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Field Modeling Method for Identifying Urban Sphere of Influence: A Case Study on Central China

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Abstract: With rapid development of urbanization and regional interaction and interdependence, regional urban agglomeration planning becomes more and more important in China, in order to promote integrated development of various cities with close interrelationship. However, it is still arguable academically on how to define the boundary or which cities to be included for the urban agglomeration of a region. This paper aims to shed lights on how to identify urban spheres of influence scientifically by introducing field modeling method and by practicing a case study on 168 cities in Central China. In our field modeling method, the influence intensities of cities were measured by a comprehensive index and urban spheres of influence were represented spatially by field intensity. Then, their classification and spatial distribution characteristics of study area in 2007 were identified and explored by using GIS and statistical methods. The result showed that: 1) Wuhan is the absolute dominant city in Central China; 2) the provincial capital cities dominate their own provinces and there are no other lower grade agglomeration centers; and 3) the basic types of organization form of urban sphere of influence are single-polar type, agglomeration type, close-related group type and loose-related group type.

Keywords: Central China; urban sphere of influence; urban influence index; field intensity; urban influence intensity

1 Introduction

At present, with the continuous advancement of urbanization and regional integration, metropolitan areas and urban agglomerations have emerged at different regions. Thus, various types of urban and regional planning become more and more important and are formulated in China. Among of those, it is critical to identify the urban spheres of influence scientifically and to promote the integrated development of cities and their hinterlands. In particular, the identification of urban sphere of influence is of great significance to the improvement of central city′s synthesized competitiveness, the building of a reasonable urban system and the establishment of supporting policies. The urban sphere of influence refers to surrounding areas whose social and economic development depends on the attraction and radiation force of the city (Wang and Zhao, 2000; Kong, 2007; Pan *et al*., 2008). The concept of urban sphere of influence came from the central place theory initiated by Christaller in 1933 (Christaller, 1998). City is an important node in regional development, in which both node-to-node link and node-to-hinterland link occur (Mulligan, 1984). Urban sphere of influence is the latter situation (in this case, we call it node center).

According to indicators, the type of urban sphere of influence and its different measurements, research methods can be divided into two types: empirical method and modeling method. Empirical method determines urban sphere of influence according to data features, regional characteristics and the comprehensive analysis of expertise on the basis of the selecting and accessing of urban

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and regional flow index (commuting data). This includes air passenger traffic (Taaffe, 1962), newspaper sales (Berry and Lamb, 1974), telephone calls (Nystuen and Dacey, 1961), and several composite indicators (Green, 1955). However, with the improvement of the convenience of urban transportation and regional reachability, relationships among cities, and of city and region are becoming extraordinary complex. Kinds of data are not easy to get and are lack of comprehensiveness, which makes the modeling method become the most important research tools (Du, 2001; Gu and Pang, 2008). Modeling method describes the interaction between spaces using theoretical model, grasps the intensity and pattern of contact between cities, and determines the urban sphere of influence. For an example, gravity model has been maturely applied for identifying the definition of urban sphere of influence in the United States, Ireland and Ghana (Huff, 1973; Huff and Lutz, 1979; 1989; 1995). In recent years, Voronoi diagram is widely used in the research of urban sphere of influence, which is considered to be a good tool to describe the interaction pattern between cities (Gold, 1992; Edwards, 1993; Okabe *et al.*, 2000). However, it also has drawbacks such as lack of a comprehensive metric only using population as a measure of urban influence index; the definition of urban sphere based on city classification, while its process more subjective; complicated calculation process and the result expression being not intuitive.

Based on those mentioned above, this paper intends to introduce the field modeling method to identify the urban sphere of influence and is expected to overcome the abovementioned shortcomings. In that method, field is used to represent and measure the change of urban radiation force from the city centre to the edge, and then urban sphere of influence can be identified through measuring urban influence index and the field intensity. The result shows spatial characteristics of continuity on the local and partly-covered on the whole, and can represent the spatial characteristics of interaction between cities and the hinterland more reasonably. Further, the characteristics of their classification and spatial distribution of the urban sphere of influence are identified and explored by using GIS and statistical methods, in order to provide references for regional urban spatial organization planning and urban economic divisions. Here Central China was chosen as a case study to get a clearer understanding on the development trend of cities and urban agglomerations, grasp the interaction between cities, and provide suggestions for regional urban system planning, regional economic division and cooperation, as well as reasonable institutional arrangements.

