Chin. Geogra. Sci. 2019 Vol. 29 No. 2 pp. 352–362
https://doi.org/10.1007/s11769-019-1032-4

Springer Science Press
www.springerlink.com/content/1002-0063

# Spatial Function Regionalization Based on an Ecological-economic Analysis in Wuxi City, China

SUN Wei[1, 2], CHEN Wen[1, 2, 3], JIN Zhifeng[4, 5]

(1. *Nanjing Institute of Geography & Limnology*, *Chinese Academy of Sciences*, *Nanjing* 210008, *China*; 2. *Key Laboratory of Watershed Geographic Sciences*, *Chinese Academy of Sciences*, *Nanjing* 210008, *China*; 3. *College of Resources and Environment*, *University of Chinese Academy of Sciences*, *Beijing* 100049, *China*; 4. *School of Resource and Environmental Sciences*, *Wuhan University*, *Wuhan* 430079, *China*; 5. *Jiangsu Research Center of Land and Resources*, *Nanjing* 210017, *China*)

**Abstract:** As a result of rapid urbanization in China, urban sprawl has increased rapidly, and land-use regulation and smart urban growth are equally important. Spatial function regionalization can provide the scientific groundwork for the regulation of land use and protection. This paper probes the system of evaluation indices and applies the methods of spatial analysis and classification clustering to the calculation of the ecologically significant value and economically significant value in each evaluation unit. After use of a classification matrix integrated by the two significant values, city space can be divided into four functional types, namely, feasible development area, moderate development area, moderate conservation area and prohibited exploiting area, and these are the basis for spatial development and control.

**Keywords:** spatial function regionalization; spatial analysis; ecologically significant value; economically significant value; urbanized region

**Citation:** SUN Wei, CHEN Wen, JIN Zhifeng, 2019. Spatial Function Regionalization Based on an Ecological-economic Analysis in Wuxi City, China. *Chinese Geographical Science*, 29(2): 352–362. https://doi.org/10.1007/s11769-019-1032-4

## 1 Introduction

Urban sprawl is posing an increasingly serious threat to the ecological environment, particularly to agricultural soil conservation. China is now entering a new stage of industrialization and urbanization, with the proportion of the entire urban population rising from 19.39% in 1980 to 57.35% in 2016. The area of built district in 2016 reached 54 331.5 km$^2$ (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2018). Indeed, cities are expanding at a breathtaking pace. The expansion of urban construction, the emergence of increasing industrial development zones and the improvement of transportation facilities are taking away green space and increasing disturbances to the ecosystem, e.g., the disappearance of high-quality soil, the obsolescence of wetlands, the impairment of biological diversity, increased vulnerability in natural disasters, and damage to historic monuments (Bryant et al., 1982; Yokohari et al., 2000; Lin and Zhang, 2015; Theurillat et al., 2016). Furthermore, damage to the ecological environment will usually have a negative impact on agriculture, inducing a grain supply crisis and affecting both sustainable social and sustainable economic development (Brown, 1995; Hanna et al., 2007; Gaspar et al., 2017; Menegaki and Tugcu, 2017).

Developed cities or regions need to not only undertake the function of high-degree population and indus-

Received date: 2018-04-02; accepted date: 2018-08-02
Foundation item: Under the auspices of the National Science Foundation of China (No. 41871119, 41871209)
Corresponding author: CHEN Wen. E-mail: wchen@niglas.ac.cn
© Science Press, Northeast Institute of Geography and Agroecology, CAS and Springer-Verlag GmbH Germany, part of Springer Nature 2019

trial agglomeration, but also maintain a good ecological environment. Besides the division of labour within production, they also need to divide labour between development and protection. American scholar Friedman, in the book ‘Regional Development Policy’ published in 1966, discussed the Core and Periphery Theory and systematically expounded the inevitable causes for the existence of the spatial function regionalization among regions. Geologists have always adhered to the idea of regional development in accordance with local conditions, while zoning and regionalization is just a typical method for embodying this idea intensively, scientifically recognizing geographical environment, judging comparative advantages, and cognizing the differences of spatial conditions (Fan, 2007). Therefore, it is easier for geography to give a scientific explanation by judging the pattern of space division for development and protection of each region through spatial function regionalization, and taking it as the regional projection and spatial expression of the paradigm of spatial balanced division.

In the early 19th century, geographers began to attempt regionalization based on their cognition of natural tokens. German geographer Humboldt’s Isotherm Table, Russian geographer Dokuchaev’s Soil Belt Theory and Hommever’s Four-grade Geographical Units Theory initiated the research on the spatial regionalization of land use (Wu et al., 2003). Based on natural and economic elements, some researchers studied spatial function regionalization to guide land use and space control. As early as the 1920s, the United States initiated started-land-use zoning, stipulating the scope of zoning, types of utilization and permitted maximums of exploitation and in the 1960s, issued a series of regulations to ensure the implementation of land-use zoning (Baics and Meisterlin, 2016; Lin et al., 2016). Land carrying capacity could be assessed with potentially restrictive elements, thereby categorizing the assessed land into four types of environmentally sensitive zones that are ecologically critical areas in perpetuity (Knaap, 2001). McHarg (1997) denoted the natural and economic attributes of a research area on a map and divided the development subarea using a map overlay. A Sino-German joint project, the Jiangning Nanjing Project, proposed the notion of a matrix classification of ecological conservation value versus economic and social development, which was quite conducive to making overall plans for land use in terms of both the environment and the economy.

