sustainability

MDPI

Article

China's New Urban Space Regulation Policies: A Study of Urban Development Boundary Delineations

Zhuzhou Zhuang [1], Kaiyuan Li [2], Jiaxun Liu [1], Qianwen Cheng [1], Yu Gao [1], Jinxia Shan [1], Lingyan Cai [1], Qiuhao Huang [1,2,*], Yanming Chen [1,2] and Dong Chen [1]

1 Department of Geographic Information Science, Nanjing University, Nanjing 210023, Jiangsu, China; zhuangzhuzhou@163.com (Z.Z.); liujiaxun_adam@sina.com (J.L.); DZ1427006@smail.nju.edu.cn (Q.C.); zb_gaoyu@163.com (Y.G.); MG1427043@smail.nju.edu.cn (J.S.); MG1427041@smail.nju.edu.cn (L.C.); chenyanming@nju.edu.cn (Y.C.); njucd@nju.edu.cn (D.C.)

2 Jiangsu Provincial Key Laboratory of Geographic Information Science and Technology, Nanjing University, Nanjing 210023, Jiangsu, China; likaiyuan@163.com

* Correspondence: qhhuang@nju.edu.cn; Tel.: +86-25-8968-1182

Academic Editor: Tan Yigitcanlar

Received: 30 August 2016; Accepted: 21 December 2016; Published: 29 December 2016

Abstract: China's rapid urbanisation has led to ecological deterioration and reduced the land available for agricultural production. The purpose of this study is to develop an urban development boundary delineation (UDBD) model using the high-tech manufacturing area of Xinbei in the District of Changzhou as a case study, and by applying remote sensing, GIS, and other technologies. China's UDBD policies are reviewed, spatiotemporal changes since 1985 are documented, and future expansion is modelled to 2020. The simulated urban-growth patterns are analysed in relation to China's policies for farmland preservation, ecological redlines protection areas, and housing developments. The UDBD model developed in this study satisfies regional farmland and ecological space protection constraints, while being consistent with urban development strategies. This study provides theoretical references and technological support for the implementation of land management policies that will optimize land allocations for urban growth, agriculture, and ecological protection.

Keywords: urbanisation; GIS; Remote Sensing; SLEUTH model; urban development boundaries

1. Introduction

China is the world's most populous and rapidly developing country, and negative impacts of urban growth are already apparent. Due to a lack of urban expansion policies, this development has been uncontrolled [1,2] and the associated land use changes are affecting ecosystem structures and services, environmental quality, and lifestyles dependent on urban residency. Urban problems—such as haze, traffic congestion, and environmental pollution—have resulted from a severe reduction to the ecological green spaces characteristic of farmlands and woodlands, increasingly homogenised urban landscapes, and the fragmentation of spatial patterns [2–5]. Boundaries are urgently needed to constrain urban growth, in order to protect agricultural land areas and sensitive ecological environments [6].

Long-term studies have revealed that the delineation of urban development boundaries (UDBs) has a profound influence on sustainable urban development [7]. Zoning delineates where urban growth is permitted, which ecological areas are to be protected, and where agricultural production can occur, and permits the implementation of differentiated land management policies. With this objective in mind, China's Central Urbanisation Work Conference in December 2013 proposed the rapid implementation of UDBs specific to each Chinese city, and especially China's large cities, to affect urbanisation in a natural setting, while preserving the country's lush mountains and clean waters for the benefit of urban residents. The conference also noted that urban-development boundaries would limit urban development to clearly defined geographical areas. Limiting the spatial extent of urban growth has become a priority for China, which is facing the question of how the country can meet the needs for both socioeconomic development and ecological and environmental protection in areas with different levels of urban development, and different regional environmental requirements.

This study uses remote sensing (RS) and GIS technologies to document urban land use, and constructs a spatiotemporal time series of urban boundaries to advance the implementation of land management policies. Findings with regard to trends in urban expansion and socioeconomic development are used to make scientific forecasts for limits to the scope of urban development, and with regard to the direction of this expansion; the study's findings also delineate boundaries for urban expansion, with a view to providing theoretical and scientific references for regional urban management and development.

2. Literature Review

2.1. Methodological Reviews

Urban development boundary delineations (UDBDs) are comprised of four parts: the extraction of time-series land use change information, land use change simulations, and the extraction of and revisions to the UDBs. The most crucial aspects are the land use change information extractions and simulations.

Changing land use over time can be documented by analysing the land used for urban development. Domestic and international scholars have used RS technologies to extract urban development land use data, due to the high speed and low costs associated with this type of computerized land use classification. In recent years, different methods such as the spectrum-photometric method, the rule-based spectral difference method, a combination of textural information and decision-tree-classifier-based extraction methods, and different indexes—such as the normalized difference vegetation index (NDVI), the normalized difference built-up index (NDBI), the soil-adjusted vegetation index (SAVI), the normalized difference water index (NDWI), and the residential ratio index (RRI)—have been used to extract urban land use information [8–12]. Meanwhile, some scholars have used high-frequency road information for their study of urban building land use information extraction [13]. Overall, of the available urban development land use information extraction techniques, supervised classification is the technique used most often, while semi-supervised classification techniques are gradually gaining the respect of scholars in the field [14,15]. Their contribution is to simulate urban sprawl by providing very accurate land use information.

The simulation of urban growth has a relatively long history, with academics in western countries having initiated research on the growth of urban areas in the 1960s [16]. The cellular automata (CA) model has been widely used in research on urban land use change; the CA model enjoys the benefits of being simple and natural, and capable of representing changes in urban land structures at a very detailed scale, thus achieving a good deal of popularity among Chinese and international scholars [17], while improving the CA model's capacity to simulate the trend of rising temperatures associated with the growth of urban land use [7,18]. In recent years, the CA model and its derivative models, such as the SLEUTH (slope, land-use, exclusion, urban extent, transportation, and hillshade) model and the Markov-CA model, have become mainstream models for simulating changes in land use [19–22]. Among them, the SLEUTH model, first proposed by Professor Clarke, is a classic CA model [23]. It is constructed using historical urban development data, and takes urban traffic, terrain, and other factors into consideration to set the appropriate parameters. Because the model has good universality and portability, and places fewer restrictions on the input data, it is widely used in urban spatial growth simulation experiments [24]. It has been proven that the SLEUTH model has great potential in urban dynamic simulations, and that it can achieve higher precision in large-scale simulations [25].

2.2. Conceptual Review of Boundary Growth and Delineation

Little research has been conducted on UDBs since this idea was first proposed in 2013 [24,26], so this idea is still very similar to the urban growth boundary (UGB). The UGB concept was introduced with urban sprawl, but from the beginning it has been constrained within the rigid limits of urban land construction, and it has not been considered from a regional perspective. In response to the so-called 'hollow cities' and unrestricted urban sprawl, scholars have proposed some new measures for urban planning and management. For instance, the 'Greenbelt' has been designed in the United Kingdom to limit urban sprawl, and 'new urbanism' and 'smart growth' as well as other theories are used to restrict the scale of urban expansion in America [27–29]. Currently, the focus of the UGB is on problems such as the following: (1) how to provide the land resources needed to accommodate urban population growth and improve the efficient use of existing urban and marginal areas; (2) how to pay more attention to the development of energy, economic, environmental, and social impacts; and (3) how to protect farmland and harmonize urban land use with nearby agricultural activities. The UGB is a means of applying multi-objective controls, which aim at maximizing ecological, economic, and social benefits [30].

