Applied Geography 71 (2016) 44–55

Contents lists available at ScienceDirect

Applied Geography

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

# Mapping and evaluation the process, pattern and potential of urban growth in China

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ARTICLE INFO

*Article history:*
Received 25 December 2015
Received in revised form
20 April 2016
Accepted 21 April 2016
Available online 29 April 2016

*Keywords:*
Urban light index (ULI)
Urbanization
DMSP/OLS
Unit circle model

ABSTRACT

In this paper, the night-time light (NTL hereafter) data obtained by the Defence Meteorological Satellite Programme's Operational Line scan System (DMSP/OLS) were used to extract urban light index (ULI) for analysing urban growth and patterns in China. A unit circle mode was established to perform a comprehensive analysis and calculation of the variation of various types of urban land covers. In order to verify the ULI ability in extracting urban spatial patterns, eight typical cities were selected to make a comparison therein using Landsat TM/ETM + data. The objectives of this research include: 1) mapping temporal process of the urban growth; 2) exploring spatial characteristics of eight typical cities; 3) analysing spatial distribution pattern of primary urban agglomerations, and 4) assessing potential and tendency for urbanization in the future. The research results indicate that: the spatial pattern features of ULI generally agree with those of the features of urban pattern extracted from Landsat TM data. The morphological change of the urban light space can reflect the objective characteristics of the evolution of urban space. The study further illustrated that the NTL Data are applicable for extracting urban space information and have the potential to deepen understanding of urban space expansion.



## 1. Introduction

It is known that man-land relationships are regarded as foci in geographical research. A city, as the main dwelling place for humans globally, has seen the main competitive interactions between humans and the land. In the past two decades (1990–2010), with significant change in China, the fierce conflicts arising from the man-land relationship have been found in many of the big cities in China (Yang, 2013). Since the reform and opening-up, the urban population has increased from 171 million in 1978 to 712 million in 2012, which means that the level of urbanization has also increased from 17.92% to 52.57% (Bai, Shi, & Liu, 2014). Urbanization is considered the essential approach, and also marks the orientation of socio-economic development worldwide today, to increasing industrialisation (Bai et al., 2014). China has witnessed rapid economic development since the reform and opening-up. The expansion of urban area and irregular urban construction result in large area loss of arable lands in suburbs (Hasse & Lathrop, 2003). Excessive building construction gives rise to low occupancy rates in many cities. This research analysed the spatio-temporal evolution of urbanization in China from the perspectives of the process, pattern, and potential of urban development. The process here refers to the development history of a city; while the pattern indicates the present spatial distribution status of cities in China; the potential represents the urbanization development potential of a city, or area. This research summarises historical experiences of urbanization in China in the past two decades, reveals the spatial distribution pattern of large, medium, and small-sized cities, as well as urban agglomeration, and recognises the development potentials of each city. It was hoped that it will provide guidance and a significant reference for the establishment of new-type urbanization in China.

Existing research shows that the night-time data from DMSP/OLS present large-scale urbanization in a timely and objective manner (Yi et al., 2014; Zhang & Seto, 2011). However, little research into long-term urban expansion is available. Although overall levels of urbanization in China are low, urban expansion in different cities has played a leading role in the world in terms of scale and speed of urbanization, which leads to various intense man-land relationships (Su, Jiang, Zhang, & Zhang, 2011; Verburg, Veldkamp, & Fresco, 1999). Under such circumstances, it is essential to summarise the experiences of urbanization in China, and

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http://dx.doi.org/10.1016/j.apgeog.2016.04.011
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illustrate the spatial distribution patterns of large, medium, and small-sized cities as well as urban agglomerations, and recognise the potentials of each city. This will provide important guidance for new-type urbanization in China. This study primarily analyses the law pertaining to, and characteristics of urbanization in China in recent decades, based on the process, pattern, and potential of urbanization therein. It is expected to provide information on the construction of new-type urbanization. The goals of this paper include: 1) research into temporal change in prefectural-level cities; 2) the characteristics of the spatial evolution of the urbanization of typical cities in China; 3) analysis of the spatial distribution patterns of prefectural-level cities and urban agglomerations; 4) the potential and tendencies of future urbanization in China.

## 2. Data

This research integrated NTL data and urban land cover types, as extracted from day-time visible lights on the Landsat platform. NTL data were able to represent long-term urban spatial variations to analyse the spatial evolution of each city from 1992 to 2010. The land cover data from 1990, 2000, and 2010 were used to perform quantitative analysis of the varying characteristics of each kind of land cover during urban expansion. Two datasets obtained from two different remote sensing satellites, represent the day-, and night-time morphological characteristics of a city. They can be mutually validated, thus overcoming the shortcoming by which remote sensing data is insufficient in only a single period (day-time or night-time).

