

Urban Sprawl and Related Problems: Bibliometric Analysis and Refined Analysis from 1991 to 2011

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Abstract: To shed light on the general patterns and trends in urban sprawl research, and to provide reference for future study, bibliometric analysis and refined analysis are conducted for publications in this area from 1991 to 2011. The general publication output, the global geographical distribution of the authors, the funding and institutions involved, the research areas, and the source titles are analyzed and discussed. Scholars in the United States and China have produced most of the documents in urban sprawl and these two countries are also the largest contributors in terms of funding and institutions. 'Environmental Sciences & Ecology', 'Urban Studies', and 'Geography' are the most common research areas, and the journal titled *Urban Studies* has contributed the most articles. Furthermore, the refined analyses on the 500 top-cited and most relevant publications have revealed that research on urban sprawl is closely associated with the categories of 'Urban form and development', 'Land use/land development' and 'environment/ecology/biology'. Conclusions are made with respect to the basic paradigm of research on urban sprawl. The multi-disciplinary research into urban sprawl are expected to be more diversified and integrated.

Keywords: urban sprawl; bibliometrics; scientific output; multi-discipline

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1 Introduction

Urban sprawl is by no means a new concept or phenomenon. It is well documented that the past 20 years have seen a proliferation of publications on urban sprawl, which is consistent with the rapid growth of urban land cover. It has been estimated that the growth rate of the urban population averaged 1.6% per year and the growth rate of urban land cover averaged 3.66% per year, according to a global sample of 120 cities between 1990 and 2000 (Angel *et al.*, 2011). As a matter of fact, 'sprawl' has been used both as a noun (condition) and verb (process) and has aroused heated discussion in the fields of urban geography, urban planning, land-use

management, and other related disciplines (Taubenböck *et al.*, 2009).

To date, there has not been a universally accepted or scientifically precise definition of 'urban sprawl', although the term 'urban sprawl' is often used quite negatively today, typically to describe low-density, inefficient suburban development around the periphery of cities (Couch *et al.*, 2007). Urban sprawl can also be interpreted as a product resulting from the complex and dynamic interactions encompassing a whole spectrum of social, economic, and environmental aspects, such as institutional contexts, market forces, technological advancements, land use and land cover, employment, immigration, poverty and crime, and sustainability (Brueck-

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ner, 2000). In addition, urban sprawl is also a regional issue related to city or metropolitan development in specific areas. The United States (US) has set an archetype for urban sprawl research, with respect to its causes, patterns, and effects, and numerous studies have highlighted the cost or impact of urban sprawl. The adverse effects are now widespread in the 20th century, and there is an urgent requirement for governments to seek remedies (Ewing, 1994; Van Metre *et al.*, 2000; Burchell *et al.*, 2002; Ewing *et al.*, 2006; Stone, 2008; Stone *et al.*, 2010; Shammin *et al.*, 2010). Unlike its US counterpart, urban sprawl in European countries is highly diverse, heterogeneous, and is more intertwined with the political and socio-economic histories (Fliege, 1999; Munoz, 2003; Waterhout *et al.*, 2005; Garcia, 2006; Couch *et al.*, 2007; Patacchini *et al.*, 2009). In developing countries, urban sprawl is taking place alongside the rapid economic development and population growth. An enormous amount of literature has emerged, with the focus on analyzing, modeling, and predicting urban growth in developing countries such as China and India (Jenks and Burgess, 2000; Yeh and Li, 2001a; Barredo and Demicheli, 2003; Sudhira *et al.*, 2004; Cohen, 2006; Wang *et al.*, 2012). In order to allow a better understanding of urban sprawl and its regional characteristics, a bibliometric analysis is therefore a pressing need.

Alternative terms such as 'urban growth' and 'urban expansion' have also been used in a number of publications to describe urban sprawl. Couch *et al.* (2005) defined urban growth in terms of either an expansion of population, or economic activity within an urban area. Meanwhile, Brueckner (2000) argued that the term 'urban sprawl' refers to the excessive spatial growth of cities. Glaeser and Kahn (2003) wrote a chapter titled 'Sprawl and urban growth', where he argued that urban growth has taken the form of sprawl, and declared that urban growth and urban sprawl were almost synonymous in US in 2003. On the other hand, there is another prevailing view claiming that urban sprawl first has to be an inefficient or excessive urban expansion, leading to a loss of amenity benefits or natural resources (Brueckner *et al.*, 2001; Deng and Huang, 2004; Liu *et al.*, 2005). The attempt to describe urban sprawl with regard to urban expansion has been fashionable in China as the depletion of scarce farmland resources is largely attributed to the expansion of urban space (Ding *et al.*, 2007; Shi *et al.*, 2009; Lu *et al.*, 2012). Camagni *et al.*

(2002) distinguished five types of urban expansion, with sprawl being one of them, which is characterized by new scattered development lots. In other words, urban sprawl can be interpreted as a specific form of urban expansion or urban growth, and these expressions are interchangeable with each other in most cases. As a result, in order to justify our retrieval operation and to clarify the analyses, we here define urban sprawl in a wider sense, including spatial growth or expansion, as well as the scattering of associated human activities, from city centers to the outer periphery.

