Method on the Evaluation of Urban Territorial Space Intensive Utilization

Wan Yuewu [1], Gong Yinxi[1], Wang Faliang [1], Cai Changyu[2], Yang Yanqin[3]

[1]National Geomatics Center of China, No.28, Lianhuachi West Road, Haidian District, Beijing 100830, – (wyw, gongyinxi, wangfl)@ngcc.cn

[2] Beijing Electric Power Maintenance Branch, No.41 Qianmen Xidajie, Xicheng District, Beijing, China 100073 – sheefy@sina.com

[3] Kunlun Digital Technology Co., Ltd., No. 1, Huanghe North Street, Changping District, Beijing, China 100007 – yangyuanqin@cnpc.com.cn

Keywords: Urban territorial space, Intensive utilization evaluation, Evaluation indicator system, Evaluation unit, Evaluation model.

Abstract

China's natural resources are relatively scarce, and with the acceleration of industrialization and urbanization, the issues arising from the development and utilization of urban territorial space have become increasingly prominent. Therefore, China's urbans need to carry out more scientific and rational land space layout and optimize land allocation, so as to improve the level of intensive utilization of land resources. This paper analyses the current situation and existing problems of the intensive use of urban land space at home and abroad, such as insufficient consideration of coordinated development between urban and rural areas, as well as between different regions. Therefore, to address these challenges, this paper proposes a scientific and reasonable evaluation method for the intensive use of urban territorial space, which involves designing an evaluation indicator system, identifying the evaluation units, and constructing a refined evaluation model for the intensive use of urban territorial space. This method not only evaluates the intensive use of urban territorial space but also uncovers the issues existing in its utilization. It aligns with the requirements for refined intensive urban territorial space management, supports the establishment of a monitoring system for land space planning implementation, and provides technical backing for the next round of land space planning.

1. Introduction

China's natural resources are relatively scarce, and with the acceleration of industrialization and urbanization, issues arising from the development and utilization of urban territorial space have become increasingly prominent (Dong et al. 2024; Wang et al. 2017). Therefore, China's urbans need to carry out more scientific and rational land space layout and optimize land allocation, so as to improve the level of intensive utilization of land resources. The Chinese government has always attached great importance to the conservation and intensive use of land and its evaluation, put forward clear requirements, and emphasized the compactness and layout optimization of land space development. Intensive utilization evaluation can help planners better understand the current land use situation and develop more reasonable spatial layout strategies. Therefore, the evaluation of the intensity of land space utilization has become a basic work for the preparation of land space planning and the improvement of spatial governance.

Intensive use of urban territorial is a crucial strategy to ensure sustainable urban development and an important component of the United Nations' Sustainable Development Goals (SDGs) (Haaland and van Den Bosch, 2015). In the 1980s, there were abundant achievements related to the intensive use of urban territorial space both domestically and internationally, but mainly focused on the analysis and evaluation of urban territorial use policies. The UK has introduced policies to promote urban intensification of land use, limiting external construction and expansion of cities through legislation and planning (Jones and Watkins, 2009; Wang and Ma, 2008). From the mid-20th century to the early 21st century, by setting urban intensification goals and indicators, monitoring and evaluating the progress and effectiveness of urban intensification, cities were guided and coordinated towards intensive development. Even in Canada, which has a vast territory with a sparse population, the government has introduced policies for intensive land use evaluation, emphasizing the rational promotion of urbanization and conducting extensive evaluations of industrial land use intensity (Plan, 2017; Zhang and Hu, 2006). In 1991, the American Planning Association (APA) initiated a research project on a new generation of urban planning regulations, and in 1999, completed the "Smart Growth Legislative Guidebook for Planning," aimed at enhancing land use efficiency and fostering the rational use of land resources to curb urban sprawl (Porter,1992;). However, these studies mainly focus on the analysis and evaluation of urban territorial use policies, and there are still gaps in the evaluation of land use intensity at the multi-level spatial scale of urban and rural areas, provinces, cities, counties, and townships. They have not fully considered whether there is coordinated development between urban and rural areas and between different regions.