2 Method

2.1 Field model

As a regional core, a big city has a strong attraction (agglomeration) and the radiation force (diffusion) for adjacent regions. Interactions between them occur with various kinds of "fluid" as carrier, and the furthest influenced edge forms the urban sphere of influence. In physics, urban regional system is referred to as city field (Okabe *et al.*, 2000; Wang and Chen, 2004). The formation of field can not be separated from the potential energy difference between the center and its edge, only when the influence of the center is strong enough, can the fluid flow in the field. On the other hand, city field decays gradually with the increase of distance from the center, until the field action disappears (Gu, 1997). Based on the above analysis, the expression of city field was as follows:

$$F_{ki} = f(Z_k, D_{ki}) \quad (1)$$
$$f'(Z_k) > 0$$
$$f'(D_{ki}) < 0$$

where F_{ki} is the field intensity of city k on point i, Z_k is the urban influence index of city k, D_{ki} is the Euclidean distance from city k to point i, f is the mapping function, f' is the partial derivative.

2.2 Setting and main steps of field model on urban sphere of influence

There are several distance attenuation models for field model, such as curve attenuation model, linear attenuation model, exponential attenuation model and so on. The distance attenuation intensity can be adjusted through the set of friction coefficient. In this paper, we used the curve attenuation model, the friction coefficient was 2 (Wang and Zhao, 2000; Pan *et al.*, 2008), and its formula was as follows:

$$F_{ki} = Z_k / D_{ki}^a \quad (2)$$

where F_{ki} is the field intensity of city k on point i, Z_k is the urban influence index of city k, D_{ki} is the Euclidean distance from city k to point i, a is the friction coefficient.

The main steps of field model on urban sphere of influence are the following: 1) measure the urban influence index; 2) get urban influence sphere based on Equation (2); 3) classify the urban sphere of influence, and explore the composition of each level; 4) study the spatial distribution of urban sphere of influence, and get the concrete condition about different provinces; and 5) classify the spatial distribution of urban sphere of influence.

2.3 Urban influence index

Urban influence index should reflect the inter-relationship between the center and its hinterland all-sidedly, in view of the comprehensive characteristics of urban influence index and the availability of data collection, our attention is paid to comprehensive economy, market, employment, investment, population, basic education, health care and the municipal infrastructure construction. We initially defined 33 indexes. In order to avoid the impact of data units, we standardized all the data. Sifted indexes of each year were correlatively analyzed to ensure the briefness of the index system and the system work best. In this paper, we calculated urban influence index using principal component analysis, that is, extracted and rotated factors whose eigenvalues were greater than 1 to minimize the number of variables with a high load. Therefore, calculation formula of urban influence index is:

$$Z_k = \sum_{n=1}^{m} [A_n \times \sum_{j=1}^{33} C_{nj} \times M_{kj}] \tag{3}$$

where Z_k is the urban influence index of city k, A_n is the contribution rate of the nth principal component, m is the number of principal component, C_{nj} is the load of the nth principal component on the jth variable, M_{kj} is the standardized city index.

2.4 Setting of urban sphere of influence

The spatial distribution patterns of field intensity can be represented according to Equation (2), and its value declines from center to edge until reaching zero. In order to measure and display uniformly, we proposed that the line connecting spatial points, whose field intensity values equal to 0.01, constitutes the urban sphere of influence of the center. In the case of a single city, the border of the periphery constitutes the urban sphere of influence (Fig. 1a).

Any point in the region can accept the radiation from all the cities. Field intensity may overlap in space, because of the spatial location of the city and urban influence index. On the one hand, we can judge the membership situation of each point based on the principle of maximum membership; On the other hand, the boundary of two different urban spheres of influence (the line connecting two points whose field intensities are the same) can be combined with the peripheral border of a single urban sphere of influence to constitute a specific urban sphere of influence (Fig. 1b). Due to different overlap situations, the interaction between cities and its development trend is different too.

2.5 Spatial distribution of urban sphere of influence

We used the semivariograms and crosscovariance cloud to further analyze the spatial distribution of urban sphere of influence, and its formula was as follows:

$$\gamma(h) = \frac{1}{2}\mathrm{E}[Z(x) - Z(x+h)]^2 \tag{4}$$

where $\gamma(h)$ is the value of semi-variant function; $Z(x)$ and $Z(x+h)$ are arbitrary urban sphere of influence. The smaller value of semi-variant function shows the smaller difference between $Z(x)$ and $Z(x+h)$, vice versa. In the cloud chart of covariance function, each point represents the value of semi-variant function of a pair of cities. If a spatial object is spatial self-correlation, the value of semi-variant function will increase with the increase of

