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Research Paper

Multi-order urban development model and sprawl patterns: An analysis in China, 2000–2010

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ABSTRACT

Characterization of urban development and sprawl patterns is essential for integrative urban planning and regional sustainability. However, classical frameworks often do not provide adequate synthetic information about temporal urban development and spatiotemporal sprawl dynamics because the individual processes are treated separately. This paper provides a multi-order urban development (MUD) model for urban development characterization along with a framework for quantifying the relationships of certain urban development indicators and sprawl patterns using Hoeffding's independence and Spearman's rank-order correlation at multiple (national, regional, provincial, inland/non and local metropolitan) levels. A case study in major cities across China during 2000–2010 indicates that the MUD model is able to quantify the spatial variations in urban development across multiple temporal periods, and the relationships between urban development and sprawl patterns are discussed for the different levels. The provided method, framework, and findings from this study can potentially benefit integrative urban planning in China and other developing countries.

1. Introduction

Drastic urbanization is affecting local and global sustainability (Salazar, Baldi, Hirota, Syktus, & Mcalpine, 2015). In particular, urban sprawl and its direct and indirect consequences (e.g., cropland erosion, urban heat island effects, ecological degradation, climate change, etc.) serve to make the ecological and socioeconomic systems more vulnerable (Garschagen & Romero-Lankao, 2013; He, Liu, Tian, & Ma, 2014; Nassauer & Raskin, 2014). As such, discussions on controlling urban sprawl in a sustainable manner are becoming more frequent in the literature (Halleux, Marcinczak, & Krabben, 2012; Xiang, Stuber, & Meng, 2011).

Considerable research has focused on characterizing sprawl and its patterns, and several frameworks have been developed explicitly for this purpose (Shahbaz, Sbia, Hamdi, & Ozturk, 2014). However, the definition of urban sprawl varies among researchers (Sutton, 2003; Tian, Ge, & Li, 2017). Previous studies, notably those in developing regions, define urban sprawl as the process of urban land expansion (Schneider, Chang, & Paulsen, 2015; Shahraki et al., 2011; Xu & Min, 2013). Sprawl patterns including infilling growth, leapfrog sprawl, and edge and concentric expansion are typically identified based on the scale and physical distributions of the added urban land (Lopez & Hynes, 2003; Poelmans & Rompaey, 2009; Sun, Wu, Lv, Yao, & Wei, 2013). In addition to the physical dimensions of urban development and sprawl, socioeconomic elements such as population, gross domestic product (GDP), and public facilities associated with urban land have effectively been considered when defining and measuring urban sprawl patterns (Gao, Huang, He, Sun, & Zhang, 2016; Hamidi & Ewing, 2014; Jaeger & Schwick, 2014; Siedentop & Fina, 2012).

A substantial body of research has also focused on measures for controlling urban sprawl, including zoning, green belts, urban growth boundaries, environmental incentives, and land taxes, which have proved successful at slowing urban land expansion in countries such as United States (Anas & Rhee, 2006; Banzhaf & Lavery, 2010; Hepinstall-Cymerman, Coe, & Hutyra, 2013). Coordinated urban land development efforts such as new urbanism, which strives to promote environmentally friendly movements through walkable neighborhoods and mixed-use development (Calthorpe, Fulton, & Fishman, 2001), and smart growth, which encourages mixed-use buildings along with a variety of housing and transportation options (Duany, Speck, & Lydon, 2010; Wey & Hsu, 2014), have also been demonstrated to slow urban land expansion in certain areas.

However, it has become quite difficult to quantify spatiotemporal

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sprawl patterns and sequential urban development along with their multiple interactions and feedback loops at various levels, which is crucial for implementing successful landscape and urban planning to create more compact cities (Bohnet & Pert, 2010; Kane, Tuccillo, York, Gentile, & Ouyang, 2014; Pham, Yamaguchi, & Bui, 2011). Notably, sprawl and urban development is a spatiotemporal process driven not only by the spatial landscape but also by temporal modes (Shafizadeh-Moghadam & Helbich, 2015). The majority of extant studies partition these sequential processes into individual periodical parts and seldom discuss their associations, which is critical for understanding urbanization (Xu & Min, 2013). Moreover, cities are usually examined as individual regions, thereby eliminating the opportunity for multi-level analyses (Oueslati, Alvanides, & Garrod, 2015). Spatially variable urban development and sprawl landscapes are rarely explored (Wu, Zhao, Zhu, & Jiang, 2015). With multi-temporal, multi-level datasets becoming more widely available, it may not be efficient to analyze these datasets using classical, static frameworks (Garschagen & Romero-Lankao, 2013) as they cannot provide synthetic information about spatiotemporal urban development and sprawl nor can they accommodate multi-level research on the inherent causative factors to refocus urban planning (Taubenböck et al., 2014). Studies have suggested that development of new frameworks based on surveys, interviews, and data mining would provide a more comprehensive synthesis of these spatiotemporal processes (Duineveld, Assche, & Beunen, 2013; Tayyebi & Pijanowski, 2014). However, these methods are costly, time consuming, and therefore infeasible for large regions (Atanassov, 2015); and findings derived from small-area studies typically cannot be scaled up to permit regional applications (Yigitcanlar, Dur, & Dizdaroglu, 2015). Thus, a framework and methods for quantifying spatiotemporal urban sprawl at various levels using multi-temporal data are urgently needed.

