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Alternative future analysis for assessing the potential impact of climate change on urban landscape dynamics☆

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HIGHLIGHTS

- We assessed the potential impact of climate change on urban landscape dynamics.
- We modeled the impacts by an integrated land model and alternative future analysis.
- This integrated model coupled a system dynamic and a cellular automata model.
- Spatial and quantitative changes under climate change scenarios can be revealed.
- Climate change affects urban landscape dynamics via water resource constraints.

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ABSTRACT

Assessing the impact of climate change on urban landscape dynamics (ULD) is the foundation for adapting to climate change and maintaining urban landscape sustainability. This paper demonstrates an alternative future analysis by coupling a system dynamics (SD) and a cellular automata (CA) model. The potential impact of different climate change scenarios on ULD from 2009 to 2030 was simulated and evaluated in the Beijing–Tianjin–Tangshan megalopolis cluster area (BTT-MCA). The results suggested that the integrated model, which combines the advantages of the SD and CA model, has the strengths of spatial quantification and flexibility. Meanwhile, the results showed that the influence of climate change would become more severe over time. In 2030, the potential urban area affected by climate change will be 343.60–1260.66 km^2 (5.55 –20.37 % of the total urban area, projected by the no-climate-change-effect scenario). Therefore, the effects of climate change should not be neglected when designing and managing urban landscape.

1. Introduction

The world has experienced accelerating urbanization during the last century. Only 14% of the world's population lived in urban areas in 1900, and 30% in 1950. In 2007, urban population exceeded 50% of the world's population. This urbanization shows no sign of slowing down (Wu, 2010). The extensive urban landscape expansion has resulted in fundamental changes in the structure and function of the global ecosystem (Cadenasso et al., 2007; Grimm et al., 2008; Luck and Wu, 2002). Urbanized areas account for about 80% of carbon emissions, 60% of residential water use, and about 80% of the wood used for industrial purposes (Grimm et al., 2008; Wu, 2010). By 2050, about 70% of the world's population will live in urban areas, and most of the increase will take place in developing countries (Bloom, 2011). The challenges of solving the environmental problems brought about by this fast urban expansion, particularly in developing countries, will continue to rise (Seto et al., 2011; Xiang et al., 2011). Undoubtedly, urban sustainability in the context of fast urban expansion is becoming an inevitable goal of current environmental science (Herold et al., 2003; Wu and Thompson, 2013; Zhang et al., 2013).

It is clear that future climate change has become an important factor influencing urban landscape dynamics (ULD) and urban sustainability (Dale, 1997; Hay and Mimura, 2006; Sánchez-Rodríguez, 2005; Solomon, 2007). The global annual mean surface temperature increased

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by 0.74 °C during the last century (Solomon, 2007) and will increase by 1.0–3.7 °C this century (Field, 2012; Stocker et al., 2013). Climate change affects urban sustainability by exacerbating the tension between water supply and demand, raising energy consumption, and increasing flood risk (Hansen, 2010; Solomon, 2007). Assessing the impact of climate change on ULD plays an important role in studying urban sustainability (Sánchez-Rodríguez, 2005; Shen et al., 2013; Wu, 2013).

Alternative future analysis (AFA) is a method of exploring plausible options for the future of a place, an organization, or a community and for estimating the effects of each option on things that matter to people (Hulse et al., 2009). As is well documented in the literatures, the AFA generally follows three steps: (1) characterizing landscape trajectory (i.e., land cover/use change) in the past; (2) developing scenarios driving alternative landscape trajectory in the future; and (3) assessing the impact of alternative scenarios on landscape trajectory, natural resources, and socio-economic development (Baker et al., 2004; Bryan et al., 2011; Hulse et al., 2009). With the ability to model and compare change trajectories under different options, AFA can effectively assess the impact of future scenarios on landscape dynamics (Gomben et al., 2012; Hunter et al., 2003; Pocewicz et al., 2008). For example, Verburg et al. (2010) modeled trajectories of land-use changes across Europe under four scenarios following the storylines developed by the Intergovernmental Panel on Climate Change (IPCC). Bryan et al. (2011) performed future landscape analysis in the Lower Murray in southern Australia with AFA. Because of the uncertainty of climate change, AFA provides a method of effectively assessing the impact of climate change on ULD (Verburg et al., 2010). However, two limitations still exist when assessing the impact of climate change on ULD with AFA: one is finding a way to link the climate change scenarios (CCSs) effectively to ULD, and the other is modeling the trajectories of ULD under different CCSs (Santé et al., 2010). Improving AFA so that it can be widely applied to assess the impact of climate change on ULD is thus a worthwhile undertaking.

