

A Bibliometric Analysis of Chinese Ecological and Environmental Research on Urbanization

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Abstract: Based on an urbanization research database, a bibliometric analysis of Chinese ecological environmental research on urbanization was conducted that examined output, focused fields, topics, theories and methods. Results show that research output in this field has been increasing since 2005. Land and industry fields in resource research, economics in ecological research, and climate and urban environments in environmental research have been studied from 1992–2011. Keywords analysis discovered that “Land Use” and “Heat Island Effect” were major keywords, making up 0.15% and 0.09% of the total frequency, respectively. “Heat Island Effect” and “Climate Change” were the most recent popular keywords. Main theories were derived from ecology, mathematics, resource environmental economics and environmental science. Ecological footprint has been a core theory since 2002. The stochastic impacts by regression on population, affluence and technology model (STIRPAT), Environmental Kuznets Curve (EKC), and slope, land use map, excluded area, urban area, transportation map and hillside area model (SLEUTH) are the latest popular theories. During 1992–2011, the main research methods can be divided into four groups: statistics (65.17%), systems (13.11%), mechanisms (11.79%) and evaluation (9.93%). Grey System Analysis from system methods and rescaled range (R/S) analysis from evaluation are the latest popular methods. Topics from macro subfields, including land use, heat island effects, water resources and the agricultural ecological environment received more attention than micro subfields such as urban environmental health problems. As urbanization problems evolve, resource environmental economic comprehensive models will advance with modeling progress and some models, such as STIRPAT and land use change simulation models, will be developed for evaluation and simulation of the ecological environmental impacts of Chinese urbanization.

Key words: bibliometrics; ecological environment; urbanization; research focus; keyword analysis

1 Introduction

The Chinese rate of urbanization was 26.41% in 1990, and reached 51.27% in 2011, with an average growth rate of 1.18% per year. During this fast urbanization process, increasing attention has been paid to urban ecological environmental research. For example, Shi and Chen (1996) pointed out that during China’s urbanization, research on the urban ecological environment is one of the strongest ways of solving sustainable development problems. In their review, Huang (2001) held that the increasing speed of urbanization was a fundamental reason for constructing ecological cities. Xu *et al.* (2007) summarized dynamic mechanisms and simulation modeling of land use change during rapid urbanization and Peng *et al.* (2005) explored retrospective

intensity calculation, formation mechanisms and the spatial distribution of heat island effects in urbanization regions. Su *et al.* (2011) summarized urban green space research and evaluated research on six kinds of ecological environmental effects related to urban green spaces. Li *et al.* (2007) provided an overview of the relationship between oasis urbanization and the ecological environment, including research perspectives, topics and methods. Qiao *et al.* (2005) reviewed the main theories around coupling mechanisms between urbanization and the ecological environment in arid regions. Li *et al.* (2008) summarized the evolution of rural human settlement topics in environmental research during urbanization. Other reviews across the field have also been done (see Ji *et al.* 2009; Kang *et al.* 2011; Li *et al.* 2009; Li *et al.* 2012; and Liu *et al.* 2011).

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A summary of the entire ecological environment research sphere as it relates to urbanization remains rare. Zhang *et al.* (2010) divided ecological environmental research into three main topics: urbanization, urban ecological environment, and urbanization and ecological environment responses. Liu *et al.* (2005) discussed perspectives and topics in Chinese and international ecological environmental research according to different disciplines. Given that research on urban ecological environments spans many detailed fields, a system wide review requires a broad scientific background.

Bibliometric analysis based on database is one way of accomplishing this work. Bibliometrics refers to visual and quantitative analytics used to summarize results and trends in selected research fields. For example, Xu *et al.* (2003) collected papers from international geography journals published between 1980–2000 and summarized Chinese urbanization research, urban spatial structure, regional urbanization, urban system, new foci and methods. Liu (2011) generalized dynamics and features of Chinese urban geographical research from papers outputs, types, methods, topics of research and author location based on 523 papers from *Acta Geographica Sinica*, *Scientia Geographica Sinica* and *Geographical Research* until 2009. Based on the SCI and SSCI databases, Wang *et al.* (2011) analyzed scientific outputs, subject categories and major journals, international collaboration, geographic distribution, and temporal trends in keyword usage across urbanization studies.

