Sustainability **2014**, *6*, 4042-4058; doi:10.3390/su6074042

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Spatiotemporal Patterns of Urbanization in a Developed Region of Eastern Coastal China

Jiadan Li [1], Jinsong Deng [1,2,*], Ke Wang [1,*], Jun Li [1], Tao Huang [1], Yi Lin [1] and Haiyan Yu [3]

[1] Institution of Remote Sensing and Information System Application, Zhejiang University, Hangzhou 310058, China; E-Mails: vaneljd@zju.edu.cn (Ji.L.); lijun_more@126.com (Ju.L.); ianczh@zju.edu.cn (T.H.); linyi11@zju.edu.cn (Y.L.)

[2] School of Civil Engineering and Environmental Sciences and School of Meteorology, University of Oklahoma, Norman, OK 73019, USA

[3] Zhejiang Environmental Monitoring Center, Zhejiang University, Hangzhou 310015, China; E-Mail: yuhaiyan69@163.com

* Authors to whom correspondence should be addressed; E-Mails: jsong_deng@zju.edu.cn (J.D.); kwang@zju.edu.cn (K.W.); Tel.: +86-571-8898-2272 (K.W.); Fax: +86-571-8898-2297 (K.W.).

Received: 3 March 2014; in revised form: 9 June 2014 / Accepted: 16 June 2014 / Published: 26 June 2014

Abstract: This study presents a practical methodology to monitor the spatiotemporal characteristics of urban expansion in response to rapid urbanization at the provincial scale by integrating remote sensing, urban built-up area boundaries, spatial metrics and spatial regression. Sixty-seven cities were investigated to examine the differences of urbanization intensity, urbanization patterns and urban land use efficiency in conjunction with the identification of socio-economic indicators and planning strategies. Planning proposals to allocate the urbanization intensity among different-sized cities by considering sustainable urban development were also explored. The results showed that the urban area of Zhejiang Province expanded from 31,380 ha in 1980 to 415,184 ha in 2010, indicating that the area of the urban region expanded to more than 13-times the initial urban area. The urban built-up area boundaries became more complex and irregular in shape as the urban area expanded throughout the entire study period. Rapid urban population growth and economic development were identified as significant in stimulating the urban expansion process. However, different-sized cities exhibited marked differences in urban development. Small cities experienced the rapidest urbanization before 2000. Large cities, which are estimated to have the highest urban land use efficiency, had the most dramatic sprawl in urban area at the beginning of the 21st century. Promoting the development of large cities to mega-cities

is recommended in Zhejiang Province to ensure sustainable urban development with consideration of land resource preservation.

Keywords: urbanization; urban built-up area boundaries; spatial pattern; land use efficiency; different-sized cities

1. Introduction

Urbanization processes have profoundly influenced urban ecological systems, which are characterized by complex interactions among social, economic, institutional and environmental issues. These interactions further generate complex human-dominated landscapes, which significantly affect the functioning of local and global Earth ecosystems and the services they provide to humans and other life [1–4]. Since the urban population surpassed the rural population in 2009, the world has become more urban than rural [5]. Developing countries, particularly China, have become the main driving force of global urbanization. As a developing country on the fast track, China has been experiencing unprecedented economic growth since the implementation of the reform and opening-up policy in 1978 [6]. Statistics from the Ministry of Construction of China reveal that the urbanization ratio of China, which is the ratio of the urban population to the entire population, increased from 17.9% in 1978 to 49.7% in 2010. China's urbanization ratio is expected to reach 60.3% by 2020 and to exceed 80% by 2030 [7].

This dramatic urbanization is significantly amplified in the economically developed eastern coastal regions of China. The most direct result of rapid urbanization is the drastic transformation of land use/cover. Although these regions have attracted researchers worldwide to estimate the spatiotemporal patterns of urbanization, urban environmental change and the driving forces of these changes [8–11], relatively less attention has been paid to the various expansion characteristics of urban regions among different-sized cities at the provincial scale.

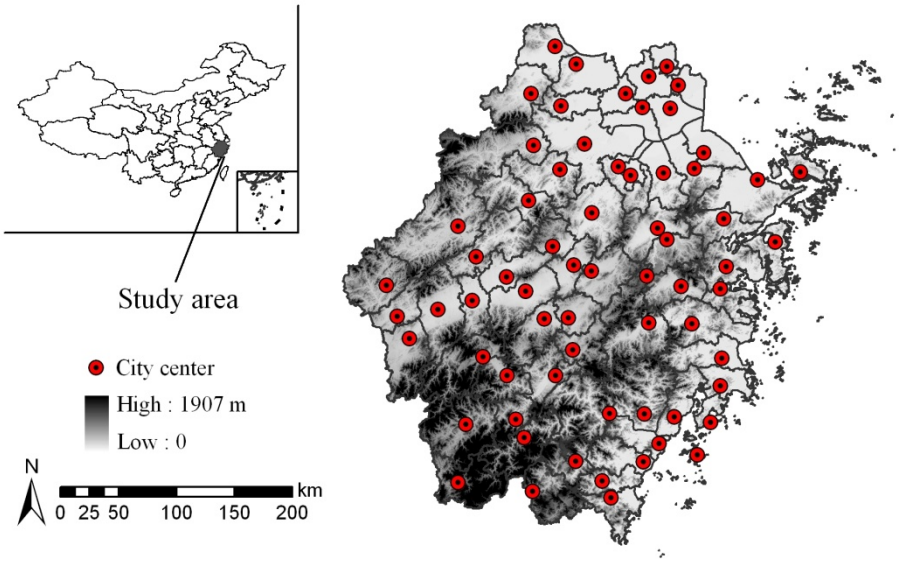
This study observes and evaluates the long-term dynamics of urban growth at the provincial scale in one of the most rapidly urbanizing regions in China, Zhejiang Province, spanning a period of rapid economic growth in the post-reform period from 1980 to 2010. Urban built-up area boundaries (UBAs) are defined as contiguously developed areas of densely inhabited districts and are characterized by vast anthropogenic features, including residential, commercial, industrial, transportation, communications and public urban facilities, which can be identified from remote sensing imagery instead of census block. UBAs are created and further developed by the process of urbanization, which can be derived from historical remote sensing images. UBAs were introduced to explore the spatiotemporal dynamics of urbanization intensity and patterns coupled with the estimation of socio-economic indicators and planning strategies. The cities and counties of Zhejiang Province were divided into three tiers in terms of administrative divisions (large cities, medium cities and small cities) to thoroughly and meticulously estimate the characteristics of urbanization for different-sized cities. The historical land use efficiency was further estimated for inquiring into future urban planning adjustments based on land resource conservation and sustainable urban development.

