Chin. Geogra. Sci. 2015 Vol. 25 No. 3 pp. 361–374
doi: 10.1007/s11769-015-0755-0

Springer Science Press
www.springerlink.com/content/1002-0063

Geographical Space Development Zone Classification: An Essential Guide for Transformation of Mountain Resource Cities

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Abstract: Sustainable development of mountain areas and resource cities has been a significant issue worldwide. Transformation of mountain resource cities is facing tremendous difficulties. In the context of National Major Function-oriented Zone Planning raised to a national strategic level in China, it is important to effectively implement the planning by studying geographical space development zone classification of prefecture- and county-level cities based on their major function orientation. This research is even more critical for the transformation of mountain resource cities. In this study, we evaluated geographical space development suitability, and classified geographical space development zones for Dongchuan Distric in Kunming City of Yunan Province, China, a typical mountain resource city. A quantitative grid-based evaluation was conducted using key-factor identification and restrictive-supportive comprehensive index determinati based on a geographic information system framework with different source data. The results included a classification of geographical space of Dongchuan into five types: the prohibited development zone, the inappropriate development zone, the controlled development zone, the moderate development zone and the preferential development zone. The distribution characteristics of geographical space development zones showed that the proportion of the prohibited development zone is the highest, while that of the other four development zones is comparatively lower and significantly fragmented. The geographical space development suitability is greatly controlled by the geomorphic pattern. Although Dongchuan is extremely restrained in terms of suitable geographical space for industrialization and urbanization, it still has the certain preferential and moderate development zones with an area of 207.81 km^2 with large parts being concentrated and contiguous, which makes these areas the most favorable for development. Only by adapting to this reality and implementing centralized development strategy in the regions with higher suitability may Dongchuan achieve smooth transformation from expansion mode to compact mode and its sustainable development capacity may be improved. Suggestions with an angle of industrial and spatial development pattern were put forward for the transformation of the city in future.

Keywords: geographical space development suitability; mountain resource city; transformation of resource cities

Citation: Zhang Jifei, Deng Wei, Liu Shaoquan, 2015. Geographical space development zone classification: an essential guide for transformation of mountain resource cities. *Chinese Geographical Science*, 25(3): 361–374. doi: 10.1007/s11769-015-0755-0

1 Introduction

Mountain development is a significant issue worldwide and holds particular concerns among mountainous countries (Kreutzmann, 2001; Jansky *et al.*, 2002; Gurung *et al.*, 2012; Maselli, 2012). China is known as one of the largest mountainous countries in the world with about 70% of its territory occupied by mountain areas (including hills). Mountain residents account for 46% of the total population (Sun *et al.*, 2012; Fang *et al.*, 2014). Due to complex terrains, limited land resources and fragile ecosystems, spatial development strategy, mode and approach of mountain areas obviously differ from those of plain areas. However, biased guiding principles

Received date: 2014-08-12; accepted date: 2014-12-05
Foundation item: Under the auspices of National Basic Research Program of China (No. 2015CB452706), National Natural Science Foundation of China (No. 41301193), Knowledge Innovation Program of Chinese Academy of Sciences (No. KZCX2-YW-333)
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and philosophy of development have led to many problems, such as cramming improper development activities and blindly copying theories and practices from the plain areas. More and more mountain areas face ecological degradation and environmental deterioration, with their regional characteristics fading away. The human-land relationship has grown increasingly intensified. Reasonable geographical space development (GSD) in mountain areas therefore has become critical for China to achieve comprehensive, balanced and sustainable development.

Covering the largest mountain areas of China, the southwest mountain area (SWMA) encounters the most serious environmental and developmental problems (Zhao, 2008). Meantime, it is also one of the most important mountain areas in China in virtue of the abundant energy, metals and non-metallic mineral resources. With rapid industrialization, urbanization and the Great Western Development Strategy entering implementing stage, resources exploitation and geographical expansion have been increasingly active in the SWMA since the last two decades. Although resource cities have experienced rapid economic growth, the well-known 'curse of natural resources' (Sachs and Warner, 2001) and unsustainable nature of their expansion development mode have raised concerns (Waker and Jourdan, 2003; Papyrakis and Gerlagh, 2007). After making tremendous contribution to the industrialization of China, a series of problems have piled upon in those resource cities (areas) in the SWMA, such as major mine depletion, ecological degradation (Lin, 2006), industrial structure imbalance and unemployment.

Transformation of resource cities (areas) has been a subject of global attention (Scarpaci and Patrick, 2006; Long *et al.*, 2013). Studies in China are focused on transformation mechanism (Liu, 2002; Shen, 2005) and economic transformation, such as leading industry and alternative industry selection (Du *et al.*, 2012; Long *et al.*, 2013). And research on transformation strategy (Dong *et al.*, 2007), transformation performance assessment (Dong *et al.*, 2013), transformation influence on city space (Shao and Zhou, 2011) and government policies (Li *et al.*, 2013) are gradually emerging. In the light of three main elements of transition, namely industry, ecology and livelihoods, transitional paths are envisaged for different resource cities on multiple fronts such as extending industrial chains, developing potential industries, reclaiming lands and upgrading slums (Yu *et al.*, 2011). From a geographical perspective, Li *et al.* (2013) investigated the features and changing patterns of how isolated mining and industrial areas came into being and further developed. According to Li *et al.* (2013), an isolated mining and industrial area was a result of the interaction between internal and external forces within a resource-rich area. The area should embark on a path toward diversified development by balancing social, economic and ecological intersections. With the implementation of National Sustainable Development Planning for Resource Cities (2013–2020), the transformation of resource cities will attract more attention, and emphasis should be placed on the transformation from a viewpoint of integrated GSD.

The National Major Function-oriented Zone Planning (NMFOZP) has been raised to a national strategic level in the outline of the 12th Five-year Plan for National Economy and Social Development (2011–2015) of China (Fan *et al.*, 2010). As the first national territorial development plan in China since 1949 (Fan *et al.*, 2009), this planning is both a theoretical innovation of regional development and an important strategic initiative to promote coordinated regional development. Researchers have conducted studies from many angles like the theoretical basis, research methods and problems faced by the Major Function-oriented Zone Planning (MFOZ Planning). 'Adaptation to local conditions' and 'sequenced spatial structure principle' were deemed as the most important scientific guidelines that underlie the MFOZ Planning (Fan, 2007; Zhang and Lu, 2009). The MFOZ Planning does not only innovate and improve the theoretical structure of regional planning (Fan *et al.*, 2009; Fan *et al.*, 2010; Wang *et al.*, 2012), but also helps integrate regional planning into other spatial plannings. The eco-oriented idea, human-land relationship theory, and spatial overlapping and spatial clustering approaches were also employed to conduct MFOZ Planning (Feng *et al.*, 2008; Ye *et al.*, 2008). Meanwhile, some scholars pointed out some theoretical and technical issues confronted by MFOZ Planning such as clarifying the concepts and relevant implications, how to link MFOZ Planning to related plannings, and inadequate attention to social spatial structure (Fang, 2008; Wu and Wang, 2009; Wang *et al.*, 2012). In addition, barriers and solutions were also summarized among some provincial MFOZ Plannings (Ma and Li, 2009;

Wang *et al*., 2009; Ma *et al*., 2011). The function zoning at prefecture-level and county-level cities that are designated as National Development-optimized Zones was preliminarily studied (Wang *et al*., 2010; Lin and Li, 2014). Some scholars also paid attention to MFOZ Planning of the river basin and islands (Tang, 2011).

