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Discussion on the effect of topographic barrier on the morphology of Chinese mountainous cities: an example of Southwest China

Abstract China is a mountainous country and mountains account for 69% of the country's land area. Therefore, relevant scholars believe that the second half of Chinese development with high quality urbanization is in the mountainous region. Topographic barrier in this mountainous district have been produced unique morphology of mountainous cities which also have negative impacts such as excessive construction costs and information blocking. So we take mountainous cities in south-western region which own the most mountainous cities in China, as the research object to analysis how to achieve high-quality development with mountainous region in China. Firstly, we summarize the types of topographic barrier such as horizontal cutting, vertical limitation and integrated guidance to form four morphological types of mountainous cities including clump, ribbon, radial and group over time by figure-to-bottom relationship and typological analysis. Then this interweaving of natural and artificial built environment forms a generalized spatiotemporal evolution model of mountainous cities. Finally, this evolutionary process has also formed spatial effects of different scales from region, urban and block perspective, respectively. Therefore, this article expects to introduce a Chinese unique mountainous urban space, providing a reference for development of mountainous cities in other countries.

Keywords Mountainous Cities, Urban morphology, Topographic Barrier, China.

Introduction

China is a mountainous country, with mountains accounting for 69% of the country's land area. Therefore, relevant scholars believe that the second half of China's high-quality urbanization development is in the mountainous region. As early as the beginning of the 21st century, China began to implement the western development strategy to promote the development and construction of mountainous cities.

However, mountainous cities have high requirements for the adaptability and coordination of natural environment and artificial build environment. Negative factors such as high construction costs and information congestion hinder the further development of mountainous cities, and give birth to some mountainous cities to 'plain' construction, causing a series of incalculable adverse impacts on the local social, economic and ecological security such as frequent geological disasters.

According to statistics, sudden mountainous disasters including collapses, landslides, and debris flows with western mountainous region account for more than 30% to 40% of the China. For a series of reasons mentioned above, it is necessary to summarize and sort out the impact of the morphological characteristics of mountainous cities on urban development from the perspective of historical retrospect, and then provide policy recommendations and implementation references for the high-quality development of mountainous cities in China.

Background

Mountainous city research is an important direction of urban planning research in China. Huang Guangyu is the innovator and founder of the mountainous city research in China. He believes that the mountainous city is a Chinese term for a city located in a mountainous landform which is different from sloping cities in foreign countries, defining the natural characteristics of a mountainous city from two aspects:

> The first is that the city is built on an undulating slope with a slope of more than 50°, regardless of its altitude. The second is that the city is built on flat land, but the surrounding complex terrain will also have a significant impact on urban development' (Huang 2006:10–11).

At present, the research on mountainous cities focuses on the overall spatial layout, historical and cultural heritage protection, transportation, ecology, natural disasters, etc. (Li 2013; Li 2017; Wang 2021; Zhao 2021). At the same time, the morphological research has always been the important foundation of academic research on mountainous cities. For example, Wu Yong believes that the evolution of the morphology of mountainous cities from a closed type to a discrete type has created a contradiction between rapid urban development and lagging structural adjustment (Wu 2012). Wei Xiaofang believes that the morphology of mountainous cities has given birth to high-density construction. As a result, the rationality of high-density development needs to be strengthened (Wei 2015). Huang Yong summarized the morphological characteristics of mountainous cities in southwest China as 'agglomeration-fragmentation-unbalanced', optimizing the morphology of mountainous cities from the three levels of group identification, connecting network identification and road connectivity planning (Huang 2017).

In general, different morphological characteristics of mountainous cities have positive or negative impact of urban development. However, current research with this aspect mostly focuses on the optimization measures by graphics, topology and typology, ignoring the generation mechanism behind morphology of mountainous cities and the systemic impact of development with urban development. Therefore, this paper starts with the influence of mountainous landforms on morphology of mountainous cities, summarizing the morphological types; then it explores a generalized spatiotemporal evolution path with the morphological formation of Chinese mountain cities; finally, it discusses the multi-scale spatial impact of morphology of mountainous cities on urban development in detail.

In the selection of the research regions, the southwest region is the most extensive distribution of mountainous landforms in China. So this paper is based on the mountainous cities in this region to conduct research, including Chongqing City, Guizhou Province, Tibet Autonomous Region, Sichuan Province and Yunnan Province. Due to the differences in historical and cultural factors, the research object is concentrated in four regions: Chongqing city, Guizhou province, Sichuan province and Yunnan province (Figure 1).

Figure 1. Research Regions
Source: authors' own work.

