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Greenspace patterns and the mitigation of land surface temperature in Taipei metropolis

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ABSTRACT

The purpose of this paper is to assess the role of greenspace patterns on cooling effects from urban greenspaces. Greenspace has been argued to have significant potential to mitigate urban heat island effect in urban areas, and thus to reduce risks to human health and wellbeing intensified by global warming. Based on remote sensing data and subsequent spatial analysis carried out for Taipei Metropolis, this paper argues that greenspace features lowering temperature within greenspaces are not necessarily to have explicit cooling contribution on surrounding built environments. For mitigating urban heat at the area nearby greenspaces, greenspace size, shape and greenness may have limited effect, whereas increasing greenery at greenspace edges and enhancing greenspace cohesion are more effective means of extending cooling benefits. In turn, findings from Taipei Metropolis suggest urban planners ought to: consider relative locations in the city when designing a cooling intervention; work to preserve large greenspaces; extent greenery at greenspace surroundings and find means to connect existing cool islands.

1. Introduction

Greenspaces providing multiple ecosystem services are essential to the Ecosystem-based Adaptation Approach for alleviating climate change impacts in cities (ASSAf, 2011; Gill, Handley, Ennos, & Pauleit, 2007; Roberts et al., 2012). Their function of regulating temperature and improving thermal comfort has gained attention recently in urban planning, as a result of intensification in Urban Heat Island (UHI) effect through global warming and radical urbanisation (Revi et al., 2014). More cities are suffering from warmer summers with more frequent, intensive and prolonged heat waves (Knowlton et al., 2014). Subsequent rising mortality rates and heat related illnesses make this a significant global urban health threat (Knowlton et al., 2014).). According to the reports of the C40 Cities, many cities have regarded greenspace as one adaptation strategy to mitigate extreme urban heat (e.g. Melbourne, Athens, Tokyo). This study assesses the role of greenspaces in mitigating urban temperature with a focus on configuration features extending cooling services from greenspaces to surrounding built environments.

Compared to impervious urban surfaces (such as roads and buildings), vegetated surfaces emitting lower radiance, increasing moisture through evapotranspiration and/or providing shading from tree canopies tend to reduce both surface and air temperature above and in their surroundings (Bowler, Buyung-Ali, Knight, & Pullin, 2010; Jusuf, Wong, Hagen, Anggoro, & Hong, 2007; Shashua-Bar & Hoffman, 2000). Temperature contrast between greenspaces and built-environments can reach 0.94 °C on average during the day (Bowler et al., 2010). This temperature difference varies with time and season (Cao, Onishi, Chen, & Imura, 2010; Li, Zhou, Ouyang, Xu & Zheng, 2012; Peng, Xie, Liu, & Ma, 2016), tending to be more distinct in daytime summer (Chang, Li, & Chang, 2007; Chen et al., 2012; Hamada & Ohta 2010). Increasing greenspace volume/vegetation abundance throughout urban areas seems to be a fundamental strategy for moderating UHI effect and providing better thermal comfort (Chen et al., 2012; Kong, Yin, James, Hutyra, & He, 2014; Li et al., 2012; Peng et al., 2016). Indeed, Gill et al. (2007) predicted that increase of green coverage by 10% could reduce surface temperatures seen under the 2080s high emission scenario by 2.4–2.5 °C. However, creating large-scale greenspaces at the ground level is challenging, particularly for densely developed cities (Chen, Yao, Sun, & Chen, 2014a).

For many built-up cities, land acquisition from buildings is difficult. Optimising greenspace cooling effect (GCE) through modification of greenspace features and reduction in the need for change in land ownership or land zoning category is more likely to

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be achieved. There is increasing interest in the relationship between greenspace/park characteristics and variation of green cooling intensity and cooling distance (Lin, Yu, Chang, Wu, & Zhang, 2015; Oliveira, Andrade & Vaz, 2011; Shashua-Bar & Hoffman, 2000). Many studies into GCE have measured air temperature by in situ thermometers located inside and outside sampled greenspaces (e.g. Chang et al., 2007; Shashua-Bar & Hoffman, 2000) or by mobile survey (e.g. Wong & Yu, 2005). However, due to the limitation of available thermometers to show spatially or temporally continuous temperature records, the results of such studies show partial observation at selected sites and do not provide comprehensive patterns of thermal-landscape relationship across entire cities (Bowler et al., 2010; Kong et al., 2014). The development of high-resolution satellite imagery has allowed this relationship to be studied with greater precision (Stone & Rodgers, 2001). Remote sensing data that provides both landscape patterns and land surface temperature (LST) over large continuous areas can hence facilitate understanding of how greenspace planning and design may contribute to UHI mitigation (e.g. Cao et al., 2010; Connors, Galletti, & Chow, 2013; Kong et al., 2014; Myint et al., 2015).