In order to solve these problems, scholars are paying more attention to the construction of a conceptual model. With the development of geographical information science, more geographical information techniques have been applied to construct the UGB delineation model [7,31,32]. Low-cost, high-precision urban boundary extraction models were developed using the geographical simulation method, remote sensing technologies, and land-use information entropy models [33,34]. Computational models tend to rely too much on mathematical calculations, thereby failing to consider the directional expansion of urban morphology, and thus overlooking structural adjustments to urban boundary morphology. To address this deficiency, many academics have used a variety of data sources and techniques to propose UGB extraction methods that are distinct from traditional computational models [5,35,36]. In addition, some academics have conducted a variety of studies on integrating theory with the practice of research for UGBs, further enriching these studies [27–30,37–41].

2.3. Urban Development Boundaries in China

UDBs were first proposed at an urbanization meeting of the central government of China [26]. It is not a component of the Land Use Master Plans, but it is a critical part of the Multiple Plans United, which were proposed recently with the objective of solving contradictions between land use master plans, urban plans, and other spatial plans [26]. The major content of the Multiple Plans United is the delineation of three controlling boundaries (ecological protection lines, permanent basic farmland protection areas, and UDBs) to protect ecologically fragile regions and important agricultural production areas, and to limit irrational urban sprawl [42]. Among them, the UDB was used to relieve the contradictions between urban plans and land use master plans. It is a compulsory document for land use management in China. It was set as the framework for the Chinese planning system for the future [42]. However, as a new land use policy in China, the UDB is still at the exploratory stage.

In July 2014, the Ministry of Land and Resources and the Ministry of Housing and Urban-Rural Development jointly conducted a first-phase experiment on UDBDs in 14 cities, including Beijing, Shanghai, Guangzhou, and Shenzhen. Among the 14 pilot cities, the initial work on Xiamen City was completed by 'combining three plans in one' (i.e., the planning of the national economy and social development, urban planning, and land planning). Xiamen City has established ecological control lines (including an ecological red line and an ecological buffer zone) and construction land use control lines that delineate ecological and urban spaces, respectively. Nanjing City has implemented strict land use planning controls on the scale of land use development [42]. On 25 April 2015, the 'Opinions of the CPC Central Committee and the State Council on Accelerating the Ecological Civilization

Construction' was published. This policy stated that there was a further need for the vigorous promotion of green urbanization, the delineation of UDBs, more stringent rules for the supply of urban land for development, promotion of the transformation of urbanization development from outward expansion to internal content improvements, and tightening of the conditions and procedures for setting up new cities and districts [43].

3. Materials and Methods

3.1. Location

The area chosen for this study is the Xinbei District of Changzhou City, in Jiangsu Province, China. The total area of the study region is 437 km^2, and its land use types can be classified as agricultural land (235 km^2), construction land (183 km^2), and other land (19 km^2) (Figure 1). In 2014, the resident population of Xinbei District was 622,400, of which 119,948 were in Chunjiangzhen, 91,560 in Menghezhen, and 40,502 in Xixiashuzhen [44]. For many years, the Xinbei District has been the administrative, economic, and cultural heart of Changzhou.

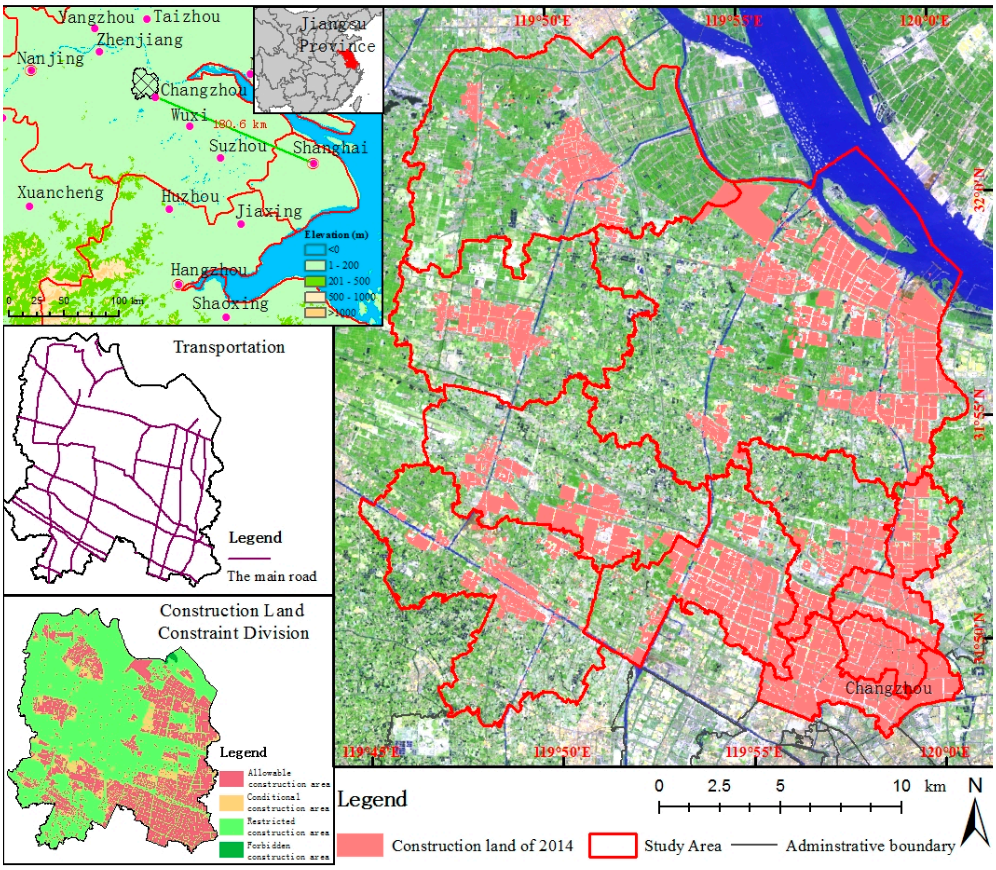

Figure 1. The study area.

Its rapid socioeconomic development has been accompanied by an increased rate of urbanisation that has led to the large-scale transformation of land formerly used for arable and ecological purposes to its use for urban development. This transformation far exceeds the environment's capacity for self-purification, thereby exacerbating pollution of the urban environment and other ecological problems.

Ecological protection and the intensive use of land for development have become the main factors influencing China's urban growth; the urban sprawl associated with urban expansion has failed to meet the requirements of sustainable urban development. The Xinbei district was one of the first areas designated as a 'National High-Tech Industrial Development Zone', and it is currently in the exploratory stage of an urban development transformation. For this reason, current socioeconomic conditions and the scale of future land-use development, as well as environmental conditions, determine the spatial scope of urban development, and constrict the spatial direction of growth, as well as its scale and pattern. The key priorities for a new model of urban development in Xinbei District are achieving a compromise between urban development and environmental protection—while satisfying both conservation and intensity-of-use requirements—and achieving the harmonious development of a new form of urbanisation premised on ecological liveability.

The land use master plan of Xinbei district started in 2006 and is due to end in 2020 [45]. It is the third-round land use master plan in Xinbei district. The first- and second-round land use master plans were shown to be failing to keep urban growth inside developable areas [46,47] because of their poor control of construction land sprawl. In response, the third round instituted three boundaries and four zones to limit uncontrolled city expansion. It is a pity that the contradictions between the urban plans and land use master plans were enlarged for this construction land management policy. As a result, an urban development boundary emerged.

