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Regional Structure and Spatial Morphology Characteristics of Oasis Urban Agglomeration in Arid Area —A Case of Urban Agglomeration in Northern Slope of Tianshan Mountains, Northwest China

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Abstract: It is great important to the health development of urban agglomeration to correctly understand the formation and development law of regional structure of urban agglomeration. Employing the analysis methods like fractal theory and quantitative statistics, coupling with the use of remote sensing images and other spatial data, this article discusses the urban agglomeration of oasis on the northern slope of the Tianshan Mountains in an arid area, and conducts the researches on its city scale, spatial distribution and individual form from 1990 to 2005. The result shows that it has loose hierarchical scale structure and polarization trend of population distribution while its hierarchical scale structure tends to mature. Under the influence of natural conditions, the spatial layout of urban agglomeration of oasis has macro characteristics that suggest cities distributed along oasis edges (dense or sparse), spatially expand along rivers, and cluster around traffic branches. The connectivity among the cities is high and shows an internal organization form of a banding distribution. The whole spatial shape of the internal structure of cities presents a "dumbbell" form, with mononuclear phenomenon receding and multi-nuclear appearing gradually. Individual cities spatially expand along rivers, portraying a long strip appearance. It indicates that the urban agglomeration of oasis shows regular and close structure but with a tendency to be complicated form and the loose structure. In the development of urban agglomeration, the authors recommend that the development of the city with good economic development conditions should be strengthened, and more attention be put into regional planning.
Keywords: fractal theory; scale structure; urban agglomeration of oasis; Tianshan Mountains

1 Introduction

A city is an urban area with a high density population and a particular administrative, legal, or historical status, which is the main carrier of modern socio-economic development. It plays an important role in human being′s present and future lives and has always been at the center of economic growth, technological advancement and cultural production. Within a certain region, a number of cities with different attributes and hierarchies come to form urban agglomeration based on the certain natural and social conditions (Nian et al., 2002; Pu et al., 2002; Fang et al., 2005; Wang et al., 2005; Miao and Wang, 2006). Judging from its self-organization structure, urban agglomeration developed from many isolated cities to a system with complete hierarchical scale structure, function and spatial structure. It is an arrangement involving many factors such as regional space, natural feature and socio-economic level. The regional space, natural condition and economic developing stage are embodied by regional spatial structure of urban agglomeration. Different natural factors, regional space and socio-economic backgrounds also form different urban regional spatial structures (Fang et al., 2007). Therefore, to understand correctly and comprehensively the formation development laws of urban agglomerations and regional spatial structure is helpful to optimize its structure and promote its health development.

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There were researches, both at home and abroad, on regional spatial structure of urban agglomeration. The fractal theory and statistical analysis were widely used in quantitative research on regional structure of urban agglomeration (Chen and Liu, 2001; Dan and Fan, 2004; Du and Liu, 2005; Fang et al., 2005). Foreign researchers have done a lot of work on the regional structure of social attribute in urban space, the concept of urban spatial structure, and the distribution and differentiation of modes of urban internal resident space. On the other hand, domestic scholars theoretically discussed and empirically analyzed the concepts, types and systems of regional structure in urban agglomeration. There has been great progress in urban agglomeration research in the whole China or socio-economically developed regions. However, there is scarce information on spatial organization character of urban agglomeration and evolution law of individual city forms, let alone urban agglomeration or town-intensive region of oasis in underdeveloped regions of the western China. Urban agglomeration of oasis of the northern slope of the Tianshan Mountains, located in Northwest China, is a typical developing area of urban agglomeration of oasis (Du and Liu, 2005). It plays a unique role as an important international hub from China to middle Asia. It is the strategic sustentation region, growth pole and core node in the economic development patterns of the western China. As such, rigorous research on regional spatial structure and its evolution law of urban agglomeration in the northern slope of the Tianshan Mountains is of great significance to optimize regional development and enrich the theory of oasis urban study.

