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Spatial-temporal change of land surface temperature across 285 cities in China: An urban-rural contrast perspective

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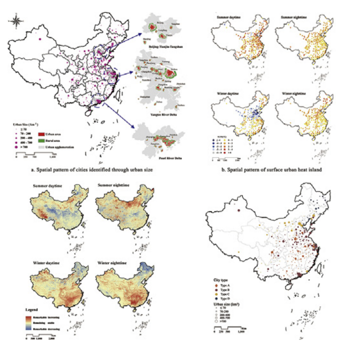
HIGHLIGHTS

- 98.9% of the cities in China showed UHI in summer nighttime.
- Most cities in China have higher increasing rate of nighttime LST in urban areas.
- Cities varied in LST characteristics have been classified into four types in China.
- The vital zone and major zone for UHI management are identified in China.

GRAPHICAL ABSTRACT



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ABSTRACT

As an important theme in global climate change and urban sustainable development, the changes of land surface temperature (LST) and surface urban heat island (SUHI) have been more and more focused by urban ecologists. This study used land-use data to identify the urban-rural areas in 285 cities in China and comparatively analyzed LST in urban-rural areas with the perspective of spatial-temporal dynamics heterogeneity. The results showed that, 98.9% of the cities exhibited SUHI effect in summer nighttime and the effect was stronger in northern cities than that in southern cities. In 2010, the mean SUHI intensity was the largest in summer daytime, with 4.6% of the cities having extreme SUHI of over 4 °C. From 2001 to 2010, the nighttime LST of most cities increased more quickly in urban areas compared with rural areas, with an increasing tendency of the urban-rural LST difference. The difference in the urban- rural LST change rate was concentrated in the range of 0–0.1 °C/year for 68.0% of cities in winter and 70.8% of cities in summer. For the higher LST increasing in urban areas compared with rural areas, there were more cities in summer than winter, indicating that the summer nighttime was the key temporal period for SUHI management. Based on the change slope of urban-rural LST, cities were clustered into four types and the vital and major zones for urban thermal environment management were identified in China. The vital zone included cities in Hunan, Hubei and other central rising provinces as well as the Beibu Gulf of Guangxi Province. The major zone included most of the cities in Central Plain Urban Agglomeration, Yangtze River Delta and Pearl River Delta. These results can provide scientific basis for SUHI adaptation in China.

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1. Introduction

Human activities have intense impacts on global material cycling and energy flow which gradually become an essential controlling factor in natural ecosystem (Zhou et al., 2016). City is the most concentrated area of human activities. The structure, function and dynamics of urban ecosystems have obvious human-induced characteristics (Xie et al., 2013), and the acceleration of urbanization has leaded to the reduction of species abundance, degradation of soil properties, changes in local climate and other negative ecological effects (Benz et al., 2017; Peng et al., 2016; Zhou et al., 2017a). The variation of the surface thermal environment is one of the important components of regional climate change.

The surface thermal environment is the manifestation of the heat exchange equilibrium between land and atmosphere, and it can be quantitatively described as land surface temperature (LST). As the result of the surface energy balance, LST is determined by local solar radiation, atmospheric properties, and surface properties (Kuang et al., 2015). During the process of rapid urbanization, impervious artificial surface, mainly construction land (Song et al., 2014), gradually replaces the natural and semi-natural surfaces, such as vegetation and water body, which originally exist in urban areas (Tran et al., 2017; Zhou et al., 2017b). This replacement changes the thermal environment of the urban surface, resulting in spatial difference in the energy exchange between the land and near-surface atmosphere (Liu et al., 2014; Weng et al., 2004; Yang et al., 2017). In addition, urban areas have more obvious surface thermal environment effect than rural areas, due to the anthropogenic heat discharge and the absorption, storage and reflection of solar radiation from urban buildings (Rizwan et al., 2008; Wang et al., 2015; Xie et al., 2013). The surface thermal environment effect generally manifests as the urban heat island (UHI) effect, which is a phenomenon that LST_u (urban land surface temperature) is higher than LST_r (rural land surface temperature) (Voogt and Oke, 2003). Many studies have shown that although UHI effect exists only as a local climate phenomenon, its impact on human health cannot be neglected (Merte, 2017; Zhao et al., 2014).