3.2. Data Collection

3.2.1. Landsat TM/ETM+ Images

This study's primary data sources were Landsat images (Landsat 5 TM, and Landsat 7 ETM+, from 1985, 1995, 2005, and 2014) of Changzhou City in the Xinbei District. These data depicted land-use development. Image quality was excellent, with cloud cover less than 1%.

Since some of the image data had been damaged by a faulty band, our study used remote sensing data from different views, at different times, and used local regression analysis to compile the images, thus optimising the quality of the restored image. This study used the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) module in ENVI (Environment for Visualizing Images) software (Harris Corporation, Melbourne, FL, USA) to make atmospheric corrections, while adjusting for artificial spectral smoothing. Finally, using government-defined boundaries for the Xinbei District as borders for the images, the study used ENVI software to achieve irregular cropping of the RS images.

3.2.2. Other Geographical Spatial Data

This study utilised the artificial visual interpretation of data from Jiangsu Province in 1985, and 1995 (1:100,000 scale, National Data Sharing Infrastructure of Earth System Science, Yangtze River Delta Data Sharing Platform), as well as land-use data from Changzhou City in the Xinbei District in 2005, and survey data on land-use changes from 2014 (1:50,000, Changzhou City, Xinbei District National Land Resources Bureau) to verify the precision of the interpreted RS data. Changzhou City DEM (30 m) was sourced from the International Scientific Data Service Platform of the Chinese Academy of Sciences, and was used to extract slope and elevation data. Traffic vector data for Changzhou City in 2012 were sourced from the National Land Resources Bureau of Changzhou City, and were used to develop our SLEUTH model. Information describing the divisions between farmland conservation areas, ecological redline protection areas, and construction areas was drawn from the National Land Resources Bureau of Changzhou City, Xinbei District, and used to adjust UDBs.

3.3. Extraction of Construction Land Use

This study used data compression to extract information documenting the land used for development. In other words, the researchers used new images constructed from the Index of Biological Integrity (IBI) spectrum that had been derived from the original spectrum, to extract urban development land-use data.

The IBI index uses three indices to establish a cumulative RS index. This method differs from the more commonly used method of constructing an index from the multispectral bands of the original image. The three indices used here are the Modification of Normalized Difference Water Index (MNDWI), representing bodies of water, the NDBI, representing land used for development, and the SAVI or NDVI, which represents vegetation [14,15]. When vegetation coverage in an urban research area is relatively low, SAVI should be used, and when this area includes a large amount of vegetation, one should choose the NDVI. Since vegetation coverage in the research area was low, this study used the SAVI. The methods of calculation used for each index are shown below:

$$\mathrm{MNDWI} = \frac{\mathrm{GREEN} - \mathrm{SWIR}}{\mathrm{GREEN} + \mathrm{SWIR}} \tag{1}$$

$$\mathrm{NDBI} = \frac{\mathrm{SWIR} - \mathrm{NIR}}{\mathrm{SWIR} + \mathrm{NIR}} \tag{2}$$

$$\mathrm{SAVI} = \frac{(\mathrm{NIR} - \mathrm{RED}) \times 1.5}{(\mathrm{NIR} + \mathrm{RED} + 0.5)} \tag{3}$$

$$\mathrm{IBI} = \frac{[\mathrm{NDBI} - (\mathrm{SAVI} + \mathrm{MNDWI})/2]}{[\mathrm{NDBI} + (\mathrm{SAVI} + \mathrm{MNDWI})/2]} \tag{4}$$

where GREEN: green band; SWIR: short-wave (length) infrared (band); NIR: near infrared (band); RED: red band.

Historical information describing the land used for development in the Xinbei District was extracted using the IBI.

3.4. Urban Growth Simulation

This study uses the SLEUTH model to simulate the growing extent of land used for urban development. It adopts the assumptions that future phenomena can be simulated on the basis of previously experienced trends, and that previous growth trends will persist. The model also has some shortcomings, because of its deficiency in giving less consideration to institutional factors, such as the effects of land use management policies on urban expansion and land use change. However, the model allows the user to define the exclusion layer, and a number of model parameters are conducive to different comparisons of future development patterns and their potential impacts on planning.

Growth rules for this model are determined by the values of five coefficients: dispersion, breed, spread, slope resistance, and road gravity. These five control coefficients produce four types of growth: spontaneous, diffusive, organic, and road-influenced. The SLEUTH model uses a calibration process to obtain optimised coefficient values for the prediction of future changes in urban growth and changes in land use. Calibration is the key to running the SLEUTH model; in the process of calibration, the model makes use of a brute-force method of iterative Monte-Carlo simulations and historical data to gradually hone in the scope of the control coefficients, finally deriving a set of five optimised control coefficient values suitable for the urban growth experienced by the research area.

This study uses two different types of layer exclusion research models for the calibration process. Exclusion layer E1 includes only water or ecological protection zones; exclusion layer E2 is formed on the basis of E1, and adds basic programming data for farmlands, with the delineation of basic farmland protection zones restricting urban growth. Next, the exclusion layer that provides greater simulation precision can be selected to simulate future urban development.

The goodness-of-fit index determined in the calibration phase follows the form proposed by Dietzel and Clarke's optimal SLEUTH metric (OSM), which is calculated as follows (see Table 1 for descriptions of indicators):

$$\mathrm{OSM} = \mathrm{compare} \times \mathrm{pop} \times \mathrm{edges} \times \mathrm{clusters} \times \mathrm{slope} \times \mathrm{xmean} \times \mathrm{ymean} \tag{5}$$

Due to the gentleness of the slopes in the research area, to avoid calculating a value of 0, the slope index is deleted, and replaced with the optimal SLEUTH metric, no slope (OSM_NS), which is calculated as follows:

$$\text{OSM\_NS} = \text{compare} \times \text{pop} \times \text{edges} \times \text{clusters} \times \text{xmean} \times \text{ymean} \quad (6)$$

The OSM_NS metric calculates the accuracy of numerical growth in the model (Compare and Population), the accuracy of growth location (X-Mean and Y-Mean), as well as the size and form (Clusters and Edges). As the value of OSM_NS increases, this indicates that the simulation results are closer to the real situation. The specific meanings of each index are outlined in Table 1.

Table 1. SLEUTH [a] model calibration indicators [48].

Indicator	Description
Compare	Final year modelled population/final year actual population (or IF $P_{\text{modelled}} > P_{\text{actual}}$ {1 − [final year modelled population/final year actual population]})
Pop	Least-squares regression score of modelled urbanization compared to actual urbanization in control years
Edges	Least-squares regression score for modelled urban edge count compared to actual urban edge count in control years
Clusters	Least-squares regression score for modelled urban clustering compared to known urban clustering in control years
X_{mean}	Least-squares regression of mean X_values for modelled urbanized cells compared to mean X_values of known urban cells in control years
Y_{mean}	Least-squares regression of mean Y_values for modelled urbanized cells compared to mean Y_values of known urban cells in control years
Slope	Least-squares regression of mean slope for modelled urbanized cells compared to mean slope of known urban cells in control years

[a] SLEUTH = slope, land use, exclusion, urban extent, transportation, and hillshade.