Inspired by these applications, here we applied bibliometric analysis on outputs, focused subfields, topics, theories and methods across urbanization research in order to help researchers grasp the current situation and future trends in urban ecological environmental research during China's rapid and continued urbanization.

2 Data and methods

Establishment of a document database is the first step in bibliometric analysis. The China National Knowledge Infrastructure (CNKI) is regarded as the most frequently used and robust Chinese database for bibliometric studies (Wu and Chen 2012). We built our bibliometric database by searching papers on urbanization in the CNKI. The time range was set from “1992” to “2011”. The topic item was filled with the term “urbanization”; this searching strategy allowed us to locate publications that contain “urbanization” in their titles, abstracts and/or keywords. Our bibliographic search resulted in 24 528 urbanization-related papers. We then extracted information about individual publications, including author name and affiliation, subject category, journal title, publication year, keywords and citation frequency. Finally, Excel VBA was employed to select items related to ecological environment and urbanization to reveal temporal evolution of outputs, subfields, topics, theories and methods. A resource subfield was used within each selection.

3 Results

3.1 Output

Research on resource use and environmental science had increased as a proportion of Chinese papers on urbanization from 1.8% in 1992 to 6.3% in 2011, divided into three stages (1992–1995, around 1.8%; 1996–2004, fluctuation around 3.5%; 2005–2011, steady rise from 2.9% to 6.3%) (Fig. 1). Further, the ratio of added papers on resource use and environmental science to added papers on urbanization was generally higher than the ratio of papers on resource use and environment science to papers on urbanization for each year since 2005. This pattern indicated that the increase in Chinese papers on resource use and environmental science in urbanization research was greater than the average increase in Chinese papers on urbanization.

3.2 Focused subfields

All 24,528 papers came from 1345 journals and to some extent journal title displayed its focused field (Wang *et al.* 2011). By extracting journals titled with “resources”, “ecology” or “environment”, detailed subfields in resources, ecology and environment in urbanization research were further explored.

Three basic clusters were noticeable in the total citation count (TC) descending order (Table 1). Journals titled with “resource” gained the highest TC, followed by ecological and environment related journals. In detail, “resource” journal cluster covered national land, industry, agriculture, water, forestry and resource exploitation and protection, in descending TC order; the “ecology” journal cluster included

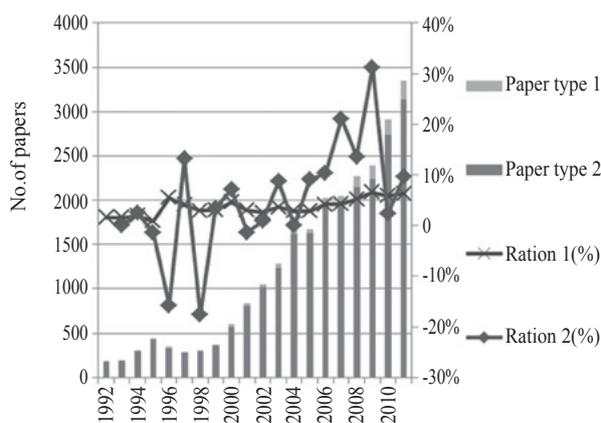


Fig.1 The number and ratio of Chinese papers on ecological environment and urbanization from 1992–2011.

Note: paper type 1, papers on resource use and environment science; paper type 2, urbanization except paper type 1; ratio 1, ratio of papers on resource use and environmental science to papers on urbanization; and ratio 2, ratio of added papers on resource use and environmental science to added papers on urbanization by year.

Data source: paper database on urbanization in The China National Knowledge Infrastructure (CNKI) from 1992–2011.

Table 1 Main professional magazines on resources, ecology and the environment.

