Dynamic Adaptive Ecological-Economic Regionalization Model and Its Application Postprint

Authors: Xu Chongqi, Li Feng, Han Baolong, Tao Yu

Date: 2017-03-22T00:00:00+00:00

Abstract

Improving the accuracy and dynamic nature of urban ecological-economic zoning holds significant theoretical importance and application value for scientifically guiding urbanization development. This study establishes a linear model using nighttime light data and population density to explore the simulation refinement of data that previously used administrative regions as the minimum statistical unit. Subsequently, by introducing variable parameters, a dynamically adaptive ecological-economic zoning model is constructed, which, while enhancing the model' s dynamic adaptability, uniformly divides the primary zoning results into four categories: ecological control areas, ecological priority areas, optimized development areas, and key development areas. Taking Zengcheng District of Guangzhou City as a typical case study, the improved dynamically adaptive ecological-economic zoning model is employed to simulate and compare Zengcheng District under two scenarios using GIS, and policy recommendations are proposed. The zoning results conform to local development characteristics and also provide a scientific methodology for ecological-economic zoning research in other cities and regions.

Full Text

Preamble

ACTA ECOLOGICA SINICA
ChinaXiv Partner Journal
Vol. 37, No. 5, March 2017
DOI: 10.5846/stxb201510082021

Adaptive Eco-Economic Regionalization Model and Its Application

XU Chongqi, LI Feng, HAN Baolong, TAO Yu
State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-

Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China
University of Chinese Academy of Sciences, Beijing 100049, China

Abstract

Improving the accuracy and dynamic adaptability of urban eco-economic regionalization holds significant theoretical and practical value for scientifically guiding urbanization development. This study addresses the simulation and refinement of data traditionally aggregated at administrative boundaries by establishing a linear model between nighttime light data and population density. By introducing variable parameters, we constructed an adaptive eco-economic regionalization model that enhances dynamic adaptability while standardizing primary regionalization results into four categories: ecological conservation zones, ecological priority zones, development optimization zones, and key development zones. Using Zengcheng District in Guangzhou as a typical case study, we applied the improved adaptive eco-economic regionalization model to simulate and compare two scenarios. The zoning results align with local development characteristics and provide scientific methods for eco-economic regionalization research in other cities and regions, along with policy recommendations.

Keywords: eco-economic regionalization; population density simulation; DMSP/OLS nighttime light data; dynamic adaptability; scenario analysis

Introduction

During rapid urbanization, many cities have experienced uncontrolled sprawl, intensifying conflicts between socio-economic development and ecological environmental protection. Balancing and managing the social, economic, and natural dimensions of urban complex ecosystems to ensure sustainable urbanization has become a critical global research issue. Eco-economic regionalization employs systematic analysis methods to comprehensively consider heterogeneity in eco-economic structure and function, dividing regions into different eco-economic zones from perspectives of socio-economic development and ecological environmental protection, and proposing pathways and countermeasures at various levels. Scientific eco-economic regionalization can provide systematic ecological and economic development directions for urbanization management, facilitating coordinated and sustainable development of urban social, economic, and natural composite ecosystems. Also termed eco-economic functional regionalization, this approach has evolved alongside eco-economic theory, integrating environmental and socio-economic factors. After years of research, the principles, index systems, calculation methods, and technologies have become increasingly sophisticated. However, existing eco-economic regionalization still faces challenges such as administrative boundary constraints, poor systematic approaches, limited dynamic adaptability, and poor horizontal comparability of results. In particular, recent Chinese concepts such as ecological protection red lines and basic ecological control lines emphasize the need to break administrative boundaries to preserve intact critical ecological lands. The Ministry of Environmental Protection's "Technical Guidelines for Ecological Protection Red Line Delineation" also emphasizes the dynamic nature of ecological protection red line areas, which can increase according to actual conditions. Improving the accuracy and dynamic adaptability of urban eco-economic regionalization on this basis holds important theoretical and practical significance for scientifically guiding urbanization development.