Therefore, to resolve these issues, this paper collects natural resource survey and monitoring data, national spatial planning data, national spatial management data, three-dimensional spatiotemporal image data, economic and social data, population data, etc. in China. Based on these data, it proposes a scientific and reasonable evaluation method for the intensive use of urban territorial space. The method involves identifying evaluation units for the intensive use of urban territorial space, establishing an evaluation indicators system for the intensive use of urban territorial space that covers both urban and rural areas comprehensively, and constructing a refined evaluation model for the intensive use of urban territorial space. This allows for the evaluation of the intensive use of urban territorial space, fulfilling the requirements for refined intensive use and management of urban territorial space across the entire city. This evaluation

method supports the construction of a monitoring system for the implementation of territorial spatial planning and provides technical support for the new round of territorial spatial planning.

2. Method on the Evaluation of Urban Territorial Space Intensive Utilization

In this paper, the evaluation of urban territorial space intensive utilization includes evaluations of intensive use of land space at different planning levels such as national, provincial, city, county, and village.

The evaluation method on intensive use of urban territorial space includes three aspects: constructing an evaluation indicators system for intensive use of land space covering urban and rural areas according to different levels of land space planning; clarifying the evaluation units for intensive utilization of urban territorial space; constructing an evaluation model for the refined and intensive utilization of urban territorial space. The method framework is shown in Figure 1.

2.1 Evaluation Indicator System for Intensive Use of Urban Territorial Space

The evaluation indicator system for the intensive use of urban territorial space refers to a set of indices used to measure the level of intensity in terms of structure, efficiency, and quality of land space development and utilization. For different administrative levels including the nation, province, city, county, and township, various regional types such as urban centers, various industries, public service facilities, land for transportation, and rural residential areas are distinguished. Corresponding to these different regional types, an evaluation indicators system for the intensive use of land space covering both urban and rural areas is established, supported by spatial data including Territory Information Model (TIM), real-scene 3D imaging, and urban territorial and space monitoring.

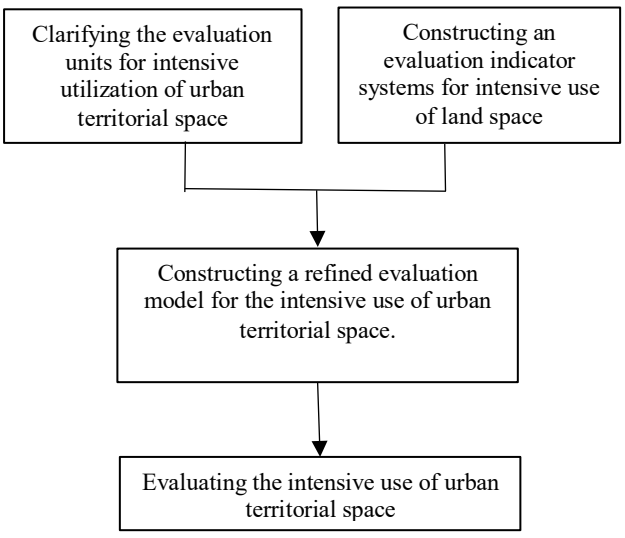

Figure 1. Framework of the evaluation method on intensive use of urban territorial space.

2.1.1 Indicators System at the National and Provincial Levels: At the national and provincial levels, we focus on the coupling between the resource carrying capacity and the urbanization trend in different types of regions, such as coastal developed areas, inland central areas, border areas, agricultural production areas, ecologically sensitive areas, and resource-based areas. The evaluation indicators system for intensive utilization of national and provincial land space is shown in Table 1.

Primary indicators	Secondary indicators	Tertiary indicators
Intensity index of land space utilization	Population density index	Population density of urban and rural construction land
	Economic intensity index	Gross domestic product per unit of construction land
		Industrial added value per unit area of industrial land
Land consumption index of population and economic growth	Land consumption index of population growth	Amount of added urban and rural construction land consumed per unit of population growth
	Land consumption index of economic growth	Decrease rate of land consumption per unit of Gross Domestic Product (GDP)
		Amount of new construction land consumed by the gross value of production per unit area of land
Management performance index	Performance index of urban land management	Supply ratio of urban stock land
		Land idle rate
Water consumption index	Water resource production efficiency	Water consumption of GDP/10000 yuan
	Water resource utilization intensity	Daily water consumption per person
	Water resource recycling rate	Industrial water recycling rate
Structure and layout of land space utilization	Layout of land space utilization	Coverage rate of public service facilities
		Distance from the urban area to the suburban town
		Distance between transportation hub and residential area
	Structure of land space utilization	Land mixed use degree
		Concentration and connectivity of agricultural land
		Connectivity of ecological land network

Table 1. The evaluation index system for intensive utilization of national and provincial land space.

