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Influences of land cover types, meteorological conditions, anthropogenic heat and urban area on surface urban heat island in the Yangtze River Delta Urban Agglomeration

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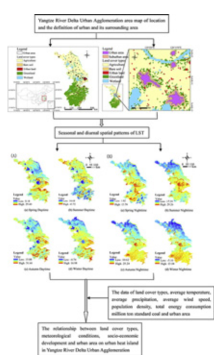
HIGHLIGHTS

- It is necessary to explore the driving factors of UHI to develop mitigating measures and reasonable urban plans.
- The UHI intensity in the Yangtze River Delta Urban Agglomeration was the strongest (0.84 °C) in summer, followed by 0.81 °C in autumn, 0.78 °C in spring, and 0.53 °C in winter.
- The daytime UHI intensity is higher than the nighttime UHI intensity.
- There is no significant correlation between population density and UHI intensity in the Yangtze River Delta Urban Agglomeration.
- Energy consumption, average temperature, and urban area were significantly positively correlated with UHI intensity.
- The average wind speed and average precipitation was significantly negatively correlated with UHI intensity.

GRAPHICAL ABSTRACT



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ABSTRACT

Urban heat islands (UHIs) reflect the localized impact of human activities on thermal fields. In this study, we assessed the surface UHI and its relationship with types of land, meteorological conditions, anthropogenic heat sources and urban areas in the Yangtze River Delta Urban Agglomeration (YRDUA) with the aid of remote sensing data, statistical data and meteorological data. The results showed that the UHI intensity in YRDUA was the strongest (0.84 °C) in summer, followed by 0.81 °C in autumn, 0.78 °C in spring and 0.53 °C in winter. The daytime UHI intensity is 0.98 °C, which is higher than the nighttime UHI intensity of 0.50 °C. Then, the relationship between the UHI intensity and several factors such as meteorological conditions, anthropogenic heat sources and the urban area were analysed. The results indicated that there was an insignificant correlation between population density and the UHI intensity. Energy consumption, average temperature and urban area had a significant positive correlation with UHI intensity. However, the average wind speed and average precipitation were significantly negatively correlated with UHI intensity. This study provides insight into the regional climate characteristics and a scientific basis for city layout.

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1. Introduction

According to the World Urbanization Prospects released by the United Nations in 2014, 54% of the world's population lives in urban areas, and this number will reach 66% by 2050 (United Nations, 2014). The accelerating urbanization process leads to rapid growth in the population and in the number of new buildings. Natural land surfaces are gradually replaced by impervious surfaces, such as cement, asphalt and concrete (Quattrochi and Luvall, 1997). This change leads to different exchange processes of water, substances and energy between the land surface and the atmosphere. Subsequently, a special micro-climate effect forms and introduces higher temperatures in the urban area than its surroundings. The effect is called the "urban heat island (UHI) effect" (Oke, 1973). Because the UHI is closely related to land cover types (LCTs), meteorological conditions, anthropogenic heat sources and the size of the urban area (Peng et al., 2012; Coseo and Larsen, 2014; Debbage and Shepherd, 2015; Guo et al., 2015; Tan and Li, 2015), it is necessary to explore the driving factors of UHI to direct scientific urban planning such as appropriate distribution of industries among cities and specially designed internal streets to help dissipate the heat.

The study of UHI effects involves all stages of development: single city, mega-city and city agglomeration. Along with these stages, research methods have also improved continuously. Early UHI research is based on meteorological observations. By analysing the observed data, the air temperature difference between urban and suburban developments is studied. This difference is called the air UHI (Arnfield, 2003). Because the observation sites are sparsely distributed, it is difficult to obtain a complete spatial distribution for the heat near the ground. In recent years, satellite remote sensing technology has developed rapidly. With the advantages of wide coverage, intuitive images and good synchronization, the technology has widely been applied in the research on UHIs and plays an increasingly important role in this field (Wan, 2008; Imhoff et al., 2010). Studies of UHIs are processed by deriving land surface temperature (LST) from the satellite images. The result is usually called the surface UHI (Voogt and Oke, 2003; Chen et al., 2014).

UHIs of single cities and mega-cities have been widely studied (Unger, 1996; Targino et al., 2014). The UHI intensity and its seasonal changes in mega-cities such as Beijing, Shanghai, Sao Paulo and Mexico City have also been explored (Cai et al., 2011; Jauregui, 1997; Ferreira et al., 2013; Zhang et al., 2010). However, UHI studies on city agglomerations remain in need of strengthening (Peng et al., 2012; Zhou et al., 2013). Urban agglomeration is an extended city or town area comprising the build-up of a central place (usually a municipality) and suburbs linked by continuous urban areas. With the continuous urbanization process, the distance between cities decreases or even disappears; thus, city agglomerations are formed. City agglomerations could change the regional thermal environment by raising the temperature in a continuous area and thus impacting the ecological environment. Therefore, it is necessary to increase the amount of study on the UHI of city agglomerations to understand such regional climate characteristics. Then, a scientific basis for a regional city layout could be provided.