As a resource city located in the SWMA, Dongchuan District in Kunming City of Yunnan Province has become a typical mountain resource city in a dilemma resulting from resource depletion (Lin, 2006). Dongchuan was designated as an ecology-related area of provincial development-restricted zone by Yunnan Province Major Function-oriented Zone Planning (Ma *et al*., 2011). With both adverse natural conditions (ecology, environment, geographical location, *etc*.) and flawed anthropogenic conditions (industrial structure, major function-oriented position, *etc*.), Dongchuan is occupied with great challenges during its transformation. According to the NMFOZP, the state and provinces will conduct MFOZ Planning and county is set as the basic unit. In principle, the MFOZ Planning is not conducted at prefecture- and county-level cities. However, these cities will lay out their own function zones based on the national and provincial MFOZ Planning and identify the position and development direction of those zones. Therefore, it is crucial that ensuring effective implementation of the MFOZ Planning by exploring GSD zone classification of county-level cities in the context of national and provincial MFOZ Planning. In particular, it is even more critical for mountain resource cities like Dongchuan, designated as development-restricted zone in the provincial MFOZ Planning.

The GSD zone classification process derives on the basis of the geographical space development suitability (GSDS). Considering the joint forces of national and provincial MFOZ Planning, GSDS in this study is referred to as the degree of how a prefecture- and county-level city is suitable for industrialization and urbanization in line with major function orientation of national and provincial MFOZ Planning. According to GSDS, GSD zone classification provides an effective path to reshape GSD priority. The GSD zone classification refers to evaluating, rating GSDS and then classifying areas into several zones by suitability of development, which is based on an index system and evaluation criteria of restrictive and supportive factors. The principle emphasizing the importance of ecosystem maintenance and socio-economic development is followed throughout the index system and evaluation criteria establishment. In the light of the GSD zone classification, socio-economic activities are arranged into the regions with low development cost (less resource and environmental constraints) and high demand for development so as to gain competitive advantages. Meanwhile, development of the regions with high ecological value is constrained and controlled in order to promote balanced development among regions, as well as between economy and environment (Chen *et al*., 2006). Therefore, the layout of industries in a region, the infrastructure, the public facilities and cities and towns can be carried out in accordance with its GSD zone, which also provides scientific basis for spatial governance (Lu *et al*., 2007). Thus, the GSD zone classification does not only guide differential and pertinent GSD, but also guides the transformation of resource cities.

This study first described the method of evaluating GSDS and classifying GSD zones, then took Dongchuan as a case study to analyze its GSD zone classification, and put forward several suggestions for its transformation. The results of this study may be of significant reference to exploring GSDS evaluation method and transformation pathways for mountain resource regions.

2 Study Area and Methodology

2.1 Study area

Dongchuan, covering an area of 1863 km^2 (25°47′–26°33′N, 102°48′–103°19′E), is a district of Kunming City, the capital of Yunnan Province, China (Fig. 1). The main peak of the Gongwang Mountain, at an elevation of 4344 m in the west, is the highest in the district. The Guniu Ridge is the main peak of the Wumeng Mountain in the east, with an elevation of 4017 m. The Xiaojiang River, a tributary of the Jinsha River, runs through the district from the north to south. The lowest point of Dongchuan lies at the junction of the Xiaojiang River and the Jinsha River, which is 695 m above sea level. Dongchuan, on the Yunnan-Guizhou Plateau, is topographically characterized by erosion and denudation. Due to erosion and dissection of the Jinsha River and Xiaojiang River, the landform pattern of Dongchuan is higher in the south and lower in the north, with one river between the east and west mountains flowing north-southward. In addition, the whole district is dominated

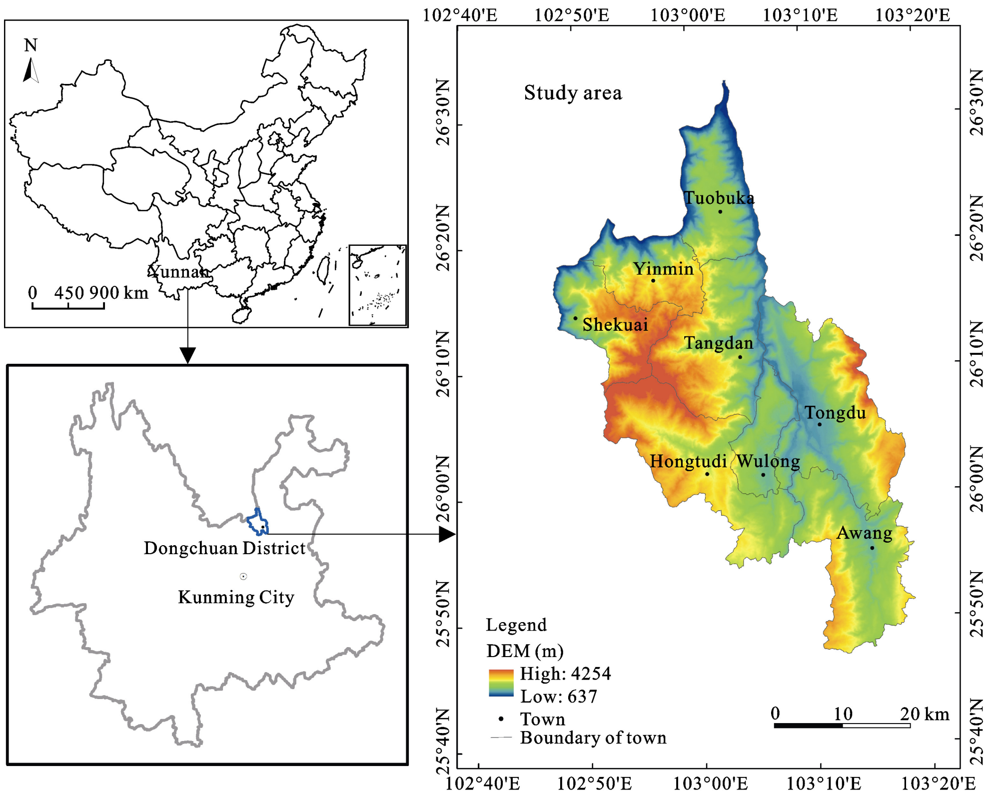

Fig. 1 Location and elevation of study area

by precipitous terrain with a maximum relative altitude of 3649 m because of middle and deep canyons. The land with the slope above 35° accounts for 29.1% of the whole area.

