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Spatial Structure of Central Places in Jilin Central Urban Agglomeration, Jilin Province, China

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Abstract: Using the radius of gyration from fractal theory, this paper describes the calculation of fractal dimensions for the four tiers of central places in the Jilin Central Urban Agglomeration (JCUA), Jilin Province, China and the structural characteristics of each tier: 1) the 1st tier central place, Changchun Proper (not including Shuangyang District), provides the most service functions and has the most stable primate position; 2) the 2nd tier central places, Jilin Proper, Siping Proper, Liaoyuan Proper and Songyuan Proper have unclear statuses and do not provide certain functions; 3) the 3rd tier central places comprise 23 county-level cities, counties and urban districts (including Shuangyang District of Changchun), exhibiting a dense spatial structure that agrees with theory; 4) the 4th tier contains the largest number of central places (248 designated towns), but they are loosely distributed. In this study, a spatial image of the JCUA was created, based on vectorized data of the urban settlement distribution, which was then modified and abstracted to create a hexagonal network covering the JCUA. Compared to the traditional central place model, the modified spatial image conforms to the $K = 3$ principle. In reality, however, the growth of some 3rd tier central places should be increased with the cities being upgraded to the 2nd tier so as to overcome that tier′s functional deficiency. The loose distribution in the 4th tier should also be changed. This apparent anomaly can be explained by the fact that the classic hexagon model used to describe the way market areas layout does not exist in the real world. However, this should not be viewed as an obstacle to using central place theory. If its assumptions are properly applied, it can still assist research into the spatial structure of regions.

Keywords: Jilin Central Urban Agglomeration (JCUA); central place system; spatial structure; fractal; spatial image

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1 Introduction

Central place theory is one of the main methods of studying regional urban systems. Since 1933 when central place theory was first put forward by Christaller (Chang and Wang, 1998), the theory has been enhanced by many geographers in terms of method innovation, regional testing and theoretical diffusion, after the value of the theory was recognized in the 1940s by the field of geography (Peter, 2001). Losch derived ′Losch′s landscape′, a central place system for more universal use (Losch, 1954). Berry and Garrison (1958) proposed a uniform distribution hypothesis of consumer spending. Skinner (1951) conducted an empirical study of the Chengdu Plain of Sichuan Province, China and put forward the concept of periodic central places. Vance (1970) created the ′Vance Business Model′.

Currently in China, there is research focused on regional testing and theoretical application through studies of urban systems, city clusters (Fang *et al.*, 2007; Lu *et al.*, 2011) and economic zones (Christopher *et al.*, 1999; Wang and Wang, 2000). At present, there are many inter-related elements that impact on regional relationships and influence development such that new regional

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functions are created. Thus, these new elements will inevitably influence the development and redistribution of central place systems, which will then bring changes to spatial relationships and structural images (Wang *et al.*, 2012). Incorporating the new background and multiple elements in the new era into central place system can further enrich central place theory and bring innovation to the traditional theory, which will make the theory more adaptable to the new era when regional development is affected by multiple elements.

From the existing literature on the fractal study of human settlements (Shan and Chen, 1998; Xing and Liu, 2007; Cao *et al.*, 2010), the distribution of urban and rural settlements exhibit self-similarity. Hence, a fractal method can be used to reveal the mathematical laws governing random agglomeration of urban systems and to explore the physical mechanism of the spatial expansion of urban agglomeration (Ma *et al.*, 2007). This paper describes the use of a fractal method to carry out a stratified analysis of the central places in different tiers within the Jilin Central Urban Agglomeration (JCUA) , Jilin Province, China and then to determine the characteristics of any self-similarity in their spatial organization. There is also a description of a spatial model of the central places within different tiers in the JCUA. The basic idea of this work is to calculate the fractal dimension of the central places as shown on maps, based on the radius of gyration, ascertain the fractal dimension of the 2nd, 3rd and 4th tiers and find the internal structural characteristics of different hierarchies.

