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A Study on the Spatial Patterns of the Qinba Mountains Region Based on High-Speed Transportation Networks

Wu Tinghai[1], **Zhang Neng**[2]

1. School of Architecture, Tsinghua University, Beijing 100084, China
2. Beijing Tsinghua Planning and Design Institute Co. Ltd., Beijing 100085, China

Abstract: Improving regional accessibility is an important means of carrying out poverty alleviation and realizing sustainable development in the Qinba Mountains region of China. This study focuses on the accessibility of central cities in the Qinba Mountains region to surrounding urban agglomerations, and determines the spatial patterns of the region using the high-speed transportation network identified in National Road Network Planning (2013–2030) and China's Medium-Term and Long-Term Railway Network Plan. The study finds that with the development and construction of China's high-speed traffic network, there are three main radial urban corridors in the Qinba Mountains region, which involve Xi'an–Wanzhou, Xi'an–Xiangyang, and Xi'an–Luoyang, separately, and three secondary urban corridors, namely, Xi'an–Tianshui, Xi'an–Guangyuan, and Dazhou–Xiangyang–Nanyang–Luoyang corridors. These urban corridors will lead to the emergence of four vast green zones centered on Longnan, Bazhong, Shiyan, and Luanchuan. This study aims to suggest establishing the spatial order in the Qinba Mountains region, keeping in mind the arrangements being made for the urban corridors and the green zones in order to achieve a balance between protection and development.

Keywords: high-speed transportation network; spatial patterns; spatial planning; Qinba Mountains region; urban corridor; vast green zones

1 Introduction

The Qinba Mountains region of China is located at the juncture of the six provinces of Shaanxi, Sichuan, Hubei, Henan, Chongqing, and Gansu, and includes the Qinling Mountains, the Daba Mountains, and the Hanjiang River Basin. In terms of administrative divisions, the region consists of 20 cities divided into districts from five provinces and one city such as Henan, Hubei, Sichuan, Shaanxi, Gansu, and Chongqing, and Gannan Tibetan Autonomous Prefecture; Shennongjia Forestry District; and 119 counties (district, county-level city). According to the findings of the major advisory project, Study on the Green & Circular Development Strategy of the Qinba Mountains, conducted by a research group at the Chinese Academy of Engineering, the Qinba Mountains region covers an area of 308 634 km^2 and has a residential population of about 40.21 million people. The Heihe–Tengchong Line—a China's major population density boundary—goes through the west of the region. The region is China's climate demarcation zone between North and South, and it reaches across the second ladder of China's topography, from the Kunlun Mountains, the Bayan Har Mountains, and the Tibetan Plateau in the west to the North China Plain and the middle and lower reaches of the Yangtze River in the east. The Qinba Mountains region is an important geographical location and ecological security barrier in China.

Due to the complexity of terrain, the region has acted as a

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Author information: Wu Tinghai, Laboratory of Capital Regional Spatial Development, School of Architecture, Tsinghua University, professor. Major research direction is urban and regional planning. E-mail: frank@mail.tsinghua.edu.cn
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natural barrier between the middle of the Yangtze River basin and the Yellow River basin. Poor accessibility has become an important factor constraining the economic and social development of the Qinba Mountains region. Currently, the region is a principal site of poverty alleviation. It is listed as one of the 14 contiguous destitute areas in the Development-Oriented Poverty Alleviation for China's Rural Areas (2011–2020). Tang Nan et al. [1] argue that improving the traffic conditions of the region will play a positive role in reviving the regional population. Zhou Liang et al. [2] demonstrate that as the altitude and gradient increase, the accessibility of the Qinba Mountains region correspondingly declines, which restricts local economic development. Wang Lu et al. [3] note that regional districts that have stronger transport linkages with the mega-cities and prefecture-level cities have a higher level of economic development. Luo Qing et al. [4] believe that improving Qinba Mountains' regional transport infrastructure could help optimize accessibility and reduce the level of poverty in local areas.