Located in Sichuan-Yunnan dry-hot valley ecosystem conservation area, Dongchuan is one of the typical ecologically fragile areas in the upper reaches of the Changjiang (Yangtze) River, and also a region with serious soil erosion. It has undergone more than one thousand years of copper mining since Western Han Dynasty (202 BC). Firewood logging for copper smelting for such a long time has led to drastic forest reduction. Forest coverage rate decreased from the highest value of 70.0% in history to 13.3% in 1985. Although the forest coverage rate is increasing nowadays, unreasonable forest structure has caused weak function. Moreover, the population growth rendered sloping field overused for agriculture. The slope cropland accounts for 70.0% of the whole and the proportion of the slope cropland above 25° is about 19.0%. About 58.4% of the whole area is threatened by soil erosion. Furthermore, geological hazards at mining sites are prominent. In the context of fragile ecosystem and geological environment, irrational human activities have induced conspicuous mountain hazards with obvious feature of rainstorm-landslide-debris flow chain. Dongchuan is well known as a typical rainwater-induced debris flow areas in China and even in the world (Cui *et al.*, 2005). Every year, more than 1.0×10^7 tons of sediment is brought into the Jinsha River by debris flow. According to Detailed Investigation of Mountain Hazards in Dongchuan, major mountain hazards have caused 141 deaths and about 5.5×10^7 U.S. dollar direct economic losses. Furthermore, 2.5539×10^4 persons and properties valued at around 2.4×10^8 remain under threat.

The economy of Dongchuan flourished and declined both due to copper resources. The Modern Dongchuan Mining Bureau was set up in 1952, and Dongchuan prefecture-level city was established in 1958. It used to be the origin of 'Dongchuan-type' copper mine deposit (Chang and Zhu, 2002), and was also a representative of cities established for mine resource. Despite once being a prefecture-level city with the lowest population, land area and built-up area in China, it made a significant contribution to the non-ferrous metal industry of China in the planned economy era (1953–1992). Because of mine exhaustion, Dongchuan was downgraded to a municipal district of Kunming in 1999. Dongchuan Mining Bureau went bankrupt in 2001. Dongchuan is the only resource city downgraded in administrative level due to mine exhaustion. In 2009, Dongchuan was designated as a resource-exhausted city by the Chinese government, and thereafter it has been depicted as a typical resource city in China.

2.2 Methodology

2.2.1 Geographical space development suitability (GSDS) evaluation method and procedure

Key-factor identification and comprehensive index determination were used to evaluate GSDS, and ArcGIS 9.3 was also applied for spatial analysis.

Key-factor identification was the first step of evaluation. For mountain cities, complex terrains and fragile ecosystems are basic geographical features. Therefore, their development background differs from plain cities. In this study, we suppose ecosystem-first as the basic premise and guide to the GSD of mountain city. Accordingly, geographical spaces that are vital for regional ecological security should be strictly protected from developing. All relevant factors that a region faces during spatial development can be grouped into two types: the restrictive factor and the supportive factor. Here the restrictive factor includes two main items: ecological index and resource index. The ecological index contains three elements: mountain hazards, ecological services and ecological vulnerability; the resource index includes four elements: arable land, water resources, terrain condition and geology condition. Furthermore, each restrictive element is represented by several indicators. In line with the ecosystem-first premise, some specific restrictive indicators, such as river surface and basic farmland, have rigid limit on the GSD. So the key-factor identification can be deemed as identifying key factors that have the strongest restraint on the GSD.

Comprehensive index determination is the second step of evaluation. Based on the Cost-benefit Analysis (Zong *et al.*, 2007), we employed restrictive-supportive comprehensive index method during the GSDS evaluation. From a quantification point of view, the GSDS evaluation can be seen as a new evaluation rank originating from one set of variables recombined by given rules (Hopkings, 1977; Anderson, 1987; Jankonwski and Richard, 1994; Malczewski, 1999). Evaluation method can be expressed as Equation (1).

$$S_d = f(x_1, x_2, x_3, ..., x_i) \quad (1)$$

where S_d represents suitability rank, x_i (i = 1, 2, 3, ..., n) is the ith variable evaluated. The basic common model is weight correction, shown as Equation (2).

$$S_d = \sum_{i=1}^{n} W_i X_i \quad (2)$$

where X_i represents the value of the ith variable, and W_i represents the weight of the ith variable. The variables for evaluating the GSDS can be divided into the supportive factor and the restrictive factor. So GSDS index equals GSD supportive index minus GSD restrictive index. The GSDS index comprehensively reflects the ecological and socio-economic laws, based on which the GSD type classification conforms to regional development reality. Therefore, Equation (2) can be revised as follow:

$$S = \sum_{i=1}^{n} W_{is} X_{is} - \sum_{i=1}^{n} W_{ir} X_{ir} \quad (3)$$

where S represents GSDS index, X_{is} and W_{is} represent the ith GSD supportive indicator X and its weight, respectively, X_{ir} and W_{ir} represent the ith GSD restrictive indicator X and its weight, respectively.

The GSDS evaluation procedure was conducted as follows.

(1) Determine the evaluation unit and the GSD types. Vector superposition and grid superposition are the common methods used to assign values to variables (Lu *et al.*, 2007). This study adopted the grid superposition according to the space distribution of the elements and data acquisition means. The grid size is in inverse proportion to the evaluation precision and computational amount. Therefore, the primary task is to determine the suitable grid size (Yeh and Chow, 1996; Bastin, 2000). Based on the reality of Dongchuan and data availability, 30 m × 30 m grid was taken as basic evaluation unit. With each grid sized of 900 m^2, the evaluation precision suited the GSD type classification requirement of county-level in mountain areas. In the light of the type classification of Major Function Oriented Zoning and the reality of study area, in this study the GSD zone was classified into five types: the preferential development zone, the moderate development zone, the controlled development zone, the inappropriate development zone

and the prohibited development zone.

(2) Construct evaluation index system. The necessity of GSDS study comes from regional spatial differences, especially the differences in the course of industrialization and urbanization. The evaluation index system should reflect these differences scientifically. This study constructed GSDS evaluation index system of Dongchuan based on its development goals and transformation directions (Table 1). Among the evaluation index system, restrictive index includes two item-level indexes, seven element-level indexes and 15 indicator-level indexes. Supportive index includes three item-level indexes, four element-level indexes and four indicator-level indexes.

(3) Quantify GSD restrictive and supportive indexes. First, digitization and coordinate registration were implemented on the non-vector data to obtain their spatial and attribute information. And then, according the results in Table 1, the quantifying procedure of each indicator was detailed as follows.