3.5. Extraction of Urban Growth Boundary Lines

Urban growth occurs at the outer edges of urban spaces. Consequently, the evolving delineation of urban boundaries should represent contiguous contours within a large area. Based on this characteristic, this study has established area parameter values to conduct edge detection, thereby extracting UGBs (Figure 2). This method follows the process of denoising, filtering the image that has been separated into small polygonal areas of land used for development, and preserving large-scale contiguously distributed polygons of land used for development. For the convolution operation, we use the brightness gradient magnitude and the brightness gradient direction that was calculated using the image generated from the original image. Parameter values are selected using the smallest value of the polygonal areas in each urban socioeconomic development centre, and filtering out the smallest area of land used for development outside of urban centres, forming an initial binary image (where 0 represents non-development land use, and 1 represents land-use development), wherein a pixel with a value of 0 adjacent to a pixel with a value of 1 represents an edge point. Based on these principles, we have extracted the image edges from which we have derived UGBs.

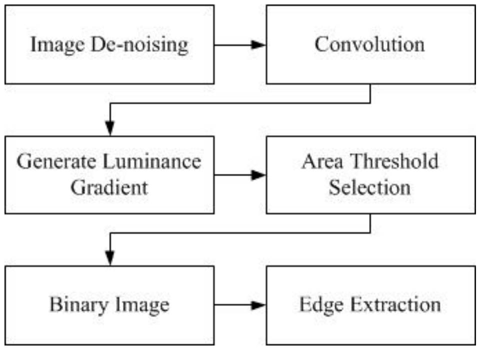

Figure 2. Flow Chart of Edge Extraction.

3.6. *Urban Growth Boundary Delineation*

The Chinese Government's official definition of UGBs is 'based on the determination of factors such as topography, natural ecology, environmental capacity, and basic farmland, spatial boundaries allowing and banning urban development construction areas can be established, permitting the largest possible boundaries for urban construction land use'.

This study established exclusion layers using basic farmland, ecological redlines, and the banned or restricted development conditions described in the Land Use Master Plan, with these types of areas strictly banning any type of urban development activities. Apart from basic farmland and ecological redline zones, and permissions stated in the Land Use Master Plan, other areas zoned for construction are within UGBs. Following this principle, this study conducted spatial overlay analysis to eliminate excluded layer areas, and deleted areas that conflicted with delineated construction restrictions in UGBs, ecological areas, and farmland (Figure 3).

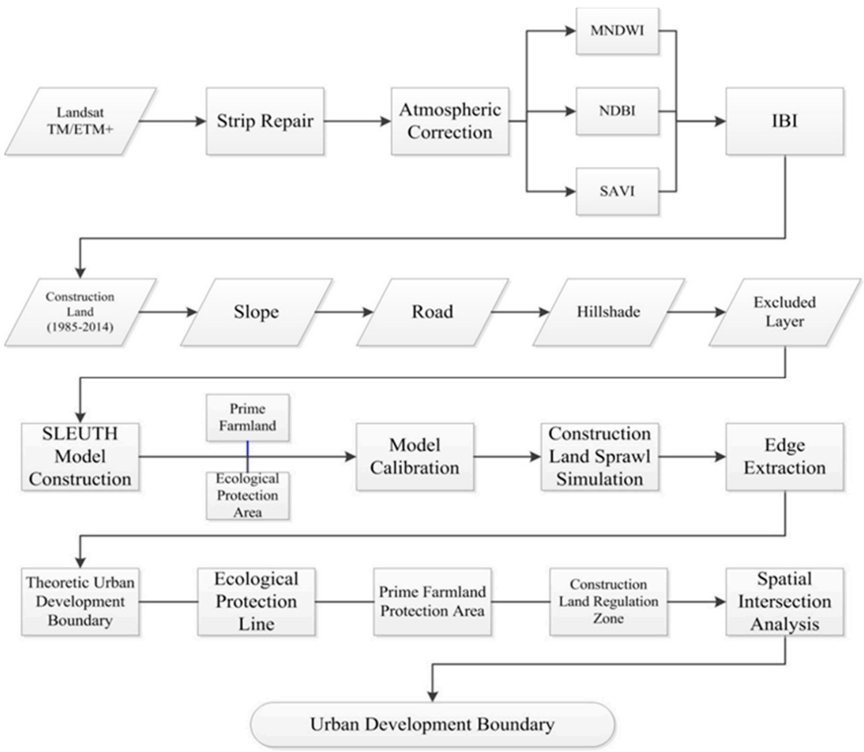

Figure 3. The Model Structure of Urban Development Boundary Delineation. MNDWI, Modification of Normalized Difference Water Index; NDBI, normalized difference built-up index, SAVI, soil-adjusted vegetation index, IBI, Index of Biological Integrity.

4. Results

4.1. Extraction of Urban Land-Use Development Information, Spatial and Temporal Change Analysis

Based on the IBI model, this study extracted time-series information for the urban development of land in the research area for 1985, 1995, 2005, and 2014. Based on the results of image classification, the study applied true vector value data for the corresponding years to conduct accuracy tests. Using the kappa coefficient, the classification accuracies for each year were, respectively, 80%, 88%, 86%, and 86%.

According to these results, during the last thirty years the extent of land used for urban development in the research area has increased consistently. However, between 1985 and 1995, with the rapid development of the economy of Xinbei district, the increase in farmers' income and the updating of their thinking led them to invest more in housing from the beginning of the Chinese reforms and opening up. As a result, the scale of rural construction lands expanded during this period. In addition, some farmers started to construct new houses without demolishing old buildings. This resulted in an increase in idle land and empty villages. Aiming to optimise rural land use patterns, 10,000 ha of fertile farmland was designated in order to convert idle land and empty villages to farmland [49]. The total area in which old buildings were demolished reached 405 ha (Figure 4). Between 1995 and 2005, land-use development increased dramatically in the research area from 4089 ha to 9047 ha, amounting to an increase of 4958 ha, or 121% (Figure 4). From 2005 to 2014, land-use development in the research area continued to increase, from 9047 ha to 20,562 ha, amounting to an increase of 11,514 ha, or 127% (Figure 4). From 1995 to 2014, urban development increased by 16,472 ha, or 402% (Figure 4).

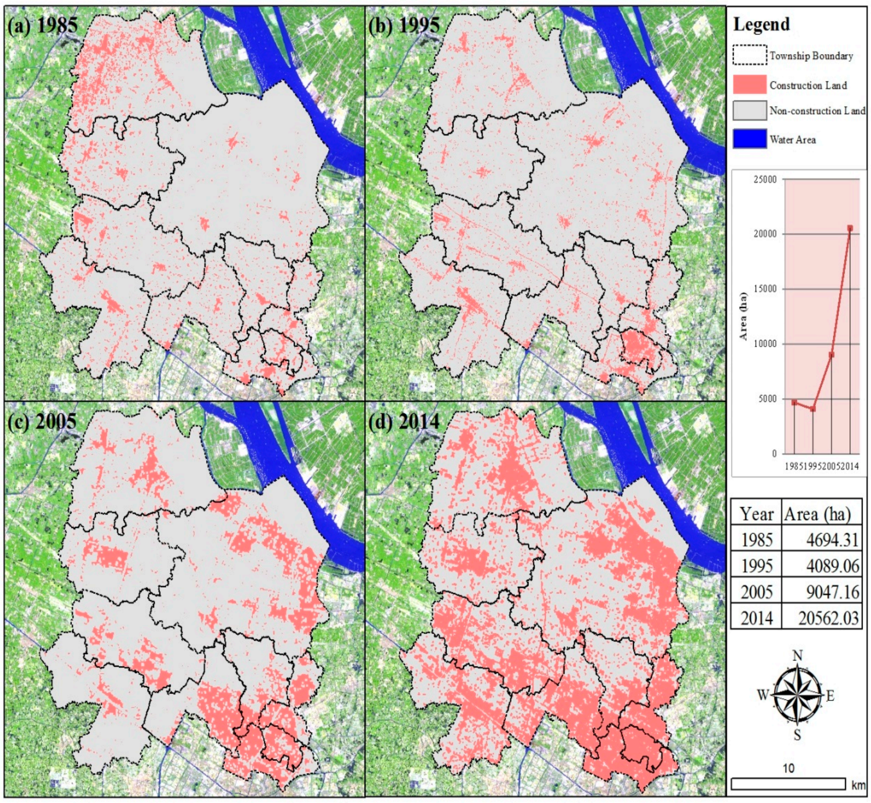

Figure 4. The Spatial Change of Construction Land during 1985–2014.