Strengthening the construction of regional transportation systems and improving the conditions of local transport are important means of launching poverty alleviation programs and realizing sustainable development in the region [5–8]. The Regional Development and Poverty Alleviation Plan for Qinba Mountains Region (2011–2020) report clearly requires the region to use the advantages of its location as a connecting point for travel in all directions across the country. Meanwhile, the National New-Type Urbanization Plan (2014–2020) proposes to strengthen the construction of urban agglomerations' external transportation networks, requires a fast railway network to cover almost all cities with more than 500 000 people residing there, and seeks to have the national highway network cover almost all areas serving more than 200 000 people by 2020. This is when high-speed transportation networks (including the high-speed railway network and highway network) will become important supporting conditions for new-type urbanization in China and facilitate the healthy development of the regional economy and society.

According to the planned national high-speed transportation network, this study discusses, in particular, the future transport linkages in the Qinba Mountains region and examines the accessibility to central cities in the region provided by this network, as well as to the surrounding urban agglomerations. Following this, the research provides a simulation of the spatial patterns of the Qinba Mountains region. The study conducts a quantitative and in-depth assessment of the impact of a high-speed transportation network on the spatial patterns of the region, and offers suggestions on how its development and protection patterns might be affected by a high-speed transportation network.

2 Study area and data sources

For various reasons, the Qinba Mountains region has not yet amassed a large population. The urban system is mainly composed of small or mid-sized cities and counties. For this reason, it is normally regarded as a typical non-urban-agglomeration area. According to the *China City Statistical Yearbook (2015)*, this area comprised 17 cities in the Qinba Mountains region, including the Wanzhou District of Chongqing Municipality but excluding the county towns, and had an average urban population of about 340 000 at the end of 2013. Among these cities, only Wanzhou (with a population of around 805 000), Tianshui (with a population of around 636 000), Dazhou (with a population of around 624 000), and Shiyan (with a population of around 498 000) qualify are reaching or close to the level of mid-sized cities. The remaining cities all have populations of less than 400 000 people.

In China's national plan on main functional areas and national plan on new-type urbanization, the Qinba Mountains region is located at a critical juncture. It is surrounded by four important metropolitan areas: the Chengdu–Chongqing urban agglomeration, the Central Plains urban agglomeration, the Wuhan metropolitan area, and the Guanzhong urban agglomeration. The transportation and communication networks of those four metropolitan areas will significantly shape the spatial patterns of the Qinba Mountains region in the future. In order to demonstrate the transportation and communication linkages that exist between the Qinba Mountains region and other metropolitan areas, we expanded the study area to incorporate the surrounding metropolitan areas into the research scope. Specifically, the study area is defined by four high-speed railway lines. The eastern boundary is indicated by the Zhengzhou–Wuhan high-speed railway. The northern boundary is constituted by the Zhengzhou–Xi'an–Baoji–Lanzhou high-speed railway. The southern boundary corresponds with the Wuhan–Chengdu high-speed railway. The western boundary follows the path of the Lanzhou–Hezuo–Chengdu high-speed railway. These four high-speed railway lines cover an area of about 4.88×10^5 km^2, encompassing 295 cities (or county towns), of which 111 are located within the Qinba Mountains region.

The study simulated the future interurban connections between the highways and high-speed railways based on the national high-speed transportation network plan. First, we selected the highways according to the National Road Network Planning (2013–2030), which include radial lines, vertical lines, horizontal lines, and loop lines, while excluding the lines of the long-term plan. Then, the high-speed railways were selected according to China's Medium-Term and Long-Term Railway Network Plan.

Following these plans, we found that the highways and the high-speed railways cover a total distance of 25 000 km and 6 600 km respectively. The major highways comprise the Beijing–Kunming Expressway (known as G5), the Shanghai–Xi'an Expressway (G40), the Erenhot–Guangzhou Expressway (G55), the Baotou–Maoming Expressway (G65), and the Shiyan–Tianshui Expressway (G7011). The major high-speed railways are the Xi'an–Chengdu High-speed Railway, the Xi'an–Chongqing High-speed Railway, the Xi'an–Wuhan High-speed Railway, the Zhengzhou–Wanzhou High-speed Railway, and the Chengdu–Nanchong–Dazhou–Wanzhou High-speed Railway, as well as the above-mentioned four railway lines.