Integration of the cellular automata (CA) and system dynamics (SD) models can provide a scenario-based solution for assessing the potential impact of various driving forces on ULD. An SD model can reflect the structure, function, and dynamics of a complex system (Forrester, 1969). The advantages of the SD model include its ability not only to arrange and describe the complicated interactions among various elements at different levels but also to deal with dynamic processes and feedback in a system. Additionally, it can predict complex system changes under different 'what-if' scenarios and is good at implementing scenario analysis and providing decision support (Liu et al., 2007; Özbayrak et al., 2007). Since the development of the SD model (Forrester, 1969), the method has been applied to various fields, including ecological modeling (Wu et al., 1993), transportation planning (Heimgartner, 2001), and regional environmental management (Guo et al., 2001; Saeed, 1994). Meanwhile, the ability of the SD model to reflect the complexity of ULD has also been demonstrated (He et al., 2005; Huang et al., 2014). However, as a top-down model, the SD model does not have the ability to represent spatial interactions, which are important factors in modeling ULD (He et al., 2006).

A CA model is a dynamic model with local interactions to reflect the evolution of a system, where space and time are considered as discrete units. It was introduced by Ulam and Neumann in the 1940s to understand complex self-organizing systems (White and Engelen, 1993). In a basic CA model, five components are essential: a space often represented as a regular lattice of two dimensions, states for each cell in the grid space; transition rules that determine the change of state for each cell, a defined neighborhood that may influence the transition of the central cell, and time steps (Clarke and Gaydos, 1998; Li et al., 2010, 2013; Liu et al., 2014; White and Engelen, 1997; Wu and David, 2002). CA models have been widely used to simulate ULD for various empirical studies during the past two decades (Al-shalabi et al., 2013; Jenerette and Wu, 2001; Liu et al., 2008; Santé et al., 2010). However, as a bottom-up method, the CA model cannot represent the macro-scale political, economic, and cultural driving forces that influence ULD (He et al., 2006; Ward et al., 2000).

Integration of the bottom-up CA model and the top-down SD model has been proposed to overcome the shortcomings of each since the 1990s (Theobald and Gross, 1994). He et al. (2005) developed a land-use scenario dynamics (LUSD) model by integrating an SD model and a CA model to simulate land-use dynamics in northern China. Combining the advantages of the CA and SD models, the LUSD model

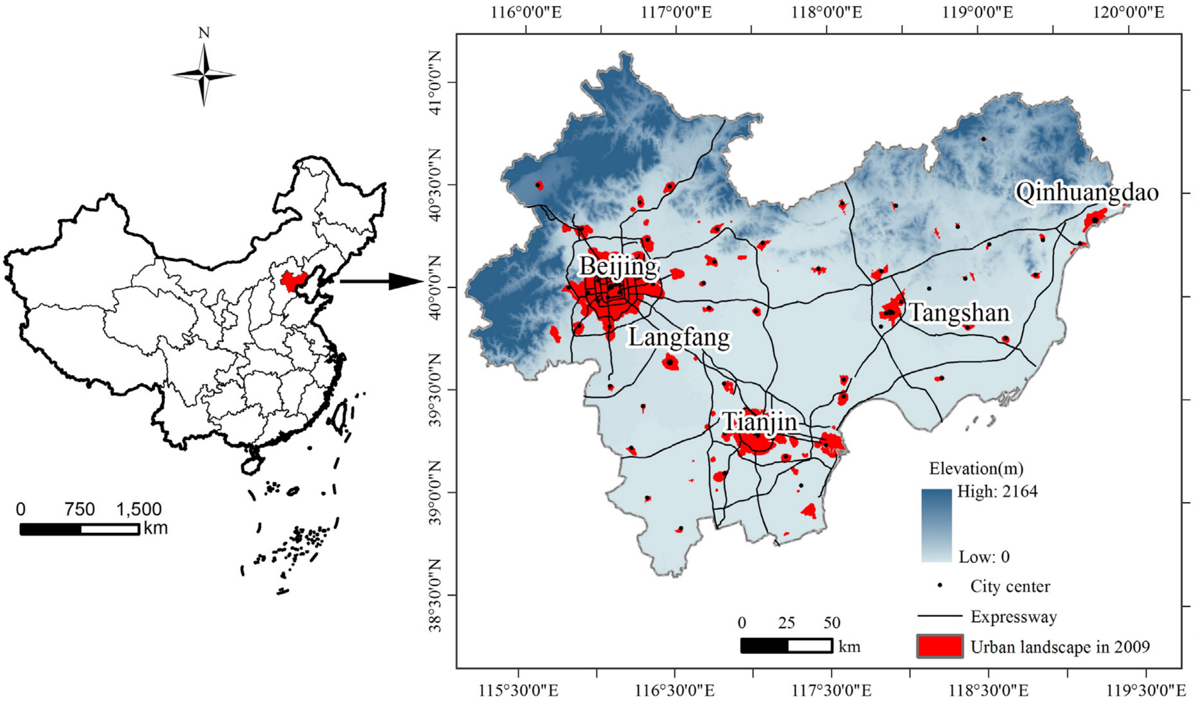

Fig. 1. Study area (urban landscape produced from the classification of Landsat TM/ETM+ images in 2009).