Methodology

The research method of this paper is based on the figure-to-bottom relationship and typological analysis methods, analysing the morphology of mountainous cities under the effect of topographic barrier. Then the mechanism of the topographic barrier effect with the morphology of mountainous cities need to be analysed. It requires the use of theoretical deduction and inductive analysis methods (Figure 2). The urban morphology is the result of the interweaving of two forces of the natural environment and the artificial build environment. There is always one force that plays a dominant role in different regions or historical periods, while the other is relatively weak according to relevant theory from 'Geographical Determinism' by Halford Mackinder to 'Clash of Civilizations' by Samuel Huntington (Mackinder 1904; Huntington 1996). Compared with the urban morphology of the plain region, which is mainly controlled by the socio-economic influence of the artificial build environment, the morphology of the mountainous cities is more affected by the natural environment, forming special human settlements that are blocked by the complex topographic barrier including mountain and river.

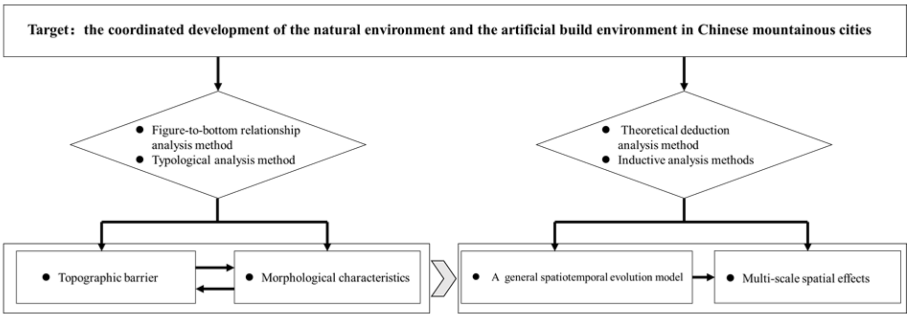


Figure 2. Research Framework
Source: authors' own work.

According to the theory of human settlements, mountainous cities need to avoid excessive intervention in the natural environment, ensuring the suitable spatial layout and construction of the artificial build environment, so the coordinated development of the natural environment and the artificial build environment is really important. To meet the needs of coordinated development, the interaction between living and non-living is a complete energy flow network from the perspective of the natural environment. Troll placed this energy flow network in the natural environment and created landscape ecology (Troll 1939; 1971).

He believes that it is necessary to take the whole natural environment as the research object, studying the optimal structure, rational use and protection of the natural environment. The ecological patches are sufficiently complete only when the connectivity of ecological corridors in the network is high enough, thus forming an excellent ecological pattern. Then from the perspective of artificial build environment, it is to place individual needs in the urban space and gradually expand from individual needs to cooperation and competition with political economy between social groups, companies, cities and even countries. During the modern architectural movement in the 1930s, Le Corbusier put forward four space function, but the attention to space was limited to the physical function, ignoring individual motivation and reflected in the Athens Charter.

The Machu Picchu Charter in the 1970s vigorously criticized this mechanical functionalism and began to focus on practical needs, arguing that the diverse functions that people need reflected in space, should be a diversification and hybridization of spatial physical functions. By the 1990s, the theory of space production further expanded the space from the physical function to the space that can be felt and practiced by people (Lefebvre 1991). If people want to satisfy their own feelings and practices in the physical space which involve the willingness to transform the space.

In addition, it is equally important to transformation ability in space with the development of science and technology because the transformation ability represents whether the ability can match willingness to transform the space. As a result, morphology of mountainous cities changes over time, having impacts on the surrounding natural environment with the willingness and ability to transform the space. It can be summarized as a general spatiotemporal evolution model. At the same time, this evolution model can form a series of spatial effects that can be summarized as regional, urban and block effects by scale thinking modes.

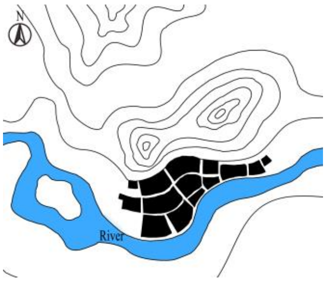
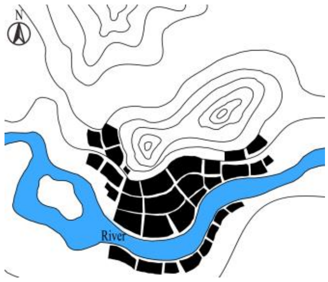
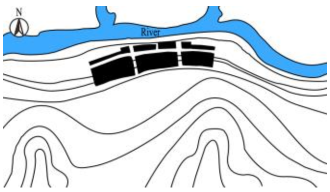
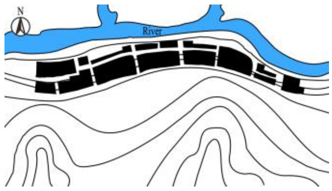
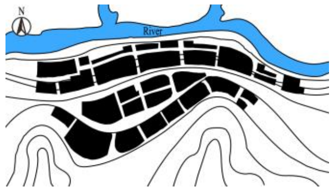
Therefore, the following research process is formed in this paper: (1) Analysis of morphological characteristics of Chinese mountainous cities under the influence of topographic barrier; (2) Summarize a general spatiotemporal evolution model of Chinese mountainous cities; (3) Multi-scale spatial effects of Chinese mountainous cities, so as to systematically analyse the impact of topographic barrier with the morphology of Chinese mountainous cities.