This article studies urban regional spatial structure and urban spatial form of urban agglomeration in the northern slope of the Tianshan Mountains from 1990 to 2005 by employing fractal theory and statistical method which is comparatively complicated but passionately mature. It discusses the developing track of urban agglomeration and its problems, aiming at offering theoretical reference for optimizing the development of urban agglomeration in the northern slope of the Tianshan Mountains. The main research objectives are: 1) to characterize urban hierarchical scale structure and changing trend of urban agglomeration in the northern slope of the Tianshan Mountains from 1990 to 2005; 2) to establish spatial patterns and interaction of urban agglomeration in the northern slope of the Tianshan Mountains; and 3) to determine the general form and spatio-temporal variation character of oasis city in the northern slope of the Tianshan Mountains from 1990 to 2005.

2 Materials and Methods

2.1 Study area and data acquisition

The study area constitutes the urban agglomeration in the northern slope of the Tianshan Mountains. It includes a total of 8 cities, namely, Karamay, Kuytun, Usu, Shihezi, Miquan, Fukang, Changji and Urumqi (Fig. 1).

Considering its location advantage, infrastructure condition and rich natural resources, this region has the highest city development levels and hence the most developed economic unit in Xinjiang. In recent years, with its speedy economic development, urban agglomeration

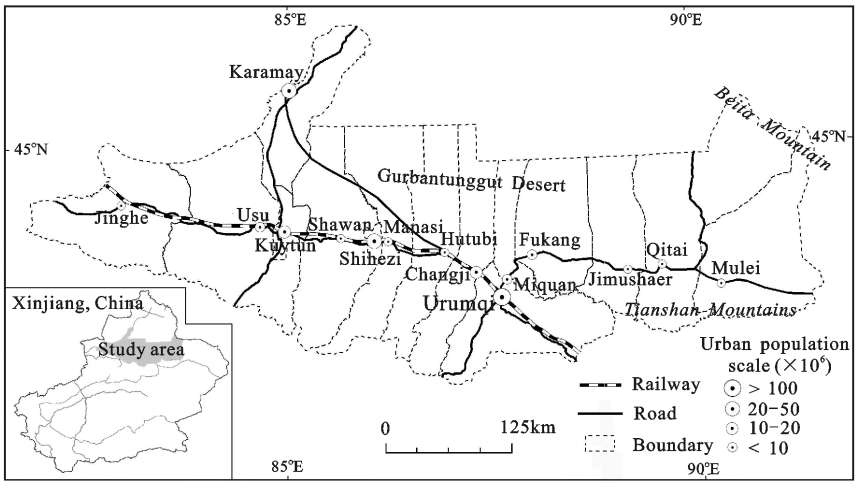

Fig. 1 Distribution of cities at the northern slope of the Tianshan Mountains

has expanded quickly, making the urbanizing process very obvious.

The research data in this article include statistic materials and remote sensing image, of which the former came from *Xinjiang Statistical Yearbook* of 1990, 2000 and 2005 (Xinjiang Statistical Bureau, 1991; 2001; 2006), and the latter consisted of Landsat TM image (1990) and China Resources Satellite Image (2005). It used ERDAS 9.2 for geometric correction and digital processing to obtain built-up patch information of eight-city stretch in the northern slope of the Tianshan Mountains in 1990, 2000 and 2005.

2.2 Methods

In recent years, fractal theory was widely used in urban agglomeration research and promotes theoretical progress of the research (Liu and Chen, 2000; Chen and Liu, 2001; Dan and Fan, 2004; Wang et al., 2005; Li et al., 2006). Fractal theory was proposed by American mathematician Benoit B Mandelbrot in 1975 and it has evident effects on explaining irregular, unstable and high-degree complicated matters in nature (Batty and Longley, 1994; Shen, 2002). Fractal dimension is a major parameter depicting fractal data character. It can quantitatively describe the hierarchical character of the set, the distribution character and the morphology character of individual patch. There are two common methods of calculating dimension, i. e. changing scale and changing size in accordance with measuring relation. To get dimension by changing scale means to divide the researched set by changing a certain scale r: when the object number in set is bigger than r, $N(t)$ satisfies the relation equation: $N(t) \propto t^{-D}$ (D means object fractal dimension). In order to understand the regional spatial structure and the developing trend of urban agglomeration, hierarchical scale dimension and spatial correlation dimension are studied. To know the spatial morphology of individual city, indicators of spatial morphology dimension and shape spatial compact ratio are researched in the study area.

