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Research Paper

Understanding uneven urban expansion with natural cities using open data

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ABSTRACT

The last several decades have witnessed a rapid yet uneven urban expansion in developing countries. The existing studies rely heavily on official statistical yearbooks and remote sensing images. However, the former data sources have been criticized due to its non-objectivity and low quality, while the latter is labor and cost consuming in most cases. Recent efforts made by fractal analyses provide alternatives to scrutinize the corresponding "natural urban area". In our proposed framework, the dynamics of internal urban contexts is reflected in a quasi-real-time manner using emerging new data and the expansion is a fractal concept instead of an absolute one based on the conventional Euclidean method. We then evaluate the magnitude and pattern of natural cities and their expansion in size and space. It turns out that the spatial expansion rate of official cities (OCs) in our study area China has been largely underestimated when compared with the results of natural cities (NCs). The perspective of NCs also provides a novel way to understanding the quality of uneven urban expansion. We detail our analysis for the 23 urban agglomerations in China, especially paying more attention to the three most dominating urban agglomerations of China: Beijing-Tianjin-Hebei (BTH), Yangtze River Delta (YRD) and Pearl River Delta (PRD). The findings from the OC method are not consistent with the NC method. The distinctions may arise from the definition of a city, and the bottom-up NC method contributes to our comprehensive understanding of uneven urban expansion.

1. Introduction

Most of the urban expansion studies use remote sensing images or statistical yearbooks, while emerging new data and open data provide novel opportunities for understanding urban expansion. In this paper, we will examine national wide urban expansion using open data as well as referring to the idea of "Natural City" (NC) which means spatially clustered geographic events, such as the agglomerated patches aggregated from individual social media users' locations (Jiang & Miao, 2015; Long, 2016). Natural city may include natural town as well. NCs are a product of the bottom-up process in terms of data collection and geographic units or boundaries, which can be extracted from RS images, GPS and location-based social media data (Jiang & Miao, 2015). Fractal geometry is the base of NCs. A fractal is a mathematical set that exhibits a repeating pattern which displays at every scale (Gouyet, 1996). Fractal geometry is a workable geometric middle ground between the excessive geometric order of Euclid and the geometric chaos of general mathematics. It is based on a form of symmetry that had previously been underused, namely invariance under contraction or dilation (Mandelbrot, 1983; Mandelbrot & Blumen, 1989). Researches on spatial analysis have concluded that artificially planned and designed spatial objects such as urban forms and transportation networks can also be treated as fractals (Batty, 2008; Clauset, Shalizi, & Newman, 2009). The fractal structure of the urban form is more evident when the urbanized areas of cities, metropolis, or urban systems are seen as a whole. Looking at urban growth/expansion in a fractal manner is an alternative perspective compared with the conventional Euclidean way (Batty, 1991; Chen, 2008, 2015). Thus, the form of the urbanized areas in a city can be treated as a fractal and effective measurement for spatial analysis. Not only does the introduction of fractal geometry provide a powerful tool for the mathematical description of a city system, but it also makes it possible for a number of geographic fractal simulations to compensate for the lack of geographic experimental studies (Batty & Longley, 1986).

Urban expansion is a geographically uneven process (Wei & Ye, 2014a). For example, uneven urban expansion in developing countries like China is due to "uneven opportunities and dualism, including the household registration system, family planning, public resource allocation and land systems", "uneven process of globalization and economic

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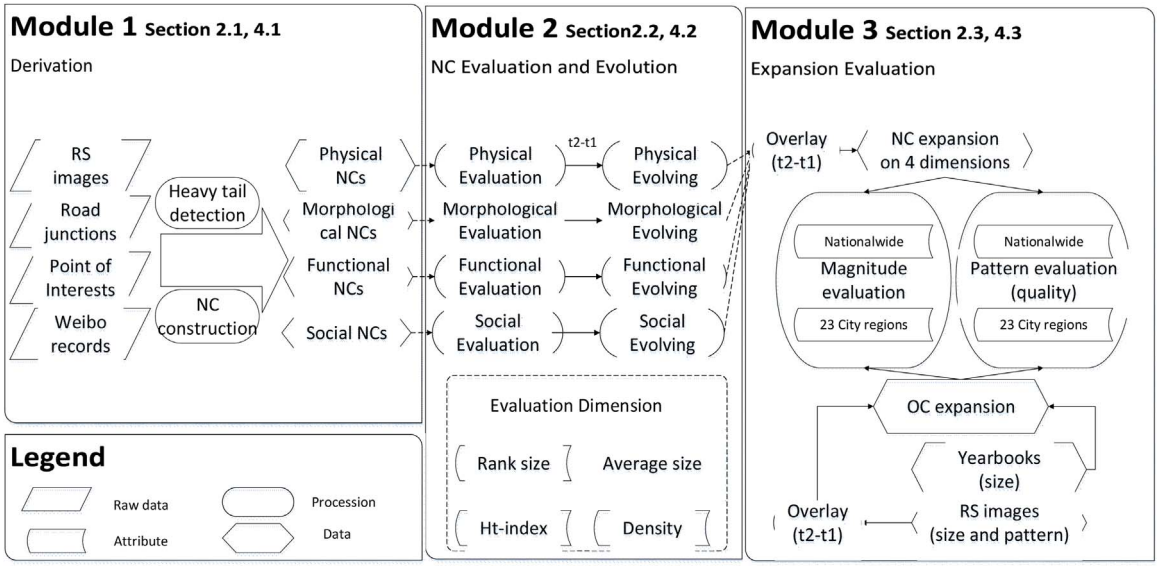

