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Measuring sprawl in large Chinese cities along the Yangtze River via combined single and multidimensional metrics

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ABSTRACT

Large cities in developing countries such as China are increasingly experiencing urban sprawl. Urban sprawl in Chinese cities has resulted in overwhelming problems, such as inefficient use of urban land, loss of farmland, and environmental degradation, all of which pose challenges to urban sustainability. To investigate urban sprawl in the Chinese context, seven large cities in the Yangtze River Economic Belt were compared. An integrated framework combining single-indicator and multidimensional-indicator measurements was employed to quantify the magnitude of sprawl. Urban spatial expansion was determined by spatially simulating the built-up area for each city based on DMSP/OLS nighttime light data, population census, and statistical data in 1992, 2000, and 2010. The single-indicator measurement employed a comprehensive metric of growth ratio to represent the mismatch of land expansion and population growth. Multidimensional measurement was composed of three key dimensions of sprawl, namely, low density, discontinuity of land use, and poor accessibility. In most cases, results of the single-indicator measurement were generally consistent with the results of the multidimensional measurement. The case study demonstrated the applicability of the new measurement framework in quantifying sprawl. The major features of sprawl, policy implications, and usage of methods were discussed.

1. Introduction

Urban sprawl in a world that is undergoing rapid urbanization is regarded as a potential threat to sustainable urban development. Despite the limited consensus on its definition, the term "urban sprawl" can be defined as an uncoordinated pattern of urban growth in the city periphery characterized by low density, single land use, and poor connectivity (Ewing, 2008; Frenkel & Ashkenazi, 2008; Galster et al., 2001; Hamidi, Ewing, Preuss, & Dodds, 2015; Torrens & Alberti, 2000). Since the mid-20th century, urban sprawl has been a prevalent problem across the cities of North America and Europe, and has thus received extensive attention in literature (Batty, Xie, & Sun, 1999; Burchell et al., 1998; Gottmann, 1957; Lopez & Hynes, 2003; Oueslati, Alvanides, & Garrod, 2015; Torrens & Alberti, 2000; Triantakonstantis & Stathakis, 2015). Urban sprawl has often been criticized because of its negative impacts on open spaces (Ewing, Pendall, & Chen, 2002; Harvey & Clark, 1965), energy consumption (Ewing, 2008; Ewing & Rong, 2008), air quality (Schweitzer & Zhou, 2010; Stone, 2008), ecosystem service (Dupras & Alam, 2015; Stone, Hess, & Frumkin, 2010), physical health (Ewing, Meakins, Hamidi, & Nelson, 2014; Lopez, 2004; Schweitzer & Zhou, 2010), poverty and inequity (Jargowsky, 2002; Le Goix, 2005), and intergenerational mobility (Ewing, Hamidi, & Grace, 2016). The impacts of urban sprawl on traffic congestion, housing affordability, and social segregation remain controversial (Brueckner & Largey, 2008; Bruegmann, 2006; Ewing, Schieber, & Zegeer, 2003, Ewing, Hamidi, Grace, & Wei. 2016; Holcombe and Williams, 2010; Le Goix, 2005).

Although urban sprawl was once a phenomenon that prominently occurred in the developed world, global urbanization and rapid population growth have transformed it into an international issue (Hamidi & Ewing, 2014). In the last three decades, increasing attention has been directed toward the issue of urban sprawl in China, as the characteristics and dynamics of urban sprawl in China largely differ with those in Western countries (Hu, Tong, Frazier, & Liu, 2015; Wei & Zhao, 2009; Wu & Yeh, 1999; Yeh & Li, 2001). China has undergone unprecedented urbanization since the launch of its economic reform and opening-up policy in 1978 (He, Chen, Mao, & Zhou, 2016; Wei, 1994, 2012). The land market reform

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and housing commercialization in the 1980s and 1990s further propelled rapid urbanization, resulting in the huge influx of rural–urban migration and dramatic urban spatial expansion (Chen, Liu, & Tao, 2013). Urban sprawl is prevalent in many Chinese cities, such as Beijing (Deng & Huang, 2004; Jiang, Liu, Yuan, & Zhang, 2007), Guangzhou (Yu & Ng, 2007), Shenzhen (Lv et al., 2011), Hangzhou (Yue, Liu, & Fan, 2013), Nanjing (Li, 2012), and Wuhan (Zeng, Liu, Stein, & Jiao, 2015).

Literature on the measurement of urban sprawl remains ambiguous. Ewing (1997) classified the patterns of urban sprawl as low-density or single-use development, strip development, scattered development, and leapfrog development. Ewing (2008) further pointed out that sprawl is a matter of degree; the line between scattered development and so-called polycentric development and that between leapfrog development and economically efficient "discontinuous development" are not always clear; similarly, the difference between strip development and other linear patterns and the difference between low-density urban development, exurban development, and rural residential development. The measurement result will change when the time scale changes; for example, leapfrog development ceases being inefficient when the time frame is short (Ewing, 2008). Identifying cities that are absolutely sprawl is difficult, but distinguishing a city that is more or less sprawling than others is relatively easy (Feng, Du, Li, & Zhu, 2015). A comparative analysis among cities with the same time frame and measurements may offer an alternative way of measuring urban sprawl.