Having determined the routes of the highways and the high-speed railways, we needed to verify the connecting conditions of the cities and the lines. This study surveyed the planning and construction context of each line and the city where its station along the route was set to determine the extent to which the cities would be connected to the high-speed railway network. In addition, we used a distance of three kilometers between the city centers and the lines as the criterion for establishing whether each city would be connected to the highway network. The connecting conditions of the cities and the lines can be seen in Fig. 1 and Table 1.

3 Simulation of time distance using a high-speed transportation network

We simulated and calculated the accessibility between cities, defined as the shortest time distance using high-speed transportation systems.

3.1 Simulation method

There are generally two different approaches used to evaluate time distance between cities. The first approach is an origin-destination (OD) survey, and the second is network analysis. This research is based on the simulation of future high-speed transportation systems, which means many routes have not yet been constructed, and therefore, it is not possible to get accurate traffic time. For this reason, we used the network analysis approach to estimate the time distances between cities.

We divided the 295 cities into four classes, according to the cities' various locations and statuses. The Class-I cities comprise six provincial capital cities located around the Qinba Mountains region, and are defined as central cities, comprising Xi'an, Zhengzhou, Wuhan, Chengdu, Chongqing, and Lanzhou. The Class-II cities comprise the other 85 cities where high-speed railway stations are situated. The Class-III cities comprise 186 highway-accessible cities; however, these cities contain no high-

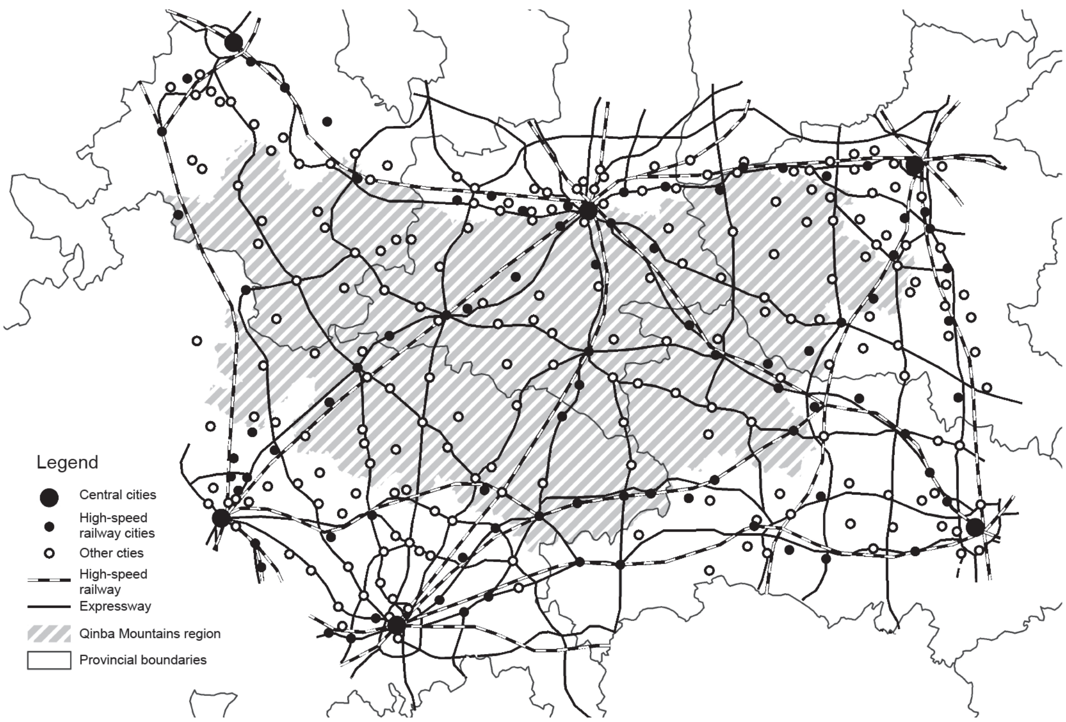

Fig. 1. The distribution of high-speed railways, highways, and cities within the study area.