This study takes Zengcheng District in Guangzhou as the research area, incorporating population density simulation data and dynamic adaptability into the eco-economic regionalization model. The objectives are threefold: first, to serve the eco-economic regionalization of Zengcheng District; second, to explore methods for improving the accuracy and dynamic nature of eco-economic regionalization; and third, to appropriately unify regionalization types to enhance horizontal comparability of results.

1. Study Area and Data Preprocessing

Zengcheng District is located in central Guangdong Province, east of Guangzhou city, at the northeastern corner of the Pearl River Delta (113°32 -114°00 E, 23°05 -23°37 N). The district features a south subtropical maritime monsoon climate with uneven rainfall distribution (more in the north, less in the south). Situated in a transition zone between hilly mountains and plains, the terrain slopes from high in the north to low in the south. The northern mountainous area contains multiple geological disaster-prone sites. The district has a well-developed water system and abundant water resources, with a large proportion of existing ecological land. The total administrative area is 1,616.47 km^2. In 2013, the registered population was 854,400, GDP reached 98.945 billion yuan, and per capita GDP was 115,900 yuan. The three-industry structure was 5.4:60.61:33.98.

As the Guangzhou municipal strategy accelerates, Zengcheng, as one of the five key development areas in Guangzhou, is gradually receiving related industries and urban infrastructure such as rail transit. Comprehensive eco-economic regionalization that considers local ecosystem importance, socio-economic development, and resource-environment carrying capacity is crucial for Zengcheng to both serve as Guangzhou' s backyard garden and seize development opportunities.

Basic research materials and base maps include: Zengcheng District administrative division maps, 2013 land use classification status maps, 2013 satellite remote sensing images, digital elevation model (DEM) data, and hydrological information provided by relevant Zengcheng departments. Under the support of ArcGIS software, all data were spatially gridded with a minimum unit of 30m×30m. Due to data source limitations, some data were spatialized by administrative boundaries. All collected and derived data were used to establish three major indices: socio-economic development degree, ecosystem protection degree, and resource-environment carrying capacity.

2. Eco-Economic Regionalization Index System and Technical Roadmap

Based on previous index systems and comprehensively considering various indicators—including economic development level, ecosystem service function importance, population activity intensity, location advantage degree, resource availability, environmental capacity overload, ecosystem sensitivity, and vulnerability—this study integrates them into three categories for comprehensive functional evaluation: socio-economic development degree, ecosystem protection degree, and resource-environment carrying capacity. The specific index system is shown in Table 1, and the model technical roadmap is shown in Figure 1.

Table 1 The index system of eco-economic regionalization

Figure 1

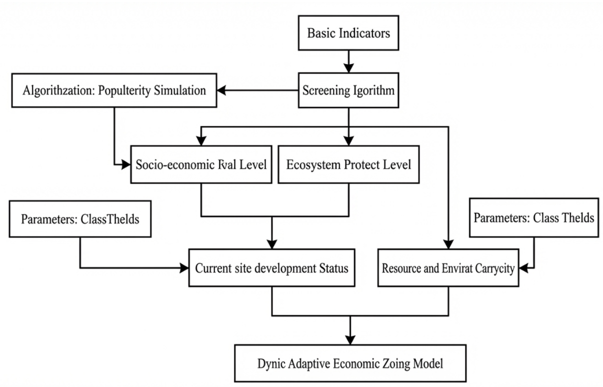

Figure 1: Figure 1

Technology roadmap of the model

3. Population Density Simulation Data Based on Nighttime Light Images

A critical factor limiting the accuracy of eco-economic regionalization is the existence of statistical data aggregated by administrative jurisdiction, such as population numbers and available resource quantities. To improve regionalization accuracy, it is necessary to scientifically simulate and grid such administrative-level statistics. One solution is to identify raster data that shows significant statistical correlation for simulation. Numerous studies have used DMSP/OLS remote sensing data for population density gridding simulation, demonstrating significant correlations between nighttime light intensity and population density within lit areas. Population density gridding simulation expresses population data spatially according to geographic grids per unit area, which more closely approximates actual population distribution than administrative unit-based expression and facilitates integration with other socio-economic and environmental data, thereby enhancing comprehensive management capabilities for population, resources, and environment.

