International Journal of Environmental Sciences & Natural Resources
ISSN: 2572-1119

Juniper Publishers key to the Researchers

Research Article
Volume 23 Issue 4 - March 2020
DOI: 10.19080/IJESNR.2020.23.556121

Int J Environ Sci Nat Res

The Systematic Evolution of Beijing: A Human Ecology Perspective

Lachang Lyu[1]* and Richard Greene[2]

[1]*College of Resource, Environment and Tourism, Capital Normal University, China*

[2]*College of Geospatial Information Science and Technology, Capital Normal University, China*

Submission: February 17, 2020; **Published:** March 04, 2020

***Corresponding author:** Lachang Lyu, College of Resource Environment and Tourism, Capital Normal University, No. 105 West 3rd Ring Road North, Haidian District, Beijing, 10004, China

Abstract

Megacity sprawl is an international phenomenon and Chinese megacities have been especially exposed to rapid sprawl since reform and the opening-up policy in the year of 1978. As the political, cultural, and international communication center of China, Beijing has witnessed a morphological transition that demonstrates typical aspects of this megacity sprawl. Though the morphological changes have been investigated by a number of scholars, emerging changes and new high resolution multi temporal global urban land data allow for a more systematic investigation that results in an evolutionary model that uncovers the urban form dynamics of megacity sprawl. In this paper, we examine the Beijing morphological evolutionary process and the geographic direction of intra-urban sprawl with the use of a new global urban land database that utilized an extensive number of LANDSAT images for five-year periods from 1980-2015. We find that Beijing's urban spatial expansion has obvious periodic sequences ranging from compact to a more loosely-shaped form but also triangular in some cases and rectangular in other cases and nearly circular as well as the shape of a cross, a pentagon, and hectogon over the 1949 to 2015 time-span. The evolution of Beijing's urban form was affected by many factors that include natural environment, policy, urban planning, economy, population, transportation, and major events. The dominant factors will be examined among the different phases of Beijing's expansion.

Keywords: Beijing; Urban morphology; Sprawl

Introduction

After China's reform and its opening to the outside world, along with the process of China's marketization, the urbanization process has sped up and as a result China's urban land system and the urban form of its cities has been radically transformed. During the last decade alone, China witnessed a forty-six percent increase in its urban population and a seventy-eight percent increase in its built-up land (Bai, Shi, & Liu, 2014). In the past 30 years, China's dragonhead cities, such as Beijing, Shanghai, and Guangzhou expanded most rapidly. Those Chinese metropolitan expansions and suburbanization brought about a series of environmental problems, such as traffic congestion, a large amount of energy consumption, automobile exhaust pollution, the massive loss of arable land, the disappearance of open space and the deterioration of the living environment. Thus, China now faces the challenge of how to implement smart growth and develop more compact cities. Beijing as the capital of China has drawn attention from planners, scholars, and the government regarding its urban form. The study of Beijing's urban morphology and expansion can be divided into five categories:

a) The first category is exploring the change of urban form in history based on the analysis of the relevant historical literature. The ancient chronicles are the important historical data for the study of urban morphology according to Cheng [1] and Su [2] who have examined Beijing's urban form from 1900 to 1949. Wu [3] has studied urban morphology evolution from the perspective of the industrial distribution changes of Beijing while Duan (1989) provides a literature review describing the changes of Beijing urban form during the 1979-1989 period. Such kinds of research describe the basic features of urban form in Beijing but fails to accurately describe the urban expansion process with its morphological characteristics.

b) A second category of research on Beijing uses mathematical fractals in the analysis of its urban morphology and expansion. Fractal theory had been introduced to the field of geography in the 1990s and Jiang & Chou [4] used it in their analysis of Beijing and

found that the city exhibited fractal characteristics during the 1984 to 1999 time period. Xiao et al. [5] also applied fractal theory to the analysis of Beijing's urban structure for 1992, 1999 and 2006. Long et al. [6] developed a scenario analysis for Beijing's urban form based on a binding CA method. Qu et. al. [7] predicted the urban morphology of the plain in eastern Beijing over the next 50 years by also applying the binding CA method.

c) The third category of research on Beijing's urban form examines land-use change. Liu summarizes expansion of land use in Beijing by using GIS analysis while Fang (2002) divided Beijing's urban form according to the evolutionary period of the urban fringe during modern times. These analyses attempt to depict the true urban form through pictures based on the actual land use pattern, but they fall short on explaining the urban morphology evolutionary process. Extending the land-use approach, Jing Ma & Mitchell (2014) et al. has analyzed the influence of working families travel routes and other social population behavior to the urban form of Beijing.

d) The fourth category of research on Beijing's urban form uses the comparative method to compare the patterns across cities. Yu [8] compared the urban morphology of the international metropolis, using such cities as Beijing, London, New York, Paris and Tokyo, however the comparison was relatively limited to the model of urban form and failed to analyze the underlying and dynamic processes of each city. Gaubatz (1999) studied the pattern and evolution of the urban morphology of Beijing, Shanghai and Guangzhou and summarized the common models and types of evolution found in Chinese cities. Rebecca (2016) extended this literature by comparing the relationship of urban morphology and urban sustainable development for Chinese dragon cities.

e) The fifth category of research on Beijing's urban form utilizes remote sensing imagery. Huang [9] has analyzed the temporal and spatial variation process of Beijing urban form from 1995 to 2002 using SAR imagery, while Han (2008) quantitatively researched the change of boundary lines in Beijing city construction using remote sensing data. Although these analyses reflect the real changes in Beijing's urban form, the studies have become outdated in terms of the data used and therefore do not reflect the morphologic characteristics of contemporary Beijing.

In order to understand Beijing's contemporary urban sprawl, the study of urban form should explore the reasons underlying the urban development with an attempt to answer how has Beijing's urban form changed over time and what are the dynamics of each evolutionary phase? To answer these questions, the paper is structured as follows. First, we introduce the research methods showing how we incorporate remote sensing image analysis, GIS spatial analysis, and fractal analysis in the analysis of Beijing's urban morphology. Secondly, we select representative years to fully reveal the track of the evolution and characteristics of the evolution of Beijing urban form which reveal the underlying dynamics of every stage of our evolutionary model.

Research Area and Methodology

Research area

The research area includes all the land inside Beijing's 6th Ring, covering 16410.54km^2 with 6338km^2 of plain area, accounting for 38.6% of the total and 10072km^2 of mountain area, accounting for 61.4% of the total. The center of Beijing is located at latitude 39°54′20″, longitude 116°25′29. Beijing is one of the "Chinese eight ancient capitals", with 6 world cultural heritages, the capital of the people's Republic of China, the National Center City and the national center of politics, culture, education, transportation as well as an international exchange center.