2 Materials and Methods

2.1 Study area and data sources

JCUA covers the whole area of Changchun, Jilin, Siping, Songyuan, Liaoyuan cities and the three other cities (counties) administered by Tonghua City, that is, Meihekou City, Huinan County and Liuhe County. This agglomeration includes one sub-provincial city (Changchun), four prefecture-level cities (Jilin, Songyuan, Liaoyuan and Siping) and 23 county-level administrative regions (including Shuangyang District of Changchun), forming a four tier urban hierarchy together with 248 designated towns (Fig. 1). The JCUA has the most developed economy and greatest level of urbanization within Jilin Province. Changchun, the primate city in the JCUA, is located at the geometric center of the JCUA and is also at the heart of provincial economic growth. In recent years, the increasing regional integration of the JCUA has brought about a rapid spatial transformation of the urban system allowing for greater complexity and versatility in the near future (Ge, 1989; Xu *et al.*, 1997).

Changchun, the primate city of the studied area, is located in the top tier of the JCUA and is considered to be the center for the fractal dimension calculation. The 2nd tier of central places includes four prefecture-level cities around Changchun. The 3rd tier of central places covers 23 county-level cities, counties and urban districts (including Shuangyang District of Changchun), located within a circle of a particular radius when Changchun is viewed as the center. The 4th tier of cen-

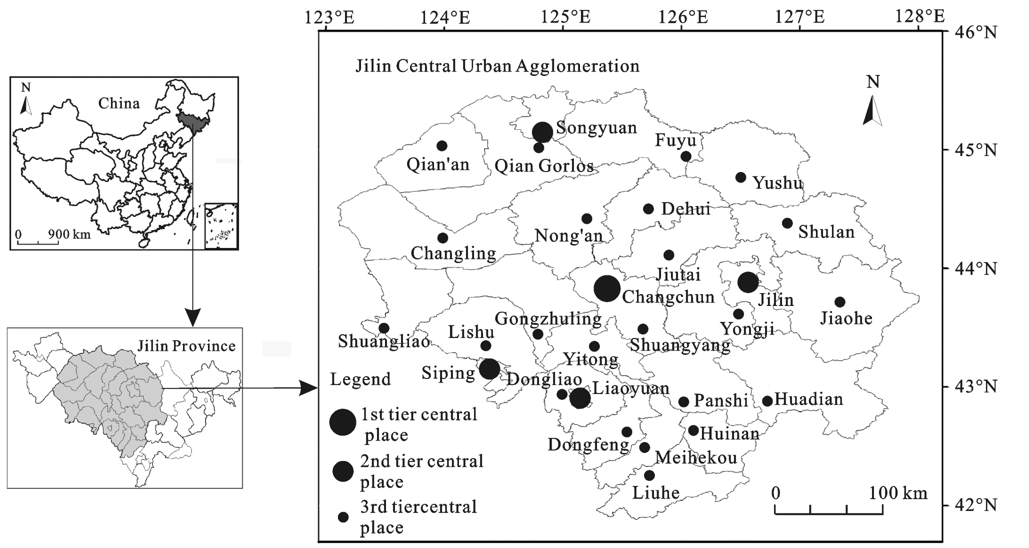

Fig. 1 Location of study area. The 4th tier central places are not marked on the map because of excessive number

tral places incorporates 248 designated towns in the studied area. In this study, designated towns under the administration of Changling County and Jiaohe City are chosen to be case study representing the large number of designated towns existing in the JCUA. Changling County and Jiaohe City are respectively situated to the east and the west of the JCUA. On the edge of the studied area, Changling and Jiaohe are less influenced by large cities and thus display the characteristics of low tier central places.

The data were derived from a vector map of Jilin Province (Feng, 2010). The distance between two central places was measured using mapping software provided by the social network Baidu.

2.2 Methods

According to the radius of gyration from fractal theory, if the settlement distribution is fractal, the following Equation (1) should be applied (Wang *et al.*, 2005; Yu and Chen, 2006; Huang and Zhang, 2009; Meng *et al.*, 2009):

$$N(r) \propto r^D \tag{1}$$

where $N(r)$ represents the number of central places (generally above a certain rank); r is the radius of a circular area and D is the fractal dimension. If the above relationship does not exist, it means that the settlement distribution is not fractal.