Table 1. City levels and accessibility of high-speed transportation networks.

Accessible conditions	Provincial capital cities	Prefecture-level cities	County-level cities or county towns	Total
Access to high-speed railway	0	0	3	3
Access to highway	0	3	183	186
Access to both	6	30	52	88
Access to neither	0	0	18	18
Total	6	33	256	295

speed railway stations. The Class-IV cities comprise 18 cities that do not feature on the high-speed railway or highway routes. The Class-IV cities are located far from high-speed transportation networks, and therefore, are defined as remote areas; we have excluded these cities from the analysis. After removing the 18 Class-IV cities, we inputted data on 277 cities into the network analysis process.

In order to calculate the shortest traffic-time matrix between each two cities among the 277 cities and carry out the network analysis, we set up a model of the shortest distance among the cities. Assuming that there are m different routes that can be taken between departure city S_1 and arrival city S_2, and when selecting the route i, n times of transfer are required ("transfer" refers to a change from railway to highway or the reverse; n = 0 applies when no transfer happens), then T (the shortest traffic time between S_1 and S_2) is expressed as:

$$T = \min\{T_i\},\ i \in (1, 2, \cdots, m)$$

$$T_i = \sum_{j=0}^{n} T_{ij} + \beta \cdot n,\ j \in (0, 1, \cdots, n)$$

$$T_{ij} = D_{ij} / (V_{ij} \cdot \varphi_{ij}),\ \varphi_{ij} < 1$$

In this model, T_i is the total traffic time of route i, T_{ij} is the traffic time of road j in route i, β is the transfer time, D_{ij} is the length of road j, V_{ij} is the design speed or limit speed of road j, and φ_{ij} is the speed-reduction coefficient of road j.

3.2 Determining the parameters

In the model of the shortest traffic time, the parameters β, V_{ij}, and φ_{ij} can be determined according to actual condition. For the transfer time β, we assume β as a constant that is needed for each transfer, equated as β = 0.5 h because there are only railway-to-highway (or reverse) scenarios included in this research. The design speed or speed limit V_{ij} of different transport modes or different roads varies. We determined that the speed limit of the highway is 120 km·h^{-1}. The determined design speed of high-speed railways according to existing railway plans can be seen in Table 2.

We consider the speed-reduction ratio φ_{ij} according to the following conditions: ① realistically, the actual traffic speed does not often correlate with the design speed; for instance, the speed limit on highways in China is 120 km·h^{-1}, but vehicles cannot possibly maintain the speed limit at all times. So in fact, the actual average speed would be much lower than the speed limit; ② Real traffic lines may be subject to the constraints of terrain or other factors, and may extend further than planned; ③ The time spent stationary or parked is a consideration. Because the situations are complex, it is difficult to accurately determine the speeds of different roads, and therefore, unique values have been assigned to highways and railways. In order to make the values of φ_{ij} accurate and valid, we investigated the actual traffic times among cities by using constructed high-speed transportation networks in our research study area, before estimating the ratio of real traffic speed to design speed, determining that the j of the highway is 0.6 and the j of the high-speed railway is 0.7.

After determining the parameters, we used the Network Analyst included in ArcGIS, a geographic information system (GIS) to practice the simulation process. Following the model, we first simulated and calculated various time distances between cities under different options of connecting routes, and then identified the shortest time distance. The simulation results show a matrix consisting of all the shortest traffic times between any two of the 277 cities.

4 Spatial patterns of the Qinba Mountains region based on the accessibility of central cities

This study analyzes the accessibility between ordinary cities and central cities in the region on the basis of simulating and calculating the time distance matrix of transport linkages so as to discern the connecting pattern among the cities in the Qinba Mountains region. Through an isochrone analysis, the city corridors in the region that will appear in the future are identified.