Data source and Data processing

This paper is a long-term dynamic analysis of the evolution of Beijing's urban morphology. Therefore, we utilize a new multi-temporal 30-m global urban land data product developed from Landsat images during the 1980-2015 period, at five-year intervals except for the first period which is 10 years 1980 to 1990 [10]. The authors report high accuracy of this global product especially for China where Beijing scored high Kappa values for all years. Additionally, the paper concludes with a call for users to take advantage of their dataset.

Researchers from all around the world are encouraged to use and evaluate this new 30-m resolution dataset. Our future efforts will be devoted to the continuous update and refinement of this dataset [10].

The Temporal and Spatial Characteristics of Urban Morphology Evolution in Beijing

Characteristics of urban morphology evolution in time

Variance in velocity of expansion in different stages

We use the formula (1) to calculate the annual growth area and expansion rate (Table 1) in each period. The formula is as follows:

$$S = [(\frac{Atn}{Atz})^{\frac{1}{(tn-tz)}} - 1] \times 100\% \quad (1)$$

In formula: S is the average annual increment rate of urban built-up area, tn、tz are the end and the early stage of the study period, Atn and Atz are their built area of initial and end respectively.

How to cite this article: Lachang Lyu, Richard Greene. The Systematic Evolution of Beijing: A Human Ecology Perspective. Int J Environ Sci Nat Res. 2020; 23(5): 556121. DOI: 10.19080/IJESNR.2020.23.556121.

Table 1: Urban construction land growth and expansion rate of Beijing from 1980 to 2015.

Time (Years)	Built-up Area (km^2)	Interval (Years)	Annual Growth Area (km^2)	Average Annual Expansion Rate (%)
1980	687	-	-	-
1990	1,082	10	49.4	5.75
1995	1,212	5	48.2	2.4
2000	1,419	5	58.6	3.41
2005	1,526	5	68.8	1.5
2010	1,632	5	54.8	3.54
2015	1,655	5	41.6	0.28

a) The rapid expansion phase (1980-1990)

During this period, Beijing urban land is in a rapid growth period, the growth rate is much higher than that during 1949-1980. As shown in Figure 1, Beijing urban built area grew from 223.70km^2 in 1980 to 1990 325.49km^2 with the average annual growth of 20.36km^2 and the average annual growth rate of 7.86%.

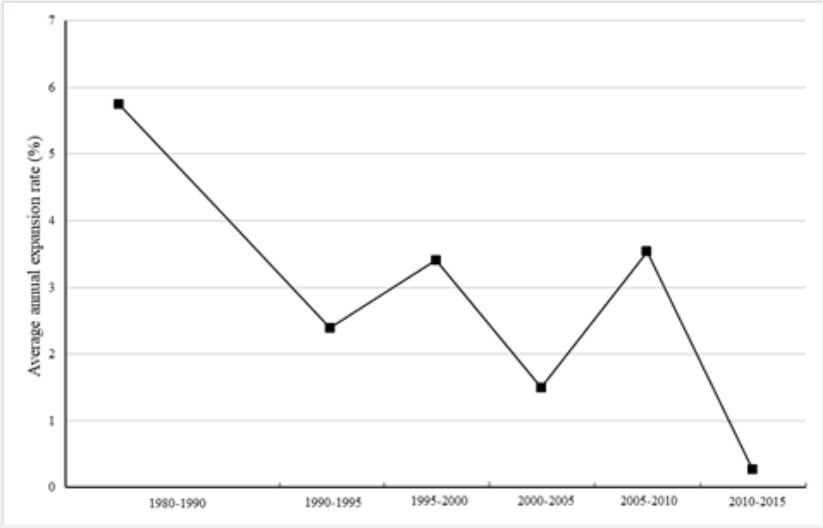

Figure 1: Urban land expansion speed of Beijing from 1980-2015.

b) The high-speed expansion phase (1990-1995)

During this period, the Beijing urban construction land is in a period of rapid expansion. From 1990 to 1995, the urban construction land soared to 625.13km^2 from 325.49km^2, with an average annual increase of built-up area 59.93km^2, the annual expansion rate of steep rise to 13.94%, the growth rate reached the highest point in the past 30 years.

c) The middle speed growth stage (1995-2000)

During this period, the speed of Beijing urban land growth had decreased slightly compared with that before. From 1995 to 2000, the urban construction land grew from 625.13km^2 to 807.08km^2, with an average annual increase of 30.33km^2 and the average annual growth rate of 4.34%.

d) The rapid expansion phase (2000-2005)

During this period, the Beijing urban land is in the rapid growth period. From2000 to 2005, urban construction land grew from 807.08km^2 to 1113.38km^2, with an average annual increase of 76.58km^2 and the average annual growth rate was 8.39%, an average annual growth rate that is the largest in the past 30 years.

e) The stable expansion phase (2005-2010)

In this period, the expansion speed was slowing down. From 2005 to 2010, the urban construction land grew from 1113.38km^2 to 1328.79km^2, with the annual increase of 43.08km^2 and an average annual growth rate of 3.54%.From2008 to 2013, the urban expansion rate slowed down, the construction land grew from 1328.79km^2 to 1508.87km^2, with an average annual increase of 36.02km^2 and the average annual growth rate of 2.66%, is the lowest level in nearly 30 years.

f) The Late stable expansion phase (2010-2015)

In this period, the expansion speed was slowing down similar to the prior five-year phase. From 2010 to 2015, the urban construction land grew from 1113.38km^2 to 1328.79km^2, with the annual increase of 43.08km^2 and an average annual growth rate of 3.54%. From 2010 to 2015, the urban expansion rate

How to cite this article: Lachang Lyu, Richard Greene. The Systematic Evolution of Beijing: A Human Ecology Perspective. Int J Environ Sci Nat Res. 2020; 23(5): 556121. DOI: 10.19080/IJESNR.2020.23.556121.

slowed down, the construction land grew from 1328.79km^2 to 1508.87km^2, with an average annual increase of 36.02km^2 and the average annual growth rate of 2.66%, is the second lowest level in nearly 30 years.

The variance in expansion strength

Expansion speed can be used to reveal the speed of urban expansion, however, due to different base years, we could not compare urban expansion intensity in different periods, so we introduce urban expansion intensity index of AGR, specifically referring to the ratio of the average annual urban land expansion area and the urban area in base year [11]. Formula (2) as shown in the following [12]:

$$AGR = \frac{UA_{n+i} - UA_i}{nUA_i} \times 100\% \quad (2)$$

Formula: AGR: the extended intensity index; UA_{n+1} and $UA_{i:n+i}$ years and I years of urban land area, n is a unit of time [13].