When the radius of gyration is used, it is normally difficult objectively to define the value of r. If a different value of r is selected, the calculated fractal dimensions will change. Hence, the mean radius R_s is used instead of r and is defined as:

$$R_S = \left\langle \left(\sum_s^i \frac{r_i}{S} \right)^{\frac{1}{2}} \right\rangle \tag{2}$$

where r_i is the distance between central place i and the top tier central place (i = 1, 2, 3, …S, $S \leq n$); S is the number of central places in each calculation (S = 1, 2, 3, …, n) and $\langle\rangle$ is a mathematical symbol meaning averaging.

For the calculation, r_i was calculated as being the distance between central places and the top tier central place for each tier being examined. Using Equation (2), r_i can be converted to R_s. ln$S$–lnR_s coordinate graphs can then be drawn. If a scale-independent range exists, the distribution is fractal. The reciprocal of the straight-line slope of a scale-independent range is the dimension found using non-linear regression (Gao *et al.*, 2011). Using Equation (3), taking logarithms and using the least square method of non-linear regression, Equation (4) can be derived:

$$\sum_{i=1}^{n} \left(\frac{1}{D} \ln S + \mathrm{A} - \ln R_S \right)^2 = \min \tag{3}$$

where A is a constant. Rearranging Equation (3) gives Equation (4):

$$D = \frac{n\sum(\ln S)^2 - \left(\sum \ln S\right)^2}{n\sum \ln R_S \ln S - \sum \ln S \sum \ln R_S} \tag{4}$$

where n represents the number of central places in the scale range.

3 Results and Analysis

Using equations (2)–(4), the dimensions of the 2nd tier and 3rd tier central places are respectively 2.342 and 1.842. The dimensions of the 4th tier, that is, the towns of Changling and Jiaohe chosen for this study, are 1.026 and 1.212 respectively (Table 1 and Fig. 2).

The results of the fractal dimension calculation show that there is no strict fractal distribution of the 2nd tier central places. According to the definition of a fractal dimension, its value should be higher than the topological dimension and lower than the dimension of the space encompassed. Hence, the dimension of central places should be lower than 2. However, the dimension of the 2nd tier of the JCUA is greater than 2 and does not agree with the experience number (the dimension predicted by theory). This phenomenon can be explained by the attraction of the 1st tier central place, Changchun Proper. Still in the development stage of polarization,

Table 1 Dimensions of 2nd tier, 3rd tier and 4th tier central places in Jilin Central Urban Agglomeration

System	n	(n)	D	R^2
2nd tier system	5	4	2.342	0.987
3rd tier system	24	23	1.842	0.983
4th tier system (Changling)	8	7	1.026	0.988
4th tier system (Jiaohe)	10	9	1.212	0.976

Notes: n represents the total number of central places; (n) represents the number of central places within the scale range, normally, (n) = n–1; D is the fractal dimension