To summarize, in our research, we have performed a bibliometric analysis and a refined analysis to explore the general patterns and trends in urban sprawl research over the past two decades. More specifically, our analyses aim to: 1) review and categorize the many retrieved documents; 2) reveal the temporal and geographical patterns in urban sprawl publications through the use of specific indicators; and 3) explore the research trends in this area.

2 Materials and Methods

All the publications used in our study were accessed from the Science Citation Index Expanded (SCIE) and the Social Sciences Citation Index (SSCI) databases. Because there were few documents before 1990, we limited our time span from 1991 to 2011. With the consideration of synonyms, we set the retrieval condition as ((sprawl OR expansion OR growth OR extension) AND urban) in titles, keywords, and abstracts for the bibliometric analysis. Unavoidably, the flexible retrieval condition generated unrelated documents; as a result, the initial search results were refined by choosing the relevant research areas from the dataset. Furthermore, the citation report was generated based on Journal Citation Reports (JCR) and Citations Per Publication (CPP), reflecting citations to source items indexed within the Web of Science.

Our bibliometric analysis was conducted in terms of publication output, the global geographical distribution of the authors, the funding and institutions involved, the research areas, and the source titles. We then extracted the 500 top-cited and most relevant documents for further review and categorization, and the research networks were analyzed accordingly. Conclusions were then made to highlight current situations and forecast

possible developments in this area.

3 Bibliometric Analysis

3.1 Publication output

The total number of publications was 10 633, and the total number of citations was 91 454, with an average of 8.6 citations per item (1991–2011). As illustrated in Fig. 1, the yearly production was below 200 before 1995, and then grew to over 600 by the year 2005. The peak appeared in 2009 with 1220 documents, and then dropped back down. In terms of numbers of citations, an irregular pattern can be discerned, with three obvious peaks in 1992, 1999, and 2004. After that, the numbers of citations presented a downward trend. Among all the documents, articles comprised 76.86% of the publications, with a total of 8173. Most of the documents were written in English (96.28%), with a minor proportion being written in European languages such as Spanish, French, and Portuguese.

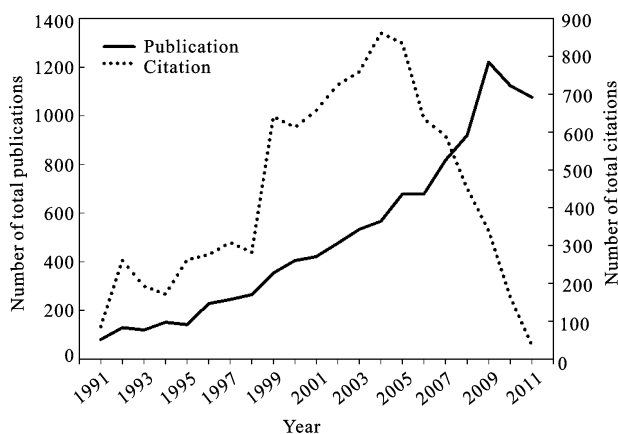


Fig. 1 Annual total number of publications and citations

Among all the retrieved documents, there were a total of 20 226 authors on the list. Using the critical value of 14 in total publications (TP), we listed the names, TP, total citations (TC1), and total citations excluding self-citation (TC2) of the authors in Table 1. For each author, the title of the most cited publication as the first author, the year of the publication, and the number of citations were also recorded. Wu F L was the most productive author, with 28 publications in total. Glaeser E L and Ewing R were the authors with the highest TC1 and TC1/TP values, which indicated the high impact of their publications. Regarding specific articles, 'Growth in cities' by Glaeser E L in 1992 had the highest number of

citations (812), and 'Relationship between urban sprawl and physical activity, obesity, and morbidity' by Ewing R published in 2003 was also noteworthy, with 367 citations.

We also extracted the affiliations of the authors to calculate the number of publications for each country. The thematic classification map of the geographical distribution of publications was produced with six categories shown in the legend, indicating the range of the numbers of publications (Fig. 2). It was found that 4044 (38.03% of the TP) publications were produced in US. China was second with 1329 publications (12.50% of the TP) and the United Kingdom was in third place with 1117 publications (10.50% of the TP). This was followed by Canada, Australia, and European countries such as Germany, France, Spain, Italy, and the Netherlands.