2. Study Area and Database

2.1. Study Area

Zhejiang Province is situated on the eastern seaboard of China and the south wing of the Yangtze River Delta (Figure 1). The area consists of dense alluvial plains in the north, a coastal zone in the east and hills in the southwest. The hilly region represents the dominant topographic type and includes approximately 70% of the total area of the province. Hangzhou is the capital of Zhejiang Province, and Ningbo is directly under the jurisdiction of the national central government. Zhejiang Province covers approximately 101,800 km^2 and had a population of 47.5 million at the end of 2010. The climate is humid subtropical. The average annual temperature is 15 to 19 °C, and the annual rainfall is 1460 mm.

Figure 1. Location and administrative divisions of Zhejiang Province.



The area has experienced unprecedented economic development and dramatic economic growth since the initiation of the reform and opening-up policy. The GDP per capita increased substantially from 313.3 U.S. dollars in 1980 to 8465.1 U.S. dollars in 2010, which is 0.91-times the national average. Additionally, the population density was 523 persons per km^2 at the end of 2010, which is five-times the national average. Thus, Zhejiang Province is one of the most densely populated regions of China. Consequently, the rampant urbanization process has resulted in large-scale soil sealing, which has attracted attention worldwide.

2.2. Data Resources

The main dataset used in this study are described as follows: (1) a series of Landsat images (Landsat MSS with a spatial resolution of 80 m; Landsat TM and ETM with a spatial resolution of 30 m) acquired around 1980, 1990, 2000 and 2010, which were downloaded from the USGS Global Visualization Viewer and processed [12]; (2) digital land use maps around 1980, 1990, 2000 and 2010, which were provided by the Chinese Ministry of Environmental Protection and were retrieved from remote sensing interpretation and field surveys with a validated overall accuracy surpassing 90%; and

(3) demographic and other socio-economic data, which were obtained from Zhejiang Statistical Yearbooks from 1981 to 2013.

3. Methodology

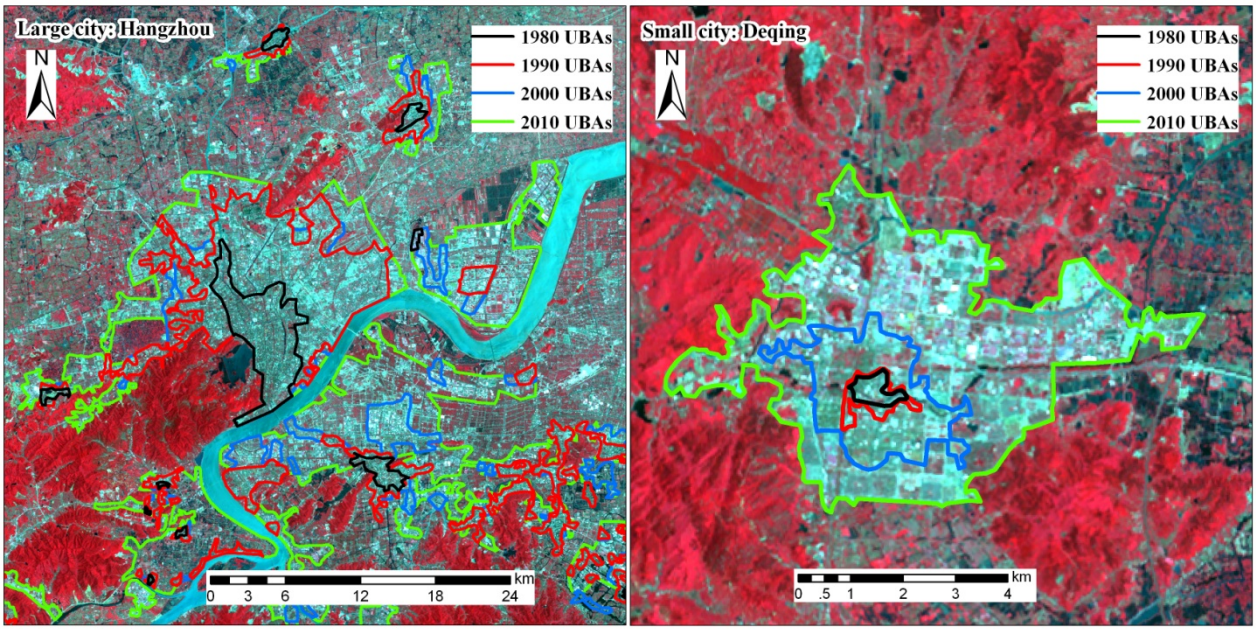
3.1. Urban Tier Classification

Based on the administrative hierarchy of Zhejiang Province, cities and counties were divided into three tiers: large, medium or small cities. Two sub-provincial-level metropolises (Hangzhou and Ningbo) were identified as large cities, whose urban populations were 3.26 and 1.41 million, respectively, at the end of 2012. The medium city tier includes nine prefecture-level cities ("Dijishi" in China) and had an average urban population of 0.38 million at the end of 2012. The small city tier composes 56 other county-level cities and counties ("Xianjishi" in China), which are often referred to as counties for simplicity. Their average urban population was 0.13 million at the end of 2012.

3.2. Urban Built-Up Area Boundary Delineation

In this study, the definition of an urban area is based on China's Standards for Basic Terminology of Urban Planning [13] and the procedures described by Wang *et al.* [14]. The scope of an urban area is determined by the contiguous built-up area where the city/county government is located. The UBAs for each of the estimated years were depicted through artificial interpretation of historical remote sensing images. Mountains, extremely large rivers, lakes and large-scale ecological conservation regions were excluded from the urban areas. Finally, the UBAs of 67 cities/counties in Zhejiang Province around 1980, 1990, 2000 and 2010 were delineated. A sample region of the depicted UBAs is exhibited in Figure 2.