Journal title	Total urbanization papers	Total citation of urbanization papers	Average citation of urbanization paper
Journal of Natural Resources	93	3311	35.60
China Population Resources and Environment	222	3019	13.60
Acta Ecologica Sinica	113	2584	22.87
Resources Science	130	2463	18.95
Resources and Environment in the Yangtze Basin	137	2303	16.81
Climatic and Environmental Research	21	907	43.19
Urban Environment & Urban Ecology	23	825	35.87
Ecological Economy	142	759	5.35
Journal of Arid Land Resources and Environment	127	754	5.94
Chinese Journal of Ecology	52	665	12.79
Chinese Journal of Applied Ecology	38	475	12.50
Environmental Protection	107	373	3.49
Ecology and Environment	20	338	16.90
Research of Environmental Sciences	11	254	23.09
Environmental Science	11	250	22.73
Natural Resource Economics of China	26	233	8.96
Shanghai Environmental Sciences	11	173	15.73
China Environmental Science	15	173	11.53
Acta Phytocologica Sinica	5	157	31.40
Environmental Science & Technology	23	147	6.39
Agro-Environmental Protection	2	139	69.50
Environmental Pollution & Control	17	126	7.41
Chongqing Environmental Science	14	118	8.43
Acta Scientiae Circumstantiae	14	89	6.36
Resources & Industries	38	87	2.29
Journal of Ecology and Rural Environment	29	86	2.97
Rural Eco-Environment	5	85	17.00
Chinese Journal of Agricultural Resources and Regional Planning	13	84	6.46
Territory & Natural Resources Study	51	81	1.59
Journal of Agro-Environment Science	9	63	7.00
Marine Environmental Science	6	51	8.50
Progress in Environment Science	5	33	6.60
Journal of Environment and Health	10	32	3.20
Environmental Chemistry	5	31	6.20
Chinese Journal of Eco-Agriculture	6	29	4.83
Water Resources Protection	5	26	5.20
Journal of Ecology and Rural Environment	5	26	5.20
Earth and Environment	5	22	4.40
Chinese Journal of Environmental Engineering	1	17	17.00
Journal of Safety and Environment	3	11	3.67
Environmental Monitoring In China	7	10	1.43
Journal of Environmental & Occupational Medicine	3	9	3.00
Journal of Natural Resources	1	5	5.00
Forest Resources Management	3	3	1.00
Journal of Hydroecology	3	3	1.00
Chinese Journal of Environmental Engineering	2	0	0.00
Resource Development & Market	1	0	0.00
Journal of Environmental Hygiene	1	0	0.00

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Journal of Hydroecology	3	3	1.00
Chinese Journal of Environmental Engineering	2	0	0.00
Resource Development & Market	1	0	0.00
Journal of Environmental Hygiene	1	0	0.00

Data source: magazine table selected from paper database on urbanization in The China National Knowledge Infrastructure (CNKI) from 1992–2011.

economics, plants, rural, agriculture and water ecology; and the “environment” journal cluster involved climate, urban environment, agriculture, rural, pollution, marine, health, chemistry, technique, security, monitoring, medicine and medical hygiene. Generally, economic urbanization as an aspect of urbanization, land and industry fields in resource research and economics in ecology research have been carefully studied from 1992–2011. Regarding environment research, macro subfields, such as climate and urban environment seemed to gain more attention than micro subfields, represented by environmental health and security, during 1992–2011. Agriculture as the basis of Chinese urbanization has been a subfield in all resource, environment and ecology research from 1992–2011.

The average citation count (ATC) descending order indicated that journals on special fields in environmental research came first, followed by journals on general fields in resource, ecology and environment science, environment engineering and technique and environment health (similar to the corresponding TC descending order). In detail, “Agro-Environmental Protection”, “Climatic and Environmental

Research”, and “Urban Environment and Urban Ecology” were the top three journals in ATC descending order. By checking the number of their papers (“Agro-Environmental Protection”, 2; “Climatic and Environmental Research”, 21; “Urban Environment & Urban Ecology”, 23), it was clear that a lack of papers on agriculture environment meant these few papers gained high citations. Generally, journals focused on special subfields in environmental research positioned higher in the ATC descending order than TC, reflecting the value of a special environmental subfield research. As concern about citizen health during Chinese urbanization grows, further research on environmental health is expected to be valuable.

3.3 Topic evolution

A total of 39 749 keywords were extracted from the Chinese urbanization article database. Further extraction of these 39 749 words was conducted to obtain keywords referring to resource, ecology or environment for topic evolution analysis.

Table 2 shows the top 10 keywords related to resource,

Table 2 Top10 keyword evolution.