The data collection, experiment analysis, and data processing technology applied in geography have employed various types of regionalization based on different objectives. For example, natural regionalization, based on elements such as climate, terrain, physiognomy, soil and vegetation, is a geographical synthesis which consists of zones of different grades (Fu and Pan, 2016; Peng et al., 2017). Agricultural regionalization is used to compartmentalize agricultural regions into different types and zones according to their interior similarities and exterior distinctions, in terms of agricultural characteristics and conditions, providing a basis for adjusting the agricultural structure and distribution. Economic regionalization is based on the regional division of labour and development phases and guiding the specialized development of the economic zones, thus shaping the new idea of the regional division of social labour (Xu et al., 2017; Zou and Zhang, 2017). Ecological function regionalization divides an area into different functional regions according to the elements, sensitivity and service functions of the ecological environment providing a scientific basis for regional ecological security, the exploitation of natural resources, and the distribution of productive forces (Bailey et al., 1985; Fu et al., 2001). The above-mentioned types of regionalization are development-oriented theories, primarily from ex-parte perspectives such as the exploitation of natural resources, ecological conservation, and economic development. The research on spatial function regionalization with regard to the ecological environment and economy, simultaneously reflecting development guidance and space control, is becoming a hot topic that is expected to provide a scientific basis for spatial regulation by the government. Spatial function regionalization is used to divide the region into several functional areas based on the ecological environment and economic development, which aims to simulate the spatial balance among the economy, the population, natural resources and the environment.

In China, the central government has brought forward the strategy of Principal Function Area (PFA) in recent years, which shall be divided into four principal functional zones of optimal development, key development, restricted development and prohibited development, according to the bearing capacity, development potential, and current development state of resource environment. Fan (2015) developed a regional function identification index system consisting of 9 quantifiable indexes (water resource, land resource, ecological importance, ecological vulnerability, environmental capacity, disaster risk, economic development level, population concentration, and traffic dominance) and 1 qualitative index (strategic choice), researched and discussed the methods, and formed the first scheme for division of PFA in China. Many scholars have attempted to research the division of PFA at provincial level (Liu, 2007; Zhang and Li, 2007; Zhao et al., 2009). The planning of PFA has been formulated only at national and provincial levels, which has caused it be such that the regional functional areas subject to space control on national and provincial scales include four types, namely the urbanized area, food safety area, ecological safety area, cultural and natural heritage area, and on this basis, the areas are converted into 4 principle function areas with county-level administrative division as the unit. Then, it is necessary to further explore how to implement, at the municipal and county levels, the principle function determined by the central and the provincial governments, and especially, how to select evaluation units and indexes and realize comprehensive integration of subareas.

This paper starts from the assessment of ecologically and economically significant value. Next, it discusses the methods and technical courses of spatial function regionalization at municipal and county levels, including elements selection, internal relationship, logic analysis and application. Wuxi City has been taken as a case study to experiment with spatial function regionalization, with towns as the units.

## 2 Materials and Methods

### 2.1 Study area

Wuxi City, where plains and water bodies overlap, is located in the humid subtropics south of the Yangtze River and north of Taihu Lake (Fig. 1). It has an area of 4627 km$^2$, with plains accounting for 70% and water surface for 20%. It is described as a land flowing with milk and honey because of its fertile soil, ample water resources, long-term development of agriculture and water conservancy, good cultivation condition for paddy, and abundant fishery resources. Wuxi, a charming ancient city with a history of Wu culture that stretches back more than 2500 years, is also a historical centre of the Yangtze River Delta. It is well known for its delicate gardens and its preservation of the primitive style of regions surrounding the rivers and lakes in South China during the Ming and Qing dynasties. It is a delight for travellers and is called the ‘Pearl of Taihu Lake’.

Wuxi is also the city that has the highest economic potential and is the closest to Shanghai, China’s leading economic centre. The ancient Wuxi was set alongside the Beijing-Hangzhou Grand Canal linking the Taihu Lake drainage area and North China water transport, which benefited Wuxi during its development into the largest city in southeast China (Sun, 2013). In the 1980s, Wuxi developed township and village enterprises as supplementary industries for state-owned enterprises in

