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Evolution Process of Urban Spatial Pattern in Hubei Province Based on DMSP/OLS Nighttime Light Data

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Abstract: This paper intends to investigate the urban spatial patterns of Hubei Province and its evolution from three different perspectives: urban nodes, urban connections and urban clusters. The research adopts nighttime light imagery of cities in Hubei Province, the viewpoint of ′point-axis-area′ in the ′point-axis system′ theory, and employs light index model, gravity model and social network analysis. The findings are as follows: 1) In terms of urban nodes, the urbanization process of Hubei has been carried out mainly on the basis of external expansion rather than internal increasing. The polarization trend of urban connection network is strengthening. 2) As for urban connections, the estimation of urban connections using light index model is capable of containing various actual flow, and the connections are getting increasingly closer. 3) In regard to urban groups, seven urban groups of varying sizes have formed. On that basis, three stable and relatively independent urban groups as the centers, namely Wuchang, Yichang and Xiangyang emerge as well. But the structures of ′Wuhan Metropolitan Area′, ′Yichang-Jingzhou-Jingmen City Group′ and ′Xiangyang-Shiyen-Suizhou City Group′, which are defined by local development strategy in Hubei Province, are different from the above three urban groups.
Keywords: Defence Meteorological Satellite Program′s Operational Linescan System (DMSP/OLS); urban spatial pattern; point-axis-area; Hubei Province, China

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1 Introduction

German, in the early nineteenth century, witnessed the birth of research on urban spatial pattern and its evolution process (Alfred, 2010; August, 2010; Walter, 2010; John, 2011). From then on, many domestic and foreign scholars raised a rich variety of the evolution models of regional urban spatial pattern such as growth pole theory (Francois, 1987), point-axial system theory (Lu, 1986). In recent years, a large number of empirical studies on urban spatial pattern at multiple spatial scales have been conducted in China (Gu *et al*., 2008; Zhang and Lu, 2010; Gong *et al*., 2011; Shen *et al*., 2012; Xu, 2013; Wang *et al*., 2014). What these studies have in common is their focus on point and axis connection in region from the perspectives of urban nodes (scale, accessibility, development level, *etc*.) and urban linkage (strength, network, *etc*.).

Spatiality is one of the essential characteristics of geography that distinguishes it from other disciplines.

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Moreover, geographical space is composed of point, line and area, and the interaction between point and line contribute to the formation of area. So it is necessary for the quantitative research on urban spatial pattern to make synthetic analysis of these three elements. The exploration of relationship between point and axis is a great achievement in Geography in China since the reform and opening-up. To following up, it is necessary to make further efforts to the evolution of point and axis towards 'area' and the point-axis-area pattern in region.

In the era of urbanization, city is increasingly playing a leading role in regional development. Based on 'point-axis' theory and RS, spatial analysis method in GIS and quantitative measurement, this study analyzed the urban spatial patterns and evolution characteristics of Hubei Province on the perspectives of urban nodes, urban connections and urban clusters in accordance with the viewpoint of 'point-axis-area'. In theory, our experiments quantitatively analyzed city clusters by applying more synthetically measuring methods. Furthermore, this study can help to provide guidance for the spatial strategy and layout of regional development and the orientation and division of urban function.

2 Materials and Methods

2.1 Study area

Hubei Province is located in the middle reaches of Changjiang (Yangtze) River, the central part of China, with an area of 185 900 km^2, containing 1 sub-provincial city, 12 prefecture-level cities, 3 sub-prefecture-level cities, 24 county-level cities and numerous small towns. By the end of 2013, the resident population of Hubei Province reached 5.799×10^7 and the urbanization rate reached 54.5%. Hubei has atypical 'point-axis-area' urban spatial pattern. In this urban spatial pattern, Wuhan is the capital and also the biggest city of Hubei Province, with its GDP and resident population respectively account for 37.4% and 20% of Hubei Province. Xiangyang and Yichang are the sub-central cities of Hubei; Huangshi, Shiyan and Jingzhou are regional center cities. Meanwhile, urban belt along the Changjiang River and Hankou-Xiangyang-Shiyan urban belt are two main urban development axes, and 'Wuhan City Circle', 'Yichang-Jingzhou-Jingmen City Group' and 'Xiangyang-Shiyan-Suizhou City Group' are at a fairly mature stage.

2.2 Defence Meteorological Satellite Program's Operational Line scan System (DMSP/OLS) nighttime light imageries

Measuring urban scale is the primary step of urban spatial pattern analysis. Using single or composite indicator derived from statistical data such as population, land use, economic outcomes has been the traditional method for the definition of urban scale. Easy availability is the advantage of that kind of data. However, it also have obvious disadvantage in reflecting urban spatial information completely. Firstly, single indicator can only report urban development level from one side. Similarly, it is impossible for the composite indicator to reveal all kinds of urban spatial information in spite of its richer information types. Secondly, statistics reflects urban information in the scope of administrative region instead of the actual land cover of city, which will ultimately results in the disparity in space between them and leads to inaccuracy. Besides, the indicator weighting is such a highly subjective matter that we can not easily get a reasonable result. Thirdly, the statistics lacks standardization. The change of region and time period will cause deviation and fluctuation of different statistic scopes, and that can easily induce information distortion.