3.2 Funding and institutions

The top 15 institutions who contributed the most publications on urban sprawl were list in Table 2. Those from China and US were more productive, with the Chinese Academy of Sciences, the University of Illinois, and the University of California, Berkeley, ranking the first three places (Table 2). With respect to funding agencies, China still appeared to be the most active participant, with the National Natural Science Foundation of China, and the Chinese Academy of Science ranking 1st and 3rd, respectively. It was noticeable that apart from the National Science Foundation in US (2nd), a considerable proportion of the funding was provided by NASA (National Aeronautics and Space Administration), the NIH (National Institutes of Health), and the EPA (US Environmental Protection Agency) in US. This shows that remote sensing technologies have been widely applied in urban sprawl, and the impact of urban sprawl on human health and environment has yielded great concerns (Table 2).

3.3 Research areas and source titles

We presented the 50 research areas with the most publications and their ranks within each of the 5-year intervals during 1991–2011 (Table 3). The results reveal that research on urban sprawl covers a wide variety of areas, ranging from social to natural science. It can also be seen that a large number of publications have been produced in the environmental or ecological areas in recent years. For example, the ranking of 'Environmental Sci-

Table 1 Twenty most productive authors and their most cited publications

Author	TP	TC1	TC2	TC1/TP	Title of most cited publication (1st author)	Year	Number of citations
Wu F L	28	767	726	27.4	Calibration of stochastic cellular automata: The application to rural-urban land conversions	2002	113
Li X	22	615	565	28.0	Neural-network-based cellular automata for simulating multiple land use changes using GIS	2002	119
Jim C Y	20	190	172	9.5	Comprehensive greenspace planning based on landscape ecology principles in compact Nanjing city, China	2003	50
Partridge M D	20	182	131	9.1	Lost in space: Population growth in the American hinterlands and small cities	2008	37
Clarke K C	19	912	878	48.0	A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area	1997	335
Li J	19	32	32	1.7	Managing carbon emissions in China through building energy efficiency	2009	24
Lin G C S	19	365	311	19.2	The growth and structural change of Chinese cities: a contextual and geographic analysis	2002	59
Nelson A C	19	288	281	15.2	Preserving prime farmland in the face of urbanization - Lessons from Oregon	1992	66
Wang J	19	65	65	3.4	Mechanistic simulation of tree effects in an urban water balance model	2008	15
Zhang Y	19	198	191	10.4	Simulation of aerosol dynamics: A comparative review of algorithms used in air quality models	1999	94
Glaeser E L	18	1801	1773	100.1	Growth in cities	1992	930
Olfert M R	18	161	118	8.9	Best practices in Twenty-First-Century rural development and policy	2010	2
Zhang L	17	26	25	1.5	Reinterpretation of China's under-urbanization: A systemic perspective	2003	9
Liu Y	16	36	35	2.3	An integrated GIS-based analysis system for land-use management of lake areas in urban fringe	2007	28
Yeh A G O	16	617	586	38.6	Economic development and agricultural land loss in the Pearl River Delta, China	1999	93
Ewing R	15	963	938	64.2	Relationship between urban sprawl and physical activity, obesity, and morbidity	2003	415
Kline J D	15	249	217	16.6	Does land use planning slow the conversion of forest and farm lands?	1999	39
Song Y	15	220	211	14.7	Measuring urban form - Is Portland winning the war on sprawl?	2004	73
Batty M	14	371	368	26.5	Possible urban automata	1997	61
Carruthers J I	14	209	183	14.9	Fragmentation and sprawl: Evidence from interregional analysis	2002	43
Haase D	14	73	56	5.2	Does urban sprawl drive changes in the water balance and policy? The case of Leipzig (Germany) 1870–2003	2007	27
Seto K C	14	304	269	21.7	Monitoring land-use change in the Pearl River Delta using Landsat TM	2002	107
Zhang X L	14	19	19	1.4	Assessing the impact of urban sprawl on soil resources of Nanjing city using satellite images and digital soil databases	2007	14

Note: number of citations were extracted from Web of Science on Jan 20, 2012

ences & Ecology' grew from 3rd in 1991–1995 to 1st in 2006–2011; 'Biodiversity & Conservation', which did not appear in 1991–1995, reached 18th in 2005–2010; and 'Water resource' went up from 27th to 11th. The upward trend can also be seen in technological areas such as remote sensing (48th to 12th) and computer science (30th to 7th). The names of the research areas were specified according to the research area list from Web of Science.

Publications on urban sprawl have appeared in a wide spectrum of source titles, and the top 20 journals were summarized in Table 4, along with the number of papers (TP), the number of citations that each journal received for these articles (TC1), TC1 excluding

self-citation (TC2), TC1/TP, and the Impact factor (IF). The average citation rate of a journal is the most direct indicator for assessing the impact of a journal. The higher the citation rate is, the greater the journal's impact is on the particular field. The results reveal that *Urban Studies* was the most productive journal with the highest number of citations. The second most cited journal in urban sprawl was *Landscape and Urban Planning*. *Atmospheric Environment*, the *Journal of the American Planning Association*, and the *International Journal of Urban and Regional Research* had the highest TC1/TP values. Among all the top 20 journals, *Atmospheric Environment* had the highest IF (3.47), followed by *Land Use Policy* with an IF of 2.29.