In terms of structure and layout, through analysing regional differences and identifying of urban systems, we focus on analysing and evaluating the compact pattern and multi-center development level of urban systems such as urban agglomerations and metropolitan areas, and promote the coordinated and compact layout of urban space.

In terms of factor matching, by analysing the contents of "determining the city and land by water" and "linking population with the scale of construction land", the matching degree between macro resources and population scale, the balance between regional water resource constraints and farmland protection needs are evaluated, providing targeted control for urban scale growth and land use structure.

In terms of space utilization efficiency, focusing on the "linkage between new urban land and inventory revitalization", we focus on analysing and evaluating the proportion of incremental and stock use of construction land at the macro level, and guide the efficient allocation of land resources.

2.1.2 Indicators System at the City and County Levels: At the city and county levels, we consider various factors such as the intensity, structure, efficiency, quality, ecology, and society of the development and protection of national land space, focusing on spatial unit types such as central urban areas, county-level central towns, development zones, and industrial parks, in order to comprehensively evaluate the intensive utilization level of national land space. The evaluation indicators system for intensive utilization of land space in cities and counties is shown in Table 2.

2.1.3 Indicators System at the Village Levels: At the village levels, we distinguish unit types such as townships, rural residential areas, and rural industrial land, focusing on factors such as urban-rural living circles, rural revitalization, industrial agglomeration development in villages and towns, and urban-rural integration.

Primary indicies	Secondary indicies	Tertiary indicies
Development zones	Spatial layout	Integration of industry and city
		Traffic convenience
		Coverage rate of public facilities
	Utilization efficiency	Number of employees absorbed per unit of land
		Tax revenue generated per unit area of industrial land
	utilization intensity	Plot ratio
		Building density
		Land development ratio
Residential area	Spatial layout	Completeness of public service facilities
		Residential land mix ratio
		Walking accessibility
	Utilization efficiency	Population density
	utilization intensity	Plot ratio
		Floor Area Ratio
		Building density
Business	Spatial layout	Composite utilization degree
		Accessibility of commercial functional areas
	Utilization efficiency	Employment population density
	Utilization intensity	Plot ratio
		Floor Area Ratio
		Building density
Administrative office	Spatial layout	Convenient transportation
		Coverage rate of public facilities
		Composite utilization degree
	Utilization efficiency	Office area per capita
		Flexible workspace ratio
	Utilization intensity	Plot ratio
		Floor Area Ratio
		Building density
Health care	Spatial layout	Traffic convenience
		Medical service coverage rate
		Overlap rate of medical service radius
	Utilization efficiency	Per capita area of permanent residents
		Average land area occupied by each hospital
	Utilization intensity	Plot ratio
		Floor Area Ratio
		Building density
Education	Spatial layout	Traffic convenience
		Coverage rate of education service
		Overlap rate of service radius
	Utilization efficiency	Number of students that can be served per unit of land area
		Number of secondary vocational schools per 400,000 people
		Number of special education schools per 300,000 people
	Utilization intensity	Plot ratio
		Floor Area Ratio
		Building density
Culture and Art	Spatial layout	Traffic convenience
		Coverage rate of service
		Overlap rate of service radius
		Composite utilization degree
	Utilization efficiency	Per capita area of permanent residents
		Average land area occupied by each museum or exhibition hall
	Utilization intensity	Plot ratio
		Floor Area Ratio
		Building density
Sport	Spatial layout	Traffic convenience

		Coverage rate of service
		Composite utilization degree
		Number of facilities or land that can be effectively used in both normal and emergency situations
	Utilization efficiency	Per capita area of permanent residents
		Average land area occupied by each sports venue
	Utilization intensity	Plot ratio
		Floor Area Ratio
		Building density
Social welfare facilities	Spatial layout	Traffic convenience
		Connectivity with medical facilities
	Utilization efficiency	Per capita area of permanent residents
	Utilization intensity	Plot ratio
		Floor Area Ratio
		Building density
Funeral and interment	Spatial layout	Traffic convenience
		Ratio of cemetery to barren mountain and land area where it is located
	Utilization efficiency	Per capita area of permanent residents
		Average land area of tombs
		The ratio of the amount of ashes stored to the amount of burials
	Utilization intensity	Plot ratio
		Building density
Parkland	Spatial layout	Traffic convenience
		Coverage rate of service
		Composite utilization degree
		Number of facilities or land that can be effectively used in both normal and emergency situations
		Ecological connectivity
	Utilization efficiency	Per capita park green area
		Average land area occupied by each park or green space
Square	Spatial layout	Traffic convenience
		Coverage rate of service
		Connectivity with other functional areas
		Number of facilities or land that can be effectively used in both normal and emergency situations
	Utilization efficiency	Per capita square area
		Average land area occupied by each square
Transportation	Spatial layout	Coverage rate of public transportation stations
		Mixed use of land in the surrounding areas of transportation hub stations
		Land utilization rate within the transportation corridor
	Utilization efficiency	Road network density
		Average commuting distance for residents
		Area of public parking lot per capita