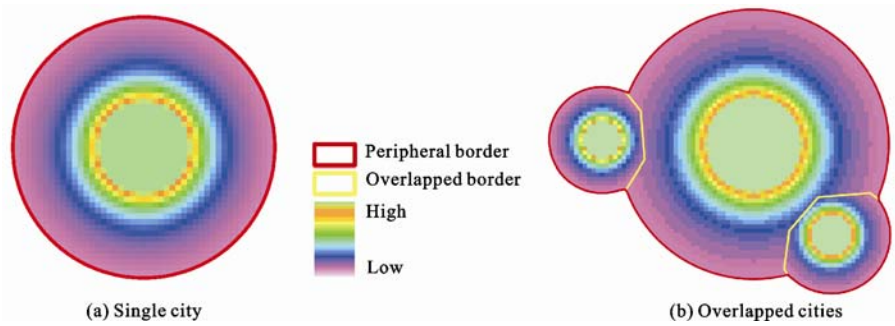
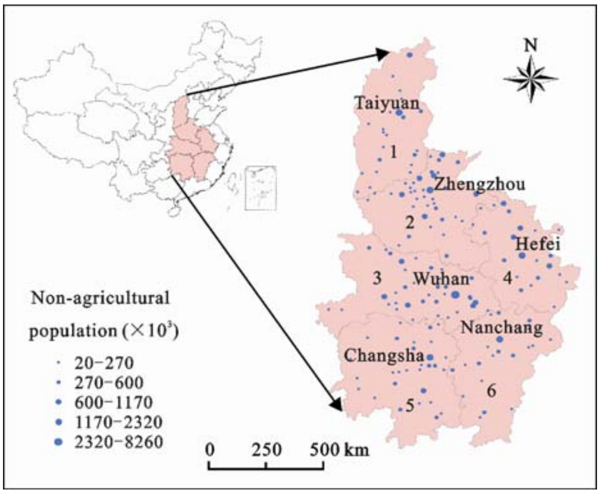


Fig. 1 Spatial patterns of urban sphere of influence

distance between sample points, until paralleling with the horizontal axis.

2.6 Classification of spatial distribution of urban sphere of influence

The spatial distribution feature of urban sphere of influence is unique. We could determine the basic type of organization form of urban sphere of influence. Here, we measured the interaction strength of urban sphere of influence by introducing ″residual″ indicators. The concrete steps were as follows: 1) process the urban sphere of influence and urban influence index by regression analysis; 2) The residual value could be obtained by the formula: residuals (C) = actual value (W) – fitting value (w). The size of the residual value is similar to the overlap ratio of cloud, and is superior to the simple calculation of the overlapping area. Residuals measure the interaction between cities taking the overall situation into account, therefore it is more uniform and lateral comparable.



1. Shanxi Province; 2. Henan Province; 3. Hubei Province; 4. Anhui Province; 5. Hunan Province; 6. Jiangxi Province

Fig. 2 Location of study area

3 Study Area and Data

The six provinces of Central China including Shanxi, Henan, Hubei, Hunan, Anhui and Jiangxi have been extremely important parts in China′s regional development (Fig. 2). With the implementation of leading development of the eastern regions, the development of the western regions and revitalizing the northeast old industrial bases, the central region stayed in the ″policy edge″ position for a long time, and fell into the embarrassing situation of ″central collapse″. In order to promote the development of the central region, the state raised clearly the strategy of ″Rise of Central China″ in 2004 (Wen, 2004; Su and Wei, 2006).

There were 168 cities in Central China at the end of 2007, of which the urban population and GDP accounted for 41% and 60% of the whole region respectively. This signified that the aggregation function of cities in Central China was strong, and those cities leaded the socio-economic development of the Central China. Overall, there are lots of small cities compared to metropolis. The spatial data in this paper are based on the electronic version of the county-level boundary map of China at the scale of 1∶100 000 000 provided by National Geomatics Center of China (Albers secant conic projection), and then used grid module to generate grids of 1000 m × 1000 m in ArcGIS (1 000 m equal to about 32″), after transformation, the size of the map of Central China was 1823 × 1052. According to different indicators, attribute data came from *China City Statistical Yearbook 2008* (National Bureau of Statistics of China, 2008), *China Population and Employment Statistical Yearbook 2008* (National Bureau of Statistics of China, 2008), *China County Statistical Yearbook 2008* (National Bureau of Statistics of China, 2008), *China Urban Construction Statistical Yearbook 2007* (Ministry of Housing and Urban-rural Development, 2008), or data calculated from the yearbooks above indirectly.

Data were rejected in two situations: 1) from the perspective of a single measure, some indicators were highly correlated with each other. In this case, we rejected those indicators to ensure the briefness of these data; 2) indicators, which had low correlations with others, may be due to the specific research background of this paper. They departed from regular practice, and could not reflect the index of urban influence. After analysis, those indicators were also rejected.