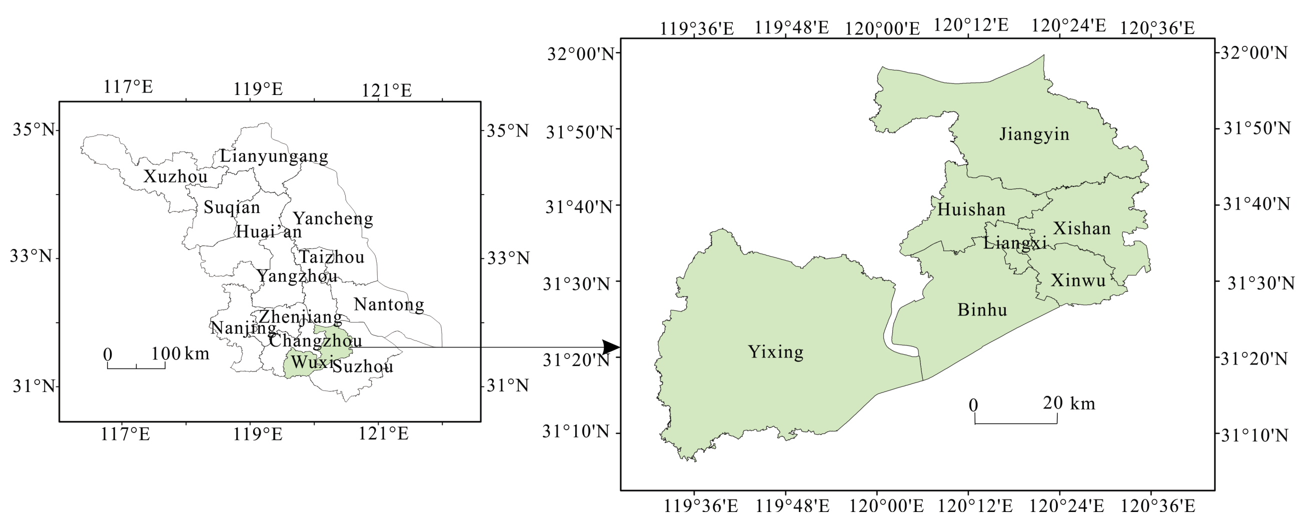


**Fig. 1** Location of Wuxi City in Jiangsu Province

Shanghai with the help of the Sunday Engineers Program. In the 1990s, Pudong Development in Shanghai attracted a great amount of FDI to Wuxi. Meanwhile, vast foreign and domestic investments flocked into Wuxi because of its geographical advantage, profound cultural accumulation, highly cultured population, peaceful and stable society, and convenient public service. Wuxi transformed itself from a region dominated by township and village enterprises and state-owned enterprises to one of the most globalized in China, the focus of both foreign direct investment (FDI) and high-tech centres (Yuan et al., 2014). FDI in Wuxi city has risen dramatically, reaching US$4.5 billion in 2016 (Jiangsu Provincial Bureau of Statistics, 2017). It has been consistently ranked among the top ten most competitive cities in China. Investment in manufacturing rapidly increased and attracted a labour force of more than 2 million outside the city, which resulted in rapid urban land expansion. According to the annotations of the remote sensing photos of SPOT4 and TM, the built-up area increased by 831.3 $km^2$ from 1985 to 2016 (Fig. 2).

The rapid urban sprawl has deteriorated the natural and cultural environment as outlined below.

(1) Damaged agricultural resources. Urban sprawl took away a large amount of cultivated land, which decreased from 2764.0 $km^2$ in 1985 to 1803.8 $km^2$ in 2016. High-quality soil was demolished and 35% of the permeable paddy soil was occupied by construction land.

(2) Increased disaster risk. The disasters with a substantial impact on the area are mainly flood disasters and ground sedimentation. The region is impacted by the subtropical monsoon climate and low and flat terrain, with an average elevation of only 4 m, and it is Vulnerable to the threat of flooding. Moreover, construction land expansion, economic and population growth, and serious ground sedimentation caused by overusing groundwater have increased the vulnerability of these disasters.

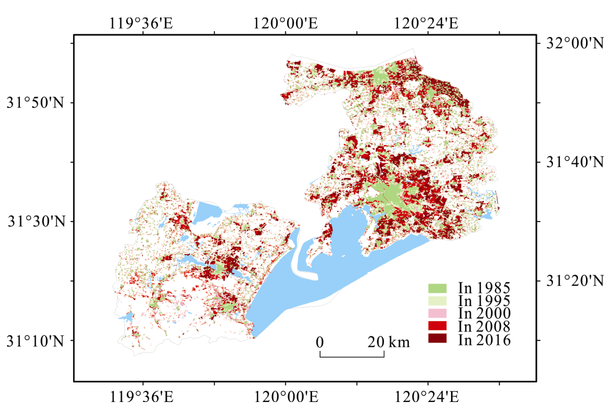


**Fig. 2** The built-up area expansion in Wuxi from 1985 to 2016

(3) Demolished historical and cultural relic. A picture of ancient city and towns, rivers, lakes, and bridges display the essence of the traditional culture of Wuxi City. However, the process of industrialization and urbanization has a strong impact on conservation of the cultural heritage described above, not only damaging ecological sights but also increasing the vulnerability of flooding for the low-lying ancient towns as a result of the change in the river network system caused by development in surrounding areas.

Furthermore, Wuxi recently proposed a development strategy, which principally would prioritize an export-oriented economy. Wuxi would also develop high- tech and traditionally advantageous industries in the area alongside vital communication lines, including the Shanghai-Nanjing Express, Yangtze Riverside, and Taihu Lakeside areas. The Yangtze Riverside area would develop heavy and chemical industries, relying on the shipping and water resources of the Yangtze River. The area alongside Taihu Lake would develop tourism. It is foreseeable that the implementation of this strategy will increase the intensity of spatial exploitation and pressure on the natural and ecological environment.

For these reasons, ecological-economic oriented spatial function regionalization, targeting a land area of 4627 $km^2$ and 64 units of towns in Wuxi City, is preferred to create the intended spatial regulation scenario and policy guarantee. Natural and human ecosystems could largely be protected while the economy maintains rapid growth.

### 2.2 Methods of spatial function regionalization

According to theories of regionalization, this paper proposes technical routes of spatial function regionalization that primarily follow four levels: elements selection, internal relationship, logic, and application.

(1) Elements level refers to the selection of basic spatial units and assessing elements. The elements are divided into two categories: natural ecological and social economic. The principle underlining the selection of the elements is to first reflect the distinctions and characteristics of the spatial units, and second to reflect that the elements have a certain particularity and can not replace one another (Sun, 2013). The elements are also restricted by data accessibility.

Ecological elements are mainly used to assess the relative ecologically significant value, which represent the need to protect the ecological system and maintain the original condition of the natural environment, including climate modulation, water regulation, soil erosion prevention, material recycling, decontamination, biological diversity, recreational value, *etc*. They are essentially composed of the indices of ecosystem services and ecological vulnerability. Ecosystem services indicates the benefits obtained directly or indirectly from an ecosystem and primarily refer to the benefits of the conservation of water sources, biological diversity and special ecological environments, such as mountain, forest, wetland and a special agriculture region, along with natural and cultural heritage. Ecological vulnerability, also referred to as the environmental sensitivity index, includes disaster risk, environment carrying capacity, ecological costs, *etc*.

Economic elements primarily assess the demand of economic development. They focus the selection on economic resources supply capacity, land exploitation benefit and development potential. The selected elements should reflect the intensity of economic development demand, such as the quality and quantity of water and soil resources, per capita revenue, output of conruction land and fixed assets, and transport accessibility (Table 1).

In terms of surface-state elements such as ecological vulnerability, spatial analysis technology can be applied over each element in the definite units to calculate ecological vulnerability. In terms of linear elements, such as the distance from the assessed units to the regional centres, a network analysis can be applied to determine the value. Statistical elements are determined through statistical annual data. Elements such as historical relic, tail water discharge condition, *etc*., are determined by the method of Delphi from expertise information. On this basis, through synthesizing and standardized extreme processing of the data as in Equation (1), a synthesized database for spatial function regionalization may be established in which the formula for the indices is explained as follows:

$$x = \frac{x' - x'_{\min}}{x'_{\max} - x'_{\min}} \tag{1}$$

where $x$ indicates the normalized value, $x'$ indicates the value of the element, $x'_{\max}$ indicates the maximum value of the element, while $x'_{\min}$ indicates the minimum value of the element.

(2) Internal relationship level is used to analyse the relative weights of the elements. These weights generally depend on regional natural, social and economic distinctions and are obtained through subjective and objective assessments. The subjective assessment methods

**Table 1** Elements of spatial function regionalization

| Elements selection | Classification | Index |
|---|---|---|
| Natural ecological elements | Ecosystem services | Drinking water sources |
| | | River and lake |
| | | Wet land |
| | | Mountain and forest |
| | | Historical relic |
| | Ecological vulnerability | Disaster risk (Flood; Earthquake) |
| | | Environmental carrying capacity (Atmosphere and water; Tail water discharge condition) |
| | | Ecological cost (Water density; Soil quality) |
| Social economic elements | Water and land resource supply | Water quantity and quality |
| | | Land quantity and quality |
| | Development benefit | Per capita revenue |
| | | Output of construction land |
| | Development potential | Human capital |
| | | Transport accessibility |

usually include Delphi, AHP, and a comparison of the elements in pairs based on previous experience. Although these methods are relatively mature and easy to operate, they are not very objective. The objective assessment method is based on a mathematical rule, such as the entropy method, OLS, maximum variance method, *etc*., to calculate weight (Sun et al., 2018). Because many of the selected elements cannot be expressed quantitatively, their weights have been identified based on the characteristics of the natural environment and economic distinctions of the regions.

(3) Logic level is used to evaluate and mark the relative ecologically and economically significant value of each unit based on the weight of each element. The assessed units will be merged according to such homological analysis methods as expert integration, matrix clustering, and stepwise merger to form a ranking of the ecologically and economically significant values. The total ecologically and economically significant value of each unit will be determined according to the given weights.

$$C_i = \sum_{i}^{n} X_{ij} \times P_j \tag{2}$$

where $C_i$ refers to the total value of the assessed unit *i*, $X_{ij}$ refers to the value of element *j* in unit *i,* and $P_j$ refers to the weight of the element *j*.

(4) Application level is used to determine the types of each assessed unit by using a final classification matrix, which is composed of ecologically and economically significant values. For instance, feasible development area, moderate development area, moderate conservation area, prohibited exploiting area and elasticity grey area. On those ground, the different land use directions and regulation are to be raised (Table 2).

# 3 Results

## 3.1 Regionalization of ecologically significant value

(1) Ecosystem services

Based on both natural and human characteristics, the ecosystem services function in the area focuses on drinking water sources, wetlands, mountainous regions, lakes, the core area of famous historical towns and cities, and neighbouring areas. Biological diversity is not obvious in this area, which is filled with intense, frequent human activities; however, biologically diversified areas are the same as mountainous regions and wetlands. The special agricultural area mainly in the rice production area, the aquaculture base alongside Taihu Lake, and the Gehu Lake aquaculture base, are all located in wetlands and the areas nearby. Forests are mainly distributed in the mountainous area. These elements may be stated through other indices and are not listed here.

Drinking water sources. It is extremely essential to guarantee the water supply for urban production and livelihood. Nine drinking water sources in Wuxi City, along with the areas within a radius of 1 km from the upper and lower reaches, serve an ecosystem services function fairly well and should be strictly protected.

Wetlands. Wetlands function to purify water, store floodwater to defend against drought, modulate water and air, and maintain biological diversity. Wuxi is abundant in rivers and lakes, where numerous wetlands are mainly located in riverine areas along the Yangtze River, Taihu and Gehu Lakes, and in the cluster of lakes in South Jiangyin. The wetlands in the protected Yangtze riverine sections and other reserved wetlands alongside Taihu Lake, Gehu Lake, and Dongjiu Lake are a super ecological service function area that should be

**Table 2** Matrix classification of ecological-economic value and development regulation

| | | Ecologically significant value | | |
|---|---|---|---|---|
| | | High | Medium | Low |
| Economically significant value | High | Conditioned protection, moderate development area | Conditioned medium-intensity exploitation, moderate development | Less restricted development feasible development |
| | Medium | Preferential protection Moderate conservation | Idem Moderate development | Id., to be reserved according to concrete situations, feasible development |
| | Low | Preferential protection Moderate conservation | Conditioned protection, moderate conservation | Elasticity grey area, determined by demand |

strictly protected. According to the Regulations of Taihu Lake Water Pollution Prevention enacted by the Jiangsu Provincial People's Congress in 1996, the areas within a range of 1 km off the Taihu lakesides and 0.5 km off the Gehu lakesides are prohibited from exploitation, and the area within a range of 5 km off the Taihu lakesides is protected as a buffer zone.

Mountainous regions and water surfaces. These areas are helpful for maintaining landscape diversity and modulating water and air and will be strictly protected in the development process to guarantee that the total area of mountainous region and water surface remains unchanged.

Historical and cultural cities and towns. The historical relic can not be reproduced and should be strictly protected. Attention should be devoted to keeping the look of the development area and the ancient cities and towns harmonious, and it would be inappropriate to carry out large-scale industrial development around historical relics. Therefore, the protected ancient cities and towns and their peripheries should reflect different ecosystem services functions.

In summary, the water sources, mountainous regions, wetlands, water surface, and core protection area of historical and cultural cities and towns are to be designated a super ecosystem services function area. Green belts around lakes, the periphery of the protected area of ancient cities and towns, and the protected areas within a range of 100–500 m off the riversides are medium ecosystem service function areas.

(2) Ecological vulnerability

The selected indices regarding ecological vulnerability include ground sedimentation, the risks of floods and earthquakes, tail water discharge condition, bottomland (terrain elevation), density of water network and soil quality of cultivable land, which represent disaster risk, environmental carrying capacity and ecological cost.

Disaster risk. The average level of ground sedimentation is approximately 450 mm and is mainly distributed in the north-western and south-eastern parts of Wuxi city. Flooding may threaten the centre part of the area, which is primarily bottomland. Earthquake impacts on Wuxi are minor, and the earthquake-affected area is primarily distributed in Western Yixing.

Environmental carrying capacity. In small regions, the flow of atmosphere does not cause a clear difference in the air quality between regions, which will not be considered here. However, the tail water discharge condition may reflect the issue of restriction on the water environment's carrying capacity. In general, the Yangtze riverine area has the largest water environment carrying capacity, whereas the area around Taihu Lake has the smallest.

Ecological cost. Bottomland, with terrain elevation less than 2 m above sea level, is prone to waterlogging, and the construction cost is high in such areas. The density of rivers and lakes represents water ecological sensitivity and reflects land-use integrality. In addition, the denser the water network, the more fragmentized the land use and the more sensitive the ecosystem. Soil quality of cultivable land refers to the appropriate extent for agricultural development. The higher the soil quality, the better the water permeability function to replenish ground water. In this area, paddy soil has the highest proportion. According to the soil classification table, permeable paddy soils are of the highest quality, followed by percolating paddy soils, stagnating paddy soils, water-logged paddy soils, and side-bleaching paddy soils.

According to experts, the importance ranks of elements of ecological vulnerability are as follows: tail water discharge condition>water network density>soil quality of cultivable land>bottomland (terrain elevation)>flood risk>ground sedimentation>earthquake risk. By overlaying the spatial classification of each element, 186 subsections for ecological vulnerability assessment are formed and then merged and zoned in four types. The most ecologically vulnerable zone is mainly distributed in the southwest areas vulnerable to flooding and ground sedimentation, with a small environment carrying capacity. In the Yangtze riverine areas, the environment carrying capacity is large and the ecosystem is less vulnerable.

(3) Comprehensive assessment of ecologically significant value

Considering the above stated ecosystem services and ecological vulnerability, Wuxi city has been divided into four zones in light of its ecologically significant value. The first-level ecological zone consists of drinking water sources, wetlands, mountainous regions, water surfaces, and the core protection zone of historical and cultural cities and towns. The second-level ecological zone, which consists of medium ecosystem services and a sensitive ecological zone, is mainly distributed in the periphery of Taihu Lake, Gehu Lake, and the cluster of lakes in southwest part. The third-level ecological zone is mainly distributed in south-eastern hi-technology industrial zones, Southern Jiangyin and some towns in the north-west. The fourth-level ecological zone is mainly distributed in the Yangtze riverine areas (Fig. 3). Based on the area proportion of the ecological zones in the assessed town units, it is proposed that the ecological zones be partitioned and distributed to the basic assessed spatial units, assessing the ecologically significant value of the towns and urban areas of the counties. The 64 towns and urban districts are divided into four ecological significance types: super, high, medium and ordinary (Fig. 4).

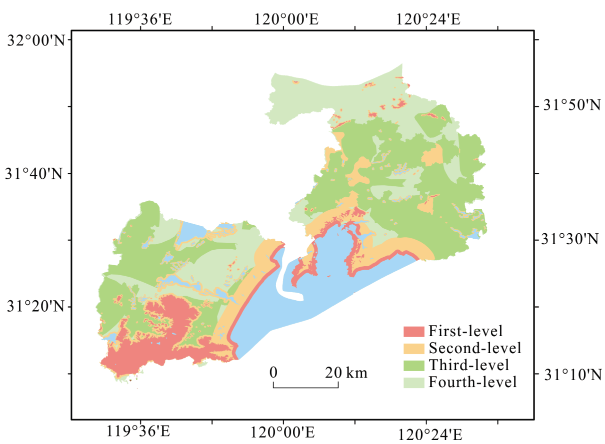


**Fig. 3** The distribution of ecological function area

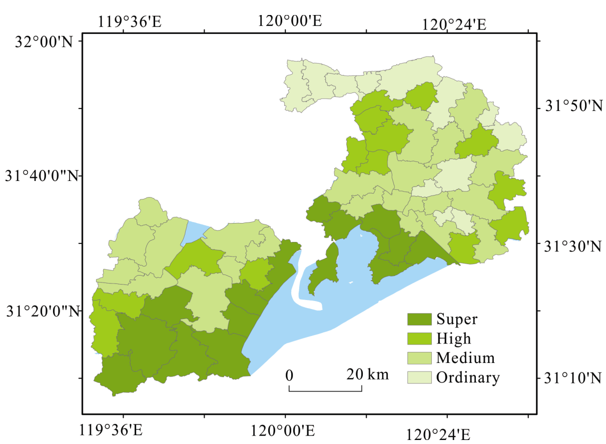


**Fig. 4** Ecologically significant value in each assessed unit

### 3.2 Regionalization of economically significant value

The regionalization of economically significant value is based on the synthesized assessment of water and land resource supply and development benefit and the development potential of each assessed unit.

(1) Water and land resource supply

Water supply capacity for large-scale industry. Wuxi is abundant in water resources and may guarantee water supply for livelihood. However, there is a regional unbalance in the spatial distribution of the water resource. According to an expert survey, the large-scale industrial water supply descends from north to south.

Land supply situation. Although land-use efficiency is considerably high, the land available for construction is quite limited. With regard to the geological condition of the construction, the land is mainly composed of hard earth and sanded land, but in a few areas, the land is composed of soft and distensible earth, for which the exploitation cost is relatively high.

Water and land supply costs. The water and land supply costs are higher from north to south. The costs in the Yangtze riverine area are the smallest, whereas the costs in the Taihu Lake area are some of the largest.

(2) Development benefit

The assessment of the development benefit of each unit is based on elements such as per capita revenue, output of land and fixed assets. Non-agricultural land use efficiency is the highest in the Wuxi New District and other urban built-up areas.

(3) Development potential

Demographic shift minimizes the influence of difference in educational attachment in areas such as Wuxi. The development potential is conducted by reference to transport accessibility in the future. Considering Shanghai's fierce impact on Wuxi, the transport accessibility assessment is based on the distance from assessed units to the Wuxi Centre and Shanghai and is also based on the transport facilities.

According to the above elements, the economically significant value of each unit is estimated, and then the whole area was divided into four categories: super, high, medium and ordinary. The super level refers to the Yangtze riverine area, Wuxi New District, the urban areas of Jiangyin and Yixing, and the area alongside the Shanghai-Nanjing Express. The high level refers to the districts of Chongan, Nanchang, Beitang, and most of the towns in Xishan and Huishan. The mid-level refers to the Binhu area and the riverine area of Taihu Lake. The ordinary level mostly refers to those areas with the highest ecological values and the historical and cultural towns (Fig. 5).

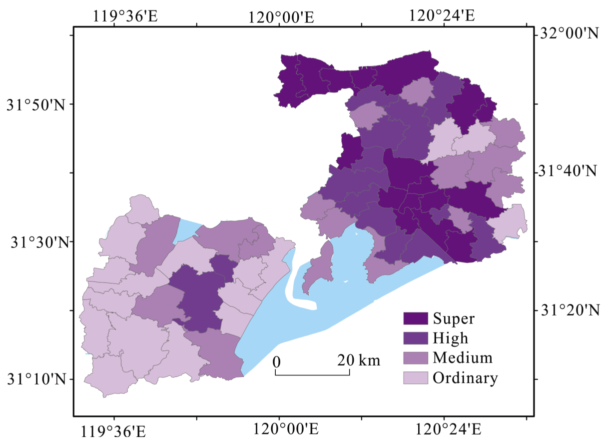


**Fig. 5** Economically significant value in each assessed unit

### 3.3 Spatial function regionalization in Wuxi

Based on the ecologically and economically significant value of each assessed unit, the grades of the ecologically and economically significant value are to be classified in a matrix (Table 3), the result of which will guide the spatial function regionalization and classify the area into three types: feasible development area, moderate development area, and moderate conservation area. Furthermore, the high-level ecosystem services area is taken as the prohibited exploiting area (Fig. 6).

Feasible development area. This refers to the areas with medium or ordinary ecologically significant value, but high economically significant value, where there is huge industrial development demand, large environment carrying capacity, high economic development benefit and less restriction from the ecological environment, which contributes to making the area perfectly fit for large-scale industrial development. The areas near the Yangtze River and Yangtze riverine speedways and the Wuxi New District.

Moderate development area. This refers to the areas with high ecologically-significant value and super economically-significant value, with ordinary ecologically significant value and medium economically-significant value, or with high or medium ecological and economically-significant value. Economic activities are dense and there are high industrial development demand and exploitation benefit. During the process of development, attention should be given to improve land use efficiency and prohibit practices such as disorderly expansion, possession without building, leaving land unused, strictly restricting exploitation intensity, the time sequence of development, and avoiding over-exploitation. It primarily refers to the urban areas of Yixing and Binhu, areas alongside the Shanghai-Nanjing Express and the Wuxi-Jiangyin Express, and some towns in Xishan and Huishan.