Nowadays, the rapid developments of remote sensing and GIS techniques have provided new means to get the data reflecting the comprehensive information of cities. Many empirical studies have proved that urban economic development, population aggregation, urban construction and energy consumption are highly correlated to the DMSP nighttime light imagery, which is able to comprehensively reflect aspects of the scale and level of urban development, including the population and socioeconomic information (Lo, 2002; Doll *et al.*, 2006; Wen *et al.*, 2012), accurate delimitation of urban boundaries (Sutton *et al.*, 2010; Liu *et al.*, 2014; Zhou *et al.*, 2014), estimation of electric power consumption (He *et al.*, 2012; Cao *et al.*, 2014), and so on. In the studies of urbanization, Yi *et al.* (2014) constructed an Urban Light Index (ULI) for the quantitative evaluation of the process of urbanization and expansion rate in Northeast China by using DMSP/OLS nighttime light data. Gao *et al.* (2015) described a method of estimating urbanization level based on OLS on the DMSP nighttime light data and analyzed the dynamics of urbanization levels in China from 1992 to 2012. Tan (2015) synthetically analyzed the urbanization process and rural transition in

China using lit areas and the intensity of nighttime light imagery. Compared with traditional statistical data, nighttime light imagery data have superior comprehensiveness and objectivity and more accurately reflecting the actual land cover scope, and is more favorable to standardized comparison of space and time.

2.3 Data resource

(1) Remote sensing data. Four DMSP/OLS nighttime light imageries in 1992, 2002 and 2012 were downloaded from the National Oceanic and Atmospheric Administration′s (NOAA), National Geophysical Data Center (NGDC), which were obtained from four individual sensors: F10 (1992), F14 (2002), F15 (2002) and F18 (2012). With a digital number (DN) ranged from 0 to 63, these imageries have a spatial resolution of 30 arc-seconds (approximately 1 km at the equator). Moreover, we use annual cloud-free composite stable nighttime light, which contains persistent lights from cities, towns and other sites, to eliminate the disturbance from cloud and superficial and temporal flare.

(2) Statistical data. The data were obtained from *China City Statistical Yearbook* (National Bureau of Statistics of China, 1994; 2003; 2013) (the lack of data for 1993 is compensated by the data for 1994).

(3) Auxiliary data. The administrative boundary map of China at province, prefecture city and county levels, and maps of the highway transportation (1992, 2002 and 2012) of Hubei Province are acquired.

2.4 Data pre-processing

All four sets of DMSP/OLS NTL imageries of Hubei Province were extracted from the DMSP/OLS NTL Chinese data using the Hubei administrative boundary map (Fig. 1). Then we re-projected the imageries into Lambert Conformal Conic Projection.

Convert the four light images into planar vector data and exclude the pixels with a DN value of 0. To ensure the accuracy of results, we firstly used intersection tool in ArcGIS to remove the inconsistent light pixels of the two imageries in 2002, and then use raster calculator to correct the DN value of other pixels (Equaton 1).