Quantitative monitoring and dynamic analysis of the UHI effect are the key contents of urban thermal environment research. Many scholars have agreed that UHI effect is increasing because of the intensifying urbanization (Chapman et al., 2017; Li et al., 2011; Mariani et al., 2016); thus, the seasonal and diurnal variation of UHI have long been key topics (Du et al., 2016; W. Zhou et al., 2014; D. Zhou et al., 2014). However, the conclusions drawn in previous studies are relatively inconsistent because of diverse quantification methods and various geographical locations, as well as the change of spatial range and other differences in the study areas. For example, Imhoff et al. (2010) found that the strongest UHI effect usually occurred in the daytime and summer in 38 most populated cities in USA. They also found that in summer daytime, the UHI intensity (7 to 9 °C) in regions that had densely planted vegetation such as temperate broadleaf and mixed forests was higher than that in the grassland vegetation region (4 to 6 °C), and the UHI effect in desert cities appeared to be weaker than in other cities. Hu and Brunsell (2013) studied the UHI in Houston, Texas, USA and the surrounding areas at six temporal scales, and found the UHI effect in spring and autumn was stronger than that in winter and summer. Schwarz et al. (2011) analyzed 11 quantitative indicators of UHI in 263 European cities, and found that most of the indicators leaded to the conclusion that the daytime UHI was stronger than the nighttime UHI, which was consistent with findings by Zhang et al. (2010). By monitoring the intensity of the meteorological heat island and the surface heat island in the Beijing-Tianjin-Hebei region of China in July, Wang et al. (2016) found that for both air UHI and surface UHI, the intensity of the nighttime heat island was much higher than that in the daytime, being the greatest (4–6 K) at 04:00 and the smallest (1−2 K) at 12:00 (noon), respectively. However, Zhao et al. (2014) pointed out that cities in humid regions experienced higher daytime annual-mean UHI intensity than cities in dry regions. Therefore, the universal law of diurnal and seasonal variation of the UHI effect under different ecological backgrounds needs further exploration and summarization.

As one of the fastest urbanizing countries in the past 30 years, China's urbanization rate is 2.14% faster than the world average, with urban areas growing by an average of 7.9% per year (Seto et al., 2011). China's urban population has increased from 170 million to 730 million since the implementation of the reform and opening up policy; and China may continue to be the world's fastest growing country in the next 50 years or more (Kuang et al., 2016; Seto et al., 2012). Accordingly, the thermal environment effect especially UHI effect in China is relatively more typical and apparent in contrast to other regions or countries (Zhou et al., 2004). In 2014, China's National New-type Urbanization Plan (2014–2020) set ecological civilization and green low carbon as one of the vital principles to guide national urbanization and social development for the next 15 years. Thus, questions about how to develop in a low-carbon way, manage greenhouse gas emission effectively and enhance the adaptability to UHI, become scientific subjects for scholars from different fields as well as the crucial social issues that affect the daily lives of urban residents in China.

Previous UHI studies in China mainly focused on a certain city or urban agglomerations, with the following key areas: (1) mega-urban agglomerations (Du et al., 2016; Liu et al., 2017; Wang et al., 2016); (2) the megalopolis (Li et al., 2011; Peng et al., 2016); (3) booming cities (Dan et al., 2011; Yu et al., 2018); and (4) furnace cities (Shen et al., 2016; Shi et al., 2012; Yao et al., 2015). There were few studies conducted at the national scale (D. Zhou et al., 2014; Yao et al., 2017), and even in these studies it was typical kind of cities that were focused. There is a lack of comprehensive understanding among cities of different sizes in various climate zones, which needs further spatial-temporal comparison analysis. Therefore, this study examined 285 cities at prefecture-level or above in mainland China and analyzed the spatial heterogeneity of LST in urban and rural areas, as well as the change tendency. The objectives of the study were to: (1) identify spatial pattern of urban and rural areas of cities in mainland China based on the land-use data using a city clustering algorithm and buffer analysis; (2) using linear regression, analyze the change tendency of UHI based on the winter-summer and diurnal change rate of LST_u and LST_r; and (3) classify the 285 cities into four types using K-means clustering based on the change of LST_u and LST_r.

2. Methodology

2.1. Study area

In essence, the entirety of mainland China was selected as the study area, although only 285 cities at prefecture-level or above were examined. China has a vast territory and abundant resources, various geological and hydrothermal conditions have inevitably resulted in diverse soil, hydrological and vegetation conditions. The average temperature in the eastern half of the country decreases from the south to the north. In the western part, the annual mean temperature in the southern Qinghai-Tibet Plateau is generally below 0 °C, but it is above 5 °C in the northern Tarim Basin. The precipitation decreases from the southeast coast to the northwest inland, and tends to decrease rapidly from coastal areas to inland areas.

Affected by natural resources, the social and economic development in China present remarkable diversity. The urbanization in China has rapidly developed from a starting point as a result of accelerating industrialization since the implementation of the reform and opening up policy. According to China's National New-type Urbanization Plan (2014–2020), the population urbanization rate had increased from 17.9% to 53.7%, and the number of cities had increased from 193 to 658 during the urbanization process by 2013 (Song and Deng, 2015), with the Pearl River Delta (PRD), Yangtze River Delta (YRD) and Beijing-Tianjin-Hebei (BTH) urban agglomerations gradually formed.