We use ArcGIS to obtain the expansion of built area of Beijing city in each period and calculate the expansion intensity index in each period (Table 2) and the overall expansion intensity curve (Figure 2). Overall, expansion intensity curve is consistent with expansion velocity curve. From 1980 to 1995 is high-speed expansion stage, expansion intensity index increased from 9.10 to 18.41 and reached the highest point in the period of 1990- 1995; from 1995-2000 is middle growth stage, expansion intensity index decreased to 4.85; the period from 2000 to 2005, entered a phase of rapid expansion again due to the establishment of the international city targets and the successful bid for the Olympic Games; the phase from 2005 to 2010 is the middle speed of expansion. After 2010, the city expanded in a relatively stable period and the expansion intensity index fell to 2.71, the lowest in 30 years.

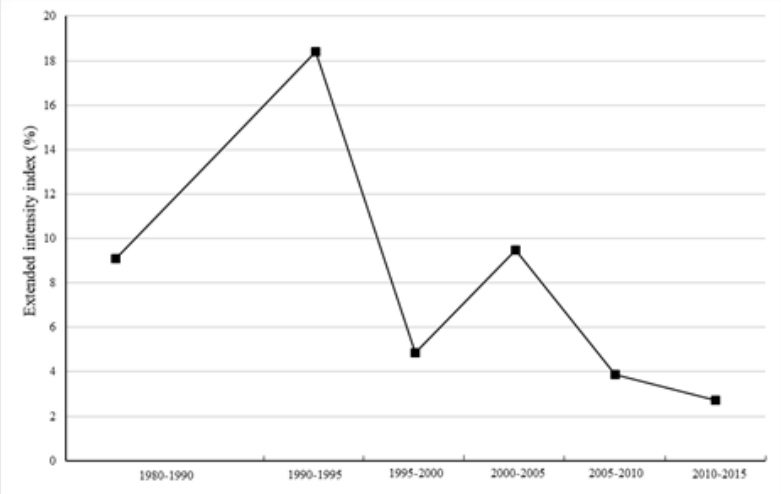

Figure 2: Construction land expansion intensity of Beijing city (1980-2015).

Table 2: Extension intensity and expansion type of Beijing city (1980-2015).

Time (Years)	Built-up area (km^2)	Interval (years)	Annual Growth Area (km^2)	Extended Intensity Index (%)	Extended Type
1980	223.7				
1990	325.49	5	20.36	9.1	rapid
1995	625.13	5	59.93	18.41	fast
2000	807.08	6	30.33	4.85	medium
2005	1113.38	4	76.58	9.49	rapid
2010	1328.79	5	43.08	3.87	medium
2015	1508.87	5	36.02	2.71	slow

Possible causes for urban expansion in velocity and intensity in each phase

Urban expansion can be caused by a number of factors, economy, population, transportation, planning and policies, however, each phase shows the dominated factors. The fast expansion during 1980-1990, caused by fast economic growth initiated by the transition from a planned economy to a market economy with GDP doubling from 1983 to 1993. On the other hand, Beijing adjusted the economic structure and relocated the industrial enterprises from the central area to the suburbs and with the renovation of old and dilapidated housing projects, the people lived in old districts but immigrated to the suburban area.

How to cite this article: Lachang Lyu, Richard Greene. The Systematic Evolution of Beijing: A Human Ecology Perspective. Int J Environ Sci Nat Res. 2020; 23(5): 556121. DOI: 10.19080/IJESNR.2020.23.556121.

These factors above enhanced the urban fast expansion. However, from 1989 to 1999, with the incident in Qiananmen Square in 1989 and a decrease in economic activity in all of China, and other factors, such as, strict arable land protection policy, controlling the heating of economic zones in 1993, as well as a strict control of population by adopting the Hukou policy, had slowed down the urban expansion. But entering the new century of 2000, the successful bid for the Olympic games, and the development of Zhongguancun Hi-tech zone as well as the establishment of the Yijuang Economic technology development zone, urban expansion accelerated, however, this high speed of urban expansion just lasted three years with the end of a strict policy for controlling land provision and a population policy was introduced. Since 2003, new urban plan for optimized the urban function keeping decreasing the urban expansion and gradually urban sprawl kept in a steady way.

The spatial characteristics of urban morphology evolution

The overall process of expansion

The overall evolutional process of expansion of Beijing city in 30 years was showed in Figure 3 & 4. In a period of 1980-1990, Beijing City built-up area increased from 223.70km^2 in 1980 to 325.49km^2 in 1990, with the average annual growth rate of 20.36km^2 and the average annual expansion rate of 7.86%. During the years of 1990-1995, Beijing city construction land entered in the period of the high-speed expansion, city construction soared to 625.13km^2 from 325.49km^2, with an average annual increase of built-up area of 59.93km^2 and an average annual growth rate rose to 13.94%, reaching the highest point in nearly 30 years. The period of 1995-2000, as medium speed expansion stage, saw slightly decreasing in the growth rate of Beijing city land. However, from 2000 to 2005, the city construction land experienced rapid growth increasing from 807.08km^2 at the end of 1999 to 1113.38km^2 in 2005, with an average annual increase of 76.58km^2, as the largest amplitude of average annual growth rate in nearly 30 years. In the period of 2005-2015 saw steadily extending in Beijing urban land, from 2000 to 2005, urban construction land grew from 1113.38km^2 at the end of 2005 to 1328.79km^2 in 2010, with annual increase of 43.08km^2, and an average annual growth rate for 3.54%. From 2010 to 2015, urban expansion rate continuously slowed down, the construction land grow from 1328.79 km^2 at the end of 2010 to 1508.87km^2 in 2015, with an average annual increase of 36.02km^2 and the average annual growth rate of 2.66%, reaching the lowest in nearly 30 years.