$$DN_{(n,i),C} = \frac{DN^{a}_{(n,i)} + DN^{b}_{(n,i)}}{2} \quad (1)$$

where $DN_{(n,i),\ C}$ is the DN value of pixel i in year n

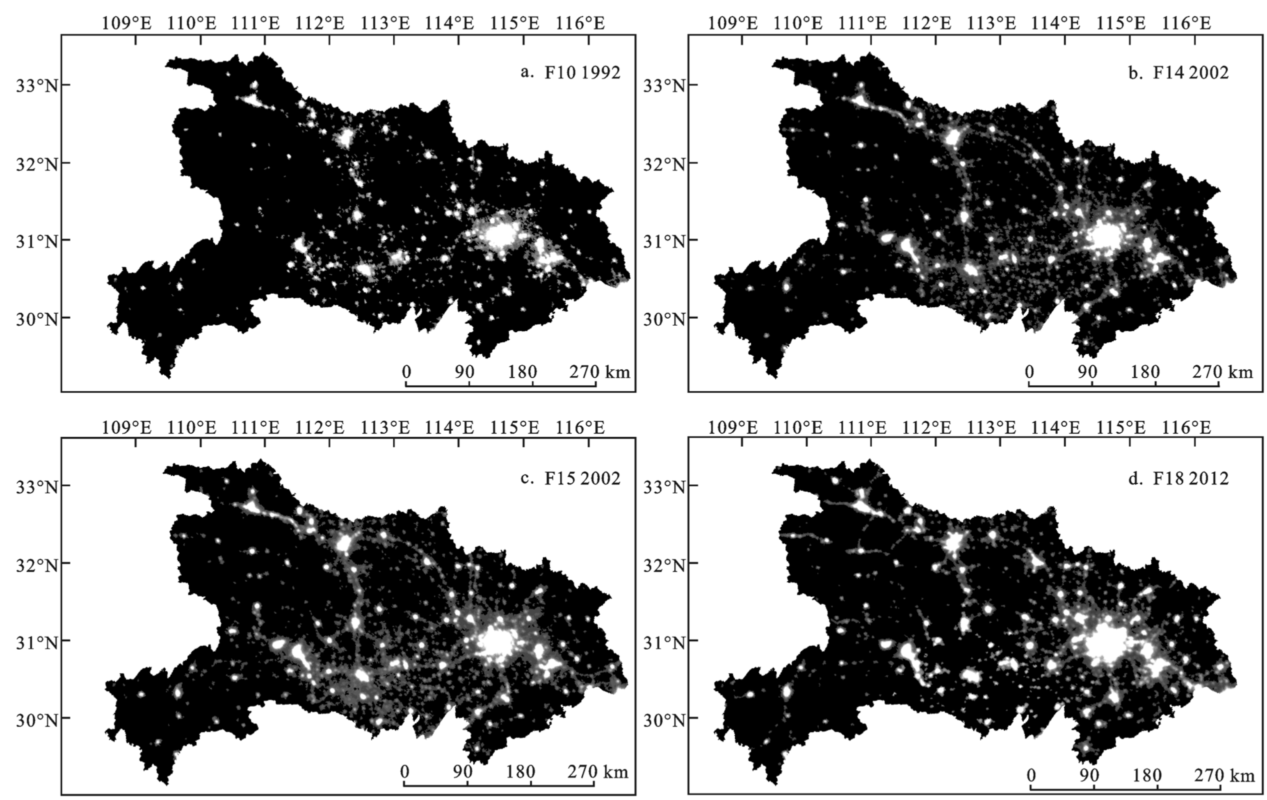

Fig. 1 DMSP/OLS nighttime lights imageries of Hubei Province in 1992, 2002 and 2012

(2002) after correction. $DN^{a}_{(n,\ i)}$ and $DN^{b}_{(n,\ i)}$ are the DN value of pixel i obtained from sensor a and b in year n before correction, respectively.

Considering the sensor signals of DMSP/OLS are easily to be interfered, causing noises, it is necessary to use a threshold to extract urban spatial information. In this study, we adopted dichotomy in spatial comparison method to identify the threshold (Fig. 2).

where DN_T represents the threshold for the identification of lit urban area, $S(DN_T)$ is the area of lit urban area in a district identified by threshold and *Area* is the built-up area of the district. $\Delta S(DN_T)$ represents the difference between $S(DN_T)$ and *Area*, DN_{max} and DN_{min} are respectively the maximum and minimum DN value of the light pixel within a district.

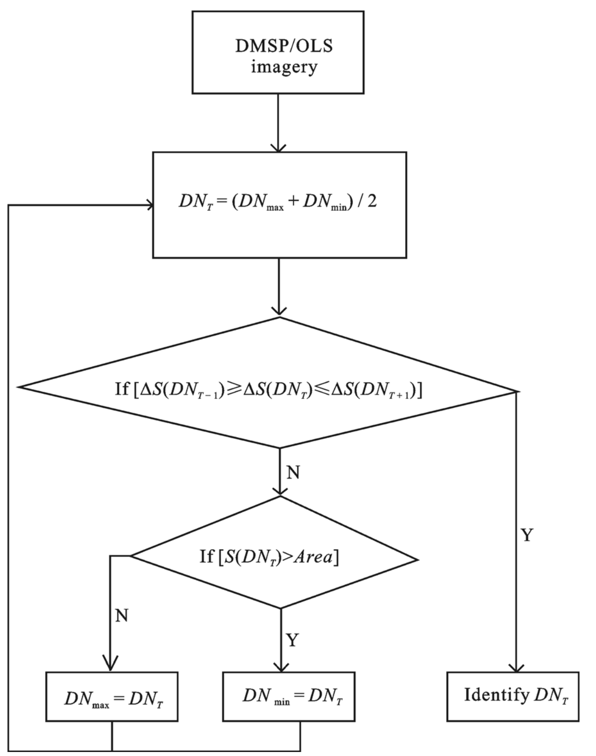

Fig. 2 Process of determining threshold value using dichotomy

In order to make the light information between different years and cities comparable, a uniform threshold is needed. According to *China City Statistical Yearbook* (National Bureau of Statistics of China, Department of Urban Socio-economic Surveys, 1994; 2003; 2013), the changes in area and boundary of Shiyan District are both smaller than the other cities of Hubei Province. In addition, considering its relatively stable built-up area, Shiyan is the most ideal city to identify the threshold value. The threshold of 1992, 2002, 2012, identified by dichotomy, are respectively 30, 36 and 45. The threshold was determined in 30 finally. With the help of overlay analysis in ArcGIS, the urban spots of Hubei Province in 1992, 2002 and 2012 have been identified and extracted (Fig. 3).