1992–2011		2007–2011		2002–2006	
Keyword	Frequency/ Rate (%)	Keyword	Frequency/ Rate (%)	Keyword	Frequency/ Rate (%)
Land Resource	197(0.15)	Land Resource	90(0.14)	Land Resource	62(0.15)
Ecological Environment	170(0.13)	Heat Island Effect	86(0.13)	Ecological Environment	57(0.14)
Heat Island Effect	122(0.09)	Ecological Environment	84(0.13)	Land Expropriation	46(0.11)
Land Expropriation	113(0.08)	Climate Change	75(0.12)	Land System	28(0.07)
Land Circulation	100(0.07)	Land Circulation	73(0.11)	Water Resource	25(0.06)
Climate Change	91(0.07)	Land Expropriation	66(0.10)	Heat Island Effect	24(0.06)
Water Resource	87(0.06)	Landscape Architecture	63(0.10)	Rural Land	22(0.05)
Environment Problem	78(0.06)	Rural Land	47(0.07)	Human Settlement Environment	21(0.05)
Rural Land	76(0.06)	Water Resource	44(0.07)	Land Circulation	21(0.05)
Land System	70(0.05)	Environment Problem	44(0.07)	Urban Land Arable Resource	20(0.05)

1992–1996		1997–2001	
Keyword	Frequency/ Rate (%)	Keyword	Frequency/ Rate (%)
Land Resource	14(0.11)	Land Resource	31(0.18)
Ecological Environment	10(0.08)	Ecological Environment	19(0.11)
Environment Pollution	9(0.07)	Urban Environment	14(0.08)
Environment Quality	9(0.07)	Environment Problem	13(0.08)
Environment Problem	7(0.05)	Water Resource	13(0.08)
Natural Resource	6(0.05)	Ecological City	9(0.05)
Urban Environment	6(0.05)	Urban Ecological Environment	8(0.05)
Land Management	6(0.05)	Heat Island Effect	7(0.04)
Land Price	6(0.05)	Environment Protection	6(0.04)
Land Ownership	6(0.05)	Mineral Resource, Agricultural Resource, Human Settlement Environment, Natural Disaster	6(0.04)

Data source: keyword table selected from paper database on urbanization in The China National Knowledge Infrastructure (CNKI) from 1992–2011.

ecology and environment from 1992–2011. Keywords related to land, including “Land Resource” (0.15%), “Land Expropriation” (0.08%), “Land Circulation” (0.07%), “Rural Land” (0.06%) and “Land System” (0.05%) comprised 0.41% of total keyword frequency. “Heat Island Effect” (0.09%) and “Climate Change” (0.07%) and “Water Resource” (0.06%) also received much attention. Additionally, the proportion of “Heat Island Effect” and “Climate Change” rose from 0.06% and 0.02% during 2002–2006 to 0.13% and 0.12% during 2007–2011, respectively, indicating these as emerging topics. Further analysis on keywords related to “Land Resource” (KLR) indicated that land use was the core topic of land resource research, with 23.74% of the total KLR frequency. Liu (2011) divided methods into three groups: qualitative, statistical quantitative and complicated metric methods in bibliometric analysis on urbanization. Since different methods were generally related to corresponding subfields in land use research, from a research method perspective, 82 of 90 keywords on land use (KLU), with clear meaning, were divided into three groups: management, pattern, process and mechanism. Management referred to those KLU on which qualitative methods were dominant, represented by “Land Use Policy”; pattern involved KLU on which statistical quantitative methods were generally used, featuring “Land Use Structure”; process and mechanism included those KLR on which metric models were mainly employed, characterized by “Land Use Change”. The proportions of frequencies of keywords in these three groups were 19.44%, 27.88% and 52.69%, respectively. Though results above showed that process and mechanism research has become mainstream inland use research, by checking keywords involved in process and mechanism research we found that most keywords were basic indicators (e.g. transfer matrix, dynamic index and dynamic degree) and rarely related to evolution process and modeling research. Keywords in pattern research revealed that the main keywords were related to land use degree, structure, type and benefit. Only a few, such as “Land Use Niche”, “Intensive Land Use”, “Land Use Distribution Pattern” and “Land Use Evaluation System” were related to comprehensive research on the ecological effects of land use during Chinese urbanization.

In order to analyze the evolution of keywords, the top 10 keywords in four periods (1992–1996, 1997–2001, 2002–2006 and 2007–2011) were obtained from the keywords database. Land use related topics were always the foci in all four periods, especially from 2002–2006 when six of the top 11 keywords related to land use. This indicated researcher concern about land use problems during Chinese urbanization. “Water Resource” had a high frequency and ranked 5th in 1997–2006. Since water resource was one of the key factors in the analysis of dynamic mechanisms of Chinese urbanization, it is expected to receive attention in the future. “Heat Island Effect” increased in frequency from 24 in 2002–2006 to 86 in 2007–2011, and ranked

2nd from 2007–2011; heat island effect factors are being studied. As Chinese megalopolises continue to grow fast (Hong and Zhang 2009), more attention will be paid to heat island intensity, heat island warming rate, heat island spatial distribution and heat island effect factors on a larger urban scale.

