Ecological Indicators 96 (2019) 127–132

Contents lists available at ScienceDirect

Ecological Indicators

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

Spatial-temporal pattern of, and driving forces for, urban heat island in China

Shijia Peng[1], Zhili Feng[1], Huixuan Liao, Bei Huang, Shaolin Peng*, Ting Zhou*

State Key Laboratory of Biocontrol, School of Life Sciences, Sun Yat-sen University, Guangzhou 510275, China

ARTICLE INFO

Keywords:
Urban heat island
Temporal pattern
Spatial pattern
Driving forces
Scale
China

ABSTRACT

Urban heat islands (UHIs) have very large negative effects on local climate features and ecological environments. However, the larger-scale temporal and spatial patterns of UHIs are still unclear. Our research explored the large-scale spatial and temporal patterns of UHIs in 155 cities across China by collecting observational data from 310 meteorological stations over a 30-year period (1984–2013). The results suggested that the UHI intensity has linearly increased over the past 30 years and is strongest in summer across different years. The UHI intensity in inland cities is significantly higher than that in coastal cities; cities in arid areas had higher UHI intensities than those in humid areas; cities in middle or high mountain areas had higher UHI intensities compared to those located in the other landforms in China. There are no significant differences in UHI intensity between cities located in different climatic zones or between cities with different GDP levels, population sizes and industrial structures. Additionally, the relationships between the UHI intensity and several factors, such as meteorological conditions, GDP level and population size, were analyzed. Our results showed that average wind speed, average precipitation and relative humidity had a significant negative correlations with UHI intensity, whereas there was no significant correlation between anthropogenic factors and UHI intensity. Our research indicated that we should consider the local climate and landscape to eliminate UHI hazards in the future urbanization processes.

1. Introduction

Rapid urbanization in the past several decades has been accompanied by various ecological issues, among which the Urban Heat Island (UHI) is one of the most worrisome. By definition, an UHI refers to an urban area that is significantly warmer than its surrounding rural areas due to a series of human activities, such as modifications of the land surface (e.g., construction, agriculture) and emissions of waste heat, gas, etc. (Oke, 1973; Peng et al., 2011). Many factors could affect the UHI intensity to different extents. These factors include road facilities, climatic conditions, anthropogenic heat release, city morphology and land cover type (Coseo and Larsen, 2014; Debbage and Shepherd, 2015; Ding and Shi, 2013; Guo et al., 2015; Tran et al., 2006; Yuan and Bauer, 2007). However, most of previous studies only focused on the UHI analyses of single cities and mega-cities (Imhoff et al., 2010; Tan and Li, 2015; Targino et al., 2014).

At present, with continuous urbanization processes, urban areas are rapidly expanding, and the distances between cities have been gradually decreasing and even disappearing. The UHI extends outwardly from its respective city center, jointly forming a “regional UHI” (Du et al., 2016). The scope of the effects of UHI is no longer only restricted within a single city, and corresponding conclusions may not be accurately applied to the assessments of UHIs at larger scales (Golden and Kaloush, 2005; Hua et al., 2008). Exploring the patterns of UHIs with a large-scale perspective will reveal the potential formation mechanisms of UHIs and provide some important guidance for future policy formulations and city regulations.

The driving forces of UHIs have been widely explored. For example, Gedzelman et al. (2003) found that UHI intensity is closely related to parameters such as cloud cover, ceiling, wind speed and direction in New York City. Elsayed (2012) explored the UHI of Kuala Lumpur City and showed that population density contributed greatly to the increase in the UHI intensity. Lemonsu et al. (2015) noted that the UHI intensity in Paris is mainly attributed to city characteristics such as the city size, shape and composition. In general, these studies basically focused on a single type of factor analysis at small scales (e.g., a single city scale). The relationship between the UHI intensity and its potential influencing factors at larger scales is still poorly constrained (Peng et al., 2011; Zhou et al., 2013). According to previous studies, it is reasonable to consider that such relationships may change with varying research

* Corresponding authors.
E-mail addresses: lsspsl@mail.sysu.edu.cn (S. Peng), zhout32@mail.sysu.edu.cn (T. Zhou).
[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.ecolind.2018.08.059
Received 10 September 2017; Received in revised form 26 June 2018; Accepted 27 August 2018
1470-160X/

scales. Cui and Shi (2012) reported that the growth of UHI intensity in Shanghai is clearly associated with its continuous increases in population intensity, GDP level and other human-activity-related factors. While Du et al. (2016) found that there is no significant correlation between population density and UHI in the Yangtze River Delta Urban Agglomeration, some natural factors, such as average precipitation and wind speed, negatively affect the UHI intensity at such a regional scale.

China is one of the fastest-growing developing countries in the world, and it is urbanizing at an unprecedented rate (Bai et al., 2014). This urban environment is directly related to the survival and development of more than half of China's population, and the variations in natural and social factors are quite complex in China due to its vast territory. A study of the temporal-spatial patterns of UHI and its potential driving forces on the scale of all of China is of crucial importance for improving urban environments, and promoting regional sustainable development. In our study, we aimed to address the following scientific questions by analyzing the observational data: (1) Does the UHI vary temporally (e.g., interannually, seasonally)? (2) Does the UHI vary between different geographic regions (e.g., coastal-inland areas; arid-humid areas; climatic zones and landforms)? (3) Does the UHI vary between cities with different GDP levels, population levels and industrial structures? (4) What is the relationship between UHI intensity and its potential influencing factors at larger scales?