2.5 Models and methods

(1) Light index model

The gross value of urban light brightness is selected to access the urban scale for this study, and the average light intensity of city is applied to access the development level of city.

$$Area_N = Area_e \times N_L \tag{2}$$

$$TNLI = \sum_{i=DN_T}^{DN_M} (DN_i \times n_i) \tag{3}$$

$$ANLI = \frac{TNLI}{N_L} = \frac{\sum_{i=DN_T}^{DN_M} (DN_i \times n_i)}{N_L} \tag{4}$$

where $Area_N$ is the area of lit urban areas in N region; $Area_e$ is the area of single lit pixel; N is the number of pixels in a region (including the pixels value in 0); N_L is the number of lit pixels with a DN value between of DN_T and DN_M; *TNLI* is the gross value of urban light brightness; DN_M is the maximum DN value; DN_T is the threshold for the identification of lit urban area; DN_i is

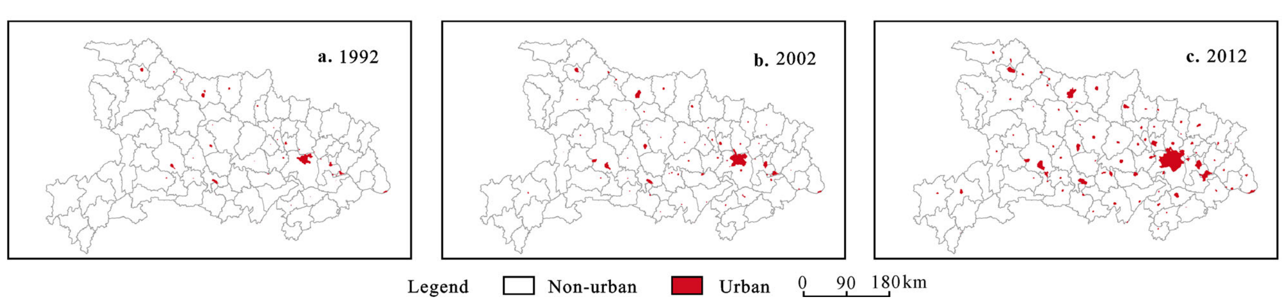

Fig. 3 Urban spots of Hubei Province in 1992, 2002 and 2012

the gray value of the pixels level at i; n_i is the number of pixels level at i; and $ANLI$ is the average light intensity.

(2) Urban connection model

The urban connection models, including urban connection intensity model, total connection model and membership degree model, were modified on the basis of gravity model and potential model to calculate the connection intensity between any two urban nodes, the total external connection of individual urban node and membership degree of each connective direction.

$$R_{ij} = \frac{M_i \times M_j}{D_{ij}^b} \tag{5}$$

$$M = TNLI \tag{6}$$

$$R_i = \sum_{j=1}^{n} R_{ij} \tag{7}$$

$$F_{ij} = R_{ij} / \sum_{j=1}^{n} R_{ij} \tag{8}$$

where R_{ij} is the economic connection intensity between i and j; M_i, M_j is respectively the urban scale of i and j; D_{ij}^b is the shortest time in traffic between i and j, b is the friction coefficient that valued in 4① $TNLI$ is the gross value of urban light brightness; R_i is the total external connection of individual urban node; F_{ij} is the membership degree of urban connection.

(3) Social network analysis

We applied the indicators of centrality in social network analysis to analyze the node connectivity of urban connection network. According to total connection, we ranked the top cities to analyze the characteristic and changes of total external connection of urban nodes. In order to test the result, we compared it with actual traffic, logistics, and information flow between urban nodes. Furthermore, we distinguished urban groups on the basis of the relationship of dominance and membership between urban nodes. Then we used cohesive subgroup analysis to explore small groups composed of major urban nodes and uncover the structure and evolution of the urban groups of Hubei Province.

Node centrality is used to quantitate the status of individual node in the whole network. It can be calculated by the following formula:

$$C_d(i) = \frac{C(i)}{N-1} \times 100 \tag{9}$$

where $C(i)$ is the number of effective connection of node i, N is the total number of urban nodes.

3 Results

3.1 Pattern of urban nodes

(1) Scale of urban nodes

From 1992 to 2012, the rapid growth in number of city and urban scale in Hubei Province embodied by the area of lit urban areas and the gross value of urban light brightness. In contrast, the average light intensity during this period was declining, which indicated that the urbanization process of Hubei has carried out mainly on the basis of external expansion not internal increasing. In addition, cities with the area of lit urban areas in the range of 10–50 km^2 were increasing fastest in number. It indicated that a large number of small cities were developing into medium cities (Table 1 and Table 2).

