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Exploring the driving forces of farmland loss under rapidurbanization using binary logistic regression and spatial regression: A case study of Shanghai and Hangzhou Bay

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ABSTRACT

The unprecedented accelerating urbanization in China has led to a sharp decline in cultivated land. In this paper, the dynamics of farmland patterns during three periods (1994–2003, 2003–2009, 2009–2015) in the Shanghai and Hangzhou Bay (SHB) area are exhibited by dynamic change models and standard deviation ellipse analysis. Additionally, further detection of the determinants of farmland loss is carried out, through a combination of binary logistic regression and spatial regression models. Seven proximate driving factors are selected: distance to water; distance to coastline; distance to city center; and distance to roads (provincial road, national road, highway, and railway). The results suggest that Shanghai experienced the most drastic changes in farmland during the study periods across the whole city agglomeration, and this impact spatially diffused to its adjacent cities. Meanwhile, the transportation routes, especially for provincial road and national road, are quantitatively verified to be the most prominent determinants with a negative influence. Our research highlights that the serious farmland loss should be addressed in highly urbanized area. Furthermore, there is an urgent need for the government to formulate efficient policies for farmland protection and to curb the spread of this phenomenon in the urban agglomeration.

1. Introduction

Soils are the foundation of our civilization, and they provide us with not only a veneer for the Earth system, but also a common rendezvous point for human activities (Haygarth & Ritz, 2009). In China, almost a quarter of soils are agricultural land (Suet al., 2012), which guarantees a long-lasting food supply and stable ecosystem service for human society (Osawa et al., 2016). However, the conflict of farmland with accelerating urbanization and industrialization is gradually becoming a subject of controversy in modern China (Huang et al., 2005). Typically, the most fertile and productive land is lost to urbanization, directly resulting in the decrease of farmland (Zhou et al., 2017). As more farmland is converted to other use, the question arises as to whether this trend represents a systematic reduction in our ability to produce food by placing our infrastructure on the valuable soil resources (Zhang et al., 2007).

Given the composite application of remote sensing (RS), geographical information systems (GIS), and regression analysis methods, considerable efforts have been made to survey the spatial pattern dynamics of agricultural land (Tan et al., 2005) and to explore the specific driving forces under rapid urbanization (Zhang et al., 2013). Su et al. (2014a,b,c) identified the interrelationship between urbanization and agricultural landscape patterns at an ecoregional scale by utilizing a series of urbanization indicators; Zhou and Li (2017) developed an evaluation framework for urban agricultural land-use efficiency to provide the mechanism of spatio-temporal changes in the Xi'an metropolitan zone; Hu and Zhang (2013) introduced a post-classification change detection technique to assess the impacts of urbanization on seasonal land use and land cover (LULC) changes. Some other studies (Durina et al., 2013; Chaudhuri and Mishra, 2016) have also hypothesized that land-use conversion could be incorporated into national and local land-use planning policies, particularly in coastal zones, in order to achieve sustainable farmland regulation and management.

Although a myriad of evidence of the threat to farmland has been

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presented, few studies have quantitatively determined the specific driving forces under rapid urbanization, especially for large urban agglomerations. Generally speaking, the megacity within a city group radiates and promotes the effects of urbanization to its adjacent small- and medium-sized cities and towns (Chace and Walsh, 2006). Among the most alarming consequences of urban sprawl onto the surrounding areas are the steady and irreversible shrinkage of farmland and the conflicts arising from the mixed functions performed by these areas (Kacprzak and Maćkiewicz, 2013). The complexity of the driving forces is closely related to the properties of the study area, and studying the same region at different scales can identify different driving forces (Yan and Cai, 2015). The neighborhood, physical factors, proximity, and socio-economic factors are the universally recognized determinants of land transition (Liao and Wei, 2014). In this paper, we focus on quantifying the relationship between the proximate driving factors and cultivated land loss under urbanization in a coastal urban agglomeration, using a novel method of combining spatial regression and binary logistic regression models. The findings will help to reveal the current farmland loss resulting from rapid urbanization. More than this, our findings will also provide a scientific basis for government to initiate agricultural protection policies, carry out urban planning, and optimize the land regulations of coastal cities.

To be specific, we attempt to: 1) evaluate the spatial pattern and temporal dynamics of cultivated land at an administrative scale over three periods (1994–2003, 2003–2009, 2009–2015) across the Shanghai and Hangzhou Bay (SHB) area; 2) identify the potential proximate determinants of farmland conversion, considering the spatial aggregation and diffusion in the coastal urban agglomeration; 3) provide an innovative way to combine multiple regression methods in driving force analysis; and 4) assist the relevant departments to translate the macro farmland policy in China into local land-use practices.

2. Study area and materials

2.1. Study area

As shown in Fig. 1(a), the SHB area is located in the coastal part of southeastern China, extending from 28.9°N to 31.2°N and from 118.3°E to 122.3°E. Along with the urban agglomeration along the Yangtze River, the SHB area forms the Yangtze River Delta megaregion. In this area, there is one provincial capital (Hangzhou), one province-level municipality (Shanghai), and four metropolises (Huzhou, Shaoxing, Ningbo, and Jiaxing). Close business contact and frequent population flow take place between these cities.