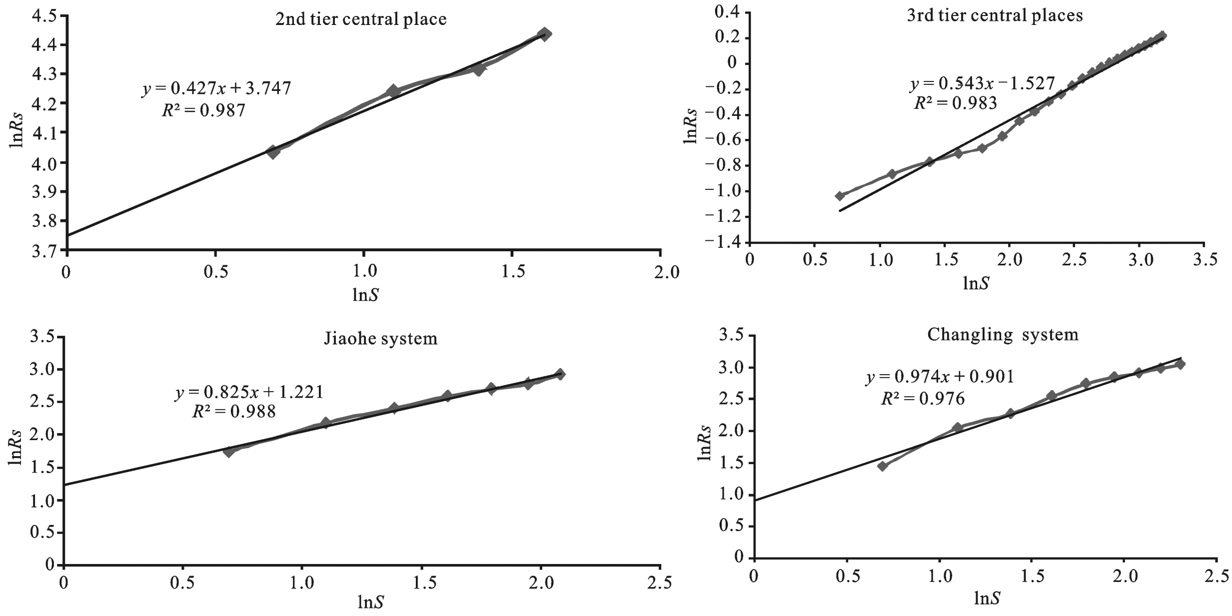

Fig. 2 Graphs showing central place spatial distribution in Jilin Central Urban Agglomeration

Changchun exerts too strong an attraction on the surrounding 2nd tier central places, slowing their growth. This is shown by two aspects. In terms of city size, there is a large gap between the 1st and the 2nd tier. In terms of city numbers, there are only 4 central places in the 2nd tier. Furthermore, the JCUA covers a vast area. The sparse distribution of the 2nd tier central places further weakens the functions that these cities should be providing. On one hand, some of these functions are provided by the 1st tier central place but on the other, these cities are obliged to provide some functions for the 3rd tier central places because of the great distances between these cities. This means that there are too few 2nd tier central places in the JCUA providing too few urban functions.

In contrast, the 3rd tier and 4th tier central places definitely display the fractal dimension of an urban spatial system. Using the definition from the fields of topology and geometry, dimension means the number of independent coordinates needed to fix a point′s position on a geometric shape; the number of dimensions can represent the number of system control variables (Liu and Chen, 1995). In this work, the dimension of the 3rd tier, 1.842, represents a dense urban distribution, indicating a more developed 3rd tier urban system in the JCUA. This study chose Changling and Jiaohe as typical 4th tier central places in the JCUA. Generally, the dimensions of the 4th tier central places are relatively low, showing that this tier exhibits a loosely distributed spatial structure and a less developed urban system. In particular, the dimension of the Changling system is only 1.026, reflecting that the west of the JCUA has a less well-developed economy, fewer cities and a loosely distributed urban system.

3.1 Spatial pattern of central places

The JCUA is composed of 4 tiers of central places. The top tier is Changchun Proper. The next tier includes Jilin Proper, Songyuan Proper, Liaoyuan Proper and Siping Proper. The 3rd tier is mainly made up of 23 cities, counties and urban areas. The lowest tier consists of 248 designated towns. Based on the different layouts predicted by Christaller's Central Place Theory (K = 3, K = 4, K = 7, *etc.*), it can be seen that the JCUA does not follow these predictions.

Losch′s Central Place Theory posits that the city sizes of central places are consecutive instead of hierarchical. According to Losch′s equation (Losch, 1954) for the number of central places in a certain level of market area, when K = 8 and j = 5 or 6, the number of central places is 247 or 259, falling within 85 or 86 level market area. The number of the 4th tier central places in JCUA is 248. Thus, the central place system describing the JCUA is a K = 8 system and the number of the 4th tier central places is close to 85 as predicted by Losch′s theory (Table 2).