(2) Centrality of urban nodes

The average connection intensity between any two cities of Hubei Province in 1992, 2002 and 2012 were respectively 163, 337 and 799. Taking the average connection intensity as threshold, we reserved the connections that beyond average intensity to calculate centrality index of each urban node (Fig. 4). The result shows

Table 1 Total amount of urban scale in Hubei Province in 1992, 2002 and 2012

Year	Number of city	Area of lit areas (km^2)	Gross value of urban light brightness (pixels)	Gross value of average urban brightness (pixels)	Average light intensity	Ratio of lit areas to area of Hubei Province (%)
1992	27	870.5	55 356	2050	45	0.472
2002	47	1842	112 119	2396	43	0.999
2012	75	4846	295 973	3839	43	2.627

Note: nodes of Yichang and Xiaoting were merged in 2012. The same is as below

① Friction coefficient usually values different in different situations. In this study, we found that it isappropriate to choose 4 as the value of friction coefficient for the result is closest to the general experience.

Table 2 Classification characteristic of urban scale of Hubei Province in 1992, 2002 and 2012

Area of lit areas (km^2)	1992	2002	2012
≤10	15	27	14
10–50	8	11	45
50–100	3	6	8
100–500	0	2	7
>500	1	1	1
Total	27	47	75

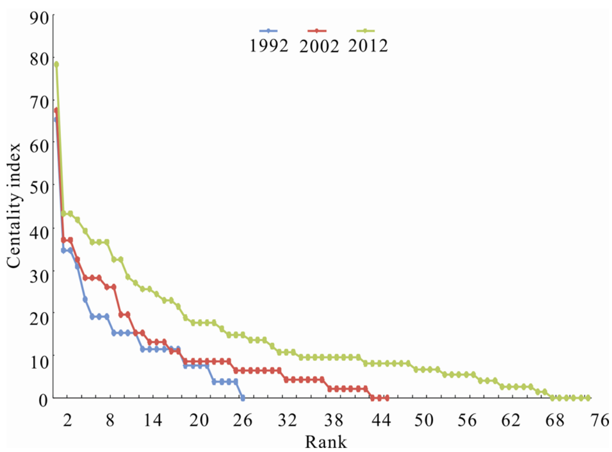

Fig. 4 Rank of centrality index of urban nodes of Hubei Province in 1992, 2002 and 2012

an obviously layered structure of centrality index of the three years, with few cities located at the core of urban connection network has relatively large centrality, while the majority located at the edge of urban connection network has relatively small centrality. In addition, the centrality index of overall nodes has been increasingly growing during 1992–2012, reflecting the strengthening polarization trend of urban connection network.

3.2 Pattern of urban connection

The distributions of total external connection of urban nodes of Hubei Province analyzed by spatial interpolation are showed in Fig. 5. The high value area around Wuhan has been increasingly expanded with a significantly faster speed in the westward expansion. At the same time, several high value areas around Yichang, Xiangyang, Jingzhou, Jingmen and Shiyan have formed gradually, and expanded to link with the high value area of which Wuhan was the center, thus creating two high value belts in the east-west and southeast-northwest directions. The low value areas have been increasingly reduced and gradually nested around the high value areas.

We use data about elements of elements of passenger traffic, logistics and information flow to analyze the external connection of urban nodes (Table 3). We inquired schedules of passenger shifts from passenger ticket network platform named Changtu and Qichezhan, and estimated the amount of traffic between urban nodes by daily passenger shifts (one-way). The calculation results of logistics and information flow intensity between urban nodes from Shen *et al.* (2011) were applied to the measurement of logistic and information element flow. Comparing Fig. 6(c) with Table 3, it can be found that the pattern of urban connection estimated by light index model contains the actual element flow, verifying that the single indicator of nighttime light is capable of reflecting abounding connection information.

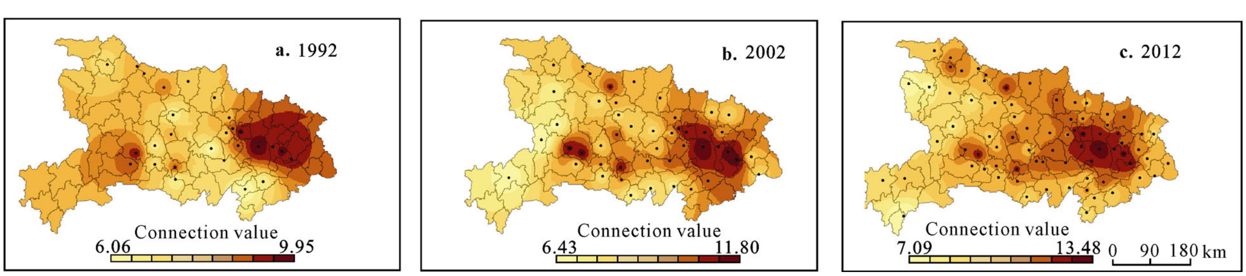

Fig. 5 Total external connection of cities of Hubei Province in 1992, 2002 and 2012

