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Article

Sustainable Urban Development and Land Use Change—A Case Study of the Yangtze River Delta in China

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Abstract: This paper introduces a sustainability assessment method for the rapidly urbanizing Yangtze River Delta in China addressing the role of land use pattern. We first calculated the sustainability component scores of 16 cities in the area in 2000 and 2005. The results showed that socioeconomic and environmental conditions improved while the performance of resource-use degraded from 2000 to 2005. We then made a spatial analysis of land use change (LUC) using geographic information systems during 1990–2000. We found that diverse spatiotemporal transformation occurred among the cities and identified urban development cluster patterns and profiles based on development density. Finally, we examined the impact of LUC on sustainable urban development (SUD). Using regression techniques, we demonstrated that urbanization, infrastructure development, industrial structure and income significantly affected environmental performance and resource-use. These results suggest a moderate pace of LUC with steady economic growth being key to SUD.

Keywords: China; sustainable urban development; land use change

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1. Introduction

In China, urbanization, which is defined as the proportion of urban population of the total population, has increased from 18% in 1978 to 47% in 2009 [1] and a large amount of arable land has been transformed into urban built-up areas. The rapid pace of urbanization has led to resource depletion, environmental degradation and rural-urban migration along with rapid economic growth. These have now become major constraints to achieving sustainable urban development (SUD) in China. Hence, in order to improve SUD, the Chinese government has implemented the concept of the Circular Economy (CE) to conserve resources including land and reduce harmful emissions to ease the environmental pressure under the Chinese 11th Five-Year Plan (2006–2010) which was released in 2006 [2].

Various studies analyzed urban land expansions, arable land losses and urban growth patterns in China. Tan *et al*. [3] found that the urban land area in the Beijing-Tianjin-Hebei region expanded by 71% between 1990 and 2000. Different-tier cities, however, were found to have great differences in urban development parameters, such as the rate of urban land expansion, growth rate of urban land per capita, and so on. Luo and Wei [4] found distinctive local patterns and effects of urban growth in Nanjing, shaped by local urban spatial and institutional structures. This study also showed the importance of policy studies and fieldwork in the interpretation of results generated from statistical and geographic information systems (GIS) modeling. Han *et al*. [5] predicted the urban area of Shanghai to increase at an annual rate of 3% (1,474 km^2 by 2020). Spatially, the new urban land is most likely to expand around the vicinity of city center or sub-centers, and mainly along a west-east axis and a north-south axis.

On the other hand, discussions about sustainable urban development have also been growing. Many past studies attempted to address sustainable urban development from environment, economic and social aspects of urban systems as the core components [6-8]. In principle, environmental aspects address ecological conditions of urban systems. Economic and social aspects address such factors as financial conditions, equity and good quality of life, among others. It is important, however, that the specific focuses under each component (environment, economy and society) vary depending on the scope of studies and detailed analyses for the status of these components are usually carried out by applying indicator systems. In fact, numerous indicator systems and assessment tools have been developed to address such components of urban sustainability. van Dijk and Mingshun [9], for example, developed 22 indicators for analyzing urban sustainability in China and calculated scores as index. Shen *et al*. [10] introduced "International Urban Sustainability Indicator List" which contains a set of indicators within four dimensions of sustainable development (*i.e.*, environmental, economic, societal and governance aspects).

Although analyses of land use changes in China and the assessment tools for urban sustainability have been vigorously developed individually, less attention has been paid to clarifying the impact of LUC on SUD. In fact, little knowledge has been accumulated about the relationship between LUC and SUD. In this paper, we selected the Yangtze River Delta (YRD) which is one of the most rapidly urbanizing regions in China to examine the relationship between SUD and LUC by looking into major 16 cities located within YRD. Specifically, we apply the Environmental Sustainability Index system developed by Esty *et al*. [11] to assess urban sustainability conditions for sixteen cities in the YRD.

We then analyze LUC for the sixteen cities and analyze during the period of 1990–2000 with a focus on density of LUC, defining LUC patterns. Of course, the mechanism of how land use influences sustainability conditions is complex. Contiguity and connectivity of landscape and mixed land-use can change provision of eco-system services, affecting sustainability conditions. Although we are unable to consider all the aspects of LUC due to data limitation, we derive insights into SUD from the analysis.

Specifically, we show that socio-economic conditions in general and some environmental conditions improved from 2000 to 2005 while resource-use performances degraded. Along with these observations, we also reveal that spatiotemporal transformation occurred among the cities. Particularly, we find substantial change in land use and population density in Shanghai, Suzhou and Nanjing, and that these cities also achieved efficient land use while these cities improved environmental conditions, leading to improvement in SUD. Furthermore, we examine the relationship between LUC and sustainability components. We identify different land use change patterns across the cities, showing those patterns to have different profiles in terms of SUD. This paper then explores the determination of sustainability conditions using regression techniques. We demonstrate that income, industrial structure and land use patterns significantly affected environmental and resource-use performances. Based on these analyses, a way to achieve both economic development and environmental conservation is discussed addressing the case of Shanghai, Suzhou and Huzhou.