Building on previous research and combining existing residential unit boundary data with nighttime light intensity data, this study attempts to grid administrative boundary-based population statistics. Using the 2013 stable average nighttime light intensity image (F182013.v4c_web.stable_lights.avg_vis.tif) and extracting urban and village residential areas from the 2013 land use status map provided by Zengcheng District's Land Bureau as the study area, we established a linear relationship between population numbers and stable nighttime light intensity values in each grid, referencing the research of Cao Liqin et al. and Zhuo Li et al. The model is expressed as:

$$PD = P \times V / \Sigma V$$

where PD is resident population density, P is year-end resident population statistics by street/town administrative unit, V is the stable average nighttime light intensity value in the grid (range 0–63), and ΣV is the sum of light intensity values within the residential boundaries of the street/town administrative unit.

The simulated resident population density within each street/town is shown in Figure 3. The results indicate that Zengcheng' s resident population is concentrated in the industrially developed southern areas and around the urban center, while the northern mountainous areas have sparse populations, matching actual conditions. This method effectively reflects population distribution at the municipal scale, accurately distinguishing residential from non-residential areas, and is significant for improving the accuracy of socio-economic development indicators.

Figure 2

Stable average nighttime light data of Zengcheng
Figure 3 [FIGURE:3] Resident population density of Zengcheng

4. Adaptive Eco-Economic Regionalization Model

For urban eco-economic regionalization, both the current urban situation and future planning management objectives are in constant dynamic change. The regionalization must both align with actual conditions to some extent and provide scientific basis for addressing unreasonable current situations. To solve the problem of flexible and variable actual conditions and planning needs, enhancing the dynamic adaptability of eco-economic regionalization models becomes crucial.