China has been striving to effectively manage and control the drastic sprawl dominated by urban land expansion since the 2000s through land-use and urban planning (Gu, Wei, & Cook, 2015; Güneralp & Seto, 2013). Approaches to guide the commensurate development of commercial, industrial, medical, educational, residential, and recreational facilities and accommodate socioeconomic increases have largely included land-use restrictions (Cheng, Turkstra, Peng, Du, & Ho, 2006). Nevertheless, efforts have suffered under the current top-down (national to local) plans due to the struggles between the need for socioeconomic growth and sprawl restriction (Abramson, 2006; Chen, Chen, Xu, & Tian, 2016; Long, Han, Tu, & Shu, 2015). Moreover, urban sprawl differs in China compared to other countries in terms of its characteristics and drivers (Tian et al., 2017). Tools that have been successfully implemented in other regions are not necessarily well suited for China. Impacted by economic reforms, industrialization processes, and other local policies, disorderly sprawl remains a distinctive characteristic of urbanization in China (Schneider et al., 2015; Wei, 2012; Yeh, Yang, & Wang, 2015).

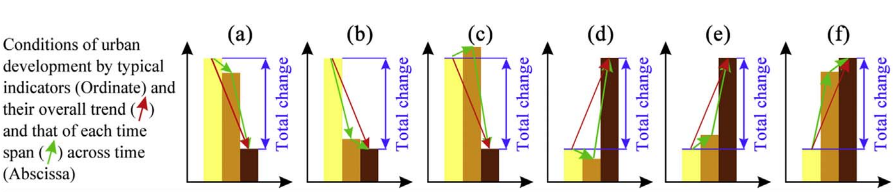
Recently, the Chinese government has endeavored to revamp urban planning into an integrated form that synthetically considers urban land development and dynamic socioeconomic conditions at various levels (Gu et al., 2015). Accordingly, this integrative framework calls for complete and open access to land-use, urban, and socioeconomic planning materials and, more importantly, it calls for full disclosure of urban land expansion and socioeconomic development (Zhou, Lu, Lian, Chen, & Wu, 2017). However, feasible strategies for implementing integrative planning strategies have not yet been developed in China due to a dearth of knowledge surrounding spatiotemporal urban development and sprawl patterns (Gu, 2015; Zhang & Fang, 2016).

This study addresses the need for a novel framework by developing a multi-order urban development (MUD) model and using the established degree-of-goodness index (Bhatta, Saraswati, & Bandyopadhyay, 2010) to assess urban development and sprawl. The study provides a general investigation into Chinese urbanization by answering the following questions: How can sequential urban development and spatiotemporal sprawl be characterized? How do urban development and sprawl behave at different levels in China? It should be emphasized that recognition of the relationship between urban development and sprawl may serve as guidance for bridging the need for growth with sprawl restrictions in China, which presently complicates integrative urban planning strategies. We define urban development and sprawl as processes of the dynamics of the socioeconomic aspects (such as population, public facilities, etc.) and the dynamics of urban land expansion, respectively, following similar studies in China and others areas (He et al., 2014; Long et al., 2015; Tian et al., 2017). The paper introduces the MUD model for characterizing urban development and computes several sprawl metrics. Next, a hierarchical framework based on the MUD model, sprawl metrics, and correlation analysis is presented for analyzing urban development and sprawl patterns at various administrative levels in China. Issues on the effectiveness of the MUD model, urban development and sprawl patterns across major Chinese cities, and the potential implications of findings derived from this study are finally discussed.

2. Methods and materials

2.1. Multi-order urban development (MUD) model

The temporal characteristics of sequential urban development processes are complex (Lee & Yang, 2005). While the end result may be the same relative change over time, the intermediary processes can be quite variable (Fig. 1). Economic responses to these different urban development conditions are also variable. For example, escalating decline, where the rate of decline of certain indicators increases over time (Fig. 1a), can be more destructive economically than the declines that characterize a curbed recession in which conditions continue declining across time (Fig. 1b). Similarly, abrupt depressions (Fig. 1c) are usually unexpected and can raise public anxiety, making them more likely to raise negative impacts on the economy than other dynamic states (Rai, Zitko, Jones, Lynch, & Araya, 2013; Starrs, 2013). From a conceptual perspective, the ideal situations for urban development are escalating



	(a)	(b)	(c)	(d)	(e)	(f)
$a_{ijm}/\lvert a_{ijm}\rvert_{max}$	[-1, 0]	[0, 1]	[-1, 0]	[0, 1]	[0, 1]	[-1, 0]
$x_{ijm}/\lvert x_{ijm}\rvert$	-1	-1	-1	1	1	1
$1+\frac{\alpha_{ijm}}{\lvert \alpha_{ijm}\rvert_{max}}\times\frac{x_{ijm}}{\lvert x_{ijm}\rvert}$	[1, 2]	[0, 1]	[1, 2]	[1, 2]	[1, 2]	[0, 1]
x^*_{ij}	$x^*_{ij} \le x'_{ij} \le 0$	$x'_{ij} \le x^*_{ij} \le 0$	$x^*_{ij} \le x'_{ij} \le 0$	$0 \le x'_{ij} \le x^*_{ij}$	$0 \le x'_{ij} \le x^*_{ij}$	$0 \le x^*_{ij} \le x'_{ij}$

Fig. 1. Six conditions of urban development across time associated with parameters for establishing the MUD model. a: escalating decline; b: curbed recession; c: abrupt depression; d: steady resurgence; e: escalating gains; f: deescalating gains.