Results and Discussions

According to the Table 1, we find that the topographic barrier can be roughly divided into three types: horizontal cutting, vertical limitation and integrated guidance. Firstly, Horizontal cutting refers to the morphology of Chinese mountainous cities formed by the cutting of mountains and river systems, resulting in urban morphology mostly concentrated in valley basin terrain and is less difficult because of the relatively flat interior of the terrain. Then vertical limitation refers to the morphology of Chinese mountainous cities affected by the height difference, slope aspect and the water level of the river system.

Most of them are located on hillsides, ridges or both, following the slopes and valleys in a stepped spatial layout. Finally, integrated guidance refers to cities with slopes and terraces are not only affected by the horizontal cutting of valleys and mountains, but also guided by the vertical limitation of the slopes. Hills, valleys, slopes are staggered inside the city, resulting that most of the grounds are undulating. So the combined action of the two natural forces gradually create the changing process of the morphology of Chinese mountainous cities and due to the continuous expansion of urban construction area, this type of topographic barrier has become the main way to shape the urban morphology.

Table 1. The topographic barrier with the morphology of Chinese mountainous cities

Type	First Phase	Second Phase	Third Phase
Horizontal Cutting	 Cities are limited by ecological boundaries such as mountains and rivers	 Cities expand across ecological boundaries	 Ecological boundaries cut urban morphology
Vertical Limitation	 Cities expand within tableland boundary	 Urban expansion is limited to the tableland	 Urban Expansion Breaks the Limits of Platform Boundary
Integrated Guidance	Two forces including horizontal cutting and vertical limitation interweave		

Source: authors' own work.

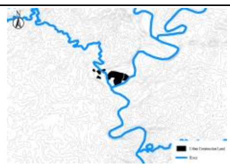
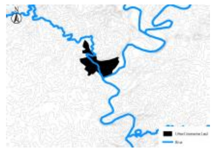
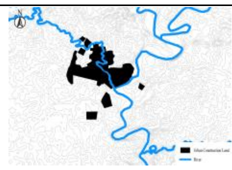
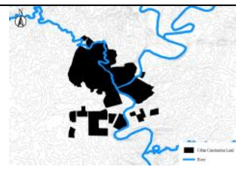
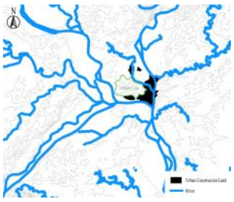
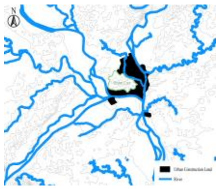
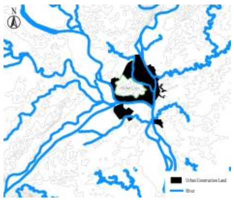
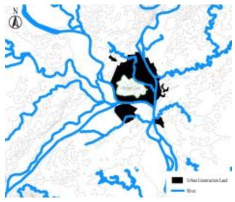
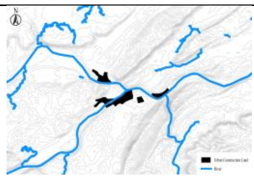
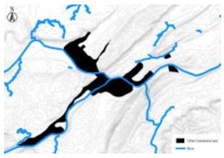
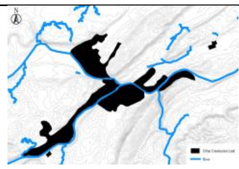
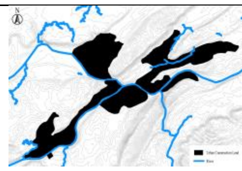
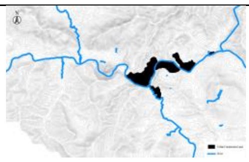
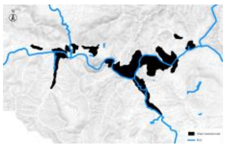
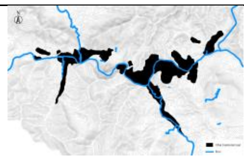
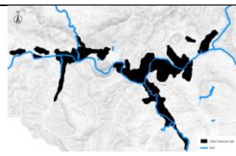
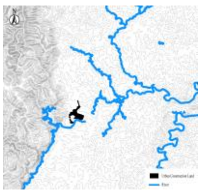
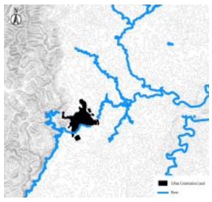
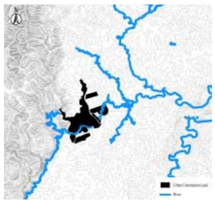
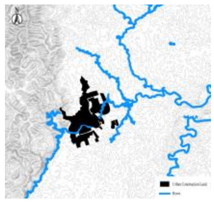
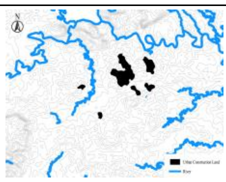
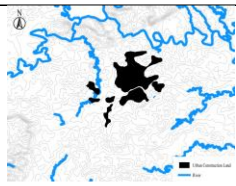
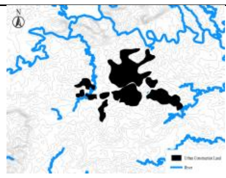
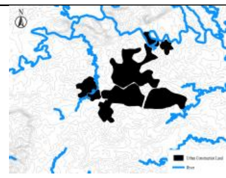
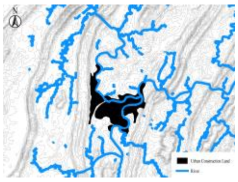
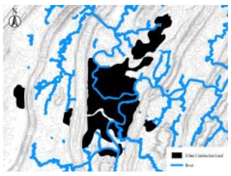
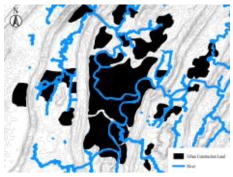
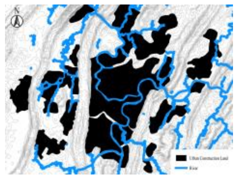
It can be seen that the formation with morphological characteristics of Chinese mountainous cities in the three types of topographic barrier, which determines that the expansion mode of the urban construction area with mountainous cities cannot be same as balanced expansion mode as the plain cities, showing a more flexible and changeable expansion mode. Through the analysis of the morphological characteristics of mountain cities by the figure-to-bottom relationship and typological analysis method, it is concluded that there are four main morphological types of mountainous cities: clump, ribbon, radial, and group. (1) clump: The type of a clump is mainly that the scale of mountainous cities is small. The contradiction between human and land is not prominent. Active spaces for people are located near the geometric centre of the plane.