Table 2. The evaluation indicators system for intensive utilization of land space in cities and counties.

The evaluation indicators system for intensive utilization of land space in rural areas is shown in Table 3.

Primary indicies	Secondary indicies	Tertiary indicies
Rural residential area	Spatial layout	Dispersion degree of rural residential areas
	Utilization efficiency	Per capita area of rural residential land
		Per capita road area
	utilization intensity	Building density
		Reclamation rate of idle and abandoned land
		Integration and reconstruction degree of residential areas
Rural industrial land	Spatial layout	Traffic convenience
		Coverage rate of public facilities
		Spatial agglomeration
	Utilization efficiency	Number of employed personnel per unit of land use
		Tax revenue per unit of industrial land
	utilization intensity	Plot ratio
		Building density
Agricultural land	Spatial layout	Traffic convenience
		Concentrated contiguous degree of agricultural land
		Shape regularity of agricultural land
		Connectivity with rural residential areas
	Utilization efficiency	Output value of unit agricultural land

Table 3. The evaluation indicators system for intensive utilization of land space in rural areas.

2.2 Evaluation Unit for the Intensive Use of Urban Territorial Space

Based on different levels, spatial scales, and scenarios of territorial spatial planning, corresponding evaluation units for the intensive use of territorial space are constructed to accurately reflect the subject entities for detailed evaluations of urban territorial spatial intensive use.

2.2.1 Evaluation Units at the National and Provincial Levels: At the national and provincial levels, the evaluation of the intensive use of land space is generally based on the district and county administrative divisions as the smallest unit, and the regional evaluation results are obtained by summarizing the evaluation results of the smallest units.

However, for county-level administrative regions with special geographical features, complex functional requirements, unique economic development models, or ecological environment sensitivity, such as those located in ecologically fragile zones, carrying the development of characteristic industries, and shouldering the important task of historical and cultural protection, it is necessary to combine specific geographical boundaries, functional zoning (such as key ecological functional areas, scenic spots, historical and cultural protection areas, etc.), economic zoning (such as characteristic industry gathering areas, etc.), and ecological environment protection requirements (such as nature reserves, national parks, etc.), and other multiple division principles to determine the minimum planning unit.

Based on the minimum planning unit, evaluation units are distinguished according to the "classification criteria for land use trend types in qualitative analysis of regional land use evaluation," taking into account border areas, agricultural areas, and ecological protection areas. These units are then assigned different thresholds, leading to the implementation of differentiated land development and utilization strategies.

2.2.2 Evaluation Units at the City and County Levels: At the city and county levels, in accordance with the requirements of national spatial planning, the evaluation results for cities and counties are summarized using the evaluation results of the minimum units, which are defined as national spatial standard units, streets (towns, management committees), or communities (neighbourhood committees).

Based on the minimum unit, we categorize areas into various sections such as development zones, residential, commercial, administrative, medical, educational, cultural, sports, funeral, park and green spaces, squares, and transportation. These sections are then grouped into evaluation units: urban areas, suburban towns (non-urban), and urban villages. Different thresholds are assigned to these units, guiding tailored strategies for land development and utilization.

2.2.3 Evaluation Units at the Village Levels: At the village levels, the national spatial standard unit or administrative village is used as the minimum unit for evaluating the intensive use of land space. Evaluation units are distinguished according to spatial functions such as urban-rural living circles, rural residential areas, and rural industrial land. The evaluation results are summarized based on the results of the minimum unit evaluations.

2.3 The Evaluation Model for Intensive Utilization of Urban Territorial Space

Based on territorial spatial information model (TIM), and guided by the principles of human-land coordination as well as comprehensive social, economic, and ecological benefits, this paper aims to develop an evaluation model and corresponding technical methodologies for assessing urban territorial spatial intensive use. These methodologies will support differentiated governance approaches for optimizing urban territorial spatial intensive use under various environmental parameter conditions.