Based on the expanded area and increase in the scale of urban growth in the research area, we can see that in the past thirty years, the pace of growth for urban development has been extremely high. In 2014, the area occupied by development was 47% of the total research area.

During this process, the land available for ecological and agricultural production in the research area was severely constricted, leading to an increasing deterioration of the environmental quality of the region [50,51]. At the same time, the large scale of the development activities described has been hard to maintain [52]. While the intensity of development in the research area remains high, the level of conflict between demands for urban development and green spaces/agricultural production is increasingly apparent [53]. Given this background, there is an urgent need to implement baseline restrictions on urban growth, from the perspectives of space and the scale of development, to achieve orderly, guided, and regulated urban development.

4.2. Simulation of Land-Use Development and Growth Boundary Extraction

According to the coarse, fine, and final calibration of data for the research area for the years 1985, 1995, 2005, and 2014, parameters were combined according to OSM_NS rankings after each stage of calibration in order to determine the optimal growth control coefficient. We obtained optimal OSM_NS values under two scenarios for each calibration stage, with the optimal OSM_NS values for coarse, fine, and final calibration for exclusion layer E2 being higher than those for exclusion layer E1. From coarse to fine calibration, and then to final calibration, OSM_NS values exhibited an upward trend. For the coarse calibration stage, the value for E1 was 0.61, and for E2 it was 0.63. In the fine calibration stage, the value for E1 was 0.62, and for E2 it was 0.66. In the final calibration stage, the value for E1 was 0.62, and for E2 it was 0.66. Because the OSM_NS index is derived from six indices, the current magnitude of accuracy optimisation is relatively significant. Consequently, in this study the exclusion layer with higher simulation accuracy, E2, was selected for the land-use development expansion model.

This study used predictive parameters to obtain the best-fit set of future development land-use expansion growth control coefficients, based on the optimal coefficient for historical land-use development that excluded layer E2. Using 2014 as the starting point for forecasts, we predict increasing urban land use growth conditions from 2014 to 2020, thus forecasting the scope of urban development for the year 2020. As shown in Figure 5, our model predicts that urban growth for Changzhou City in the Xinbei District will exhibit edge expansion and infill development trends. Comparing predictions for urban growth by 2020 to urban growth in 2014, we predict that urban growth of land use will increase by 7645 ha, or 37%. According to the results forecast by our simulation, new urban development in Changzhou City in the Xinbei District will be located primarily in the southwestern Benniu Town (Figure 5).

Due to the fact that government planning largely directs the development of land use in China, changes in land use are heavily influenced by land-use policies. Thus, simulations of land-use development in Chinese regions must emphasize the effects of land-use policies; such as basic farmland preservation zoning policies, land-use regulations, and policies that link increases and decreases in urban and rural development [54,55]. Through the addition of factors associated with land-use policies, simulations of changes in land use can more closely parallel actual outcomes, thereby increasing the accuracy of simulations, and providing more reliable results for future simulations. Since farmland with high quality and continuity are protected by Chinese Land Use Management Law, random transformations from farmland for non-agricultural land use purposes are forbidden. However, lakes, grasslands, forests, and other areas are not protected, and they will have effects on cities. Therefore, we selected the farmland protection area as providing restrictions on urban sprawl. In peri-urban China, farmland protection areas may have the only land use policy that can constrain urban expansion. In this study, basic farmland protection zones formed a reference layer for calibrating the SLEUTH model in order to consider the effects that the current implementation of farmland protection policies are having on urban development. The model established on this basis achieved greater accuracy, and simulated the delineation of UDBs that were consistent with what actually occurred in the research area.

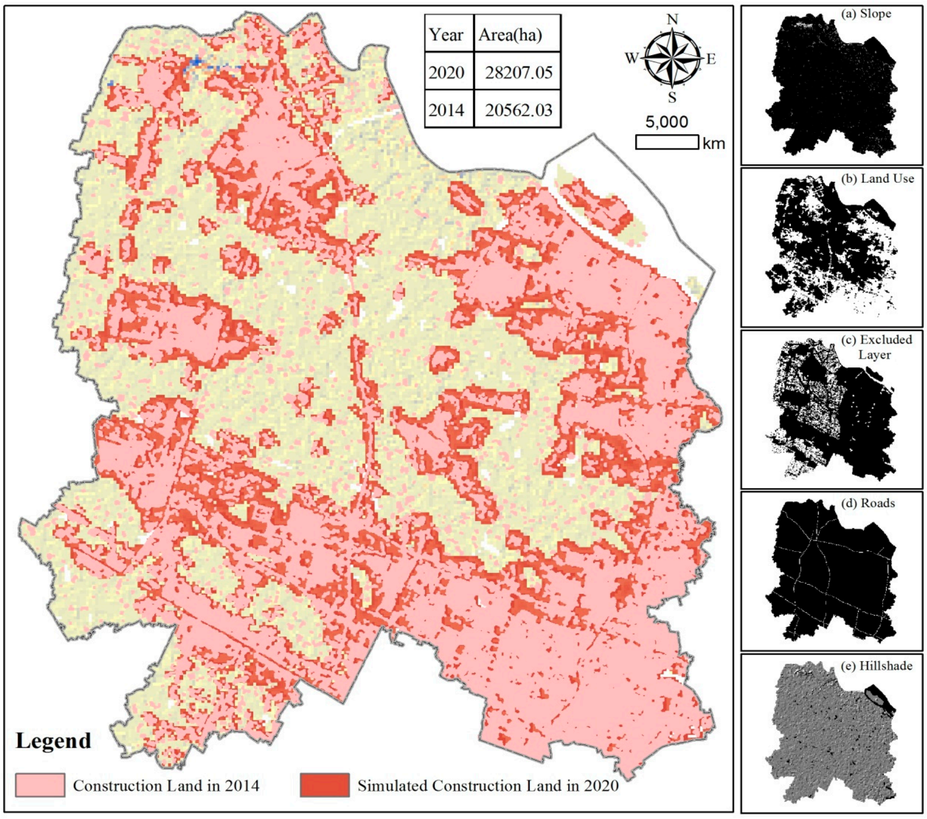

Figure 5. The Simulation Result of Construction Land Sprawl in 2020. Correction of urban development boundary delineation.