So the internal connection is relatively convenient which can effectively organize the urban production and life and reduce the cost, investment and operation of urban construction. However, with the needs of urban development, the scale of urban construction continues to expand. The monocentric clump is often difficult to maintain under the conditions of mountainous terrain and gradually develops into polycentric clump. Take Ziyang, Sichuan Province as an example. In 1984, Ziyang City was a monocentric clump. By 2021, the spatial layout of Ziyang consisted one core and four districts.

In addition, the general monocentric clump is the urban core area where human beings live and work but in the specialized clump, Leshan city places green core in the centre of the city, constructing the basic pattern of a 'green-core city' and realizing the organic blend of natural and artificial build environment; (2) ribbon: The urban development space in the ribbon morphology is linear, mostly along the banks of rivers or stretches along narrow canyons, running through the interior with a major traffic arterial as the main axis.

However, it is difficult to form a loop with the main internal communication roads which makes it difficult for the connect every district with a large spatial scale. Therefore, when the cities with ribbon morphology develop into a polycentric state, considering the development along both sides of the river valley and strengthening the connection by infrastructures. For example, Yibin, Sichuan Province emphasizes the connection between the north and the south district, shifting from monocentric ribbon to open development with polycentric ribbon by constructing a series of infrastructures. (3) radial. The radial morphology is further developed from the clump and ribbon morphology. And it can be classified the radial morphology of the mountainous city into 'Tree-like Radial' and 'Palm-like Radial'. The 'Tree-like Radial' is to choose the city on the high ground between the gullies or valleys and the municipal infrastructure such as roads are arranged along the gullies, such as Panzhihua, Sichuan Province. The 'Palm-like Radial' indicates that every district is divided by rivers, gullies, farmland and green space, forming open spaces with natural landscapes that become an important ecological conservation area, such as Renshou, Sichuan Province. However, developmental direction with most of the radial cities are restricted by the complex terrain. The connection between different districts is difficult and the urban stability is poor. In the planning of public service facilities, more consideration should be given to internal connection to avoid excessive pressure in the central area (4) group.