1) Mountain disaster index. Goaf & collapse area of main mines was confirmed as a key restrictive indicator. Point Density Analysis tool was used to obtain the disaster point density. Natural Break method was used to divide them into five grades: low density (0.0000–0.4668 point/km^2), relatively low density (0.4668–0.8935 point/km^2), moderate density (0.8935–1.3403 point/km^2), relatively high density (1.3403–1.7870 point/km^2) and high density (1.7870–2.2338 point/km^2). The restrictive value of the five grades was 1, 3, 5, 7 and 9, respectively. For the areas exposed to main mine debris flows and areas exposed to main open-pit mine, both of their restrictive values were 5.

2) Ecosystem services index. Protected areas (national mine park, forest park, nature reserves and main river shores conservation areas), protected water source areas, forest lands were confirmed as key restrictive indicators. Protected water source areas were generated by

Table 1 Geographical space development suitability (GSDS) evaluation index system

Objective	Criterion	Item	Element	Indicator	Weight
GSDS index	GSD restrictive index (weight = 1)	Ecological restrictive index (weight = 0.6457)	Mountain hazards index (weight = 0.3596)	Disaster density	0.1876
				Areas exposed to main mine debris flow	0.1030
				Goaf & collapse area of main mine	+∞
				Areas exposed to main open-pit mine	0.0690
			Ecosystem services index (weight = 0.0887)	Protected areas	+∞
				Protected water source areas	+∞
				Forest land	+∞
				Mudflat and wetland	0.0887
			Ecological vulnerability index (wight = 0.1974)	Elevation	0.0699
				Water and soil loss intensity	0.1275
		Resource restrictive index (weight = 0.3543)	Arable land index (weight = +∞)	Basic farmland	+∞
			Surface water index (weight = 0.1099)	Water accessibility	0.1099
			Terrain condition index (weight = +∞)	Land with slope > 25°	+∞
			Geological condition index (weight = 0.2445)	Engineering geological condition	0.1464
				Fault zone	0.0981
	GSD supportive index (weight = 1)	Transportation supportive index (weight = 0.4018)	Inter-county transportation accessibility index (weight = 0.4018)	Journey time from each township center to Dongchuan District center	0.4018
		Assemble effective index (weight = 0.3289)	Economic development index (weight = 0.1969)	Net income per farmer of each township	0.1969
			Built-up area scale index (weight = 0.1320)	Built-up area of each township	0.1320
		Resource supportive index (weight = 0.2693)	Mineral resources deposit index (weight = 0.2693)	Promoted & limited exploitation region	0.2693

the Buffer tool as ecological isolation belt around water sources. According to Nation Environmental Protection Standards (HJ/T338-2007), the buffer distance was determined as 1000 m. The restrictive value of mudflat and wetland was determined as 5.

3) Ecological vulnerability index. Based on relevant studies (Han *et al.*, 2008; Zhu *et al.*, 2008; Yan *et al.*, 2009), and the complex terrains and its serious water and soil loss in the study area, we selected elevation and water and soil loss intensity[①] to study ecological vulnerability. We used 30 m × 30 m digital elevation model (DEM)[②], and according to the spatial distribution of population and Natural Break method, reclassified the elevation of Dongchuan into three grades: 637–1600 m, 1600–2400 m and 2400–4254 m, designated with restrictive value of 1, 5 and 9, respectively. Additionally, the six-grade soil erosion intensity was reclassified into three grades: the micro and the slight combined as the low intensity, the moderate and the strong combined as the moderate intensity, the extreme and the severe combined as the high intensity, designated with restrictive value of 1, 5 and 9, respectively.

4) Arable land index. Basic farmland was regarded as another key restrictive indicator in this study. Its spatial distribution was obtained from the land use data of Dongchuan.

5) Surface water index. Dongchuan has abundant water resources, and most ground water enters river in the form of springs. Because river runoff contains ground water runoff, its surface water can represent the total water resource. Due to the influence of terrain, most regions in Dongchuan have difficulties in accessing water, which greatly increases the construction cost and limits GSD. This study took surface water accessibility (Fan, 2010) as a representation of the restrictive degree of water resources (Table 2). Water accessibility mainly lies in the distance from the rivers and the relative altitude. Thus, water accessibility evaluation includes three factors: distance, slope and elevation. We carried out quantitative evaluation on the water accessibility based on Table 2, and the three grades were designated with restrictive value of 0, 5 and 9, respectively.

6) Terrain condition index. This index was expressed by slope. Slope is one important control indicator of construction investment and development intensity (Zhou *et al*., 2007). When the slope is above 25°, it is difficult to arrange concentrated construction, and is not suitable for traffic, industry warehouse or production activities. Only small-scale residential houses could be planned there, and both the longitudinal traffic and pipe network distribution are greatly limited. Besides, construction cost will increase significantly while safety and accessibility greatly decrease (Fan, 2010). In addition, constructing on land with the slope above 25° is prone to inducing landslide, debris flow and other mountain hazards. Based on the DEM, slope mapping was done by Surface Analysis, and the spatial distribution of three slope grades (slope < 8°), 8° < slope < 15°, 15° < slope < 25°) was obtained. The land with the slope above 25° was confirmed as prohibited development zone, and the land with the three slope grades was designated with restrictive value of 1, 5 and 9, respectively.

7) Geological condition index. Geological conditions of mountain areas are of tremendous difference, and play a key role in regional development. In this study, it is represented by engineering geological condition and fault zone. Based on the evaluation results of Detailed Investigation of Mountain Hazards in Dongchuan, we classified the engineering geological condition into three grades: good, medium and poor. The minimum setback distance of causative fault stipulated in China Earthquake Resistant Design (GB50011-2001, 2008 Revision) is

Table 2 Grade of water accessibility

Water accessibility	Grading standard	Area (km²)	Percentage (%)
Good	(water access distance ≤ 500 m) ∩ (slope ≤ 6°) ∩ (elevation ≤ 2000 m)	53.77	2.86
Medium	(water access distance ≤ 2000 m) ∩ (slope ≤ 15°) ∩ (elevation ≤ 2000 m)	404.93	21.53
Poor	(water access distance > 2000 m) ∪ (slope > 15°) ∪ (elevation > 2000 m)	1421.89	75.61

① Yunnan Province Erosion Remote Sensing Investigation Report, 2004

② International Scientific Data Service Platform, http://www.cnic.cas.cn/zcfw/sjfw/gjkxsjjx/

more suitable for the plain areas. Due to impacts of mountain hazards, available land of mountain areas is extremely limited. The above-mentioned minimum setback distance is obviously inappropriate for mountain areas (Zhou *et al*., 2008; Zhang *et al*., 2010). Referring to the setback distance of seismic fault in Revised Active Fault Bill in California, the USA (1997) (Earl and William, 1997), this study designated 30 m at both sides of fault zone as prohibited development zone and 30–200 m as "developable region" with constraint. Their spatial information was obtained by the Buffer tool. Geological condition for engineering of the good, the medium and the poor grades were designated with restrictive value of 0, 5 and 9, respectively. The values of 30–200 m at both sides of fault zone are 5.