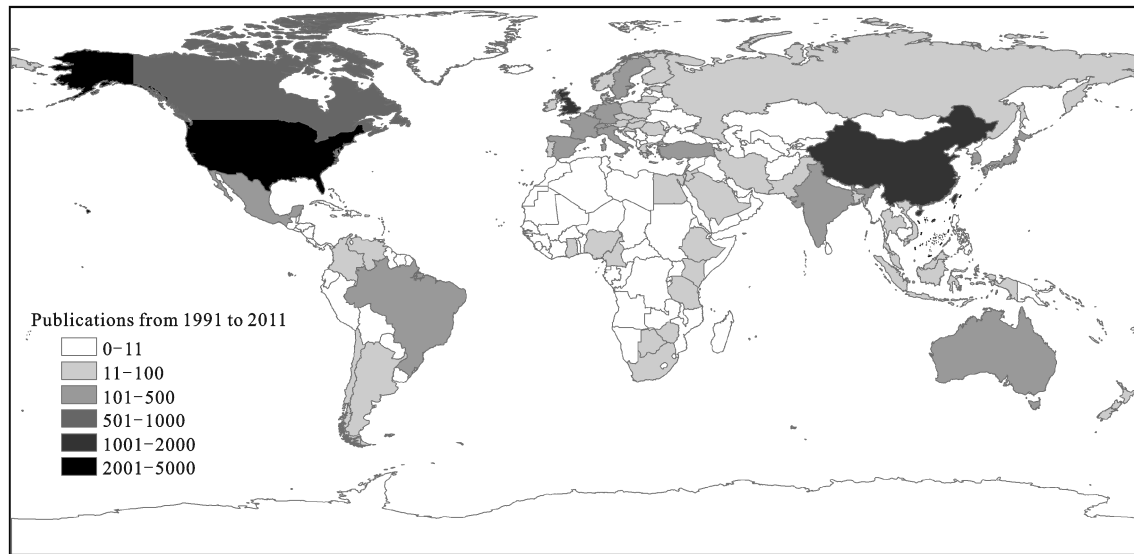


Fig. 2 Global geographical distribution of publications based on authors' locations. The base map was retrieved from the Global Administrative Areas (GADM) database, and the boundary was revised according to the latest map of The People's Republic of China from Sino Map Press (2012)

Table 2 Distribution of institutions and foundations

Ranking	Institution	TP	Ranking	Foundation	TP
1	Chinese Academy of Sciences	219	1	National Natural Science Foundation of China	102
2	University of Illinois	111	2	National Science Foundation in US	68
3	University of California, Berkeley	110	3	Chinese Academy of Sciences	36
4	University of Toronto	104	4	European Union	23
5	University of Hong Kong	103	5	European Commission	12
6	University of North Carolina	101	6	NASA (National Aeronautics And Space Administration) in US	12
7	University of Wisconsin	93	7	National Basic Research Program of China	12
8	Ohio State University	92	8	Robert Wood Johnson Foundation in US	9
9	University of Maryland	88	9	NIH (National Institutes of Health) in US	9
10	Arizona State University	87	10	Australian Research Council	7
11	Harvard University	79	11	CNPQ (National Council For Scientific And Technological Development) in Brazil	7
12	University of Minnesota	74	12	Natural Science Foundation of China	7
13	Peking University	70	13	EPA (Environmental Protection Agency) in US	7
14	University of Washington	70	14	Swiss National Science Foundation	6
15	Rutgers, State University of New Jersey	69	15	Chinese Postdoctoral Science Foundation	5

4 Refined Analysis

In recent decades, research on urban sprawl has engaged problems beyond the basic theories and scientific inquiries in this area. Previous analyses on the publication output, source titles, and research areas have shown that research on urban sprawl have involved a number of different fields. In order to support a retrospective

analysis and to explore the interdisciplinary nature of urban sprawl, we undertook a refined analysis of the top 500 most frequently cited and relevant documents.