Fig. 1. The overall framework for this study.
Note: t1 = 2009 and t2 = 2014 in this paper.

growth", and "unequal ecological carrying capacities ranging from overloading to richness" (Wei & Ye, 2014b, p759). Despite the importance of urban expansion research, the rate and magnitude have not been universally validated in various sources. For instance, the statistical yearbooks are the main data sources for describing urban expansion for Chinese official cities (OCs), each of which has the explicit administrative boundary. Yearbooks have long been the basic channel for understanding urban expansion in China (Anderson & Ge, 2004; Li, Wei, Liao, & Huang, 2015). Most of, if not all, existing urban studies for China adopt the administrative boundaries of OCs. The shortcomings of this dataset are summarized as the following. First, the existing OCs are not an objective way to observe the Chinese city system. Many towns have a large population, and they should be regarded as cities in the western context. However, they are not counted as the official city in China. In addition, some OCs are very rural. Second, the data quality of statistical yearbooks has been criticized for their resolution and informational richness. The geometrical properties and land use details of urban expansion are not recorded. Therefore, we cannot fully understand Chinese urban expansion using statistical yearbooks.

Besides the statistical yearbooks, remote sensing (RS) images are used to understand urbanization pattern and urban expansion. These RS images range from images with a resolution higher than 100 m by Landsat Thematic Mapper (TM), enhanced TM plus (ETM+) (Deng, Huang, Rozelle, & Uchida, 2010; Kuang, Liu, Zhang, Lu, & Xiang, 2013; Liu et al., 2005; Van de Voorde, Jacquet, & Canters, 2011) to the Operation Line-scan System (OLS) of the Defense Meteorological Satellite Program (DMSP) with 500 m resolution (He et al., 2006; Liu, He, Zhang, Huang, & Yang, 2012). Due to its labor and cost consuming nature in some cases (Liu, Liu, Zhuang, Zhang, & Deng, 2003; Liu et al., 2005, 2010), remote sensing images cannot be easily applied to study urban expansion for all the cities in a timely fashion. In addition, RS analysis emphasizes the physical perspective of urban expansion without taking into account other dimensions. Therefore, an alternative approach to redefine the city system and understand its urban expansion from various dimensions is urgently needed.

Open Data have provided opportunities for quantitative urban studies (Reichman, Jones, & Schildhauer, 2011). Open data is the idea that some data should be freely available to everyone to use and republish as they wish, without restrictions from copyright, patents or other mechanisms of control (Auer, Bizer, & Kobilarov, 2007). Our definition of open urban data is broad and refers to urban data that are openly accessible to the public, mainly coming from three overlapping though different sources (Gurin, 2014): official data portals, big data initiatives, and the broader open data community. Ubiquitous open data from governments, commercial and social media websites are increasingly available to researchers (Shaw, Tsou, & Ye, 2016; Wang, Jiang, Liu, Ye, & Wang, 2016; Wang, Ye, & Tsou, 2016). Open urban data have been a viable and cost-efficient option for understanding the built environment from both physical and social aspects, which has been particularly useful for the developing countries where data infrastructure is not sufficient (Long & Liu, 2015). The applications of open data have demonstrated their importance and suitability for urban studies, planning practice and commercial consultancy (Liu, Derudder, & Wu, 2016; Long & Liu, 2015; Wang, Wang, Ye, Zhu, & Lee, 2015; Wang, Jiang et al., 2016; Wang, Ye et al. 2016).

In this study, we first redefine the city system by means of NCs using open data. We then derive urban expansion from various dimensions based on the derived NCs. In this paper, we initially distinguish urban expansion in two basic categories: size expansion and spatial expansion, corresponding to the conventional urban expansion using yearbooks and RS images, respectively. In this line, we are able to evaluate the identified size/pattern of urban expansion for various types of NCs for better understanding the process of urban growth. The identification and evaluation results for OCs can be benchmarked with those for NCs. Our proposed framework for understanding urban expansion with NCs is based on the fractal concept, within which the dynamics of internal urban contexts are reflected in a quasi-real-time manner. The expansion is apart from an absolute one in the traditional method.

This paper is structured as follows: Section 2 introduces the main methods of the NC generation as well as the identification and characteristics of urban expansion. Section 3 presents the study area of and data used in the research. Section 4 outlines the results of urban area extraction, urban expansion identification and evaluation, along with benchmarking with other existing data sources. Section 5 summarizes contributions and indicates future work. Finally, Section 6 draws a conclusion.

2. Methodology

This paper adopts the analytical framework consisting of three modules depicted in Fig. 1. The first module focuses on the identification of NCs. The second concentrates on the evaluation and the shift in the evolution of NCs on physical, morphological, functional and social dimensions for understanding urban expansion in size. The third module illustrates urban expansion in space and evaluates its quality