In addition, due to the proximity of the geographical location, the climatic conditions and soil environments of this urban agglomeration are very similar. The SHB area enjoys a humid subtropical climate. Its average temperature in January is generally above 0 °C, and the temperature in July is generally around 25 °C. The average annual precipitation amounts to 1460 mm. Under the combined effects of rivers, rainfall and climate, the soil in the Yangtze River Delta is moist and full of nutrients, which give the productivity and thereby attracting a great number of people to settle down and develop here. According to the statistics, the population of the SHB area increased from 20.52 million to 47.81 million during the 20 years of 1994–2015. From Fig. 1(b), it can be seen that a large area of plains is found in the northeast and the central part of the SHB area, which provides suitable topographic conditions for crops to grow. The entire SHB area covers an area of 50,764 km^2, and in 2015, the total cultivated land area amounted to 19.84% of it (Zhejiang Statistical Yearbook, 2016; Shanghai Statistical Yearbook, 2016).

The SHB area is equipped with three major natural harbors (Shanghai port, Ningbo port, Yangshan port), which provide convenient transportation and business conditions (Fig. 1(c)). Driven by these economic benefits, the SHB area has mushroomed to become one of the most urbanized regions in the world. Such rapid urbanization has had a significant impact on the soil, and especially the cultivated land. Therefore, we chose the SHB area as a typical example to investigate the determinants of farmland loss in the process of urbanization.

2.2. Land-use data acquisition and processing

The data for the cultivated land in Hangzhou Bay (1995, 2000, 2005, 2010) and the city of Shanghai (1995, 2000, 2005, 2010) were obtained from Xiao et al. (2013a,b) and Su et al. (2014a,b,c), respectively. On this basis, we downloaded Landsat Thematic Mapper (TM) remote sensing images at a 30-m resolution (1994, 2003, 2009, 2015) from http://glovis.usgs.gov/. Before the interpretation, all the images were geometrically corrected and false-color composited. To allow us to compare these remote sensing images, we extracted the cultivated land data by visual interpretation in the corresponding year. Considering the coarse resolution and the presence of mixed spectral phenomena, farmland was not subdivided into specific categories (e.g., red soil, paddy soil, etc.) in the process of classification. To check the result of the interpretation, we linked Google Maps with ArcGIS 10.1 software and selected 500 random points on the map within the scope of the study area. The accuracy reached 78.2% for 1994, 81.1% for 2003, 83.4% for 2009, and 85.2% for 2015, respectively, satisfying the accuracy requirements. After obtaining the data of farmland distribution in each year, we further processed it and got the change maps of farmland between 1994 and 2003, 2003–2009, 2009–2015, which are shown in Fig. 2.

2.3. Selection of potential driving factors

A transition in land use is not a stationary pattern, nor is it deterministic (Lambin and Meyfroidt, 2010). Farmland loss can be caused by the negative socio-ecological feedback that arises from a set of structural or behavioral factors (Tayyebi and Pijanowski, 2014). In this study, we referred to previous studies (Shu et al., 2014; Li et al., 2013), which proposed that among the potential variables, accessibility is the most important one. The spatial characteristics of the surface features and the availability of the data were also taken into consideration. Thus, in this study, we finally focused on exploring the role of the different proximate driving factors.

More specifically, proximity determinants include the distance to city centers, rivers and lakes, transportation routes, or some special objects (Xiao et al., 2015). In this study, the administrative center of each city was extracted as a representative of the city center. The early urbanization demonstrated an expansion pattern from the city centers into the rural areas (Wu et al., 2015). The distance to city center (D_{cc}) indicates the degree of human aggregation. Located near the Yangtze River Basin, the SHB area features an extensive water system, which plays an important role in the agricultural production activities and urban development. Thus, the distance to water (D_{wt}) was also included in the analysis. Land use along the major roads has undergone a substantial level of change from agricultural farm land to residential and commercial uses (Oruonye, 2014). We therefore selected four traffic variables for complete exploration: distance to provincial road (D_{pr}), distance to national road (D_{nr}), distance to highway (D_{hw}), and distance to railway (D_{rw}). Furthermore, as a coastal urban agglomeration, the coastlines affect the LULC and human societies significantly (Wu et al., 2018), so the distance to coastline (D_{cl}) was also taken into account. The spatial patterns of these determinants in the study area are shown in Fig. 3 in detail.

All the digital geographic data were obtained from the national basic geographic data sets (1:4000,000 scale). In particular, the coastline data were downloaded from https://shoreline.noaa.gov/. Using these data sources, we calculated the distance to each factor using the NEAR module in ArcGIS 10.1. What should be mentioned is that our research was carried out on a large-scale basis, so census-based variables such as population density and gross domestic product (GDP)