4.1 Interpretation of categorization

We reviewed these 500 publications in detail to summarize their methodologies and main findings, apart from extracting their keywords, authors, source titles, public-

Table 3 Distribution and temporal variation of research areas

Research area	TP	Ranking			
		1991–1995	1996–2000	2001–2005	2006–2011
Environmental Sciences & Ecology ↑	4050	3	1	1	1
Urban Studies ↓	2058	1	2	2	2
Geography ↓	1633	2	4	4	4
Engineering ↑	1619	10	3	3	3
Business & Economics ↓	1440	4	6	6	5
Public Administration ↓	1142	5	5	5	6
Public, Environmental & Occupational health	644	7	8	9	8
Computer Science ↑	527	30	22	13	7
Geology	489	31	12	7	10
Physical Geography ↑	480	21	15	11	9
Transportation	475	13	7	8	13
Water Resources	427	27	9	12	11
Remote Sensing	384	48	20	10	12
Social Sciences Other Topics	307	9	14	18	15
Meteorology & Atmospheric Sciences ↑	301	34	17	15	14
History	269	8	13	19	17
Sociology ↓	258	6	10	17	21
Forestry	203	43	16	16	22
Government & Law ↓	201	11	11	24	24
Imaging Science & Photographic Technology	201	45	33	14	20
Operations Research & Management Science	198	19	44	26	16
Agriculture	188	15	18	20	19
Area Studies ↓	159	12	21	22	25
Science & Technology Other Topics	143	20	27	28	23
Biodiversity & Conservation ↑	138	NULL	28	30	18
Construction & Building Technology	134	39	23	23	26
Demography ↓	121	14	19	36	29
Mathematics ↓	118	24	26	27	27
Energy & Fuels	106	41	24	31	28
Telecommunications	106	36	25	29	30
Marine & Freshwater Biology	86	46	29	25	31
Architecture	71	NULL	65	21	36
Biomedical Social Sciences	66	16	31	40	34
Life Sciences Biomedicine Other Topics ↓	54	23	32	35	39
Information Science & Library Science	52	32	34	39	37
General & Internal Medicine	48	44	48	56	32
Psychology	48	35	45	34	40
Education & Educational Research	47	40	41	45	35
Nutrition & Dietetics	47	18	50	37	44
Plant Sciences ↑	46	NULL	55	49	33
Toxicology	46	NULL	52	32	43
Anthropology ↓	42	22	30	42	45
Health Care Sciences & Services	40	NULL	37	38	41
Zoology	35	NULL	47	41	47
Automation & Control Systems ↑	33	NULL	57	53	38
Mathematical Methods In Social Sciences ↓	32	33	38	46	46
Social Issues	32	NULL	40	50	42
Tropical Medicine	30	49	46	43	51
Physics	28	26	82	48	48
International Relations ↓	22	25	35	60	62

Note: NULL means there is no such research area in specific time period; ↑ and ↓ represent rising and declining trend, respectively

Table 4 Top 20 most active journals

Source titles	TP	TC1	TC2	TC1/TP	IF
<i>Urban Studies</i>	275	3910	3739	14.22	1.28
<i>Landscape and Urban Planning</i>	206	2717	2484	13.19	2.17
<i>Cities</i>	153	1195	1139	7.81	1.14
<i>Environment and Planning A</i>	144	2060	2014	14.31	1.89
<i>Atmospheric Environment</i>	119	3137	3070	26.36	3.47
<i>Urban Geography</i>	119	773	738	6.50	1.36
<i>Environment and Planning B</i>	111	1570	1434	14.14	0.83
<i>Transportation Research Record</i>	101	72	65	0.71	0.47
<i>International Journal of Urban and Regional Research</i>	96	1538	1518	16.02	1.34
<i>Habitat International</i>	89	565	532	6.35	1.43
<i>Urban Affairs Review</i>	86	1127	1084	13.10	1.10
<i>Journal of Urban Economics</i>	83	1203	1151	14.49	1.89
<i>Journal of the American Planning Association</i>	77	1512	1456	19.64	2.04
<i>Journal of Urban Affairs</i>	75	675	643	9.00	0.84
<i>Land Use Policy</i>	72	595	541	8.26	2.29
<i>Regional Studies</i>	72	956	945	13.28	1.19
<i>Environmental Monitoring and Assessment</i>	70	340	327	4.86	1.40
<i>International Journal of Remote Sensing</i>	70	1028	953	14.69	1.12
<i>Regional Science and Urban Economics</i>	63	782	764	12.41	1.01
<i>Water Science and Technology</i>	62	421	415	6.79	1.12

Note: IF is obtained from '2011 Journal Citation Reports' published by Thomson Reuters in 2012

cation years, and research areas. We then classified them into 16 categories, namely: Environment/ecology/biology, Human health and behavior, Land use/land development, Policy/management, Urban form and development, Integrated modeling, Technological application, Transportation and travel mode, Built environment, Decomposing urban sprawl, Micro-and macroscopic economy, Open space/green space, Social aspects, Landscape, Forest, and Others. It was in fact difficult to explicitly group these documents into different categories. In most cases, an individual article would mention keywords related to a couple of categories; however, the criteria for categorization was the judgment on the key motivations and conclusions, while the case of multiple grouping was reserved for articles with keywords of equal importance.

