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Changes in arable land in response to township urbanization in a Chinese low hilly region: Scale effects and spatial interactions

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ABSTRACT

Rapid urbanization leads to losses in arable land; quantitatively analyzing the impact of urbanization on arable land is significant for arable land management. However, changes in arable land due to urbanization with scale and neighborhood effects remains poorly understood at the town scale. In this study, high-resolution historical land use data, landscape metric analysis and spatial regression were integrated to quantify the impacts of urbanization on arable land use change (abandonment and conversion) at spatial scales of 300 m–3300 m using a block size increment of 200 m and at the catchment scale in the town of Jinjing in subtropical central China. Arable land abandonment was the predominant type of arable land change and presented strong spatial autocorrelations at each spatial scale. Arable land was converted to tea fields because agricultural structure transformations were occurring around the urban cores, and the amount of arable land converted to residential land accounted for only a small proportion of the total arable land loss and had no spatial autocorrelation. The significance and robustness of the arable land changes impacted by urbanization had obvious scale effects and strong neighborhood effects in nearby regions. Compared with block scales, the catchment scale is an optimal scale for assessing the influence of urbanization and applying planning policy. Our results highlight the significance of incorporating spatial interactions in urbanization research, which can generate less biased estimations and consequently lead to proper policy implication and recommendations. In addition, multi-scale comparisons are helpful for better understanding the relationships between arable land changes and urbanization and provide further insights into the harmonious development of rural settlements and urban cores to preserve arable land.

1. Introduction

China has been experiencing an unprecedented rate of urbanization (Chen, 2007; Chen, Liu, & Lu, 2016; Long, 2014), and urban expansion has had enormous impacts on natural resources and the environment due to the large scale of residential, industrial and infrastructural land expansion across the country (Irwin & Bockstael, 2007; Long, 2014; McBeath & McBeath, 2008; Su, Jiang, Zhang, & Zhang, 2011; Zeng, Liu, Liu, & Qiu, 2013). Among these impacts, the loss of arable land has attracted the greatest attention of governments and researchers, especially in the urban agglomerations in the coastal and central provinces of China, e.g., the Beijing-Tianjin-Tangshan Urban Agglomeration, the Yangtze River Delta Urban Agglomeration and the Pearl River Delta Urban Agglomeration (Chen, 2007; He et al., 2013; Liu, Zhang, & You, 2014; Song, Cai, Deng, Wang, & Shen, 2015; Su et al., 2011, 2010; Tan, 2005; Wang, Ma, & Zhao, 2014; Xiao et al., 2013a, b; Xie, Wang, & Yao, 2014; Zhang, Chen, Tan, & Sun, 2007; Zhong, Huang, Zhang, Scott, & Wang, 2012). China's urban system includes multiple hierarchical levels, i.e., urban clusters, provincial capital cities, prefectural-level cities and towns or villages (Gu, Wu, & Cook, 2012; Wu, Xiang, & Zhao, 2014). To fully understand and solve the problem of arable land loss due to urbanization in China, the relationships between arable land loss and urbanization at each hierarchical level of the urban system should be examined. However, although numerous studies have analyzed the loss of arable land due to urbanization in large urban fringe areas (Zhang, Li, &

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Song, 2014), less attention has been paid to arable land loss at the town scale and in rural areas (Zhong, Huang, Zhang, & Wang, 2011).

Two types of arable land loss generally occur: conversion and abandonment. During conversion, arable land is converted to other land use types according to agricultural structure changes and urban sprawl (e.g., build-up, woodland and tea fields), mainly due to socio-economic development (Munroe, van Berkel, Verburg, & Olson, 2013; Pandey & Seto, 2015). The conversion of arable land to urban areas is the main type of land use change that has occurred since the beginning of the socio-economic development and urban sprawl period in the 1970s, especially surrounding megacities (Liu, Liu, Chen, & Long, 2010; Liu, Wang, & Long, 2010; Lu, Liang, Bi, Duffy, & Zhao, 2011). During abandonment, arable cultivated land is deliberately not cultivated by the land owner and consequently becomes barren. Arable land abandonment is often viewed negatively although it has a positive impact on ecological services (Beilin et al., 2014; Hatna & Bakker, 2011; Renwick et al., 2013). Unfortunately, little information about arable land abandonment in China is available. Although some data can be obtained from the yearly published statistics book, these data are not very accurate or reliable (Tang, Mason, & Wang, 2015; Zhong et al., 2011). In fact, the urbanization and urban core development that were prolific during the period of economic expansion occurred near urban zones and in rural areas, where urbanization is complex because small patches of arable land are converted to other uses (Xu, 2004). Therefore, quantitative analysis of the impacts of urbanization on arable land loss is critical for managing and preserving arable land at the town scale.