Based on the ecological principles in the theory of Landscape Ecology, several greenspace attributes have been evaluated through landscape metrics for GCE. These include greenspace size (Tan & Li, 2013), greenspace shape/edge density (c.f. Chen et al., 2012; Li et al., 2012; Ren et al., 2013), greenspace coherence/patch density (e.g. Maimaitiyiming et al., 2014), presence of waters (e.g. Chen et al., 2012), and degree of greenery (e.g. Ren et al., 2013). The underlying urban matrix of greenspaces may exert a background effect on GCE and influence cooling extension from greenspaces to surrounding environments (Feyisa, Dons, & Meilby, 2014; Li et al., 2012). Continuous forested greenspaces which are clustered together seemingly have a greater cooling effect than small, fragmented, grassed greenspaces distributed far apart (Li et al., 2012; Maimaitiyiming et al., 2014). However, as research into configuration effect on GCE is still emerging, findings across previous research are not consistent. For example, Li et al. (2011) suggest that dispersing greenspaces can better mitigate urban heat. This divide is further confused by research methods that discuss GCE by using the mean LST of a sampled tract which contains different types of land cover (Kong et al., 2014; Li et al., 2012; Maimaitiyiming et al., 2014). As the mean LST of a sampled tract consists of multiple land cover/land use types, it will be unable to distinguish temperature of greenspaces from surrounding built environments.

The discussion of GCE at a patch level has provided more direct observation regarding temperature association with greenspace patterns. As it is consistent with the scale used by urban planners and designers, the results of patch level studies are more applicable to greenspace planning (Chen et al., 2014a; Connors et al., 2013; Li et al., 2012; Peng et al., 2016; Tan & Li, 2013; Zhou, Huang, & Cadenasso, 2011). However, most of these studies focusing on temperature of greenspace per se or its temperature contrast with a reference point at built environments have provided less/indirect observation regarding how built environments adjacent to greenspaces are influenced by the cooling effect (Cao et al., 2010; Kong et al., 2014; Tan & Li, 2013). As a result, less is known about whether positive factors of cooler greenspaces are also effective in lowering temperatures in their surroundings.

Given that GCE extending from greenspaces to surrounding built environments is a key mechanism to mitigate urban heat and improve thermal comfort in cities (Bowler et al., 2010), it is important to examine the effect of greenspace features on temperature variation not only within greenspaces, but also in their adjacent built environments. To this end, this study applied LANDSAT 8 satellite imagery to extract greenspace features at a patch-level and evaluated their relationship with LST both within and beyond greenspaces in Taipei metropolis. Findings from Taipei suggest that characteristics contributed to cooler greenspaces might have limited effect on surroundings. To maximise greenspace cooling benefits, urban planners ought to consider interventions on built environments.

2. Study area

Taipei metropolis (25°'N, 121°'E) is situated on the north basin of Taiwan, which includes parts of New Taipei City and Taipei City (Fig. 1). The urbanised area covers approximately 2726 km^2 and has population estimated to 6.67 million by 2014 (DBAS, 2015). The climate in the region is humid subtropical and influenced by monsoon. According to the Central Weather Bureau of Taiwan (2014), the annual average air temperature from 1981 to 2010 in Taipei City is 23 °C; the warmest month is July (29.6 °C) and the coolest month is January (16.1 °C). Due to global warming and urbanisation, Taipei has shown a remarkable warming trend (Bai, Juang, & Kondoh, 2011). Both the annual mean temperature and extreme hot days are rising (Hsu et al., 2011). The number of extremely hot days recorded between 2000 and 2009 in Taipei had increased by more than 10 days per year compared to between 1911 and 1920 (Hsu et al., 2011). The Taiwan Climate Change Projection and Information Platform Project predicts that average annual temperatures on North Taiwan will increase by between 0.89 °C and 2.36 °C by 2080 (TCCIP, n.d.). This leads to concerns over deterioration of environmental sanitation and public health impacts, particularly on the large aged society (Hsu et al., 2011). Green infrastructure is regarded as a planning strategy for mitigating heat in the Adaptation Strategy to Climate Change in Taiwan (CEPD, 2012). Yet, the lack of understanding of the greenspace-thermal relationship undermines the development and provision of evidence-based planning guidelines.

2.1. Meteorological conditions on the satellite acquisition date

According to two CWB weather stations, Taipei and Ban-ciao, the weather conditions on 9 June 2015 were warm and dry. At 10am the mean air temperature was 33.3 °C at Taipei station and 32.8 °C at Ban-ciao station, with relative humidity of 52% and 51% respectively. The mean hourly wind speed showed light breeze, 2 m/s at Taipei and 2.1 m/s at Ban-ciao. There was no record of precipitation on the day. These conditions make the date ideal for exploring LST without the need to consider wind and humidity effects on the ground.

3. Methods

The principal remote sensing data used in this study is LANDSAT 8 satellite images taken on 9 June 2015 at 10:20 local time (summer morning), gained from the United States Geological Survey (USGS). The first 9 bands of LANDSAT 8 are multispectral data from the Operational Land Imager (OLI). Except for Band 8 providing panchromatic data with a spatial resolution of 15 m, the other OLI bands have a spatial resolution of 30 m. Thermal data are provided by bands 10 and 11 with 100 m resolution taken by the Thermal Infrared Sensor (TIRS). To facilitate spatial analysis with multispectral data, the thermal data was resampled to 30 m by the USGS. This study utilized Band 4 to Band 5 for calculating Normalised Difference Vegetation Index (NDVI) and Band 10 for retrieving land surface temperature. The location of clouds was detected by the Quality Assessment (QA) band. For defining the fringe of mountains Quantum GIS (QGIS) Desktop 2.8.1 was applied to prepare satellite images and to perform spatial analyses. Fig. 2 shows the data used in the process of spatial analysis.