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The Structure and Pattern of Urban Network in the Lanzhou-Xining Urban Agglomeration

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Abstract: In this paper, we use factor analysis to evaluate the urban comprehensive quality of each city in the Lanzhou-Xining (Lan-Xi) urban agglomeration. The time distance was obtained by using GIS spatial analysis, and the structure and pattern of the spatial network were analyzed by using the gravity model and social network analysis method. The results show that: 1) The scale effect of the Lan-Xi urban agglomeration is gradually emerging, and it is gradually forming the urban agglomeration with Lanzhou and Xining as the core, the Lan-Xi high-speed railway as the axis, and a high-dense connection. 2) Lanzhou and Xining are at the core of the Lan-Xi urban agglomeration, which has a strong attraction and spreads to neighboring cities. 3) In the network structure of the Lan-Xi urban agglomeration, Lanzhou, Baiyin, Gaolan, Yuzhong, Yongdeng, Dingxi, Lintao, Xining, Ledu, Huangzhong, Ping'an, Minhe and Datong are located in the network core position, which have the superiority position and lead to the entire regional communication enhancement and the regional integration development. 4) This urban agglomeration has significant subgroups, eight tertiary subgroups and four secondary subgroup; the tertiary subgroups which compose secondary subgroup have a close connection and mutually influence each other. 5) The Lanzhou Metropolitan Area and the Xining Metropolitan Area have an important impact on the surrounding cities, and the peripheral cities are basically controlled by the central city. The Dingxi subgroup, Lintao-Linxia subgroup, Gonghe subgroup have more structural holes than the subgroups within the Lanzhou Metropolitan Area and the Xining Metropolitan Area, so the peripheral cities of these subgroups have relatively less connection with surrounding cities.

Keywords: urban network; spatial structure; spatial pattern; Lan-Xi urban agglomeration; China

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1 Introduction

With the development of new urbanization, urban agglomeration is regarded as an important form of promoting urbanization in China (Sun et al., 2015; Zhen et al., 2017). In the development report of China's urban agglomeration of 2016, the new pattern '5+9+6' of China's urban agglomeration spatial structure has been formed, namely five national large-scale urban agglomerations, nine regional medium-sized urban agglomerations and six regional small urban agglomerations (Fang et al., 2016). The function of the strategic node of the urban agglomeration space organization in China's economic and social development has been highlighted, and will continue to perform its function of agglomeration, diffusion, leadership and demonstration in urbanization, integration and economic development (Fang and Yu, 2017). As one of the six regional small urban agglomerations, the Lan-Xi urban agglomeration is one of the most dynamic regions in the northwest of China, and it is an important growth pole for the development of the whole northwestern region. It is located in the interna-

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tional economic cooperation corridor of the new Eurasian land bridge, which is an important support of the China-Central Asia-West Asia economic corridor, and is also located in an important position within the Silk Road Economic Belt, whose strategic position is outstanding. The state's 'New Urbanization Planning (2014–2020)', 'Economic and Social Development 'Thirteen-Five' Planning Outline' and 'West development 'Thirteen-Five' planning' proposals guide the development of the Lan-Xi urban agglomeration. In February 2018, the State Council formally approved the development plan of the Lan-Xi urban agglomeration. Thus the development of the Lan-Xi urban agglomeration has become an important subject for scholars to study.

Urban agglomeration refers to a city space, consisting of a high-density connection between the large, medium and small cities (Wang et al., 2016; Ye and Liu, 2018). Currently, there are a number of scholarly studies on the network structure of urban agglomerations, and the existing research is based on the use of social networks analysis (Sun et al., 2015; Ma and Li, 2017), space pattern analysis (Liu et al., 2014; Wang and Zhai, 2015; Ye and Liu, 2018), and the development rule of urban agglomeration (Zhao et al., 2015a; Chen et al., 2017), such as the general pattern (Champion, 2001; Parr, 2002; Chen et al., 2013; Zhen et al., 2019), structure (Leng et al., 2011;Wu et al., 2011; Wang and Zhai, 2015; Zhao et al., 2016), hierarchy (Leng et al., 2014; Wang and Jing, 2017) and patterns of the structure (Wang et al., 2012; Li and Jin, 2016), but research is mainly concentrated on the urban agglomeration which is located on the plains. This paper took Lan-Xi urban agglomeration as the study area which is located in the area of the upstream region of Yellow River, between the Tibetan plateau ecological barrier and the northern soil defence of China, whose network of cities is different from others on the plains. Due to the constraints of geographical location, traffic conditions, and fragile ecological environment, the development of the Lan-Xi Urban Agglomeration is insufficient and the urbanization process is relatively slow. Compared with the urban agglomerations in the developed eastern regions, its development level is relatively low, and its development stage is still that of urban agglomerations cultivation. Therefore, studying the spatial structure and pattern of the Lan-Xi urban agglomeration has important regional significance for promoting the development of the Hehuang urban belt and promoting the rapid development of the social economy in Gansu and Qinghai and even the whole western region. At the same time, it enriches the research content of the urban agglomerations, which has important comparative significance for the study of eastern and central urban agglomerations.

In the application of data, although a variety of 'flow' data can be visualized to reflect the spatial connection, currently in the study of urban areas abroad and the developed domestic urban agglomeration, the data of corporate organizations (Beaverstock et al., 2000; Yin et al., 2011; Wu and Ning, 2012), news (Zhen et al., 2012; Tranos et al., 2014; Zhao et al., 2015b; Zhen et al., 2017) and business logistics (Liu et al., 2017; Feng et al., 2018), commodity chain (Burger and Meijers, 2012; Burge et al., 2014) and other data (Li et al., 2015;Wang et al., 2018; Ye et al., 2018) were used to measure the urban network. However, the acquisition of such data is difficult, and in the less developed regions of Northwest China, due to the relatively small number of companies, where even some counties are small towns, basically no industrial and corporate organizations even exist. These small towns have small populations and less commodity flows and information flows. Therefore, this study mainly used statistical data combined with night light data-NPP/VIIRS and the gravitational model to determine the spatial connection of the urban agglomeration. On this basis, the social network analysis method was used to analyze the spatial network structure and pattern of the Lan-Xi urban agglomeration.

2 Materials and Methods

2.1 Study area

The Lan-Xi urban agglomeration has been a relatively densely populated area of the western region since ancient times. The civilization of the Hehuang Valley has been continued here. Since the Han Dynasty, this area has been an important area of settlement, where, after the Sui and Tang dynasties, the famous 'tea horse market' also flourished. Secondly, Xining, Ping'an and Ledu which belongs to Qinghai Province, and Lanzhou, Baiyin, Linxia which belongs to Gansu Province, are the region's best economic development areas. The former represents the economic development level of the Qinghai Province, the latter represents the economic development level in the Gansu Province. Taken together, in this phase, they demonstrate mutual influence and communication with each other, thereby becoming a unique unit across their administrative boundaries.