2.2.1 Hierarchical scale dimension

This article analyzes and explains the character of hierarchical scale structure of urban agglomeration area by the employing urban hierarchical scale dimension, the mode is:

$$\mathrm{Ln}N(P_{op}) = \mathrm{Ln}A - D_H \mathrm{Ln}P_{op} \quad (1)$$

where $N(P_{op})$ indicates the cumulating number of cities whose population is bigger than threshold, A is constant, D_H is urban hierarchical scale dimension, and its value directly reflects hierarchical scale structure of urban system. When $D_H>1$, the city scale distribution is comparatively concentrated, city number in medium rank is bigger than others, population distribution is even and the whole urban system develops comparatively mature; when $D_H<1$, the city scale distribution is comparatively dispersive, population distribution is uneven and the development of whole urban system is at the primary stage (Liu and Chen, 2000; Pu et al., 2002).

2.2.2 Spatial correlation dimension

Chosen in the analysis of spatial correlation of factors distributed in urban system, the spatial correlation dimension reflects the spatial distribution evenness of various factors in urban agglomeration. Its basic mode is:

$$\mathrm{Log}C(r) \propto D_c \log(r) \quad (2)$$

where D_c means the spatial correlation dimension; r means yardstick, i.e. Euclidean distance; $C(r)$ is the correlation function, namely, the ratio of each distance number corresponding with distance value to the total distance number (N). It depicts that only within appropriate value range can $C(r)$ and r show the relation of $C(r) \propto r$ (Chen and Liu, 2001). D_c ranges from 0 to 2, when $D_c \to 0$, regional cities are mostly distributed only in one place; when $D_c \to 1$, factors of city system focus on one geographical line; when $D_c \to 2$, the distribution of cities is quite even, meaning that city distribution density is evenly changing with a certain city as its center (Miao and Wang, 2006). In Equation (2), if r is the actual traffic mileage, spatial relation fractal dimensions D_c' of the traffic network can be obtained. Then the arriving degree of network (ρ) can be defined as:

$$\rho = D_c'/D_c \quad (3)$$

where the closer ρ is to 1, the better the traffic network connection among cities is, and the higher correlation degree the factors in the urban system are with (Pu et al., 2002).

2.2.3 Spatial morphology dimension

Spatial morphology dimension is used to roughly and visually process the researched patch with a small grid whose side is a, that is, to calculate the minimum degree $P_{er}(a)$ of covered patch perimeter by small grid and the minimum degree $A_c(a)$ of covered area, in accordance with fractal theory, there is:

$$\mathrm{Ln}P_{er}(a) = 1/2\, D_m \ln A_c(a) + c \quad (4)$$

where D_m is the urban spatial morphology dimension; c

is a constant. D_m ranges from 1 to 2. The greater the human activity influence is, the smaller the urban spatial morphology dimension of graphic is, and the more regular the graphic′s shape is (Leorey and Nariida, 1999).

2.2.4 Spatial compact ratio

The article uses spatial compact ratio mode, which means the certain patch compact is the ratio of plot area to the plot perimeter (Boyce and Clark, 1964). Equation (5) can be given as:

$$K=2\sqrt{\pi A_p}/P_p \quad (5)$$

where A_p means the area of patch, P_p means the perimeter of patch, K means the spatial compact ratio of patch and its range is $0<K\leq 1$. The smaller K is, the lower value of patch compact, the bigger the loose degree, and the lower the stability of the internal resources is, and vise versa.