Table 2. The morphological types of Chinese mountainous cities

Type	Sub-Type	First Phase	Second Phase	Third Phase	Forth Phase
Clump	Generalized Clump	 1985-Ziyang, Sichuan Province	 2002-Ziyang, Sichuan Province	 2014-Ziyang, Sichuan Province	 2021-Ziyang, Sichuan Province
	Specialized Clump	 1984-Leshan, Sichuan Province	 2005-Leshan, Sichuan Province	 2010-Leshan, Sichuan Province	 2021-Leshan, Sichuan Province
Ribbon	Generalized Ribbon	 1985-Yibin, Sichuan Province	 2004-Yibin, Sichuan Province	 2014-Yibin, Sichuan Province	 2020-Yibin, Sichuan Province
Radial	Tree-like Radial	 1985-Panzhihua, Sichuan Province	 2003-Panzhihua, Sichuan Province	 2012-Panzhihua, Sichuan Province	 2021-Panzhihua, Sichuan Province
	Palm-like Radial	 1985-Renshou, Sichuan Province	 2009-Renshou, Sichuan Province	 2014-Renshou, Sichuan Province	 2021-Renshou, Sichuan Province
Group	Bead-like Group	 1984-Zigong, Sichuan Province	 2007-Zigong, Sichuan Province	 2014-Zigong, Sichuan Province	 2021-Zigong, Sichuan Province
	Constellation-like Group	 1984-Chongqing, Chongqing city	 2006-Chongqing, Chongqing city	 2014-Chongqing, Chongqing city	 2021-Chongqing, Chongqing city

Source: authors' own work.

The group morphology is a relatively common spatial layout in Chinese mountainous cities. Due to the limitation of natural terrain such as mountains, hills, canyons, rivers, etc. Cities cannot be developed and constructed in a concentrated areas. Instead, they develop by leaps and bounds in combination with terrain conditions to form multiple connected areas. And due to the complex characteristics of the terrain, the group morphology has different types including bead-like group and constellation-like group.

According to the needs of the coordinated development of the natural environment and artificial build environment in accordance with the morphological characteristics of Chinese mountainous cities, it can be seen that the formation with the morphology of Chinese mountainous cities can be summarized as a generalized spatiotemporal evolution model, that is, 'constraint stage-breakthrough stage-symbiosis stage' (Figure 3). In the Figure 3, There are 3 interacting curves and lines which is A curve: the curve of artificial transformation process; B curve: the combined effect curve with transformation willingness – transformation ability and C line: the line of topographic barrier – ecological effect respectively.

A curve indicates the degree of transformation of the natural environment changes, and this change is deeply affected by the B curve. B curve is a curve formed by combining people's willingness to transform the space and their ability to transform the space m. In the process of transforming the natural environment, transformation willingness or transformation ability will always play a leading role. The C line is the boundary of the coordinated development of the natural environment and the artificial build environment. If the B-curve exceeds this limitation, it means that the construction of the artificial build environment is in a dominant position which may break through the constraints of the topographic barrier, resulting in the appearance of plain urban landscapes and breeding possibility of disaster. From constraint stage to symbiosis stage, people's willingness to transform space in mountainous cities is increasing and with the development of science and technology, people's ability to transform the space is also gradually enhanced, which can overcome and weaken the topographic barrier and carry out rapid changes to the surrounding natural environment.

However, when the transformation willingness ignores the important ecological effect of the natural environment, having an immeasurable effect on the destruction of the natural environment, the human ecological consciousness begins to awaken and consciously suppress the transformation behaviour. And people can utilize technological innovation with transformation ability, protecting the natural environment. The construction of mountainous cities moves towards the coordinated development of the natural environment and artificial build environment.

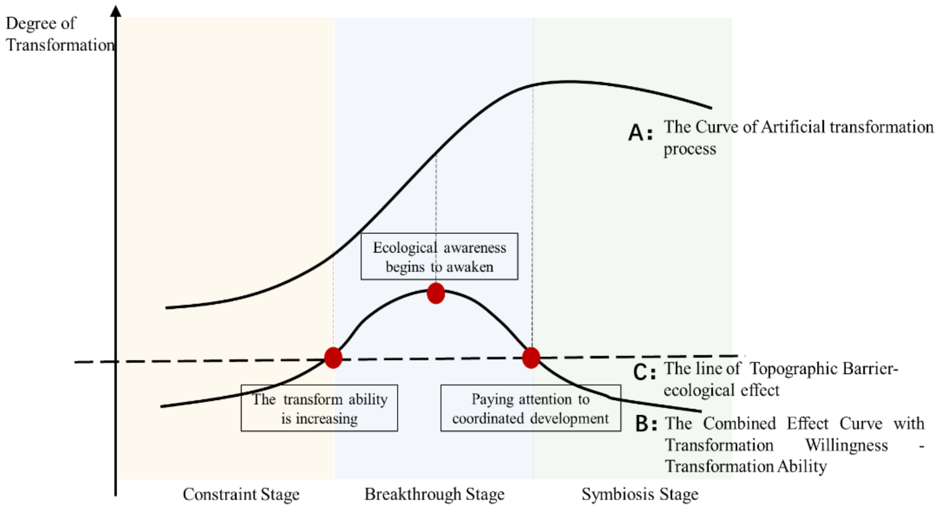


Figure 3. A general spatiotemporal evolution model of Chinese mountainous cities
Source: authors' own work.