4.2 Categorization analysis

Based on the above categorization, we then analyzed the number of TP and TC in each category and the proportion of TP in the 1st to 100th, 101st to 200th, 201st to 300th, 301st to 400th, and 401st to 500th place lists (Table 5). It can be seen that the top three groups of TP

are 'Urban form and city development', 'Land use/land development' and 'Environment/ecology/biology'. They occupy almost half of the total of 500 documents. The number of total citations was also analyzed, with the categories of 'Environment/ecology/biology', 'Land use/land development', and 'Micro-and macroscopic economy' taking the first three places. In the 1st to 100th place list, 'Environment/ecology/biology' stands out with 20.3%, followed by 'Micro-and macroscopic economy'. This backs up the assertion that more attention has been devoted to linking the different urban forms with environmental, ecological, and biological issues (Van Metre *et al.*, 2000; Johnson, 2001; Hansen *et al.*, 2005; Muñiz and Galindo, 2005; Zhang *et al.*, 2007). As a matter of fact, urban sprawl has resulted in agricultural land loss, air and water pollution, climate change, and biological effects (Yeh and Li, 1999; Blair, 2004; Patz *et al.*, 2005; Shao *et al.*, 2006; Chan and Yao, 2008). Investigations and models have therefore been devised to explore the relationships between urban development and atmospheric, aquatic, and terrestrial physical changes (Fenger, 1999; Weng, 2001; Brabec, 2002; Antrop, 2004). The 'Micro-and macroscopic economy', which

Table 5 Production indicators in different categories in 500 most cited documents

Categorization	TP	TC	Ranking (Proportion of TP in different ranks)				
			1st–100th	101st–200th	201st–300th	301st–400th	401st–500th
Decomposing urban sprawl	46	2423	4.8	3.8	5.6	11.5	8.3
Human health and behavior	45	3646	10.8	9.6	7.2	2.3	3.1
Environment/ecology/biology	71	5933	20.3	10.7	7.0	7.2	8.2
Built environment	13	953	2.0	4.2	2.0	0.8	0.0
Open space/green space	8	331	0.0	0.6	2.7	1.6	0.9
Land use/land development	86	4881	9.9	14.5	8.7	13.9	12.4
Landscape	20	1186	2.6	2.0	4.9	3.1	1.5
Micro-and macroscopic economy	54	4340	13.4	9.1	6.3	7.0	6.2
Transportation and travel mode	16	744	0.7	2.2	2.1	2.5	4.6
Policy/management	66	3617	6.0	11.4	9.7	10.4	8.4
Social aspect	53	3513	8.6	9.1	8.5	5.5	6.2
Urban form and development	88	3779	2.4	8.8	18.1	14.0	20.4
Integrated modeling	51	3500	10.1	6.9	6.4	4.8	8.6
Technological application	55	2918	6.1	4.6	8.6	9.7	9.8
Forest	12	613	0.6	2.6	0.7	4.1	0.8
Others	8	538	1.9	0.0	1.4	1.5	0.7

refers to market orientation, tax regulation, and housing prices, has also been frequently cited. Other topics such as 'Urban form and city development', 'Human health and behavior', and 'Policy/management' have gained popularity in recent years, and in fact they embody an important 'cause-effect-response' relationship with urban sprawl.

4.3 Research network

The technique of network analysis has been used in exploring the collaborations and associations among different institutions, countries, and disciplines (Liu *et al.*, 2011). In an attempt to better understand the linking strengths among the different categories in urban sprawl, a network analysis was applied in the work of relating urban sprawl to the related categorizations, as well as their synergistic relations.

Figure 3 illustrated the research network among the different related categories. The size of the nodes of related categories (marked in circle) corresponded to the number of total publications (TP) in each category (Table 6). For the node of urban sprawl (marked in square), it was given the aggregate number of 200. The thickness of the line was determined by the linking strengths among different categories. The strength of the line between urban sprawl and each group was obtained by Delphi method. Investigations have been made among

20 experts and they scored the relationship between urban sprawl and these 16 categories, with 5 indicating the closest bond and 0 the weakest. The final scores were calculated by averaging the scores from all the experts. The strength of the lines between the related categories was given in view of their synergistic effects, which was recorded during the aforementioned refined analysis. For example, if 'Integrated modeling' and 'Technological application' appeared in 20 documents simultaneously, the strength of the line between these two categories would be given the value of 20. In the end, the linking strength was transformed into a numeric scale from 0 to 5 through the max-min normalization method.