Figure 2. Sample of the depicted urban built-up area boundaries (UBAs) with the 2010 TM image as the background.



3.3. Spatiotemporal Urban Expansion Index

3.3.1. Average Annual Expansion Rate (R)

The average annual expansion rate we used to estimate the urban expansion intensity [15] is expressed as follows:

$$R_{\mathrm{i}} = \sqrt[n-1]{\frac{R_2}{R_1}} - 1 \quad (1)$$

where R_{i} is the average annual expansion rate of the urban area in city i; R_1 and R_2 represent the urban area at the start year and end year, respectively; and n is the number of years between the two dates.

3.3.2. Built-Up Density Index (BDI)

A certain proportion of non-developed areas, such as urban parks and green belts, existed within the boundaries of urban built-up areas. The built-up density index is presented to describe the construction intensity by the ratio of built-up land cover area to urban built-up area. The "built-up land cover" was derived from digital land use maps, which comprised residential sites, industrial and commercial facilities, transportation infrastructure and other associated artificial impervious surfaces. The built-up density index (BDI) within each UBA was calculated with Equation (2).

$$BDI_i = \frac{A_{built-up\ land\ \ cover}}{A_{UBAs}} \quad (2)$$

where BDI_i is the built-up density within the UBAs of city i; $A_{\text{built-up land cover}}$ represents the built-up area within the UBAs; and A_{UBAs} is the total area of the UBAs of city i.

3.3.3. Spatial Pattern Metrics

The boundary of an urban built-up area expands to a particular shape during the urbanization process. As the urbanization pattern transforms from a single-core to a multi-nuclei pattern during various development periods, an urban region can expand to develop a certain number of satellite towns near the city proper. Landscape metrics are effective at quantifying the spatiotemporal pattern of land use [16]. For this study, we applied two landscape metrics to describe the spatial patterns of urban development: the number of urban patches (NUP) and the urban shape index (USI). The USI describes the complexity and irregularity of the UBA shape relative to the geometry of a circle (the value is 1 or higher). A USI = 1 means that the UBA is circular, whereas higher values convey a more complex urban shape. The USI is expressed as follows:

$$USI_i = \frac{1}{N}\sum_{i=1}^{j}\left(\frac{P_{ij}}{2\sqrt{\pi A_{ij}}}\right) \quad (3)$$

where USI_i is the urban shape index of city i; P_{ij} and A_{ij} represent the perimeter and area, respectively, of the urban patch j of city i; and N is the number of urban patches in city i.

3.4. Elasticity of Urban Land Expansion to Urban Population Growth

The elasticity of urban land expansion to urban population growth [17], which is denoted as E(UBAs) in this study, was first proposed by the Chinese Academy of Urban Planning and Design (CAUPD). The concept was developed to assess the relationship between urban land expansion and urban population growth. The calculation is performed as follows:

$$E(UBAs) = \frac{R_{(UBAs)}}{R_{(pop)}} \quad (4)$$

where E(UBAs) is the elasticity of urban land expansion to urban population growth; $R_{(UBAs)}$ is the annual rate of increase of the UBAs of a city; and $R_{(pop)}$ represents the annual rate of the urban population growth of a city.

The administrative divisions were not yet well-established in 1980; thus, we only used post-1990 demographic data for the analysis. We employed the non-agricultural population to represent the urban population, because it more accurately represented the urban residents [14,18].

4. Results

4.1. General Characteristics of UBAs Expansion

At the provincial scale, the entire urban area expanded from 31,380 ha to 415,184 ha at an average annual expansion rate (denoted as R for simplicity) of 9.3% over the past three decades. The most intense urban expansions were observed during 1980–1990 (with an R of 17.3%), followed by 2000–2010 (8.5%) and 1990–2000 (4.6%). The BDI of the urban built-up areas in Zhejiang Province revealed an upward tendency that fluctuated over time (Table 1). For instance, the index was high in 1980 and 2000, but it was relatively low in 1990 and 2010.

Table 1. Variation of area and built-up density index (BDI) within the UBAs among different-sized cities.

	City tier	1980	1990	2000	2010
Area of UBAs/ha	Zhejiang Province	31,380.2	132,286.3	199,079.5	415,184.3
Average area of UBAs/ha	Large city	4265.5	18,832.6	24,781.3	54,676.1
	Medium city	986.3	3375.8	5047.0	10,437.1
	Small city	249.5	1147.1	1858.8	3783.9
Average BDI within UBAs	Zhejiang Province	81.8	70.3	83.7	76.6
	Large city	85.7	73.8	86.2	78.2
	Medium city	82.4	74.1	86.6	78.7
	Small city	78.3	65.6	80.0	73.9

Among the different-sized cities, the average area of UBAs in large cities expanded from 4265 ha to 54,676 ha during the entire study period. This result is nearly five times the UBAs expansion of medium cities and 15 times that of small cities. The most intense expansion of UBAs over the total period occurred in small cities (with an R of 9.8%), followed by large cities (9.2%) and medium cities (8.5%). In terms of multiple time periods, the highest average annual expansion rate was observed in small cities during 1980–1990 (18.5%). Nevertheless, small cities exhibited the lowest BDI for each of the estimated years. At the beginning of the study period, large cities had the highest BDI. However, medium cities were observed to have the highest built-up density after 1990.