In this study, the scope of the Lan-Xi agglomeration is based on the regional development planning which was approved by the State Council in 2018 (Fig. 1), and it includes a total of 39 districts and counties. In this paper, 39 counties (districts) were combined into 31 research units. Among them, Chengguan District, Qilihe District, Xigu District, Anning District, Honggu District merged into Lanzhou City as one research unit; Baiyin District and Pingchuan District merged into Baiyin City as one unit; Chengdong District, Chengxi District, Chengzhong Distritc and Chengbei Distric merged into Xining City as one unit, and each county is a research unit for the others. Lanzhou and Xining belong to the big city category. The Lan-Xi urban agglomeration belongs to an important economic belt and urban economic zone in the upper reaches of the Yellow River, and will form a '3-hour City Circle', which becomes a very dynamic urban economic agglomeration area in northwestern China.

2.2 Data sources

The research data include statistical data and transportation vector data of 2016. The statistical data was obtained from the public Statistical Yearbook, mainly the China County Statistical Yearbook (National Statistical Bureau of China, 2016a), China City Statistical Yearbook (National Statistical Bureau of China, 2016b), Gansu Development Yearbook (Gansu Development Yearbook Editorial board, 2016), 'Qinghai Statistical Yearbook (Qinghai statistical yearbook Editorial Board, 2016), and regarding individual non-recorded data in the Statistical Yearbook was derived from government work reports and statistical bulletins. The transportation vector data include highways, high-speed railways, national highways, provincial highways, county roads, rural roads, and ordinary railways within the Lan-Xi urban agglomeration. This data was obtained from the Chinese Academy of Sciences and the China Resource and Environmental Science Data Center (http://www.resdc.cn). The night light intensity data (NPP/VIIRS 500 m × 500 m) was obtained from the National Oceanographic Information Center (NOAA/NCEI) of the National Oceanic and Atmospheric Administration. The website is https://www.ngdc.noaa.gov/eog/viirs/download_dnb_composites.html.The nightlight data of 31 research units was extracted and the average night light intensity of each research unit was calculated.

2.3 Methodology

2.3.1 Construction of urban comprehensive quality evaluation index

The city's radiation ability is determined by the city's

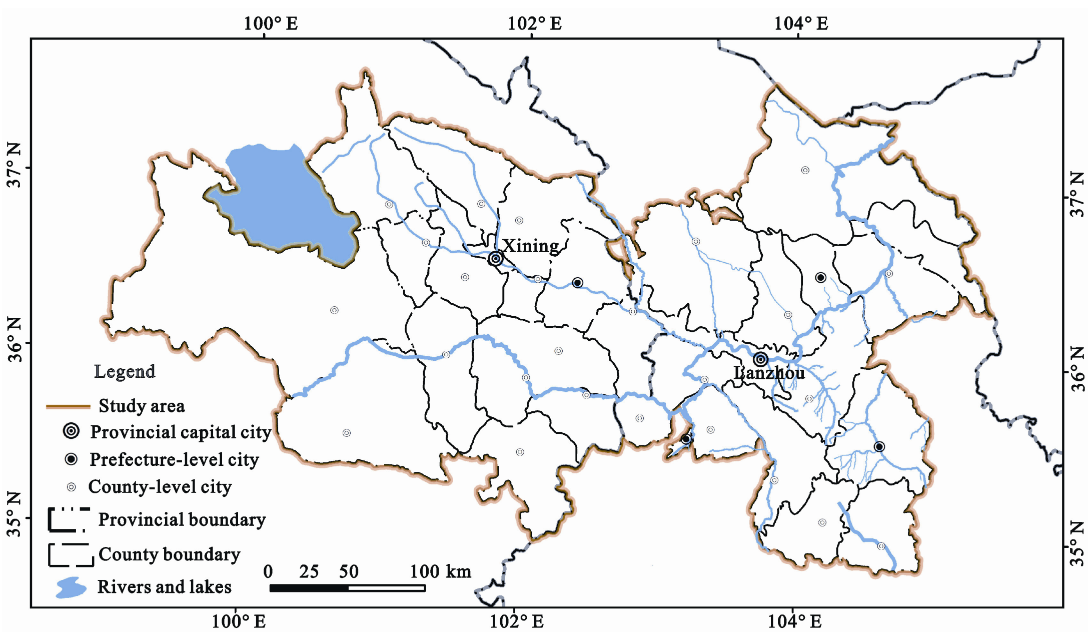

Fig. 1 The location of the study area

own scale, economic and service and changes with the competitiveness of the surrounding cities. Therefore, this paper used the comprehensive index system to analyze the comprehensive quality of the cities in the Lan-Xi urban agglomeration. Combined with the availability of data, this paper selected the city's total economic amount, industrial structure, urbanization level, and infrastructure as the four aspects. The factor analysis method was used to extract the primary components. The weighted accumulation of the primary components denoted by the eigenvalues is called the comprehensive value, that is, the comprehensive quality values of the cities (Table 1).

2.3.2 Gravity model

This study mainly used the gravity model to determine the spatial connection between cities. The distance in the gravity model was corrected by the shortest time distance between each two cities, and the spatial connection between 31 cities and counties was obtained. The calculation formula is:

$$R_{ij} = k_{ij} \frac{M_i M_j}{D_{ij}^2}, \left(k_{ij} = \frac{M_i}{M_i = M_j} \right), R_i = \sum_{j-1}^{n} R_{ij} \quad (1)$$

where R_{ij} is the spatial connection between cities i and j; R_i is the total amount of external connection of city i; M_i and M_j are the comprehensive quality of cities i and j respectively; k_{ij} is the contribution rate of city i accounted for R_{ij}; D_{ij} is the travel time between the cities of i and j based on the shortest path of the road network.

The network data sets needed to be established first. The road grade was set according to the Engineering Technical Standard. The high-speed railway is 250 km/h, the railway is 100 km/h, the expressway is 120 km/h, the national road is 80 km/h, and the provincial road is 60 km/h. The county and township road are 40 km/h. At the same time, 31 cities and counties were loaded as nodes in the road network. The shortest traffic time between nodes was obtained by network analysis in ArcGIS 10.2.