8) Inter-county transportation accessibility index. Currently, transportation in Dongchuan is dominated by motorways (railway is only used for small freight), with few highways and an immature transportation network. Since Dongchuan lacks outbound traffic routes, this study chose traffic accessibility within the district to reflect transportation accessibility in different areas. According to the final road planning in the Comprehensive City Plan of Dongchuan District, Kunming (continued revision, 2007), the transportation accessibility of each township was expressed by the journey time from its township center to the district center, Tongdu Town. The journey time was classified into 3 grades: short time, medium time and long time, endowed with supportive value of 9, 5 and 1, respectively. The transportation accessibility of other areas was obtained by Kriging interpolation.

9) Economic development index. Given the data availability, the net income per farmer of each township was used to reflect their economic development level and agglomeration effect. The net income in 2008 was classified into 3 levels: high (389–432 U.S. dollar), medium (360–389 U.S. dollar) and low (317–360 U.S. dollar), designated with development supportive value of 9, 5 and 1, respectively.

10) Built-up scale index. For Dongchuan, the larger the town scale is, the higher the economic benefit is. Therefore, the built-up scale of each township was selected to reflect its agglomeration effect. The built-up scale was classified into large, medium and small, endowed with development supportive value of 9, 5 and 1, respectively.

11) Mineral resource deposit index. Though the copper mine has been exhausted, a variety of other metal and non-metal mineral deposits are still to be exploited. It is very difficult for a resource-based city to accomplish transformation development in a short period. It should rely on its traditional advantageous resource-based industries for a long time. Therefore, taking current mineral resource endowment into consideration and according to Mineral Resource Planning of Dongchuan District, Kunming (2005), this study endowed the promoted exploitation region and limited exploitation region with supportive values of 9 and 5, respectively.

2.2.2 Calculation of geographical space development suitability (GSDS) index (S value) and classification of geographical space development (GSD) zones

The weight of each index was determined by Delphi-AHP method (Xu, 2002). The role of restrictive indexes is contrary to that of supportive indexes, which makes it difficult to compare. Therefore, the approach adopted was to independently give weight to the two kinds, namely supposing the weight coefficient sum of both respectively to be 1. On the basis of Equation (3) and 30 m × 30 m grid, the map algebra operation was carried out on each index layer by restrictive-supportive method using Spatial Analyst module of ArcGIS. *S* value of ′developable region′ out of ′prohibited development region′ was calculated, and GSD zones were classified. Specific procedures were explained as follows: 1) based on weights and ranked values of restrictive and supportive indexes, Grid Calculation function was used to calculate *S* value of each grid unit; 2) *S* value frequency histogram and the development trend of Dongchuan were comprehensively considered to determine GSD zone threshold values; 3) GSD zone classification was made according to threshold values.

2.3 Data

In accordance with GSDS evaluation, the data of 11 elements and 18 indicators and DEM was collected (Table 3). Firstly, the data was projected to the same projection as DEM. Then the primary database was established with all the spatial data in the same projection systems WGS1984UTM and geographic coordinate system GCSWGS1984. Besides, the attribute data, such as rural resident′s income and journey time of each township were linked to the relevant spatial data.

Table 3 Data set for geographical space development suitability (GSDS) evaluation

No.	Item	Format	Projection	Processing/Remarks
1	Map of mountain hazards	JPEG file	No projection	Projecting and digitalizing
2	Map of main mine debris flows	JPEG file	No projection	Projecting and digitalizing
3	Map of main mine goaf & collapse	JPEG file	No projection	Projecting and digitalizing
4	Map of influence area of main open-pit mine	JPEG file	No projection	Projecting and digitalizing
5	Map of nature reserve	JPEG file	No projection	Projecting and digitalizing
6	Map of forest park	JPEG file	No projection	Projecting and digitalizing
7	Map of nation mine park	JPEG file	No projection	Projecting and digitalizing
8	Map of main rivers two-bank ecological reserve	JPEG file	No projection	Projecting and digitalizing
9	Map of drinking water sources	JPEG file	No projection	Projecting and digitalizing
10	Land use	MapGIS file	No projection	Conversing and rejecting
11	Digital Elevation Model (DEM)	Grid	WGS1984UTM	Reference standard
12	Map of soil erosion	Grid	Clarke1866Albers	Projecting
13	Map of geological condition evaluation	JPEG file	No projection	Projecting
14	Map of geological structure	JPEG file	No projection	Projecting
15	Map of mineral resource use plan	MapGIS file	No projection	Transforming and projecting
16	Map of transportation plan	JPEG file	No projection	Projecting
17	Map of administrative boundary	MapGIS file	No projection	Transforming and projecting
18	Rural resident's income	Excel file	–	Attribute data
19	Journey time of each township	Excel file	–	Attribute data

3 Results

Evaluation results showed that S values ranged between –3.7869 and 5.7592, no regions with $S = 0$ (Fig. 2). The basic unit evaluated was 30 m × 30 m grid and each grid corresponding to a unique S. The S size of a unit reflected its suitability for GSD. In order to make the evaluation result more understandable, practical and instructive, the further reclassification of GSDS was necessary. The reclassification rule was as follows. 1) When $S > 0$, units with $S < 2.8796$ were classified as the moderate development zone and units with $2.8796 < S < 5.7592$ as the preferential development zone. 2) When $S < 0$, units with $S > -3.7869$ were classified as the inappropriate development zone and units with $-1.89345 < S < 0.0000$ as the controlled development zone. 3) Developable units with elevation above 3500 m were classified as the inappropriate type based on the population vertical distribution of China (Chen, 2004) and spatial development reality of Dongchuan. Thus, the geographical space of Dongchuan was classified into five development zones: the prohibited zone, the inappropriate zone, the controlled zone, the moderate zone and the preferential zone (Table 4).

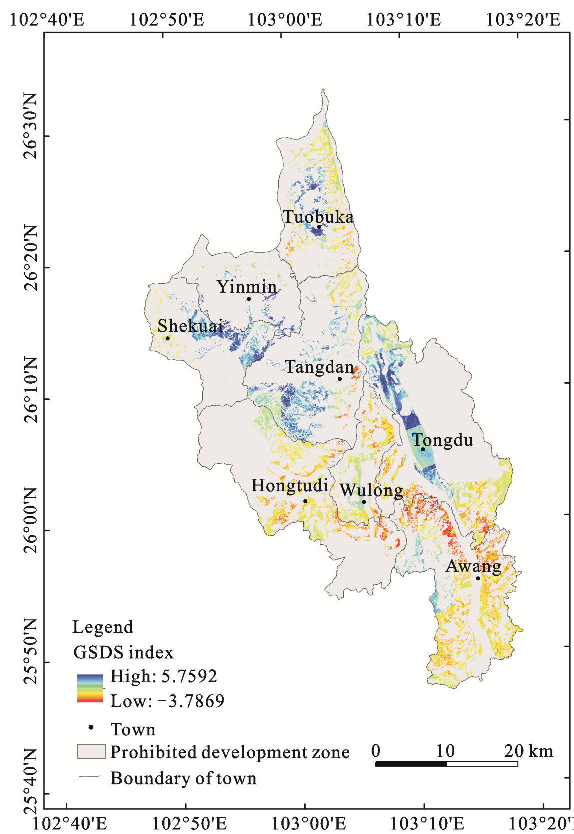

Fig. 2 Spatial distribution of geographical space development suitability (GSDS) index (S value) in study area