The frequency of “Climate Change” had grown from 10 in 2002–2006 to 75 in 2007–2011, an increase of 6.5 times. Relative humidity, average temperature, annual precipitation and annual sunshine hours were the main topics in climate change research. Limited to data accessibility, citizen health resulted from climate change received unexpected low attention, compared to its significance. As health geography develops (Yang *et al.* 2010), this topic is expected to attract increased attention. Rarely seen during 2002–2006, “Landscape Architecture” had a frequency of 63 during 2007–2011. This kind of sudden growth was not accidental, and Yang (2011) asserted that more emphasis on ecological civilization, climate and environment problems, globalization and localization, fast urbanization and a growing spiritual demand for material were all reasons for this kind of explosive increase. However, its lasting increase will be left to prove. Besides these keywords, many others were listed, such as “Municipal Solid Waste”, “Urban Rain Flood”, “Air Pollution”, “Heavy Metal Pollution”, “Underground Water Pollution”, “Urban Non-Point Source Pollution” and “Rural Surface Pollution”. Research on these topics has tended to ignore the environmental effects on citizens’ health; but since urban region is an ecological system, how to analyze these factors requires further exploration.

The proportion of the top 10 keywords rose from 0.59% in 1992–1996 to 1.05% in 2007–2011, indicating agglomerating and maturation in ecological environment research topics.

3.4 Theory evolution

To analyze theory evolution we searched for keywords containing “theory”, “model”, “law” or “curve” in the urbanization keywords database (Table 3). A total of 136 keywords denoting clear theory were found, with a total frequency of 270. “Ecological Footprint”, “STIRPAT (stochastic impacts by regression on population, affluence and technology) model”, and “Entropy Method” had frequencies of 34, 16, and 13, accounting for 12.59%, 5.93% and 4.81%, respectively. According to the source and main application of each theory, they can be classified into five groups. The first group was mainly about ecological theory, featuring “Ecological Footprint” and “Lotka-Volterra Model”. The second group included mathematical and physical models, including the Logistic Model, Grey Forecasting Model, Entropy Theory, Gravity Model, Markov Model, Fractal Theory, Grading Theory, System Dynamic Model, Catastrophe Model and Matter-element Model. The third group was within resource environment

economics, including EKC (Environmental Kuznets Curve), Land Rent Theory, Public Resource Theory, Externality Theory, NRCA (Normalized Revealed Comparative Advantage Index) Model, and CGE (Computable General Equilibrium) Model. The fourth group was centered around environmental science, including the Hydrological

Table 3 Main theory evolution.

