The mitigation effect of configuration and context optimization of urban holdings on heat island

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Abstract. The urban heat island (UHI) phenomenon has become a serious problem in recent years. It is necessary to study the mitigation methods and quantify their effects on UHI. In this paper, based on the remote sensed data, an empirical model was established as a negative function of land surface temperature (LST) to vegetation coverage. Urban heat island intensity (UHII) was estimated by a robust statistic algorithm. Compared with the current condition (vegetation coverage equaling to 0%), five high vegetation coverage building scenarios (10%, 20%, 30%, 40%, and 50%) were designed to explore mitigation effects on UHI separately. The results showed that the mean LST increase by about 0.5 ℃ when vegetation coverage decrease by 0.1. UHII has a considerable decrease when the scenarios of vegetation coverage equaling to 20% and 40%, respectively. The reasonable vegetation configuration is the effective UHI mitigation.

1. Introduction
In 2030s, it is predicted more than 5 billion people (60% of the world population) will live in cities [1]. The dwelling demand of these inhabitant calls for massive building constructions. This growth of urbanization has caused urban heat island (UHI) phenomenon. UHI effect is considered one of the major problems to influence human living environment since it was found in 1833. Generally, human activities influence urban climate by changing the properties of underlying surface or releasing anthropogenic heat from vehicles, air conditioners and other heat resources [2, 3].

Presently, based on meteorological data, remote sensing and GIS technology, many scientists are involved in developing a number of methodologies to monitor and mitigate UHI [4-9]. Some researchers have studied the mitigation effects of configuration and context of urban albedo [10, 11], vegetation cover [12, 13], ventilation corridors [14, 15], and availability of water resources [16] on the intensity of urban heat island. Most of mitigation methods showed higher vegetation cover provides more capacity to convert solar radiation into latent heat instead of sensible heat through evapotranspiration [17]. The mitigating mechanism of vegetation cover is clear but the magnitude is still obscure. This paper discussed the quantitative relationship between the land surface temperature (LST) and vegetation cover, and tried to obtain an integrated method to mitigate the UHI effect.
2. Materials and methods

The LANDSAT ETM+ 7 image for free-cloudy on September 2001 was collected to represent the UHI in Changsha, China. Only the central urban areas were analyzed. Through atmospheric correction, the digital number (DN) was converted to reflectance using 6S algorithm and software ENVI. Normalized difference vegetation index (NDVI) was calculated by the corrected reflectances of LANDSAT ETM+ band 3 and 4. Next, NDVI was converted to vegetation coverage using equation (1):

\[ VC = \frac{(NDVI_i - NDVI_s)}{(NDVI_v - NDVI_s)} \]

where VC is vegetation coverage, \( NDVI_i \) is the NDVI value of the \( i \) pixel, \( NDVI_v \) is the NDVI value when the pixel consists of pure vegetation, \( NDVI_s \) is the NDVI value when the pixel consists of bare soil. Based on the results from field investigations, \( NDVI_v \) and \( NDVI_s \) were set to 0.70 and 0.05, respectively.

According to thermal band of LANDSAT, LST was retrieved based on mono-window algorithm. Urban heat island intensity (UHII) was calculated using a robust statistic algorithm [18]. This algorithm covered the entire image through multiple slide windows (with size of 3×3 to 51×51 pixels) and calculated a threshold for each window. If the LST of each pixel was higher than the corresponding threshold, it was recorded as thermal anomaly. After the slide window scanned the entire image, the algorithm could distinguish UHI and non-UHI areas across the study area and assessed UHII according to the cumulative number of the pixels identified as thermal anomalies.

Five high vegetation coverage scenarios (10%, 20%, 30%, 40%, and 50%) in the sub-studied area (Fig.1 (c)) were designed to explore the mitigation effects on UHI separately. Each scenario includes the quantitative simulation on vegetation coverage and LST changes. The quantitative relationship between the LST and vegetation coverage was analyzed using regression model which was established through 21,982 random samples. In each high vegetation coverage building scenario, we revised the LST of study area (red rectangle in Fig.1 (c)) according to the regression model. Finally, UHII was calculated according to the robust statistic model under each scenario. The mitigation effects of configuration and context changes of urban holdings on UHII were calculated so as to obtain a rationally optimized scheme.

Figure 1. Overview in Changsha, China: (a) Land surface temperature, (b) vegetation coverage, and (c) high resolution image for study area (the area in red rectangle in (c) was used to simulate the

3. Results

The results showed that higher satellite observed vegetation coverage corresponded to lower LST in Changsha (Figure 1(a) and (b)). A negative linear relationship exists between LST and vegetation coverage - the mean LST increases by about 0.5 °C when vegetation coverage decreases by 0.1 (Figure 2).
The LST of each scenario was retrieved and then used to analyze the relationship between the UHII and vegetation coverage (Figure 3). For the baseline (e.g., vegetation coverage equaling to 0%), mean LST in the study area (red rectangle in Figure 1 (c)) was 26.8°C and UHII was 93%. With the scenario of vegetation coverage equaling to 20%, LST decreased to 25.8°C and UHII decreased to 17% (Figure 3). With the scenario of vegetation coverage equaling to 40%, LST decreased to 24.8°C and the study area was detected with non-UHI area (Figure 3).

![Figure 2. Relationship between LST and vegetation coverage](image)

The LST of each scenario was retrieved and then used to analyze the relationship between the UHII and vegetation coverage (Figure 3). For the baseline (e.g., vegetation coverage equaling to 0%), mean LST in the study area (red rectangle in Figure 1 (c)) was 26.8°C and UHII was 93%. With the scenario of vegetation coverage equaling to 20%, LST decreased to 25.8°C and UHII decreased to 17% (Figure 3). With the scenario of vegetation coverage equaling to 40%, LST decreased to 24.8°C and the study area was detected with non-UHI area (Figure 3).

**4. Conclusions**

In recent years, heat island phenomenon and degradation of the urban thermal environment have become serious problems. It is necessary to study the mitigation methods and quantify their effects on UHI. The analysis in our study showed that higher vegetation coverage is consistent with lower LST because vegetation cover provides more capacity to convert solar radiation into latent heat instead of sensible heat through evapotranspiration. Our finding stressed the correlation between local temperature and vegetation abundance. In the evaluations of the mitigation effects, the results indicated that the increase in vegetation coverage is the effective to mitigate UHI. A more detailed evaluation can be carried out by urban meteorological model [9].

Additionally, our study provides useful information for decision-makers about environmentally preferable choices in urban planning and highlights the quantitatively positive mitigation effects of vegetation on the UHI.

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