3 Results and Analyses

3.1 Spatio-temporal character of hierarchical structure

Hierarchical scale structure of urban agglomeration could reveal distribution law (dense or sparse) of regional city scale and reflect regional spatial structure and developing stage of urban agglomeration (Dan and Fan, 2004; Li et al., 2006). Urumqi is always to be the primary city in the study area (Table 1), whose proportion of non-agricultural population to the total of the study areas was 59.8%, 54.3% and 48.7% in 1990, 2000 and 2005, respectively (Fig. 2). It has the reducing trend, but it is still higher than the amount of other seven cities. The city scale is mainly between 50×10^3 to 200×10^3 persons; however, the phenomenon of imbalanced urban scale structure is receding while the even development becomes the inevitable tendency in the future. In 2005, the average city scale was a population of 100×10^3 to 500×10^3 while some cities with a population of 500×10^3 to 1×10^6 appeared in the study area. The hierarchical scale structure is becoming mature.

Utilizing fractal theory and Equation (1), the hierarchical scale dimensions were 0.615, 0.622 and 0.547 in 1990, 2000 and 2005, respectively (Fig. 3). It can reflect the spatio-temporal changing character of city scale distribution. The result showed that all hierarchical scale dimensions from 1990 to 2005 were smaller than 1, indicating that hierarchical scale structure of the urban agglomeration was loose, the primary city stayed in monopoly place, the population distribution was uneven, and urban system development was immature. However, as observed from the changing tendency of hierarchical scale dimension, the imbalance of population distribution from 1990 to 2000 was receding. From 2000 to 2005, it appeared even more imbalanced as more population clustering in the study area. This is probably because that, from 1990 to 2000, the economy in the study area developed rapidly and the pace of urbanization accelerated the growth of such cities as Shihezi which has the capability to attract population from other new centers. The multi-center is the tendency in the future development of the urban agglomeration.

Table 1 Rank and non-agricultural population quantity of city in study area in 1990–2005 (unit: $\times10^4$ persons)

Scale	1990	2000	2005
>100	Urumqi (104)	Urumqi (134)	Urumqi (151)
50–100			Shihezi (52)
20–50		Shihezi (34.4), Karamay (23.9), Changji (20. 6)	Kuytun (28), Changji (28), Karamay (25)
10–20	Karamay (19), Shihezi (17), Changji (13), Kuytun (12)	Kuytun (15.2)	
5–10	Usu (3.7), Miquan (3.5), Fukang (2.2)	Fukang (7.5), Usu (7.2), Miquan (6.6)	Fukang (9.4), Miquan (9.3), Usu (7.3)

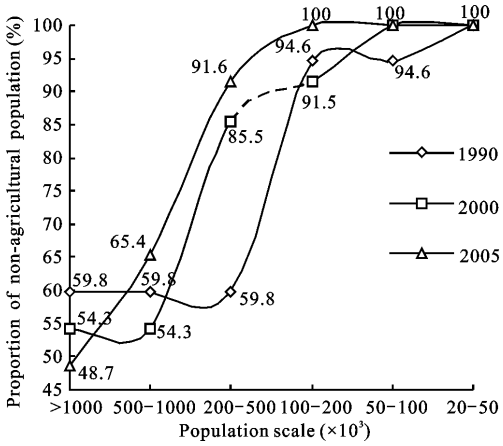

Fig. 2 Changes of non-agricultural population in Urumqi from 1990 to 2005

3.2 Characteristic of urban spatial distribution

Spatial distribution is an important part of regional spatial structure in urban agglomeration (Fang et al., 2007). Geomorphologic shape and water resources control are

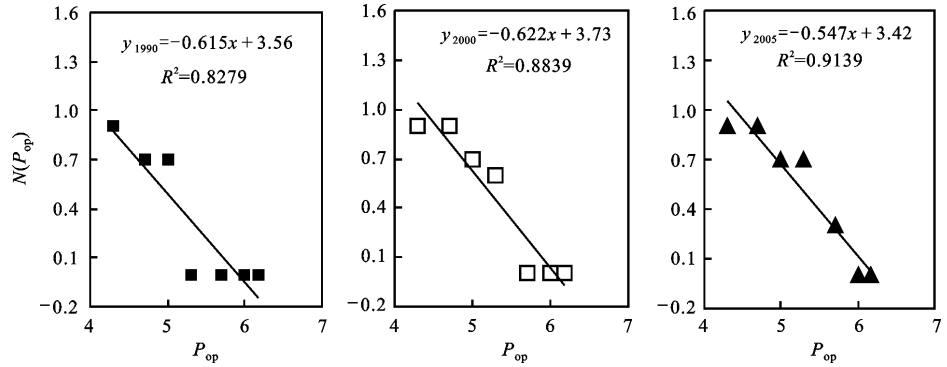

Fig. 3 Ln-ln plot of urban system-size distribution of urban agglomeration in study area