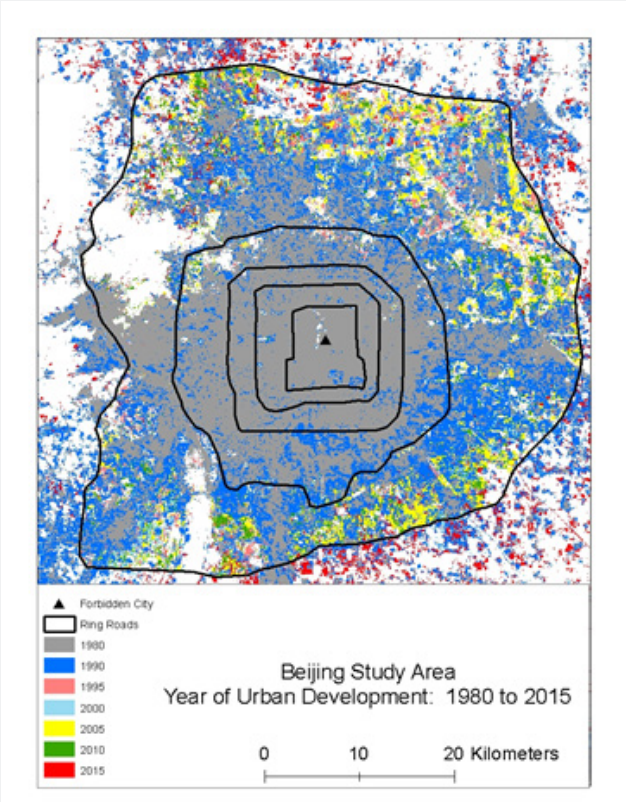

Figure 3: The expansion process of Beijing built-up area from 1980 to 2015.

How to cite this article: Lachang Lyu, Richard Greene. The Systematic Evolution of Beijing: A Human Ecology Perspective. Int J Environ Sci Nat Res. 2020; 23(5): 556121. DOI: 10.19080/IJESNR.2020.23.556121.

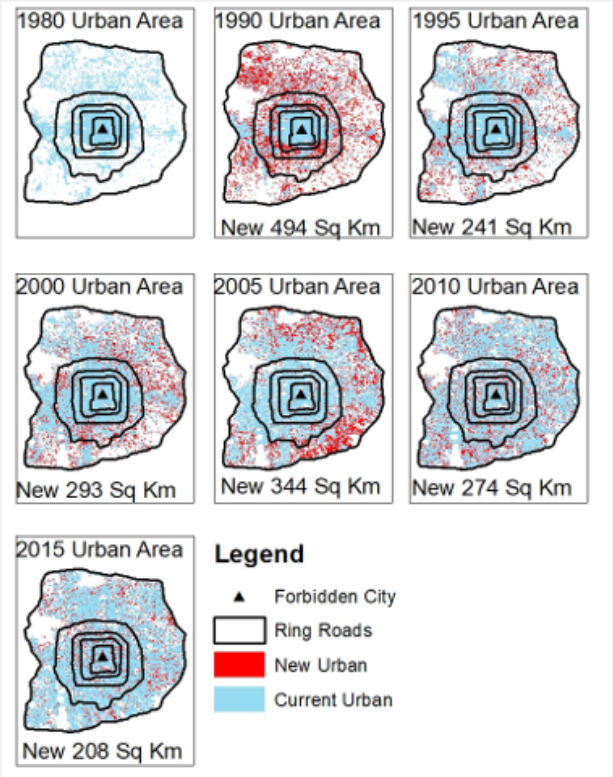

Figure 4: Urban expansion trajectories of Beijing from 1980 to 2015.

Direction of expansion

The method of equal fans analysis is introduced to analyze the specific direction of expansion of Beijing urban morphology. The study area is divided into 16 fan areas with equal area and equal angle. Specific steps are as follows: with reference to previous studies [14-16], as the center of intersection between the north-south axis in front of Tiananmen Square and Chang'an Street and as the radius of 45km (including all of the research of the urban area), and as a starting point of the north-east 11.25 degrees [17], we overlap the figure of urban morphology of the years of 1980, 1990, 1995, 2000, 2005, 2010, 2015 (Figure 5) and obtain the changes of urban built-up area in 16 directions with different years (Table 3) by using AreGIS10.2 software.

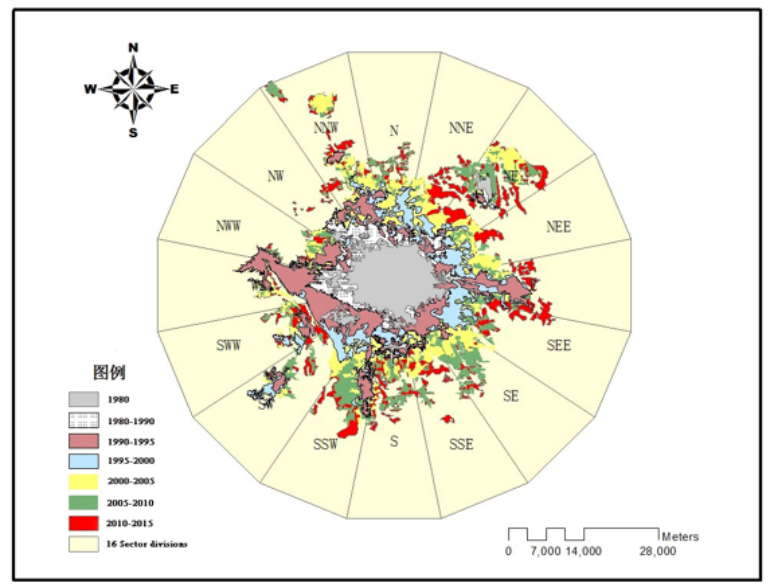

Figure 5: The figure of 16 Sector divisions.

How to cite this article: Lachang Lyu, Richard Greene. The Systematic Evolution of Beijing: A Human Ecology Perspective. Int J Environ Sci Nat Res. 2020; 23(5): 556121. DOI: 10.19080/IJESNR.2020.23.556121.

Table 3: The statistics of the construction land in different directions in different years (km^2).

Position	1980	1990	1995	2000	2005	2010	2015
E	16.39	21.32	56.79	82.72	85.56	100.6	121.17
N	11.72	17.93	25.8	47.46	76.08	88.64	95.46
NE	19.82	28.13	39.54	51.82	94.75	117.41	148.43
NEE	13.19	14.63	21.62	41.14	60.85	65.02	73.76
NNE	14.23	16.94	21	36.62	61.63	65.23	86.15
NNW	14.94	29.38	53.5	64.06	103.7	112.73	130.87
NW	20.72	39.16	41.91	45.01	52.63	59.06	63.5
NWW	17.39	23.72	51.23	51.23	57.68	70.43	73.82
S	11.68	16.48	26.45	34.24	47.44	68.1	85.25
SE	6.88	8.46	24.42	29.77	54.39	89.34	89.38
SEE	11.86	13.41	20.48	41.5	48.69	63.57	73.79
SSE	10.15	11.76	21.63	24.27	46.42	53.31	63.43
SSW	6.16	8.69	35.7	53.75	79.68	114.25	131.54
SW	10.81	13.73	37.07	65.82	75.7	87.55	87.55
SWW	17.19	22.92	56.9	64.11	68.71	73.54	87.58
W	20.57	38.84	84.43	84.43	99.47	99.76	104.05

Counting the intensity index of expansion in Beijing city in each period and each sector (Table 4), shown in Figure 6 radar chart in 16 directions in different periods, we find variance of urban expansion intensity in each period in different directions. Figure 7, the overall map of 30 years, shows clearly variance of expansion intensity in 16 directions of different periods.