4.1 Urban spatial linkages

Urban spatial structure can be understood as a system that comprises a "dot" (city) and an "axis" (the relationship between cities) [9]. The study constructs center cities (Class I), high-speed railway station cities (Class II), and ordinary cities (Class III) by referring to the transportation distance as a measure of linkages between the cities. This is done to reveal the spatial patterns of the Qinba Mountains region based on future high-speed transportation networks.

According to the criterion of the nearest transportation dis-

Table 2. The design speed of different railways.

Design speed (km·h^{-1})	Railway
350	Zhengzhou–Wanzhou railway, Zhengzhou–Xi'an high-speed railway, Zhengzhou–Wuhan high-speed railway, Xi'an–Wuhan high-speed railway, Chengdu–Nanchong–Dazhou–Wanzhou high-speed railway, Xi'an–Chongqing high-speed railway
250	Xi'an–Chengdu high-speed railway, Xi'an–Baoji/Baoji–Lanzhou high-speed railway, Chongqing–Wanzhou railway
200	Lanzhou–Hezuo railway, Chengdu–Hezuo railway

tance, the steps to establish linkages between cities are as follows: First, the Class-III cities were marked as starting points, and the Class-I or II cities that had the nearest transportation distance were established. Second, all forms of Class-II cities were marked as starting points and the connections to the nearest Class-I cities were made. Third, time thresholds, eliminating the linkages where the transportation distance between the cities exceeded the threshold, were constructed. At present, plans related to the development of Chinese urban agglomerations often use a "one-hour traffic circle" as the main goal in building a rapid transportation network, with the time distance within urban agglomerations not exceeding more than two hours [10]. Based on the above formula, this research set a two-hour distance from the central cities and a one-hour distance from high-speed railway station cities as thresholds, removing the linkages that were more than two hours away from central cities, or more than one hour away from high-speed railway station cities. From this, the urban spatial linkage patterns in the form of "points-axes" emerge, as shown in Fig. 2.

Fig. 2 clearly shows the linkages between the cities of the Qinba Mountains region and the central cities that surround the region based on the high-speed transportation network. As is shown in the figure, Xi'an is playing a prominent and leading role in the future development of the Qinba Mountains region. Ankang, Xunxi, and Foping will be incorporated into the Xi'an one-hour radial scope, and Hankou, Chengkou, and Danjiangkou will be incorporated into the Xi'an two-hour radial scope. Compared with Xi'an, Zhengzhou, Chengdu, Chongqing, and Lanzhou all have weaker influences on the Qinba Mountains region, and the edge of the region is beyond the two-hour radius of these central cities. The central cities and the cities within their radial scopes are shown in Table 3 below.

Fig. 2. Urban spatial patterns of the Qinba Mountains region and surrounding areas.

Table 3. Linkages between central cities and major cities in the Qinba Mountains region.

Central city	Time (h)	Cities within radial scope
Xi'an	<5	Zhashui, Lantian, Huxian
	0.5–1	Ankang, Shangluo, Xunxi, Poping, Lingbao, Shanyang
	1–2	Sanmenxia, Shiyan, Danjiangkou, Langao, Chengkou, Chenggu, Hanzhong
Zhengzhou	0.5–1	Fangcheng
	1–2	Dengzhou, Lushan, Yiyang, Yichuan, Yexian
Chengdu	1–2	Jiange, Guangyuan, Ningqiang
Chongqing	1–2	Dazhou, Wanzhou, Yunyang, Fengjie, Wushan
Wuhan	1–2	Gucheng, Nanzhang
Lanzhou	1–2	Tianshui

4.2 City corridors

Following the time distance matrix of transport linkages to the center cities, high-speed railway station cities, and ordinary cities, the study drew isochrones for the center cities by using the ArcGIS and analyzed the accessibility among cities based on future transportation networks, therefore finding potential city corridors.

