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Impact of the 2008 Olympic Games on urban thermal environment in Beijing, China from satellite images

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ABSTRACT

Beijing has suffered from a rapid development of urbanization in recent years especially since the successful bidding of the 2008 Olympic Games on July 13, 2001 in Moscow. To identify the influence of this paramount sporting event on development of the urban heat island (UHI) effect, this paper examined the spatial expansion of the urban size and UHI effect in Beijing from the years 1999, 2004 to 2008 and 2008 to 2013 using Landsat satellite images. These time spans indicated the process of urbanization in Beijing before and after hosting the 2008 Olympic Games. A new method was proposed to delineate the whole urban boundaries in Beijing governmental area by combining the Remote Sensing (RS) and Geographical information Science (GIS) technologies. The spatial expansion intensity and directions both for urban size and UHI effect were computed and analyzed. By 2013, the urban size of Beijing expanded to more than twice its size in 2008. The sprawl directions for the urban size and the areas with a severe UHI effect were the same, whereas the areas with a severe UHI effect were not enlarged with the increasing urban size. This indicated that the urban development in Beijing after hosting the games was more reasonable which makes the Beijing city be more livable. Statistically, the UHI effect was mitigated when the ratio of areas with water-pervious surfaces to the whole urban region was more than 35%. The urban thermal environment has been improved by increasing the areas of the water-pervious surfaces since hosting the 2008 Beijing Olympic Games.

1. Introduction

Beijing hosted the 2008 Summer Games of the XXIX Olympiad successfully from August 8 to 24, 2008. Many measurements were taken to ensure its complete success including odd-even traffic restriction on travel speed and traffic volume (Li & Guo, 2016), new emission control strategies on air pollution (Norra et al., 2016) and so on. Additionally, large areas of urban construction with energy saving buildings, different kinds of grass, shrubs and trees as well as water bodies have been developed. As the same with many other cities hosting the Olympic Games, Beijing has obtained many lasting benefits beyond the sporting facilities, transport and other citizen-living related infrastructures (Luo et al., 2013). The hosting of Beijing Olympic Games has not only improved the peoples' self-consciousness of environment protection, but changed the world's perception of China (Davis & Thornley, 2010). In this paper, we will discuss the impact of this game on the Beijing urban heat island (UHI) effect as well as urban spatial expansion.

UHI effect refers to the phenomenon of a higher atmospheric temperature in a central urban area compared to the surrounding rural areas. It makes the urban area like a warmer island in contrast to the rural area that surrounds it (Oke, 1973). UHI has become a common phenomenon in cities around the world as a result of rapid economic and urban development in recent years (Clinton & Gong, 2013; Taubenböck, Esch, & Felbier, 2012). The existence of UHI might cause the cities to suffer a greater socio-economic impact as a result of extreme temperature events. Such events as heat waves or rainstorms may lead to increased levels of mortality and human discomfort (Holderness et al., 2013). Additionally, the UHI effect may also increase energy consumption because of the large areas of use of air conditioners and prevent the dispersal of pollutants within urban areas, leading to a greater number of human fatalities. Furthermore, the UHI effect might impact the

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local and regional climate change (Senanayake et al., 2013). For these reasons, many scientists is focusing their researches on the causes, developments and results of UHI effect and its minimisation or elimination.

The UHI phenomenon was first investigated and described by Howard in the 1810s by comparing the atmospheric temperature difference between urban and rural areas (Arnfield, 2003; Howard, 1818). He named this temperature difference effect the UHI effect. There were not enough weather stations to gather the necessary data from large areas of atmospheric temperatures across counties or cities, so many studies measured the UHI intensity using the surface temperature retrieved from satellite images. Satellite images, which cover large geographical areas, provide long-term archive data that can be compared to current data. To distinguish the UHI effect named by Howard (Howard, 1818), the UHI effect identified by imagery is called the surface UHI effect. No simple general relationship was found between surface UHI and conventional UHI (Voogt & Oke, 2003). The two major physical parameters to study are atmospheric and surface radiated temperatures. These can be studied individually or combined (Sobrino et al., 2013). This paper addresses the surface UHI collected through satellite imagery.