Table 4: The statistics of construction land extension intensity in different directions.

Position	1980-1990	1990-1995	1995-2000	2000-2005	2005-2010	2010-2015
E	0.0602	0.3327	0.0761	0.0086	0.033	0.0409
N	0.106	0.0878	0.1399	0.1508	0.033	0.0154
NE	0.0839	0.0811	0.0518	0.2071	0.0478	0.0528
NEE	0.0218	0.0956	0.1505	0.1198	0.0137	0.0269
NNE	0.0381	0.0479	0.124	0.1707	0.0117	0.0641
NNW	0.1933	0.1642	0.0329	0.1547	0.0174	0.0322
NW	0.178	0.014	0.0123	0.0423	0.0244	0.015
NWW	0.0728	0.232	0	0.0315	0.0442	0.0096
S	0.0822	0.121	0.0491	0.0964	0.0871	0.0504
SE	0.0459	0.3773	0.0365	0.2068	0.1285	0.0001
SEE	0.0261	0.1054	0.1711	0.0433	0.0611	0.0322
SSE	0.0317	0.1679	0.0203	0.2282	0.0297	0.038
SSW	0.0821	0.6216	0.0843	0.1206	0.0868	0.0303
SW	0.054	0.34	0.1293	0.0375	0.0313	0
SWW	0.0667	0.2965	0.0211	0.0179	0.0141	0.0382
W	0.1776	0.2348	0	0.0445	0.0006	0.0086

From the stage of development, the period of 1990 to 1995, and 2000 to 2005, saw the maximum in Beijing mean intensity of urban spatial expansion, which indicates that these two periods are the peak of Beijing urban construction (Table 5).

From 1980 to 1990, as Table 6 shows, the city rapidly expanded outward with the variation of extended intensity in every direction 0.6666, in fan-shaped expansion to the northwest, mainly in three directions of NW, NNW and W (Figure 6).The two important factors stress the urban development direction, first, Beijing Urban Construction Master Plan in 1982 emphasized the development of exurban and marginal groups, as well as the establishment of satellite cities; second, the traffic is another important factor in 1984, subway 1st Line shaped as a line in the east-west help the development of the west of Beijing, subway 2nd Ring Line nearly shaped as four square, enhanced the east and west development.

How to cite this article: Lachang Lyu, Richard Greene. The Systematic Evolution of Beijing: A Human Ecology Perspective. Int J Environ Sci Nat Res. 2020; 23(5): 556121. DOI: 10.19080/IJESNR.2020.23.556121.

Table 5: The differences of construction land expansion intensity in different directions in each period.

Time period (Year)	Mean Value	Maximum Value	Minimum Value	Standard Deviation	Coefficient of Variation
1980-1990	0.0825	0.1933	0.0218	0.0533	0.6666
1990-1995	0.2075	0.6216	0.014	0.1521	0.7568
1995-2000	0.0687	0.1711	0	0.0556	0.836
2000-2005	0.105	0.2282	0.0086	0.0723	0.7107
2005-2010	0.0415	0.1285	0.0006	0.0331	0.822
2010-2015	0.0284	0.0641	0	0.0184	0.6699

Table 6: Urban spatial expansion trend and the main axial of Beijing from 1980 to 2015.

Time Slot	Population Expansion Model	Main Extension Direction	Secondary Expansion Direction
1980-1990	Sector rapid expansion	NNW-NW、W	N
1990-1995	Axial type-high speed expansion	SSW	SE、SW、E
1995-2000	Multi airfoil expansion	NEE、SEE	N-NNE、SW
2000-2005	Double wing type rapid expansion	NNW-N-NNE-NE、SSE-SE	NEE、SSW
2005-2010	Axial expansion	SE	S-SSW
2010-2015	Low velocity spread	NNE-NE、S-SSE	E、SWW

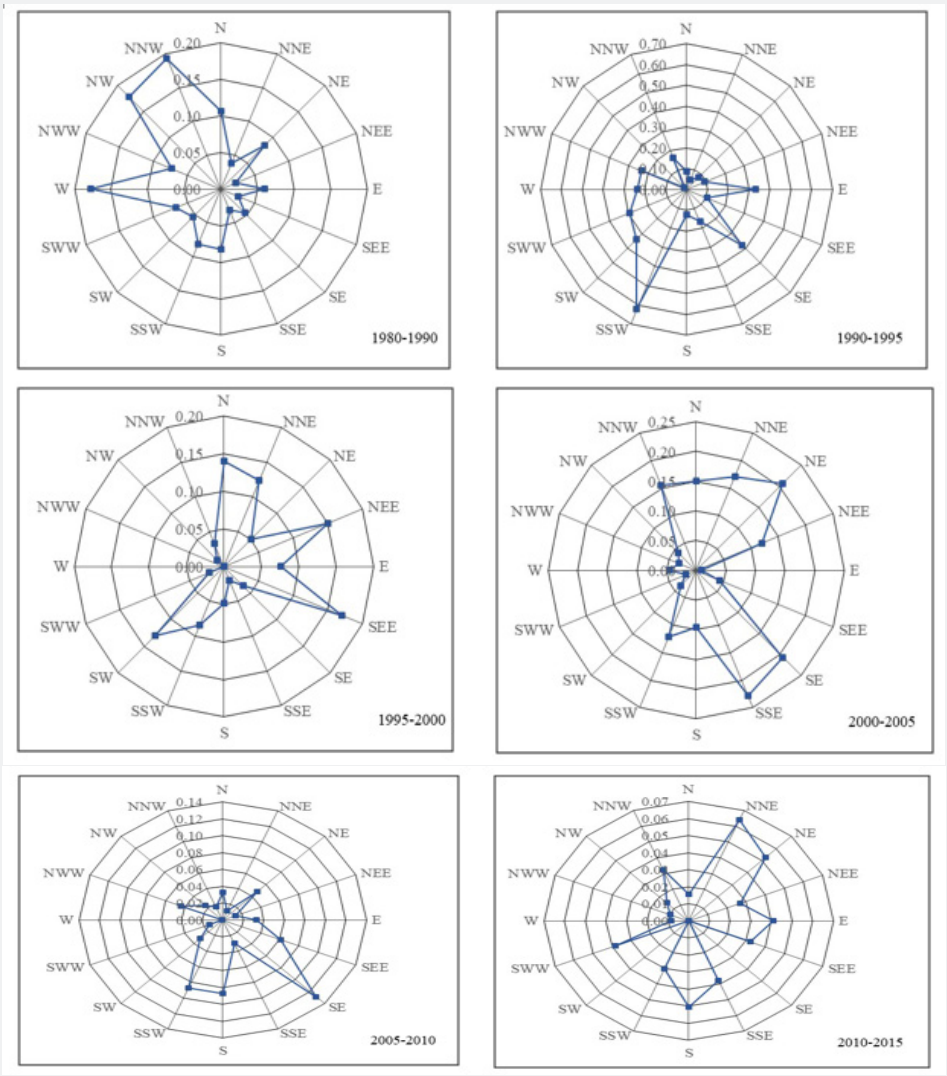

Figure 6: the radar map of construction land expansion intensity in different directions of each period from 1980 to 2015.