Within the JCUA, there is an interactive relationship between all the cities. As the top tier central place,

Table 2 Number of central places, *K* and *j* in market areas at different levels within Jilin Central Urban Agglomeration

	Level of market area	Number of central places	*K*	*j*
1st tier central places	1	1	–	–
2nd tier central places	2	4	1	1
3rd tier central places	10	23	2	1<j<2
4th tier central places	85	248	8	5<j<6

Note: *K* represents the central place model type; *j* = 0, 1, 2, …, *K*

Changchun Proper plays a dominant role in the whole central place system. The 2nd tier central places, Jilin Proper, Liaoyuan Proper, Songyuan Proper and Siping Proper, are nodes of a core-periphery structure within the JCUA, providing some functions to the outside region. The 3rd tier forms a solid foundation for the future development of the JCUA and also a transition tier between the higher and lower tiers. The 4th tier includes the greatest number of towns. There are a variety of types of terrain across the area, so both dense and loose distribution of towns and cities can be seen in the spatial structure. It should be noted that, with the area studied, the accuracy of this study may not be sufficient to allow the whole picture to be seen. However, in terms of the two areas studied, the different physical landscapes of the east and west of the JCUA produce different spatial structures of the corresponding 4th tier central places.

3.2 Spatial relationship of central places

3.2.1 Spatial polarization in 1st tier and 2nd tier central places

Changchun Proper, as the undeniably top central place, is still in the development stage of spatial polarization, as are the smaller 2nd tier cities (Jilin Proper, Siping Proper, Liaoyuan Proper and Songyuan Proper). Therefore, the competition for resources and space between these central places is evident. In particular, Changchun, being the core of Jilin Province, has the opportunity to be treated preferentially both politically and through the provision of large quantities of resources and the building of industrial sites, thus stifling the development of other cities. In an era of flexible, diversified shopping behaviors, the influence of Changchun over the JCUA has been strengthened, leading to shrinkage in the market area of the adjacent cities. Correspondingly, the market area of Changchun has enlarged. This is especially obvious in surrounding cities such as Jilin, Siping and Liaoyuan. The dimension value of the 2nd tier cities (2.342, so greater than 2) further proves this point. In contrast, Songyuan, a core city of the western area of the JCUA and a good distance from Changchun, has the potential for further development. Indeed, recent years have seen a rapid development of this city. Overall, the 2nd tier spatial structure is currently irregular and unstable but is becoming more regular and stable.

3.2.2 Dense and reasonable spatial structure of 3rd tier central places

Judging by the dimension value (1.842), the 3rd tier central places form a relatively reasonable and complete system that described by fractal theory. Neither suppression of market area nor loose distribution can be observed. This can be attributed to the high number and reasonable spatial development of county-level administrative regions. As a connecting tier, the future development and evolution of the 3rd tier will be the key to further growth of the whole JCUA. As such, an effective way to grow the JCUA would be to encourage economic development of the counties. With the further growth and development of the 3rd tier central places, the JCUA will have complete system and reasonable spatial structure as predicted by theory; thus, the 3rd tier will form a solid connecting tier for the whole JCUA.

3.2.3 Loose spatial structure of 4th tier central places

The 4th tier is the foundation of the JCUA, providing services to counties and rural settlements. This case study has shown that the growth of this tier is constrained by physical conditions. There is a loose distribution of central places both in the dry climate of Changling and in the wet climate of Jiaohe. This follows the idea of physical and geographical conditions constraining the growth of a central place system and also reflects the fact that the fractal dimension of an urban system is the combined effect of human and natural elements. However, the two case areas selected in this study might not show the whole picture. In some regions where the natural environment has less influence, the dense distribution of the 4th tier central places might not occur. This might be attributed to the spatial differentiation often observed in central place spatial structures. Different spatial characteristics can help to create different spatial structures of central places.