The development stage of Chinese mountainous cities determined by a general spatiotemporal evolution model is further figurative explained. First of all, due to technical conditions and the worship of traditional natural landscapes, people's willingness to transform the space was low in the constraint stage. The construction of mountainous cities took adopt to the types with backing, connecting and surrounding mountains, showing the development of a agglomerated development mode. On the one hand, this mode was to reduce the economic cost of urban construction.

On the other hand, it was to fortify against enemy with the help of the precipitous natural terrain. In general, the development of mountain agriculture had brought urban construction to its peak. Traditional mountainous cities had spread all over the mountainous region in China. At the same time, it has also laid the foundation for the development of mountain cities in the industrial age. Secondly, the development of social productive forces made the people's ability and willingness to transform improve simultaneously in the breakthrough stage and the continuous innovation of technological paradigms gradually weakened or even broke through the topographic barrier, showing a strong transformation of mountain urban space. According to statistics in 1985, the urban density in the western region of China increased by 6.5 times, while that in the eastern coastal region increased by only 0.75 times. The number of cities in the western region also increased from 65 to 370 by 1995. In the mountainous areas of southwest China, a large number of cities had formed. The urban agglomeration area, which was mainly distributed along the Chengdu-Chongqing Railway, gathered 9 cities and 227 towns such as Chongqing, Chengdu, Mianyang, Zigong, Neijiang, Deyang, Leshan, Yibin, Luzhou, having become the area with the highest urban density in the country.

At the same time, the urban construction area had increased significantly. Taking typical mountainous cities such as Chongqing, Guiyang, Kunming, and Panzhihua as examples, the built-up areas had nearly doubled by the end of 2018 compared with 2008 (Table 3). From the inside of the urban construction area of mountainous cities, each district of the mountainous cities pays attention to the agglomeration of working space and living space under the influence of the agglomeration effect. This change makes the urban space present a developmental mode of polycentric group because the frequent flow of people, capital and information in these various groups. However, regional infrastructure construction and urban land expansion continued to break through the original ecological boundaries and spread to the surrounding complex terrain.

According to statistics, the area of ecological land was 2.044 million km² in 1990, accounting for about 87.78% of the total area of southwest region. After 2005, the ecological land greatly reduced. The changes in ecological space were mainly concentrated in the Sichuan Basin and south-eastern Yunnan district. The main reason was the implementation of the Chengdu-Chongqing urban agglomeration strategy and the urbanization development planning of other major cities. The final stage of symbiosis is the active ‘co-balance’ under the influence of ecological awareness which is manifested as the ‘revenge’ of the imbalance of the ecological environment for the excessive build artificial development and construction and also increases the marginal cost of urban development. So the construction of mountain cities begins to move towards the symbiosis of human and nature.

At present, the coordinated development of artificial build environment and natural environment in domestic mountain cities is still in its infancy. For example, the Chengdu-Chongqing urban agglomeration development plan in 2016 clearly proposed to fully integrate the concept of green urbanization into the construction of various mountain cities. So construction need to respect the natural pattern, relying on the existing landscape and optimizes the urban spatial layout form. In addition, this planning proposed four major requirements including maintaining the ecological security pattern, implementing environmental co-governance, building a green city and strengthening environmental impact assessment.

Table 3. The built area with some Chinese mountainous cities

The built-up areas	2008	2011	2015	2018
Chongqing	783.29	1051.71	1329.45	1496.72
Panzhihua	54.6	66.39	74.08	81.05
Guiyang	175	211.34	299.00	369.00
Kunming	285.30	334.10	435.81	441.13

Source: authors’ own work.

By the general spatiotemporal evolution model of Chinese mountainous cities mentioned above, the multi-scale spatial effects of mountain cities can be summed up. The regional scale with mountainous cities forms a ‘point-axis’ network pattern, forming a complex network effect; The urban scale corresponds to the polycentric landscape pattern, forming a group network effect; the block scale represents the high-density building ‘cluster pattern’, forming a sub-group three-dimensional effect. Regarding these spatial effects, we use Chongqing City in the South-western region for further analysis and explanation because this city can better reflect a series of spatial effects.

(1) Spatial effect of regional scale: The spatial effect of the regional scale with Chinese mountainous cities manifests the formation of socio-economy agglomeration in a few advantageous cities. With the establishment of infrastructure systems, a point-axis development pattern in region is formed, which can be summarized the above-mentioned spatial development process into the ‘point-axis’ system theory, that is, most social, economic and other elements should be gathered at the ‘point’ and the ‘axis’ refers to the infrastructure systems including transportation, energy and water channels.