2. Urbanization in the Yangtze River Delta

The Yangtze River Delta is the largest delta among the three Economic Deltas (which are the YRD, Beijing-Tianjin-Hebei (BTH) and the Pearl River Delta (PRD)) in China. Although it accounts for only 2.2% of China's total land area, it produced 22.3% of China's total GDP in 2005. The YRD, BTH and PRD have experienced about half of the total land use change from arable land to urban built-up areas in China during 1990–2000 and the YRD has shown the most rapid changes amongst these three megalopolises [12]. Therefore, we have selected the YRD as our case study.

The YRD is located in the Eastern part of China, and includes Shanghai Municipality, some cities in Jiangsu Province (Nanjing, Wuxi, Changzhou, Suzhou, Nantong, Yangzhou, Zhenjiang, and Taizhouj) and some cities in Zhejiang Province (Hangzhou, Ningbo, Jiaxing, Huzhou, Shaoxing, Zhoushan, and Taizhouz), making a total of sixteen case study cities in this paper (Figure 1). Shanghai is by far the largest city in the YRD, Nanjing is a provincial city in Jiangsu province, and Hangzhou is a provincial city in Zhejiang province. Geographically, Shanghai, Suzhou, Wuxi, Hangzhou, Shaoxing, Ningbo and Zhoushan are the coastal cities, and other cities are the inland cities. In terms of the scale of urban built-up areas, Shanghai, Nanjing and Hangzhou are the large cities; others are medium and small cities. The total area of the YRD is 180,935 km^2. The cities in YRD have experienced rapid economic growth. For example, the per capita GDP in Shanghai increased from 11,112 Yuan in 1990 to 34,435 Yuan in 2000 and 58,656 Yuan in 2005 at a constant price of 2000 [13-15].

With rapid economic growth, urbanization in the YRD has also increased remarkably (Figure 2). During 1990–2000, Shanghai experienced a remarkable increase in the urbanization ratio, 25.0% while other cities showed lower pace of urbanization during the period of 1990–2000: the increase rate of Nanjing, Hangzhou, and Suzhou were 3.4%, 5.5%, and 4.1%, respectively in the same period. During 2000–2005, however, those cities also experienced a rapid urbanization: for example, the urbanization rate of Nanjing increased by 33.0%, that of Hangzhou increased by 33.2%, and that of Suzhou increased by 17.9%.

Figure 1. Map of the Yangtze River Delta (YRD) in China (16 cities).

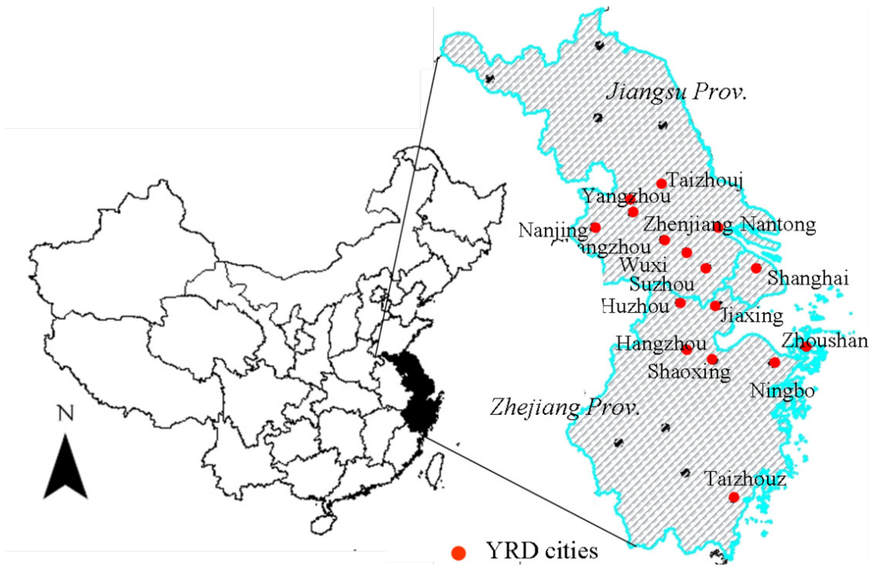
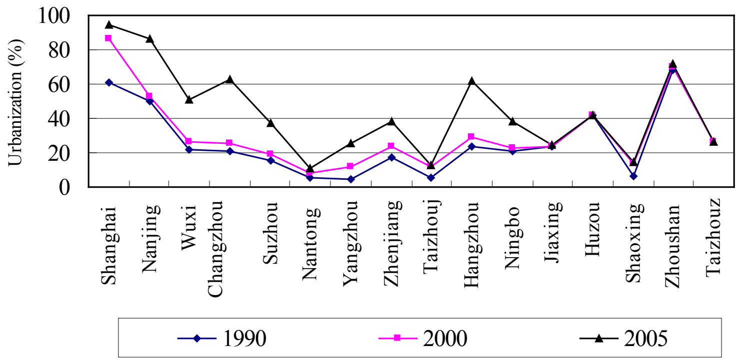


Figure 2. Urbanization in the Yangtze River Delta (1990, 2000, 2005).