3.3 Spatial image of central places

3.3.1 Principle and method of spatial image creation

In the real world, the symmetry exhibited by the spatial model of central places is inevitably shown as asymmetrical due to geographical and human effects; this effect is termed 'symmetry breaking' (Chen, 2003; 2004). Therefore, it is necessary to account for the symmetry breaking by abstracting and modifying the complex spatial image of the central places. In this process, major spatial elements are extracted and minor complex elements are ignored. Based on this idea, this study uses only the 1st, 2nd and 3rd tier central places to create the spatial image, as too many central places and too many interference factors exist in the 4th tier. As it is, some adjacent towns have had to be combined. The spatial image created is thus a modified form of the real situation. Finally, the modified view is abstracted so as to produce a spatial image that has a broad range of uses.

3.3.2 Spatial image composition

Based on vectorized data (Feng, 2010) for city and town distribution and using ArcGIS 9.3 software, this study abstracted and processed the data for the JCUA and then created a spatial image of the central places in the JCUA using the previously mentioned spatial image creation method (Fig. 3).

In the original spatial image shown in Fig. 3, the 1st tier central place is Changchun Proper with the 2nd tier central places forming a quadrilateral network where the four cities surrounding Changchun, that is Songyuan Proper, Jiling Proper, Liaoyuan Proper and Siping Proper, are the vertexes. The 3rd tier is composed of two complete polygon systems and other irregular systems. The two polygons include a hexagon centered on Changchun and a heptagon centered on Jilin. These polygons are similar to the hexagonal network put forward by Christaller, but the other 3rd tier central places do not form a polygonal network around the higher tier central place.

In the next step, the area covered by the original spatial image is increased so that the polygon network can extend to adjacent areas of the JCUA, breaking the administrative boundaries. This study, by considering the routine contacts and economic links between these cities as well as maintaining the integrity of regional cultures, has extended the study area to the adjacent external regions felt to be highly influential on the JCUA (Yan and Feng, 2009; Qin and Zhang, 2011). As such, Zhaoyuan, Da'an, Horqin Left Wing Middle Banner, Changtu and Xifeng have also been taken into consideration as these areas are similar to the JCUA both in economic terms and culturally. Changling County and Fuyu City have been upgraded to being 2nd tier central places in order to equalize the level of services in the tiers and minimize the symmetry breaking. After modification, the 2nd tier and 3rd tier central places of the JCUA form an idealized spatial image (Fig. 4), consisting of hexagons, pentagons and quadrangles. Changchun Proper, the highest central place, controls the whole central place system. Jilin Proper, Songyuan Proper, Liaoyuan Proper and Siping Proper, central places themselves, control the lower central place systems. The modified central places of the JCUA show completeness and symmetry. The

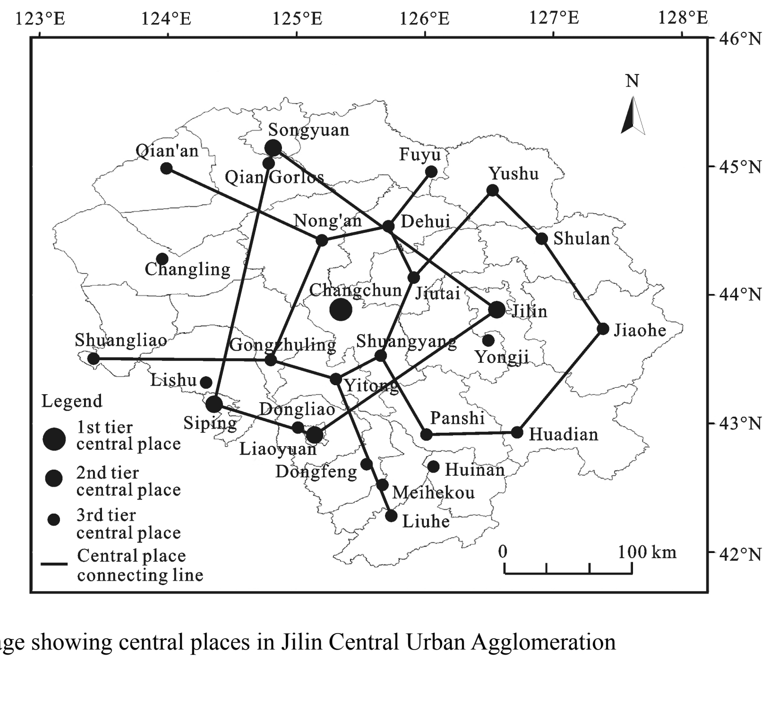

Fig. 3 Original spatial image showing central places in Jilin Central Urban Agglomeration