Given the high accuracy of the model's land-use forecasting, this study used edge detection to extract urban development boundary lines for Changzhou City in the Xinbei District for 2020 as the theoretical UGBs (Figure 6a). Due to unequal socioeconomic development in various areas of the region, the scale of development in each area in the Xinbei District is different; this has led to the coexistence of segmented and contiguous growth. Thus, there exists the problem that theoretical UGBs have a scattered layout, and the direction of urban spatial development is disorganized. For this reason, this study is based on a new Chinese form of urbanisation, under the requirements for 'urban and rural unified development', 'urban and rural unity', and 'intensive conservation'. Integrating urban development land-use change data from each area of the Xinbei District in 2014, and applying area parameters, we have eliminated spatially dispersed or relatively small polygonal areas of urban development. At the same time, through the inclusion of ecological redlines (Figure 6c), basic farmland preservation redlines (Figure 6d), and areas regulated by the Land Use Master Plan (Figure 6e), and applying spatial analysis to adjust theoretical UGBs, we have delineated UGBs for the Xinbei District (Figure 6b). The UGBs delineated in this study encompass an area of 17,558 ha, with this space being concentrated around the southern and eastern riverside belt. This is consistent with the urban space development strategy contained in the Xinbei District Land Use Master Plan (2006–2020) and the Changzhou City Land Use Master Plan (2011–2020).

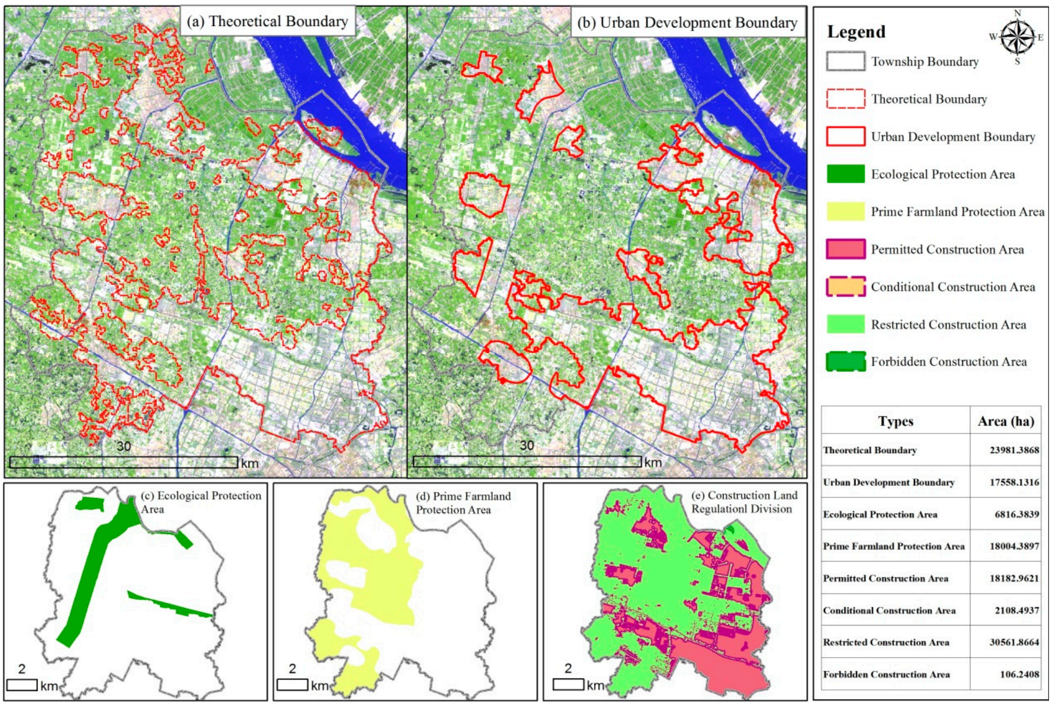

Figure 6. The Spatial Scale of Theoretical Boundary (**a**) and Development Boundary (**b**) (**c**–**e** are constraining layers of development boundary delineations).

5. Discussion

As an absolutely new land use policy, the UDB shares some similarities with the UGB. China's research on UGBs is relatively weak. The new edition of the 'Measures for Formulating City Planning', published in China in 2006, provides a clear summary for overall city planning and the need to 'study urban growth boundaries' in the planning of city centres [56]. It means that urban planning in China's major cities began to gradually introduce the concept of the UGB. Currently, it is still an auxiliary tool of urban plans in China, and it has not been applied in urban land use management [7,57]. Research on the UGB in China mostly focuses on the delineation techniques rather than theoretical studies [58,59]. In contrast, the UDB is proposed as a dominant planning tool for urban land use management, and it has been accepted and incorporated into the nation's new type of urbanization planning (2014–2020) coupled with permanent farmland [26,60]. However, in China the concept of a UDB does not have a precise definition, and is not yet distinguished from the UGB. As a result, research on the UDB is closer to the UGB [24]. However, unlike the UGB, the UDB will be used to relieve the contradiction between urban plans and land use master plans in the future, not just to limit the irrational spatial sprawl of cities [42]. Since the land use master plan defined the spatial regulation policy of construction land, it provided a reference for urban sprawl control from the perspective of spatial management. Moreover, the spatial regulation policy of 'Three Boundaries and Four Zones' was written in the third-round land use master plan and supported by China's related land use management law [51]. Three Boundaries and Four Zones reflected the 'bottom line thinking' of the government's spatial regulation policy. It turned urban sprawl space management from passive to active. Thus, China's UDB delineation depends more on the land use master plan. Once the UDB is delineated, the scale of construction land defined in urban plans and land use master plans must be located within the limits defined by this boundary.

The model we constructed integrates the related spatial planning, such as land use master planning, and unifies the same content into a common spatial planning platform to improve the rationality of the UBD. In addition, the proposed UDB can parallel the current situation of urban construction and development in China. It can also adapt to the real needs of managing China's urban development in the context of new urbanization, and can be used to identify urban control strategies that are consistent with their own development plans. By delineating UGBs, and isolating areas for agricultural development, ecological protection, and urban development, socioeconomic development can be better harmonized with the ecological protection of the environments that surround urban areas. In so doing, we can further ease the environmental and social pressures precipitated by urban growth, while promoting the orderly development of reasonable urban scales in appropriate locations. Still, facing the effects of uncertain socioeconomic developments, there is some dynamism in the demand for urban development. Once considered unsuitable for socioeconomic development, the controlling mechanisms for UGBs will result in frequent changes to urban growth plans, thereby disrupting the continuity of these plans. Thus, the establishment of UDBs should accommodate different regulatory goals and types of growth, and should apply appropriate controls on aspects that require strict controls. Where unclear boundaries or unpredictable elements exist, flexible solutions must be put into place. In this way, the management of urban development can be improved, and resilience in the face of uncertain socioeconomic development can be strengthened.

There are serious spatial imbalances in China's urban development. In the eastern coastal areas, urban development is occurring too quickly. However, urban construction in the central region is in the developmental stage, and urban construction in the western region has just started. Consequently, the definition of UDBs has regional differences. Depending on the regional economic and social status, the UDB is too difficult to delineate in the same way. It is necessary to implement rigid UDB controls for over-expanded cities. For the developing city, rigid UDB controls should be based on the urban development space remaining. In addition, because of the uncertainty of China's socio-economic development, it is difficult to quantify the demand for regional construction land accurately. Therefore, the UDB cannot accurately meet urban development needs, which makes it difficult to be applied to sustainable urban land use management.

6. Conclusions

The methods used to conduct this study are based on a combination of RS land-based observation images, socioeconomic statistics, and land classification results, and the application of GIS spatial analysis and SLEUTH model simulation techniques. This paper develops an UGB delineation model suitable for China, by conducting a comprehensive analysis of farmland redline and ecological redline restrictions, and a variety of land-use policies delineated in national land-use spatial plans.