This study comprehensively considers multiple factors, systematizes the primary

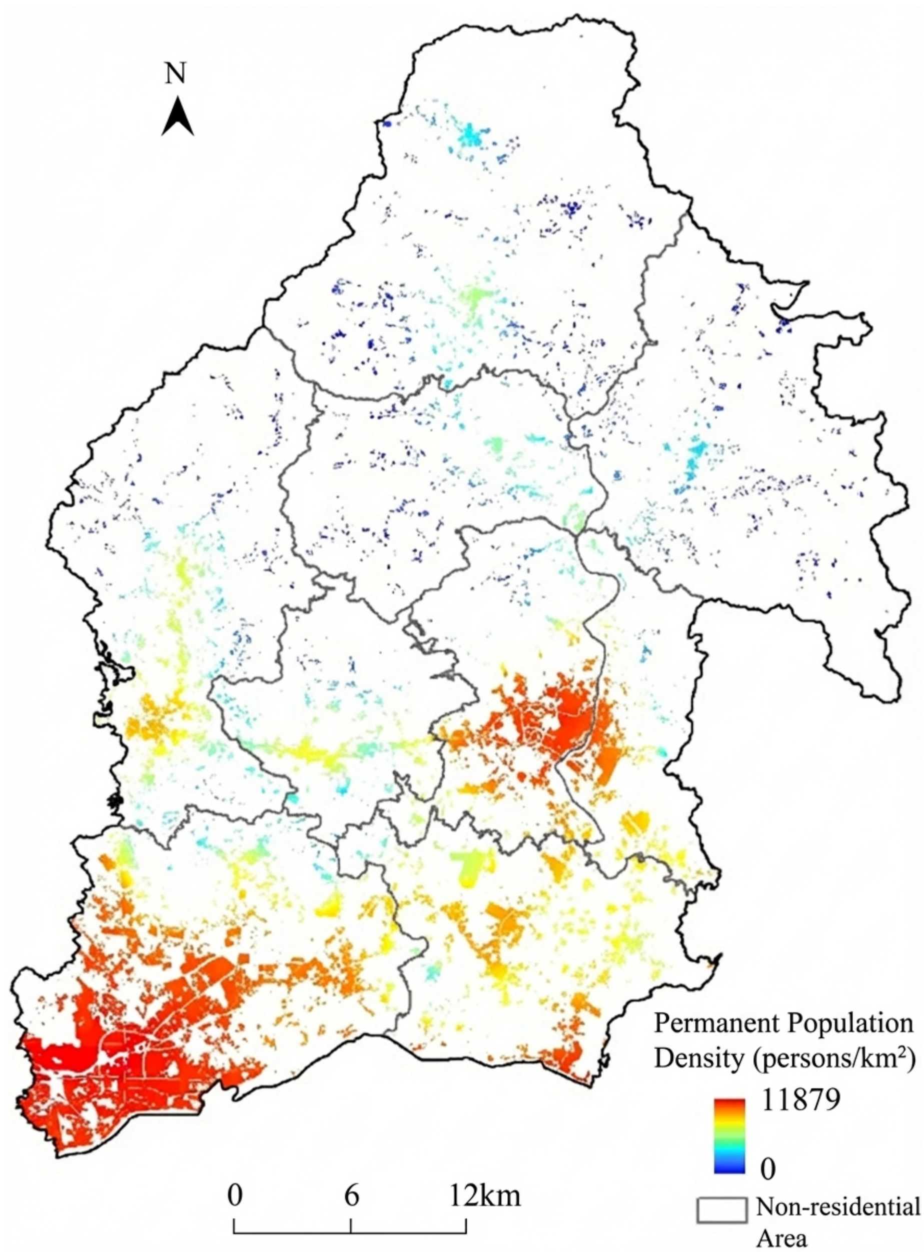

Figure 2: Figure 2

regionalization method in eco-economic regionalization, and constructs an adaptive eco-economic regionalization model by introducing adjustable parameters. The model attempts to divide urban areas into four primary zones—ecological conservation zone, ecological priority zone, development optimization zone, and key development zone—whose proportions can be adjusted according to needs, thereby determining their spatial locations and enhancing model adaptability and practicality. The current status and future development trends covered by the model' s regionalization types are detailed in Table 2 and Table 3.

Table 2 Adaptive eco-economic regionalization model
Table 3 Present situation and future development suggestions for different regionalization types

The model results are obtained through three operational steps:

Step 1: Calculate the current eco-economic development value by subtracting the ecosystem protection degree index from the socio-economic development degree index. The calculation methods for both indices directly reference Wang Sen' s research. All index values are spatially gridded data with the same value range. The development status results can be divided into four situations: higher values indicate the research unit currently leans toward socio-economic development, lower values indicate orientation toward ecosystem protection, and middle values suggest either a win-win situation between economic development and ecological protection or deficiency in both.

Step 2: Under the four situations from Step 1, consider local resource-environment carrying capacity conditions. The resource-environment carrying capacity calculation method directly references Wang Sen' s research, where larger values indicate relatively more available resources and lower environmental pollution levels, and smaller values indicate the opposite. The model consolidates all situations into eight categories.

Step 3: Based on actual conditions and protection principles, the eight categories are merged into four primary zones: ecological conservation zone, ecological priority zone, development optimization zone, and key development zone.

Applying the adaptive eco-economic regionalization model for primary classification can fully consider management department requirements for the area ratio of ecological protection land and construction development land in their region. By adjusting model parameters (, ESP, REC1, REC2), the area of each primary zone can be controlled, increasing model flexibility without compromising scientific rigor and accuracy. Under ArcGIS, parameter adjustments enable rapid model construction, enhancing intuitiveness and practicality.

5. Scenario Analysis Based on Dynamic Adaptive Regionalization

To validate the adaptive eco-economic regionalization model, this study selected two scenarios: (1) current status values of ecological land-related data for model accuracy verification; and (2) simulated Zengcheng ecological land meeting ecological county requirements for model dynamic adaptability verification.

