ISPRS Journal of Photogrammetry and Remote Sensing 124 (2017) 119–132

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

Characterizing the relationship between land use land cover change and land surface temperature

Duy X. Tran [a,*], Filiberto Pla [b], Pedro Latorre-Carmona [b], Soe W. Myint [c], Mario Caetano [d], Hoan V. Kieu [a]

[a] Department of Geography, Hanoi National University of Education, Hanoi 10000, Viet Nam
[b] Institute of New Imaging Technologies, Universidad Jaume I, 12071 Castellón, Spain
[c] School of Geographical Sciences and Urban Planning, Arizona State University, Tempe, AZ 85287-0104, United States
[d] Instituto Superior de Estatística e Gestão de Informação, Universidade Nova de Lisboa (ISEGI-NOVA), 1070-312 Lisboa, Portugal

ARTICLE INFO

Article history:
Received 22 June 2016
Received in revised form 24 December 2016
Accepted 2 January 2017

Keywords:
Urban heat island
Land use land cover change
Kernel ridge regression
Urbanization

ABSTRACT

Exploring changes in land use land cover (LULC) to understand the urban heat island (UHI) effect is valuable for both communities and local governments in cities in developing countries, where urbanization and industrialization often take place rapidly but where coherent planning and control policies have not been applied. This work aims at determining and analyzing the relationship between LULC change and land surface temperature (LST) patterns in the context of urbanization. We first explore the relationship between LST and vegetation, man-made features, and cropland using normalized vegetation, and built-up indices within each LULC type. Afterwards, we assess the impacts of LULC change and urbanization in UHI using hot spot analysis (Getis-Ord *Gi** statistics) and urban landscape analysis. Finally, we propose a model applying non-parametric regression to estimate future urban climate patterns using predicted land cover and land use change. Results from this work provide an effective methodology for UHI characterization, showing that (a) LST depends on a nonlinear way of LULC types; (b) hotspot analysis using Getis Ord *Gi** statistics allows to analyze the LST pattern change through time; (c) UHI is influenced by both urban landscape and urban development type; (d) LST pattern forecast and UHI effect examination can be done by the proposed model using nonlinear regression and simulated LULC change scenarios. We chose an inner city area of Hanoi as a case-study, a small and flat plain area where LULC change is significant due to urbanization and industrialization. The methodology presented in this paper can be broadly applied in other cities which exhibit a similar dynamic growth. Our findings can represent an useful tool for policy makers and the community awareness by providing a scientific basis for sustainable urban planning and management.

1. Introduction

The increase in the heat storage capacity of urban surfaces creates so-called urban heat islands (UHI), in which built up areas are hotter than nearby rural areas (Oke, 1982; Taha, 1997; Rizwan et al., 2008). This local difference in temperatures creates a negative impact on people and environment because it hampers air quality, increases energy consumption, loses biological control, and affects people's health (Kikegawa et al., 2003; Grimmond, 2007; Meineke et al., 2014; Plocoste et al., 2014). Advances in thermal remote sensing, geographical information systems (GIS), and statistical methods have enabled the research community to characterize and examine UHI versus landscape relationship. A great number of studies that deal with UHI analysis have been carried out, providing a significant feedback to policy makers and researchers (Quattrochi and Luvall, 1999; Yuan and Bauer, 2007; Rizwan et al., 2008; Junxiang et al., 2011; Kumar et al., 2012; Radhi et al., 2013; Myint et al., 2013; Zhou et al., 2014; Adams and Smith, 2014; Coseo and Larsen, 2014; Song et al., 2014; Chun and Guldmann, 2014; Rotem-Mindali et al., 2015; Kourtidis et al., 2015). Besides air temperature, LST derived from remote sensing data is unique source of information in order to define surface urban heat islands and it has been widely used as indicator for UHI research (Weng et al., 2004; Weng, 2009; Imhoff et al., 2010). With the introduction of thermal remote sensing, LST information is available from a series of satellite sensors (such as Landsat,

* Corresponding author.
E-mail addresses: txduy@hnue.edu.vn (D.X. Tran), pla@uji.es (F. Pla), latorre@uji.es (P. Latorre-Carmona), soe.myint@asu.edu (S.W. Myint).

http://dx.doi.org/10.1016/j.isprsjprs.2017.01.001
0924-2716/

MODIS, and ASTER) that cover a wide range of the earth surface. Compared to air temperatures collected from weather stations, thermal imagery provides full spatial coverage at various temporal scales (Myint et al., 2013). In addition, LST derived from remote sensing imagery might be better to show the hottest and coolest areas as compared to temperature collected from urban weather station, which is located in the tree park-like surroundings (Nichol and To, 2012). Surface temperature also has a direct interaction with LULC characteristics (Quattrochi and Luvall, 1999). Therefore, the analysis of the relationship between LULC and LST is crucial in order to understand the effects of LULC on UHI.

Exploring the spatial pattern of UHI is important in understanding how the distribution of LULC and changes in that distribution influence LST. However, using absolute LST values presents the main challenge. Absolute LST can be used to characterize UHI on a particular date but, in principle, it is not appropriate to use it to compare the UHI spatial patterns through time. Comparing absolute LST values acquired on different dates under different atmospheric conditions cannot properly quantify UHI trends from a spatio-temporal perspective. Walawender et al. (2014) proposed the use of normalized LST to investigate the LST spatial distribution in relation to LULC. This guarantees that LST values retrieved from different images are comparable. However, LST values of locations/pixels are not independent but are correlated with the LST of its neighboring pixels (Song et al., 2014). In this case, normalized LST cannot deal with spatial autocorrelation problems. Therefore, the effect of spatial autocorrelation must also be considered when comparing UHI patterns through time.