According to the distribution of the isochrones, we divided the Qinba Mountains region into four parts that reflect different accessible conditions. Area I refers to the areas located in range of traffic linkages within one hour of the central city, which is about 1.3×10^4 km^2 (about 4.4% of the total area of Qinba Mountains region). Area I are centered around Xi'an, and, based on the close transport linkages, will become a part of the Guanzhong urban agglomeration. Driven by the high-speed railways, cities such as Ankang, Lingbao, and Fuping can also be incorporated into the comprehensive planning and development of the Guanzhong urban agglomeration. Area II refers to the areas located in range of traffic linkages within one to two hours of central cities, which is about 9.2×10^4 km^2 (about 31.2% of the total area of Qinba Mountains region). Although Area II does not belong to urban agglomeration, it is intimately connected to urban agglomerations or centre cities and will benefit from the radial and economic effect of the central cities. This area will become an actual transportation corridor zone. Area III refers to areas outside the range of traffic linkages that are further than two hours to central cities but are inside the range of one-hour traffic linkages with high-speed rail stations, which is about 9.3×10^4 km^2 (approximately 30.1% of the total area of the Qinba Mountains region). Although these areas are out of the radial range of the urban agglomerations or metropolises, they have close linkages with some cities where high-speed railway stations are located, so their traffic conditions are expected to be improved. Area IV, which is about 3.41×10^5 km^2 (about 32.9% of the total area of the Qinba Mountains region), is outside the range of two-hour traffic linkages with its centre city and one-hour traffic linkages with the high-speed railway station. In the forthcoming high-speed transportation network pattern, these areas remain as remote ones. The various areas listed above are shown in Fig. 3.

The areas' distribution of different accessibility in Fig. 3 shows that Area II and Area III reflect good accessible conditions, and they both conform to the high-speed railway network. These areas constitute the potential corridor zones in the future urban development of the Qinba Mountains region. Table 4 shows three major city corridors and three secondary city corridors, as well as contiguous areas surrounded by the corridors, which can be identified by the accessible conditions of the corridors.

In general, five of the six corridors take the Guanzhong urban agglomeration as the center of their radial distribution, and the Dazhou–Xiangyang–Nanyang–Luoyang corridor is laid out as an arc. These corridors come together to form a triangular development pattern. City corridors are on the edges of the triangle, while the non-corridor areas inside the triangle are formed by four areas, with Longnan, Bazhong, Shiyan, and Luanchuan as the cores. These are mainly contiguous mountain areas and constitute the green zones that lie between the corridors.