The occurrence of UHI is mainly caused by an increased in the amount of impervious surface area, and by the simultaneous reduction of water pervious vegetation cover. This leads to an increase in anthropogenic heat discharge in the urban areas (Zhang, Balzter, & Wu 2013). This indicates that the man made structures are the major reason for the formation of the UHI effect. The relationship between the magnitude of UHI and urban size measured by its population has been demonstrated by Wang et al. (2007). Research from Wang et al. (2007) also showed that the urban heat island was approximately proportional to the fourth root of the population. Urban geometry or morphology is also a factor influencing the UHI effect through the interception of wind and air flow in the urban region along the streets and between tall buildings. Furthermore, landscape patterns and metrics in urban areas play an important role in the formation of the UHI effect (Zhang, Odeh, & Ramadan 2013). Research from Clinton and Gong (2013) indicates that 'development intensity', amount of vegetation and the size of the urban metropolis were the most important urban variables leading to the prediction of urban heat islands or heat sinks according to variable ranking analysis. Urban extraction and land use identification were important prerequisites establishing the relationship between urban size and the UHI effect. The urban region could be extracted from high resolution images with spatial resolution of 0.5 m to 10 m (Durieux, Lagabrielie, & Nelson 2008; Poglio et al., 2006), and medium resolution images from sensors such as Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM^+) or Indian Remote Sensing (IRS) satellites (Bhatta, 2009; Belal & Moghanm, 2011; Kumar et al., 2011). The areas of land use or land cover types were extracted through image classification, but the urban boundary can not be obtained because the land covers of green lands or water bodies are distributed separately among the built-up regions. The extraction of urban boundaries is one of the objectives of this research.

China, as a developing country, has been undergoing a rapid transformation in its urban development since the reform and opening-up policy, which was implemented in 1979. Correspondingly, there has been a rapid rise in the number of cities that have sprawled and grown to a large extent; this has increased the phenomenon of the UHI effect (Cai, Du, & Xue 2011; Quan et al., 2014; Zhou et al., 2014). Beijing, as the capital city of China, has undergone perhaps the greatest and most rapid urbanization, especially since the successful bid for the 2008 Olympic Games in 2001. In this paper, we have focused on the spatial expansion of the urban size and correspondingly UHI effect during periods of pre-Olympics Games, mid-Olympic Games and post-Olympics Games using Landsat images.

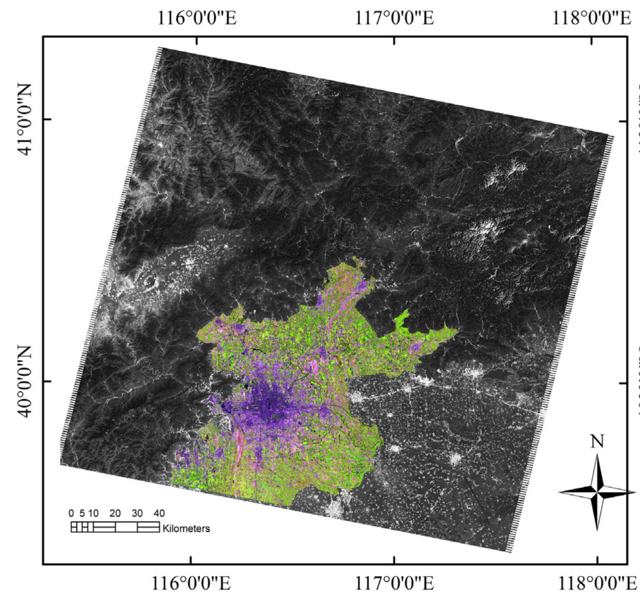

Fig. 1. Study area refers to the false colour composition image embedded in one Landsat 5 gray image.

We will commence by introducing the study area, data sources, and data pre-processing methods. We will then introduce the method for extracting urban boundaries, retrieval of Land Surface Temperature (LST), and calculation of UHI intensity, derivation of surface albedo as well as UHI spatial expansion directions. Finally, we will analyse the results and suggest some tentative conclusions.

2. Methodologies

2.1. Study area

Beijing is located in the North of the Northern China Plain and is surrounded on three sides by The Taihang and Yanshan Mountains and faces the Bohai Bay on one side. The administrative region of Beijing is more than 16 thousand square kilometres, with 62% mountains and 32% plain area. In this research, we focused on the plain region as showed by the false colour composition image in Fig. 1, primarily the urban areas and surrounding rural areas excluding peri-rural mountain regions.

2.2. Satellite images and preprocessing

One Level 1T Landsat 7 image on 2 August 1999; two level 1T Landsat 5 images on 8 September 2004 and 2 August 2008; and one level 1T Landsat 8 image on 31 July 2013 in Beijing were collected to carry out this research. All of these four cloud free Landsat images with path 123 and row 32 were downloaded from the Earth Resources Observation and Science Center, USGS at http://glovis.usgs.gov. The spatial resolution of the thermal infrared band onboard the TM, ETM+, and Thermal Infrared Sensor (TIRS) images was re-sampled to 30 m using the nearest neighbourhood algorithm.

The level 1T TM products employed in this research have been performed through systematic radiometric and geometric accuracy, by incorporating ground control points while employing a Digital Elevation Model (DEM) for topographical accuracy. There were some pre-processing procedures, which included the following: