Stress Relationship between Ecological Security and Urban Expansion Suitability

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Abstract. Systems integration assessment can provide the comprehensive information for practice and policy, reducing conflict in decision-making. Using Beijing city as a case study, this paper proposed a systematic stress assessment method to describe the stress relationship between urban expansion suitability and ecological security. Firstly, Minimum Cumulative Resistance Model (MCR) was adopted to depict the ecological security pattern from 2000 to 2018, and the pattern of high, moderate and low ecological security was protracted. Secondly, the index weights of urban expansion suitability were calculated by Analytic Hierarchy Process (AHP) to eliminate subjectivity, and 5 levels of urban expansion suitability were established by weighted overlay. Finally, this study evaluated the stress effect. Results showed that the overall regional ecological security of Beijing decreased first (2000-2010) and then increased (2010-2018). The suitable area for urban expansion was getting larger, but the expansion rate dropped. Stress effect on urban expansion from ecological security pattern raised from 2000 to 2010 and then dropped. However, the stress effect on ecological security from urban expansion was continuously increasing, stimulating potential risks to the natural ecosystem. The changes of stress effect were stimulated by the policy and planning, driving urban expansion in early period and ecological conservation latterly. Comprehensively, the integrated stress effect assessment improved the recognition of the spatiotemporal variation of ecological security patterns and urban expansion in Beijing.

1. Introduction
The world is undergoing massive urbanization, and by 2050, the global population lived in urban areas will reach 66%. In the period of 1050 to 2014, global urban population had exploded from 746 million to 3.9 billion, accounting for 54%. Urbanization is the process of spatial and social change, including the population and land transformation from rural to urban areas [1]. As a key driver in land use change, urbanization had changed the landscape pattern and ecosystem function, resulting in the decrease of ecosystem service value and ecosystem productivity, which endangered the ecological security [2-4]. Ecological security referred to the natural and semi-natural ecosystems’ security, reflecting the ecosystem integrity and health. Because of the variety of threats to ecosystems and environments, research on ecological security started as early as the late 1970s.

Human activities such as pollution had caused ecological problems worldwide and urbanization generated land use change, modifying the surface terrestrial biogeochemical cycle. Many key global sustainability challenges were closely intertwined, including water shortages, climate change, biodiversity and air pollution, which were interconnected across the time and space dimensions, but
were often separately discussed and managed [5]. Systems integration approaches were essential to assess sophisticated interactions and take available measures to deal with the challenges [6].

Urban expansion and natural ecological were interconnected, and there was a need to simultaneously consider eco-environmental and socioeconomic effects rather than considering them separately. In recent years, researches on ecological security had increased, focusing on the evaluation methods, concept, strategic role and management of ecological security [7-10]. Ecological security assessment identified the sustainable ability to maintain human and the ecosystem integrity being under various risks. It was a quantitative description to the quality of ecosystem [9, 11]. Under rapid urbanization process, urban construction land had experienced densification, expansion and shrinkage patterns. Ecological security and socioeconomic development were two key considerations in the urbanization process. Worldwide, the trade-offs and conflicts between them had become the common focus, particularly in developing countries with large population [12, 13].

China is experiencing urban sprawl at the unprecedented speed, and urban construction land has continued expanded and encroached upon arable land in the last decade [14, 15]. Within 40 years of reform and opening up, the urbanization rate of China increased from 17.9% to 58.5%. The urban population increased from 172 million to 813 million. Forty years of unprecedented urbanization and uncontrolled urban sprawl had resulted in severe eco-environmental issues. Cites’ natural ecological security was quickly becoming a central issue. Unbalanced development strategy led to unsustainable socioeconomic development, including resource depletion, agricultural land loss and land degradation, and biodiversity losses, as well as other undesirable ecological consequences [16-19]. Urban expansion had led to natural habitat loss, and most cropland reclamation resulted in the natural habitat degeneration, such as wetland and grassland. Urbanization had far-reaching impacts and severe stress on eco-environment [20, 21]. In order to mitigate ecological degradation, Chinese government proposed the strategy of ecological civilization. Since the late 1990s, a series of nature conservation and ecological restoration programs had been implemented, including the Wildlife Conservation and Natural Reserve Program, the redline paradigm, the Grain to Green Program and the three-North Shelter Forest Program [22]. More consideration had been on natural ecological conservation. Therefore, the spatial distribution and expansion of urbans was restricted by natural conditions. The speed of urban expansion has slowed down, shifting from high-speed to high-quality development.

There exited the interaction between natural ecological security and urban expansion. Integrated researches of ecosystems and urban sprawl revealed the complex and new patterns, not evident when studied by natural or social scientists separately. In recent years, RS, GPS and GIS technology developed rapidly, and had brought the wide application. The utilization of geographical information technologies gradually improved the integrated research of regional urban expansion and ecological security.

As the capital of China, Beijing has experienced more rapid urbanization, with the unorderly urban spreading like standing pancake [23]. The ecosystem was relatively fragile and ecological safety was in a slow downtrend [1, 16]. Hosting Olympic Games has improved the quality of ecological environment and promoted the greening process. However, there was still a big gap between the current situation and the requirement to become an “ecological city”. The balance between urban expansion and ecological security should be explored though the stress effect assessment.

The evaluation of the evolution of Beijing’s ecological security had a lot of prospective significance for the urban space research. Taking Beijing as the research object, this paper described the relationship between urban expansion and landscape ecological security, revealing the characteristics and models of the ecological security evolution and urban expansion in Beijing, which was enhanced by remote sensing technology. Under the influence of different policies, the dynamic stress effect assessment of urban expansion and ecological security become possible to establish an early warning and assessment system of sustainable development.
2. Methods and Materials

2.1. Research Area
Beijing is situated at northwest of the North China Plain, adjacent to Tianjin and surrounded by Hebei Province. Beijing is near the meeting point of the Xishan and Yanshan mountain ranges. The total area is 16410 km$^2$, 62% of which is mountainous terrain and the rest is plains. The northwest of terrain in Beijing is high and the highest altitude is 2303 m. The southeast is low and the average altitude is 20-60 m. Beijing’s climate is a typical warm-temperate semi-humid continental monsoon climate. The permanent population is 21.7 million in 2018, with the Gross Regional Product (GDP) of 2801.5 billion RMB and a per capita GDP of 1.4 *10$^5$ RMB. The comprehensive economic strength of Beijing was at the top places in China. With the rapid development in Beijing, land use had experienced a shift from agriculture to construction land. Urban construction land sprawled from the centre to the peripheral areas, and there are six ring roads. Urbanization was becoming increasingly significant in the suburban areas.

2.2. Research Methods
Ecological security and urban expansion suitability were assessed by several appropriate indexes. Contribution to ecological security and urban expansion suitability of each index could be determined by AHP method. AHP was an effective multi-target decision method combining qualitative analysis with quantitative analysis. Moreover, it was applied to define the various index weights by four steps, including constructing hierarchy structure model, setting up judgement matrixes, ranking all the evaluation indexes and consistency checking [1].

2.2.1. Evaluation Systems for Natural Ecological Security Pattern. Natural ecological security pattern, known as the framework of ecological security, referred to the potential spatial pattern of ecosystem, which consisted of some key parts and their spatial connection. Natural ecological security pattern was of great significance to maintain the ecological process and ecosystem function in a specific area, and always evaluated by Minimum Cumulative Resistance model (MCR). Ecological security pattern research improved our understanding of its ecological process and the stress effect to urban development.

(1) Minimum Cumulative Resistance model (MCR)
MCR referred to the minimum resistance or the minimum cost of going through landscapes from the “source” to the destination, which reflects the accessibility. The MCR was given by

$$MCR = f_{\min} \sum_{j=1}^{n} D_{ij} * R_{i}$$

where $D_{ij}$ represented the distance of species from source $j$ to other $i$. $R_{i}$ was the diffusion resistance coefficient; and $f$ reflected the positive correlation between MCR and the land landscape type. MCR was reclassified into three level: high security, moderate security and low security.

(2) Evaluation indicator
Since resistance of ecological security pattern originated from both geomorphology and land use, slope and land cover type were selected as the factors to depict the ecological security pattern resistance (table 1).

2.2.2. Evaluation Systems for Urban Expansion Suitability.
(1) UEI (Urban Expansion Index)

$$UEI = \sum_{i=1}^{m} W_{pi}X_{i}$$

where UEI denoted the urban expansion index, and $W_{pi}$ represented the weight of evaluation indicator. $X_{i}$ was the indicator score of indicator $i$, and $m$ was the number of indicators. UEI were
reclassified into 5 levels: minimum suitability, low suitability, moderate suitability, high suitability and the highest suitability.

| Type                                  | Indicators | Classification | Resistance value |
|---------------------------------------|------------|----------------|------------------|
| Landscape ecological security         | Slope      | 0-6°           | 0                |
|                                       |            | 6-15°          | 20               |
|                                       |            | 15-25°         | 45               |
|                                       |            | 25-45°         | 75               |
|                                       |            | >45°           | 100              |
| Land use types                        | forestland | 5              |                  |
|                                       | grassland  | 5              |                  |
|                                       | farmland   | 30             |                  |
|                                       | water bodies | 15         |                  |
|                                       | construction land | 100 |                  |
|                                       | unutilized land | 60        |                  |

(2) Evaluation indicator
In the period of 2000 to 2018, urban construction land of Beijing sprawled from 2300 km² to 2990 km². The rapid development had brought pressure to agricultural land loss, and accelerated the landscape patterns change. Urban expansion suitability predicted the potential pattern of urban development, better reflecting the change of land use. Understanding of this change and its driving factors could benefit natural ecological protection and sustainable urban development in Beijing. 4 types of evaluation indicators were selected and the Xi would be decided though Natural Breaks of GIS (table 2).

| Type                                  | Indicators                  | Weight |
|---------------------------------------|-----------------------------|--------|
| Geomorphology                         | Elevation                   | 0.05   |
|                                       | Slope                       | 0.15   |
| Landscape types                       | Forestland                  | 0.4    |
|                                       | Grassland                   |        |
|                                       | Water bodies                |        |
|                                       | Construction land           |        |
|                                       | Unutilized land             |        |
| Transportation facilities             | Distance to expressway      | 0.1    |
|                                       | Distance to arterial traffic | 0.1    |
|                                       | Distance to urban secondary road | 0.1  |
| Urban development                     | Population density          | 0.1    |

2.2.3. Evaluation Systems for Stress Relationship. Ecological stress usually referred to the situation, in which the structure of ecosystem was not directly damaged but its function was affected. Based on the
integrated analysis, this study depicted the stress relationship between ecological security and urban expansion suitability.

\[ S_{ij} = U_i \cap E_j \cdot U_i \rightarrow E_j = \frac{U_i \cap E_j}{U_i} \cdot E_j \rightarrow U_i = \frac{U_i \cap E_j}{E_j} \]

where \( S_{ij} \) represented the intersecting area of urban expansion suitability and natural ecological security. \( U_i \) was the area of urban expansion suitability in level \( i \) (minimum suitability, low suitability, moderate suitability, high suitability and the highest suitability). \( E_j \) was the area of natural ecological security in \( j \) level (high security, moderate security and low security). \( U_i \rightarrow E_j \) expressed the stress effect on natural ecological security form urban expansion, and it was the ratio of the intersecting area in the urban expansion suitable area of each level. \( E_j \rightarrow U_i \) was the stress effect on urban expansion suitable area form ecological security pattern, and it could be obtained through the ratio of the intersecting area in the natural ecological security area of each level. \( U_i \rightarrow E_j \) and \( E_j \rightarrow U_i \) were bigger, and the stress effect was greater.

2.3. Data Sources

Socioeconomic data and natural science data were collected for this study (table 3).

1. Socioeconomic data from Statistical Yearbook, government work reports and urban planning were integrated to evaluate the development of Beijing.

2. Remote sensing images data were applied to retrieve urban cover changes. Based on Landsat TM/ETM remote sensing images as the main data source, data production was generated through manual visual interpretation. A classification scheme of 6 primary land types was categorized from Landsat 8 remote sensing image in ENVI 5.0. Land use data of 2018 was generated by manual visual interpretation based on remote sensing monitoring data of 2015. 6 land use types included water bodies, forestland, farmland, grassland, construction land and unused land (table 4). The land use data were transferred to a 30×30 m raster grid cell in ArcGIS 10.3, and the land use change was depicted from 2000 to 2018.

| Data type                      | Dataset                                                                 | Date               |
|-------------------------------|------------------------------------------------------------------------|--------------------|
| Socioeconomic data            | Statistical Yearbook, government work reports and urban planning document | 2000-2018          |
| Remote sensing images         | Landsat TM images (30×30 m)                                            | 2000, 2005, 2010, 2015, 2018 |
|                               | Digital Elevation Model data (DEM)                                     | 2015               |
|                               | Nighttime data                                                         | 2000, 2005, 2013   |
| Vector dataset                | Map of transportation                                                  | 2000, 2010, 2018   |
|                               | Map of land cover                                                      | 2000, 2005, 2010, 2015, 2018 |

| Primary land types            | Secondary land types                                                   |
|-------------------------------|------------------------------------------------------------------------|
| 1 Forestland                  | forest, shrubbery, sparse woodland, other woodlands                    |
| 2 Water bodies                | rivers, lakes, reservoirs, permanent glaciers and snow, shoals, beaches, water conservancy facilities land |
| 3 Farmland                    | paddy land, dry land                                                   |
| 4 Grassland                   | dense grassland, mid-density grassland, sparse grassland               |
| 5 Construction land           | residential areas, industrial construction land                         |
| 6 Unutilized land             | Gobi, sandy land, swamp land, bare rock gravel land, saline alkali land, bare land, other unused land |
(3) Population density distribution was calculated by the night-time data. Night-time data and Digital Elevation Model data (DEM) were all acquired from the Resource and Environment Data Cloud Platform (http://www.resdc.cn/Default.aspx).

3. Results

3.1. Natural Ecological Security Pattern
In Beijing, forestland was dominant from 2000 to 2018, representing 48%-57% of total land. Second was the farmland with the 26.9% of total land in 2000 reduced to 15.8% in 2015. Construction land escalated form 13.3% in 2000 to 18.2% in 2015, and then reduced slightly to 17.4% in 2018.

Based on the MCR, the ecological security pattern of 2000, 2010 and 2018 in Beijing were established (figure 1). Natural Breaks classified 10 levels of landscape ecological security pattern into three types: high security, moderate security and low security. In 2000, the proportion of the three ecological security areas were 53.8%, 35.5% and 10.7% respectively. There was a huge change in 2010 that the shares of the three ecological security areas were 27.2%, 54.5% and 18.4%, and the high ecological security area reduced by 49.5%. However, in 2018, the reverse has happened. The high ecological security area increased with the part of 61%. The moderate and low security areas proportions were 30% and 9%.

![Figure 1. Natural ecological security pattern of 2000, 2010 and 2018 in Beijing.](image)

3.2. Urban Expansion Suitability Pattern
Urban construction land in Beijing sprawled from 2183.89 km² in 2000 to 2846.97 km² in 2018. In the period of 2000 to 2010, the city expanded rapidly with 78 km² per year, and after 2010 the growth rate slowed down. Noteworthy, the urban construction land decreased for the first time from 2017 to 2018. The expanded land was mainly distributed outside the Fifth Ring Road, and towns in periphery of central urban area emerged in large numbers after 2000. Construction land expansion promoted the spreads out of the centre city. The driving force of urban sprawl was the low-cost land. Land at low costs for the purpose of urban expansion had gradually evolved into a spatial spread, surrounding the central city. Anything else, the rapid development of peripheral towns also benefited from the excellent geographic condition and low development costs.

According to the weighted-overlay analysis, the suitability score of urban expansion in Beijing was divided into five levels: the highest, high, moderate, low and the minimum suitable area. From 2000 to 2018, the highest and high urban expansion suitable area in Beijing were increasing. The area proportion increased from 7.3% to 15.6% and 7.7% to 16.2% respectively. The accounting of minimum and moderate urban expansion suitable area dropped from 26% to 21% and 31.5% to 20% (figure 2).
The suitable area extended along the traffic line and distances to outer-ring expressway was most influential to urban expansion. The convenient traffic condition generated the better traffic and employment accessibility; hence, residents were more willing to settle residential land according to traffic preference.

3.3. Urban Expansion Suitability Pattern

3.3.1. Stress Effect on Urban Expansion from Ecological Security. The report of the 19th National Congress of the communist party of China (CPC) made important arrangements for “accelerating institutional reform on ecological progress and building a beautiful China”, stressing that “we must give priority to conservation, protection and natural restoration”. Sticking to the priority of ecological protection, the core was to deal with the relationship between ecological conservation and urban development.

The new Urban Planning (2016-2030) required that the urban construction area in Beijing would reduce from 2990 km$^2$ in 2018 to around 2900 km$^2$ by 2020 with 60 km$^2$ decrease per year. Urban expansion was restricted by ecological protection. With the urban development, the influence of ecological security pattern on urban expansion was constantly strengthened.

The stress effect on urban expansion from ecological security was illuminated (figure 3).

In 2000, the high ecological security area had the greatest impact on urban expansion suitability, followed by the moderate ecological security area. The low ecological security area had the minimal impact on urban expansion suitability. For low, moderate and high urban expansion suitability area, the high ecological security area all accounted for the maximum proportion with 64%, 56% and 60% respectively.

In 2010, the moderate ecological security area had the greatest impact on urban expansion suitability. Second was the high ecological security area, and the low ecological security area had the minimal impact on urban expansion suitability. For every levels of the urban expansion suitability area, the moderate ecological security area all had the largest proportion with 62%, 52%, 52%, 55% and 50% respectively.

In 2018, the high ecological security area had the greatest impact on each levels of the urban expansion suitability area, and the second was the moderate ecological security area. The low ecological security area had the minimal stress on urban sprawl suitability.

The evolution of the stress effect on urban expansion from ecological security demonstrated that more stress was pouring into urban expansion. Early, urban expansion suitability area was small, and natural ecology was in excellent conditions, therefore, the ecological security pattern dominated. With further speed up of the urbanization process, ecological security pattern was facing increasingly complex environment problems, and numbers of conflicts was rising. Nowadays, due to the
improvement of the government and public awareness of ecological conservation, ecological security pattern dominated the direction of urban land use.

3.3.2. Stress Effect on Ecological Security from Urban Expansion. Obviously, from 2000 to 2018, the highest and high urban expansion suitability area were increasing, and the minimum suitability area decreased, leading to the growing stress effect on ecological security (figure 4). From 2000 to 2018, minimum, low and moderate urban expansion suitability area accounted the larger part of the ecological security pattern, producing the less influence on ecological security. The highest and high urban expansion suitability area continued to increase with the proportion of 14% to 26%. More stress was exerted on the natural ecological security pattern.

![Figure 3. The stress effect of ecological security on urban expansion in 2000, 2010 and 2018.](image)

![Figure 4. The stress effect of urban expansion on ecological security in 2000, 2010 and 2018.](image)

4. Policy Driver Analysis of the Stress Effect

4.1. Macroeconomic Policy Context
Cities and towns were the important spatial carriers for gathering population. The speed of gathering population was closely related to national policies on rural areas and towns. In the past 40 years, China’s urbanization had achieved a major transformation from high-speed growth to high-quality growth. China’s urbanization could be divided into two development stages: firstly, from the reform and opening up to the high-speed growth stage in 2011. Secondly, from 2012 to the present stage of high-quality (new urbanization) development.
4.1.1. *High-Speed Growth of Urbanization*. In this period, the driver of urban sprawl changed from the rural economic system reform (1978-1983) to urban economic system reform (1984-1991). After 1991, the urbanization trended toward the comprehensive and rapid development. Ecological and environmental problems had become increasingly prominent.

4.1.2. *High-Quality Development of Urbanization*. With the implementation of the ‘national ecological protection and Construction Plan (2013-2020)’, more attention had been given to ecological protection, affecting the urban development strategy choose. At the 18th national congress of the CPC in 2012, the connotation of the ‘new urbanization path with Chinese characteristics’ had been proposed, with more emphasis on improving the quality of urbanization. In 2013, the Third Plenary Session of the 18th CPC Central Committee clearly proposed to adhere to the new urbanization road with Chinese characteristics. In 2014, the new national urbanization plan (2014-2020) was officially promulgated and implemented, giving priority to strengthening eco-environmental protection and promoting harmonious coexistence between man and nature.

4.2. *Policy Driver in Beijing*

As a tool, the policy of urban development was always used to optimize urban spatial structure by governments. Since 1990s, Beijing had experienced three major urban development stages.

(1) Stage I

Beijing entered the rapid development period in 1990s, and the construction of ring highways played the key role in the urbanization. The 2nd and 3rd Ring Road were completed in 1992. The average annual growth rate of urban built-up areas was 2.46% before 1998, and the rate rose to 9.94% rapidly after 1998 (Wang et al. 2019). In 2000, the construction land was 2183.89 km², 13.31% of Beijing’s total area. Urban agglomeration occurred within the 4th Ring Road.

(2) Stage II

From 2000 to 2005, 400 km² of construction land increased by 80 km² per year and expansion intensity of construction land was 3.6%. In 2005, Beijing Urban Planning (2004-2020) was released, establishing the ‘Two axes-Two belts-Multiple centres’ pattern and proposing the multi-centre city construction. This policy played the huge role in population control and industrial guidance, alleviating the stress on the natural ecological environment in the urban core area.

From 2005 to 2010, 381 km² of construction land increased by 76.2 km² per year and expansion intensity of construction land was 2.9%. In 2008, with the success of bidding for 2008 Olympic Games, Beijing had entered a period of fastest urban expansion. The 6th Ring Road was completed in 2009, and all of the ring roads improved the traffic accessibility to Beijing’s urban region. The construction land around the traffic routes expanded outward greatly.

During this period of 2000-2010, the high ecological security area reduced with 8847 km² to 4482 km², and the stress effect on urban expansion suitable area was decreasing. In the highest, high, moderate, low and minimum urban expansion suitable area, the $E_{\text{high,security}} \rightarrow U$ decreased from 29% to 15%, 60% to 29%, 56% to 27%, 54% to 38% and 47% to 21%, respectively. Meanwhile, the highest and high urban expansion suitable area increased. For the high, moderate and low ecological security area, the $U_{\text{high, suitability}} \rightarrow E$ increased from 5% to 7%, 8% to 11%, 24% to 25%, and the $U_{\text{high, suitability}} \rightarrow E$ increased from 9% to 11%, 7% to 11% and 7% to 9%, improving the stress effect on ecological security area gradually.

(3) Stage III

After 2010, the urban environment received unprecedented attention, and the urban expansion rate slowed down without the unlimited sprawl. In 2017, the Beijing City Planning (2016-2030) was implemented. In this plan, Beijing’s urban population would be controlled within 23 million by 2020. Construction land must drop from 2945 km² to 2860 km² in 2020 and 2760 km² in 2030, with an average annual reduction task of about 30 km². Beijing was the first city in China to put forward the reduction development, which would be help to inspire the existing land assets and land use conversion.
Natural ecological security pattern limited the sprawling urban expansion. From 2010 to 2018, the high ecological security area had doubled with 9975 km², restraining the accelerating urban sprawl. For the highest, high, moderate, low and minimum urban expansion suitable area, the $E_{\text{high security}} \rightarrow U$ increased dramatically from 15% to 44%, 29% to 58%, 27% to 62%, 38% to 69% and 21% to 63%. The expansion intensity of highest suitable area reduced from 51% to 26%, and Beijing had turned to high-quality development concentrating on natural ecological conservation.

In addition to policy and planning, the urban functions and land values spill over had the great attraction for farmers into the city. In the early stages, urban development needed the migrant population. The driving force was stimulating the urban sprawl and had more pressure on natural eco-environment.

5. Conclusions
This paper established the integrated evaluation models, targeting at reflecting the stress effect between construction land and urban natural ecological pattern. The assessment models monitored and diagnosed the dynamic information of urban socioeconomic and ecological system. Based on the integrated evaluation models, this research proposed the connection between supply and demand, and it useful to identify important ecological patches. Important ecological land should be appropriately distributed within consideration of the evaluation principle. With the integrated models established in this study, a holistic view for identifying how to balance ecological environments and socioeconomic under rapid urbanization was provided.

Results showed that the overall regional ecological security of Beijing decreased first (2000-2010) and then increased (2010-2018). The suitable area for urban expansion was getting larger, but the expansion rate dropped. Stress effect on urban expansion from ecological security pattern raised from 2000 to 2010 and then dropped. However, the stress effect on ecological security from urban expansion was continuously increasing, stimulating potential risks to the natural ecosystem. The changes of stress effect were stimulated by the policy and planning, driving urban expansion in early period and ecological conservation latterly.

To alleviate the stress relationship between ecological security and urban expansion, the stock of construction land must be fully utilized, and more consideration should be focused on the increment change, with reducing the construction land increment and increasing the ecological land increment. Stock value can be exploited through the thinking of increment and more stocks may be converted into increments, therefore, the eco-city will be achieved.

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References
[1] Pei L, Du L M and Yue G J 2010 Ecological security assessment of Beijing based on PSR model Procedia Environmental Sciences 2 0-841.
[2] Zhang L Q, Peng J, Liu Y X and Wu J S 2017 Coupling ecosystem services supply and human ecological demand to identify landscape ecological security pattern: A case study in Beijing-Tianjin-Hebei region, China Urban Ecosyst. 20 701-714.
[3] Lauf S, Haase D and Kleinschmit B 2014 Linkages between ecosystem services provisioning, urban growth and shrinkage—A modeling approach assessing ecosystem service trade-offs Ecological Indicators 42 73-94.
[4] Feng Y, Yang Q, Tong X, et al. 2018 Evaluating land ecological security and examining its relationships with driving factors using GIS and generalized additive model Science of The Total Environment 633 1469-1479.
[5] Liu J, Dietz T, Carpenter S R, et al. 2007 Complexity of coupled human and natural systems Science 317 1513-1516.
[6] Liu J, Mooney H, Hull V, et al. 2015 Systems integration for global sustainability Science 347 1258832.
[7] Holling C S 2001 Understanding the complexity of economic, ecological, and social systems Ecosystems 4 390-405.
[8] Han B L, Liu H X and Wang R S 2015 Urban ecological security assessment for cities in the Beijing-Tianjin-Hebei metropolitan region based on fuzzy and entropy methods Ecological Modelling 318 217-225.
[9] Huang H, Chen B, Ma Z Y, et al. 2017 Assessing the ecological security of the estuary in view of the ecological services-A case study of the Xiamen Estuary Ocean and Coastal Management 137 12-23.
[10] Me’ira M, Stephanie D, Robert L, et al. 2019 Global opportunities and challenges for shark large marine protected areas Biological Conservation 107-115.
[11] Fang C, Liu H and Li G 2016 International progress and evaluation on interactive coupling effects between urbanization and the eco-environment Journal of Geographical Sciences 26 1081-1116.
[12] Cen X T, Wu, C F, Xing X S, et al. 2015 Coupling intensive land use and landscape ecological security for urban sustainability: An integrated socioeconomic data and spatial metrics analysis in Hangzhou City Sustainability 7 1459-1482.
[13] Choi C Y, Peng H B, He P, et al. 2019 Where to draw the line? Using movement data to inform protected area design and conserve mobile species Biological Conservation 64-71.
[14] Tan M, Li X, Xie H, et al. 2005 Urban land expansion and arable land loss in China—A case study of Beijing-Tianjin-Hebei region Land Use Policy 22 0-196.
[15] Peng J, Du, Y, Liu, Y, et al. 2016 How to assess urban development potential in mountain areas? An approach of ecological carrying capacity in the view of coupled human and natural systems Ecological Indicators 60 1017-1030.
[16] Qi J, Chen J, Wan S, et al. 2012 Understanding the coupled natural and human systems in dryland East Asia Environmental Research Letters 7 015202.
[17] Cao S, Lv Y, Zheng H, et al. 2014 Challenges facing China’s unbalanced urbanization strategy Land Use Policy 39 412-415.
[18] Xiao W and Zhao G C 2018 Agricultural land and rural-urban migration in China: A new pattern Land Use Policy 74 142-150.
[19] Lin J Y and Li X 2019 Large-scale ecological red line planning in urban agglomerations using a semi-automatic intelligent zoning method Sustainable Cities and Society 46 101410.
[20] Wang H J, He S W, Liu X J, et al. 2013 Simulating urban expansion using a cloud-based cellular automata model: A case study of Jiangxia, Wuhan, China. Landscape and Urban Planning 110 99-112.
[21] Feng Y, Liu Y and Tong X 2018 Spatiotemporal variation of landscape patterns and their spatial determinants in Shanghai, China Ecological Indicators 87 22-32.
[22] Guo X, Chang Q, Liu X, et al. 2018 Multi-dimensional eco-land classification and management for implementing the ecological redline policy in China Land Use Policy 74 15-31.
[23] Wang S D, Zhang X Y, Wu T X, et al. 2019 The evolution of landscape ecological security in Beijing under the influence of different policies in recent decades The Science of the Total Environment 49-57.