuous and significant negative relationship with the surface temperature, though the size of these correlations varies in different classes. The correlation also showed that besides size and significance, the direction of green marginal density of each class also differs. It should be noted that the surface area of green space classes (as a composition metric) has a great impact on the results so that the correct and clear correlation of configuration metrics with temperature could not be distinguished. This issue was resolved by using Partial Pearson correlation coefficient and controlling the effect of Class Area metric. As a result, the relationship between configuration metrics and LST changed significantly. Before controlling the Class Area metric, almost all metrics were correlated with LST, however, the new detailed findings showed that only the Mean Size of Patches in A and D classes and Edge Density in B and C classes had a significant relationship with surface temperature.

The study shows that spatial composition of green spaces in Tehran in relation to the Class area of classes A, B and D had a negative and inverse relationship with surface temperature. Class B, located in the east and west of Tehran, has the highest negative correlation. Class A, in the east and center of the city with the lowest surface area and its scattered distribution pattern in comparison to other classes, has the least negative correlation with surface temperature (95% confidence level). Class D, located mostly in the south and west of the city, has a negative relationship between class area and temperature at the 99% confidence level. The correlation of spatial composition of class C in the northern half of the city is not like the other three classes and indicates a positive and significant relationship with surface temperature due to the presence of shrubs and grasslands with low density, scattered shrubs, and soil.

Regarding the partial Pearson correlation of spatial configuration metrics, the Mean Patch size of Class A at 99% confidence level shows a negative and significant relationship with temperature, but due to its subdivision and uneven distribution of green space in this class, the effect of this class in the reduction of temperature is not significant. The Mean Patch size of class D has a significant negative relationship with surface temperature at 95% confidence level, although its cooling effect is not considerable.

Both Edge Densities of classes B and C at 95% confidence level had a significant positive correlation with surface temperature, but as trees did not exist in a dominant and dense manner to cause shading and temperature adjustment in these type of greenspace classes, a positive correlation between the Edge Density of them and surface temperature is occurred.

Conclusion

This paper has demonstrated the relationship between urban heat islands and spatial patterns of green spaces in Tehran city. The literature based study showed the scope of the problem explaining that urban greenspaces contribute to mitigate climate change impacts through decreasing the surface temperature. The spatial form and pattern of urban green spaces have different effect on surface temperature as indicated in several studies. Importantly, planners and designers need more detailed studies to take into account the relation between effects of spatial composition and configuration of different classification of plants in Tehran and the needs for the development for built areas to have a control on urban surface temperature. In this research, greenspaces patterns were studied using Local Climate Zone (LCZ) method and correlation of spatial pattern (composition and configuration) of each of LCZ green classes with the surface temperature were provided. The results of the analysis of the spatial composition of these classes showed that tree canopy greenspaces in both cases of high/ low density and low plants have a reducing effect on temperature, but low-density grasslands and scattered shrubs with soil cover have a positive relationship with temperature. More detailed results on the spatial configuration show that only the mean patch size in dense tree areas and low plants has a significant negative correlation with temperature. Nevertheless, Edge density of scattered trees and open arrangement of bushes had a significant positive relationship with temperature. Thus, urban green space planning and management, through determining the type, composition, and configuration of existing patterns and their improvements based on their effect on the reduction of surface temperature will help to decrease urban heat island impacts.

Based on the findings, in order to reduce the average temperature of the city of Tehran, it is recommended to increase the area of class B greenspaces in the central part of Tehran. In addition, changing the green space of class C to one of the classes A (if possible) or B will reduce the surface temperature and improve the thermal comfort.