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Determining the Optimal Roof Covering of Buildings in Order to Control Urban Heat Islands Using Genetic Algorithm and Spatial Analysis

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Abstract
One of the most important factors on UHI value, which is attended deeply in developed countries, is the covering type of parcels' roof. However, due to the different effects of various covering types and also their distinct results in various locations, developing a spatial decision support system (SDSS) to select the optimal covering in the optimal location is inevitable, which has not been investigated before. Therefore, in this research, an SDSS has been developed including two main stages: 1) estimating land surface temperature of the study area and 2) selecting the optimal parcels to change their roof covering types with three predefine roof covering types. Then, in order to evaluate the results, new land surface temperature values and urban heat islands were recalculated. According to the proposed model, the standard deviation of the UHI values in the study area has decreased from 13.222 ° C to 10.781 ° C, which leads into an increment in the thermal uniformity in the region. Additionally, the results show that in order to control the thermal islands, it is necessary to use green roof areas around the region because this cover type has wider effects than other types. In other words, roofs with materials such as flagstones or high albedo materials have local effects in controlling the UHI values of the region.

Keywords: Genetic algorithm, Spatial analysis, Landsat 8 images, Urban Heat Islands, Linear regression model

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Extended abstract

Introduction

Migration to cities and urban development have led to the irregular growth of cities and the uncontrolled transformation of natural land cover into artificial and impenetrable cover. As a result, it has created numerous environmental consequences for cities, including the phenomenon of heat islands, as a result of which the temperature of urban areas has increased compared to the surrounding areas, causing changes in ambient temperature, air pollution and harmful effects such as greenhouse emissions. Therefore, measuring and controlling the effects of urban heat islands, based on scientific and justifiable principles, helps decision-makers to overcome the resulting problems. Today, one of the most effective ways to control the effects of heat islands in developed countries is to use less heat-absorbing coverings, such as green infrastructure, high-albedo materials and flagstone, to cover the roofs of buildings. Therefore, in this study, an optimal planning based on spatial analysis, using the remote sensing and computational intelligence in the form of a spatial decision support system that can determine the effects of changing the roof covering of buildings in the study area.

Materials and Methods

To survey the research, a neighborhood from a central region of Tehran, the 7th region, was chosen to develop a software package for green roof planning. The main reasons for choosing the neighborhood (i.e. Khaghani) are existing the various land uses and high level of density in the neighborhood. The total population and area of this neighborhood are about 10000 persons and 0.366 km^2, respectively. This neighborhood consists of 988 parcels with a variety of 15 land uses. It is expected that the UHI effect has a significant role in this neighborhood since the region that the neighborhood belongs to, is one of the central regions in Tehran. Moreover, for developing the software package, map of parcels with attributes related to the area and land use and Images of Landsat 8 over the neighborhood are employed:

In this research, a software is introduced for changing parcels’ roofs intellectually to alleviate the UHI effect in the study area. To this end, the satellite data mentioned above are utilized and then some atmospheric and radiometric corrections are applied by the FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercube) method. These corrections endorse and enhance the validity of images’ digital numbers, which contain data about bands of the satellite. Now, the images are ready to excavate for computing indices related to the UHI effect. Two main groups have a pivotal role in calculating these indices including vegetation and urban groups. When the indices are developed, the relationship between UHI and indices is investigated using the linear regression method (LRM) to obtain indices’ coefficients. So, the UHI effect can be modeled through the values of indices and their coefficients. Afterward, the software package tries to find some parcels, which constitute a certain and predefined percentage of area, that have a significant impact on UHI’s standard deviation by changing their roofs’ covers into three types cover including green, high albedo materials, and flagstones as the novelty of the research. Since there are a lot of feasible solutions, it is necessary to use a metaheuristic algorithm for finding the optimal solution. Therefore, in the second step of the proposed method, the optimal solution is conveyed by the Genetic algorithm (GA), as the most common algorithm in metaheuristic algorithms. After finding the optimum parcels for changing roofs’ cover, the UHI effect is computed once again to show the improvements.