In scenario analysis, the proportion of protected areas to national territory refers to the percentage of various protected areas (scenic spots, nature reserves, ecological function conservation areas, water source protection areas, closed mountain afforestation areas, etc.) to total land area. This area should be classified as ecological conservation zones from structural and functional perspectives. The proportion of ecological land area to national territory area refers to the percentage of ecological land (water bodies, vegetation, etc.) to total land area. Most of this area should be classified into ecological conservation zones and ecological priority zones. The main difference between the two scenarios lies in delineating ecological conservation zones and ecological priority zones according to different proportions and clarifying their corresponding spatial locations.

Table 4 Scenario analysis

Scenario 1: Zengcheng' s Current Status
If Zengcheng' s future ecological environment development primarily maintains the status quo, ecological conservation zones account for approximately 27% of the national territory, while ecological priority zones account for 31%. The corresponding regionalization is shown in Figure 4. Comparing with actual conditions, existing natural scenic areas in Zengcheng' s northern mountains, the headwaters of the Paitan River, and other important ecological lands are all included in ecological conservation zones, while ecological priority zones cover areas with higher vegetation coverage and transition zones around strongly urbanized areas. This indicates good simulation accuracy of the adaptive eco-economic regionalization model.

Scenario 2: Ecological County Requirements
If Zengcheng aims to develop into a low-carbon eco-city, referencing the Ministry of Environmental Protection' s "Ecological Province Construction Indicators" and Zengcheng' s 12th Five-Year long-term plan, ecological conservation zones should increase to approximately 42% of the national territory, while ecological priority zones should remain basically unchanged at about 27%. The regionalization results are shown in Figure 4. From the spatial distribution perspective, the ecological conservation zone area in Scenario 2 completely contains that in Scenario 1 and expands continuously around its edges. The expansion prioritizes areas with strong ecosystem service functions or high ecological vulnerability. Through practical verification, even though the ecological priority zone area hasn' t changed significantly, its spatial location has changed substantially due to the expansion of ecological conservation zones. In addition to covering the ecological priority zone range from Scenario 1 that wasn' t annexed by the expanded ecological conservation zones, Scenario 2' s ecological priority zones also incorporate some adjacent development optimization zones. Some optimization development zones remain within ecological priority zones, representing actual villages and towns that are preserved and reflected. The model results maintain good accuracy while preserving dynamic adaptability and details.