Table 1 City comprehensive quality evaluation index system in the Lan-Xi urban agglomeration

Index class	Index	Index No.
Total economy	Population (Ten thousand people)	X_1
	Population density (person/km^2)	X_2
	GDP (Ten thousand yuan)	X_3
	Local finance revenue (Ten thousand yuan)	X_4
	Fixed assets investment (Ten thousand yuan)	X_5
	The total retail sales of social consumer goods (Ten thousand yuan)	X_6
Industrial structure	Second industry added value (Ten thousand yuan)	X_7
	Third industry added value (Ten thousand yuan)	X_8
	Number of employees in the secondary industry (person)	X_9
	Number of employees in the tertiary industry (person)	X_{10}
Urbanization level	Urban population (Ten thousand person)	X_{11}
	Urbanization rate (%)	X_{12}
	Construction land area (km^2)	X_{13}
	Proportion of construction land (%)	X_{14}
	The proportion of the second and third production (%)	X_{15}
	Night light intensity	X_{16}
Infrastructure	Per capita urban road area (m^2)	X_{17}
	Green area coverage in built-up areas (%)	X_{18}
	Per capita public green area (m^2)	X_{19}
	Water popularity rate (%)	X_{20}
	Drainage pipe density in built-up area (km/km^2)	X_{21}
	Weighted road network density (km/km^2)	X_{22}
	Railway network density (km/km^2)	X_{23}
	Number of beds in medical institutions	X_{24}

2.3.3 Social network analysis

(1) Centrality

The node's centrality quantitatively analyzes other nodes' dependence on the designated node, and is represented by three indicators: degree centrality, closeness and betweenness (Sun et al., 2015). In the urban agglomeration network, each city has a different connection quantity with the other cities, and thus its power is different. Degree centrality refers to the connection quantity a city has in an urban agglomeration network. It is used to measure the power of a city to connect with other cities directly. A higher degree centrality of a city indicates that a particular city has more power to connect to other cities. The betweenness centrality is measured by the sum of geodesic distance between nodes in the network, indicating the ability that node city has to be an 'intermediary' of other node cities. It measures the controlling ability of a node city and its mediating role between cities. If the node city is located on the shortest path of other cities, the city has a higher betweenness centrality. This city would be less dependent on other cities. Closeness centrality refers to the domination condition of one node city. If a city is connected to many other cities by a relatively short path, then the city is close to the network center. A higher closeness centrality means that a city has access to other cities in the network and is relatively uncontrolled by other cities. Closeness centrality should not be computed until within a fully connected network. Besides, closeness has significant correlation with degree centrality. Therefore, it is rarely used to describe the centrality of nodes (Luo, 2010; Sun et al., 2015; Liu et al., 2018).

1) Degree Centrality

Degree Centrality in a directed network is divided into an outdegree centrality and an indegree centrality. A high outdegree centrality means the city has strong radiation and a high indegree means strong attraction. The formula is used as follows (Liu,2014):

$$C_{DO}(n_i) = d_o(n_i) = \sum\nolimits_j x_{ij} \tag{2}$$

$$C_{DI}(n_i) = d_I(n_i) = \sum\nolimits_j x_{ji} \tag{3}$$

$C_{DO}(n_i)$ is the value of outdegree; $C_{DI}(n_i)$ is the value of indegree; x_{ij} is 0 or 1, indicating whether city i has connection with cities j; x_{ji} is also 0 or 1, indicating whether city j has connection with city i.

2) Betweenness Centrality

The formula of betweenness centrality is:

$$C_B = \sum\nolimits_{j<k} g_{jk}(n_i) / g_{jk} \tag{4}$$

Where g_{jk} represents the number of geodestations existing between point j and point k; $g_{jk}(n_i)$ indicates the number of geodesics of city i on the shortcut of city i to city k.

(2) Network core-periphery model

The core-periphery model in social networks is the inheritance of the 'core-edge' structure of western economic development theory, which can distinguish a series of actors with high density (core) and a series of actions with low density (edge). At the core the actors can coordinate actions, marginal actors cannot coordinate actions, and the core actors are therefore located in the dominant position (Liu, 2014). The 'core-periphery' can reveal the central and peripheral locations of each city node in the network.

(3) Subgroups analysis

This is an important tool for using social network analysis to understand the structure of the network and the embeddedness of individuals is subgroups. The general definition of a subgroup is as follows: a subgroup is nothing more than a subset of actors, and the connections between actors in a subset are relatively close. In general, an 'aggregated subgroup' is a subset of actors that meet the conditions of a relatively strong, direct, close, frequent, or positive connection between the actors in the set.

(4) Structure hole analysis

Burt found that structural holes represent a non-redundant tie between two actors. In a network, the nodes occupying the structural hole position are the bridges for the resource exchange of other nodes. Structural holes dominate the flow of information and resources throughout the network and are able to capture resources. There are two main types of indices used to measure structural holes. The first is Burt's measurement of structural holes, and the other is Freeman's recommended betweenness centrality (Sun et al., 2015). Burt's measurements take into account four indicators namely effective size, efficiency, constraint, and hierarchy. This approach is more influential in assessing network information than the Freeman approach. Therefore, we used Burt's method to measure structural holes.

3 Results and Discussion

3.1 Evaluation of comprehensive quality of cities

Since the measurement units of the raw data for each index are different, the original data was first standardized by the *Z* value standardization method to eliminate the dimension influence. The SPSS24.0 software was used to analyze 24 indicators of urban comprehensive quality, and the initial eigenvalue and contribution rate was obtained (Table 2). The maximum variance rotation method was selected to extract five principal components, and the KMO value was 0.815. The rate reached 87.643%. The comprehensive factor score was calculated according to the contribution rate of the principal components.

Since the comprehensive quality index score calculated by the factor analysis method had a negative value, data transformation was needed to make all of them positive, so the data was transformed according to the method mentioned in the reference (Zhang, 2013), so that the data all is positive (Table 3).

Table 2 The eigenvalue and contribution rate of urban centrality evaluation factors in study area

Principal component	Initial eigenvalue (%)			The sum of squared loads (%)			Sum of squared rotational loads (%)		
	Total	Percentage	Accumulative percentage	Total	Percentage	Accumulative percentage	Total	Percentage	Accumulative percentage
1	14.190	59.126	59.126	14.190	59.126	59.126	10.660	44.415	44.415
2	2.453	10.220	69.347	2.453	10.220	69.347	5.092	21.218	65.633
3	1.808	7.535	76.881	1.808	7.535	76.881	2.382	9.923	75.556
4	1.540	6.416	83.297	1.540	6.416	83.297	1.790	7.457	83.012
5	1.043	4.345	87.643	1.043	4.345	87.643	1.111	4.630	87.643
6	0.691	2.878	90.520						
7	0.620	2.582	93.103						
8	0.508	2.117	95.219						
9	0.432	1.801	97.020						
10	0.287	1.195	98.215						
11	0.161	0.671	98.886						
12	0.148	0.618	99.504						
13	0.043	0.178	99.682						
14	0.036	0.150	99.832						
15	0.017	0.071	99.904						
16	0.010	0.042	99.946						
17	0.004	0.018	99.963						
18	0.003	0.013	99.976						
19	0.002	0.010	99.986						
20	0.001	0.006	99.992						
21	0.001	0.005	99.997						
22	0.000	0.001	99.999						
23	0.000	0.001	99.999						
24	0.000	0.001	100.000						