leading factors to restrain the existence and development of oasis cities. Oasis cities have macro distribution character of "develop with water and soil, expand with well and stream, lie around basin place, and sit at foot of mountain" (Zhang and Zhang, 2002; Du and Liu, 2005). The adequate surface water runoff, good vegetation and soil condition ensure oasis cities′ development and maturity. Therefore, cities (except Karamy) comparatively concentrate in the northern Tianshan Mountains and south of Junggar Basin. The macro distribution resembles an urban strip like "string of bead" and even looms a miniature strip urban agglomeration. The individual city development and maturity in the urban agglomeration appears to be extending around the river and its branch (including diverse canals). Because of the comparative independent location of oasis, it also appears that oasis city is relatively secluding property.

The spatial distribution of a city is constrained by a transport element as well. Whether for an ancient Silk Road, or for a modern complex transport network, the transport deeply affects the agglomeration distribution of an oasis city (Fang et al., 2003). Based on Equation (2), this spatial correlation dimension of direct distance in urban agglomeration of the northern Tianshan Mountains was 0.625, road network fractal dimension was 0.582, and based on Equation (3) arriving degree of network was 0.93 (Fig. 4). This indicated that regional cities are comparatively concentrated and located along a certain geographical factor (road branch or public railway) and the traffic connectivity among cities is good enough and even close to linear connectivity.

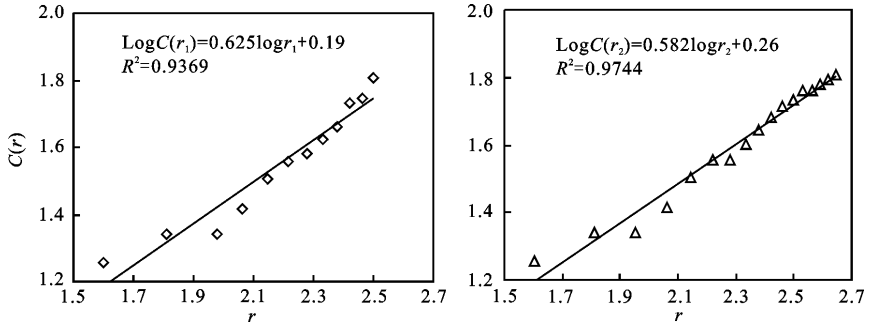

Fig. 4 Spatial correlation dimension of direct distance (r_1) and of road network (r_2) in study area

In reference to the formation process of urban agglomeration, it can be classified as typical urban agglomeration and atypical urban agglomeration according to the mature degree of, spatial factors aggregation trait, and economic interactive method of spatial factors. Among above, it is named atypical urban agglomeration whose mature degree and spatial aggregation form are still at primary stage (Fang et al., 2007), and economic interaction is principal in the evident concentration. It is characterized by "dense-and-sparse" distribution in study areas. Its urban macro distribution of urban agglomeration appears in the edge of oasis, densely or sparsely interlacing among river and traffic branch. There is a quadrilateral transiting structure formed by four main node cities (Urumqi, Fukang, Usu and Karamay) (Fang et al., 2007).