2. Methodology

2.1. Data origin

Meteorological data analysis is one of the most classical methods in UHI studies, and a series of meteorological stations located throughout the various cities are important components of the integrated meteorological observation systems in China (Rong et al., 2009). Meteorological data (from 1984 to 2013) were downloaded from the China Meteorological Science Data Sharing Service Network (data.cma.cn). After rectifying a large number of incorrect data points and manually supplementing missing digitalized data, all the data were flagged with quality control codes, and the reliability and accuracy of this dataset reached nearly 99% and 100%, respectively. This network contains data from a total of 824 stations across China. Every station was precisely located with the help of Google Earth and the printed maps of China. There are no uniform criteria for calculating the UHI intensity. In many studies, this calculation was performed by subtracting the temperature recorded at a representative station located in a rural area from the temperature recorded at another representative station located in an urban area (Lee, 1979). Our study adopted this method, and both stations located in the same city were paired to calculate the approximate UHI intensity. The stations we selected have recorded relatively complete meteorological data over the 30-year study period. In our final database, we successfully paired 155 groups (155 cities $^{*}2 = 310$ stations) (see Appendix).

2.2. Data extraction

In this original dataset, the mean values of the daily four times of observational data (02:00, 08:00, 14:00, 20:00) were automatically calculated; we then extracted the station number and the daily measurement data (i.e., mean temperature, precipitation, sunshine hours, relative humidity and wind speed) from these 310 meteorological stations. The population size and gross domestic production (GDP) data of these 155 cities were also collected from statistical yearbooks. Because some earlier population and GDP data are not easily available, these types of data and their corresponding daily measurements from 2009 to 2013 were collected and extracted to better conduct subsequent statistical analyses (see below). If there were still some missing datapoints in a single city group, we deleted that group when calculating the mean value of a certain category; because a single city only accounts for a small fraction of the entire database, our every datapoint does not depend on any other datapoints in the dataset and the data are missing due to non-arbitrary causes (Scheffer, 2002).

2.3. Urban heat island value

By referring to the definition of UHI from Oke (1982), we calculated the UHI intensity as follows: $\Delta T = T_{urban} - T_{suburban.}$ The UHI intensity here represents the air temperature difference between urban and suburban areas because our present research is based on meteorological observations. This difference is called the air UHI (Arnfield, 2003).

2.4. Data analysis

To explore the temporal-spatial patterns of UHI and its potential driving forces in China, we classified these 155 city pairs into subgroups based on the following factors: (1) locations, (2) climatic zones, (3) landforms, (4) humid-arid zones, (5) GDP level, (6) population size and (7) industrial structure. More specifically, we assumed that the UHI intensity may be different between coastal and inland areas, between different climatic zones (i.e., warm temperate, middle temperate, plateau temperate, northern subtropical, middle subtropical, marginal tropical and southern subtropical zones) (Zheng et al., 2013), between cities in different landforms (i.e., eastern low mountain plain, southeastern low mountains, central and northern middle mountains and plateau, northwestern middle and high mountains and basins, southwestern subalpine and middle mountains, and the Tibetan plateau) (Li et al., 2013a), between humid-arid zones (i.e., humid, arid, semi-humid and semi-arid zones) (Zheng et al., 2013), between cities with different GDP levels (low: 0–100 billion; low-medium: 100–300 billion; medium: 300–500 billion; medium–high: 500–1000 billion; and high: 1000 billion or more), between cities with different population sizes (small: 0–3 million; medium: 3–5 million; large: 5–10 million; and extremely large: 10 million or more) and between cities dominated by a 2nd industry and cities dominated by a 3rd industry. The UHI values between subgroups were compared using a permutation test generated from 999 iterations. Regression equations were used to fit the changes in the magnitude of UHI intensity across 30 years and different months; then, the landscape map of China's UHI intensity was drawn based on the UHI values in the hottest month using ArcMap10.2. Finally, we selected four meteorological parameters (average wind speed, average precipitation, sunshine hours and relative humidity) and two anthropogenic parameters (population size and GDP level) as the explanatory variables. Stepwise regression analysis was performed to characterize the relationships between UHI intensity and these influencing factors. Before this analysis, we calculated the Pearson's correlation coefficient between explanatory factors and the corresponding "Variance Inflation factor" (VIF) to rule out multicollinearity. If $VIF > 5$, we randomly kept one of the highly correlated predictors. The temporal patterns of UHI intensity were analyzed by using UHI data spanning 30 years (1984–2013), while the spatial patterns of UHI were analyzed using the recent five-year UHI data. All statistical analyses were conducted in R ver. 3.3.2.

3. Results

3.1. The temporal patterns of UHI in China

Our results suggested that the UHI intensity linearly increased from 1984 to 2013 (Fig. 1a, $p < 0.001$, $R^2 = 0.2484$), while the UHI intensity showed a significant quadratic relationship with different months. The largest UHI values were found in June and July (Fig. 1b, $p < 0.001$, $R^2 = 0.9543$).