From an administrative perspective, Shanghai, Nanjing and Hangzhou were designated as the core cities of the YRD until 1995; however, in 2000, Suzhou also became a core city of YRD. Figure 2 also shows that the rate of urbanization in the YRD was higher for coastal cities than for inland cities. Furthermore, the growth rate was higher for core cities and large cities than other cities. From these observations, other small cities in the inland area will likely experience rapid urbanization and substantial LUC in the future. Thus, it is of importance to draw lessons by understanding how LUC influences the sustainability conditions of cities.

3. Sustainability Component Assessment in Yangtze River Delta

3.1. Sustainability Component Assessment Framework

We posit that it is possible to define components such as environment and resource-use, which are important for sustainability for a particular region and time period, while the relations between the components are unknown. Thus, our strategy to examine the impact of LUC pattern on SUD in the YRD is as follows. We first identify sustainability components for the 16 case study cities and evaluate the sustainability conditions for each component. We then analyze the relationship between the components, highlighting the land use factors as a determination of the environmental and resource-use conditions.

The data used for sustainability assessment are obtained from National Bureau of Statistics in China and Chinese Academy of Sciences, which are official statistics and have been used for national and provincial level studies. Although Chinese official data have widely been regarded as invalid or unreliable, several studies demonstrated that their error margins in much of published statistics are acceptable [16,17]. Given the current status of China, SUD should consider both the means and vision of a society to be achieved. It is particularly important in a sustainable society to ensure good quality of life. On the one hand, in China, where poverty and income inequality are serious issues, ensuring economic and social development is crucial [18]. On the other hand, environmental conservation and sustainable use of resources including energy are necessary as they are the major constraint for future socio-economic development [19]. Based on these observations, we selected four key sustainability components for the YRD cities: social, economic, environmental and resource-use components. Considering significance, comparability and data availability, we then selected eleven variables to calculate each components score for the cities for the period of 2000 and 2005 (Table 1).

Table 1. Sustainability components and variables.

Sustainability component score	**Component**	**Variable**
	Social index	Per capita education, science and technology expenditure
		Per capita physicians
		Per capita housing area
	Economic index	Per capita GDP
		Per capita total investment in fixed asset
	Environmental index	Ratio of industrial wastewater treatment before discharge
		Green area coverage in urban zone
		SO_2 emission
	Resource-use index	Per GDP residential water consumption
		Per GDP residential electricity consumption
		Per GDP residential propane gas and LPG consumption

[a] Data were obtained from National Bureau of Statistics of China [14,15]; [b] GDP per capita is calculated at constant year 2000 prices.

First, three variables regarding education, housing, and health were selected to represent the social component, each of which also considers the current situation of the YRD region. International bodies such as United Nations address these as important elements for social and human development [20]. The economic component variables aim to capture the aspect of current income as well as the future prospective of economic development. Regarding the environment component variables, we used only three variables because of data limitation. Of course, these cannot account for all the environmental aspects. Yet, we attempted to capture different dimensions of the environment including solid waste, land use, and air pollution. Finally, as for resource use, we selected three variables of per capita water and energy (electricity and gasses). All the data were obtained from the China Urban Statistical Yearbook [14,15].

Hence, we are aware that, with this approach, our assessment results will rely on the variable selection, implicitly ignoring other important components for SUD. For example, achieving social and economic equity is one of the main goals for sustainable development for cities [19]. It is well documented that economic inequality is increasing between and within regions in China [18]. Also, China has now become the world largest carbon dioxide emitter in the world [21], and cities are probably among the major sources of emissions because of mass motorization in recent years. However, due to lack of specific data we did not include these variables in our assessment. Nevertheless, with having noticed these limitations, it is still significant to understand the relative status of cities conditional on the selected variables with respect to urban development. In addition, the corresponding outcomes enable us to examine the relationship between LUC and conditional sustainability performances to produce insights into SUD.

Finally, the calculation procedure was conducted according to Esty *et al*. [11]. First, we normalized the variables obtained from statistics by taking either a logarithm or a square root so that all they follow normal distributions. Second, we computed the z-score for each of the normalized variables $z_j^i = (X_j^i - \mu_j)/\sigma_j$ where i represents the city, j is a variable allocated to the four sustainability components (environment, social, economic, and resource-use), X is the normalized variable, and μ and σ denote the average and standard deviation of the variable being considered. Because the mean and standard error of each variable become zero and one respectively for each z-score, variables with different scales can be aggregated. Finally, we aggregate the z-scores within the same component using an equal weight to yield the four component scores.