Table 3 Standardization of the scores of the comprehensive quality factor of the Lan-Xi urban agglomeration

City/County	Comprehensive score on mapping interval [1, 3.924]	Comprehensive score after Standardization	City/County	Comprehensive score on mapping interval [1, 3.924]	Comprehensive score after Standardization
Lanzhou	3.924	100	Datong	1.209	31
Yongdeng	1.395	36	Huangzhong	1.203	31
Gaolan	1.251	32	Huangyuan	1.098	28
Yuzhong	1.283	33	Ledu	1.206	31
Baiyin	1.654	42	Ping'an	1.206	31
Jingyuan	1.286	33	Minhe	1.173	30
Jingtai	1.142	29	Huzhu	1.235	31
Dingxi	1.292	33	Hualong	1.189	30
Longxi	1.232	31	Xunhua	1.111	28
Weiyuan	1.154	29	Haiyan	1.083	28
Lintao	1.186	30	Tongren	1.000	25
Linxia	1.416	36	Jianzha	1.044	27
Yongjing	1.182	30	Gonghe	1.201	31
Dongxiang	1.072	27	Guide	1.182	30
Jishishan	1.066	27	Guinan	1.077	27
Xining	2.494	64			

The ArcGIS 10.2 was used to link the attribute table of the study area, and the natural break method was used to classify the comprehensive quality of each city. The results can be divided into five levels (Fig. 2). The first level includes Lanzhou and Xining, which are the largest central cities in the study area. The urban comprehensive quality is greater than 60, which far exceeds other cities. As can be seen from Fig. 2, generally, the urban comprehensive quality is higher in the east than the west. Only Jishishan and Dongxiang's urban comprehensive quality are very low in Gansu. There is no cities with medium urban comprehensive quality in Qinghai. Except for the provincial capital Xining, the others all are low or very low. There are six small towns whose urban comprehensive quality is very low in Qinghai, which account for 75% of the total number of very low level in the entire region.

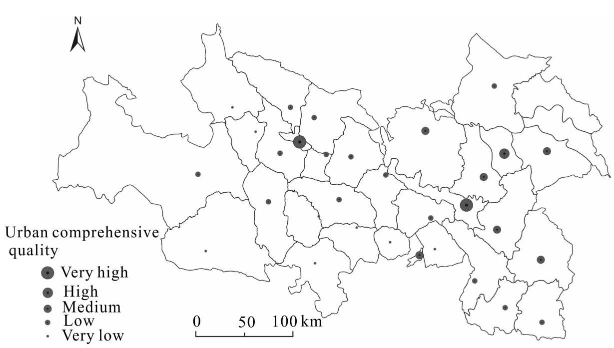

Fig. 2 Urban comprehensive quality level map of the Lan-Xi urban agglomeration

3.2 Analysis of the spatial connection network structure

3.2.1 Estimation of city's total external connection

The gravitational model was used to calculate the spatial connection between each two cities. According to the modified gravitational model, the connection matrix between the 31 research units was calculated. The total amount of external connection of the 31 cities was measured accordingly (Table 4). The results show the following characteristics. First, the spatial differences in the total external connection quantity are significant. The polarization effect is obvious. Lanzhou ranks first and it is larger than the sum of 10 cities who rank as the last 10, namely Guinan, Jishishan, Tongren, Jingtai, Dongxiang, Gonghe, Xunhua, Guide, Weiyuan and Haiyan. The reason for this is the difference in population size, economic scale, urban comprehensive quality, and accessibility between the cities and counties. The greater the population, the larger the economy amount, the better the comprehensive quality of the city, and the better the transportation conditions, the closer the spatial connection between cities, and vice versa. Secondly, the scale effect centered on the regional central city is gradually emerging. On the whole, the Lan-Xi urban agglomeration is gradually forming an urban agglomeration with Lanzhou and Xining as the core and the Lanxin High-speed Railway as an axis. In the third instance, the natural environment has a great impact on the spatial connection of the Lan-Xi urban agglomeration. Judging by the natural and geographical conditions, among the ten cities ranked as the last, Haiyan, Guide, Tongren, Xunhua, Weiyuan, Gonghe and Guinan all are surrounded by many mountains, they are at a high altitude and blocked by mountains. The inconvenience of transportation has increased the economic costs of communicating with other cities, resulting in a relatively small external connection with these areas. Fourthly, the traffic pattern has largely shaped the spatial pattern of total urban connections. Most of the top ranked cities are distributed along the transportation lines, especially the developed transportation networks such as the Lan-Xi high-speed rail, expressways and railways. They are connected by various modes of transportation and provide strong support for economic connection.

3.2.2 Network centrality analysis

According to the statistical analysis of the spatial connection between the cities, the distinguishing point value was selected to convert the matrix. After many repeated attempts, we found that when the distinguishing point value is 300, the network structure is relatively stable and representative, so 300 was considered the distinguishing point of the connection quantity. The connection quantity greater than or equal to 300 was set to 1 and less than 300 to 0. Ucinet6.0 software was used for network analysis to obtain the centrality of inter-city connection between the 31 cities (Table 5).

Table 4 Quantity and rank of each city's total external connection

Rank	City	Sum of external connection
1	Lanzhou	43600.81
2	Xining	24858.21
3	Baiyin	9083.91
4	Ledu	8742.30
5	Ping'an	7899.73
6	Huangzhong	6919.32
7	Datong	6760.96
8	Gaolan	6686.46
9	Huzhu	6131.27
10	Yongdeng	6111.86
11	Minhe	6090.56
12	Yuzhong	5894.02
13	DingXi	5632.14
14	Linxia	5519.97
15	Huangyuan	5363.10
16	Hualong	4867.06
17	Jingyuan	4801.90
18	Lintao	4706.30
19	Jianzha	4600.08
20	LongXi	4594.30
21	Yongjing	4405.84
22	Haiyan	4194.08
23	Weiyuan	4147.25
24	Guide	4024.45
25	Xunhua	3969.72
26	Gonghe	3893.04
27	Dongxiang	3500.70
28	Jingtai	3308.75
29	Tongren	3131.61
30	Jishishan	2799.37
31	Guinan	2208.31