Table 4 Geographical space development (GSD) zones of study area and its townships

Township/ Dongchuan	Item	GSD zone				
		Prohibited development zone	Inappropriate development zone	Controlled development zone	Moderate development zone	Preferential development zone
Awang	Area (km^2)	199.83	6.72	46.00	27.03	0.87
	Percentage (%)	13.11	23.46	38.38	17.10	1.75
Tuobuka	Area (km^2)	163.92	0.01	9.95	16.01	5.52
	Percentage (%)	10.75	0.02	8.30	10.13	11.09
Yinmin	Area (km^2)	145.55	0.00	0.00	2.85	4.20
	Percentage (%)	9.55	0.00	0.00	1.80	8.45
Shekuai	Area (km^2)	141.77	8.27	1.03	11.40	7.44
	Percentage (%)	9.30	28.88	0.86	7.21	14.96
Tangdan	Area (km^2)	233.10	6.56	3.61	25.87	13.09
	Percentage (%)	15.29	22.89	3.01	16.37	26.32
Hongtudi	Area (km^2)	284.99	6.27	26.27	12.47	0.05
	Percentage (%)	18.70	21.87	21.91	7.89	0.09
Wulong	Area (km^2)	77.91	0.21	11.68	13.80	0.00
	Percentage (%)	5.11	0.72	9.74	8.73	0.00
Tongdu	Area (km^2)	277.24	0.62	21.32	48.64	18.57
	Percentage (%)	18.19	2.15	17.79	30.77	37.34
Dongchuan	Area (km^2)	1524.30	28.65	119.87	158.06	49.75
	Percentage (%)	81.05	1.52	6.37	8.40	2.65

The spatial distribution of GSD zones in Dongchuan was shown in Fig. 3. The proportion of prohibited development zone was the highest, while that of developable zone (the other four development zones) was low with significant fragmentation. Most area of Dongchuan, which accounted for 81.05% of its territory, fell into prohibited development zone, while the developable zone only accounted for 18.95%. It was clear that the prohibited development zone was superior in number. On contrast, the developable zone was not only small in size, but also surrounded by the prohibited development zone. Few of developable zone was concentrated and contiguous, which indicated that the suitable geographical space for construction and development was much limited and the constraint for the GSD was extremely prominent.

4 Discussion

According to the classification result, the entire spatial differentiation of GSD zones is significant with each type of zone varied distribution. The spatial distribution of the prohibited and the developable zone coincides well with the terrain. Most of the developable zone scatters from the south to north along the Xiaojiang River

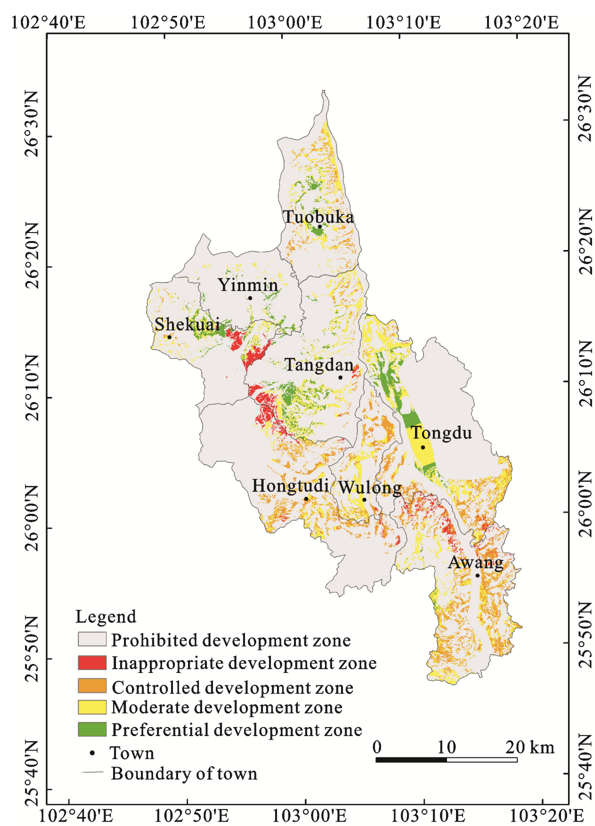

Fig. 3 Geographical space development (GSD) zone classification in study area

Valley. Specifically, main part of the developable zone is in the Xiaojiang River Valley and mid-mountainside within five townships: Tuobuka, Tangdan, Tongdu, Wulong and Awang. Small part of the developable zone is in the mid-mountain planation surface within five townships: Yinmin, Shekuai, Tangdan, Hongtudi, and Awang. Only a few developable zone is located in the Jinsha River Valley, including some parts of Tuobuka, Yinmin and Shekuai. The prohibited development zone can be found at various elevations, but mostly in the east and west high altitude and some in the middle mountainside in the north.

The GSD of Dongchuan should observe both natural and socio-economic rules. In deference to the particular vulnerability of mountain resource city, bearing ecosystem-first in mind during GSD implies a prioritized sequence in spatial structure that roots in natural laws. The restrictive factors of the GSD mainly include mountain hazards, fragile ecosystems, and limited land resources and water accessibility. The supportive factors of the GSD mainly consist of transportation conditions, economic development and mineral exploitation potentials. Given the factors mentioned above depict a significant spatial variation, and they present different impacts on the GSDS, it ultimately leads to a distinctive spatial heterogeneity of the GSD zones in Dongchuan. Besides, the above distribution feature is consistent with the geomorphic pattern of 'one river between the east and west mountains flowing north-southward', which evinces that the GSDS is greatly controlled by the geomorphic pattern in mountain areas.

The preferential and the moderate development zones show point-like discrete distribution on the whole, accounting for 13.96% and 44.35% of developable zone, 2.65% and 8.40% of the territory of Dongchuan, respectively. Therefore, suitable geographical space for industrialization and urbanization in Dongchuan is extremely limited. However, the preferential and the moderate development zones still account 11.05% of the whole district with a total area of 207.81 km². Moreover, as the most suitable space for developing, the concentrated and contiguous preferential and moderate development zones are found in Tongdu, Tangdan and Tuobuka. In particular, the preferential development zone in Tongdu is the most concentrated and has a great development potential. Therefore, the GSD of Dongchuan in future should follow the basic spatial pattern and implement centralized and compact development in the regions with higher GSDS. Only in this way may its development achieve the transition from expansion mode to compact mode and its sustainable development capacity be improved as well.