Discussion of Results

In this research, software package is designed and the Landsat8 images related to 31 July, 2020 were employed to compute SHI value in the study area. In this regard, all bands of Landsat8 had been used and corrected through the FLAASH algorithm and then the SHI’s indices were evaluated based on the mentioned formulas. In the next step, in order to determine the coefficients of indices, an LRM as expressed in the methodology section was applied. In the regression, the 14 indices and the measured actual temperature in each location were assumed as independent and dependent variables respectively. In addition, 1500 locations in Tehran were considered as observation points for measuring indices and actual temperature. The extent of observations’ locations was selected over

Tehran to cover more observation points and thereby achieve better UHI estimation. Among these 1500 observation points, 70% and 30% of points were selected as training and test sets respectively. Additionally, the RMSE and R^2 for the regression were computed over the training and test data. According to the obtained coefficients of indices, the SHI values for the study area were achieved through Weighted Linear Combination (WLC).

As mentioned, the Genetic Algorithm is used to select the optimum subset of parcels for changing their roofs' infrastructure with three covering classes including vegetation, high-albedo materials, and flagstones. This subset is assumed as 10 percent of all parcels in the area. However, some parameters should be set before using the algorithm such as the number of population and generation, the ratio of selection, crossover, and mutation. Besides, minimizing the standard deviation of SHI values was assumed as a fitness function for GA. As a result of the algorithm, the selected parcels and their appropriate roofs' infrastructure for minimizing the standard deviation of SHI in the area are presented. This optimal solution was obtained through 252 generations that its convergence trend is presented. Additionally, based on the changes of selected parcels for roofs' cover, the SHI values for the study area are computed again. These new values for the SHI and UHI effects are presented. However, the obtained standard deviation of SHI values for the changed roofs' cover is 10.781°C while this value before changes is 13.222°C.

By examining the selected parcels obtained from the GA results with green spaces in and around the study area, it is found that the GA selects parcels for changing the roof covering with vegetation that is not contiguous with the green spaces in their surrounding area. whereas, according to results, the GA did not choose any parcel in these areas to change their roofs' infrastructure to vegetation cover. However, highly efficient covering in SHI values such as vegetation and high albedo materials circumscribed the study area. This fact shows that in order to control the variation of UHI in the center of the area, it is necessary to curb the SHI values in the border of the study area. However, the less efficient cover compared to vegetation and high-albedo materials, which is flagstones, are located dominantly in the center of the study area since their influence is more limited and local than the other types.

It is also can be perceived that all changes in roofs' infrastructure are not in line with changing to the vegetation cover, although this type of covering has the best effect to reduce SHI value. This consequence is because of the fitness function of GA, which is based on the standard deviation and not the mean value. The type of vegetation for covering decreases the SHI value, and thereby leads to decreasing mean value, while the objective of the software is to minimize the variation of SHI values. Therefore, vegetation cover is used in a location where the study area confronts with hotspot SHI value at that location. To verify this claim, the vegetation cover is utilized for all parcels selected by the GA to compute the SHI value for this scenario.

Conclusion

With the widespread growth of cities and the increase in population, natural covers have been changed to artificial and impenetrable land cover, which lead to several environmental problems for cities, including UHI effects. Due to these changes, which are caused by the UHI effects, the temperature of urban areas becomes higher than the surrounding areas. One of the most practical and efficient methods for controlling the effects of urban heat islands is utilizing the green infrastructure and high albedo materials for roofs' infrastructures; however, previous studies did not model this subject in quantitative practice. Based on this shortcoming, the present study proposed a software package to investigate quantitatively the changes of UHI effects based on the substitution of present roofs' infrastructures to three selected types of covering class including vegetation, high-albedo materials, and flagstones. Additionally, the software used GA as a sub-model of the software to select the best set of parcels in the study area for changing their roofs' infrastructure according to a specified fitness function. The fitness function assumed for this research is the standard deviation of the SHI values in the study area. This fitness function controls the variation of the SHI values and prevents the creation of UHI hotspots in the study area. This investigation is conducted in a neighborhood of a central region in Tehran, which in the Khaghani neighborhood in the 7th region of Tehran. Examining the selected parcels obtained from the results of the GA with the surrounding green space and the study area, it was found that the genetic algorithm selects parcels to change the roof covering with vegetation that is not adjacent to the green space. This fact shows that in order to control the change of UHI in the center of the region, it is necessary to limit these values at the border of the region. However, less efficient cover compared to vegetation and high albedo materials, which is flagstone, is predominantly studied in the center of the area. It can be also seen that not all changes in roof infrastructure are consistent with changes in vegetation, although this type of cover has the best effect on reducing the amount of urban heat islands. This result is due to the fitness function of the genetic algorithm, which is based on minimizing the standard deviation of SHI in the area. Therefore, the vegetation is used in a place where the study area is exposed to a high amount of urban heat islands. Additionally, this cover type is more effective in the range of 100 and 150 meters of green areas.