4.2. Dynamics of Spatial Pattern among Different Tier Cities

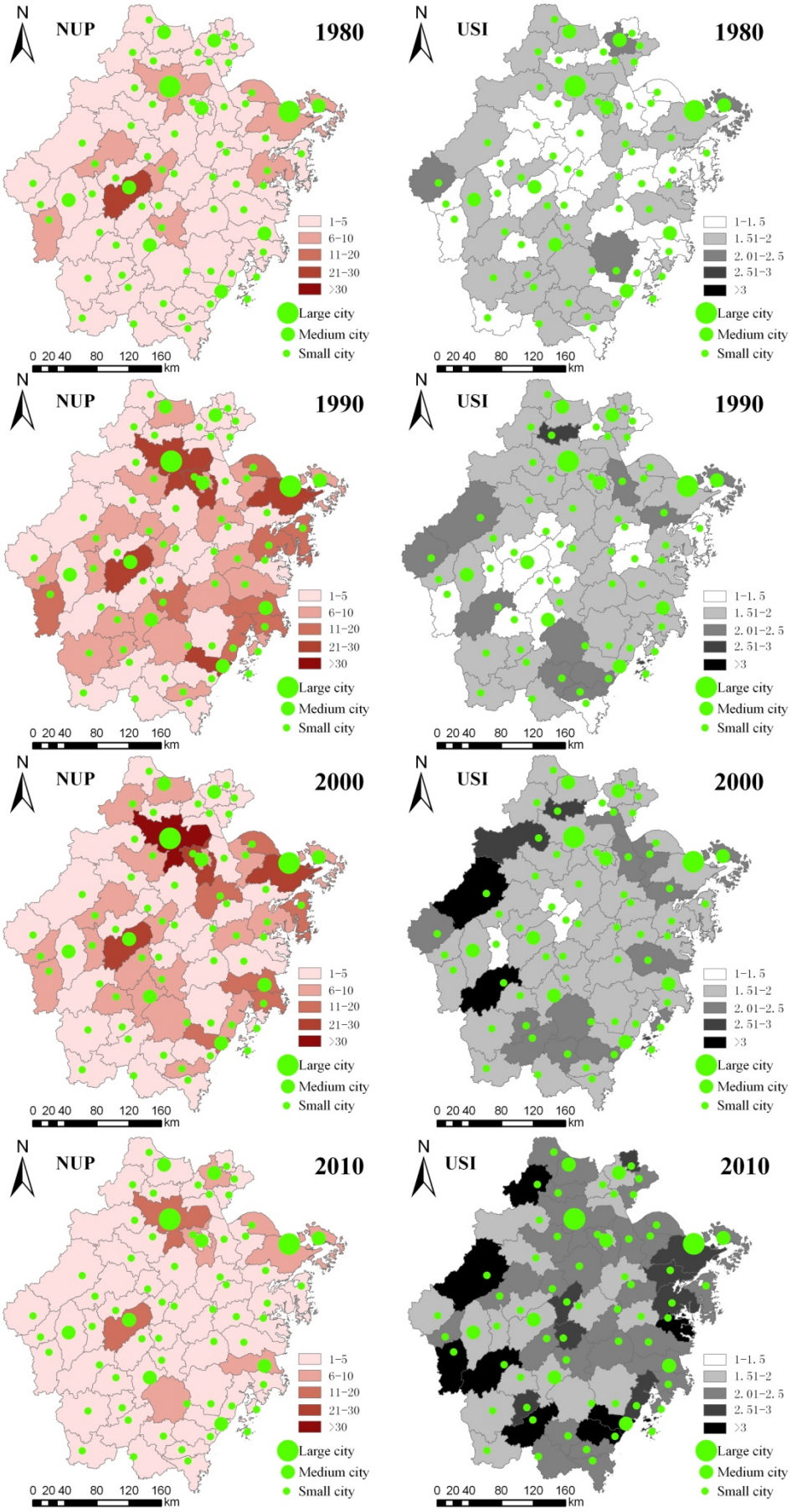
The peak number of total UBAs over the entire province was observed in 1990 (514 patches). It also indicates that larger cities had more UBAs (Table 2). Additionally, the distribution of NUP showed spatial autocorrelation. A city with many urban patches was often adjacent to large or medium cities (Figure 3). Note that large cities had an average of 29 urban patches in 2000, the highest value for all of the years for which estimates were calculated. The most rapid increment of NUP was observed during 1980–1990. Many towns in the suburban regions visibly expanded to a considerable extent due to the accelerated development of private enterprises and rapid population growth. During 2000–2010, the number of urban patches decreased significantly. Neighboring urban patches combined to shape the new city region with the continuous expansion of urban patches.

Table 2. Average results of number of urban patches (NUP) and urban shape index (USI) of different tier cities.

	City tier	1980	1990	2000	2010
Average NUP	Zhejiang Province	3.3	7.7	6.8	3.3
	Large city	9.5	27	29	10.5
	Medium city	5.2	12.2	10.2	5.8
	Small city	2.8	6.3	5.5	2.7
Average USI	Zhejiang Province	1.57	1.75	1.92	2.31
	Large city	1.55	1.73	1.84	2.46
	Medium city	1.67	1.70	1.73	2.10
	Small city	1.55	1.76	1.95	2.34

The upward tendency of the USI indicates that the shape of the UBAs became more irregular and complex as time progressed (Figure 3). Consequently, in 2010, all of the cities in Zhejiang Province had an estimated USI higher than 1.5. Moreover, eight of the nine cities with a USI greater than three were small sized. Most of these cities were concentrated in western Zhejiang Province, where the topography is hilly. Table 2 indicates that large cities had the most complex urban shapes in 2010, followed by small cities and medium cities. However, medium cities had the highest USI in the initial study year.

Figure 3. Spatial pattern metrics for each city type during the various study periods.



4.3. Urbanization Spurred by Rapid Socio-Economic Growth

In this study, significant qualitative relationships were also identified between the expanded area of the UBAs, the urban population and the GDP among 67 cities in Zhejiang Province during the past two decades (Table 3). Rapid urban immigration and economic growth played noticeable roles in stimulating the expansion of the UBAs.

Table 3. Relationships between the expanded area of UBAs and socio-economic indicators explored by spatial regression (N = 67).

Variables (Y)	Predictors (X)	Regression	R^2
Area of UBAs between 1990 and 2000 (ha)	Urban population growth (persons)	$Y = 45.56 \times X + 475.2$	0.804 **
Area of UBAs between 1990 and 2000 (ha)	GDP growth (million RMB Yuan)	$Y = 10.1 \times X + 194.4$	0.818 **
Area of UBAs between 2000 and 2010 (ha)	Urban population growth (persons)	$Y = 27.21 \times X - 13{,}957$	0.814 **
Area of UBAs between 2000 and 2010 (ha)	GDP growth (million RMB Yuan)	$Y = 9.63 \times X - 959.7$	0.917 **

Note: ** Significant at the 99% confidence level.

To comprehensively explore the variations in the GDP output relative to the area of UBAs among the different-sized cities, the data presented in Table 4 were generated. Note that medium cities had the lowest GDP output per unit UBAs area for each of the estimated years. Small cities had the highest GDP output per unit UBAs area in 1990 and 2000. However, in the last study year, large cities exceeded small cities in exhibiting the highest GDP output per unit UBAs area.