Based on the study results, we put forward intensive compact development mode for the transformation of Dongchuan. The mode contains three points. Firstly, conduct entire balanced spatial governance (Table 5). Different GSD zones have different geographical space development functions in line with industry type and urbanization intensity. Therefore, differential spatial governance measures should be implemented in the GSD zones. By means of secondary distribution of ecological compensation among five GSD zones, the balance between protection and development of geographical space can be achieved and maintained. Secondly, develop mountain eco-friendly industries. Developing mountain ecological agriculture may benefit from the vertical differentiation of tropical and subtropical climates, and avoid the shortcoming of land scarcity in Dongchuan. Promoting resource recycling in eco-industrial parks and deepening circular economy may revitalize the mining industry. Actively pushing the mountain tourism forward may accelerate the development of related service industry. The long-term copper mining, unique landscape of red earth, spectacular Xiaojiang landslide and Jiaozi Snow Mountain provide advantaged tourism resources to develop mining heritage tourism, sport tourism, ecotourism and adventure travel. Thirdly, implement 'dotted' development strategy of urbanization and industrialization. That is, the vast majority of territory of Dongchuan, namely the prohibited and inappropriate development zones should be protected from further development, and the moderate and preferential development zones representing 'dotted' distribution should be actively developed. The controlled development zones are taken as reserve geographical space with no development in recent. Through ecological migration and compact development, the most residents and economic activities can be carried in the moderate and preferential development zones. Consequently, Dongchuan GSD may finally achieve a sustainable state by mutually coupling human initiative and natural laws.

Table 5 Development directions of five geographical space development (GSD) zones

GSD zone	Development direction
Preferential zone	Give priority to developing renewable energy industry (wind and solar power), to promoting efficient ecological farming and featured agricultural and side-product processing industry, and to intensively developing existing towns and improving their public services; centralize population and properly resettle migrants from the prohibited and inappropriate zones; strictly control pollution and reinforce ecological protection.
Moderate zone	Moderately develop renewable energy industry (wind and solar power); actively promote efficient ecological agriculture; moderately centralize population; actively develop ecotourism; give emphasis on ecological conservation.
Controlled zone	Give priority to maintaining ecosystems; moderately develop featured ecological agriculture and facility agriculture; control excessive population growth; moderately develop ecotourism; moderately develop renewable energy industry (wind and solar power).
Inappropriate zone	Actively implement Grain for Green; enhance mountain hazards prevention; prevent soil erosion; restore mountain ecosystems; strictly control population growth; implement migration policy in regions of ecological degradation; moderately develop ecotourism; moderately develop renewable energy industry (wind and solar power).
Preferential zone	Follow natural reserve regulations, implement migration policy to reduce population; establish no-man area in places that are ecologically highly sensitive and/or extremely disaster-prone (equivalent to core area of nature reserves); strictly protect basic farmland from encroachment; strictly protect vegetation; strictly prohibit reclamation or excavation on steep slopes.

5 Conclusions

In this study, industrialization and urbanization were taken as the main contents of mountain GSD. Reconciling need for economic development with concern for environment was regarded as a key task for GSD of mountain areas. It takes both need and concern into consideration when determining whether a region is suitable and/or how suitable it is for industrialization and urbanization. A comprehensive evaluation method was constructed to obtain the GSDS, by which the GSD zone classification was made. Dongchuan District, a typical mountain resource city of China, was selected to conduct the case study by identifying key factors combined with the composite index assessment. This study could provide positive practices on exploring the GSDS evaluation method and transformation of mountain resource regions. Moreover, the results provided a referential lesson for the GSD and transformation of Dongchuan in future.

Acknowledgments

The authors would like to acknowledge Zhang Haiya and Liu Rongkun for their helpful insights and comments on this article.

References

Anderson L T, 1987. *Seven Methods for Calculating Land Capability/Suitability. Planning Advisory Service (PAS) Report*. Chicago: American Planning Association.

Bastin O, 2000. Landscape classification in Saxony (Germany): a tool for holistic regional planning. *Landscape and Urban Planning*, 50(3): 145–155. doi: 10.1016/S0169-2046(00)00086- 4

Chang X Y, Zhu B Q, 2002. Isotope geochemistry of the Dongchuan copper deposit, Yunnan, SW China: stratigraphic chronology and application of lead isotopes in geochemical exploration. *Chinese Journal of Geochemistry*, 21(1): 65–72. doi: 10.1007/BF02838054

Chen Guojie, 2004. *The Report of Chinese Mountain Area Development 2003*. Beijing: The Commercial Press, 165–166. (in Chinese)

Chen Wen, Sun Wei, Duan Xuejun *et al*., 2006. Regionalization of regional potential development in Suzhou City. *Acta Geographica Sinica*, 61(8): 839–846. (in Chinese)

Cui P, Chen X Q, Wang Y Y *et al*., 2005. Jiangjia Ravine debris flows in south-western China. In: Jakob M *et al*. (eds.). *Debris-flow Hazards and Related Phenomena*. Heidelberg: Springer Berlin Heidelberg, 565–594.

Dong F, Long R Y, Chen H *et al*., 2013. The convergence test of transformation performance of resource cities in China considering undesirable output. *Mathematical and Computer Modeling*, 58(5–6): 948–955. doi: 10.1016/j.mcm.2012.10.020

Dong Suocheng, Li Zehong, Li Bin *et al*., 2007. Problems and strategies of industrial transformation of China's resource-based cities. *China Population, Resource and Environment*, 17(5): 12–17. (in Chinese)

Du J M, Yu B, Yao X L, 2012. Selection of leading industries for coal resource cities based on coupling coordination of industry's technological innovation. *International Journal of Mining Science and Technology*, 22(3): 317–321. doi: 10.1016/j.ijmst.2012.04.006

Earl W H, William A B, 1997. *Fault-rupture Hazard Zones in California: Alquist-Priolo Earthquake Fault Zoning Act with Index to Earthquake Fault Zones Maps*. California: Division of Mines and Geology, 7–34.