Figure 4

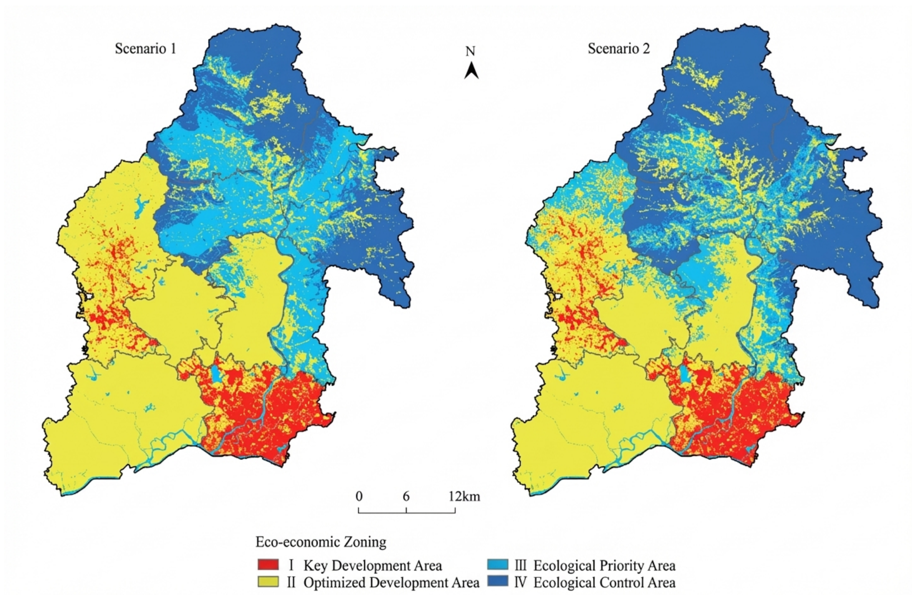

Figure 3: Figure 4

First-level eco-economic regionalization map

6. Empirical Regionalization Results and Policy Recommendations

Referencing Zengcheng' s planning goal of building a low-carbon eco-city and applying the above adaptive eco-economic regionalization model, this study obtained first-level eco-economic regionalization through expert discussion to determine various model parameters. Using a bottom-up approach, we layered and clustered natural ecological factors (water pollution, vegetation, etc.) and socio-economic factors (population, transportation, etc.), then comprehensively considered administrative boundaries, land use types, and natural boundaries such as terrain to obtain second-level eco-economic regionalization through qualitative analysis. The area ratio of each zone is: key development zone: development optimization zone: ecological priority zone: ecological conservation zone = 15:27:27:31. The main development directions for each second-level zone were clarified, and relevant recommendations were proposed.

Table 5 Second-level eco-economic regionalization

Southern Urban Ecological Industrial Zone (II-2)
As Zengcheng' s industrial and commercial center, this zone has high development levels but also large resource consumption. Water and air pollution are

most severe due to concentrated industrial production, processing, and sewage outfalls. While ensuring economic development, the zone should prioritize improving river water quality and air quality. For the existing industrial layout, green buffer zones should be established. For the local pillar industry—denim garment manufacturing—industry access should be regulated, printing and dyeing processes should be improved, exhaust treatment devices should be installed, and small-scale wastewater treatment plants for printing and dyeing wastewater can be appropriately built. Green isolation belts should be established around industrial concentration areas to reduce noise impacts on surrounding residents. Relying on the local national-level economic and technological development zone, the industrial structure should gradually eliminate high-energy-consumption and high-pollution enterprises while introducing energy-saving and high-tech industries. Commercial and service land use should be appropriately increased to improve urbanization levels and the proportion of residential land, improve people' s livelihoods, and transform rural residential areas to promote intensive and economical land use and enhance urban image.

Paitan River Headwaters Ecological Function Conservation Area (IV-1)
With large terrain undulations, high biodiversity, and important water conservation and soil retention functions, this area contains multiple forest parks and the Baishuizhai Scenic Area due to its rich natural landscape resources. It should be protected as permanent ecological land. Relying on locally abundant and unique natural landscapes and resources, tourism development should be reasonably planned. Tourism-related infrastructure should adopt appropriate engineering measures for low-intensity development to reduce environmental disturbance. The number of agritourism facilities and domestic waste discharge should be strictly controlled, with corresponding reward and punishment measures and strengthened supervision to avoid excessive environmental pressure.

7. Conclusions and Discussion

This study first established a linear model between nighttime light data and population density to explore the simulation and refinement of data traditionally aggregated at administrative boundaries. By introducing variable parameters, we constructed an adaptive eco-economic regionalization model that enhances dynamic adaptability while standardizing primary regionalization results into four zones: ecological conservation zone, ecological priority zone, development optimization zone, and key development zone. Using Zengcheng District as a case study, we conducted scenario simulations to verify the model' s accuracy and dynamic nature, followed by analysis and policy recommendations.

Compared with previous studies, the proposed population density model avoids errors from determining population distribution ranges by simply finding nighttime light intensity thresholds. It accurately distributes street/town-level administrative population statistics to population concentration areas, effectively improving population distribution accuracy across spatial scales. Within population concentration areas, the linear proportional relationship between light intensity and population data further optimizes internal population distribution. Since the model applies to the minimum population statistical unit (street/town administrative units), it effectively avoids discrepancies in the correspondence between nighttime light intensity and population distribution across different towns due to economic development differences.

The constructed adaptive eco-economic regionalization model standardizes primary regionalization results into four categories, enhancing systematicity and facilitating horizontal comparison across regions. Primary regionalization results break administrative boundaries, preserve the integrity of important ecological processes, and reflect functional differences within administrative units. By combining local planning and management objectives to adjust model parameters, the proportions of each zone can be modified, further enhancing model flexibility and practicality.