Moderate conservation area. This refers to the areas with super ecologically-significant value and high or medium economically significant value, high ecologically-significant value and high or medium economically-significant value, or super ecologically-significant value, but ordinary economically-significant value. The area mainly focuses on the city centres in Chongan, Nanchang and Beitang, South Jiangyin and South Yixing. This area has very limited land available for construction and ordinary industrial development demand, but high ecological sensitivity. Therefore, it is not fit for large-scale development, except for temperate development of the green industry with ecological conservation significance and economic development benefits, such as tourism, the holiday economy and the recreation economy.

Prohibited exploiting area. This refers to the areas that have high-level ecosystem services functions such as

**Table 3** Matrix classification of ecologically-economically significant value of assessed units in Wuxi

| | | Ecologically significant value | | | |
|---|---|---|---|---|---|
| | | Super | High | Medium | Ordinary |
| Economically significant Value | Super | | Suofang, Yuqi | Beitang, Nanchang, Chongan, Core area of Huishan, Core area of Xishan, Huashi, Anzhen, Wuxi New District | Dongbeitang, Xinqiao, Core area of Jiangyin, Xiagang, Shengang, Ligang, Huangtu |
| | High | Core area of Binhu, Taihu, Huazhuang | Qianzhou, Qiangyang, Nanzha | Core area of Yixing, Qiting, Qianqiao, Luoshe, Hongshan, Xiake | Fangqiang, Zhouzhuang |
| | Medium | Xinjie, Dingshu, Mashan, Hudai, Binhu, Yangshan | Yangjian, Yuecheng, Yunting | Wanshi, Donggang, Guanlin, Heqiao | Meicun, Xibei, Gushan |
| | Ordinary | Zhangzhu, Hufu, Taipu, Xinzhuang, Zhoutie, Taihua | Jiangtang, Fangqiao, Gaocheng, Ehu, Changjing, Xizhu | Xushe, Fangzhuang, Yangxiang, Xinjian, Zhutang | |

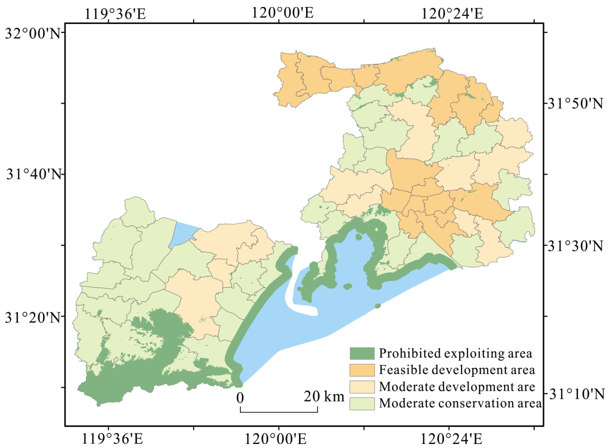


**Fig. 6** Spatial Function Regionalization

drinking water sources, wetlands, mountainous regions, lakes, and core areas of famous historical towns and cities. It would be inappropriate to conduct any construction activities that could injure the ecosystem. They should be strictly protected and prohibit any land-use mode. Efforts can be made to boost biological diversity and channel and communicate the green spaces.

## 4 Conclusions

Wuxi City is facing fierce competition caused by economic globalization and regional integration, with increasing risks and fluctuations in its development. It has become critical to maintain Wuxi's rapid and sustainable economic development, to set as many economic activities as possible in economically low-cost and high- demand areas, to take full advantage of land space and maximize the benefit of putting the slim economic resources into a certain space, to encourage the economic potential and advantages of the areas, and to sharpen competitiveness with spatial advantage. Thus, based on the consideration of both ecosystem and economy, it is proposed that Wuxi city be classified through spatial function regionalization into four areas as follows: feasible development area, moderate development area, moderate conservation area, and prohibited exploiting area. The above regionalization reflects the axes of location and transportation guidance. It combines well with the development demand and the support condition of regional resources and environment, and it helps guide and regulate spatial exploitation.

With regard to the contrast between the proposed regionalization idea and the factual development, these two aspects are generally in conformity with each other. Nevertheless, based on feasibility-oriented spatial function regionalization, some areas still need to adjust their development intensity and density. For instance, in the feasible development area, land output is relatively high, whereas the proportion of land for construction is small; hence, there remains great potential in development. In contrast, the area with the highest development intensity is the moderate conservation area, where population density has exceeded the average level of the city, and both land exploitation intensity and population density are high. Therefore, it is necessary to disperse the population in the future.

With respect to the regionalization method, the key factor influencing scientificity and the reliability of the regionalization result lies in the selection and weight of the elements, which vary with different spatial measures and in different assessed areas. Therefore, in the study of spatial function regionalization, a scientific impact evaluation of the elements in the regional ecosystem and economic development is based on detailed and authentic knowledge of all the elements. This matter deserves further study.

## References

Baics G, Meisterlin L, 2016. Zoning before zoning: land use and density in mid-nineteenth-century New York City. *Annals of the American Association of Geographers*, 106(5): 1152–1175. doi: 10.1080/24694452.2016.1177442

Bailey R G, Zoltai S C, Wiken E B, 1985. Ecological regionalization in Canada and the United States. *Geoforum*, 16(3): 265–275. doi: 10.1016/0016-7185(85)90034-X

Brown L R, 1995. *Who Will Feed China? Wake-Up Call for a Small Planet.* New York: W.W. Norton & Company.

Bryant C R, Russwurm L H, McLellan A G, 1982. *The City's Countryside: Land and Its Management in the Rural-Urban Fringe.* London: Longman.

Fan Jie, 2007. The scientific foundation of major function oriented zoning in China. *Acta Geographica Sinica*, 62(4): 339–350. (in Chinese)

Fan Jie, 2015. Draft of major function oriented zoning of China. *Acta Geographica Sinica*, 70(2): 186–201. (in Chinese)

Fu Bojie, Liu Guohua, Chen Liding et al., 2001. Scheme of ecological regionalization in China. *Acta Ecologica Sinica*, 21(1): 1–6. (in Chinese)

Fu Bojie, Pan Naiqing, 2016. Integrated studies of physical geography in China: review and prospects. *Journal of Geographical Sciences*, 26(7): 771–790. doi: 10.1007/s11442-016- 1298-8

Gaspar J D S, Marques A C, Fuinhas J A, 2017. The traditional energy-growth nexus: a comparison between sustainable development and economic growth approaches. *Ecological Indicators*, 75: 286–296. doi: 10.1016/j.ecolind.2016.12.048

Hanna K S, Webber S M, Slocombe D S, 2007. Integrated ecological and regional planning in a rapid-growth setting. *Environmental Management*, 40(3): 339–348. doi: 10.1007/s00267-006-0225-7

Jiangsu Provincial Bureau of Statistics, 2017. *Jiangsu Statistical Yearbook 2017*. Beijing: China Statistics Press.

Knaap G J, 2001. *Land Market Monitoring for Smart Urban Growth*. Cambridge, MA: Lincoln Institute of Land Policy.

Lin Aiwen, Zhan Xuan, Peng Yuling et al., 2016. Study on functional zoning of land use in the greater mekong sub-region: a case study of central laos. *Geomatics & Spatial Information Technology*, 39(11): 1–5. (in Chinese)

Lin G C S, Zhang A Y, 2015. Emerging spaces of neoliberal urbanism in China: land commodification, municipal finance and local economic growth in prefecture-level cities. *Urban Studies*, 52(15): 2774–2798. doi: 10.1177/0042098014528549

Liu Yulin, 2007. Research on the main function division of Tibet. *Ecological Economy*, (6): 129–133. (in Chinese)

McHarg I L, 1997. Natural factors in planning. *Journal Soil and Water Conservation*, 52(1): 13–17.

Menegaki A N, Tugcu C T, 2017. Energy consumption and sustainable economic welfare in G7 countries: a comparison with the conventional nexus. *Renewable and Sustainable Energy Reviews*, 69: 892–901. doi: 10.1016/j.rser.2016.11.133

Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2018. *Urban Construction Statistics Yearbook 2016*. Available from: http://www.mohurd.gov.cn/xytj/index.html. (in Chinese)

Peng Jian, Du Yueyue, Liu Yanxu et al., 2017. From natural regionalization, land change to landscape service: the development of integrated physical geography in China. *Geographical Research*, 36(10): 1819–1833. (in Chinese)

Sun W, 2013. *The Theory, Methods and Applications of Spatial Function Regionalization*. Science Press. (in Chinese)

Sun Wei, Chen Cheng, Wang Lei, 2018. Spatial function regionalization and governance of coastal zone: A case study in Ningbo City. *Journal of Geographical Sciences*. 28(8): 1167–1181. doi: https://doi.org/10.1007/s11442-018-1548-z.

Theurillat T, Lenzer J H Jr, Zhan H Y, 2016. The increasing financialization of China's urbanization. *Issues & Studies*, 52(4): 1640002. doi: 10.1142/S1013251116400026

Wu Shaohong, Yang Qinye, Zheng Du, 2003. Comparative study on eco-geographic regional systems between China and USA. *Acta Geographica Sinica*, 58(5): 686–694. (in Chinese)

Xu Chongqi, Li Feng, Han Baolong et al., 2017. Adaptive eco-economic regionalization model and its application. *Acta Ecologica Sinica*, 37(5): 1740-1748. (in Chinese)

Yokohari M, Takeuchi K, Watanabe T et al., 2000. Beyond greenbelts and zoning: a new planning concept for the environment of Asian mega-cities. *Landscape and Urban Planning*, 47(3–4): 159–171. doi: 10.1016/S0169-2046(99)00084-5

Yuan F, Wei Y D, Chen W, 2014. Economic transition, industrial location and corporate networks: remaking the Sunan Model in Wuxi City, China. *Habitat International*, 42: 58–68. doi: 10.1016/j.habitatint.2013.10.008

Zhang Guanghai, Li Xue, 2007. A study on the division of main-functional zones in Shandong Province. *Geography and Geo-Information Science*, 23(4): 57–61. (in Chinese)

Zhao Yali, Wu Qun, Long Kaisheng, 2009. Regional land main function division based on fuzzy cluster analysis: a case study of Jiangsu Province. *Bulletin of Soil and Water Conservation*, 29(5): 127–130. (in Chinese)

Zou Fengqiong, Zhang Ganghua, 2017. A study of economic regionalization of Jiangxi province based on multi-scale spatial clustering. *Areal Research & Development*, 36(5): 7–10, 63. (in Chinese)