### *2.1. Land cover data*

Urban expansion is mainly reflected by the expansion of construction land with the decrease of arable land and forest cover in suburbs. The change of land cover in a city records much urbanization information. Hence, this research used land cover maps of eight typical cities in China in 1999, 2000, and 2010 generated by through remote sensing based on Landsat TM/ETM + data. The eight cities were: Shenyang in the Northeast, Beijing in North China, Xi'an on the WeiHe Plain, Urumqi in the Northwest, Chengdu in the Southwest, Wuhan in Central China, Nanjing in East China, and Guangdong in South China. The eight cities and the remote sensing image (Landsat 5 RGB: 4-3-2) from 2010 are shown in Fig. 1.

Object-oriented software for the classification of remote sensing images, eCognition, was used to extract artificial information. Then, multi-resolution segmentation was used for statistical analysis of the spectral characteristics (Zhang, Wu, Li, & Xing, 2014). Thereafter, the authors constructed rule sets to classify the images and conduct DN sampling of the artificial information. For settlements, as a complex land-use type, its electromagnetic waves were reflected in Bands 4 and 5 of the TM data and as such exhibited obvious heterogeneity. On this basis, the normalised difference built-up index (NDBI), equation is as follows:

$$NDBI = (TM5 - TM4)/(TM5 + TM4) \quad (1)$$

Where TM4 and TM5 indicate the DN values in Bands 4 and 5 of the Landsat TM data. Slope and construction indices were extracted to establish information about construction land which consisted of residential land, industrial land, and transportation use land. Firstly, transportation use land was extracted based on a shape index and then residential and industrial lands were classified based on their brightness. The NDBI was greater than 0.12 for construction land; while Slope was less than 10 owing to residential lands usually being distributed in low, level areas; moreover, the information relating to residents living on arable land can be extracted by texture values. A value greater than 2.25 indicated residential land. Through reasonable use of the information including spectral characteristics, texture, and geospatial features, object-oriented classification was used in the statistical analysis of spectral characteristics (Zhang, Wu et al., 2014). Then multi-resolution segmentation was undertaken to extract information from segmented images on a step-by-step basis. Consequently, the classification results of artificial information are shown in Fig. 1.

### *2.2. Night-time DMSP/OLS data*

The Version 4 DMSP/OLS NTL product was obtained from the National Geophysical Data Centre (NGDC) of the National Oceanic and Atmospheric Administration (NOAA) of the United States. An OLS sensor was placed on the DMSP Block 5D-1 satellite F-1 in September 1976 (Elvidge, Baugh, Kihn, Kroehl, & Davis, 1997). There are two channels in the OLS sensor: 1) a visible and near-infrared channel (VNIR, 0.4–1.0 μm, 6-bit spectral resolution); and 2) a thermal infrared channel (TIR, 10–13 μm, 8-bit spectral resolution). The images are taken from an altitude of 3000 km and the spatial resolution of a full-resolution data set is 0.56 km (Small, Pozzi, & Elvidge, 2005). The initial purpose for which this sensor was designed is to observe clouds in moonlight at night (Elvidge et al., 1999). Therefore, the sensor has a large spectral region, which enables it not only to observe clouds but also electromagnetic waves emitted by lights, flares, and lights on fishing boats (Imhoff, Lawrence, Elvidge, et al., 1997; Owen, 1998; Small et al., 2005). The Version 4 global DMSP/OLS night light series data products, mainly provide annual stable global light data. In this study, an inter-calibration was conducted by using all six satellites in the DMSP system: F10 (1992–1994), F12 (1994–1999), F14 (1997–2003), F15 (2000–2007), F16 (2004–2009), and F18 (2010). Due to there is no available NTL data in 1990, in this study, all night light related data for 1990 are derived from F10-1992.

## 3. Research method

### *3.1. NTL data calibration*

The DMSP-OLS NTL time series dataset suffers from pixel saturation effect and lacks of on-board radiance calibration, making it less comparable through different temporal dataset. So, we conducted a NTL data calibration from this two regards in this section.

#### *3.1.1. Inter-calibration of the NTL annual composites*

Although NTL data do not measure land cover directly and many non-urban places are lit at night, including agricultural fields and fishing vessels, it has been shown to be strongly correlated with population density (Sutton, 1997; Zhuo et al., 2009). However, the DMSP-OLS NTL time series dataset cannot be directly used to study urbanization due to the absence of on-board calibration in the OLS (Elvidge, Ziskin et al., 2009; Elvidge et al., 1999). For each year, NTL data acquired by different satellites has no strict inter-calibration. The lack of continuity and comparability means that these data cannot be directly used to extract the dynamics of global and regional urban expansion. In order to reduce these discrepancies and impart comparability to the NTL dataset it is essential that the data should be inter-calibrated first. In order to improve the consistency and comparability of the NTL time series dataset in China from 1992 to 2010, we followed an empirical procedure which is the so-called second order regression model proposed by Elvidge in 2009 (Elvidge, Sutton et al., 2009). We created 60 random points within each unit circle for each city. The total prefecture-level cities in China were treated in the same way. Then, all the random points were taken as the samples to establish the empirical relationship