How to cite this article: Lachang Lyu, Richard Greene. The Systematic Evolution of Beijing: A Human Ecology Perspective. Int J Environ Sci Nat Res. 2020; 23(5): 556121. DOI: 10.19080/IJESNR.2020.23.556121.

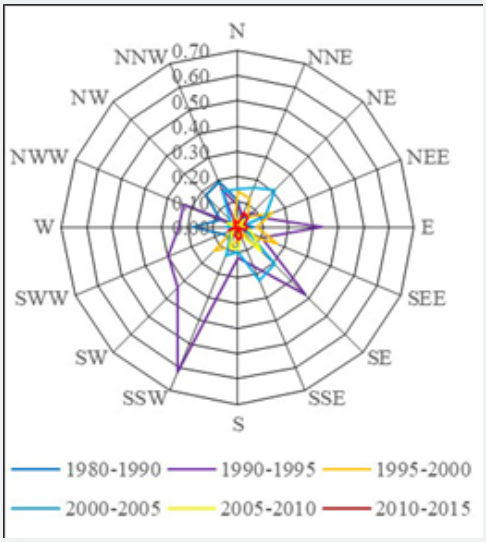

Figure 7: The radar map of construction land expansion intensity in different directions in each period from 1980 to 2015.

From 1990 to 1995, Beijing urban morphology showed typically axial accelerating expansion, with the expansion coefficient of variation 0.7568, rapidly expanded along the SSW, SE, SW, E direction, especially in SSW direction. Main factors are the construction of Beijing Development Zone in Yi Zuang in southwest of Beijing, and Beijing-Hong Kong-Macao expressway construction strengthened the urban expansion along the expressway to the southwest of the city.

From 1995 to 2000, the city expansion rate decreased, with high discrete degree and high, the coefficient of variation 0.8360, urban expanded in SEE, NEE, N, NNE, and significantly in SW direction. Dominant factors are the policy system, national housing reform started in 1998, Beijing new residential areas emerged in the outskirts [17], especially dense in the north and northeast of the suburban area, for example, Tian Tongyuan residential area covering 480 thousand square meters. However, due to the impact of national cultivated land protection policy, the rate of urban expansion declined than that previous stage.

From 2000 to 2005, the city expanded in another climax in the shaped of wing trend----NNW-N-NNE-NE and SSE-SE, with the variation coefficient of expansion falling to 0.7107. The main factors influenced the expansion of the city contribute Beijing's successful bid of Olympic and China successfully joined the WTO. Olympic venues and main facilities were arranged in the north of the city axis. Beijing began to rapidly construct in large-scale, the 4th and 5th ring Rd of city opened, line 13 subway that located in the north of the city and line 8 subway that located in the eastern of the city were put into operation in 2003. Beijing to Haerbin Expressway in the southeast of the city and Beijing to Tibet Expressway in the northwest of city respectively gone into service in 2000 and 2001, additionally, Beijing to Harbin Expressway is obviously driving the development of the southeast Beijing.

From 2005 to 2010, the city showed the axial expansion trend along SE, S and SSW, with coefficient of variation 0.8220 and more prominent dispersion. The dominant factors for the urban expansion in this stage were the urban planning and traffic. The main stadium of Beijing Olympic Games was planned in the north of the axis of Beijing, where extended from the north of 4th ring Rd to Qinghe, the Northern 5th ring Rd. In addition, the construction of Chaoyang Park located in the northeast of Beijing also was planned. Another dominant factor is the traffic. The subway Line 5 that runs through the north and south of the city gone into service in 2007, subways, such as ring line 10, line 8 that radiated to the north, airport line radiated to the northeast and S2 line radiated to the northeast, were put into operation in 2008; light railways, Changping line extended to the north, Daxing line extended to the south, Yizhuang line extended to the southeast and Fangshan line extended to the southwest were also come into operation in 2010. The 3 radioactive main expressways, for example, Beijing-Tianjing expressway, Beijing-Pinggu expressway and second highway to Beijing airport were opened to traffic in 2008. Under the drive of the traffic, Beijing urban morphology extended to the south and north directions.

From 2010 to 2015, the expansion rate of the city declined relatively, with the average of expansion strength only 0.0284. The coefficient of variation was 0.6699 that indicate the low dispersion, the city expand in relatively balanced sprawl, but significant in the direction of NNE, NE, S, E, SWW. The dominant factor for influencing expansion was urban planning. The Tongzhou Modern International city located in the eastern of Beijing established in 2010 and the planning of Future Science and Technology City in Changping planning drove development of the city towards the north and east. Another dominant factor is traffic. On the road aspect, the opening 6th ring road marks the formation of Beijing highway networks. Beijing to Chengde expressway and Beijing to Kaifeng expressway obviously drove the development of the northeastern and south of the city .On the subway aspect, Line 4 to the north and south, Line 15 radiated to northeast, Line 9 to north and south, Line 6 to east and west, Line 14 to the east and west all gone into service in 2013. Transportation network extending in all directions made the city spread around. During this period, because the government's aware of controlling the urban expansion, neither urban expansion speed nor strength is relatively low.

Urban external morphological evolutional characteristics

Compactness

Compactness is important indicator for measurement of urban external morphology. When city in the stage of rapid expansion, the compact degree decreased; when the city turned

How to cite this article: Lachang Lyu, Richard Greene. The Systematic Evolution of Beijing: A Human Ecology Perspective. Int J Environ Sci Nat Res. 2020; 23(5): 556121. DOI: 10.19080/IJESNR.2020.23.556121.

to the internal filling and the development phase transformation, compact degree rise in the urban (Yang, 2008) [17].