It can be seen that 'Decomposing urban sprawl' and 'Land use/land development' have the highest degree of relevance to urban sprawl, followed by 'Landscape' and 'Transportation and travel mode'. On the other hand, the most synergistic effect exists between 'Land use/land development' and 'Technological application'. It indicates that urban sprawl has close relationship with land use change and technologies such as remote sensing and geographical information systems have been widely applied in this area. (Weng, 2001; Weng, 2002; Yang and Lo, 2002). 'Land use/land development' is also closely associated with 'Integrated modeling' and 'Environment/ecology/biology'. This reflects that research on the modeling of land use change and the environ-

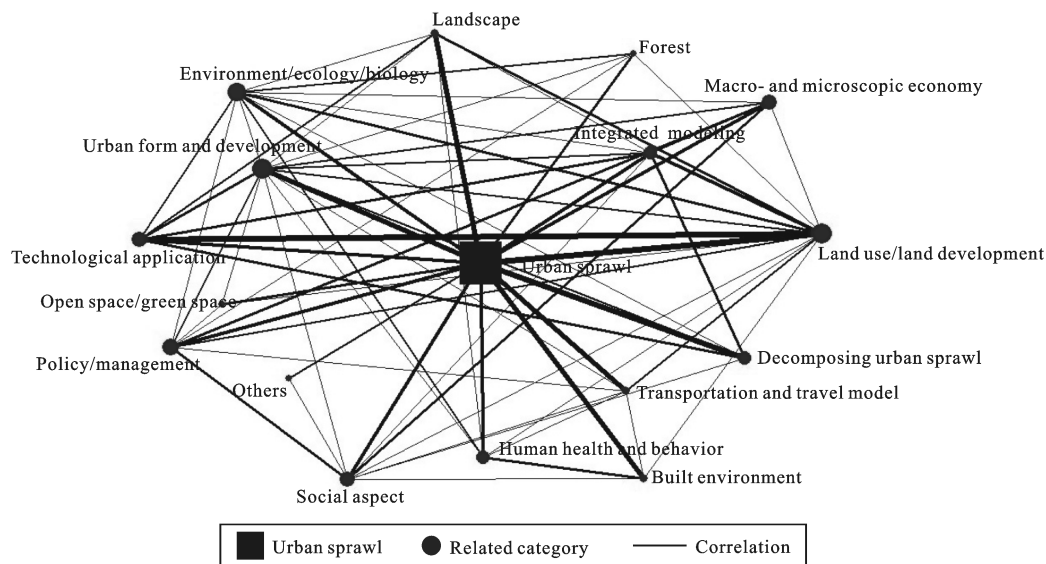


Fig. 3 Research networks among e different related categories (The size of node represents number of publications in each category and thickness of line refers to linking strength. The detailed description is in Section 4.3)

mental, ecological or biological effects caused by land use have been broadly investigated (Wu and Webster, 1998; Tan *et al.*, 2005; Chen, 2007). 'Human health and behavior' and 'Built environment' intersect with each other and embody the chain structure of the 'urban sprawl–built environment change–physical activity change–human health problem' in the research (Northridge *et al.*, 2003; Papas *et al.*, 2007).

5 Discussion

5.1 Basic paradigm of urban sprawl research

Among the mass of literature on urban sprawl, different scholars have approached it from different aspects, spanning a range from urban form, urban pattern, urban development, urban density, and land use, to diversified cost, and the effects arising from urban expansion (Ewing, 1994; Galster *et al.*, 2001; Eckenrodt and Holahan, 2004; Couch *et al.*, 2007). However, the basic paradigm can be identified as 'characteristic–cause–impact'. Each dimension is supposed to be probed into independently and thoroughly or, on the other hand, integrated analysis is expected to be performed. The characteristic of urban sprawl can be interpreted as the composition and configuration of urban areas, which is closely associated with landscape, land use, and land cover (Steo and Fragkias, 2005). As a result, institutions such as the University of Maryland, which have established their credibility in city and regional planning and resource

management, have become active in the production of literature on land use and land cover (Irwin and Bockstael, 2004; 2007; Claggett *et al.*, 2004; Shen and Zhang, 2007). Journals such as *Landscape and Urban Planning* and *Land Use Policy* have emerged to be the preferred choice of publication. In terms of causes, the rapid development of public transportation and private vehicles can never be underestimated, which is exemplified by the fact that 'Transportation' ranked 11th in the research areas, and journals such as *Transportation Research Record* (8th) were also included in the most active source titles. A great deal of attention has been given to the 'cost' or 'effect' of urban sprawl. Most of the top-cited articles in our list are concerned with this dimension, among which environmental- or ecological-related problems are prominent. This is because the expansion of urban areas and the concentration of population, transportation, resources, and energy consumption results in the pollution of atmospheric, terrestrial, and aquatic ecosystems, as well as the degradation of the biological environment (Van Metre *et al.*, 2000; Liu *et al.*, 2003; Patz *et al.*, 2005; Radeloff *et al.*, 2005). It is also evidenced by the fact that 'Environment/ecology/biology' ranked the 1st in TC and the 3rd in TP in the refined document list (Table 5), and the top placing and upward trend of 'Environmental Sciences & Ecology' (3rd to 1st) in the research area list (Table 3). The other focus has been on human health, the obesity problem in particular, which has been studied by a number of re-

searchers in recent years (Ewing *et al.*, 2003; Lopez, 2004; Papas, 2007). This can be reflected by the funding support from the NIH in US, where the obesity problem prevails.