The UGB delineation model proposed in this study combines the land-use policies related to basic farmland preservation redlines, ecological protection redlines, and spatial restrictions, for land-use development. With respect to the region's actual development needs, the model delineates a unified boundary for urban development, while defining its spatial extent, promoting orderly development, and providing a spatial reference. In addition, the delineated UGBs harmonise with agricultural preservation redlines and ecological land-use restriction redlines, thus preserving the areal extent of farmland, and preserving the ecological environment, while enforcing farmland and ecological preservation policies. To avoid the concentration of agricultural production areas and ecologically fragile areas, the model coordinates urban development with the environmental protection of neighbouring areas.

However, urban development under conditions of socioeconomic volatility is inherently dynamic, so UGBs must be flexible and adaptive measures must not conflict with socioeconomic development. For this reason, future research is needed to explore how UGBs can be used to achieve socioeconomic development that is consistent with the scale and direction of land-use development.

Acknowledgments: This work is supported by the Special Research Fund of the Ministry of Land and Resources for Non-Profit Sector (No. 201411014-03). Sincere thanks are given for the comments and contributions of the anonymous reviewers and members of the editorial team.

Author Contributions: All authors contributed to this work. In particular, Zhuzhou Zhuang and Kaiyuan Li had the original idea for the study, and coauthors conceived and designed the experiments. Jiaxun Liu, Qianwen Cheng, Yu Gao, Jinxia Shan, and Lingyan Cai analysed the data. Zhuzhou Zhuang and Kaiyuan Li drafted the manuscript, which was revised by Qiuhao Huang, Yanming Chen, and Dong Chen. All authors have read and approved the final manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Liu, J.; Zhan, J.; Deng, X. Spatio-temporal patterns and driving forces of urban land expansion in China during the economic reform era. *Ambio* **2005**, *34*, 450–455. [CrossRef] [PubMed]
2. Huang, Z.; Duan, W.; He, C.; Li, H. Urban land expansion under economic transition in China: A multi-level modeling analysis. *Habitat Int.* **2015**, *47*, 69–82. [CrossRef]
3. Smil, V. China's environment in the 1980s: Some critical changes. *Ambio* **1992**, *21*, 431–436.
4. Wei, Y.; Zhang, Z. Assessing the fragmentation of construction land in urban areas: An index method and case study in Shunde, China. *Land Use Policy* **2012**, *29*, 417–428. [CrossRef]
5. Wei, Y.; Liu, H.; Song, W.; Yu, B.; Xiu, C. Normalization of time series DMSP-OLS nighttime light images for urban growth analysis with Pseudo Invariant Features. *Landsc. Urban Plan.* **2014**, *128*, 1–13. [CrossRef]
6. Ding, C.; Knapp, G.; Hopkins, L. Managing urban growth with urban growth boundaries: A theoretical analysis. *J. Urban Econ.* **1999**, *46*, 53–68. [CrossRef]
7. Long, Y.; Han, H.; Lai, S.; Mao, Q. Urban growth boundaries of the Beijing Metropolitan Area: Comparison of simulation and artwork. *Cities* **2013**, *31*, 337–348. [CrossRef]
8. Yang, C.; Zhuo, C. Extracting residential areas on the TM imagery. *J. Remote Sens.* **2000**, *4*, 146–149.
9. Xu, H. Spatial expansion of urban/town in fuqing and its driving force analysis. *Remote Sens. Techol. Appl.* **2002**, *17*, 86–92. (In Chinese)
10. Masek, J.; Lindsay, F.; Goward, S. Dynamics of urban growth in Washington DC metropolitan area, 1973–1996, from Landsat observations. *Int. J. Remote Sens.* **2000**, *20*, 220–223. [CrossRef]
11. Zha, Y.; Gao, J.; Ni, S. Use of normalized difference buit-up index n automatically mapping urban areas from TM imagery. *Int. J. Remote Sens.* **2003**, *24*, 583–594. [CrossRef]
12. Che, F.; Lin, H. Remote sensing information extraction of urban built-up land. *Sci. Surv. Mapp.* **2010**, *35*, 97–99. (In Chinese)
13. Zhang, Q.; Wang, J.; Peng, X. Urban built-up land change detectionwith road density and spectral information from multi temporal Landsat TM data. *Int. J. Remote Sens.* **2002**, *23*, 3057–3078. [CrossRef]
14. Xu, H. Modification of normalized difference water index (NDWI) to enhance open water features in remotely sensed imagery. *Int. J. Remote Sens.* **2006**, *27*, 3025–3033. [CrossRef]
15. Xu, H. A new index for delineating built-up land features in satellite imagery. *Int. J. Remote Sens.* **2008**, *29*, 4269–4276. [CrossRef]
16. Peterson, R.E.; Seo, K.K. Macroeconomics of unbalanced productivity growth and urban crisis: A simulation. *Simul. Trans. Soc. Model. Simul. Int.* **1974**, *22*, 97–100.
17. Zhang, X.; Cui, W. Integrating GIS with cellular automation model to establish a new approach for spatio-temporal process simulation and prediction. *Acta Geod. Cartogr. Sin.* **2001**, *30*, 148–152. (In Chinese)
18. Kuang, W. Simulating dynamic urban expansion at regional scale in Beijing-Tianjin-Tangshan Metropolitan Area. *J. Geogr. Sci.* **2011**, *21*, 317–330. (In Chinese) [CrossRef]
19. Sakieh, Y.; Amiri, B.; Danekar, A.; Feghhi, J.; Dezhkam, S. Simulating urban expansion and scenario prediction using a cellular automata urban growth model, SLEUTH, through a case study of Karaj City, Iran. *J. Hous. Built Environ.* **2015**, *30*, 591–611. [CrossRef]
20. Rienow, A.; Goetzke, R. Supporting SLEUTH—Enhancing a cellular automaton with support vector machines for urban growth modeling. *Comput. Environ. Urban Syst.* **2015**, *49*, 66–81. [CrossRef]
21. Yang, X.; Zheng, X.; Chen, R. A land use change model: Integrating landscape pattern indexes and Markov-CA. *Ecol. Model.* **2014**, *283*, 1–7. [CrossRef]
22. Sun, X.; Liu, H. Identification of factors affecting expansion of Spartina alterniflora and their intensities using Markov-CA model. *J. Ecol. Rural Environ.* **2014**, *30*, 38–43.