3.2. Results and Discussion

Table 2 reports the sustainability component scores in the YRD in 2000 and 2005. Through analysis of these results, we found substantial improvement of socio-economic and environmental situations across the cities. These results are reasonable given that the whole China also experienced rapid economic growth during the period.

Interestingly, we observe substantial improvements in the environmental component scores across the observed years. An explanation for this is that after 2000, the economic structure in YRD has paid increasing attention to the environment protects. In addition, Circular Economy (CE) concept was introduced by the Shanghai municipal government in 1998, which means the YRD became the first region to implement the CE in the whole China. In particular, because of improvements in water treatment, mitigation of SO_2 emissions and increasing green areas, the composition of the environmental component can be demonstrated through economic investment and introduction of technologies.

To the contrary, the results show degradation of resource-use performance over the years. Recall that the resource scores are calculated based on per GDP units. Given that improvement of intensity is a necessary condition to make a balance between development and energy conservation, this result is undesirable for the regional sustainability. Moreover, as the variable selection for the resource components consist of water, electricity and gas consumption, the results naturally imply an increase in CO_2 emissions in those cities.

Table 2. Sustainability component scores in the YRD (2000 and 2005).

	Social Index		**Economic Index**		**Environmental Index**		**Resource use Index**	
	2000	2005	2000	2005	2000	2005	2000	2005
Shanghai	0.87	0.95	0.78	0.94	0.20	0.50	0.82	0.51
Nanjing	0.31	0.73	0.34	0.82	0.32	0.62	0.94	0.63
Wuxi	0.29	0.83	0.36	0.93	0.64	0.61	0.53	0.08
Changzhou	0.27	0.69	0.21	0.81	0.43	0.67	0.94	0.32
Suzhou	0.25	0.79	0.35	0.93	0.48	0.64	0.73	0.15
Nantong	0.14	0.38	0.04	0.48	0.32	0.75	0.80	0.44
Yangzhou	0.17	0.48	0.07	0.46	0.33	0.70	0.75	0.26
Zhenjiang	0.24	0.65	0.22	0.76	0.39	0.64	0.84	0.35
Taizhouj	0.19	0.61	0.04	0.36	0.66	0.77	0.53	0.13
Hangzhou	0.44	0.79	0.47	0.86	0.44	0.74	0.82	0.29
Ningbo	0.41	0.71	0.41	0.88	0.40	0.59	0.52	0.20
Jiaxing	0.13	0.72	0.33	0.80	0.37	0.50	0.80	0.34
Huzou	0.19	0.75	0.20	0.74	0.44	0.72	0.60	0.29
Shaoxing	0.21	0.67	0.27	0.79	0.48	0.80	0.36	0.15
Zhoushan	0.36	0.70	0.14	0.66	0.13	0.36	0.73	0.42
Taizhouz	0.31	0.64	0.10	0.58	0.13	0.34	0.23	0.34
Average	0.30	0.69	0.27	0.74	0.38	0.62	0.68	0.31

In terms of location, we found that coastal cities had higher scores in the socioeconomic components than inland cities. From a political aspect, the provincial cities and the core cities in the YRD had higher scores than other cities. From an urbanization aspect, the rapidly developing cities generally had higher scores in the three components than slowly developing cities. Also, we found that many of the cities with overall low performance tend to be located inland, including Taizhouj and Taizhouz in each period. These cities not only have low urbanization (see Figure 2) and undeveloped economies resulting in less socio-economic development, but also present poor conditions in the environment and resource efficiency.

4. Analysis of Land Use Change Patterns and SUD

4.1. Land Use Change in Cities

In this subsection, we reveal the trend and characteristic of LUC in the YRD by using geographic information systems (GIS), which include ArcGIS9 and 1-km mesh Chinese GIS land data, to spatially analyze the LUC (arable land converted to urban built-up area) in each city in YRD during the period of 1990–2000. The spatial data used in this study were provided by Data Center for Resources and Environmental Sciences (DCRES), Chinese Academy of Sciences, in Beijing. Specifically, each mesh contains information of the newly developed area. According to DCRES, remote sensing data from Landsat Thematic Mapper are used to map land-use information into national 1:100,000 map with a complete man-machine interaction method [22].