4 Results

4.1 Urban influence index

The Kaiser-Meyer-Olkin value of data of 2007 was 0.872. Therefore, the sample size of original data was quite sufficient. Bartlett Sphericity test showed that in approximate chi-square value of 2007 was 8 438.662, degree of freedom (F) was 300, and the significance of the test (P)

was much less than 0.01. Here, we explored the existing hypothesis that the correlation matrix was a unit matrix. Therefore, factor analysis had a good applicability. On the other hand, the regenerations of 2007 were more than 50%, and most of them were more than 80%. Therefore, information extraction of this analysis was effective.

Eventually, we selected five kind of factors. Overall, the results of factor analysis reflect the practical situation reasonably. First of all, the first kind of factor which makes the greatest contribution to population variance reflects the whole economic strength of the city clearly. The second one reflects the aggregation degree of urban economy, embedding the economic development manifested on unit land area. The third one means the public services. The fourth one mainly focuses on per capita indicators, that is, urban per capita economic situation. The fifth one clearly reflects the municipal infrastructure situation.

4.2 Classification of urban sphere of influence

The classification of urban sphere of influence is shown in Table 1. In the grade classification of urban sphere of influence in central China, Wuhan—the provincial capital of Hubei Province is the only one first-level city. The area of its urban sphere of influence reached 5 914 km^2. This indicates the absolute leading position of Wuhan in central China. There are five second-level cities, which are the capitals of the remaining five provinces. Their urban spheres of influence were very large and only second to Wuhan City. There are 11 third-level cities, and most of them are the regional center of each province. On the whole, although the urban sphere of influence of third-level cities was significantly smaller than first-and second-level cities′, they still showed a considerable area (Fig. 3). The urban sphere of influence of fourth-level cities was slightly smaller than that of the third-level cities and they were generally better developed cities within the provinces they belong to. The total number of fourth-level cities in Central China was 47, accounting for 28% of the total. A small number of large cities were classified into this class as a result of their urban spheres of influence being squeezed and so on. But overall, the fourth-level cities all had good economic strength. The fifth-level cities in Central China were general and the number of such cities (a total of 71) was the largest which accounted for 42.3% of the total cities in Contral China. The development of sixth-level cities in Central China was on a weak level and their urban spheres of influence were the smallest. Such cities had a total of 33 in the number, accounting for 19.6% of the total.

Table1 Classification of urban sphere of influence

Grade	Number	Criteria (km^2)	City
First-level	1	$S > 3000$	Wuhan
Second-level	5	$1700 < S < 3000$	Changsha, Taiyuan, Hefei, Zhengzhou, Nanchang
Third-level	11	$1000 < S < 1700$	Luoyang, Datong, Wuhu, Xiangfan, Yichang, Yueyang, Huainan, Hengyang, Pingdingshan, Zhuzhou, Nanyang
Fourth-level	47	$660 < S < 1000$	Changde, Xinyu, Huaibei, Shiyan, Maanshan, Bengbu, Jiujiang, Anyang, Puyang, Tongling, Yangquan, Huangshi, Jiaozuo, Luohe, Xinxiang, Xiangtan, Kaifeng, Anqing, Xinmi, Yuzhou, Changzhi, Jingzhou, Jincheng, Pingxiang, Xuchang, Shuozhou, Chenzhou, Suzhou, Liuyang, Shangqiu, Jingdezhen, Jiyuan, Qianjiang, Fuyang, Xinyang, Jingmen, Linzhou, Linfen, Loudi, Xinzheng, Gongyi, Yongcheng, Ganzhou, Dengfeng, Yiyang, Yongzhou, Xiantao
Fifth-level	71	$480 < S < 660$	Huaihua, Lu′an, Sanmenxia, Huangshan, Leiyang, Yima, Suizhou, Hebi, Fengcheng, Zhoukou, Hejin, Hanchuan, Lingbao, Shaoyang, Fuzhou, Zhumadian, Chuzhou, Changning, Liling, Xiangxiang, Qinyang, Ezhou, Tianmen, Lengshuijiang, Chaohu, Xingyang, Xiaogan, Tongcheng, Bozhou, Ruzhou, Yichun, Guixi, Xiaoyi, Xinzhou, Zhongxiang, Dengzhou, Chibi, Zhangjiajie, Xiangcheng, Chizhou, Ningguo, Jishou, Enshi, Jian, Tianchang, Xuancheng, Wuxue, Yidu, Huozhou, Leping, Macheng, Yanshi, Zhangshu, Xianning, Shangrao, Houma, Yuncheng, Gaoping, Miluo, Wugang, Yuanjiang, Yingcheng, Lianyuan, Changge, Zixing, Daye, Zaoyang, Guangshui, Honghu, Yuanping, Danjiangkou
Sixth-level	33	$S < 480$	Nankang, Jiexiu, Shishou, Dexing, Gao′an, Hongjiang, Dangyang, Jinzhong, Laohekou, Mengzhou, Songzi, Gujiao, Huixian, Zhijiang, Yingtan, Linxiang, Wugang, Jieshou, Yongji, Mingguang, Luliang, Anlu, Ruijin, Weihui, Ruichang, Fenyang, Yicheng, Jinshi, Lucheng, Lichuan, Shaoshan, Jinggangshan, Huanggang