Table 3 Element flow between urban nodes of Hubei Province

City	Traffic (passenger shifts)	Logistics	Information Flow (web pages)
	Ezhou-Huanggan (150)	Yichang	Yichang (76100)
Wuhan	Hong'an (135)	Xiangyang	Huangshi (66100)
	Gedian (120)	Xiaogan	Xiangyang (65000)
	WudangMoutains (40)		Yichang (23900)
Xiangyang	Huji (28)	Wuhan	Shiyan (23200)
	Shayang (23)		Jingzhou (14700)
	Changyang (100)		Xiangyang (23900)
Yichang	Xiaoting (46)	Wuhan	Jingzhou (20800)
	Yidu (24)		Huangshi (15500)
	Wuhan (99)		Ezhou (25600)
Huangshi	Xishui (68)	Wuhan	Yichang (15500)
	Yangxin (48)		Xiangyang (14400)
			Yichang (20800)
Ezhou	Wuhan (150)		Xiangyang (14700)
	Gedian (144)	—	Jingmen (13500)
	Xishui (39)		
Huanggan			—
	Gongan (133)		
Jingzhou	Jingmen (64)	Wuhan	—
	Songzi (36)		
	WudangMoutains (124)		
Shiyan	Xiangyang (22)	Wuhan	—
	Yichang (5)		
	Shayang (78)		
Jingmen	Jingzhou (64)	Wuhan	—
	Zhongxiang (32)		

3.3 Pattern of urban group

3.3.1 Maximum connection

Firstly, the maximum connection direction of everyurban node of Hubei Province in 1992, 2002 and 2012 were selected to construct the TOP1 network of urban connection, which reflects the relationship of dominance and membership between urban nodes. Then we divided the urban groups with respective year (Fig. 6). In 1992, five relatively independent urban groups formed, of which Jingzhou, Wuhan, Yichang, Xiangyang, Shiyan were the central city. Among the five urban groups, two subgroups of which Xiaogan-centered and Huanggan-Ezhou-centered groups, have formed in the largest Wuhan-centered group. While in the Jingzhou-centered urban group, Jingmen possessed a certain independence. In 2002, the scale of Wuhan-centered urban group was constantly expanding, with its structure was increasingly complicating; three relatively independent but closely related to each other, of which Yichang, Jingzhou, Jingmen were the central cities, have formed. In addition, two urban groups, Shiyan-centered and Huangshi-centered, have formed. In 2012, several secondary centers have formed within the Wuhan-centered urban group; a smaller urban group of which Enshi was the central city has formed. In addition, two urban groups that small in scale and weak in strength have formed, of which Danjiangkou, Qianjiang were the central cities.

3.3.2 Condensed subgroup

The results of condensed subgroup analysis of the connection between urban groups of Hubei Province are shown in Fig. 7. During 1992–2012, the connection between the subgroups was getting increasingly closer. In terms of the internal and external connection intensity of the connection density of each subgroup, the strongest connection lays between Huangshi and Ezhou-Huanggan all the time, followed with Jingzhou and Yichang, Shiyan and Xiangyang. In contrast, Xiaogan, Suizhou and Xianning have formed a relatively loose subgroup,

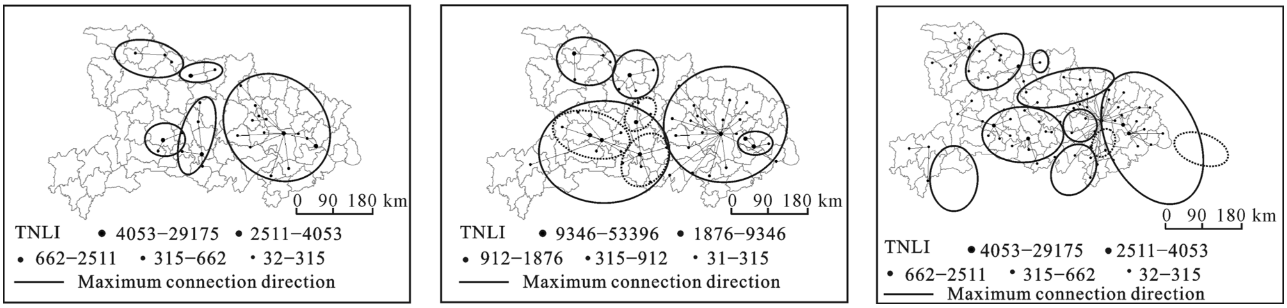

Fig. 6 TOP1 network of urban connection of Hubei Province in1992, 2002 and 2012. TNLI is the gross value of urban light brightness