Overall, the results show that coastal cities (e.g., Shanghai) experienced higher LUC than inland cities (e.g., Nanjing), and that cities in Jiangsu Province (e.g., Nanjing) had higher LUC than cities in

Zhejiang Province (e.g., Hangzhou). This implies that LUC and economic development are closely associated. The comparison of LUC with the level of urbanization shows that LUC are positively associated with the urbanization level. Shanghai, Suzhou, Wuxi, Changzhou and Nanjing have shown a remarkable LUC during 1990–2000. Clearly, advantages in location and political status influence on this (Figure 3). Through the chronological analysis, we found that there were only two core cities (*i.e.*, Shanghai and Nanjing) in the YRD during the period of 1990 to 1995. However, Hangzhou and Suzhou were also added and thus four cities became the cores in land use during the period of 1995 to 2000, based on the GIS spatial analysis on the urban built-up area of Chinese 1-km mesh land data in 1995 and in 2000. We also found that the LUC during the period of 1990–1995 was greater than from 1995 to 2000 (Figure 4). This slowdown in LUC during the period of 1995–2000 may presumably be due to the enactment of the law on Farmland Protection Regulation in 1994 and the New Land Administration Law in 1998 by the Chinese government.

Figure 3. GIS Map of land use change (LUC) in the Yangtze River Delta (1990–2000).

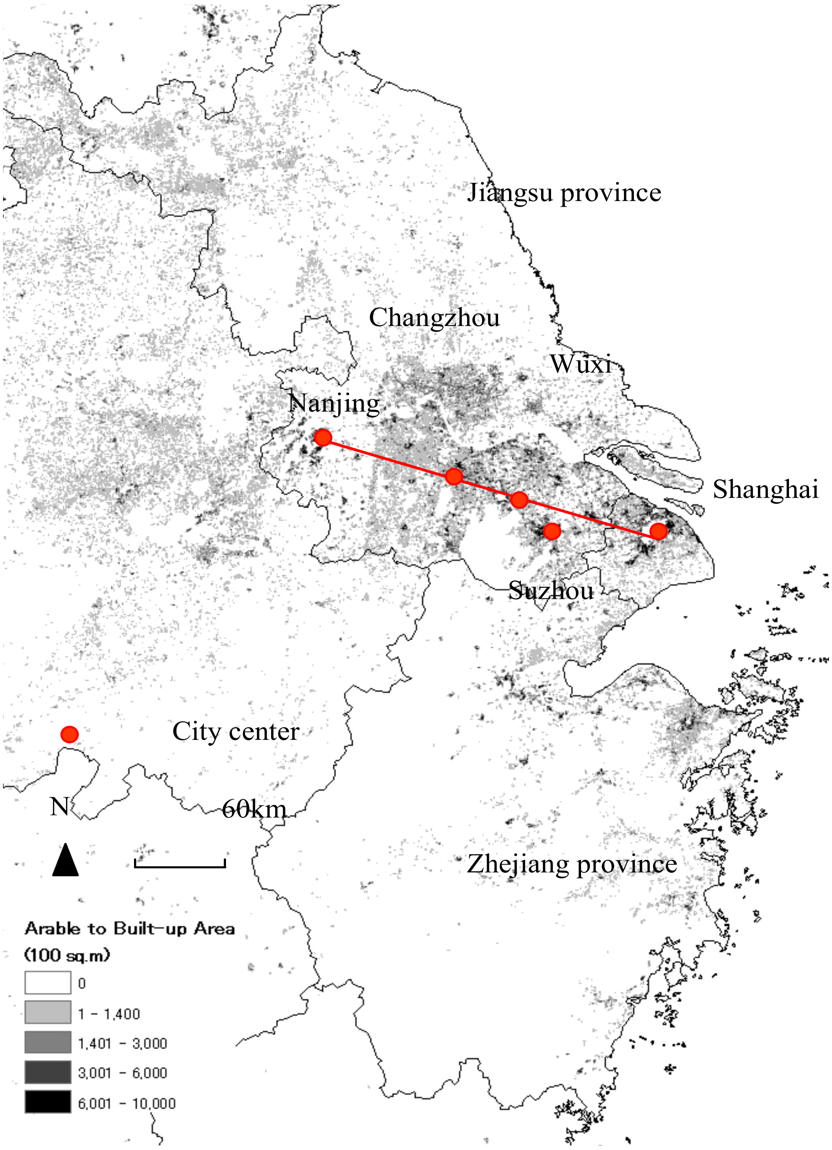
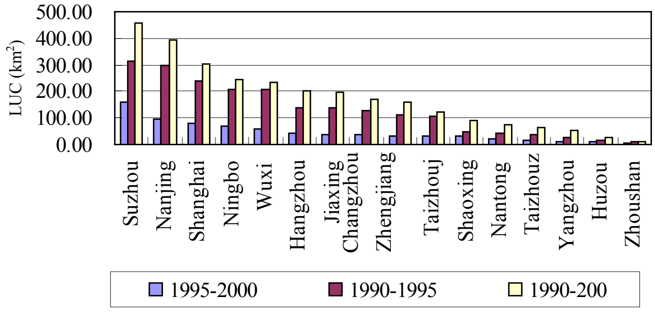


Figure 4. Details of LUC in each of the 16 cities (1990–2000).



4.2. Clustering Land Use Change Patterns

This subsection determines the spatial characteristics of LUC patterns in each city in the YRD during 1990–2000. For this, we first estimate LUC in the following four spatial areas for each city: Area 1 (0–5 km), Area 2 (5–10 km), Area 3 (10–15 km), and Area 4 (15–20 km) respectively, from the political center. Overall, the estimation results of LUC in the four circle areas show that Shanghai experienced the largest LUC during the period 1990–2000 within the radius of 20 km, followed by Nanjing (provincial city in Jiangsu) and Suzhou (adjacent to Shanghai) (Figure 5). We then conduct a k-mean clustering based on the LUC estimates of the four areas. By clustering, we classified the 16 cities into four LUC patterns based on the estimates.

Figure 5. LUC within a radius of 20 km in the Yangtze River Delta (1990–2000).

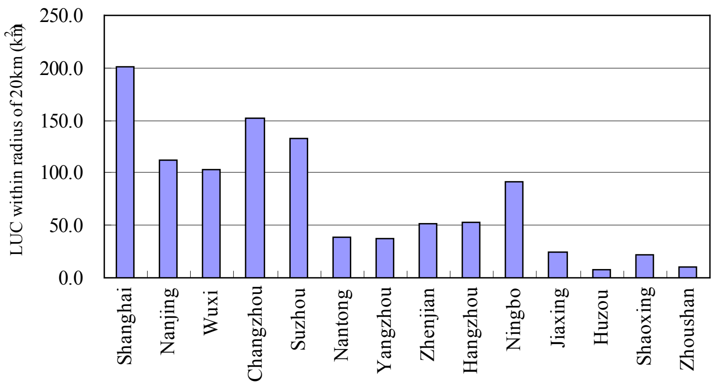


Table 3 presents the cities belonging to each of the four estimated clusters. Likewise, Table 4 reports the five clusters' profiles in terms of industrial structure, GDP per capita, urbanization rate, road area, and population density. According to the average LUC in each of the circle areas and the clusters' profiles, the four groups were characterized as follows. The LUC pattern 1 shows extremely dense land development with a peculiar profile: it has the smallest share of the primary sector while having by far the largest GDP per capita and urbanization rate. Only Shanghai belongs to this group (Figure 6). The LUC pattern 2 experienced rapid and disperse development within the radius of 20 km. This group consists of Nanjing and Suzhou, Wuxi, Changzhou and Ningbo. While these cities show rapid economic growth and sprawling urban development (Figure 7), their infrastructure (road area per capita) and income level are yet behind some of the other cities in the region. The LUC pattern 3 shows a moderate development rate. Cities in this group seem to succeed to conserve arable land, making development compact: its share of the secondary sector and road areas per capita are the highest. Hangzhou is a typical city under this group (Figure 8). Finally, the LUC pattern 4 group demonstrates much less development. Most cities in this group are agricultural cities that have suffered from the economic stagnation in recent years. Huzhou belongs to this pattern (Figure 9).

What we observe here is there are associations between LUC and development patterns. Particularly, when it comes to causal relationships, the land use pattern characterizes some of the development factors such as population size urbanization and road areas. The next section demonstrates those factors as one aspect of the characterization of land use pattern in fact affect particular sustainability conditions with respect to the environment and resource use.

Table 3. LUC patterns in YRD (1990–2000).

Pattern	Characteristics	City name
Pattern 1	Dense, rapid, and large scale development (Mega city)	Shanghai
Pattern 2	Rapid and sprawling development	Nanjing, Suzhou, Wuxi, Ningbo, Changzhou
Pattern 3	Moderate and compact development	Hangzhou, Zhenjiang Yangzhou, Nantong,
Pattern 4	Slow development	Jiaxing, Shaoxing, Huzhou Zhoushan, Taizhouj, Taizhouz

Table 4. Clusters' profile.

		Pattern 1	Pattern 2	Pattern 3	Pattern 4
Sector share (to GRP)	Primary (%)	1.34	12.30	4.79	10.28
	Secondary (%)	48.07	53.34	56.66	53.28
	Tertiary (%)	50.54	34.36	38.54	36.43
GDP/capita (Yuan)		46546.18	21241.26	32287.34	18982.80
Road area/ capita (m^2)		11.72	8.08	12.09	10.30
Urbanization rate (%)		90.43	35.43	42.19	23.36
Population density		2081.61	616.10	776.46	720.50

Figure 6. LUC in Shanghai (1990–2000).

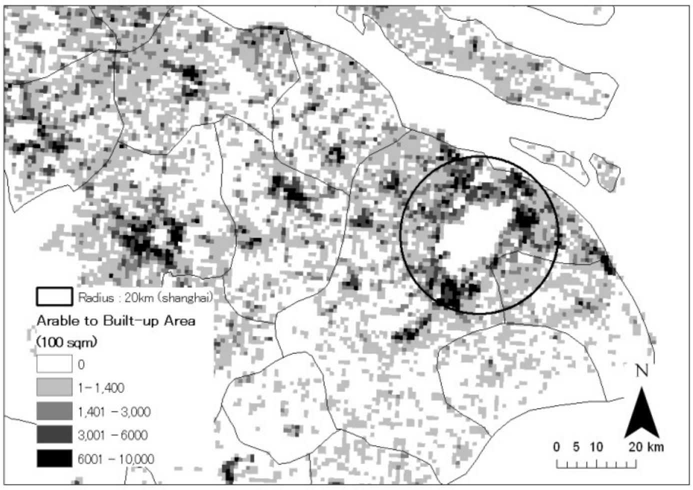


Figure 7. LUC in Suzhou (1990–2000).

Figure 8. LUC in Hangzhou (1990–2000).

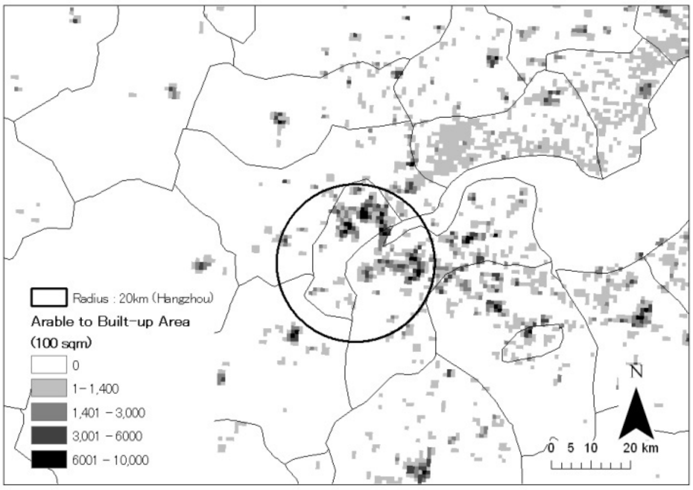


Figure 9. LUC in Huzhou (1990–2000).

5. Impact of LUC on SUD

5.1. Regression Analysis—Determination of Environmental and Resource Sustainability

In this subsection, we analyze the determination of environment and resource component scores, by which we also aim to confirm that those land-use factors in fact affect SUD. For this purpose, we hypothesize that three major factors affect environmental sustainability: economic structure, income and land use. Firstly, economic structure determines the level of environmental burden and resource-use: cities where manufacturing is the main sector likely generate a greater environment burden and larger resource consumption than other cities. Likewise, people's income affects both environmental conditions and resource use. Generally, higher income means larger consumption of goods and services, creating additional environmental degradation and resource-use. Thirdly, urbanization and road area per capita as a representative of land-use factors may also determine the use and waste of energy and resources. For example, extremely rapid change of land use may cause the short supply of public services such as public transportation system and green amenities. These factors also can possibly increase environmental degradation and resource consumption through urban sprawl.

To test our hypothesis, we use regression analysis in which the estimated environmental and resource-use component scores, which were calculated in the previous subsection, are used as a dependent variable. For the independent variables, we use the share of the primary and tertiary industries in the city's economy, GDP per capita, square of GDP per capita in addition to population, urbanization rate, and road area per capita as characterization of LUC patterns. These data, except for the LUC data, were obtained from NBSC [14,15].

We included the square of GDP per capita as a regressor because such inclusion enables us to capture the U-shaped relationship between income and environment and resource performances. If the estimated coefficients of the first term and second term of GDP per capita are significantly negative and positive, respectively, the results indicate the U-shaped relationship between them, supporting the environmental Kuznets curve hypothesis. That is, environmental pressure and resource-use performances first decline as income grows, but they turn to start improving after income reaches some level [23].

Table 5 reports the regression results. The fit of the regression models is statistically significant based on the F-test for the two regression estimations (adjusted R squared were 0.35 and 0.52, respectively, for the two estimated equations and the sample size was 32 for both). Firstly, economic structure has significant impacts on only in the Resource regression equation. The results show that the larger the share of the tertiary sector, the more efficient use of resources. To the contrary, the primary sector has an adverse effect on resource efficiency. The service sector is generally the least energy intensive; thus high share of tertiary sector leads to better performance in the resource efficiency. However, the regression results show that industrial structure is not associated with environmental performance, other effects being equal.

Table 5. Regression results—determination of environmental and resource index (2000 and 2005).

Dependent variables	**Environmental Index**	**Resource-use Index**
Primary	+	−**
Tertiary	−	+**
Urbanization	−***	−
Road area per capita	+**	−*
Per capita GDP	+*	−***
(Per capita GDP)^2	+	+**
Constant	−***	+***
# of observations	32	32
Adjusted R square	0.32	0.50

*, **, and *** denote statistical significance at the10%, 5%, and 1% level, respectively.

Regarding income, per capita GDP has a positive effect on the environment, all other things being equal. The interpretation of this result is as follows. Higher income can enhance the awareness of the environment among the citizens and firms: Citizens put more value on better environment which increases the pressure of environmental regulations. Meanwhile, industrial sectors are likely to invest more in the environmental technologies, resulting in less environmental impacts and conserving the environment. This interpretation makes sense given the components of the environmental performance, which include green space, solid waste treatment, and SO_2 emissions. On the other hand, the results suggest the U-shaped relationship between resource efficiency and income. The coefficient of the first term of GDP per capita is significantly positive and the second term of GDP per capita is significantly negative. Although the average of the resource-use component score worsened from 2000 to 2005 (Table 2), this result indicate that decoupling economic growth and resource use can occur if a city goes beyond a certain level of development.

Finally, the regression results show that land use factors also affect the performance of the environment and resource use in different manners. Interestingly, the coefficient of road area per capita in the environmental index equation is positive and statistically significant but that in the resource use index equation is negative and statistically significant. As for urbanization, it has a negative sign for both equations, but is significant only for the environmental equation. How do we interpret these results? As we have already controlled for the effect of other possible factors, the effects of the road area imply that proper supply of updated infrastructure and technologies such as wider road, subway and sewage systems have positive effects on a city's environmental status. In view of administrative capacity, rapid urbanization would prevent from taking such a development strategy. These results suggest a moderate pace of LUC with steady economic growth is a key to SUD.

5.2. Discussion

Based on the results from the above analyses, we first would like to pay attentions to the following three cities: Shanghai (LUC pattern 1), Suzhou (LUC pattern 2) and Huzhou (LUC pattern 4). All three cities obtained higher sustainability component scores in 2005. They show different LUC patterns groups, land use efficiency and, at same time, they enjoy sharing the economic activities in industrial sectors (*i.e.*, primary, secondary and tertiary industries) among those cities [24]. In fact, Shanghai (commercial center) and its adjacent medium-smaller cities, including Suzhou (industrial city) and Huzhou (agricultural city) share economic roles within the region, which not only enhances the overall economy but also increases the efficiency of land resource use, potentially resulting in the reduction of environmental pressure. As explained in Section 2, inland cities and medium-small cities are predicted to increase rapidly in urbanization in the future, thus this harmonious connection at the regional level would be relevant in land use and could improve the cities' SUD and the regions' SUD in the future.

Furthermore, although we addressed density of land development exclusively as the effects of LUC on sustainability, land itself has much more functions and roles in sustainability through provision of eco-system services: examples include resource supply (e.g., wood and water), adjustment functioning (e.g., flood control and carbon storage), and cultural service supply (e.g., fishing) [25]. As far as the GIS maps of land use present, discontiguity of development pattern is observed in Shanghai, Suzhou, Hangzhou, and Huzhou, which potentially lowers the provision of eco-system services due to spillover of negative effects of development in one location. Recent studies now make valuation of eco-system services by taking into account spatial and temporal effects of land use [26]. With detailed geographical information in hand, this kind of assessment could reveal mechanism of how LUC affects SUD through eco-system services and provide useful implications for development and conservation policies.

Finally, the 1990–2000 time frame of LUC analysis possibly affects the robustness of our results. We conjectured similar patterns of LUC have been continuing from the literature in the urban and land studies [4,5], and hence, our qualitative interpretations that were derived from the quantitative analysis are thus effective to consider the current situations of the 16 cities as well as those in other regions in China. Nevertheless, the degree of conversion from arable land to built-up areas varies from years to year and across cities. In particular, urban sprawl is now a major concern as a threat to sustainability particularly eco-systems around the world. The majority of the population now live in the urban areas and the cities are expanding with unplanned land-use change [27,28]. Those cities in the YRD, particularly Shanghai, are plausibly experiencing urbanization as well as population increase. Future research should investigate the degree to which such sprawl affects on eco-system services and bio-diversity in the region.

6. Conclusions

In this paper, we examined urban sustainability and LUC for 16 cities in the YRD in China and demonstrated the impact of LUC on SUD over different time periods. Our findings are summarized as follows. Since the 1990s, those cities have experienced rapid increases in urbanization and LUC. LUC is clearly associated with socio-economic development. Specifically, the YRD core cities, such as Shanghai, Nanjing, Hangzhou and Suzhou, experienced a relatively high increase in socio-economic scores and substantial LUC over the study period. These core cities attained not only high socio-economic development along with moderate environmental pressure, which led to a better situation in SUD. Besides income and industrial structure, we also show that LUC pattern has an influence on SUD: compact city with moderate pace of economic growth probably resulted in better environment and more efficient resource use through better infrastructure and less urbanization. Finally, the share of economic roles among cities is potentially beneficial not only to a region's economy but also to region's SUD and land use efficiency. Our analysis was demonstrated within the limited aspects of land use and sustainability as well as time range. Yet, the results provided important insights into SUD and this information might be useful in considering SUD in the future, particularly for other regions in China.

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