5.2 Highlighted places and participants

The US has dominated the research into urban sprawl in terms of global geographical distribution of publications based on authors' locations, institutions, and foundations. This preponderance maintained throughout 1991 to 2011. This justifies the generally accepted opinion that the US is the 'ancestor' of the research into urban sprawl, and that it has a leading role in guiding the world to explore better urban form and development (Couch *et al.*, 2007). The rise of China in this area can be largely attributed to its rapid urban and economic development, which in turn has stimulated the research. In fact, China has faced great challenges in realizing sustainable urban development for a long time, and explorations of the optimal urban form are urgently needed in the many different cities and provinces in China (Chen, 2007). Furthermore, the decentralization in the US and the centrality in China are particularly discernible in the listed institutions and foundation sources. In the US, these studies have been supported by the National Science Foundation and diverse agencies, institutions, and organizations in the related disciplines, such as the NIH, NASA, and the EPA (Milder and Clark, 2011; Boone-Heinonen *et al.*, 2011). Simultaneously, a number of well-established universities have also been carrying out research and have published numerous articles. Conversely, in China, the foundation for the research into urban sprawl has primarily come from the 'National Natural Science Foundation of China' and the 'Chinese Academy of Sciences'.

5.3 Multi-disciplinary nature of urban sprawl research

The most striking feature of the research into urban sprawl is its wide range and multi-disciplinary nature. This is evidenced by the wide variety of source titles, research areas, foundations, and institutions. The refined analysis also confirms the diverse nature of the research, as the categorization presents extraordinarily varied fields and a comparatively complex network. Although the 16 groups in the refined analysis seem to be quite independent topics, they interact with each other, and

their network is established through the changing urban form.

In fact, when we explore urban sprawl, we need economic, mathematical, physical, or artificial intelligence models to analyze it, remote sensing and geographical information systems to acquire and process data for it, engineering or construction technology to implement it, and all these processes are unavoidably linked to environmental science, ecological conservation, public health, and public administration (Yeh and Li, 2001b; Chakir and Parent, 2009; Sarvestani *et al.*, 2011). This is why the scholars have a wide range of choices for the publication of their works, depending on the specific focus, such as the planning category (*Landscape and Urban Planning*, the *Journal of the American Planning Association*), the land-related category (*Landscape and Urban Planning*, *Land Use Policy*), the environment or ecology category (*WIT Transactions on Ecology and the Environment*, *Environment and Planning A*, *Environment and Planning B*, *Environmental Management, Ecology and Society*), the economic category (*Journal of Urban Economics*, *Regional Science and Urban Economics*), as well as the general urban-related category (*Urban Studies*, *Cities*, *Urban Geography*, *Urban Affairs Review*). A similar multi-disciplinary nature can also be found in the list of research areas: the domains of environment, geography, administration, engineering, economics, transportation, computing, remote sensing, architecture, conservation, and medicine are all included. In fact, when attempts are made to analyze urban sprawl, social or economic scientists, transportation planners, land-use planners, architects or urban designers, and landscape ecologists will all seek different dimensions. Knaap (2004) analogized sprawl to an elephant when describing the disciplinary boundaries in the paper entitled 'Seeing the Elephant: Multidisciplinary Measures of Urban Sprawl'. The multifaceted features of urban sprawl are indeed vivid.

6 Conclusions

To summarize, based on the bibliometric analysis and the refined analysis conducted on publications from 1991 to 2011, we have investigated general publication output, geographical distribution of publications, funding and institutions, research areas, and source titles. In particular, we have made an in-depth refined analysis of

the 500 most cited and relevant articles and have portrayed the research network related to urban sprawl.

In the future, it is predictable that the general output of publications on urban sprawl will continue, along with the sprawling process of urban development. Meanwhile, funding and the institutions contributing to the research, and the journals publishing related articles, will become more diversified as urban sprawl involves an increasingly wider subject range from urban form and city development to human health and behavior, from micro-and macroscopic economy to technological application, and from policy and management to integrated modeling. Although the basic paradigm of 'characteristic-cause-impact' has been identified and is unlikely to change much in urban sprawl research, they are expected to become more interrelated. The metrics for describing urban sprawl can either be characteristic or consequential, aggregated indices or multi-dimensional, spatial or temporal, or can be accomplished through a combination of these approaches. The techniques for characterizing and diagnosing urban sprawl are currently in a state of great advancement as remote sensing and GIS techniques are applied in the research, enabling researchers to undertake integrated modeling. On the other hand, the negative impact of urban sprawl will inevitably necessitate research into environmental or ecological changes caused by urban sprawl, as most countries are still experiencing rapid urban development. As a result, we anticipate further diverse and multi-disciplinary research into urban sprawl.

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