Selecting appropriate indices for characterizing urban expansion is a prerequisite for quantifying the relationships between arable loss and urban expansion (Wang et al., 2014). However, according to the literature, few researchers have proposed convenient and feasible approaches for quantifying urban expansion patterns, especially at the town scale. Prior investigations of urbanization have mainly focused on economic and social issues and have neglected the performance of environmental and ecological parameters (Li et al., 2010; McBeath & McBeath, 2008). Therefore, the morphology and evolution of each urban hierarchy due to urban sprawl have gradually become hot topics in geography and other disciplines. However, the spatio-temporal characteristics of urban expansion have long been neglected or have remained hypothetical due to the difficulties of data assemblage (Zhong et al., 2012). In fact, urbanization processes and their related ecological aspects are complex and varied. The rapid development of high-resolution aerial photography and remote sensing technology together with the proliferation of landscape metrics also provides a potential means for understanding how urban patterns evolve and change over time (Su, Ma, & Xiao, 2014). Because landscape metrics can describe the spatio-temporal changes of landscape patterns, they provide an alternative method for measuring urban change (Jiang, Deng, & Seto, 2012). Morphological metrics have been used to quantify the spatial process of urbanization to characterize urban expansion patterns (Sudhira, Ramachandra, & Jagadish, 2004). Several studies have shown that landscape metrics can be used to quantify the spatio-temporal properties of urban development (Herold, Goldstein, & Clarke, 2003; Pan & Zhao, 2007). However, little research has been conducted at the lowest level of the urban hierarchy in China.

According to the literature, the pattern, process and scale should be considered in studies of arable land loss (Munroe et al., 2013; Pandey & Seto, 2015; Pazúr, Lieskovský, Feranec, & Oťaheľ, 2014; Pilehforooshha, Karimi, & Taleai, 2014; Su et al., 2014; Verburg, Mertz, Erb, Haberl, & Wu, 2013; van Vliet, de Groot, Rietveld, & Verburg, 2015). The modifiable areal unit problem (MAUP), which reflects scale effects and zonal effects, may also influence the relationships between arable land change and urbanization. Several studies have partially proven that the MAUP is encountered when considering the impacts of urbanization (Munroe et al., 2013; Su et al., 2014). Wu, Jeliski, Luck, & Tueller, 2000 indicated that scale variance, the Gear' C index and the Moran's I index can not only quantify the spatial autocorrelations of variables but also efficiently characterize landscape hierarchies, which contain distinct ecological processes and functions. For instance, in scale effects research, the spatial scale with the lowest peak Moran's I index could be considered as a threshold for different landscape hierarchies, including several spatial scales. Among the hierarchies, the landscape presents distinct patterns and processes. Although several studies have investigated agricultural landscape changes and urbanization at different spatial scales, few researchers have explored these relationships among different landscape hierarchies. In this study, we hypothesis that patterns of arable land loss have spatially heterogeneous and homogeneous characteristics. A series of spatial scales represented by block sizes was chosen to validate the scale effect in the relationships between arable land loss and urbanization at the town scale. In addition, compared with equal-sized blocks, the hydrological catchment border was delineated to validate the zoning effects among these relationships.

In addition to scale effects, spatial autocorrelation and spatial non-stationarity exist widely in geographical processes (Gao & Li, 2011). Although previous studies of arable land loss have been conducted, few studies include spatial interactions that allow for the neighborhood effects from neighborhood land use activities (Gellrich & Zimmermann, 2007; Gellrich, Baur, Koch, & Zimmermann, 2007). Land conversion is considered to be spatially autocorrelated due to the similarity of the surrounding conditions (e.g., soil quality, accessibility and land management) and the socio-economic determinants mainly impacted by urban sprawl (Haarsma & Qiu, 2017; Wang, Qiu, & Ruan, 2016). Therefore, ignoring spatial autocorrelation and interactions may lead to biased estimates and consequently improper policy implications and recommendations (Wang et al., 2016). Traditional regression models fail to explain the actual phenomena because such models only generate an average set of relationships that is assumed to be spatially constant across the study area (Gao & Li, 2011; Xiao, Su, Wang, et al., 2013). In contrast with the traditional ordinary least squares model, we used spatial auto-regression models with spatial weight factors to deeply explore the relationships between arable land loss (abandonment and conversion) and urbanization at different landscape hierarchy and spatial scales (multi-block and catchment).

In this study, by combing historical maps and aerial photos between 1990 and 2012, we chose a typical agricultural town in subtropical central China to perform the following investigations: (I) quantify the relationships between arable land loss (abandonment and conversion) and urbanization at the town level and (II) investigate the scale and neighborhood effects in these relationships.

2. Study area

The town of Jinjing is located in the northeast region of the Changsha-Zhuzhou-Xiangtan Urban Agglomeration, with a population of 41,600 people (2015) and an area of 135 km^2 (Fig. 1).

The land use types in Jinjing include woodlands, paddy fields, tea fields, roads, residential areas and water bodies (e.g., drainage and irrigation channels, rivers and reservoirs), and the main types of land use are woodlands (56%) and paddy fields (34%). Several changes in land use have taken place in Jinjing town in recent decades. The history of the study area can be divided into three major periods. The first period was prior to the foundation of the People's