Note: S is the urban sphere of influence

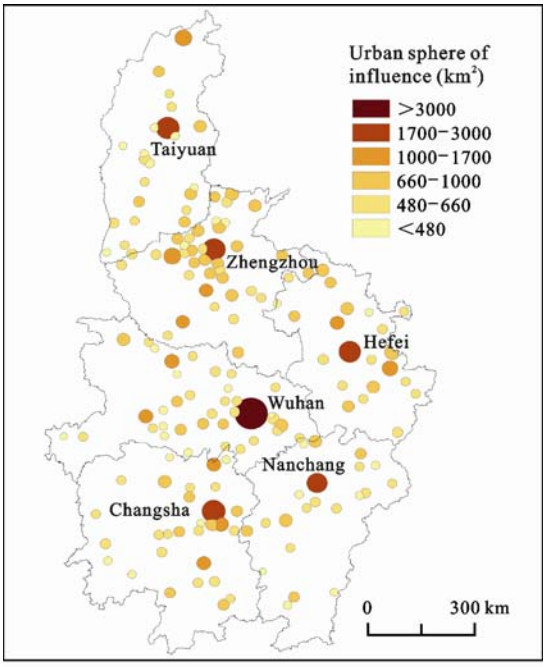


Fig. 3 Urban sphere of influence in Central China

As seen in Table 2, the number of the fourth-, fifth- and sixth-level cities accounted for 89.88% of all the cities in Central China. About 50.00% of all the cities in Hubei Province were fifth-level cities, 16.67% were fourth-level cities, and 25.00% were sixth-level cities. It can be seen, although the urban sphere of influence of Wuhan was the largest in Central China, urban spheres of influence of other cities of Hubei Province were small. This is mainly due to the weak overall economic strength of Hubei, which is a typical example of ″weak province with strong city″. But for Hunan Province, the number of fourth-level cities accounted for 24.14% of all the cities, sixth-level cities accounted for 17.24%, and fifth-level cities accounted for 44.83%. It showed that urban spheres of influence of cities in Hunan were in the middle of Central China, which also reflected the moderate economic strength level of this province. The number of fourth-level cities was 17 in Henan Province, accounting for 44.74% of all the cities in that province. Accordingly, its fifth-level cities accounted for 36.84%, sixth-level cities only accounted for 7.89%. It could be seen that the urban spheres of influence in Henan Province had an obvious advantage in Central China. This also reflected the economic development level of that province was relatively high. The numbers of cities in Shanxi, Anhui and Jiangxi were not large. The numbers of fourth-, fifth- and sixth-level cities in Shanxi and Jiangxi were almost the same; fourth-level cities accounted for 22.73% and 23.81% respectively; fifth-level cities accounted for 36.36% and 38.10% respectively; sixth-level cities accounted for 31.82% and 33.33%. From the urban sphere of influence, the numbers of low- and middle-level cities in the two provinces were large, and the overall economic development levels were weak. The fourth-level cities accounted for 31.82% in Anhui Province; fifth-level cities accounted for 45.45%; sixth-level cities accounted for 9.09%, which reflected the equilibrate economic strength of this province.

4.3 Spatial distribution of urban sphere of influence

The Fig. 4a is a chart of semivariograms and crosscovariance cloud, Fig. 4b, c, d represent the lines connecting corresponding point between cities. It can be seen from the Fig. 4a that the cloud chart is not spatial self-correlated but the points are divided into four layers which reflects the hierarchical relationships of urban sphere of influence in central regions. The highest layer represents that almost all the lines connect Wuhan and the other cities of Central China, and the large value of semi-variogram reflects the dominant position of Wuhan City in Central China. Wuhan is also the regional heterogeneous point. The second layer which represents the lines con-

Table 2 Urban sphere of influence divided by province

Grade	Hubei		Hunan		Shanxi		Henan		Anhui		Jiangxi	
	Number	Proportion (%)	Number	Proportion (%)	Number	Proportion (%)	Number	Proportion (%)	Number	Proportion (%)	Number	Proportion (%)
First-level	1	2.77	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Second-level	0	0.00	1	3.45	1	4.55	1	2.64	1	4.55	1	4.76
Third-level	2	5.56	3	10.34	1	4.54	3	7.89	2	9.09	0	0.00
Fourth-level	6	16.67	7	24.14	5	22.73	17	44.74	7	31.82	5	23.81
Fifth-level	18	50.00	13	44.83	8	36.36	14	36.84	10	45.45	8	38.10
Sixth-level	9	25.00	5	17.24	7	31.82	3	7.89	2	9.09	7	33.33
Total	36	100.00	29	100.00	22	100.00	38	100.00	22	100.00	21	100.00