1992–2011		2007–2011		2002–2006	
Keyword	Frequency	Keyword	Frequency	Keyword	Frequency
Ecological Footprint	34	Ecological Footprint	24	Ecological Footprint	10
STIRPAT Model	16	STIRPAT Model	16	Matter-element Model	3
Entropy Method	13	Entropy Method	13	Ecological Footprint Method	2
EKC	10	Environmental Kuznets Curve	9	Markov Model	2
Logistic Model	8	SLEUTH model	7	Logistic Model	2
SLEUTH Model	7	Environmental Carrying Capacity	6	Environmental Carrying Capacity	1
Environmental Carrying Capacity	6	Gravity Model	5	Long-term Hydrological Effect Analysis Model	1
Gravity Model	5	Logistic Model	5	Modified Logistic Model	1
System Dynamics Model	5	System Dynamics Model	4	System Dynamics Model	1
Ecological Niche	5	Ecological niche	4	Theory of Decoupling	1
Ecological Footprint Method	4	Factorization Model	3	Garden City Theory	1
Threshold Theory	4	Catastrophe Model	3	Ecological Footprint Model	1
Markov Model	4	Hydrological Model	3	Ecological Niche	1
Factorization Model	3	Fractal Theory	3	Social Burning Theory	1
Matter-element Model	3	PSR Model	3	MAC of Regional Arable Land	1
Catastrophe Model	3	Linear Spectral Immixture Model	2	Human Settlement Environment Theory	1
Hydrological Model	3	Water Environmental Capacity	2	Man-Land Relationship Behavior Model	1
Fractal Theory	3	Ecological Footprint Method	2	Threshold Theory	1
PSR Model	3	Threshold Theory	2	Landscape Design Theory	1
Linear Spectral Immixture Model	2	Markov Model	2	Comprehensive Economic and Energy Model	1
Garden City Theory	2	Distributed Hydrological Model	2	Grey Forecasting Model	1
Water Environmental Capacity	2	Urban Environment Entropy	2	EKC	1
Ecological Footprint model	2	Grossman Model	2	Environmental Cybernetics	1
Ecological Transect	2	GKSIM Model	2	Environmental Protection Investment Index	1
Social Burning Theory	2	DPSRC Frame	2	Public Finance Theory	1
Forest Ecological Transect	2	Resource Consumption Stratification Hypothesis	1	Crime Theory	1
Economic Niche	2	CA Model Land Exploitation Model	1	Inverted U-shape Curve	1
Distributed Hydrological Model	2	CA Model	1	Urban CA Model	1
Urban Storm Water Model	2	Epidemic Spread Model based on Cellular Automata	1	SCS Model	1
Urban Environment Entropy	2	Rainwater Management Model	1	L-THIA.GIS Model	1
		Garden City Theory	1	Horton Law	1
		Ecological Footprint model	1		
		Social Burning Theory	1		
		Economic Niche	1		
		Urban Storm Water Model	1		

1997–2001		1992–1996	
Keyword	Frequency	Keyword	Frequency
Forestry Ecological Transect	2	Urban Storm Water Model	1
Ecological Transect	2	Distributed Hydrological Model	1
Logistic Model	1	Scenic Environmental Capacity	1
Environmental Carrying Capacity	1	Land Price Curve	1
Economic Niche	1	Externality Theory	1
Theory of Landscape Heterogeneity	1		
Threshold Theory	1		

Note: STIRPAT, Stochastic Impacts by Regression on Population, Affluence and technology; EKC, Environmental Kuznets Curve; SLEUTH, Slope, Land use map, Excluded area, Urban area, Transportation map and Hillside area; PSR, Pressure-State-Response; GKSIM, Generalized Kane's Simulation; DPSRC, Drive-Pressure-State-Response-Control; CA, Cellular Automata; MAC, Model of Allowable Conversion; SCS, Soil Conservation Service; L-THIA, GIS, Long-Term Hydrologic Impact Assessment Geographic Information System.

Data source: keyword table selected from paper database on urbanization in The China National Knowledge Infrastructure (CNKI) from 1992–2011.

Model, SWAT (Soil and Water Assessment Tool) Model, SCS (Soil Conservation Service) Model, SWMM (Storm Water Management Model), Soil Erosion Model, and Urban Region Heat Forecasting Model, SCS-CN (Soil Conservation Service Model-Curve Number) Modified Model, CITYGREEN Model and CASA (Carnegie Ames Stanford Approach) Model. The fifth was a collection of resource environmental economic comprehensive models, including the urban land use model (SLEUTH: slope, land use map, excluded area, urban area, transportation map, and hillside area; CLUE-S Model: conversion of land use and its effects at small regional extent; GKSIM: generalized Kane's simulation model; ANN-CA: artificial neural network-cellular automata model; GIA-CA: gaming intelligence agency-cellular automata model; and MAC: model of allowable conversion of regional arable Land), STIRPAT Model, PSR (Pressure-State-Response) Model, DPSIR (Drive-Pressure-State-Response-Control) Model, MARKAL-MACRO Model and Man-Land Relationship Behavior Model. Four of the top 10 theory keywords came from mathematical and physical groups, though these models have a robust ability for forecasting most lack a strict micro theory basis (Yu *et al.* 2007). Ecological Footprint Theory had an advantage in the evaluation of ecological effects during urbanization (Chen *et al.* 2006), yet there remains potential for it to be explored in describing man-land relationship mechanisms. The resource environmental economic group had a strict economic theory basis, yet was still limited in economic and social factors, leaving us a great challenge for how to imbed the strict economic theory core into greater man-land systems (Zhou *et al.* 2012). In contrast to the resource environmental economic group, environmental science research had an emphasis on natural factors (Ma 1986), lack of economic and human behavior factors, except a few newly introduced comprehensive models including L-THIA, GIS (Long-Term Hydrologic Impact Assessment Geographic Information System) Model, Sherman Folland Health Production Model