23. Clarke, K.; Gaydos, L. Loose-coupling a Cellular Automaton Model and GIS: Long-term urban growth prediction for San Francisco and Washington/Baltimore. *J. Int. Geogr. Inf. Sci.* **1998**, *12*, 699–714. [CrossRef] [PubMed]
24. Jiang, P.; Cheng, Q.; Gong, Y.; Wang, L.; Zhang, Y.; Cheng, L.; Li, M.; Lu, J.; Duan, Y.; Huang, Q.; et al. Using urban development boundaries to constrain uncontrolled urban sprawl in China. *Ann. Am. Assoc. Geogr.* **2016**, *106*, 1321–1343. [CrossRef]
25. Badwi, I.; El-Barmelgy, M.; Ouf, E. Modeling and simulation of greater Cairo region urban dynamics using SLEUTH. *J. Urban Plan. Dev.* **2014**, *141*, 04014032. [CrossRef]
26. Xi, J.; Li, K.; Zhang, D.; Yu, Z.; Liu, Y.; Wang, Q.; Zhang, G. The main tasks of Chinese urbanization. In Proceedings of the Central Urbanization Work Conference, Beijing, China, 12–13 December 2013.
27. Benfield, F.; Raimi, M.; Chen, D. Once there were greenfields. How urban sprawl is undermining America's environment, economy and social fabric. In *Surface Transportation Policy Project*; Natural Resources Defense Council: New York, NY, USA; Washington, DC, USA, 1999.
28. Daniels, T. *When City and Country Collide: Managing Growth in the Metropolitan Fringe*; Island Press: Washington, DC, USA, 1999.
29. Pendall, R.; Martin, J.; Fulton, W. *Holding the Line: Urban Containment in the United States*; The Brookings Institution Center on Urban and Metropolitan Policy: Washington, DC, USA, 2002.
30. Bengston, D.; Fletcher, J.; Nelson, K. Public policies for managing urban growth and protecting open space: Policy instruments and lessons learned in the United States. *Landsc. Urban Plan.* **2004**, *69*, 271–286. [CrossRef]
31. Jun, M. The effects of Portland's urban growth boundary on urban development patterns and commuting. *Urban Stud.* **2004**, *41*, 1333–1348. [CrossRef]
32. Tayyebi, B.; Pijanowski, A. An urban growth boundary model using neural networks, GIS and radial parameterization: An application to Tehran, Iran. *Landsc. Urban Plan.* **2011**, *100*, 35–44. [CrossRef]
33. Jokar, A.; Helbich, M.; Vaz, E. Spatiotemporal simulation of urban growth patterns using agent-based modeling: The case of Tehran. *Cities* **2013**, *32*, 33–42. [CrossRef]
34. Hu, S.; Tong, L.; Frazier, A.; Liu, Y. Urban boundary extraction and sprawl analysis using Landsat images: A case study in Wuhan, China. *Habitat Int.* **2015**, *47*, 183–195. [CrossRef]
35. Tannier, C.; Vuidel, G.; Frankhauser, P. A fractal approach to identifying urban boundaries. *Geogr. Anal.* **2011**, *43*, 211–227. [CrossRef]
36. Arsanjani, J.; Helbich, M.; Mousivand, A. A morphological approach to predicting urban expansion. *Trans. GIS* **2014**, *18*, 219–233. [CrossRef]
37. Mubarak, F. Urban growth boundary policy and residential suburbanization: Riyadh, Saudi Arabia. *Habitat Int.* **2004**, *28*, 567–591. [CrossRef]
38. Anas, A.; Rhee, H. When are urban growth boundaries not second-best policies to congestion tolls. *J. Urban Econ.* **2007**, *61*, 263–286. [CrossRef]
39. Brueckner, J. Urban growth boundaries: An effective second-best remedy for unpriced traffic congestion. *J. Hous. Econ.* **2007**, *16*, 263–273. [CrossRef]
40. Cho, S.; Poudyal, N.; Lambert, D. Estimating spatially varying effects of urban growth boundaries on land development and land value. *Land Use Policy* **2008**, *25*, 320–329. [CrossRef]
41. Gennaio, M.-P.; Hersperger, A.M.; Bürgi, M. Containing urban sprawl—Evaluating effectiveness of urban growth boundaries set by the Swiss Land Use Plan. *Land Use Policy* **2009**, *26*, 224–232. [CrossRef]
42. MLR (Ministry of Land and Resources of the People's Republic of China). Nanjing City Started the Work of Urban Development Boundary. 2014. Available online: http://www.mlr.gov.cn/xwdt/dfdt/201411/t20141102_1334182.htm (accessed on 2 November 2014).
43. MLR (Ministry of Land and Resources of the People's Republic of China). The CPC Central Committee and the State Council's Views on Promotion of Ecological Civilization. 2015. Available online: http://www.mlr.gov.cn/xwdt/jrxw/201505/t20150506_1349780.htm (accessed on 6 May 2015).
44. Changzhou Municipal Statistics Bureau; Changzhou Investigation Team of the National Bureau of Statistics. *Changzhou Statistical Yearbook 2014*; China Statistics Press: Beijing, China, 2014.
45. The Government of Xinbei District. The Land Use Master Plan of Xinbei District of Changzhou City. 2012. Available online: http://xbgt.changzhou.gov.cn/html/xbgt/2012/OMJBKFOC_0713/4434.htm (accessed on 13 July 2012).

46. Zhong, T.; Mitchell, B.; Huang, X. Success or failure: Evaluating the implementation of china's national general land use plan (1997–2010). *Habitat Int.* **2014**, *44*, 93–101. [CrossRef]
47. Xu, G.; Huang, X.; Zhong, T.; Chen, Y.; Wu, C.; Jin, Y. Assessment on the effect of city arable land protection under the implementation of China's National General Land Use Plan (2006–2020). *Habitat Int.* **2015**, *49*, 466–473. [CrossRef]
48. Dietzel, C.; Clarke, K. The effect of disaggregating land use categories in cellular automata during model calibration and forecasting. *Comput. Environ. Urban Syst.* **2006**, *30*, 78–101. [CrossRef]
49. Guan, W. Study on the intensive use of construction land in Xinbei district of Changzhou based on Urban-Rural harmonious development. Master's Thesis, Nanjing Agricultural University, Nanjing, China, 2010. (In Chinese)
50. Song, Y.; Fu, C. The eco-environmental effects of urbanization. *Soc. Sci. Front* **2005**, *3*, 186–188. (In Chinese)
51. Xiao, C.; Ou, M.; Li, X. Research on spatial optimum allocation of construction land in an eco-economic comparative advantage perspective: A case study of Yangzhou City. *Acta Ecol. Sin.* **2015**, *35*, 696–708. (In Chinese)
52. Li, J.; He, C.; Li, X. Landscape ecological risk assessment of natural/semi-natural landscapes in fast urbanization regions: A case study in Beijing, China. *J. Nat. Resour.* **2008**, *23*, 33–47. (In Chinese)
53. Zhou, Y. Thoughts on the speed of China's urbanization. *City Plan. Rev.* **2006**, *30*, 32–35. (In Chinese)
54. Chen, B. Situation and counter meacures for protection of arable land and basic farmland. *J. China Agric. Resour. Reg. Plan.* **2004**, *25*, 1–4. (In Chinese)
55. Gong, Y.; Li, F.; Hong, W.; Wang, L.; Huang, Q.; Li, M.; Jiang, P. Dynamic change analysis of construction land under the restriction of regional space control—Taking Changzhou city for example. *Resour. Environ. Yangtze Basin* **2015**, *24*, 1813–1818. (In Chinese)
56. GOV (The Central People's Government of the People's Republic of China). Order of the Ministry of Construction of the People's Republic of China. 2006. Available online: http://www.gov.cn/ziliao/flfg/2006-02/15/content_191969.htm (accessed on 15 February 2016).
57. Feng, K.; Wu, C.; Wei, S.; Liu, Y. Urban Expansion Management: Review on the Theory of UGB and Its Reference for China. *China Land Sci.* **2008**, *22*, 77–80. (In Chinese)
58. Zhang, Z.; Zhang, S. The ideas and methods of spatial structure-oriented urban growth boundary delimitation—A case study of Hangzhou city. *Urban Plan. Forum* **2013**, *32*, 33–41. (In Chinese)
59. Zheng, X.; Lv, L. A WOE method for urban growth boundary delineation and its applications to land use planning. *Int. J. Geogr. Inf. Sci.* **2015**, *388*, 691–707. [CrossRef]
60. Cheng, Q.; Jiang, P.; Cai, L.; Shan, J.; Zhang, Y.; Wang, L.; Li, M.; Li, F.; Chen, D. Delineation of a permanent basic farmland protection area around a city centre: Case study of Changzhou City. *China Land Use Policy* **2016**, *60*, 73–89.