After years of research by Chinese scholars, eco-economic regionalization principles, methods, and indicators have become increasingly mature. However, requirements for regionalization result accuracy and operability are growing higher, especially for small- and medium-scale regionalization. Future improvements should focus on:

1. **Data spatial refinement:** Higher spatial refinement brings results closer to reality, improving accuracy and operability. Spatially explicit input data for index calculation (such as GDP and available resources, normally aggregated administratively) is key to improving zoning result accuracy.

2. **Dynamic adaptability:** EER model results are only useful when the zoning process is more adaptive to local management objectives. Introducing target management mechanisms combined with local strategic planning can further improve regionalization precision and usability.

3. **Systematic zoning schemes:** Zoning results should consider both administrative and natural-economic boundaries rather than simply clustering indicator data. This facilitates practical zoning and management within administrative boundaries while enabling comparison between them. Combining top-down and bottom-up approaches with clustering methods is recommended.

References

[1] Ma Shijun, Wang Rusong. Social-Economic-Natural Complex Ecosystem. Acta Ecologica Sinica, 1984, 4(1): 1-9.
[2] Li Feng, Wang Rusong. Urban Complex Ecology and Ecological Space Management. Chinese Journal of Ecology, 2014, 33(1): 1-11.
[3] Ouyang Zhiyun, Wang Rusong, Li Feng. Ecological Demonstration Area, Ecological Province, and Ecological City Construction: Indicators, Plans, and Assessments. Beijing: Chemical Industry Press, 2003.

[4] Zhang QF, Wu FQ, Wang L, Yuan LF, Zhao LS. Application of PCA integrated with CA and GIS in eco-economic regionalization of Chinese Loess Plateau. Ecological Economics, 2011, 70(6): 1051-1056.
[5] Wang Rusong, Ouyang Zhiyun. Principles of Eco-Economic Regionalization. Acta Ecologica Sinica, 1983, 3(2): 102-120.
[6] Wang Rusong, Feng Changchun. Urban Eco-Economic Regionalization: A Case Study of Chengde City. Geography and Territorial Research, 1994, 10(1): 36-41.
[7] Bai Y, Xu HL, Ling HB. Eco-service value evaluation based on eco-economic functional regionalization in a typical basin of northwest arid area, China. Environmental Earth Sciences, 2014, 71(8): 3715-3726.
[8] Common M, Perrings C. Towards an ecological economics of sustainability. Ecological Economics, 1992, 6(1): 7-34.
[9] Wang Sen. Research on Eco-Economic Regionalization Based on Ecological Environment and Socio-Economy. Taiyuan: Taiyuan University of Technology, 2010.
[10] Li FM. Ecological Economic Index Evaluation of Poyang Lake Eco-Economic Zone. Journal of Anhui Agricultural Sciences, 2014, 42(2/3): 18-21.
[11] Zhang QF, Wu FQ, Wang L, Yuan LF, Zhao LS. Application of PCA integrated with CA and GIS in eco-economic regionalization of Chinese Loess Plateau. Ecological Economics, 2011, 70(6): 1051-1056.
[12] Liu HM. Comprehensive carrying capacity of the urban agglomeration in the Yangtze River Delta, China. Habitat International, 2012, 36(4): 462-470.
[13] Wang Sen. Research on Eco-Economic Regionalization Based on Ecological Environment and Socio-Economy. Taiyuan: Taiyuan University of Technology, 2010.
[14] Bai Y, Xu HL, Ling HB. Eco-service value evaluation based on eco-economic functional regionalization in a typical basin of northwest arid area, China. Environmental Earth Sciences, 2014, 71(8): 3715-3726.
[15] Li FM. Ecological Economic Index Evaluation of Poyang Lake Eco-Economic Zone. Journal of Anhui Agricultural Sciences, 2014, 42(2/3): 18-21.
[16] Gao Jixi, Wang Rusong. Construction Framework of National Ecological Protection Red Line System. Environmental Protection, 2014, 42(2/3): 18-21.
[17] Han Baolong, Li Feng, Xu Chongqi. Empirical Research and Reflection on Shenzhen' s Basic Ecological Control Line. Urban Planning Forum, 2014, (7): 48-53.
[18] Cao Liqin, Zeng Hui, Zeng Zheng. Urban Population Estimation Based on DMSP/OLS Nighttime Light Data: A Case Study of Hubei Province Counties. World Regional Studies, 2009, 18(4): 91-99.
[19] Zhuo Li, Ichinos T, Zheng J, Chen J, Shi PJ, Li X. Modeling the population density of China at the pixel level based on DMSP/OLS non-radiance-calibrated nighttime light images. International Journal of Remote Sensing, 2009, 30(4): 1003-1018.
[20] Liu HM. Analysis and application of traffic advantage degree in provincial-level main functional area planning: A case study of Hebei Province. Journal of Geo-Information Science, 2011, 13(2): 170-176, 280-280.