and Becker and Grossman Health Demand Model. With growing concern over urban environment quality (Wu *et al.* 2009), more research will focus on environmental behavior and its effect on household and individual health. Since the model from the fifth group was comprehension of theories and models from the first four, advance in the first four groups will push the fifth forward. Researchers should keep abstracting progress from other fields including computer science, and should also develop and modify these models both at macro and micro spatial scales in order to play a greater role in the simulation and prediction of the ecological environment effects of urbanization in China.

As for evolution, theories during 1992–1996 were represented by Hydrological Models from environment science and Land Rent Theory from environmental economics. Ecological niche and Landscape Theory from ecology began to be imported into urbanization research during 1997–2001. During 2002–2006, Ecological Footprint Theory appeared and grew quickly into mainstream ecological environmental research in urbanization studies. At the same time, mathematical and physical models were also applied, including the Matter-element Model, Markov Model, Logistic Model and System Dynamic Model. During 2007–2011, the STIRPAT Model, SLEUTH Model and PSR Model, together with former Ecological Footprint Theory, had been core theories of ecological environmental research in Chinese urbanization studies. New mathematical and physical models were introduced, including Entropy Theory, Gravity Model, Catastrophe Model and Fractal Theory. Theory evolution convinced the conclusion that the resource environment economic comprehensive model would advance with models in subfields, and it was believed the comprehensive trends would be enhanced as urbanization problems include more and more factors. Some problems were also exposed during theory evolution analysis. For example, only a few theories, such as Ecological Footprint Theory (Fang *et al.* 2010) and Logistic Modeling (Tao 2008) showed some heritages or accumulation; most models

lacked the necessary accumulation, and especially those from mathematical and physical science were featured over a short life. It is expected that more effort will be devoted to adaptation and extension of classical models in order to build a theory system of ecological environmental research and urbanization.

3.5 Method evolution

Based on the urbanization keyword database, keywords containing “method”, “analysis”, “model”, “technique” and “metrics” were found and divided into 1992–1996, 1997–2001, 2002–2006 and 2007–2011 (frequencies: 61, 103, 257 and 561, respectively). Considering the source and application of methods, methods with clear meaning were classified into four groups, including statistics, system, mechanism and evaluation. These four groups had a total frequency of 755, statistics accounting for 65.17%, system accounting for 13.11%, mechanism accounting for 11.79% and evaluation accounting for 9.93%. Statistical method was the widest method employed in Chinese urbanization studies. Further analysis on keywords related to statistical method indicated that statistical methods could be divided into metric and spatial analysis methods. Metric methods clustered around multivariate statistical analysis, including Principal Component Analysis, Factor Analysis and Correlation Analysis. Modified methods, such as Error Correction Model (ECM), Spatial Econometric Model, and Panel Data Analysis were increasingly common. These methods considered resource factors but ignored environmental factors, and how to introduce environmental factors into models is a challenge for researchers. Spatial Analysis methods were mainly about GIS analysis, reflecting the truth that GIS had been widely applied in urbanization pattern analysis (Liu *et al.* 2004). Yet it was also noticeable that “Gradient Analysis” and “Buffer Analysis” were among main keywords related to GIS analysis, which showed application of GIS in urbanization papers at a basic level and a lack of comprehensive analysis of ecological environmental problems. As concerns over living environments and health equality grow, GIS seems to have a potential role in the analysis of urban environmental health and urban landscape patterns. In the system method group, Analytical Hierarchy Process (AHP) and Grey System Analysis were among the main methods. As for the mechanism method group, Game Analysis had great potential in analyzing different social agents’ behaviors on environment problems caused by renewal of the inner city and expansion of the outer city. Most evaluation methods were from ecology in urbanization papers, including Energy Analysis (Lin *et al.* 2001) and Ecological Niche (Wang *et al.* 2012).