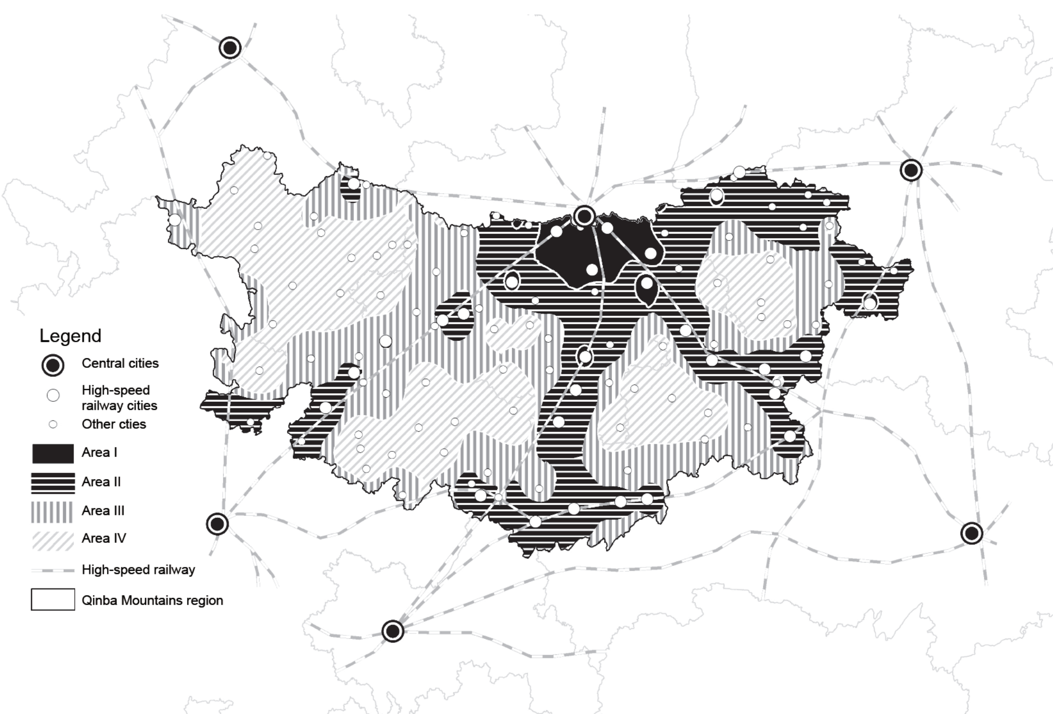

Fig. 3. Spatial patterns of the Qinba Mountains region based on accessibility.

Table 4. City corridors and non-city corridors in the Qinba Mountains region.

Area classification	Number	Name
Major city corridor area	3	Xi'an–Wanzhou Xi'an–Xiangyang Xi'an–Luoyang
Secondary city corridor area	3	Xi'an–Tianshui Xi'an–Guangyuan Dazhou–Xiangyang–Nanyang–Luoyang
Non-city corridor area	4	Longnan area Bazhong area Shiyan area Luanchuan area

5 Conclusions and discussion

National planning and policies have put forward clear principles and requirements for the development in the Qinba Mountains region. The regions is classified as a biodiversity-protection area belonging to development-restricted areas in China's National Planning of Main Functional Areas, and as a part of these planning, efforts are being made to reduce forest cutting, restore mountainous vegetation, and protect wild species. Overall, it is necessary for the region to protect the natural ecological environment and effect poverty alleviation through appropriate regional development. Coordinating the dual task of "protection" and "development" is a prerequisite for the green and circular development of the Qinba Mountains region. Establishing the spatial order of future urban development through planning is an important means of balancing the protection and development of the region. The Regional Development and Poverty Alleviation Plan for Qinba Mountains Region (2011–2020) promulgated by the State Council clearly requires creating a spatial pattern that takes account of production factors, reasonable industry layout, close regional linkage, and improved urban systems.

Based on the high-speed transportation network, we studied the spatial patterns of the Qinba Mountains region. The results show that the region is surrounded by a multiplicity of urban agglomerations, except for the northern region around Xi'an City (an area of about 1.3×10^4 km^2), which is obviously affected by that urban agglomeration. The other areas account for 95.6% of the total area of the region, which are typical of non-urban-agglomeration areas. These areas are faced with dual tasks of ecological protection and poverty alleviation and development. For the vast majority of non-urban areas in the Qinba Mountains region, with the development and construction of the planned national high-speed transportation network, the three main radial urban corridors including Xi'an–Wanzhou, Xi'an–Xiangyang, and Xi'an–Luoyang, and the three secondary urban corridors involving Xi'an–Tianshui, Xi'an–Guangyuan, and Dazhou–Xiangyang–Nanyang–Luoyang, will take shape in the region. These urban corridors will influence the emergence of the four vast green zones centered on Longnan, Bazhong, Shiyan, and Luanchuan. The authors suggest establishing a spatial order for the region, with reasonable arrangements being made for urban corridors and vast green zones in order to achieve a balance between protection and development.

It is well established that protection and development are closely linked to each other. There is no straightforward form of protection, and there is no straightforward form of development. Academician Pan Jiazheng has pointed out that development, as well as protection, is of overriding importance, and we should, therefore, recognize the contradiction between development and protections, and rather see that both development and protection are required to achieve sustainability. In this way, underdevelopment and delayed development do not equate with protection [11]. An ideal model of development is to seek a balance between protection and development.

There are different types of development, ranging from no development to weak and moderate development to strong development. For the Qinba Mountains region, the reasonable, scientific, and appropriate use and development of the natural and cultural heritage is the premise for its protection. There are also different types of protection, ranging from no protection to weak protection and protection to strong protection. For the Qinba Mountains region, based on the possibility of development, we suggest dividing the overall protection policies into different types and responding appropriately to explore a feasible way of moving towards regional poverty alleviation and sustainable development.

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