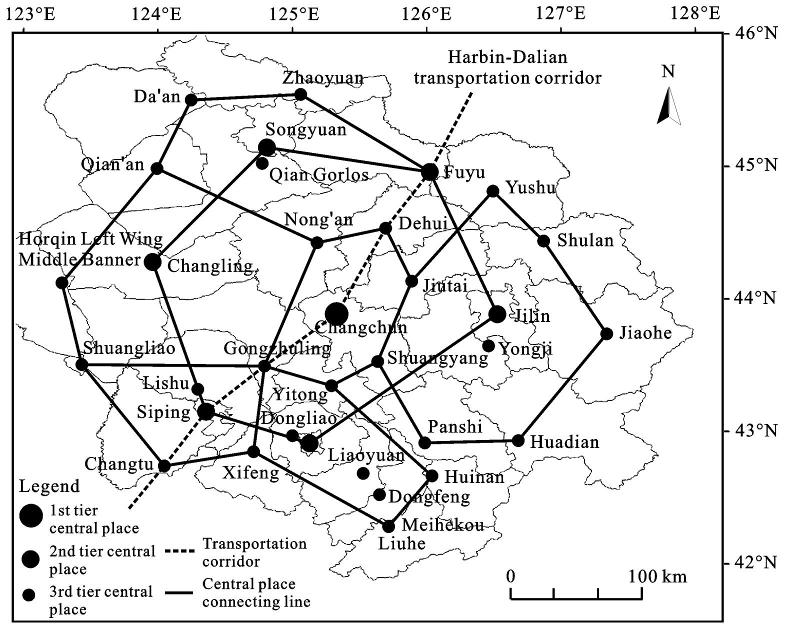

Fig. 4 Modified spatial image of central places in Jilin Central Urban Agglomeration

symmetry axis is located along the Harbin-Dalian transport corridor (Wang *et al.*, 2007).

3.3.3 Comparison of JCUA model with traditional central place model

The modified spatial image is then abstracted to remove unnecessary complicating factors as well as their effects on central places. This image can be used to ascertain which of Christaller′s principles the JCUA corresponds with and what the relationships between the central places are.

The abstracted and simplified spatial image of the JCUA is shown in Fig. 5. Compared to the traditional model (Fig. 6), after rotation the JCUA generally conforms to a K = 3 central place system as defined by Christaller. K = 3 means that the central place system growth is based on market rules. With the modification, the symmetry of JCUA can not be maintained until Changling and Fuyu are moved to a higher tier. This indicates that a deficiency exists in certain tiers, created as the JCUA has grown, so Changling and Fuyu lack the support of 2nd tier central places. Near to Harbin City, Fuyu is greatly impacted by this higher central place and the northern lower central places can not be developed. The integrity of the system is thus broken due to the constraints caused by the adjacent large city, a common phenomenon in urban systems.

In addition, multiple 3rd tier central places are located within the Liaoyuan central place system. This can be explained by the weak influence of Liaoyuan, a city that can not dominate the whole system. Meihekou City, a 3rd tier central place, is economically powerful enough to deprive the 2nd tier of some functions, forming a small system covering Liuhe County, Dongfeng County and Huinan County. Therefore, if Meihekou, Liuhe, Dongfeng and Huinan are abstracted as an individual tier adjacent to Liaoyuan City, the Liaoyuan central place system will be more complete and reasonable.