Under the trend of globalization, the continuous flows with social, economic and other elements on the 'axis', prompting the region to develop more and more into a flow space, driving a series of development in the 'point' of cities. From the perspective of the regional scale of Chongqing city, we draw on Taylor's network chain model (Taylor 2001) utilizing the relationship between the general head-quarter branch of enterprises. The data of the head-quarter branch of enterprises is obtained by python to poi data and we get a total of 95619 pieces of Chongqing enterprise data in 2019. As result, we demonstrate the 'point-axis' network effect with Chongqing city and finding that the network effect has a radial structure. Social, economic and other elements expressed by a series of enterprises embedded in local development are increasingly spreading from a few advantageous cities to many peripheral cities more conveniently. The interaction between the two types of area promote the development of regional spatial networks.

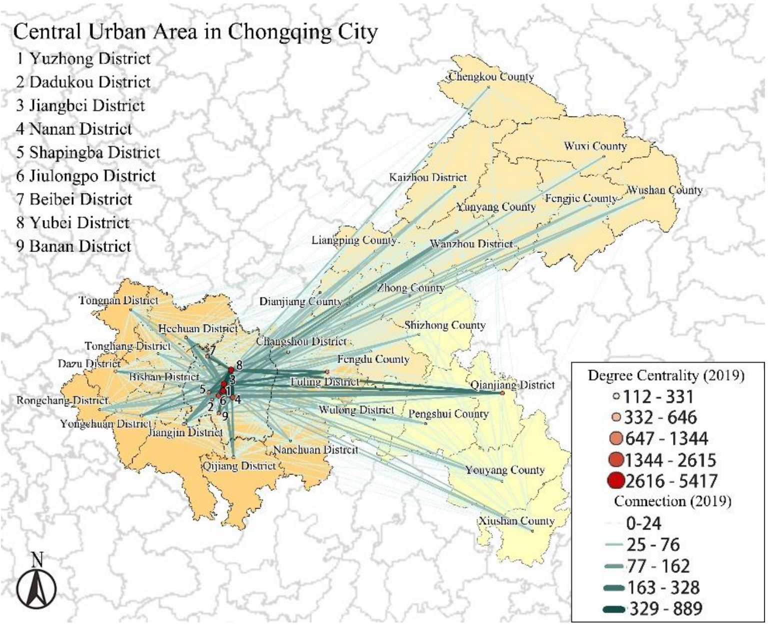


Figure 4. A 'point-axis' network effect of the Chinese mountainous cities: taking a Chongqing City as an example
Source: authors' own work.

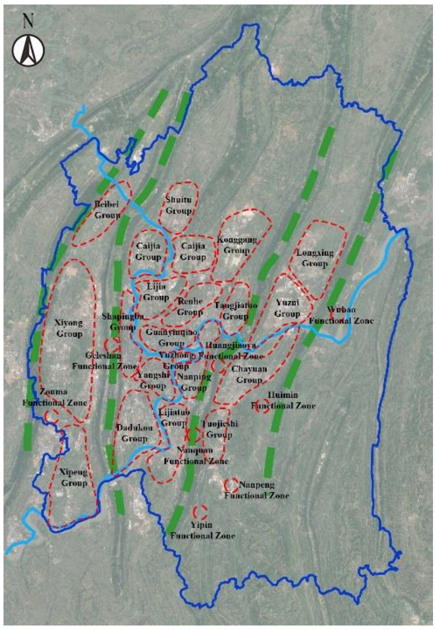


Figure 5. A group network effect of the Chinese mountainous cities: taking a Central Urban Area in Chongqing City as an example
Source: authors' own work.

(2) Spatial effect of urban scale: The spatial effect of the urban scale with Chinese mountainous cities is that mountains and rivers become ecological barriers and boundaries for the expansion of urban construction land. Because of the urban expanded pattern of 'maximum effect and least resistance', mountainous cities increasingly emphasize the shaping of coordinated development with 'production-life-ecosystem' in each group. Taking the distribution of groups in the central urban area of Chongqing city as an example, a total of 21 groups and 8 functional zones were planned to ensure that the functions of each group are relatively complete in the revised comprehensive plan of Chongqing in 2010.

The purpose is to ensure that the functions of each group are relatively complete, the working and living functions within each group are basically balanced and compact; the functional zone is an independent urban construction area outside the group with existing small towns (Figure 5). The combination of the two types not only ensures the ecological boundary and avoids breaking through the limitations of mountains and rivers, but also improves the possibility of job-housing balance among residents in the group and reduces unnecessary commuting cost.