There are a variety of methods of compactness of calculation, we use the formula of compactness that was put forward by Batty in 2001 (Batty, 1991) [18].

$$BCI = 2\sqrt{\pi A}/P \quad (3)$$

Formula (3), BCI: urban land compactness, A: city-built area, P: the perimeter of urban contours (Qi,2009) [19]. BCI: between 0 and 1, the bigger of BCI, the closer to circular for the shape of urban boundary (Shang, 2011) [20]; otherwise the smaller of BCI, the poorer compactness and more loose.

As Figure 8 shows, the compactness index of Beijing urban built-up area was relatively low, showing overall downward trend, which indicate Beijing's urban morphology from tight to loose. During the period of 1980 – 1990, Beijing's compactness had an upward trend, peaked to 0.095 in 1990, after 1990, the compactness sharply declined to 0.055, although, a slight rise, it reaches 0.049 in 2015, the lowest point in 30 years.

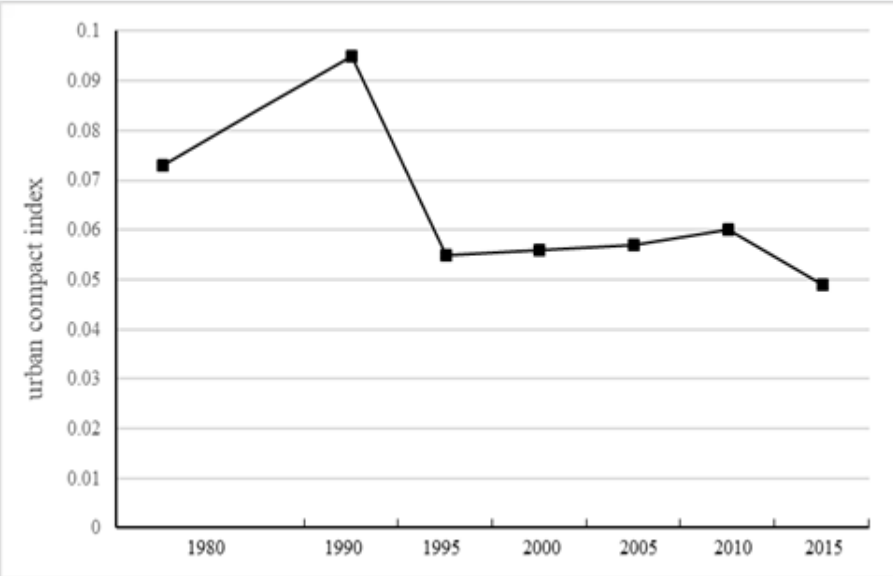

Figure 8: The graph of urban compact index of Beijing (1980-2015).

Fractal dimension

Fractal dimension is another method reflected the urban morphology, proposed by Batty and Longley [21], fractal dimension can be used to analyze the complexity of the urban boundary. The general formula is:

$$D = \frac{2\ln(\frac{P}{4})}{\ln(A)} \quad (4)$$

In formula (4), D: the fractal dimension of city, A: city area, P: city perimeter [17]. Generally, urban fractal dimension is between 1 to 2, the greater the value of D, the more complex the city contour. When the fractal dimension is lower than 1.5, graphics tends to be simple; when the fractal dimension is equal to 1.5, the city contour is in Brown random motion state, the closer to 1.5, the more poor the stability is; when the fractal dimension is bigger than 1.5, the urban contour tends to be complex [17]. if urban area increased and the fractal dimension increased, it indicate that the city show mainly external expansion during this period; if urban area increased and the fractal dimension decreased, it indicate the city show mainly internal filling; if the urban area increased and the fractal dimension of city remains unchanged, it indicate the urban external contour without major changes, the city enter a relatively stable stage of development [22].

It can be seen from Figure 9, Beijing urban morphology fractal dimension always ranged from 1.53 to 1.67 in 30 years, higher than 1.5, indicating Beijing urban morphology has been complicated. Since 1980, the built areas have been grown, but it shows different fractal dimension in different stage. In the period of 1980-1990, the Beijing fractal dimension was decreased, showing that Beijing urban spatial expansion was mainly internal infilling in this stage; however, Beijing fractal dimension rose rapidly in the period of 1990-1995, indicating the city expansion in external way with the irregular shape; during the period of 1995-2000, the fractal dimension decreased compared to the previous period, indicating that of Beijing city expand was mainly internal infilling. From the year of 2010- 2015, the urban fractal dimension rose again, showing that Beijing urban spatial expanded outward in branch shaped and the urban-contour became more complex [23-31].

How to cite this article: Lachang Lyu, Richard Greene. The Systematic Evolution of Beijing: A Human Ecology Perspective. Int J Environ Sci Nat Res. 2020; 23(5): 556121. DOI: 10.19080/IJESNR.2020.23.556121.

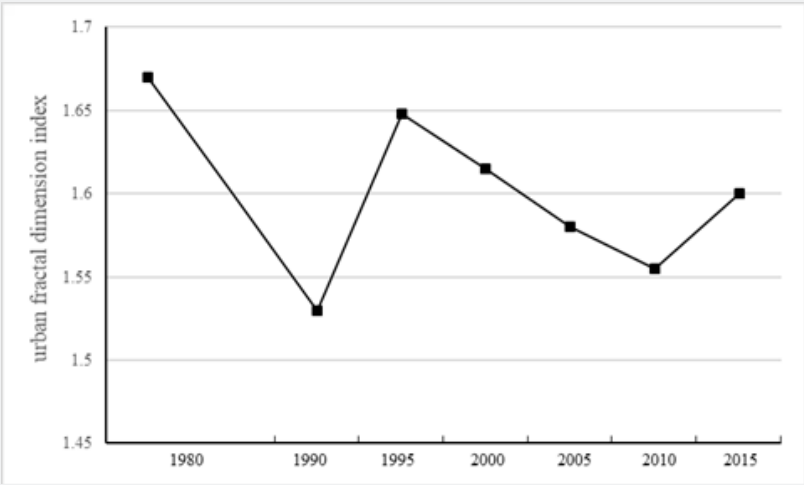

Figure 9: The graph of urban fractal dimension index of Beijing from 1980 to 2015.