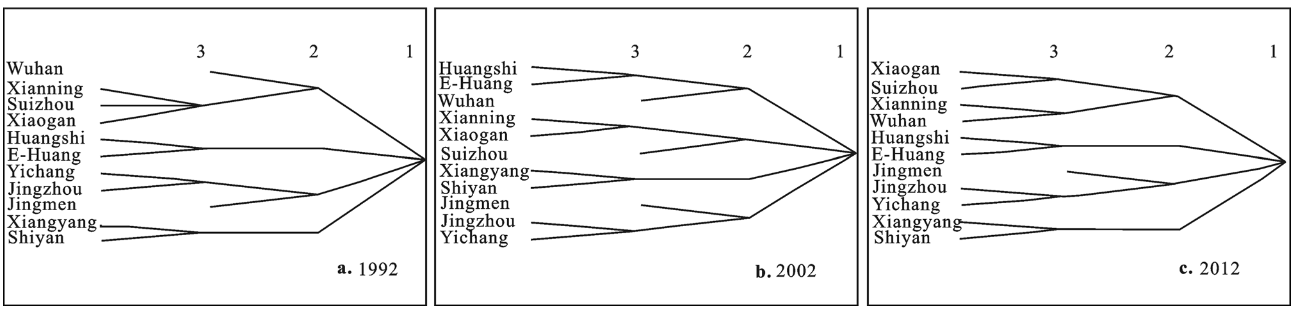

Fig. 7 Condensed subgroup analysis of urban connection network of Hubei Province in 1992, 2002 and 2012. E-Huang represents Ezhou-Huanggan

however, owing to their strong connections with Wuhan, the connections between themselves have been improved. For the same reason, a subgroup, made up of these three cities and Wuhan, has formed and better agglomerated with Huangshi and Ezhou-Huanggan. The connections between Jingmen, Yichang and Jingzhou were stable and gradually enhanced, and then formed a fairly stable 'growth triangle'. The strong connections between the Wuhan-located subgroups and other subgroups have a great effect of agglomerationon the whole system. On the whole, twelve prefecture-level cities can be divided into three independent groups, namely Xiangyang-Shiyan, Yichang-Jingzhou-Jingmen and Wuhan-Xianning-Xiaogan-Huangshi-Ezhou-Huanggan-Suizhou. The former two groups have close urban connection, while the connection of the last one is so loose that can be further divided into several subgroups.

3.3.3 Group structure

During 1992–2012, three urban groups of which Wuhan, Yichang, Xiangyang are central cities have formed with the gradually mature scale and structure (Fig. 8).

In 1992, eastern Hubei urban group, of which Wuhan was the central city, covered a wide range, and the primacy index of the gross value of urban light brightness of Wuhan reached 10.07, resulting in the extremely prominent phenomenon of 'centre-city polarization', Huangshi-Ezhou-Huanggan-centered and Xiaogan-centered subgroups have formed in the urban group. In southwestern Hubei urban group, the central position of Jingzhou, the biggest city, was not prominent for its primacy index only reached 1.37, while Yichang and Jingmen were close to the central city both in terms of urban scale and their central position. In northwestern Hubei urban group, Xiangyang and Shiyan were respectively the central city and sub-central city with the primacy index reached 1.37. At provincial level, the first-order urban nodes lay in Wuhan, Jingzhou and Xiangyang, the second-order lay in Huangshi, Ezhou-Huanggan, Xiaogan, Yichang, Jingmen and Shiyan, and the others were the lowest-order urban nodes.

In 2002, the structures of the three urban groups have obviously changed. The primary index of Wuhan, central city of eastern Hubei urban group, increased to 10.48, which indicated the polarization effect of Wuhan was strengthening. The structures of the urban subgroups of which Huangshi, Ezhou-Huanggan and Xiaogan were respectively the central cities were relatively stable. For the southwestern Hubei urban group, the urban spatial structure was featured by the coexistence of one central city and two sub-central cities; what different from before were that Yichang replaced Jingzhou to be the central city with the primary index reached 1.46, and Jingzhou, Jingmen became the sub-central cities. For the northwestern Hubei urban group, the spatial structure was relatively stable and the primary index of Xiangyang reached 2.28. At provincial level, the first-order urban nodes changed into Wuhan, Yichang and Xiangyang, and the second-order urban nodes changed into Huangshi, Ezhou-Huanggan, Xiaogan, Jingzhou, Jingmen, and Shiyan, the other were the lowest-order urban nodes.