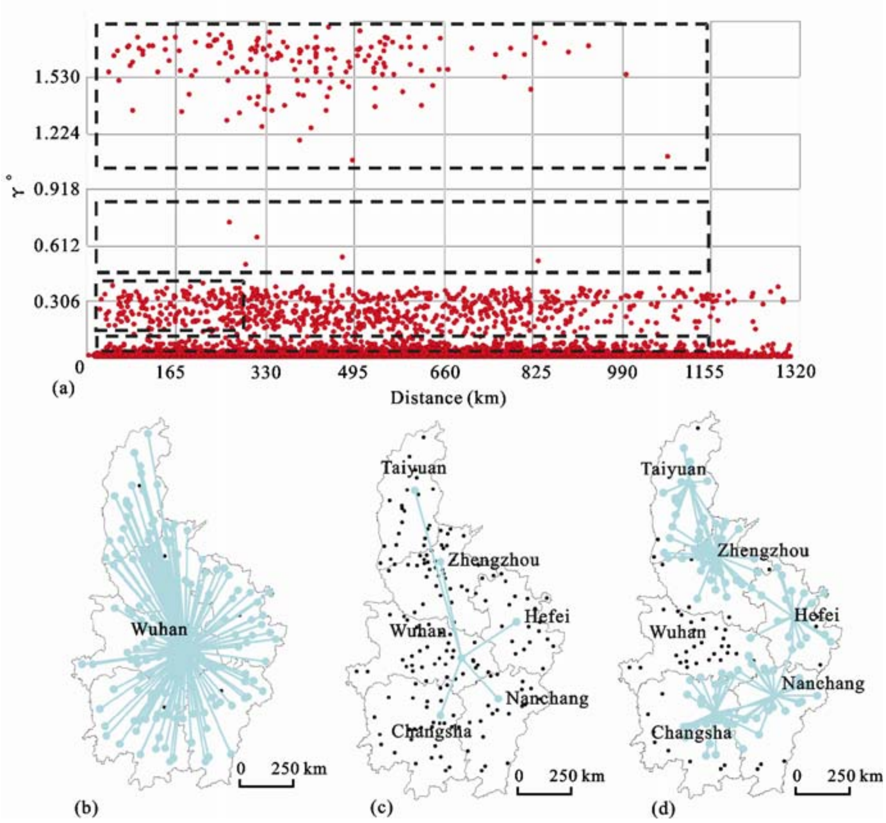


Fig. 4 Semivariograms and crosscovariance cloud and pair of cities

necting Wuhan and other provincial capital cities is a transitional layer; the first half of the third layer is the lines connecting the provincial capital city and its surrounding cities. With the increase of distance between cities, their connecting lines become scattered, instead of aggregated towards provincial capital cities. This fully explains the dominant position of the provincial capital city which is also the local maximum in provinces of Central China; the fourth layer is disturbed connected point pairs, and there is no lower grade agglomeration centre city.

4.4 Classification of spatial distribution of urban sphere of influence

The result of regression analysis on urban sphere of influence was satisfied (R^2 = 0.990, P < 0.01), and the equation was:

$$\mathrm{Log}(S) = 0.96 \times \mathrm{Log}(Z) + 19.55 \quad (5)$$

where S is the total area of urban sphere of influence; Z is the urban influence index; and the Log transformation can reduce the difference of data scope between indicators. About 80% of the cities were above the regression line, symmetrically distributed, while the points below the line were scattered distributed (Fig. 5).

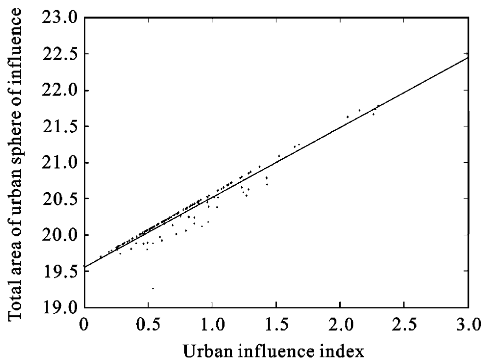


Fig. 5 Linear regression between total area of urban sphere of influence and urban influence index

The former resulted from the monopolar development of most cities in the central region and there was no direct overlap between cities; the latter was because that the level of urban spheres of influence and the interaction strength differed between them. As mentioned previously, the overlapping situation of field intensity which contains the relationship type between cities varies due to urban spatial location and urban influence index. Therefore, the recognition of overlapping situation of field intensity is the premise to further identify the relationship type between cities. We used spatial morphological characteristics, urban sphere of influence level and the residual to define the basic type of organization form of urban sphere of influence: single-polar type, agglomeration type, closed-related group type and loose-related group type (Table 3).