The driving factors of UHI intensity have been studied widely. These factors include LCT, meteorological conditions, anthropogenic heat release and urban morphology (Nichol, 2005; Hung et al., 2006; Grimm et al., 2008). Stabler et al. (2005) noted that urban micro-climates were greatly influenced by variations in vegetation cover. Gedzelman et al. (2003) explored the UHI of New York City and found that the UHI was significantly correlated with the wind speed, wind direction, cloud cover and surface temperature. Elsayed (2012) showed that UHI intensity correlated significantly with population density. In addition, Lemonsu et al. (2015) reported that the UHI was impacted by morphologies of the city such as size, shape, composition and arrangement of its neighbourhoods. Tan and Li (2015) studied the UHI of the Hebei Plain in Northern China and found that UHIs increased with cluster size and this relationship could be approximated by a logarithmic function. Most of the previous research focused on single variable analysis (Oke, 1973; Jusuf et al., 2007; Imhoff et al., 2010; Tan and Li, 2015), and the influence of multiple factors on the UHI of city agglomerations were seldom reported (Peng et al., 2012; Coseo and Larsen, 2014).

The Yangtze River Delta Urban Agglomeration (YRDUA) is one of the most developed, densely populated and concentrated industrial areas in China. In the YRDUA, cities and regions are closely linked with each other. The diversity and spatial heterogeneity of land surface conditions, dense population and close connection of city regions makes the YRDUA an ideal area for the study of city agglomeration UHIs. This study aims to examine the seasonal variations in LST with different LCT and to explore the relationship between surface UHI intensity and influencing factors (meteorological conditions, anthropogenic heat release and urban area). This enhances the understanding of the driving factors of UHIs and provides corresponding mitigation measures.

2. Study area

The YRDUA is one of six influential world-class metropolitan areas and plays an important role in Chinese economic and social development (Tian et al., 2011). It is located along the central-eastern coastline of China (Fig. 1). The region belongs to an alluvial plain with a long agricultural history and moderate climate. The boundaries of what constitutes the Yangtze River Delta (YRD) are different based on different perspectives in culture, economy and geography. In this paper, the YRD refers to the area composed of Shanghai, Jiangsu Province and northern Zhejiang Province, including 11 big cities (urban populations exceeding 1 million), 51 cities (urban population from 0.5 to 1 million) and 39 counties (urban population smaller than 0.5 million) (Table 1). This region is one of the most developed, densely populated and concentrated industrial areas in China. It covers an area of 239,528 km^2, and the population is 139.2 million. The average population density is 581 people/km^2 (Table 1).

3. Data and methods

3.1. Data

In this study, four major data sets were used: LST, LCT, (average wind speed and average air temperature) and the statistical census data from 2014 (population and total energy consumption).

The LST data, at a spatial resolution of 1000 m, were obtained from Terra-MODIS composite products (MOD11A2). The retrieval of LST was improved by correcting for noise caused by cloud contamination, topographic differences and zenith angle changes (Wan, 2008). The

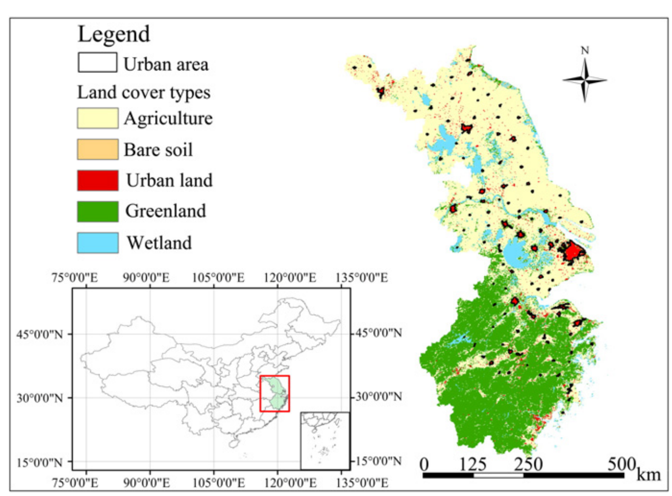

Fig. 1. The location and land cover types of the YRDUA (YRDUA: Yangtze River Delta Urban Agglomeration).