Based on the indicator system, using the evaluation unit system and GIS technology, this paper conduct multi-scale and multi-dimensional spatial transmission. using Analytic Hierarchy Process and Principal Component Analysis, the intensive

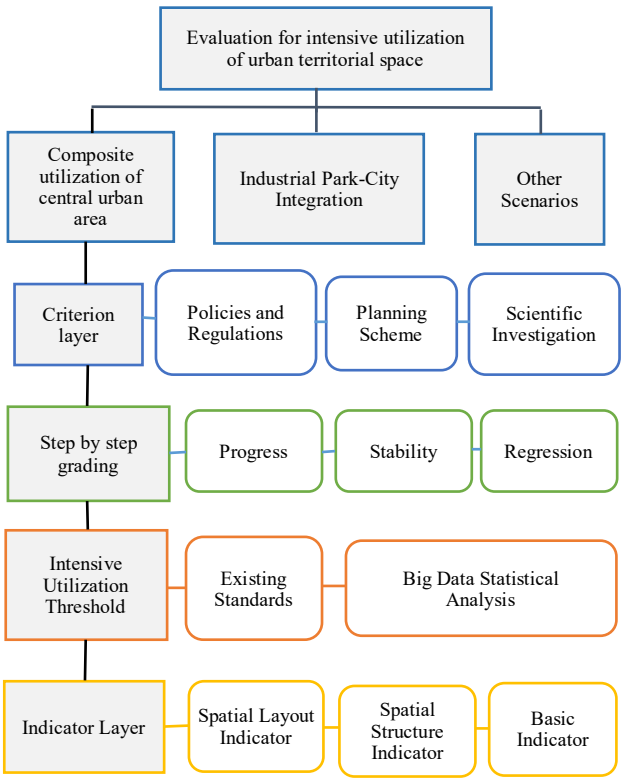

Figure 2. Diagram of analytic hierarchy process for intensive utilization of urban territorial space.

utilization index are comprehensively calculated. The mathematical statistical results of a region or specific scenario are taken as the ideal values for evaluating the level of territorial spatial intensive utilization. Analytic hierarchy process for intensive utilization of urban territorial space is shown as Figure 2.

Then, this paper constructs a multi index comprehensive evaluation model for evaluating the intensive use of urban territorial space, including indicator normalization, weight determination, and weighted comprehensive calculation, etc, which is shown as Figure 3.

2.3.1 Indicator Normalization: Given the varying dimensions and ranges of different indicators, this paper adopts the "Min-Max normalization" method (also known as range normalization)

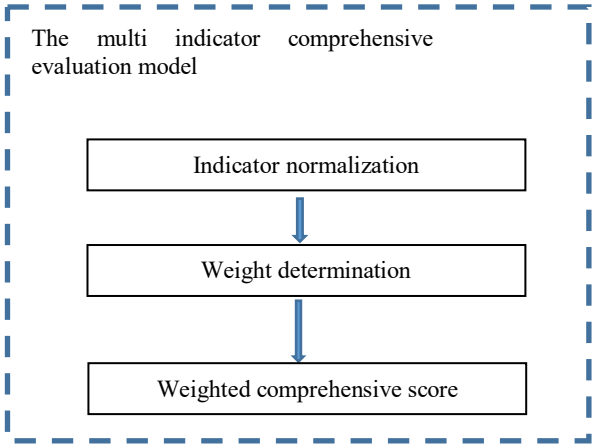

Figure 3. Diagram of the multi indicator comprehensive evaluation model.

to convert all indicators to the [0,1] interval for normalization. For "positive indicators" (the higher the value, the better the evaluation, such as economic output, utilization rate, etc.):

$$\mathrm{R}(x_{ij}) = \frac{x_{ij} - min\{x_{ij}\}}{max\{x_{ij}\} - min\{x_{ij}\}} \quad (1)$$

For 'reverse indicators' (the smaller the value, the better the evaluation, such as pollution emissions, vacancy rates, etc.):

$$\mathrm{R}(x_{ij}) = \frac{max\{x_{ij}\} - x_{ij}}{max\{x_{ij}\} - min\{x_{ij}\}} \quad (2)$$