1) Single-polar type. About 73% of the cities belonged to this distribution type whose urban sphere of influence was broadly similar to a circle (Fig. 6a). For example, Hefei and Nanchang are found to belong to this single-polar type rather than the agglomeration type, which have been proposed as the Wanjiang urban agglomeration and the Poyang Lake urban agglomeration respectively by some pervious literatures (Fang, 2008; Wang *et al.*, 2008). Main reasons of this phenomenon include historical evolution, sparsely distribution of cities in these provinces, and no county-level or above cities near the provincial capital. Such as, there is no countylevel city within 60 km around Hefei, which sub-stantially hinders the group between Hefei and its surrounding cities. In addition, low economic development level of the two provinces is also an important reason. Since the whole province′s economic strength is weak, economic development capacity of its capital and other cities is limited. Nanchang is also in a similar situation.

2) Agglomeration type. This distribution type which had high-grade (first- and second-level) cities intermingled with low-grade cities mainly concentrated around large cities (Fig. 6b). Combination of Taiyuan, Jinzhong and Gujiao in Shanxi Province formed a big group, because the three cities were close to each other. There was no city above the county-level within 50 km around Wuhan, but due to its large influence, it could integrate with cities far away from it. Henan Province is one of the birthplaces of Central Plain culture. Because of its geographical, historical and many other reasons, there are large numbers of intensive-distributed cities in this province. Thus, eight cities aggregated in the group with Zhengzhou at its core, and the area of this group was big. There is potential and tendency of integrated development in Changsha-Xiangtan-Zhuzhou region because of their approximate sizes, the short distance between them and continuous policy guidance. As regional core cities, the city levels of Wuhan, Taiyuan and Zhengzhou are much higher than other cities. It illustrated their strong

Table 3 Classification of spatial distribution of urban sphere of influence

Type	Number	Criteria	City
Single-polar type	122	Independent distribution	Hefei, Nanchang, Luoyang, Datong, Wuhu, Xiangfan, Yichang, Yueyang, Huainan, Hengyang, Pingdingshan, Nanyang, Changde, Xinyu, Huaibei, Shiyan, Maanshan, Bengbu, Jiujiang, Puyang, Tongling, Yangquan, Jiaozuo, Luohe, Kaifeng, Anqing, Jingzhou, Pingxiang, Shuozhou, Suzhou, Liuyang, Shangqiu, Jingdezhen, Jiyuan, Qianjiang, Fuyang, Xinyang, Jingmen, Linzhou, Linfen, Loudi, Yongcheng, Ganzhou, Dengfeng, Yongzhou, Xiantao, Huaihua, Lu′an, Sanmenxia, Huangshan, Leiyang, Yima, Suizhou, Fengcheng, Zhoukou, Hejin, Lingbao, Shaoyang, Fuzhou, Zhumadian, Chuzhou, Changning, Liling, Xiangxiang, Qinyang, Tianmen, Chaohu, Tongcheng, Bozhou, Ruzhou, Yichun, Xinzhou, Zhongxiang, Dengzhou, Chibi, Zhangjiajie, Xiangcheng, Chizhou, Ningguo, Jishou, Enshi, Ji′an, Tianchang, Xuancheng, Yidu, Huozhou, Leping, Macheng, Zhangshu, Xianning, Shangrao, Houma, Yuncheng, Gaoping, Miluo, Wugang, Yingcheng, Zaoyang, Guangshui, Honghu, Yuanping, Nankang, Shishou, Dexing, Gao′an, Hongjiang, Dangyang, Songzi, Zhijiang, Linxiang, Wugang, Jieshou, Yongji, Mingguang, Luliang, Anlu, Ruijin, Yicheng, Jinshi, Lichuan, Shaoshan, Jinggangshan
Agglomeration type	4	With high-grade city (first- and second-level), and surrounding low grade city	Wuhan-Ezhou-Huangshi-Huanggang-Daye-Xiaogan-Hanchuan, Zhengzhou-Xingyang-Xinmi-Xinzheng-Changge-Yuzhou-Xuchang, Changsha-Xiangtan-Zhuzhou, Taiyuan-Gujiao-Jinzhong
Close-related group type	5	Residuals < 0	Fenyang-Xiaoyi-Jiexiu, Xinxiang-Huixian-Weihui, Lucheng-Changzhi, Anyang-Hebi, Yingtan-Guixi, Yanshi-Mengzhou-Gongyi
Loose-related group type	5	Residuals > 0	Danjiangkou-Laohekou, Wuxue-Ruichang, Lengshuijiang-Lianyuan, Chenzhou-Zixing, Yuanjiang-Yiyang