Table 4. Variation of GDP relative to the urban built-up area among different-sized cities.

	1990 (Yuan/m^2)	2000 (Yuan/m^2)	2010 (Yuan/m^2)
Zhejiang Province	63.2	334.3	646.0
Large city	55.7	329.6	713.6
Medium city	54.8	281.5	537.8
Small city	71.6	359.5	659.1

4.4. Potential Impacts on Sustainable Urban Development

The urban built-up area per capita in Zhejiang Province increased by 5.4% during 1990–2000 and by 41.8% during 2000–2010, despite the rapid urban population growth (Table 5, Figure 4). Small cities had the largest urban built-up area per capita, which reached 297.2 m^2 in 2010. However, the most rapid growth in urban built-up area per capita was observed in medium cities during 2000–2010 (54.2%).

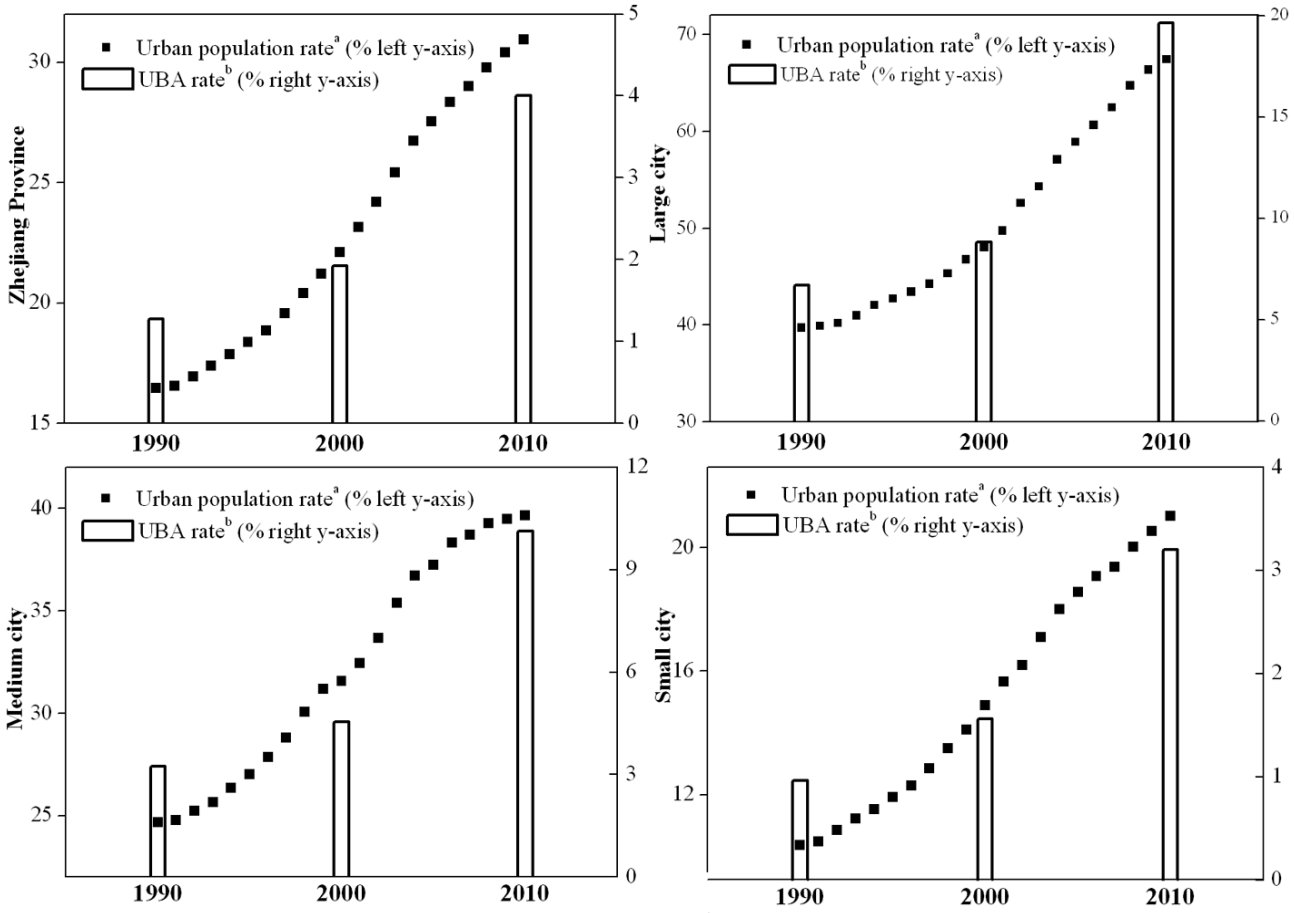
Furthermore, the E(UBAs) index of Zhejiang Province dramatically increased from 1.15 (1990–2000) to 1.94 (2000–2010), which greatly exceeded the value of 1.12 suggested by the CAUPD. Considering different city levels, the highest E(UBAs) value during 1990–2000 was observed in small cities. However, during 2000–2010, medium cities exhibited the highest E(UBAs) at 2.53, indicating

that the expansion speed of the UBAs was surprisingly more rapid than the urban population growth in these medium cities. In contrast, the unique negative values of the E(UBAs) of the estimated periods occurred in large cities during 1990–2000. Thus, the growth of migration exceeded urban expansion, and large cities became denser.

Table 5. Statistics of the urban built-up area per capita and E(UBAs).

	Urban built-up area per capita (m^2/person) 1990	**Urban built-up area per capita (m^2/person) 2000**	**Urban built-up area per capita (m^2/person) 2010**	**E(UBAs) (1990–2000)**	**E(UBAs) (2000–2010)**
Zhejiang Province	186.4	196.4	278.4	1.15	1.94
Large city	184.4	181.6	246.3	0.95	1.65
Medium city	172.4	182.3	281.1	1.16	2.53
Small city	195.1	211.8	297.2	1.21	1.95

Figure 4. Trends of the urban population rate [a] and UBA rate [b] during 1990–2010.



Notes: [a] rate of urban population to total population; [b] rate of UBAs area to administrative area.