In 2012, the primary index of Wuhan, the central city of the eastern Hubei urban groups, dropped to 8.69 because of the rapid development of other cities, lessening the phenomenon of 'center-city polarization'. At the same time, in addition to the original urban subgroups of which Huangshi, Ezhou-Huanggan and Xiaogan were central cities, two urban subgroups of which Xianning and Suizhou were central cities have newly formed. In the southwestern Hubei urban group, the primary index of Yichang reached 1.79, meanwhile Jingzhou and Jingmen have well-established their sub-central position. Simultaneously, an urban subgroup composed of Qianjiang and Tianmen has newly formed with a relatively small scale. In the northwestern Hubei urban group, the primary index of Yichang dropped to 1.84, and an urban subgroup composed of Danjiangkou, Laohekou and Gucheng has newly formed between the location of Xiangyang and Shiyan, with very small group scale and center size. In addition to the three urban groups, a relatively independent urban group of which Enshi was the central city has newly formed, with not mature enough scale and structure.

4 Conclusions

Combining nighttime light imagery and the viewpoint of 'point-axis-area' and 'point-axis gradual spread' in 'point-axis system' theory, this study synthetically analyzed the urban spatial pattern of Hubei Province and its evolution characteristics from three different perspectives, namely urban nodes, urban connections and urban clusters. The main conclusions are as following:

(1) We analyzed the urban spatial pattern through urban scale figured out by the gross value of urban light brightness, and then modeled the evolution of the urban spatial pattern of Hubei Province. It is found in data pre-processing period that the number of urban spot will be huge when the threshold is too low, and the area of urban spot will be too large to be contained in the administrative boundary, which is especially obvious in Wuhan. In order to avoid that impractical result, we selected a city whose changes in area and boundary are both smaller than the other cities as the reference region to diminish the disturbance for the analysis of urban spatial pattern and evolution.

(2) The rank of large-scale urban nodes was stable. Among all the urban nodes, Wuhan, Xiangyang, Yichang, Huangshi, Ezhou-Huanggan, Jingzhou and Shiyan were always the top seven largest cities. As the largest city of Hubei Province, Wuhan has the largest scale of lit urban area five times as large as the second one, which confirmed its dominant position in Hubei Province. Xiangyang and Yichang have escalated their rank to second and third, which gradually showed their role of provincial sub-central city. The rank of Jingzhou and Shiyan has declined, while the rank of Huangshi and Ezhou-Huanggan has fluctuated.

(3) There are a variety of socioeconomic connections between urban nodes. Urban scale and accessibility between urban nodes can both influence urban connection. Generally, the bigger the urban scales are and the smaller the distance between nodes are, the greater the scales and accessibility of urban nodes affect urban connection. With the increase in the number of urban nodes, the scale of urban nodes and the transportation

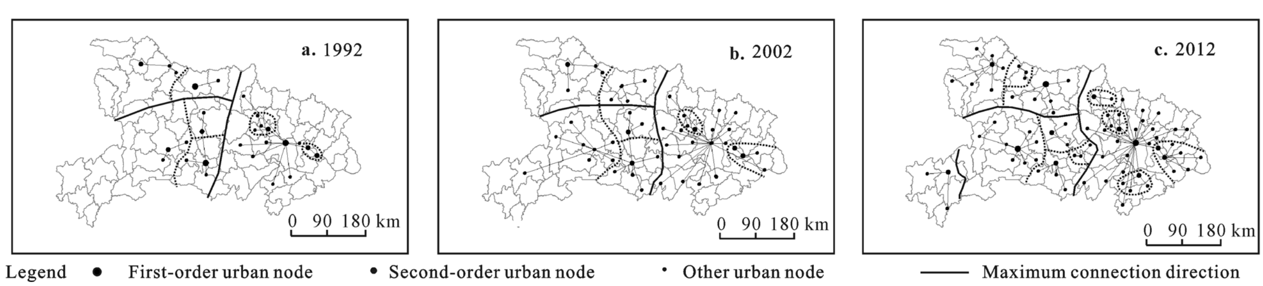

Fig. 8 Inner structure of major urban groups of Hubei Province in 1992, 2002 and 2012

accessibility, the total external connection of cities of Hubei Province have been in a trend of rapid growth. The membership degree of urban connection is influenced by urban scale, urban centrality of location, and density of surrounding cities, and accessibility to higher-grade city, and so on. There are two obvious indicators of an urban node that has a high membership degree to some city, one is that it is close to that city with a small scale, and the other is that it has a big scale but far away from that city. The membership degrees of urban connection are developing from relatively concentration toward equilibrium.

(4) The number of urban group of Hubei Province has been growing during 1992–2012 and thus made their patterns gradually fractionized. The cohesive subgroups composed of twelve prefecture-level cities had a stable pattern with the increasingly high connection density and close connection between subgroups. Three urban agglomerations, of which Wuhan, Yichang, Xiangyang are central cities, have newly formed during 1992–2012 with gradually mature scale and structure. However, differ from the structures of ′Wuhan metropolitan area′, ′Yichang-Jingzhou-Jingmen City Group′ and ′Xiangyang-Shiyan-Suizhou City Group′, the connection between Suizhou and Wuhan metropolitan area is obviously stronger than the connection between Suizhou and Xiangyang, Shiyan. Moreover, for its remote location, Enshi can be given development priority as a small city group in the future.

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