Table 5 Network centrality of the Lan-Xi urban agglomeration

Degree centrality				Betweenness	
City	Outdeg	City	Indeg	City	Centrality
Lanzhou	17	Lanzhou	30	Lanzhou	35.369
Xining	16	Xining	25	Xining	14.63
Ledu	12	Baiyin	14	Ledu	2.566
Ping'an	9	Pingan	10	Baiyin	2.315
Baiyin	8	Minhe	9	Minhe	1.571
Huangzhong	8	Gaolan	9	Lintao	1.362
Huangyuan	8	Yuzhong	8	Ping'an	1.34
Datong	8	Huzhu	8	Yongdeng	0.886
Gaolan	8	Ledu	7	Gaolan	0.886
Minhe	8	Yongdeng	7	Yuzhong	0.857
Jianzha	7	Dingxi	7	Linxia	0.837
Yuzhong	7	Huangzhong	7	Huangzhong	0.826
Dingxi	7	Datong	7	Jianzha	0.705
Huzhu	6	Jianzha	6	Dingxi	0.551
Yongdeng	6	Lintao	5	Datong	0.543
Lintao	6	Longxi	5	Huangyuan	0.402
Longxi	6	Hualong	5	Weiyuan	0.188
Hualong	6	Weiyuan	4	Haiyan	0.172
Jingyuan	5	Huangyuan	4	Longxi	0.125
Weiyuan	5	Jingyuan	3	Xunhua	0.115
Yongjing	5	Linxia	3	Huzhu	0.099
Linxia	4	Xunhua	3	Hualong	0.092
Xunhua	4	Haiyan	3	Yongjing	0
Tongren	3	Jingtai	2	Jingyuan	0
Haiyan	3	Dongxiang	2	Jingtai	0
Dongxiang	2	Guide	2	Jishishan	0
Guide	2	Gonghe	1	Guide	0
Jingtai	2	Yongjing	1	Tongren	0
Gonghe	1	Tongren	0	Dongxiang	0
Jishishan	1	Jishishan	0	Guinan	0
Guinan	0	Guinan	0	Gonghe	0
Mean	6.129	Mean	6.354	Mean	2.143

(1) Degree centrality

From the perspective of outdegree, Lanzhou, Xining and Ledu are the top three cities, indicating that Lanzhou, Xining and Ledu are the three cities with the strongest external radiation ability. The outdegree of Ledu is much larger than the indegree, indicating that its radiation capacity is greater than its attraction capacity. Among the 13 cities whose outdegree value is greater than the mean outdegree value, there are only 5 in Gansu Province and 8 in Qinghai Province, indicating that the outdegree of the Xining Metropolitan Area is higher than the Lanzhou Metropolitan Area. As shown in Fig. 3, the distribution of external radiation capacity of the Xining Metropolitan Area is relatively balanced, and there is a large spatial difference in the Lanzhou Metropolitan Area.

From the perspective of the indegree, the top three cities are Lanzhou, Xining, and Baiyin, which have strong attractiveness. It should be pointed out that the indegree value of Baiyin City is much larger than its outdegree value, indicating that its attractiveness is far greater than its radiation capacity. Among the 13 cities whose indegree value is larger than the mean value, Gansu Province accounts for 6 and the proportion is greater than the proportion of the outdegree value, indicating that the attraction of the Lanzhou Metropolitan Area is greater than its radiation capacity. The outdegree and indegree values of Jingtai, Dongxiang, Guide, Gonghe, Yongjing, Tongren, Jishishan and Guinan are relatively low, their radiation power and attractiveness both are relatively weak. They are located on the periphery of the urban agglomeration. On the whole, the outward radiation capacity of the central city is lower than its attraction. Besides, the radiation ability is relatively balanced, and the condensation attraction varied more in spatial distribution.

(2) Betweenness centrality

The betweenness centrality of Lanzhou and Xining are in the leading position, indicating that Lanzhou and Xining are in a key position in the Lan-Xi urban agglomeration. They are bridges between cities, and well communicated with other cities. The results also show that Lanzhou and Xining control a large amount of information and a wide range of resources. They are followed by Ledu, Baiying, and Ping'an, indicating that these three cities are also important transit cities. As can be seen from Fig. 3, most of the cities whose betweenness centrality value is larger than 1 are along the Lanxin high-speed rail except for Baiyin and Lintao; all the other cities have a very low betweenness value. The counties with a betweenness degree value of 0 indicate that these counties have less connection with other cities and counties. Most of these counties are in remote areas with small populations and inconvenient transportation systems.

Compared with the degree centrality, the betweenness centrality value is generally low, and the spatial distribution varies more. In the core cities such as Lanzhou and Xining, the urban network centrality values are more than 10 times that of the other cities. The betweenness centrality value of Lintao and Linxia ranks higher than the degree centrality value. This is because the lower centrality degree makes the spatial connection between the cities loose, which needs a central city to perform an intermediary role. The betweenness of Huzhu, Hualong, Huangzhong and Gonghe ranks lower than their degree centrality, which implies the intermediary ability of these cities is weaker than their attraction and radiation ability.

Based on the ranking of the above three centrality indicators, the centrality of Lanzhou and Xining is much higher than that of the other cities, indicating that the two cities are more closely connected with the other cities, they can communicate more with the neighboring cities and have a stronger radiation ability and attractiveness. Lanzhou is at the core of the Lan-Xi urban agglomeration and has strong attraction to surrounding cities. It constantly absorbs the superior resources of the surrounding cities, and spreads information technology to surrounding cities and thereby forms an interactive relationship. Xining follows closely, and as the provincial capital of Qinghai Province, it also continuously