(3) Spatial effect of block scale: The spatial effect of the block scale with Chinese mountainous cities indicates that buildings often combine the slope of the mountain terrain to show the characteristics of point-like vertical growth, forming a sub-group three-dimensional building model because of lacking suitable construction land. This is particularly evident in the historical and cultural blocks and modern high-rise buildings in the southwest region (Figure 6). Taking the ancient buildings of Taiping Street in Anju Town in Chongqing city as an example, Due to the steep slope in the south, the construction land is limited and the entire building cluster is located on the gentle terrace of the river bank. And in order to adapt to this terrain, the building is 'crawling' on the ground, changing flexibly with the terrain; the architectural cluster model of modern high-rise buildings is influenced by the compact city theory which is characterized by the vertical utilization of buildings, a large number of high-rise buildings are gathered and the underground space is also fully utilized (Zhao 2015). Taking Shapingba Transit-Oriented-Development project in Chongqing city as an example, it not only provide a commercial property

development with a total construction area of 480,000 square meters and a plot ratio of 5.8 but also includes: the minus 1 floor is a bus station; the minus 2 floor is a taxi station and high-speed rail platform; the minus 3 floor is the parking lot; the minus 4 floor is the high-speed rail transfer hall and some parking garages; the minus 5 floor and the minus 6 floor are the parking lots; the minus 7 floor is the station hall of the rail transit line 9.

(1) Anju Town

(2) Shapingba Transit-Oriented-Development project

Figure 6. A sub-group three-dimensional effect of the Chinese mountainous cities: taking Anju Town and Shapingba Transit-Oriented-Development project in the Chongqing City as an example
Source: authors' own work.

Conclusions

This paper summarizes the morphology of Chinese mountainous cities by using the figure-to-bottom relationship and typological analysis methods, and then get a general spatiotemporal evolution model and multi-scale spatial effect of Chinese mountainous cities through theoretical deduction and inductive analysis methods. This paper draws the following conclusions:

(1) The morphological characteristics of Chinese mountainous cities urban is affected by three types of horizontal cutting, vertical limit and integrated guidance. Through the mutual influence of natural environment and artificial build environment, four morphologies including clump, ribbon, radial and group of Chinese mountainous cities are formed. Among them, clump can be further divided into general clump and special clump dominated by the developmental mode of green core. The ribbon is a general linear shape and the radial is evolved from the clump and the ribbon, which can be further classified by 'tree-like radial' and 'palm-like radial'. Group is a more common spatial layout in Chinese mountainous cities which can also be further divided into 'bead-like group' and 'constellation-like group'.

(2) According to the analysis of the morphological characteristics of mountainous cities, a general spatiotemporal evolution model of Chinese mountainous cities is obtained. The model finds that the formation of morphology of Chinese mountainous cities follows the three stages of 'constraint stage – breakthrough stage – symbiosis stage'. These stages indicates that under the mutual influence of ecological awareness and transformation ability, although people have high transformation ability, people's ecological awareness is gradually rising, they are increasingly paying attention to how to shape the organic integrated development of natural environment and artificial build environment.

(3) Through the multi-scale spatial effects of Chinese mountainous cities determined by a general spatiotemporal evolution model, it can be found that the multi-scale spatial effects are the 'point-axis' network effect at the regional scale, the group network effect at the urban scale and the sub-group three-dimensional effect at the block scale. First, from the of perspective 'point-axis' network effect at the regional scale, the increasing flow of socio-economic and other elements among mountainous cities pays more and more attention to inter-regional cooperation. Then due to the impact of topographic barrier, each group pays great attention to the organic integration of work and life in order to avoid urban monocentric development mode. Finally, from the perspective of the s sub-group three-dimensional effect at the block scale, mountain buildings are often built along slopes according to topography and landforms, so the buildings are often clustered and the distance between the buildings is small.

All in all, the authors believe that the development of mountainous cities is increasingly ensuring the coordination of natural environment and artificial build environment, especially with the advanced science and technology, how to reduce the negative impact on the natural environment is the key content that needs to be paid attention to in the future development of mountainous cities. First, we must follow the morphological texture of mountain cities and avoid excessive pursuit of flat-like construction in plain cities. Second, we must prudently utilize transformation ability combined with the fact of topographic barrier, advocating the organic growth of mountain cities and guiding the natural environment with ecological advantages in mountains into artificial build environment.

The third is for the limited artificial construction area of mountainous cities, we need to ensure the coordinated development of large, medium, small cities and small towns from both macro and micro level. What is more, it is necessary to further strengthen the agglomerated development of high-density construction with mountainous buildings from the micro level. In response to this construction, it is also necessary to improve the construction of mountainous public space. Therefore, on the one hand, most of mountainous buildings are built on the sloping land or other terrain, leaving flat land for the construction of outdoor public space. On the other hand, it cannot be ignored to strengthen the construction of indoor public space in the mountainous buildings.

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