However, the measurements of urban sprawl may vary with different case studies in literature. These differences make across-study comparisons inconvenient. Studies that have attempted to quantitatively measure urban sprawl across multiple cities prefer the use of a single indicator (e.g., Lopez & Hynes, 2003) or several indices of one dimension (e.g., Fulton, Pendall, Nguyen, & Harrison, 2001; Oueslati et al., 2015; Triantakonstantis & Stathakis, 2015) rather than using multidimensional measurement. Across-study was rarely conducted to measure urban sprawl in multiple Chinese cities (e.g., Feng et al, 2015; Ma, Gu, Pu, & Ma, 2008). The gap in quantifying and comparing sprawl across multiple cities can be primarily attributed to the lack of basic agreements on the measurement method and the shortage of reliable spatial indicators.

To deal with the above issues, the present study attempts to establish a new methodology framework that combines a single-indicator measurement with a multidimensional measurement. This framework is then used to quantify urban sprawl. This paper aims to quantitatively measure and compare urban sprawl in China from 1990 to 2010 by selecting seven big cities in the Yangtze River Economic Belt (YREB). The YREB is the largest development corridor in China's New-type Urbanization Plan. It connects the developing central and western China with the relatively developed eastern China. The seven investigated cities, namely, Shanghai–Nanjing–Hangzhou, Wuhan–Changsha, and Chongqing–Chengdu, belong respectively to three typical metropolitan areas in east-coastal, central, and western China. Various geographic and social-economic conditions could result in distinct features of urban sprawl among cities in the YREB. Given this possibility, the present study provides an appropriate perspective for investigating the relationship between urbanization stages and urban sprawl in China. This study considers national strategies of balanced regional development, namely, the "Prior Development of Coastal Areas" in the 1980s and 1990s, the "Great Western Development" in the 2000s, and the "Rising of Central China."

The rest of this paper is organized as follows. Section 2 introduces the approaches for measuring urban sprawl. Section 3 describes the study area and the processing of data. Section 4 illustrates the results of the two measurements. Section 5 discusses the outcomes and causes of urban sprawl, the policy implications, and the potential uses and limitations of the method. Section 6 presents the conclusions.

2. Dimensions and measurements of urban sprawl

2.1. Three dimensions of urban sprawl

Urban sprawl is a multidimensional phenomenon (Ewing, 2008). Galster et al. (2001) offered eight dimensions of land use to characterize sprawl, namely, density, continuity, concentration, clustering, centrality, nuclearity, mixed uses, and proximity. Chin (2002) categorized four elements of sprawl, namely, urban form, land uses, effects, and density. Arribas-Bel, Nijkamp, and Scholten (2011) offered six dimensions of urban sprawl, namely, scattering, connectivity, and availability of open space under the category of urban morphology; density; decentralization; and land-use mix under the internal composition category. Hamidi and Ewing (2014) and Hamidi et al. (2015) claimed four dimensions of urban sprawl, including development density, land-use mix, activity centering, and street accessibility.

To reach a coherent measurement of urban sprawl, the primary task is to understand its cardinal dimensions. Despite the debate on a rational definition, the cardinal dimensions of urban sprawl can be derived from existing studies. After a thorough analysis of literature, this study extracted three commonly accepted dimensions: low density, discontinuity of land use, and poor accessibility. The details of the three dimensions are discussed as follows.

Low density is the most important criterion of sprawl. From the perspective of density, sprawl is regarded as a condition of relatively low density or a decline of density in newly urbanized areas (Frenkel & Ashkenazi, 2008; Knaap, Song, Ewing, & Clifton, 2005). The density of urban activities includes the number of dwelling units and the population of residents or employees (Galster et al., 2001; Razin & Rosentraub, 2000).

Discontinuity of land use is one of the most cited dimensions of urban sprawl. Discontinuous development can be characterized as sprawl in most cities and includes, but is not limited to, patterns of fragmentation, leapfrog, and single-use development (Clawson, 1962; Hamidi & Ewing, 2014). Water bodies, preserved wetlands, forests, and public reservations and facilities are not viewed as interruptions of continuous development. Urban development with moderate-to-high densities and are separated along a transportation corridor by greenbelts or other open spaces may be characterized as rational development (Galster et al., 2001).

Poor accessibility is another feature of urban sprawl (Ewing, 1997, 2008). According to Hamidi and Ewing (2014), poor accessibility is the most important indicator of sprawl. Accessibility is inversely proportional to the average distance or time cost that people spend to commute from one destination to another. Low-density, single-use, and leapfrog development may result in the segregation of land uses. This type of development results in residents and workers being forced to commute long distances. Poor accessibility is also assumed to be related with a car-dependent lifestyle. The belief that public transportation shortens average travel time than traveling by car has persuaded numerous advocates for public transport services to increase a city's accessibility.

These three dimensions were generated from Western literature, but their dimensions are widely accepted by Chinese scholars. Some scholars have identified the features of urban sprawl in China, and these features were different from those in developed countries (e.g., Gu, Zhen, & Zhang, 2000; Li, 2008). For example, the high-density pattern and large open spaces coexist with the pattern of low-density and limited open spaces (Wei & Zhao, 2009). This situation increases the debate on whether or not the dimension of