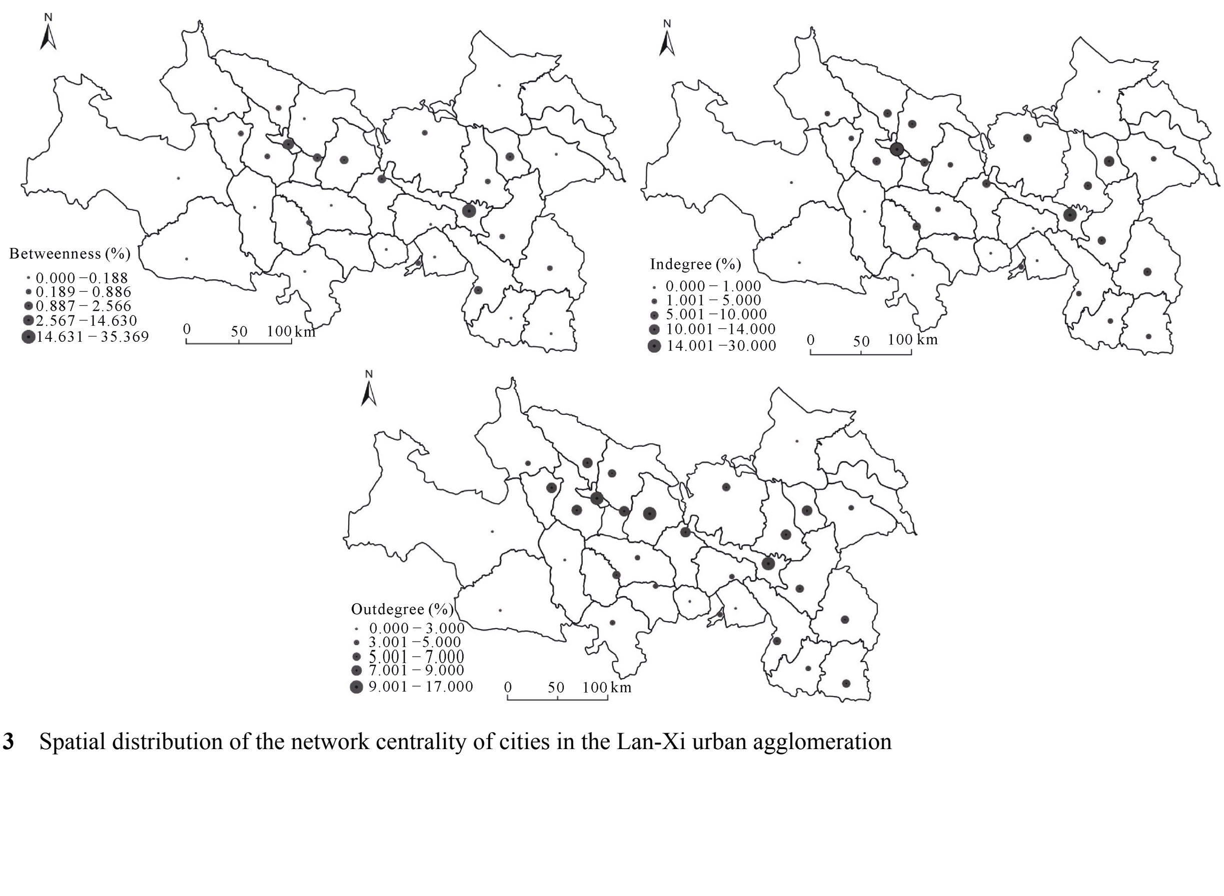

Fig. 3 Spatial distribution of the network centrality of cities in the Lan-Xi urban agglomeration

absorbs the surrounding resources, which also has a great impact on the surrounding cities. In addition, the attraction of Baiyin is greater than its radiation capacity, and the radiation capacity of Ledu is greater than its attraction. The main reason for this is because the comprehensive quality of Baiyin City is higher than Ledu. The economy, technology, human resources and other aspects are more attractive in Baiyin City than in Ledu, but with respect to the transportation situation, Ledu is superior. After the opening of the Lanxin high-speed rail, the position of Ledu was further promoted. The closer communication with major cities has therefore improved the position of Ledu.

3.2.3 Core periphery analysis

Using the core periphery model (Liu et al., 2010, 2014), the core and periphery area of the Lan-Xi urban agglomeration was analyzed to distinguish the central cities and marginal cities. Within the network structure, Lanzhou, Baiyin, Gaolan, Yuzhong, Yongdeng, Dingxi, Lintao, Xining, Ledu, Yuzhong, Ping An, Minhe, and Datong are at the core of the network, with a fitness value of 0.657. Generally, neighboring cities centered on Lanzhou and neighboring cities centered on Xining are at the core of the spatial connection among the entire urban agglomeration, and have an advantageous position in the network, which can lead to the strengthening of regional spatial connection and the development of regional integration. Lanzhou-Baiyin, Lanzhou-Dingxi, Lanzhou-Yuzhong, Xining-Ledu, Xining-Ping'an have an obvious strong connection in the network. Jingtai, Jingyuan, Weiyuan, Jishishan, Longxi, Yongjing, Linxia, Dongxiang and Hualong are located on the half periphery of the network, Xunhua, Wuyuan, Jianzha, Huzhu, Guide, Tongren, Haiyan, Guinan, Gonghe are located in the peripheral area (Fig. 4).

3.2.4 Subgroups analysis

Subgroups are an important part of social network analysis. Subgroups in urban networks do not mean urban alliances but describe the sub-sets of cities with relatively strong and direct internet connections between cities, which are conductive to regional development and planning. In this paper, the network was clustered and its density was calculated by CONCOR method. The results are shown in Table 6 and Fig. 5. Considering the overall pattern, the Lan-Xi urban agglomeration has four second subgroups and 8 tertiary subgroups. The eight tertiary subgroups include Lanzhou subgroup, Baiyin subgroup, Dingxi subgroup, Lintao-Linxia subgroup, Xining subgroup, Gonghe subgroup, Hualong-Jianzha subgroup and the Xunhua subgroup. These subgroups are basically consistent with the administrative boundaries of Lanzhou, Baiyin, Dingxi and Linxia, but they are not completely consistent with all the administrative boundaries. For example, Minhe is more closely connected with Lanzhou than Xining, Lintao is more closely connected with Linxia than Dingxi, and Xunhua is divided separately. As a subgroup, this indicates that regional differentiation is largely influenced by factors such as spatial location, central city attractiveness, and transportation, rather than being completely blocked by administrative boundaries.

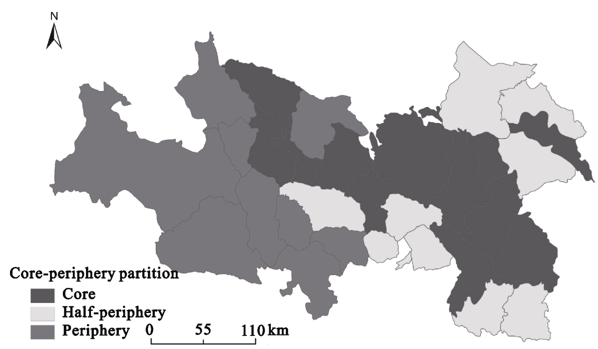

Fig. 4 The core-periphery partition map of Lan-Xi urban agglomeration

Table 6 Density of subgroups of spatial connection network in the Lan-Xi urban agglomertion