The urbanization curve, which was first proposed by Northam (1979), is S-shaped with three identifiable stages: initial, acceleration and terminal. The results indicate that Zhejiang Province was in a transition between the last two stages until 2010 (Figure 4). Moreover, the results vary among the different-sized cities. For instance, the medium cities in Zhejiang Province had already entered the

terminal stage, whereas the small cities were still in the acceleration stage. Thus, future urbanization will primarily be concentrated in large and small cities.

5. Discussion

5.1. Government-Driven Urban Expansion and Land Use Policy

Rapid economic growth since 1978 indicates the great success of the new Chinese spatial policies. Zhejiang Province, one of the provinces comprising the Yangtze River Delta, has witnessed a dramatic urbanization process. The urban built-up area expanded to 13-times the initial area during the past three decades. In addition to urbanization theory, which hypothesizes that urban areas expand in terms of alternating processes of diffusion and coalescence [19], the phase of urban growth can be detected by investigating the UBAs expansion and BDI. For Zhejiang Province, the absolute dominance of the diffusion process was observed during 1980–1990 and 2000–2010. However, the urbanization pattern was characterized by the phase of coalescence during 1990–2000.

Unlike developed countries, the Chinese government plays a dominate role in urban development and economic growth by implementing a series of incentive policies and planning. After the reform of fiscal decentralization in 1994, the central government has substantially increased the financial contribution required from local governments, placing financial pressure on the local governments. Thus, the local governments are motivated to take advantage of their monopolistic positions in the local urban land supply and to extract as much extra-budgetary revenue as possible [20,21]. The substantial implementation of land acquisition and land leasing attracts investments and accelerates industrialization and commercialization for the purpose of obtaining high economic growth and employment. Meanwhile, with this tax revenue, local governments can improve the construction of urban infrastructures and real estate to attract migrants and, thus, effectively promotes the process of urban expansion.

5.2. Urbanization Strategies across Different Tier Cities

Zhejiang Province, under the limiting conditions of few natural resources, weak technology and backward infrastructure, became more pro-business by accelerating the reform of state-owned enterprises and promoting scale economics. Many radical market reforms were implemented to encourage private enterprises and, thus, the stimulate the development of medium- and small-sized cities [22]. Under the implementation of its distinctive development model, Zhejiang, which claims 3.5% of China's population, produced 6.7% of China's GDP in 2012. Meanwhile, medium and small cities in Zhejiang Province contributed 4.6% of China's GDP. More surprisingly, in 2012, 27 counties of Zhejiang Province were ranked among the top 100 economically developed counties of China. Zhejiang was at the forefront of the economic transformation and drastically benefited, thus becoming one of the richest provinces in China.

The urban expansion intensity in the small cities in Zhejiang Province was the highest at the early stage of the reform. This result is consistent with the findings in other provinces, such as Hebei and Heilongjiang [17,23,24] and can be attributed to China's urbanization policy of the 1980s and 1990s of "controlling large cities, moderating development of medium cities and encouraging growth of small

cities" [25], along with the release of the household registration policy in small cities beginning in 1984. Small cities witnessed the most dramatic immigration flow from rural areas, which were stimulated by the rapid development of privately owned enterprises during these two decades.

As the government recognized the major contributions of large cities to economic development and to sustaining China's long-term growth, the development of large cities has been strongly encouraged, especially since 2005 [25]. Meanwhile, because of the population's increasing desires to access better education and healthcare, as well as other basic public services, such as communication, utilities and sanitation, rapid urban sprawl and population growth were significantly stimulated in large cities at the beginning of the 21st century. However, it is apparent that the sizes of these two large cities in Zhejiang Province are much smaller than global mega-cities, such as New York, Tokyo, Mexico City and even other large cities in China [26].

5.3. Response of the Spatial Pattern to Urbanization

The NUP displayed a parabolic shape, as shown by the transition from a single-core urbanization pattern to a multi-nuclei pattern in the cities in Zhejiang Province. City seeds began to generate during 1980–1990, expanded during 1990–2000 and combined during 2000–2010. Large cities are estimated to have more urban patches, which comprise satellite towns and industrial zones, among other features. Similar results were found in Mexico City: 63% of its population resided in the peri-urban regions in 2000 [27]. Furthermore, the substantial change in the NUP resulted in a concomitant decrease in the built-up density within UBAs. The massive constructions of the Economic and Technological Development Zone (ETDZ) and Industry Park initially formed a dispersed landscape pattern with low compactness [11]. However, as the sprawl of these satellite towns continued and the road network transport system improved, urban patches gradually merged. However, low built-up density remained in the peri-urban region between the urban patches.

Meanwhile, the metric of the USI continuously increased. This finding implies that the UBAs became more complex and irregular in shape. Many studies have also found the characteristics of fragmentation and irregularity in expanded built-up areas [28–30]. We infer that two of the most important reasons for this result are the accelerated construction of the road network and the topographical constraints in Zhejiang Province. Roads are known to be the most important factor in models for predicting urbanization [31–33]. The general consensus is that transportation guides the directions of urban sprawl. Cities often show characteristic patterns of star-shaped urban sprawl due to the radicalized distribution of roads in Europe [9]. The length of the transportation routes (including railways and highways) in Zhejiang Province increased from 26,443 km in 1985 to 111,938 km in 2010. Open land adjacent to traffic routes is more likely to be occupied by urban construction. The topographical features of the dominantly hilly regions (which represent approximately 70% of the total area), many water bodies (10% of the total area) and the limited area of plains in Zhejiang Province also constrain the direction of urban sprawl. The combined effects of these factors lead to an irregular urban shape as urbanization progresses.

5.4. Implications for Sustainable Urban Development in the Future

Along with the numerous benefits of rapid urbanization and economic development, debates on intensified resource scarcity and environmental degradation have aroused concerns worldwide. Urbanization in developed countries has been associated with urbanization, suburbanization, counter-urbanization and re-urbanization [34]. In the past decade, concepts of sustainable urban development, such as smart growth/compact development, have been widely discussed [35]. Given the constantly widening gap between land urbanization and population urbanization, the Ministry of Land and Resources of China (MLR) decided to implement measures to control the rampant urban sprawl by restraining the urban land per capita in the subsequent urbanization stage. According to these measures, urban land per capita would be restricted to 80–100 m^2/person in large cities, 90–110 m^2/person in medium cities and 100–120 m^2/person in small cities. However, the cities in Zhejiang Province far exceeded the suggested range until 2010.