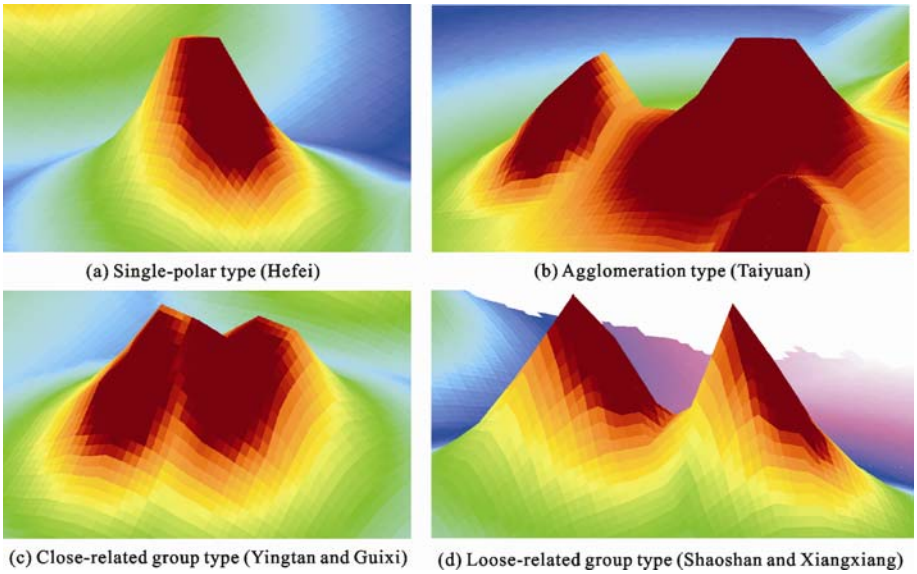


Fig. 6 Type of urban sphere of influence

accumulation ability and the position of regional development core. On the other hand, however, it showed the excessive concentration of limited development resources. The development prospect of small- and medium-sized cities was far from optimistic, and it was not conducive to the harmonious development of regional economy.

3) Close-related group type. The residual of this type of distribution was less than 0. The urban sphere of influence was squeezed like Yingtan and Guixi, Yanshi, Mengyi and Gongyi cities (Fig. 6c). Proximity space and approximate influence index aggravated the competition on resources and space, and substantially reduced the urban sphere of influence.

4) Loose-related group type. The residual of this type of distribution was larger than 0. The overlap between urban sphere of influence was small like Shaoshan and Xiangxiang, Lengshuijiang and Lianyuan, and Chenzhou and Zixing (Fig. 6d). The accumulation ability of single city of this type of distribution was not strong, and there may exist two cores in this group.

5 Conclusions

This paper proposed that the field modeling method is a promising method to overcome the current shortcomings. Field can represent the spatial characteristics of interaction between cities and the hinterland more reasonably, and also the characteristics of their classification and spatial distribution of the urban spheres of influence can be further explored to provide references for various types of urban and regional planning by using GIS and statistical methods. A case study was done to identify urban spheres of influence of 168 cities in Central China in 2007. The results showed:

1) Wuhan was the absolute dominant city in Central China. There were a large number of low-grade cities with small urban sphere of influence in Central China. Different provinces had different development characteristics: Hubei was "weak province with strong city"; medium-sized cities of Hunan and Henan were well developed; development of the whole Jiangxi and Shanxi was backward, while the development of Anhui was more balanced.

2) The semivariograms and crosscovariance cloud showed that the spatial structure of urban sphere of influence of Central China was hierarchical. The first-level city is correspondly in the first layer. After the filtration of the second layer, the third layer expressed the dominant position of the second-level cities in the provincial region. Wuhan City was the leader in the central region, provincial capital cities dominated the whole province, and there was no other lower grade agglomeration center.

3) We identify four basic types of organization form of urban sphere of influence: namely single-polar type, agglomeration type, close-related group type and loose-related group type, through analyzing their spatial

characteristics, level and residual of urban sphere of influence. For examples, Wuhan, Zhengzhou, Taiyuan and Changsha all belonged to the agglomeration type while the number of cities is different among those urban agglomerations. Further, Hefei and Nanchang are found to belong to the single-polar type rather than the agglomeration type, which are named as the Wanjiang urban agglomeration and the Poyang Lake urban agglomeration respectively by some researchers.

Certainly, Euclidean distance in this paper is an idealized expression of space. Therefore, comprehensive measure of regional accessibility helps to ascertain the distribution feature of urban sphere of influence. Investigation of urban development track based on dynamic analysis of time series is the focus of future work.

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