	1	2	3	4	5	6	7	8
1	2750.985	1243.696	840.809	748.986	1102.921	387.802	451.643	442.107
2	1243.696	1078.299	430.009	372.334	444.440	216.867	258.128	249.094
3	840.809	430.009	1231.96	484.075	326.996	158.61	187.547	172.000
4	748.986	372.334	484.075	676.157	266.524	155.403	212.393	254.015
5	1102.921	444.44	326.996	266.524	1928.177	595.888	642.632	514.969
6	387.801	216.867	158.61	155.403	595.888	478.778	275.807	251.494
7	451.643	258.128	187.547	212.392	642.632	275.807	734.203	862.913
8	442.107	249.094	172	254.015	514.969	251.494	862.913	0

Notes: 1 represents the Lanzhou Subgroup, 2 the Baiyin Subgroup, 3 the Dingxi Subgroup, 4 the Lintao-Linxia Subgroup, 5 the Xining Subgroup, 6 the Gonghe Subgroup, 7 the Hualong-Jianzha Subgroup, 8 Xunhua

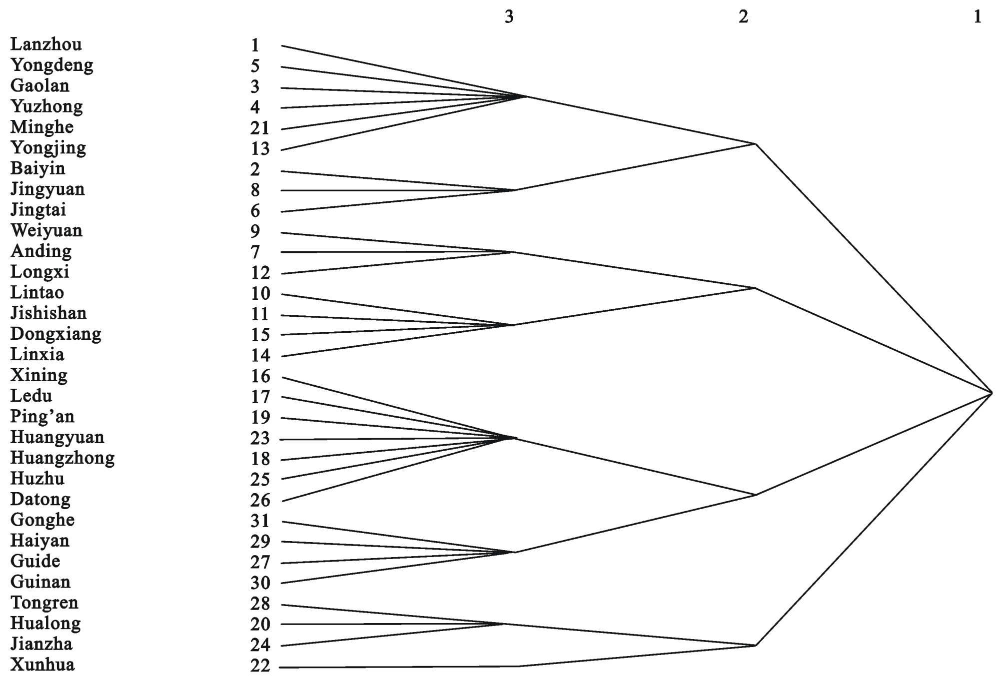

Fig. 5 Cohesive subgroups in the Lan-Xi urban agglomeration whole city network

From the network density of each subgroup (Table 6), the most closely related is the Lanzhou subgroup, mainly due to the operation of the Lanxin high-speed rail and the strong attraction and radiation of Lanzhou to surrounding cities. It is followed by the Xining subgroup, then by the Dingxi subgroup and the Baiyin subgroup. The Gonghe subgroup is relatively remote, the connectivity and accessibility are relatively poor, and the network density is relatively low.

This urban agglomeration has significant subgroups which include eight tertiary subgroups and four secondary subgroups (Fig. 6). From Fig. 5 and the mutual density between subgroups, we note that the subgroup consisting of Lanzhou, Minhe, Yuzhong,Yongdeng, Gaolan, Yongjing and the subgroup consisting of Baiyin, Jingyuan, Jingtai mutually influence each other, so these two tertiary subgroups compose one second subgroup which is the Lanzhou metropolitan subgroup (Fig. 6). Similarly, the subgroup consisting of Weiyuan, Dingxi and Longxi closely connect with the subgroups consisting of Lintao, Jishishan, Dongxiang and Linxia. The subgroups consisting of Xining, Ledu, Ping'an, Datong, Huangyuan, Huangzhong and Huzhu are closely connected with the subgroups composed of Guide, Gonghe, Haiyan and Guinan. The subgroup consisting of Tongren, Hualong and Jianzha is closely connected with Xunhua. Considering the members of these subgroups, Lanzhou is mainly closely connected with its hinterland including Yuzhong,Yongdeng and Gaolan, besides, it's also closely connected with Yongjing and Minhe; Baiyin is closely connected with Jingyuan and Jingtai; and Xining is closely connected with Datong, Huangzhong, Huangyuan, Huzhu, Ledu and Ping'an. On the whole, each city tends to form a subgroup with a city closer to itself. Among them, the Minhe County has crossed the provincial administrative boundary, that is, Minhe in Qinghai Province has not formed a subgroup with Xining, but formed a subgroup with Lanzhou.

3.2.5 Structure hole analysis

Table 7 shows the results of measuring the structure holes of the Lan-Xi urban agglomeration. From this table, we can see Lanzhou and Xining rank in the top two, indicating that these two cities have non-redundancy connection with other cities. Therefore, Lanzhou and Xining are more important in controlling and directly affecting the circulation of various resources. The effective size of Jingtai, Jingyuan, Jishishan, Weiyuan, Yongjing, Linxia, Dongxiang, Guide, Haiyan, Guinan, Tongren and Gonghe is less than 2, indicating that they have less communication with other cities. At the same time, the efficiency of Jishishan is 1, which is the highest among all cities. The reason is the effective size and actual size of Jishishan both are small. In addition to Jishishan, Lanzhou has the highest efficiency index,