Regarding method evolution, Fig. 2 shows statistical and mechanism methods dominated from 1992–2001. During 2002–2006, methods were greatly enriched, attributed to fast development of system and evaluation methods, and

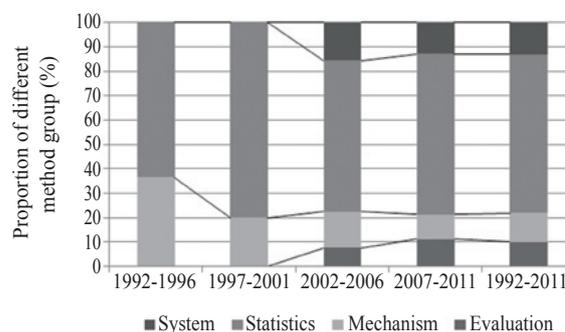


Fig. 2 Key method evolution.

Data source: keyword table selected from paper database on urbanization in The China National Knowledge Infrastructure (CNKI) from 1992–2011.

the introduction of AHP, Grey System Analysis and R/S (rescaled range) analyses. On the contrary, there was only a minor increase in the number of traditional statistical and mechanism methods. Represented by the STIRPAT Model, ECM and Co-integration Analysis, development of evaluation and statistical methods experienced great progress during 2007–2011. Considering our topic analysis, we infer that more applied resource environmental economic comprehensive models will be developed for the evaluation and simulation of ecological environmental effects of urbanization in China.

4 Discussion and conclusions

Starting from 2005, ecological environmental research has increased in attention. Land and industry fields in resource research, economics in ecology research, and climate and urban environment in environmental research have been carefully studied from 1992–2011.

Detailed topic evolution indicated that urban land related topics and water resource were hot topics from 1997–2011. The heat island effect topic received more and more attention from 1997, while heat island effects, climate change and landscape architecture emerged as popular topics in 2007–2011.

Main theories involved a wide range of subjects, grouped into ecology, mathematics and physics, resource and environment economics and environment science. Based on these special theories, more comprehensive theory models, represented by the STIRPAT Model, ECM and Co-integration Analysis had been gradually developed for evaluation and simulation.

By source and application, main methods were divided into four groups: statistics accounted for 65.17%, system accounted for 13.11%, mechanism accounted for 11.79% and evaluation accounted for 9.93%, respectively. Statistical and mechanism methods dominated from 1992–2001. During 2002–2006, due to wide application of AHP and Grey System Analysis from system methods, and R/S

analysis from evaluation, the proportion of system and evaluation methods emerged.

China is experiencing rapid urbanization. Despite comprehensive ecology, resource environment economics and system theory, the challenge to develop comprehensive man-land system models to study the ecological environmental effect of large urban regions remains. At a micro scale, urban land development and its management will be a core topic for a long time given China's special situation. As for urban land topics, Rent Theory and Game Theory, with potential in strict logical modeling of micro social agent behavior will be of extreme interest in future urbanization research

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中国城市化过程中生态环境研究的文献计量分析

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摘要: 中国城市化过程中生态环境研究成果丰富, 总结其演变过程利于把握该领域现状与趋势。本文从城市化文献视角对中国城市化过程中的生态环境研究在研究成果、研究子领域、研究主题、理论和方法等方面进行总结。结果表明, 从2005年起中国城市化文献中关于生态环境的研究呈加速增长的态势; 资源领域的国土资源和产业子领域, 生态领域内经济子领域和环境领域内气候和城市环境子领域受到了较多的关注; “土地利用”和“热岛效应”一直是最热的关键词, 分别占全部关键词出现频次的0.15%和0.09%, “热岛效应”和“气候变化”则是近期热点; 主要理论涉及生态学、数理模型、资源与环境经济学、环境科学等, 其中生态足迹理论从2002年起一直占据主流, STIRPAT模型、环境库兹涅茨曲线等综合理论模型是近期热点理论; 依方法来源和主要应用领域将1992-2011年主要方法分为4类, 即统计类(65.17%)、系统类(13.11%)、机理类(11.79%)和测评类(9.93%)。灰色系统分析和R/S分析近年来常见的方法。由此得出主要结论: 中国城市化研究对城市土地利用、城市热岛、气候变化和水资源等大尺度的生态环境问题更加重视, 对城市环境健康等微观尺度生态环境问题关注相对不足; 以STIRPAT和多种土地利用变化模型为代表, 综合自然和经济理论采用系统建模方法评价和模拟城市化过程中的生态环境效应将是未来研究的重点。

关键词: 文献计量学; 生态环境; 城市化; 研究热点; 关键词分析