Discussion and Conclusion

We systemically examine the Beijing morphological evolutionary process, urban sprawl directions, and characteristics of Beijing morphology by employing LANDSAT every five years from 1980-2015, we find Beijing urban spatial expansion has obvious periodicity: slow expansion period before 1980; rapid expansion stage in 1980-1990 in fan-shaped model; high-speed expansion in 1990-1995 in axial shaped model; medium speed expansion in 1995-2000 in low sprawl model; a rapid period of expansion in 2000-2005 with double wings shaped model; after 2005, steady expansion period with axial expansion model and low sprawl model in 2010 -- 2015. In term of the direction of expansion, 1950s mainly along west - east direction, 1960s mainly for east, west and Northwest. In 1970s, the direction was not obvious. 1980-1990 mainly for the west - northwest - north direction, 1990 – 1995 for the southwest, 1995 - 2000 for the east, north and southwest, 2000 - 2005 for the north, southeast, 2005 - 2010 for southeast direction, 2010 - 2015 for the northeast, south direction. The Beijing urban expansion result in varied urban shape in different stage, from 1949 to 2015, Beijing's urban form experienced the evolution that "凸" shape to rectangular, suborbicular, cruciform, pentagonal, horns and heptagon. The evolution of urban morphology in Beijing is a process from compact to loose, and the fractal dimension of the city is always in the range of 1.5-2, which indicates that the urban morphology of Beijing has been more complex in 30 years.

We also investigated underlined cause of urban expansion including urban planning, policies, transportation, great events etc., although in each phase, the dynamics are varied, the urban planning transportation networks, as decisive factors influenced the urban expansion.

According to the analysis of 64 years' Beijing urban morphology evolution in all aspects. It is found that there are many problems in Beijing urban form, such as pan-cake expansion, loose structure and external contour tends to be more complex, showing urban morphology of heptagon, which is being eroded between angles.

Acknowledgement

We acknowledge the contribution by Chen Bogun who worked on the project for her thesis as a post graduate student in Guangzhou University.

Funding

This research was funded by China's Natural Science Foundation, grant number 41971201.

References

1. Cheng YN (2001) The value of Chinese ancient local records in the study of the city form [J]. China local chronicles (Z1): 136-140.
2. Su R (2009) The study on the evolution of urban spatial form in modern Beijing (1900-1949) [D]. Xi'an University of Architecture and Technology.
3. Wu J (1990) Chinese urban morphology: structure, characteristics and evolution [M]. Jiangsu science and Technology Press.
4. Jiang SG, Zhou YX (2006) Fractal characteristics of urban morphology in Beijing and its practical significance [J]. Geographical research 25(2): 204-212.
5. Xiao H, Li ZP (2010) Fractal theory in Beijing city morphology analysis based on remote sensing [J]. Science & technology 28(16): 57-62.
6. Long Y, Shen ZJ, Mao QZ (2010) Analysis of city form scenarios in Beijing constraints based on CA method [J]. Journal of Geographical Sciences 65(6): 643-655.
7. Ou JM, Wang RS, Yang WR (2007) The form of city expansion in Beijing eastern plain area of the scenario analysis of CA [J]. City environment and city ecological solutions. Based on the simulation 20(1): 5-8.
8. Yu CM (2012) Large city land use pattern, London, Paris, New York, Tokyo and Beijing [J]. Beijing planning and construction (5): 8-12.
9. Huang YQ (2006) Study on the temporal and spatial change of urban morphology based on SAR image [D]. Graduate University of Chinese Academy of Sciences.

How to cite this article: Lachang Lyu, Richard Greene. The Systematic Evolution of Beijing: A Human Ecology Perspective. Int J Environ Sci Nat Res. 2020; 23(5): 556121. DOI: 10.19080/IJESNR.2020.23.556121.

10. Liu X, Hu G, Chen Y, Li X, Xu X, et al. (2018) High-resolution multi-temporal mapping of global urban land using Landsat images based on the Google Earth Engine Platform. Remote Sensing of Environment 209: 227-239.

11. He D, Cai JM, Zhou J (2009) Dynamic expansion and driving force analysis of urban land use -- a case study of Tianjin city [J]. Glacier frozen soil 31(1): 148-157.

12. Wang Q (2007) The study on the characteristics and driving factors of urban expansion in China in recent 30 years [D]. Beijing: Institute of remote sensing applications, Chinese Academy of Sciences.

13. Yang HQ (2008) 21 century Beijing city [N]. China Surveying and mapping, 2008-08-05.

14. Wang L, Jia YL (2013) The evolution and expansion of spatial structure of Beijing city spatial analysis [C]. Chinese city planning conference proceedings.

15. Feng J, Zhou YX (2003) Population growth and distribution in the urban area of Beijing in the last 20 years [J]. Chinese Journal of geography 58(6): 903-916.

16. Wang FH, Zhou YX (1999) Modeling Urban Population Densities in Beijing 1982-90: Suburbanization and its Causes [J]. Urban Studies 36: 271-287.

17. Yang LG (2008) Characteristics and influencing factors of urban morphology evolution in Huaihua [D]. Hunan Normal University.

18. Batty M (1999) Cities as Fractals: Simulating Growth and Form[M]. Fractals and Chaos, pp. 43-69.

19. Qi NT (2009) The study of homogeneous land expansion of urban construction in Yichun City[D], Jiangxi Normal University.

20. Shang YZ (2011) A study on the evolution of urban spatial morphology [D]. Nanjing Normal University.

21. Batty M, Longley PA (1987) Fractal-based description of urban form[J]. Environment and Planning B: Planning and Design 14: 123-134.

22. Wang Q (2002) Preliminary study on quantitative research of urban morphology spatial evolution: a case study of Taiyuan city [J]. Economic geography, p. 34.

23. Liu K (2006) The world capital of [J]. Chinese National Geographic, (9).

24. Liu YJ (2004) Study on urban morphology of Wuhan city [D]. Hua Zhong Normal University.

25. Lu Y, Cui YP, Cheng C (2008) The spatial and temporal evolution of the expansion of urban land and above ground level in the central part of the central region [J]. Geographical research and development 04: 99-103.

26. Liu ZD, Zhang P, Song Y (2012) Promote the sustainable development of the city: the multi-dimensional study on city morphology and Study on city morphology review and Inspiration of [J]. International city planning scale 27(2): 47-53.

27. Wu Q, Hu D, Li HQ (2008) The Beijing city GIS morphology of the [J]. World geology 27(2): 220-224.

28. Zhou AM (2009) The study on the scale expansion of urban land use in the process of urbanization in Zhengzhou [D]. Henan University.

29. Zheng C, Lin L (2002) Domestic urban morphology research review in 1990[J]. Urban planning (7): 59.

30. Zhou GH, Yang LG (2010) Characteristics of urban morphological evolution and its influence factors in Huaihua city [J]. Progress in geography science 29(5): 627-632.

31. Zhao X, Hu ZL (2006) Study on the built-up area of Xuzhou city based

DOI:10.19080/IJESNR.2020.23.556121

How to cite this article: Lachang Lyu, Richard Greene. The Systematic Evolution of Beijing: A Human Ecology Perspective. Int J Environ Sci Nat Res. 2020; 23(5): 556121. DOI: 10.19080/IJESNR.2020.23.556121.