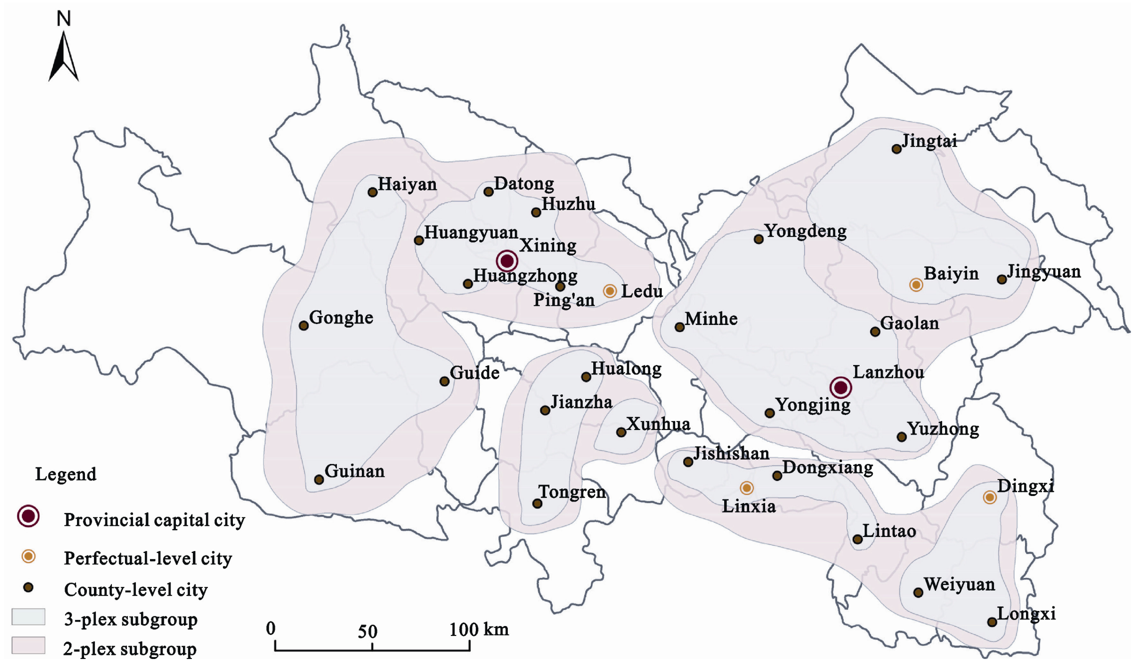

Fig. 6 Subgroup diagram of Lan-Xi urban agglomeration urban network

above 0.8, indicating that Lanzhou's effective size is closest to its actual size. In addition, the efficiency of Xining, Baiyin and Ledu is over 0.5, indicating that these cities have relatively important influences on other cities. Viewed from the constraint, Lanzhou and Xining are below 0.2, so they occupy most of the structural holes in the network and always occupy the position of bridging other cities. Most of the resources will flow through these two cities. The constraint of Jishishan is 1, which means it is subject to the greatest constraints or dependencies, and it is strictly bound by other cities. The hierarchy of Jishishan is 1, indicating it is constrained the most within the network. This is because in the binary matrix, Jishishan only has connection with Lanzhou, which means that Jishishan has no connection with other cities. It shows Jishishan is absolutely restricted by Lanzhou, so the hierarchy of Jishishan reaches the maximum which is 1.The Guinan and Jingtai grades have the lowest index, indicating that the restrictions from other cities are usually equal.

4 Conclusions

There is a significant difference in the total amount of external ties within the Lan-Xi Urban Agglomeration and the polarization phenomenon is obvious. The greater the population, the larger the economy amount, the better the urban comprehensive quality, and the better the transportation conditions, the greater the spatial connections between cities is, and vice versa. The scale effect centered on the regional central city is gradually emerging, and the urban agglomeration with Lanzhou and Xining as the core and the Lan-Xin high-speed rail as the axis, are gradually emerging. Natural geographical factors have a significant impact on the spatial connection. The spatial connections blocked by many mountains are generally small towns. The transportation has largely shaped the spatial pattern of total urban connections.

Lanzhou is at the core of the study area. It has a strong attraction and continuously absorbs the superior resources of the surrounding cities. At the same time, it also spreads information technology to neighboring cities. Xining follows closely behind, as the provincial capital of Qinghai Province, it also continuously absorbs the surrounding resources, which also has a great impact on the surrounding cities. The attraction of Baiyin is greater than its radiation capacity. The radiation capacity of Ledu is greater than its attraction. Due to the operation of the Lanxin High-speed railway, the communications between Ledu and major cities has been promoted, which in turn has improved the position of Ledu.

Table 7 Measurements of structure holes in the Lan-Xi urban agglomeration

City	Effective Size	Efficiency	Constraint	Hierarchy
Lanzhou	23.462	0.811	0.142	0.126
Baiyin	8.523	0.609	0.241	0.142
Gaolan	3.938	0.438	0.300	0.059
Yuzhong	3.167	0.396	0.283	0.034
Yongdeng	3.607	0.401	0.302	0.081
Jingtai	1.000	0.500	0.569	0.001
Dingxi	3.533	0.442	0.281	0.041
Jingyuan	1.313	0.262	0.370	0.064
Weiyuan	1.944	0.389	0.387	0.046
Lintao	3.864	0.552	0.345	0.115
Jishishan	1.000	1.000	1.000	1.000
Longxi	2.500	0.417	0.358	0.036
Yongjing	1.333	0.267	0.362	0.095
Linxia	1.929	0.482	0.484	0.115
Dongxiang	1.000	0.333	0.619	0.069
Xining	19.098	0.764	0.155	0.120
Ledu	7.457	0.533	0.225	0.079
Huangzhong	3.469	0.385	0.301	0.043
Ping’an	4.026	0.403	0.274	0.030
Hualong	2.182	0.364	0.342	0.024
Minhe	4.206	0.421	0.248	0.036
Xunhua	2.143	0.429	0.437	0.085
Huangyuan	3.654	0.406	0.326	0.097
Jianzha	3.893	0.487	0.307	0.040
Huzhu	2.733	0.304	0.372	0.049
Datong	3.219	0.358	0.378	0.033
Guide	1.300	0.433	0.597	0.099
Tongren	1.700	0.425	0.625	0.100
Haiyan	1.429	0.357	0.525	0.059
Gonghe	1.000	0.417	0.608	0.187
Guinan	0	0	0	0

Lanzhou, Baiyin, Gaolan, Yuzhong, Yongdeng, Dingxi, Lintao, Xining, Ledu, Huangzhong, Ping’an, Minhe, and Datong are at the core of the network. The core area of network has an advantageous position and can lead to the strengthening of spatial connections and the development of regional integration. This urban agglomeration has significant subgroups, eight tertiary subgroups and four second subgroups; the tertiary subgroups which compose one second subgroup have a close connection and mutual influence on each other.

The Lanzhou Metropolitan Area and the Xining Metropolitan Area have an important impact on the surrounding cities whereby the peripheral cities are basically controlled by the central city. The Dingxi subgroup, Lintao-Linxia Subgroup and Gonghe Subgroup have more structural holes than the subgroups in the Lanzhou Metropolitan Area and the Xining Metropolitan Area, so the peripheral cities of these subgroups have less connection with surrounding cities. The peripheral cities are therefore more easily controlled by the central city. The sub-group cities in the Lanzhou Metropolitan Area and the Xining Metropolitan Area are less constrained and controlled than the other subgroups.

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