Simulation of future surface temperatures based on LULC plays an important role in mitigating UHI effects. Such understanding can be used to adapt new strategies and policies in land use planning and urban design that reduces the UHI effect. Linear regression has been commonly used in many studies to gain insight into the landscape–UHI relationship (Yuan and Bauer, 2007; Adams and Smith, 2014; Rotem-Mindali et al., 2015) and has been applied to future LST prediction (Ahmed et al., 2013). However, this correlation is non-linear due to the seasonal variability of land cover data (Owen et al., 1998; Zhou et al., 2014), the complex landscape structure (Guo et al., 2015), and urban morphology heterogeneity (Guo et al., 2016). In the case of the LST prediction, a non-linear regression method could be a better approach in order to achieve a greater insight into the LULC-UHI relationship.

Analyzing the impact of LULC change on UHI needs to consider urbanization effects. Urbanization leads to the expansion of built-up and impervious surface that intensify UHIs (Chun and Guldmann, 2014). Previous studies applied different methods such as diurnal temperature range (DTR) (Wang et al., 2007; Mohan and Kandya, 2015), land use change trajectories (Feng et al., 2014), or a surface urban heat island index (SUHI) (Dihkan et al., 2015) to quantify the effects of urbanization on UHI. These studies were successful in demonstrating the contribution of urban growth to the UHI effect as well as investigating the differences in UHI between urban and rural areas. However, applying these methods could not provide insight into the effect of urban development types on UHI. Urban growth can occur in different ways, such as including infill, extension, or leapfrog development (Angel et al., 2012). It is crucial to examine how UHI is affected by different spatial patterns of urban growth. For urban planners, understanding which kinds of urban expansion exacerbate or mitigate impacts on UHIs can contribute significantly to UHI mitigation strategy.

The main contributions of the present work are directed to provide tools for a reliable analysis of LST patterns on the UHI effect and develop methodologies for predicting urban climate patterns in relation to LULC changes, exploiting the relationship between LULC and LST through time. Therefore, the objectives of this work are to (i) explore the relationship between LST and main LULC types (vegetation, man-made features, cropland) using normalized vegetation and built-up indices within each LULC type, (ii) assess the impact of LULC change and urbanization on UHI using hot spot analysis (Getis-Ord *Gi*∗ statistics) and urban landscape analysis, and (iii) apply non-parametric regression using kernel ridge regression (KRR) to estimate future urban climate patterns using the predicted changes in land cover and land use. An inner city area of Hanoi was selected to implement the proposed methodology because it has experienced fast LULC change and urbanization. The results from this study will support the effectiveness of the methodology in UHI characterization and provide crucial feedback to policy makers and urban planners in developing UHI mitigation strategies.

The paper is structured as follows. Section 2 briefly describes the study area. Section 3 explains the methodology and data used to infer the LST as a function of the LULC spatial distribution. Section 4 presents the main results and discussion about the LULC-UHI relation and LST prediction results for the Hanoi city. Conclusions are given in Section 5.

2. Study area

The study area, Hanoi inner city, is a small and flat plain located in the center of the Red river delta, the second largest delta in Vietnam (Fig. 1). Hanoi inner city covers approximately 304.3 km^2 (HSO, 2013a) and has an average elevation of less than 10 m above sea level (Yonezawa, 2009). This area was selected as a case study because it is undergoing rapid LULC change and urbanization in addition to having extremely hot summers, which is strongly linked to the UHI effect.

Located within the warm humid subtropical climate zone, the city has a typical climate of northern Vietnam with hot, humid summers and cold, dry winters. The summer season starts in May and ends in August, during which the average temperature is 29 °C (NCHMF, 2015). As a low altitude area, combined with the impact of the Foeln (a type of dry, warm, down-slope wind occurring on the leeward side of a mountain range), the city often experiences several hot periods during the summer time. This area has suffered unusual hot temperatures during the last few years. On 16 June 2010, the mean temperature in the city reached 34.6 °C (a night temperature of 30.4 °C and a day temperature of 39.6 °C), which was the highest recorded value since 1961 (NCHMF, 2015). On 28 May 2015, the temperature exceeded 40 °C, which was the highest temperature since the beginning of historical records (NCHMF, 2015).

Urbanization was faster in and around Hanoi inner city than in other surrounding areas. While the study site covers only 9% of the total area of Hanoi city, this small area contains more than 40% (2.9 million people) of the city population and around 20% (140 km^2) of the city urban land (HSO, 2013a,b). Urbanization has led to the acquisition of agricultural land, which in turn has resulted in land use changes, subsequently increasing the built-up area. The transformation between different LULC types associated with urban expansion will crucially influence the LST pattern and the magnitude of UHI effect. According to socio-economic planning from the Vietnamese government, urban area will occupy more than 60% of the city land use structure in 2030 (VGP, 2016). In accordance with negative climate change impacts (Niem et al., 2013), UHI will be one of the key challenges for the city development.

3. Data sources and methods

3.1. Data used

Surface reflectance high level data products images including Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic