Evaluation and zoning of various urban land spaces based on restrictive indicators: the case of Shanghai, China

Hefeng Wang, Yuan Cao, Xinxia Liu and Yantao Yang
Hebei University of Engineering, Handan, China

Abstract

Purpose – Using Shanghai as an example, the purpose of this paper is to perform grade evaluation and zoning for different land use spaces by GIS by identifying the major restrictive factors in current socio-economic development.

Design/methodology/approach – Based on short plate theory, 11 major restrictive indicators that will restrict socio-economic development in Shanghai are identified, and urban land is divided into four subspaces and the restrictive grade evaluation of urban land subspace is achieved with GIS spatial analysis; then, land development zoning is processed according to the results of the evaluation.

Findings – In all, 11 major restrictive indicators that will restrict socio-economic development in Shanghai are identified. The restrictive grades of the agricultural production, urban construction and ecological protection subspaces are mainly common, weak and weaker, and the relatively strong restrictive grade of industrial development subspace is mainly concentrated in the more developed industrial districts (counties). The areas of the common and good regions of constructive development and ecological development zones account for 87.4 and 98.3 per cent of each total area, respectively, and urban land still has significant development potential in Shanghai.

Originality/value – This paper proposes various urban land space evaluations and zoning strategies based on restrictive indicators and perspectives, enriching the ideas and methods of urban land use evaluation.

Keywords Shanghai, Zoning, GIS spatial analysis, Restrictive grading evaluation, Restrictive indicators

Paper type Research paper

1. Introduction

In recent years, the rapid development of industrialization and urbanization has greatly promoted social and economic development, but it has also led to the rapid expansion of urban land scale. Land use has undergone significant extension, which not only causes land resource waste but also destroys the urban ecological environment. Statistics indicate that the urbanization level in China increased from 27.99 per cent in 1993 to 49.95 per cent in 2010, or approximately 21.96 per cent, while the total area of cities expanded from 3.006 to 4.712 million km^2, an increase of approximately 56.75 per cent (National Bureau of Statistics of China, 1994/2011); thus, the speed of urban land expansion has not adapted to the urbanization level. Currently, China is in the development stage of the acceleration of a new type of industrialization and urbanization. The amount of urban land use will continue to increase; therefore, the problems of irrational urban interior land use structure, inefficient land use and backward land output levels will exacerbate the contradictions between urban social and economic development and land use. Land resources are increasingly becoming the major restrictive factor in rapid urban development (Zhu and Zhang, 2008), and rationally and efficiently using urban land resources will become the focus of urban sustainable development.

In the future, in some cities, especially large cities, land development intensity will further increase, and the constraints of land resources and the ecological environment will become more apparent in urban social and economic sustainable development. Faced with limited land resources, controlling the spread of urban land use, using existing urban land effectively, optimizing urban interior land use structures and emphasizing urban land connotation and utilization are the inevitable strategies to maintain healthy and sustainable urban development (Amnon, 2004; Liu and Zhang, 2008). Therefore, considering the current urban social and economic development conditions and the existing land use problems, evaluating urban land use in a timely and dynamic manner, determining land development intensity and suitability changes and then monitoring and providing early warnings on land use spaces can not only ensure the scientific nature, compatibility and effectiveness of urban land use but also provide references for rationally planning, developing and utilizing land resources in the future, with important practical significance for achieving rapid, healthy and sustainable development of cities.

The current issue and full text archive of this journal is available on Emerald Insight at: **www.emeraldinsight.com/1708-5284.htm**

World Journal of Engineering
14/4 (2017) 307–317
© Emerald Publishing Limited [ISSN 1708-5284]
[DOI 10.1108/WJE-08-2016-0052]

Foundation items: supported by Hebei Education Department Scientific research program of China (No. QN2016236) and Doctoral Foundation of Hebei University of Engineering (No.20120149).

Received 7 August 2016
Revised 25 August 2016
Accepted 1 September 2016

Currently, scholars have published a great deal of fruitful research on urban land use evaluation, and significant progress has been made in the following three aspects:

1. *Urban land use sustainability evaluation*: Since Brundtland released the "Our common future" report in 1987 (WCED, 1987), sustainable land use has been the subject of many studies and scholars have performed analyses of urban land use sustainability from many perspectives by selecting a large number of indicators, adopting different techniques and methods (Fu *et al.*, 1997; Haberl and Schandl, 1999; Jane and Chris, 2000; Douglas *et al.*, 2003; Zhang *et al.*, 2011);
2. *Urban land-intensive use and land use efficiency evaluation*: Studies have mainly been designed to establish evaluation indicator systems, which have then been used to evaluate urban land qualitatively or quantitatively for whether it meets the requirements of intensive or efficient use, including establishing evaluation indicator systems, evaluation methods, evaluation result analysis, suggestions and so on (Yi *et al.*, 2011; Wang, 2011; Yang *et al.*, 2012, 2014; Thanh *et al.*, 2015; Liu and Wu, 2015); and
3. *Urban land suitability evaluation*: The fundamental research on urban land use planning and management services comprehensively evaluated the impact of natural, economic and social factors on the land, developing suitability grades for urban land use and rationally distributing and optimizing urban land resources.

Additional considerations of the existing evaluation studies are indicator selection and method use (Joan *et al.*, 2007; Zong *et al.*, 2008; Xu *et al.*, 2011; Khaemba *et al.*, 2012; Saba *et al.*, 2013). From the aforementioned references, there have been few studies evaluating urban land use spaces using the restrictive factors of social and economic development based on the background characteristics of urban natural resources and the current problems. Therefore, this paper, using Shanghai as an example, attempts to perform grade evaluation and zoning for different land use spaces by GIS by identifying the major restrictive factors in current socio-economic development. The results not only provide references for optimizing land structure and future land use planning in Shanghai, but also enrich the ideas and methods of urban land use evaluation.

2. Restrictive indicator identification and data

2.1 Study area

Shanghai is located at the mouth of the Yangtze River and is connected to the two provinces of Jiangsu and Zhejiang. It is China's largest industrial and commercial city and a famous international metropolis, which has become an important economic center in China and the primary city of the Yangtze River Delta. It is being built into an international economic, financial, trade and shipping center. Since China's reform and opening up, the society and economy have developed rapidly, and the population of Shanghai has increased substantially. By 2010, the gross domestic product (GDP) of Shanghai reached approximately 1.72 trillion yuan, the resident population was approximately 23.02 million and urban population accounted for 89.3 per cent of the total population; its urbanization level ranked first in China.

2.2 Restrictive indicator identification

With the rapid population size expansion, large-scale urban construction, high intensity land development and utilization and so on, Shanghai has faced problems such as a shortage of quality water, scarce land resources, increasing risk of land subsidence and localized deterioration of the ecological environment. According to the present background characteristics of land resources, water resources, the ecological and geological environment and the problems associated with the current socio-economic development of Shanghai, based on short plate theory, the major restrictive indicators are identified as follows:

- *Development land per capita*: Development land per capita of Shanghai was approximately 128.30 m^2 in 2009, while the reasonable standard range value in Shanghai is approximately 95.0-110.0 m^2 according to the "code for classification of urban land use and planning standard of development land" (GB50137-2011). Therefore, the development land per capita is over capacity, and the land use structure is unreasonable, which exacerbates the tension of land resources in Shanghai.
- *Proportion of industrial land*: The proportion of industrial land accounting for urban construction land is increasing and was greater than 25 per cent from 1998 to 2009 and even as high as 29.7 per cent in 2009, compared to approximately 5 to 17 per cent of all foreign cities and 5 to 10 per cent of cities in developed countries (Shi *et al.*, 2010). The proportion of industrial land in Shanghai is obviously high, and the transition expansion of industrial land is obvious.
- *Floor area ratio*: In 2009, the average floor area ratio in Shanghai was approximately 0.31, which was higher in the central urban areas but lower in the suburbs, and there were greater differences between districts (counties). While the floor area ratios of the urban centers of some international cities are generally greater than 2.0 (Ding and Li, 2012), some scholars have proposed a proper ratio of approximately 0.9 to 1.2 to control ground subsidence in Shanghai (Yan *et al.*, 2002). In contrast, the ratio is still low as a whole, construction land use efficiency is not high, and the land waste phenomenon is serious in Shanghai.
- *Cultivated land per capita*: The cultivated land of Shanghai decreases yearly; the cultivated land per capita of the agricultural population was only 0.055 hm^2 in 2009, approaching the limit of 0.053 hm^2 identified by the FAO (Sun *et al.*, 2008), and it is considerably lower than the national level of 0.091 hm^2 reported by the State Statistical Bureau in 2009. Therefore, strictly to protect the limited cultivated land resources, it is necessary not only to ensure the food needs of the agricultural population but also to meet the agricultural sustainable development needs of the suburbs.
- *Ambient air quality*: The pollutants SO_2, PM_{10} and nitrogen oxides created by industrial production and vehicle exhaust emissions are the substances that contribute the most to changing the atmospheric

environmental quality. The mean concentration of PM_{10} and the annual daily mean concentration of NO_2 are, respectively, 0.081 and 0.053 mg/m^3 in the central urban areas of Shanghai, higher than the relevant national Grade 2 standards of the "Ambient Air Quality Standard" in 2009. Thus, PM_{10} and NO_2 are the most important influencing factors.
- *Water resource conditions*: Shanghai is a typical city with a shortage of quality water. In 2009, the water quality evaluation results of 16 main rivers showed that the water quality pollution of river networks is serious, and the proportion of rivers better than Class III water (including Class III) is only 28.7 per cent (Shanghai Water Authority, 2009). Water environmental issues have become one of the important constraints on economic and social sustainable development in Shanghai.
- *Land subsidence*: Research has found that the main factors affecting land subsidence are groundwater exploitation, followed by ground engineering load and other factors (Chen *et al.*, 2009). Although Shanghai has strengthened the controls of groundwater exploitation and the number of high-rise buildings constructed, the average amount of land subsidence was still 5.2 mm in 2009, and it is 5.6 mm in the central urban areas. Therefore, to maintain land subsidence in a safe and controllable state requires significant effort.

In addition, considering the constraints of natural conditions and the impacts of human activities in Shanghai, the suitability of the natural foundation for construction, the potential for geological disasters and soil environmental quality are incorporated into the restrictive indicator system, and the water resources condition is represented by a comprehensive index of water quality. Based on the above analysis, 11 major restrictive indicators are identified.

2.3 Data

2.3.1 Data sources

The main data sources were as follows:
- Shanghai Statistical Yearbook in 2010 and 2011 and Shanghai Statistical Yearbook of Districts (Counties) in 2010;
- Second Shanghai Land Survey Database (2009);
- Shanghai Water Resources Bulletin in 2009;
- Shanghai Geological Environment Bulletin in 2009;
- Contour Map of Shanghai Land Subsidence in 2009; and
- Atlas of Shanghai Urban Geology (Wei *et al.*, 2010).

2.3.2 Data processing

According to the Second Shanghai Land Survey Database, statistical data for various restrictive indicators were imported into a district (county) boundary layer attribute table using ArcGIS software, version 10.0. The indicator of land subsidence was obtained by digitizing a contour map of Shanghai land subsidence in 2009; three indicators of the suitability of natural foundation for construction, potential for geological disaster and soil environmental quality were obtained by digitizing a suitability division map of the foundation for construction, a potential geological disaster zoning map and an environmental quality assessment plan for topsoil and assigning values for them according to five grades, with higher grades indicating weaker, more restrictive and smaller values (Table I). Then, the various indicators were processed into raster layers with a cell size of 30 m × 30 m, and the raster layers were submitted to standard processing with maximum difference normalization methods for data preparation of restrictive evaluation subspaces; each raster layer consisted of approximately 7.5 million cells.

3. Research methods

3.1 Dividing land subspaces

According to the Second Shanghai Land Survey Database, regarding land use classification and planning, the study area (main terrene) was divided into four subspaces, that is, urban construction, industrial development, agricultural production and ecological protection. The urban construction subspace included urban land, rural residential land and land devoted to transportation and other construction. The industrial development subspace mainly included industrial and warehouse areas. The agricultural production subspace included cultivated land, gardens, aquaculture and pond water surfaces and other agricultural land in nine districts (or counties) in the suburbs. The ecological protection subspace included forests, rivers and lakes, beaches, reed land and other unutilized land. The vector data of the four subspaces were extracted from the database with ArcGIS software, version 10.0, and the results are shown in Figure 1. Deducting water area, the total area of the four subspaces was approximately 6,763.6 km^2 (Table II).

3.2 Evaluation indicators and weights

3.2.1 Evaluation indicator selection

Land is a highly complex synthesis, and in small land units, the restrictive factors that impact land use may be a single factor or various agglomerations (Zhang and Yang, 2009). Based on the aforementioned restrictive indicators and the four identified subspaces, the main 11 restrictive indicators were distributed into each subspace (Table III). In the urban construction subspace, the four main indicators of development land per capita, floor area ratio, land subsidence and suitability of natural foundation for construction were chosen to reflect the scale of construction land, land development intensity and natural condition constraints. In the industrial development subspace, the indicators of the annual daily mean concentration of NO_2 and mean concentration of PM_{10} were chosen to reflect the impact constraints of industrial development, and the proportion of industrial land signifies the resource constraints. In the agricultural production subspace, cultivated land per capita and soil environmental quality were selected mainly to indicate cultivated resources and the constraints of soil resources on agricultural production. In the ecological protection subspace, the main factors are the comprehensive index of water quality and the potential for geological disaster, which reflect the constraints of water and geology resources, respectively.

Table I Grades and their values of three digital indicators

Indicators	Grade and value				
Suitability of natural foundation for construction	Excellent	Good	Common	Inferior	Poor
Potential geological disaster	Safe	Low	Middle	Easy	High
Soil environmental quality	Excellent	Good	Common	Inferior	Poor
Value	1	3	5	7	9

Note: Data source: Wei *et al.* (2010)

Figure 1 Distribution of four subspaces in Shanghai

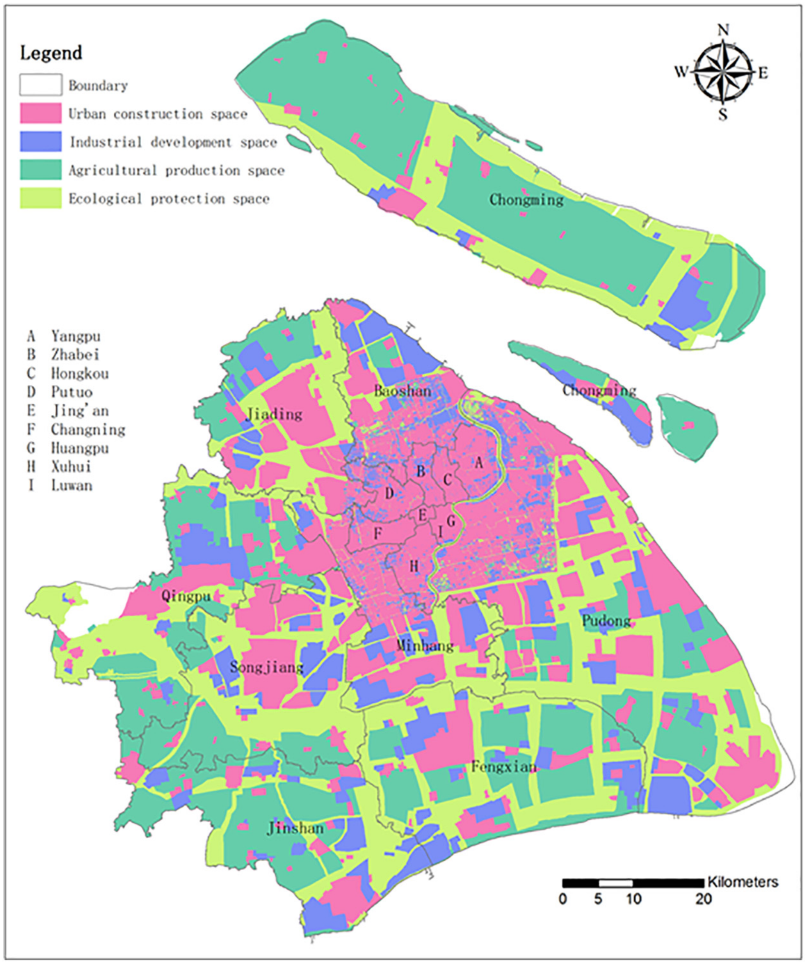


Table II Area statistics of four subspaces in Shanghai (km^2)

Urban construction space	Industrial development space	Agricultural production space	Ecological protection space	Total
1,855.02	900.77	2,115.44	1,892.37	6,763.6

3.2.2 Weighting method

Weights were calculated for each indicator before evaluating the restrictive status of the subspaces. To avoid the influence of subjective factors, the entropy method was adopted to calculate weights. The advantage of the entropy method is that the indicator weight in the ultimate goal is decided by judging the dramatic change extent of the various indicators, which is an objective weighting method. When an indicator value of the various evaluation objects is greatly different, the entropy value is smaller, indicating that the indicator provides a large amount of effective information, and its weight should also be larger and vice versa. The steps of the entropy method are as follows (Yang and He, 2007):

Table III The restrictive indicators of four subspaces and their weights

Urban construction subspace		Agricultural production subspace		Industrial development subspace		Ecological production subspace	
Indicator	Weight	Indicator	Weight	Indicator	Weight	Indicator	Weight
Floor area ratio	0.511	Cultivated land per capita	0.655	Annual daily mean concentration of NO_2	0.300	Comprehensive index of water quality	0.498
Suitability of natural foundation for construction	0.125	Soil environmental quality	0.345	Mean concentration of PM_{10}	0.414	Potential for geological disaster	0.502
Development land per capita	0.243	/	/	Mean concentration of inhalable particulate	0.286	/	/
Land subsidence	0.120	/	/	/	/	/	/
Total	1	Total	1	Total	1	Total	1

- $A = (a_{ij})_{m\times n}$ is the original data matrix, which has m evaluation objects and n evaluation indicators. $R = (r_{ij})_{m\times n}$ is obtained by normalization processing of the original data matrix.

For positive indicators, the formula is as follows:

$$r_{ij} = \frac{a_{ij} - \min_j \{a_{ij}\}}{\max_j \{a_{ij}\} - \min_j \{a_{ij}\}}$$

In contrast, for negative indicators, the formula is as follows:

$$r_{ij} = \frac{\max_j \{a_{ij}\} - a_{ij}}{\max_j \{a_{ij}\} - \min_j \{a_{ij}\}}$$

Then, $F = (f_{ij})_{m\times n}$ is achieved by performing column vector normalization processing for $R = (r_{ij})_{m\times n}$.

- The entropy value of the j indicator is calculated as follows:

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m} f_{ij}\ln(f_{ij})$$

- The difference coefficient of the j indicator is calculated as follows:

$$g_j = 1 - e_j$$

- Based on the difference coefficient of each indicator, the weight of the j indicator is calculated as follows:

$$w_j = \frac{g_j}{\sum_{j=1}^{n} g_j}$$

Table III shows that floor area ratio has higher weight in the urban construction subspace, followed by development land per capita. In agricultural production subspace, cultivated land per capita has the highest weight, approximately 0.655, followed by soil environmental quality. In industrial development subspace, the greatest weight is the proportion of industrial land, followed by annual daily mean concentration of NO_2 and mean concentration of PM_{10}. In ecological protection subspace, the weights of comprehensive index of water quality and potential for geological disaster are equivalent approximately 0.498 and 0.502, respectively.

3.3 Evaluation and zoning methods

3.3.1 Evaluation methods

According to the identified restrictive indicators and their weights of four subspaces, weighted algorithms for raster layers of each subspace indicators are processed with ArcGIS 10.0 software, and the restrictive evaluation indexes of the various subspaces are obtained. A higher index indicates a stronger constraint of the restrictive indicators, and a lower index represents less constraint. Then, the subspace evaluation result is assigned one of five grades by equal intervals in ArcGIS10.0, that is, weaker, weak, common, strong or stronger. Finally, the restrictive grading results of the subspaces are obtained, with a stronger grade indicating a stronger restriction.

3.3.2 Zoning methods

In ArcGIS10, the grading evaluation results undergo raster to vector conversion processing, urban construction and industrial development subspaces are merged into the constructive development region and agricultural production and ecological protection subspaces are merged into the ecological development region. The constructive development region is the activities area of land development and utilization based on urban construction and industrial development subspaces, which can host high-intensity socio-economic activities. The ecological development region is the activities area of land development, utilization, rearrangement and protection based on agricultural production and ecological protection subspaces, which can host agricultural production and ecological protection functions. Then, the restrictive grades of constructive development and ecological development regions are respectively grouped into three class regions, with better classes indicating weaker restrictions, which could include better land use and development. The specific zoning schemes are shown in Table IV, and the zoning results can be finally obtained.

4. Evaluation and zoning results

4.1 Evaluation results

According to the above-mentioned evaluation method, the evaluation results for the restrictive indexes are obtained with

Table IV Zoning schemes

Region name	Class region	Remarks	
Constructive development region	Good	Urban construction and industrial development subspaces	Weaker and weak
	Common		Common
	Inferior		Strong and stronger
Ecological development region	Good	Agricultural production and ecological protection subspaces	Weaker and weak
	Common		Common
	Inferior		Strong and stronger

the "Map Algebra" and "Extract by Mask" tools of spatial analysis in ArcGIS 10.0, and the descriptive statistics information is shown in Table V. According to the statistics information and the status of various subspaces and comparative analysis of the grade results by the different classification methods, to distinguish the internal differences, finally, the evaluation results are assigned to five grades with the "Reclassify" tool in Spatial Analysis by equal intervals. The threshold values and areas of various grades are shown in Table VI, and the grade results are shown in Figure 2.

In the urban construction space [Figure 2(a), Table VI], relatively strong restrictive areas are mainly concentrated in Huangpu, Luwan and Jing'an in the central urban areas; less restrictive areas are mainly distributed in Pudong, while weak restrictive areas are widely distributed in space. Regarding area statistics, the area of the weaker and weak grades is approximately 1,633.26 km^2, accounting for 88.04 per cent of the total area, and the weak grade accounts for 75.2 per cent, while the area of strong and stronger grades accounts for only 1.34 per cent of the total area.

In the industrial development space [Figure 2(b), Table VI], strong and stronger restrictive grade areas are mainly distributed in the suburbs, which are also more industrially developed districts, such as Baoshan, Jiading, Minhang, Songjiang and Putuo in the central urban areas. The area is approximately 397.87 km^2, accounting for 35.9 per cent of the total area, with less restrictive grades mainly distributed in Chongming, Jinshan and Pudong in the suburbs, their area accounting for 42.05 per cent, while weak restrictive grades are distributed in central urban areas, accounting for only 2.12 per cent of the total area.

In the agricultural production space [Figure 2(c), Table VI], restrictive grades of nine districts (counties) in the suburbs are mainly common, weak and weaker, and the area of the three grades are also relatively close, accounting for 35.9, 31.02 and 31.7 per cent of the total area, respectively; the farther away from the center urban area that an area is, the less restrictive the grade is, with less restrictive grades mainly distributed in Chongming. Strong and stronger restrictive grades are scattered in space, with the area accounting for only 1.38 per cent of the total area.

In the ecological protection space [Figure 2(d), Table VI], the restrictive grades are also mainly common, weak and weaker, and they are staggered in the same district (county); the area of common and weak grades is approximately 81.61 per cent of the total area, mainly distributed in the suburbs, and strong and stronger restrictive grades are scattered in space, with the area accounting for only 2.11 per cent of the total area.

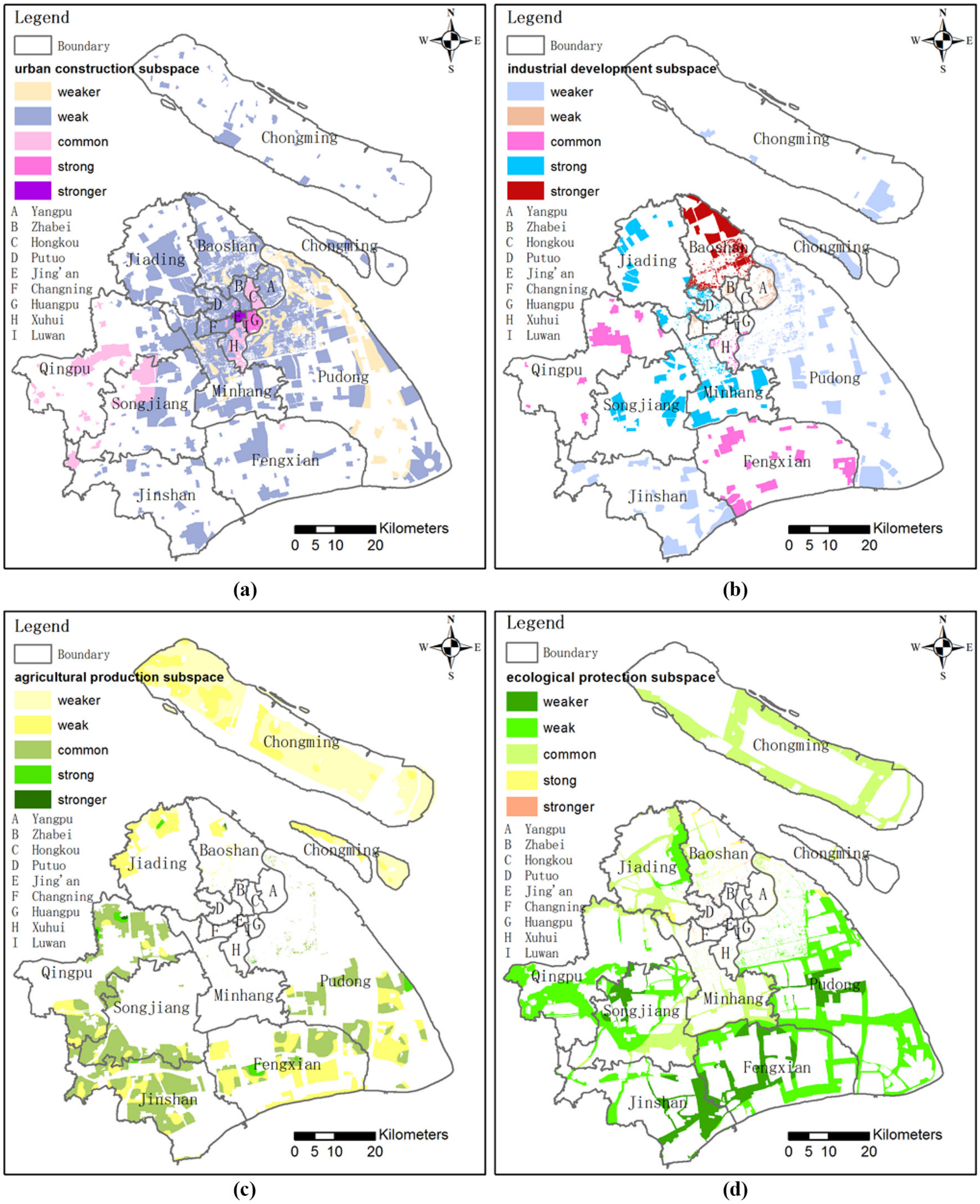
Table V Descriptive statistics of the restrictive evaluation indices of subspaces

Subspace types \ Items	Maximum	Minimum	Mean	SD	Total cells
Urban construction subspace	0.67	0.18	0.33	0.05	2,052,820
Industrial development subspace	0.88	0.32	0.56	0.18	1,000,487
Agricultural production subspace	0.80	0.16	0.36	0.10	2,342,207
Ecological protection subspace	0.87	0.17	0.42	0.10	2,098,380

Table VI The threshold values and areas of various grades of subspaces (area: Km^2)

	Urban construction subspace		Industrial development subspace		Agricultural production subspace		Ecological protection subspace	
Rank	**Threshold**	**Area**	**Threshold**	**Area**	**Threshold**	**Area**	**Threshold**	**Area**
Weaker	<0.28	238.22	<0.43	378.78	<0.29	670.68	<0.31	307.93
Weak	(0.28, 0.38)	1395.04	(0.43, 0.54)	19.09	(0.29, 0.42)	656.21	(0.31, 0.45)	843.70
Common	(0.38, 0.47)	196.93	(0.54, 0.65)	179.48	(0.42, 0.54)	759.41	(0.45, 0.59)	700.70
Strong	(0.47, 0.57)	17.41	(0.65, 0.77)	222.05	(0.54, 0.67)	25.80	(0.59, 0.73)	33.71
Stronger	≥0.57	7.42	≥0.77	101.37	≥0.67	3.34	≥0.73	6.33
Total	–	1,855.02	–	900.77	–	2,115.44	–	1,892.37

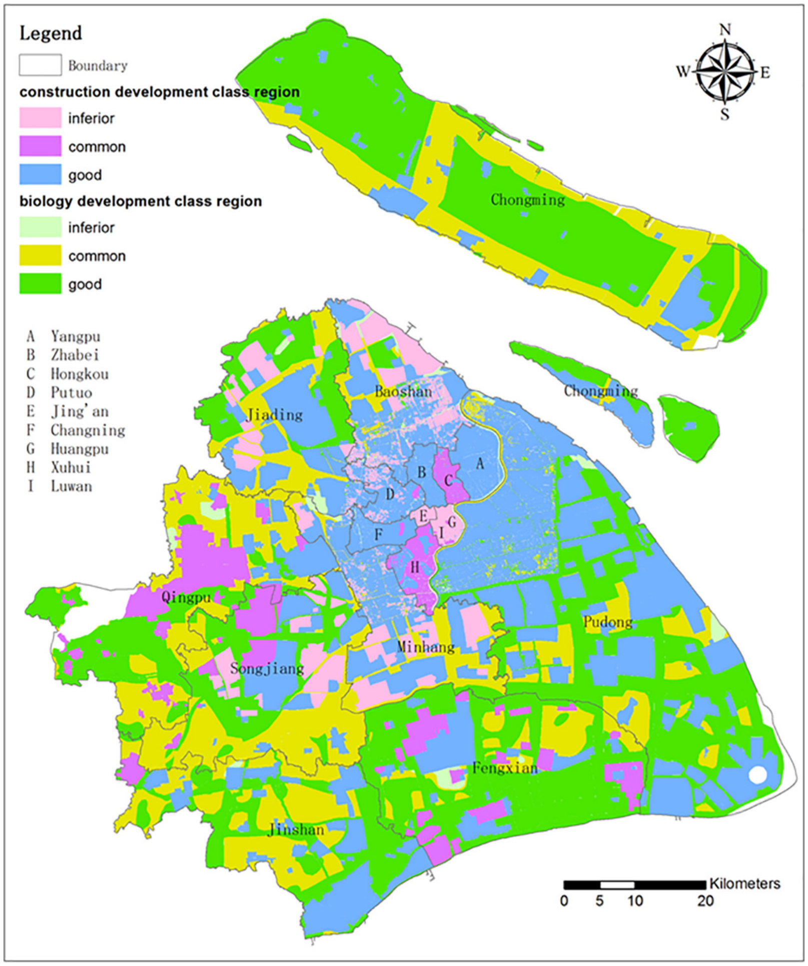
Figure 2 The grade evaluation results of various subspaces



4.2 Zoning results

According to the identified restrictive zoning scheme in Table IV, the overlay analysis and classification are processed to the vector data of various subspaces, and the zoning results and the statistics area of the class region are obtained and shown in Figure 3 and Table VII. From the spatial distribution, the different class regions of constructive development zones are distributed in all of the central urban areas and suburbs, and good regions are widely distributed, mainly concentrated in the suburbs and parts of the central urban areas, such as Putuo, Changning, Zhabei and Yangpu. The inferior region is mainly distributed in Baoshan, Minhang, Songjiang, Jiading, Jing'an, Luwan and Huangpu in the central urban areas, and the common region is mainly located in Fengxian, Qingpu and Hongkou, Xuhui in the central urban areas. Ecological development regions are mainly located in the suburbs with less distribution in the central urban areas, and inferior regions are scattered in the central urban areas; common regions and good regions are

Figure 3 The zoning results



staggered in the suburb districts (counties), distributed widely and concentrated in sections.

From the statistical analysis, the area of the constructive development zone is approximately 2,755.79 km^2, accounting for 40.7 per cent of the total area of the four subspaces, and in the constructive development zone, the area of the good region is approximately 2031.13 km^2, accounting for 73.7 per cent of the total area; only approximately 12.6 per cent of the area belongs to the inferior region. The area of the ecological development region accounts for 59.3 per cent of the four subspaces' total area, in which the area of the common and good regions is approximately 3,938.63 km^2, accounting for 98.3 per cent of the total area, and the inferior region area only accounts for 1.7 per cent.

The class area percentage analysis of districts (counties) in Table VII indicates that:

- in the central urban areas, the area percentages of the inferior regions in Huangpu, Jing'an and Luwan are all greater than 85 per cent for the constructive development zone, while the area percentages of the good regions in Yangpu, Zhabei, Changning and Putuo are also higher; except for the high area percentage of the common region in Hongkou, the area percentages of the inferior regions in other districts are high for the ecological development region;
- in the inner suburbs, the area percentage of the good region of the constructive development zone is higher than that of the other two classes and that of the common region is very small or even close to zero; the area percentages of the good and common regions of the ecological development zone are both higher than that of the inferior region, and the sum of them is greater than 75 per cent; and
- in the outer suburbs, except for Songjang, the area percentage of the inferior regions of other districts (counties) is zero for the constructive development zone, while the area percentage of good and common regions of the ecological development zone are large, and the sum of them in the districts (counties) is greater than 97 per cent.

5. Conclusions and discussions

- To address a series of problems in Shanghai, based on the short plate theory, 11 major restrictive indicators that will constrain the socio-economic development of Shanghai are identified, a restrictive grading evaluation

Table VII The area of class region and the area percentage of class region in districts (counties)

Name	Constructive development Class region			Ecological development Class region		
	Good	Common	Inferior	Good	Common	Inferior
Total area (km^2)	2,031.13	376.42	348.24	2,478.52	1,460.11	69.18
Central area (%)						
Huangpu	1.81	1.71	96.48	0.00	2.51	97.49
Jing'an	1.74	0.33	97.93	0.00	0.00	100.00
Luwan	0.13	14.02	85.85	0.00	0.75	99.25
Xuhui	29.79	70.18	0.04	0.61	0.64	98.75
Yangpu	99.86	0.12	0.02	0.00	1.22	98.78
Hongkou	9.58	90.40	0.02	0.00	98.36	1.64
Zhabei	99.75	0.14	0.11	0.00	7.70	92.30
Changning	96.76	3.21	0.03	0.04	0.01	99.95
Putuo	75.21	2.58	22.21	0.16	0.05	99.79
Inner suburbs (%)						
Pudong	100.00	0.00	0.00	74.48	23.73	1.79
Minghang	67.21	0.01	32.77	8.92	87.68	3.40
Baoshan	58.06	0.01	41.93	27.44	49.83	22.73
Jiading	77.02	0.00	22.98	56.52	40.28	3.20
Outer suburbs (%)						
Jinshan	93.88	6.12	0.00	48.81	50.86	0.34
Songjiang	47.48	22.79	29.74	41.90	58.07	0.03
Qingpu	28.99	71.01	0.00	46.62	51.01	2.37
Fengxian	47.44	52.56	0.00	81.05	17.31	1.64
Chongming	100.00	0.00	0.00	70.82	29.18	0.00

of various land use spaces is achieved with GIS spatial analysis, and land development restrictive regions are processed according to the results of the evaluation; then, based on space and quantity, the land development restrictive status of the whole and the districts (counties) of Shanghai is analyzed. The results provide an early warning system and a reference for rationally adjusting the intensity of land development. The study also evaluates ideas and reference cases for other cities.

- The grade evaluation results show that in urban construction space, the weak and weaker restrictive grades have wide distribution in space, accounting for 88.04 per cent of the total area, while relatively strong restrictive regions are mainly distributed in the central urban area and account for less of the total area. In the industrial development space, the relatively strong restrictive region is mainly distributed in the more developed industrial districts (counties) in Shanghai, and the less developed industrial districts (counties) mainly present weaker restrictions. In the agricultural production space and ecological protection space, the main restrictive grades are common, weak and weaker, and the area of the three grades accounts for 98.62 and 97.89 per cent of the total area of the respective spaces. In the agricultural production space, the farther from the center urban areas an area is, the lower the restrictive grade is.
- The good region of the constructive development zone is widely distributed and mainly concentrated in the suburbs and parts of the central urban areas, accounting for 73.7 per cent of the total area. The inferior region is mainly concentrated in Huangpu, Jing'an and Luwan in the central urban areas, and the area percentages accounting for their respective areas of districts (counties) are all greater than 85 per cent. The common and good regions of the ecological development region are mainly distributed in the suburbs and are concentrated in sections, accounting for 98.3 per cent of the total area, and the sum area of them is greater than 97 per cent of their respective district (county) area. Expect for Hongkou, the area percentages of the inferior region in the central urban areas are all greater than 90 per cent. As a whole, the area of inferiority is smaller.
- There is significant development potential in Shanghai. However, the land development intensity of Huangpu, Jing'an and Luwan should be controlled; ecological protection in the central urban area should be strengthened; and the internal land development differences of the districts (counties) should be emphasized. So Shanghai should strengthen land use structure adjustment, innovate land use modes, reduce the proportion of industrial land and development land per capita, perfect the economical land use standards, improve the development intensity of the suburb industrial land, effectively strengthen the natural environment comprehensive control and protect the ecological land in the central urban areas, reduce the constructive development of the ecological land with stronger restrictive grades, upgrade the floor area ratio of the suburbs, at the same time pay attention to potential mining, meet the land needs of urban

development by the measures including the stock optimization, flow efficiency, quality improvement and so on.

- With the improvement of related urban problems, land use structure optimization and development intensity adjustment of urban land, the main restrictive indicators will change, and for the cities with different resource background elements, their restrictive indicators will also have some particularity and differences. The restrictive evaluation indicators of cities are not static but dynamic, and there are differences between different cities. In addition, with land use changes, urban land subspaces will change; therefore, re-evaluating and zoning should be undertaken in different urban land use spaces by re-identifying the restrictive indicators in different periods.

References

Amnon, F. (2004), "The potential effect of national growth-management policy on urban sprawl and the depletion of open spaces and farmland", *Land Use Policy*, Vol. 21, pp. 357-369.

Chen, Z., Luo, Z. and Li, Q. (2009), "Analysis of cause of land subsidence in Shanghai", *Journal of Geodesy and Geodynamics*, Vol. 29 No. 8, pp. 90-94.

Ding, Y. and Li, Y. (2012), "The feasibility study to improve floor area ratio on urban planning: a case study of the central area in Shanghai", *ChengShi Jianshe LiLun Yan Jiu*, Vol. 19, available at: http://d.g.wanfangdata.com.cn/Periodical_csjsllyj201219698.aspx

Douglas, P.W., Murray, A.T. and Phinn, S.R. (2003), "Integrating spatial optimization and cellular automata for evaluating urban change", *The Annals of Regional Science*, Vol. 37 No. 1, pp. 131-148.

Fu, B., Chen, L. and Ma, C. (1997), "The index system and method of land sustainable use evaluation", *Journal of Natural Resources*, Vol. 12 No. 2, pp. 112-118.

Haberl, H. and Schandl, H. (1999), "Indicators of sustainable land use-concepts for the analysis of society-nature interrelations and implications for sustainable development", *Environmental Management and Health*, Vol. 10 No. 3, pp. 177-190.

Jane, S. and Chris, M. (2000), *Land-use Planning for Sustainable Development, in Sustainable Community Development Series*, CRC Press LLC.

Joan, M., Joan, P., Josep, M.M. and María, J.C. (2007), "A land suitability index for strategic environmental assessment in metropolitan areas", *Landscape and Urban Planning*, Vol. 81 No. 3, pp. 200-212.

Khaemba, W.A., Mwasi, B. and Opata, P.G. (2012), "Urban land suitability assessment using geoinformation techniques for Kisumu municipality in Kenya", *IJRRAS*, Vol. 13 No. 2, pp. 522-530.

Liu, G. and Wu, M. (2015), "Benefit evaluation of urban construction land use in developed area: a case study of Guangdong province", *Acta Agriculturae Jiangxi*, Vol. 27 No. 11, pp. 99-102.

Liu, H. and Zhang, A. (2008), "Review of progress of control on urban land expansion in foreign countries", *China Land Science*, Vol. 22 No. 5, pp. 72-76.

National Bureau of Statistics of China (1994/2011), *China City Statistical Yearbook*, China statistics Press, Beijing.

Saba, R.S., Abdolrassoul, S.M., Seyed, M.M. and Ali, A.A. (2013), "Sustainability through uncertainty management in urban land suitability assessment", *Environmental Engineering Science*, Vol. 30 No. 4, pp. 170-178.

Shanghai Water Authority (2009), *Shanghai Water Resources Bulletin*, available at: www.shanghaiwater.gov.cn/web/sw/2009_1_1.jsp

Shi, Y., Fan, W. and Pu, S. (2010), "Comparative analysis of scale, structure and benefits of metropolitan industrial land in China", *Tongji University Journal Social Science Section*, Vol. 21 No. 2, pp. 25-31.

Sun, A., Zhang, F. and He, Q. (2008), "Study on the present situation, causes and countermeasures of cultivated land utilization in China", *Agricultural Economy*, No. 11, pp. 36-39.

Thanh, T.N., Ann, V., Tran, V.Y., Nele, D., Thuy, C.T. and Eric, V.R. (2015), "Design of a GIS and multi-criteria based land evaluation procedure for sustainable land-use planning at the regional level", *Agriculture, Ecosystems and Environment*, Vol. 200, pp. 1-11.

Wang, Y. (2011), "Study on the intensive use of urban land – a case study of hill area in the middle of Sichuan province", *Energy Procedia, No.* 5, pp. 85-89.

Wei, Z., Zai, G. and Yan, X. (2010), *Atlas of Shanghai Urban Geology*, Geology Press, Beijing.

World Commission on Environment and Development (WCED) (1987), *Our Common Future*, Oxford University Press, Oxford.

Xu, K., Chunfang, K., Jiangfeng, L., Zhang, L. and Wu, C. (2011), "Suitability evaluation of urban construction land based on geo-environmental factors of Hangzhou, China", *Computer and & Geosciences*, Vol. 37 No. 8, pp. 992-1002.

Yan, X., Gong, S., Zeng, Z., Jun, Y., Guo, S. and Tie, W. (2002), "Relationship between building density and land subsidence in Shanghai urban zone", *Hydrogeology and Engineering Geology*, Vol. 6, pp. 21-25.

Yang, J., Yang, Y. and Wen, T. (2012), "Development of evaluation model for intensive land use in urban centers", *Frontiers of Architectural Research*, Vol. 1 No. 4, pp. 405-410.

Yang, L. and Xuefeng, H. (2007), "On the sustainable development index of trade based on entropy method – exemplified by the empirical research of Zhengjiang province", *Journal of Ningbo University (Liberal Arts Edition)*, Vol. 20 No. 1, pp. 22-27.

Yang, Q., Duan, X., Ye, L. and Zhang, W. (2014), "Efficiency evaluation of city land utilization in the Yangtze River Delta using a SBM-undesirable model", *Resources Science*, Vol. 36 No. 4, pp. 712-721.

Yi, X., Chao, F. and Ke, Y. (2011), "Recent 10 year land use change and evaluation of their performance, in Chongqing, China", *Energy Procedia, VoL.* 5, pp. 457-461.

Zhang, H. and Yang, Y. (2009), "Assessment of limiting factors of undeveloped agricultural land over newly reclaimed areas in Yili, Xinjiang", *Resources Science*, Vol. 31 No. 12, pp. 2009-2015.

Zhang, X., Wu, Y. and Shen, L. (2011), "An evaluation framework for the sustainability of urban land use: a study of capital cities and municipalities in China", *Habitat International*, Vol. 35, pp. 141-149.

Zhu, C. and Zhang, J. (2008), "Dilemmas and reasons of urban non-construction land protection", *City Planning Review*, Vol. 32 No. 11, pp. 41-45.

Zong, Y., Wang, R., Wang, C. and Zhang, L. (2007), "Ecological suitability assessment on land use based on potential-constrain approach: the case of urbanized areas in Dalian city, China", *Geographical Research*, Vol. 26 No. 6, pp. 1117-1127.

Corresponding author

Yuan Cao can be contacted at: caoyuanyusn86@163.com