With the accelerating development of Urumqi and its strengthening attraction and radiation continuously, it has so close relationship with its neighboring smaller cities like Changji, Miquan and Fukang that they have formed one economic entity. Shihezi located in the middle of the northern Tianshan Mountains is originally a highly industrial city. With its industrial development and rapidly increasing population, it has become a new economic clustering node and promoted the development of towns in the vicinity like Shawan, Manasi and so on. Kuytun, Usu and Karamay in the west of the northern Tianshan Mountains have mainly engaged in petroleum exploitation and processing. With their transport advantage, their textile industry and trade have also developed rapidly, making them another node of economic elements cluster. Furthermore, with the overall increase of city scale, the "dumbbell" spatial shape of urban agglomeration composed of three economic centers including Urumqi metropolitan area, Shi-Ma-Sha (Shihezi-Manasi-Shawan) area and Kuy-U-Ka (Kuytun-Usu-Karamay) economic zone has already come into being (Fig. 5).

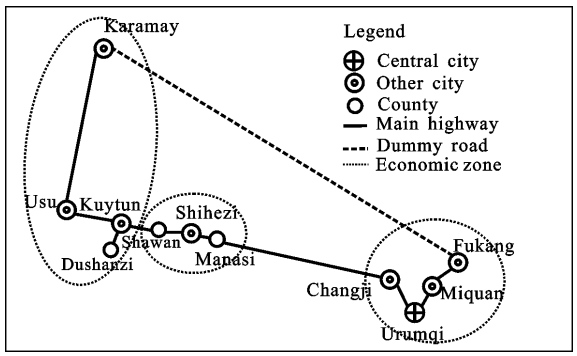

Fig. 5 Spatial structure of urban agglomerations at northern slope of Tianshan Mountains

3.3 General feature and spatio-temporal change of urban morphology

Supported by ArcGIS 9.2, the study utilizes box-counting dimension, spatial compact ratio and urban spatial morphology to describe the spatial morphology character of external city and its evolution law. The oasis urban morphology in the study area changed visibly from 1990 to 2005 (Fig. 6).

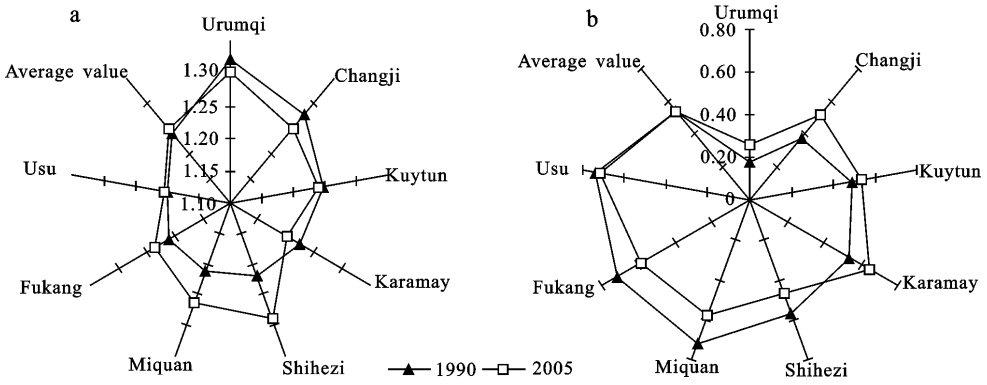

Fig. 6 Urban spatial morphology (a) and compact ratio (b) of 8 cities in study area in 1990 and 2005

In 1990 and 2005, from the urban spatial morphology, Urumqi and Changji were big while Fukang and Usu were small. Urumqi and Changji had longer developing history, whose early urban constructions lacked planning and instruction and were constrained by the complicated natural environment so as to form the rugged urban periphery and irregular urban shape. However, urban constructions of Karamay and Usu were mostly under planning and instruction, so they have tidy and regular urban periphery. In 1990, the Usu and Fukang had bigger spatial compact ratios while in 2005 Karamay and Fukang had. In 1990 and 2005 spatial compact ratios of Urumqi and Changji were smaller. It indicates that urban structure of Fukang was compact but those of Urumqi and Changji were loose. Urumqi and Changji were clustering points of Urumqi city circle, their economies were developed, urban attraction was strong, and material and energy circulation with external area was smooth. Therefore, they got more interference from outside, but their own internal stability was weak and spatial compact ratio of urban spatial morphology was comparatively small.