More importantly, the majority of the urban expansion occurred at the expense of arable land [17,31,36,37]. The State Council of China promulgated regulations to protect high-quality agricultural land (basic agricultural land) in 1994 and 1998. These policies have directly restricted urban expansion by controlling the rate of land conversion. However, the urbanization curve among different-sized cities in Zhejiang Province revealed that large and small cities would continue to show drastic urbanization in the following decade, implying that there is a continuous demand for land exploration for urban and economic development. Confronted with the practical situation of a lack of plains and agricultural land supply, Zhejiang Province will inevitably witness particularly intense pressure and conflict between sustainable urban expansion and land supply. According to the results of the urban built-up area per capita and GDP output per unit of urban built-up area, a large city is estimated to accommodate more of the urban population and have a higher GDP output than a medium/small city. Due to accelerated urbanization and industrialization, urban agglomeration has been introduced and widely adopted by the local governments of Zhejiang Province. Cities at a regional scale have agglomerated to form metropolitan cities or city clusters to promote the intensive use of land resources and environmental conservation. Meanwhile, small cities should receive increased attention from the central and local governments, which should formulate extensive and strict rules to improve the efficiency of urban land use in small cities.

6. Conclusions

This study presented a practical methodology to monitor the spatiotemporal characteristics of urban expansion and to explore the pattern of urban sprawl in response to rapid urbanization by integrating remote sensing, urban built-up area boundaries, spatial metrics and spatial regression. Urbanization strategies and urban land use efficiency among different-sized cities over the past three decades were further evaluated. The results showed that despite strict land planning and management policies, the urban region of Zhejiang Province, China, sprawled to more than 13-times the initial urban area. Of the total expanded urban area of 383,804 ha, two large cities comprised 26.3%, nine medium cities comprised 22.2% and fifty-six small cities comprised 51.6%. Through the evaluation of urban built-up area boundaries growth and urban built-up density over different periods, an integrated cycle of

diffusion and coalescence was demonstrated in the urbanization process. As urbanization progressed, the UBAs became more complex and irregular in shape, and the urban area per capita continuously increased. The regression results suggested that the urban population and GDP greatly affected the overall growth of the UBAs.

Small cities in Zhejiang Province experienced the rapidest urban sprawl before 2000. However, at the beginning of the 21st century, large cities witnessed the most drastic urbanization. The urbanization curve implied that future urbanization would focus on large and small cities. Large cities were estimated to accommodate more of the urban population and to create higher GDP output per urban unit area compared with medium and small cities; we proposed that a metropolitan model can be applied to Zhejiang Province to promote compact urban development and land resource preservation. Furthermore, small cities, which accommodate 48% of the total provincial urban population and occupy 51% of the provincial urban area, should also receive increased attention from the local governments, which should implement strict planning and execution of land use policies in small cities. Planning tools, such as urban growth boundaries, are also expected to control the rampant urbanization and alleviate the conflict between continuous urban sprawl and land resource conservation.

This study focused on a typical study area of the economically developed region of eastern coastal China at the provincial scale. The results quantified the characteristics of urbanization patterns and urban land use efficiency among different-sized cities during various stages of urbanization periods and highlighted their implications for sustainable urban development. The results are expected to improve the decision-making processes of city planners, economist, ecologists and resource managers in Zhejiang Province. Overall, the combined application of UBAs and spatiotemporal analysis may provide rational and efficient tools for urban analysis. Further studies will be conducted to identify additional socio-economic indicators that encourage dramatic urban expansion. Moreover, a more detailed classification system of city tiers will also be adopted to comprehensively explore the effects of locational factors and terrain geography on urbanization intensity and landscape patterns.

Acknowledgments

This research was funded by the Zhejiang Province Key Science and Technology Innovation Team (No. 2010R50030), Zhejiang University Seed Funding (No. 2011028) and the Chinese Ministry of Environmental Protection (No. STSN-05-11). The authors thank Editor Siyang Liu and two anonymous reviewers for their constructive comments, suggestions and help in enhancing the manuscript.

Author Contributions

Jiadan Li, Ke Wang and Jinsong Deng had the original idea for the study and all co-authors conceived and designed the methodology. Jiadan Li, Jun Li，Tao Huang Yi Lin and Haiyan Yu were responsible for the processing and analysis of the data. Jiadan Li drafted the manuscript, which was revised by Jinsong Deng. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Grimm, N.B.; Grove, J.M.; Pickett, S.T.; Redman, C.L. Integrated approaches to long-term studies of urban ecological systems: Urban ecological systems present multiple challenges to ecologists-pervasive human impact and extreme heterogeneity of cities, and the need to integrate social and ecological approaches, concepts, and theory. *Bioscience* **2000**, *50*, 571–584.
2. Lambin, E.F.; Turner, B.L.; Geist, H.J.; Agbola, S.B.; Angelsen, A.; Bruce, J.W.; Coomes, O.T.; Dirzo, R.; Fischer, G.; Folke, C. The causes of land-use and land-cover change: Moving beyond the myths. *Global Environ. Chang.* **2001**, *11*, 261–269.
3. Wu, K.; Zhang, H. Land use dynamics, built-up land expansion patterns, and driving forces analysis of the fast-growing hangzhou metropolitan area, eastern china (1978–2008). *Appl. Geogr.* **2012**, *34*, 137–145.
4. Galea, S. Urbanization, urbanicity, and health. *J. Urban Health* **2002**, *79*, S1–S12.
5. United Nations Department of Economic and Social Affairs. Urban and Rural Areas 2009. Available online: http://www.un.org/en/development/desa/population/publications/urbanization/urban-rural.shtml (accessed on 1 June 2014).
6. Longley, P.A. Geographical information systems: Will developments in urban remote sensing and gis lead to 'better'urban geography? *Prog. Hum. Geogr.* **2002**, *26*, 231–239.
7. Yue, W.; Liu, Y.; Fan, P. Measuring urban sprawl and its drivers in large chinese cities: The case of hangzhou. *Land Use Policy* **2012**, *26*, 231–239.
8. Wu, J.; Jenerette, G.D.; Buyantuyev, A.; Redman, C.L. Quantifying spatiotemporal patterns of urbanization: The case of the two fastest growing metropolitan regions in the united states. *Ecol. Complex* **2011**, *8*, 1–8.
9. Antrop, M. Landscape change and the urbanization process in europe. *Landscape Urban Plan.* **2004**, *67*, 9–26.
10. Buyantuyev, A.; Wu, J.; Gries, C. Multiscale analysis of the urbanization pattern of the phoenix metropolitan landscape of USA: Time, space and thematic resolution. *Landscape Urban Plan.* **2010**, *94*, 206–217.
11. Deng, J.S.; Wang, K.; Hong, Y.; Qi, J.G. Spatio-temporal dynamics and evolution of land use change and landscape pattern in response to rapid urbanization. *Landscape Urban Plan.* **2009**, *92*, 187–198.
12. USGS Global Visualization Viewer. Available online: http://glovis.usgs.gov (accessed on 4 March 2013).
13. Ministry of Construction of P.R. China. *China's Standards for Basic Terminology of Urban Planning*; China Architecture & Building Press: Beijing, China, 1999. (In Chinese)
14. Wang, L.; Li, C.; Ying, Q.; Cheng, X.; Wang, X.; Li, X.; Hu, L.; Liang, L.; Yu, L.; Huang, H. China's urban expansion from 1990 to 2010 determined with satellite remote sensing. *Chinese Sci. Bull.* **2012**, *57*, 1388–1399. (In Chinese)
15. Su, S.; Zhang, Q.; Zhang, Z.; Zhi, J.; Wu, J. Rural settlement expansion and paddy soil loss across an ex-urbanizing watershed in eastern coastal china during market transition. *Reg. Environ. Chang.* **2011**, *11*, 651–662.