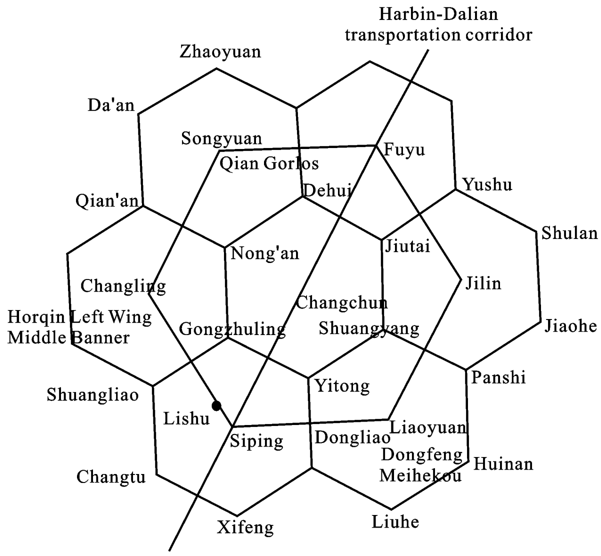

Fig. 5 Hexagon network of Jilin Central Urban Agglomeration

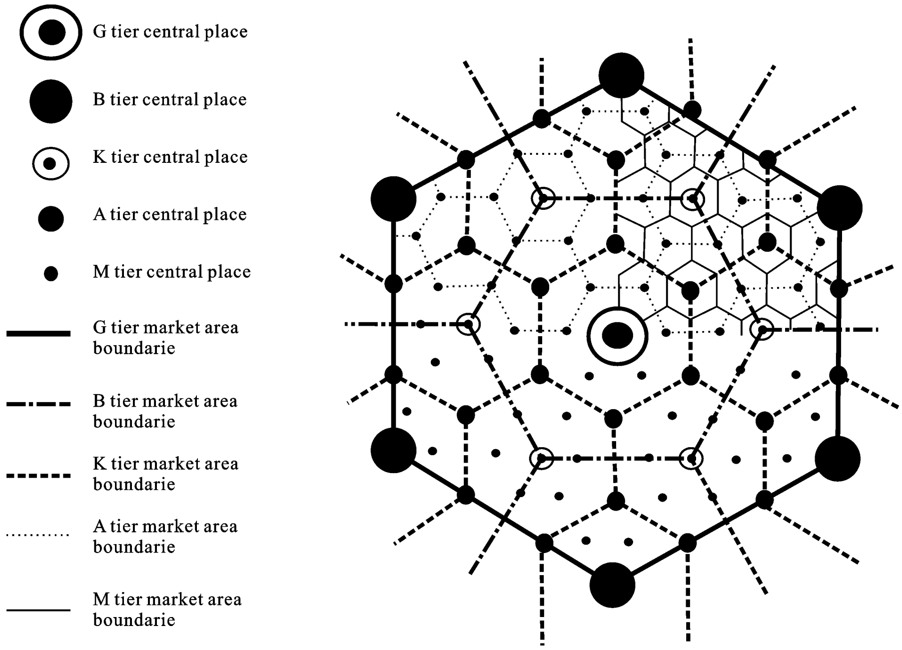

Fig. 6 Central place hierarchy of $K = 3$ marketing principle (Chang and Wang, 1998)

4 Conclusions

Using a fractal method and GIS software, this study has reanalyzed the spatial structure of the JCUA and has revealed the current spatial relationships between the central places in it.

By calculating the fractal dimension, the central places of different tiers in the JCUA have been shown to exhibit different characteristics. The 1st tier central place, Changchun, provides the most service functions and has the most stable primate position. However, 2nd tier central places are not growing as expected. Dense and even distribution can be seen in the 3rd tier, while loose distribution can be seen in the 4th tier.

In terms of spatial image, the central places of the JCUA form what Christaller defined as a $K = 3$ system i.e., a system developed and guided by market rules. The spatial image also shows differences with the traditional $K = 3$ system, even after removing interference factors. This may explain why, based on Losch′s rule, the central places are considered to form a $K = 8$ system (as mentioned in 3.1). This apparent anomaly can be explained by the fact that the classic hexagon model used to describe the way market areas layout does not exist in the real world. However, this should not be viewed as an obstacle to using Central Place Theory. If its assumptions are properly applied, it can still assist research into the spatial structure of regions.

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