Figure 6 shows that urban spatial morphology and spatial compact ratio seemed to have bigger changes from 1990 to 2005 (except for Usu). Besides, the increase in range of urban spatial morphology dimension

was big, spatial compact ratio sharply decreased in Shihezi, Fukang and Miquan. Meanwhile their urban morphology tended to be complicated and non-compact ratio of urban structure became stronger. The probable reason behind this observation is that, Miquan and Fukang lie near Urumqi and become the destination of its urban population migration and industrial transfers. The rapid economic development increases the demand for land resources, which leads to the expansion and extension of the city, furthermore, the land use structure becomes complicated, the shape loose and development irregular. Nevertheless, the urban spatial morphology dimension sharply decreased and spatial compact ratio widely increased in the cities of Karamay, Kuytun, Urumqi and Changji. Their spatial morphology became more regular, the structure more compact and land use more intensive. The explanation could be that those cities are at mature stage, or their urban construction is restrained by many plans and rules or the regular degree of their urban spatial morphology is consequently increasing.

When it comes to the average level of various indicators of urban spatial morphology, the average value of spatial compact ratio of oasis city in the study area decreased from 0.54 in 1990 to 0.538 in 2005, while the average value of urban spatial morphology dimension increased from 1.24 to 1.25. This indicates that the overall morphology of the urban structure of oasis in the study area is compact and regular, but appears to have a tendency of loosening and become more complicated. The result is contrast to the research of Wang Xinsheng's on urban structure developing tendency of 31 big cities in China, who argued that city structure tends to be compact and regular (Wang et al., 2005). It can be explained that the development of the study area is lower than the national level. Therefore it justifies the conclusion that urban agglomeration of oasis in the study area is still at a primary stage from a viewpoint of urban morphology.

4 Conclusions

Urban agglomeration in the northern slope of the Tianshan Mountains is one of the most active and potential areas in economic development layout of the western China. The description of spatio-temporal character of hierarchical scale structure, spatial distribution, and general morphology character in the northern slope of the Tianshan Mountains show that the spatial distribution of urban agglomeration in study area is largely restrained and influenced by its natural condition. Thus, it is characterized by "dense-and-sparse" distribution at the edges of oasis, expanding distribution along river, and traffic branch clustering on both sides. The connectivity among cities is high; spatial organization morphology portrays a strip pattern with point-strip and circle-surface integration. The population cluster turns from "mononuclear" to tendencies of "multi-nuclear", changing from infant stage of scattered development with "mononuclear" into primary stage of center city transiting to metropolitan area, and the hierarchical scale structure of urban agglomeration is becoming mature; along direction of watershed, spatial expansion of individual cities in the northern Tianshan Mountains resembles the shape of a long strip. The total changing process of city morphology tends to be more complicated in shape and looser in structure. In a nutshell, urban agglomeration of oasis in the northern slope of the Tianshan Mountains exhibits atypical urban agglomeration. Its spatial clustering degree is low and its economic interaction is weak and irregular. It stays in the primary stage of urban agglomeration. The phenomenon of mononuclear is receding and multi-nuclear is becoming more and more obvious.

However, the urban agglomeration in the northern slope of the Tianshan Mountains is in the primacy and there still lacks core radiant source and obvious interaction among cities. Meanwhile, blind urban expansion leads to the waste of urban resources use in land, water and other public facilities. The coordination of scale hierarchy, reasonability of spatial distribution, and intensive urban land use are the three indispensable factors of healthy development of urban agglomeration. Considering the special region of urban agglomeration in the northern slope of the Tianshan Mountains with low bearing capacity of resources and environment, big-scale aggregate economy and population, and vulnerable ecological environment, more efforts need to be put not only into strengthening the development of citifies with good economic development condition and making it a powerful core radiant source to impel the development of whole region, but also into region planning. Through regional planning and policy, the relationships among cities and regions will become more

coordinated so as to achieve reasonable city division, increase utilization efficiency of various resources, and instruct harmonious development in urban agglomeration. Furthermore, through planning, urban spatial morphology becomes as compact as possible so as to increase soil utilization efficiency and publicizing rate of public facilities and decrease the occupation of cultivated land.

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