Where x_{ij}represents the original value of the jth evaluation object (or plot) on the ith indicator
$\mathrm{R}(x_{ij})$ represents the result of normalizing the original value x_{ij}, with a value range of [0,1]
$min\{x_{ij}\}$ and $max\{x_{ij}\}$ represent the minimum and maximum values of the ith indicator among all evaluation objects, respectively

2.3.2 Weight Determination: Normalized indicators are assigned corresponding weights w_i, which satisfy the following criteria:

$$\sum_{i=1}^{n} w_i = 1, w_i \geq 0 \quad (3)$$

Where w_i represents the weight of the ith indicator, which can be determined by these methods such as Analytic Hierarchy Process, Delphi Method, or expert scoring
n is the total number of indicators

2.3.3 Weighted Comprehensive Score: We multiply the normalized value of each indicator by its corresponding weight and accumulate to obtain the comprehensive score sj :

$$s_j = \sum_{i=1}^{n} \left(w_i \times R(x_{ij})\right) \quad (4)$$

Where s_j represents the comprehensive score (final evaluation value) of the jth evaluation object (or plot)
$R(x_{ij})$ represents the normalized value of the jth evaluation object on the ith indicator
w_i represents the weight of the ith indicator

According to the size of s_j, it can be sorted or compared with preset thresholds/benchmark values to evaluate the level of efficiency (such as high efficiency, average, low efficiency) or overall performance of each evaluation object. Thus, an evaluation conclusion on the intensive use of urban territorial space can be drawn.

3. Application Example

This paper takes Jinan City in Shandong Province as a pilot, based on relevant data from Jinan City, selects five typical scenarios including the spatial complex utilization of central urban areas, the " normal and urgent dual-use" spatial utilization, the integrated development of industry and city, the allocation of public service resources linked to population, and the development of industrial agglomeration in villages and towns. Based on the evaluation indicator system, using the above models and methods, the evaluation analysis results are formed.

By calculating the composite utilization index of public service land in the central urban area and comparing it with the average level of the Shandong Peninsula urban agglomeration, the following conclusion is reached: the composite utilization level of public service land in the urban area of Jinan is comparable to the average level of the Shandong Peninsula urban agglomeration.

By calculating the per capita basic education facilities area and the coverage rate of basic education facilities, we analyse the areas with high intensive and idle basic education resources. The following conclusions are drawn: 46 of the 523 community township units in Jinan City located in the central urban area showed high intensive characteristics, while the 92 peripheral community township units showed low intensive characteristics.

4. Conclusion

This paper designs a spatialized and refined urban indicator system, divides evaluation units, constructs an evaluation model for the intensive use of urban territorial space, achieving the evaluation of urban land space intensive utilization in urban and rural areas, urban functional areas, etc. Taking Jinan City in Shandong Province as an example, it evaluates the composite utilization degree of public service land in the central urban area and evaluates the level of public service resource allocation linked to population. It reveals the problems existing in the utilization of urban land space resources, assists governments at all levels in the preparation of land space planning and scientific decision-making in urban land space management, and improves the supervision mechanism of land space. It provides scientific basis and data support for countries, provinces, cities, counties, and villages in carrying out land space intensive management and development protection.

References

Dong, Y., Jin, G., Deng, X. Z., 2024: Optimization of territorial space layout in China. ACTA GEOGRAPHICA SINICA, 2024, 79(3), 672-687.

Haaland C, van Den Bosch C K., 2015: Challenges and strategies for urban green-space planning in cities undergoing densification:

A review[J]. Urban forestry & urban greening, 2015, 14(4): 760-771.

Jones C, Watkins C. ,2009: Housing markets and planning policy[M]. John Wiley & Sons, 2009.

Plan G., 2017:Growth Plan for the Greater Golden Horseshoe[J]. Ontario Ministry of Municipal Affairs. In effect as of July, 2017, 1: 2017.

Porter, D. R., 1992:State Growth Management: The Intergovernmental Experiment [J]. Pace Law Review, 1992.

Wang, Q., Wang, W.M., Jin, W., 2017: New perspectives and new methods on the research of intensive urban territorial use in China: literature review and prospect. China Population, Resource and Environment, 2017, 27(5): 95-100.

Wang, X.P., Ma, H.,2008: Experience and Enlightenment from the UK in Intensive Land Use [J]. Urban Planning International, 2008(02):79-82.

Zhang, J.X., Hu,Y., 2006: Experience and Insights from Urban Growth Management in Canada. Urban Planning International, 2006(04): 79-83.