16. Urban, D.L. Landscape ecology. In *Encyclopedia of Environmentrics*; Wiley & Sons Press: Hoboken, NJ, USA, 2006. Available online: http://onlinelibrary.wiley.com/doi/10.1002/9780470057339.val005/pdf (accessed on 15 December 2013).
17. Tan, M.; Li, X.; Xie, H.; Lu, C. Urban land expansion and arable land loss in china—A case study of Beijing-Tianjin-Hebei region. *Land Use Policy* **2005**, *22*, 187–196.
18. Zhao, X.; Chen, Z.; Xue, D. Globalization and trend of major cities development in china. *Urban Plan. Overseas* **2002**, *5*, 7–14.
19. Dietzel, C.; Herold, M.; Hemphill, J.J.; Clarke, K.C. Spatio-temporal dynamics in California's central valley: Empirical links to urban theory. *Int. J. Geogr. Inf. Sci.* **2005**, *19*, 175–195.
20. Cao, G.; Feng, C.; Tao, R. Local "land finance" in China's urban expansion: Challenges and solutions. *China World Econ.* **2008**, *16*, 19–30.
21. Ding, C. Policy and praxis of land acquisition in china. *Land Use Policy* **2007**, *24*, 1–13.
22. Wei, Y.D.; Ye, X. Regional inequality in china: A case study of zhejiang province. *Tijdschr. Econ. Soc. Geogr.* **2004**, *95*, 44–60.
23. Jinling, L. The analysis on regional differences of urbanization level in shaanxi province based on grey correlative analysis. *Phys. Procedia* **2012**, *33*, 1510–1517.
24. Liu, S.; Zhang, P.; Lo, K. Urbanization in remote areas: A case study of the heilongjiang reclamation area, northeast china. *Habitat Int.* **2014**, *42*, 103–110.
25. Kamal-Chaoui, L.; Leman, E.; Zhang, R. *Urban Trends and Policy in China*; OECD Publishing: Paris, France, 2009; p. 10.
26. Desmet, K.; Rossi-Hansberg, E. Analyzing urban systems: Have mega-cities become too large? Available online: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2439695 (accessed on 26 May 2014).
27. Cohen, B. Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. *Technol. Soc.* **2006**, *28*, 63–80.
28. DiBari, J.N. Evaluation of five landscape-level metrics for measuring the effects of urbanization on landscape structure: The case of Tucson, Arizona, USA. *Landscape Urban Plan.* **2007**, *79*, 308–313.
29. Shoyama, K.; Braimoh, A.K. Analyzing about sixty years of land-cover change and associated landscape fragmentation in shiretoko peninsula, northern Japan. *Landscape Urban Plan.* **2011**, *101*, 22–29.
30. Xiao, R.; Su, S.; Zhang, Z.; Qi, J.; Jiang, D.; Wu, J. Dynamics of soil sealing and soil landscape patterns under rapid urbanization. *Catena* **2013**, *109*, 1–12.
31. He, C.; Zhao, Y.; Tian, J.; Shi, P. Modeling the urban landscape dynamics in a megalopolitan cluster area by incorporating a gravitational field model with cellular automata. *Landscape Urban Plan.* **2013**, *113*, 78–89.
32. Hu, X.; Wang, W.; Sheng, H. Urban traffic flow prediction with variable cell transmission model. *J. Transport. Syst. Eng. Inf. Technol.* **2010**, *10*, 73–78.
33. Poelmans, L.; Van Rompaey, A. Detecting and modelling spatial patterns of urban sprawl in highly fragmented areas: A case study in the flanders-brussels region. *Landscape Urban Plan.* **2009**, *93*, 10–19.

34. Champion, T. Urbanization, suburbanization, counterurbanization and reurbanization. In *Handbook of Urban Studies*; SAGE Publications: London, UK, 2001; pp. 143–161.
35. Daniels, T. Smart growth: A new american approach to regional planning. *Plan. Pract. Res.* **2001**, *16*, 271–279.
36. Deng, J.S.; Qiu, L.F.; Wang, K.; Yang, H.; Shi, Y.Y. An integrated analysis of urbanization-triggered cropland loss trajectory and implications for sustainable land management. *Cities* **2011**, *28*, 127–137.
37. Su, S.; Jiang, Z.; Zhang, Q.; Zhang, Y. Transformation of agricultural landscapes under rapid urbanization: A threat to sustainability in hang-jia-hu region, china. *Appl. Geogr.* **2011**, *31*, 439–449.