[21] Li FM. Ecological Economic Index Evaluation of Poyang Lake Eco-Economic Zone. Journal of Anhui Agricultural Sciences, 2014, 42(2/3): 18-21.
[22] Li FM. Ecological Economic Index Evaluation of Poyang Lake Eco-Economic Zone. Journal of Anhui Agricultural Sciences, 2014, 42(2/3): 18-21.
[23] Li FM. Ecological Economic Index Evaluation of Poyang Lake Eco-Economic Zone. Journal of Anhui Agricultural Sciences, 2014, 42(2/3): 18-21.
[24] Li FM. Ecological Economic Index Evaluation of Poyang Lake Eco-Economic Zone. Journal of Anhui Agricultural Sciences, 2014, 42(2/3): 18-21.
[25] Li FM. Ecological Economic Index Evaluation of Poyang Lake Eco-Economic Zone. Journal of Anhui Agricultural Sciences, 2014, 42(2/3): 18-21.
[26] Li F, Ye YP, Song BW, Wang RS. Evaluation of urban suitable ecological land based on the minimum cumulative resistance model: A case study from Changzhou, China. Ecological Modelling, 2015, 318: 194-203.
[27] Li F, Ye YP, Song BW, Wang RS. Evaluation of urban suitable ecological land based on the minimum cumulative resistance model: A case study from Changzhou, China. Ecological Modelling, 2015, 318: 194-203.
[28] Liu HM. Comprehensive carrying capacity of the urban agglomeration in the Yangtze River Delta, China. Habitat International, 2012, 36(4): 462-470.
[29] Liu HM. Comprehensive carrying capacity of the urban agglomeration in the Yangtze River Delta, China. Habitat International, 2012, 36(4): 462-470.
[30] Liu HM. Analysis and application of traffic advantage degree in provincial-level main functional area planning: A case study of Hebei Province. Journal of Geo-Information Science, 2011, 13(2): 170-176, 280-280.
[31] Liu HM. Analysis and application of traffic advantage degree in provincial-level main functional area planning: A case study of Hebei Province. Journal of Geo-Information Science, 2011, 13(2): 170-176, 280-280.
[32] Amaral S, Monteiro AMV, Camara G, Quintanilha JA. DMSP/OLS night-time light imagery for urban population estimates in the Brazilian Amazon. International Journal of Remote Sensing, 2006, 27(5/6): 855-870.
[33] Lo CP. Modeling the population of China using DMSP operational linescan system nighttime data. Photogrammetric Engineering & Remote Sensing, 2001, 67(9): 1037-1047.
[34] Zhuo L, Ichinos T, Zheng J, Chen J, Shi PJ, Li X. Modeling the population density of China at the pixel level based on DMSP/OLS non-radiance-calibrated nighttime light images. International Journal of Remote Sensing, 2009, 30(4): 1003-1018.
[35] Sutton P. Modeling population density with nighttime satellite imagery and GIS. Computers, Environment and Urban Systems, 1997, 21(3/4): 227-244.