Fan J, Tan A J, Ren Q, 2010. On the historical background, scientific intentions, goal orientation, and policy framework of Major Function-Oriented Zone Planning in China. *Journal of Resources and Ecology*, 1(4): 289–298. doi: 10.3969/j.issn.1674-764x.2010.04.001

Fan Jie, 2007. The scientific foundation of Major Function Oriented Zoning in China. *Acta Geographica Sinica*, 62(4): 339–350. (in Chinese)

Fan Jie, 2010. *Resource Environment Carrying Capacity Evaluation for Post-Yushu Earthquake Restoration and Reconstruction*. Beijing: Science Press, 34–50. (in Chinese)

Fan Jie, Sun Wei, Chen Dong, 2009. Scientific and technological innovation in spatial planning during 'the 11th Five-Year Plan' period and suggestions to the spatial planning of 'the 12th Five-Year Plan'. *Bulletin of Chinese Academy of Sciences*, 24(6): 601–609. (in Chinese)

Fang Y P, Fan J, Shen M Y *et al*., 2014. Sensitivity of livelihood strategy to livelihood capital in mountain areas: empirical analysis based on different settlements in the upper reaches of the Minjiang River, China. *Ecological Indicators*, 38: 225–235. doi: 10.1016/j.ecolind.2013.11.007

Fang Zhongquan, 2008. The problem and adjusting thinking on construction of Principal Function Area. *Areal Research and Development*, 27(6): 29–33. (in Chinese)

Feng Dexian, Zhang Li, Yang Ruixia *et al*., 2008. A study of panning in the main function regions based on the man-nature relationship theory of Henan Province. *Areal Research and Development*, 27(1): 1–5. (in Chinese)

Gurung A B, Dach S W, Price M F *et al.*, 2012. Global change and the world's mountains: research needs and emerging themes for sustainable development. *Mountain Research and Development*, 32(S1): 47–54. doi: 10.1659/MRD-JOURNAL-D-11-00084.S1

Han Guifeng, Zhao Ke, Yuan Xingzhong *et al*., 2008. Evaluation of ecological sensitivity in mountain area based on spatial analysis: a case study of Wanyuan City in Sichuan Province. *Journal of Mountain Science*, 26(5): 531–537. (in Chinese)

Hopkings L D, 1977. Methods for generating land suitability maps: a comparative evaluation planners. *Journal of American Institute of Planners*, 43(4): 386–400.

Jankonwski P, Richard L, 1994. Integration of GIS-based suitability analysis and multi-criteria evaluation in a spatial decision support system for route selection. *Environment and Planning B*: *Planning and Design*, 21(3): 323–340. doi: 10.1068/b210323

Jansky L, Ives J D, Furuyashiki K *et al.*, 2002. Global mountain research for sustainable development. *Global Environmental Change*, 12(3): 231–239. doi: 10.1016/S0959-3780(02)00015-8

Kreutzmann H, 2001. Development indicators for mountain regions. *Mountain Research and Development*, 21(2): 132–139. doi: 10.1659/0276-4741(2001)021[0132:DIFMR]2.0.CO;2

Li H J, Long R Y, Chen H, 2013. Economic transition policies in Chinese resource-based cities: an overview of government efforts. *Energy Policy*, 55: 251–260. doi: 10.1016/j.enpol.2012.12.007

Li Qian, Zhang Wenzhong, Wangdai, 2013. Geographical research on isolated mining and industrial areas. *Progress in Geography*, 32(7): 1092–1101. (in Chinese)

Lin Jinlin, 2006. *Research on Ecospace Construction of Mountain Resource-based Cities*. Chongqing: Chongqing University. (in Chinese)

Lin Jinyao, Lixia, 2014. MFOZ planning of Dongguan based on spatial autocorrelation by using genetic algorithms. *Geographical Research*, 33(2): 349–357. (in Chinese)

Liu Yungang, 2002. *Study Of Development Mechanism and Regulation of Chinese Resource-based City*. Changchun: Northeast Normal University. (in Chinese)

Long R Y, Chen H, Li H J *et al*., 2013. Selecting alternative industries for Chinese resource cities based on intra- and inter-regional comparative advantages. *Energy Policy*, 57: 82–88. doi: 10.1016/j.enpol.2012.10.047

Lu Yuqi, Lin Kang, Zhang Li, 2007. The methods of spatial development regionalization: a case study of Yizheng City. *Acta Geographica Sinica*, 62(4): 351–363. (in Chinese)

Ma Haixia, Li Huiling, 2009. Discussions about same problems to the western region of the main function division and construction. *Areal Research and Development*, 28(3): 12–16. (in Chinese)

Ma Renfeng, Wang Xiaochun, Zhang Meng *et al*., 2011. The application and reflection of Major Function Oriented Zoning in Yunnan. *Geographical Research*, 30(7): 1296–1308. (in Chinese)

Malczewski J, 1999. *GIS and Multicriteria Decision Analysis*. Hoboken: John Wiley and Sons.

Maselli D, 2012. Promoting sustainable mountain development at the global level. *Mountain Research and Development*, 32(S1): 64–70. doi: 10.1659/MRD-JOURNAL-D-12-00131.1

Papyrakis E, Gerlagh R, 2007. Resource abundance and economic growth in the United States. *European Economic Review*, 51(4): 1011–1039. doi: 10.1016/j.euroecorev.2006.04.001

Sachs J D, Warner A M, 2001. The curse of natural resources. *European Economic Review*, 45(4–6): 827–838. doi: 10.1016/S0014-2921(01)00125-8

Scarpaci J L, Patrick K J, 2006. *Pittsburgh and the Appalachians*: *Cultural and Natural Resources in a Postindustrial Age*. Pittsburgh: University of Pittsburgh Press, 1–3.

Shao J, Zhou J Q, 2011. Study on the influences of industry transformation on the sustainable development of resource-exhausted city space. *Procedia Engineering*, 21: 421–427. doi: 10.1016/j.proeng.2011.11.2034

Shen Lei, 2005. *Theortical Study on the Transformation of Resources-based Cities in China*. Beijing: Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences. (in Chinese)

Sun W, Han X X, Sheng K R *et al*., 2012. Geographical differences and influencing factors of rural energy consumption in southwest mountain areas in China: a case study of Zhaotong City. *Journal of Mountain Science*, 9(6): 842–852. doi: 10.1007/s11629-012-2355-0

Tang Changchun, 2011. Construction of method and index system of MFOZ in a river basin: a case study of Yangtze River Basin. *Geographical Research*, 30(12): 2173–2184. (in Chinese)

Walker M, Jourdan P, 2003. Resource-based sustainable development: an alternative approach to industrialization in South Africa. *Minerals & Energy Raw Materials Report*, 18(3): 25–43. doi: 10.1080/14041040310019435

Wang Chuansheng, Zhao Haiying, Sun Guiyan *et al*., 2010. Function zoning of development-optimized area at a county level: a case study of Shangyu, Zhejiang. *Geographical Research*, 29(3): 481–490. (in Chinese)

Wang Qiang, Wu Shidai, Li Yongshi *et al*., 2009. The application of Major Function Oriented Zoning in Fujian Province. *Acta Geographica Sinica*, 64(6): 725–735. (in Chinese)

Wang Shengyun, Ma Renfeng, Shen Yufang, 2012. The turn of China's regional development research paradigms and the theoretical response of Major Function Oriented Zoning. *Areal Research and Development*, 31(6): 7–11. (in Chinese)

Wu Jing, Wang Jinwu, 2009. Comprehensive summarization and discussion on the progress of Major Function Regionalization. *Tropical Geography*, 29(6): 532–538. (in Chinese)

Xu Jianhua, 2002. *Mathematical Methods in Contemporary Geography*. Beijing: Higher Education Press, 224–230. (in Chinese)

Yan lei, Xu Xuegong, Xie Zhenglei *et al*., 2009. Integrated assessment on ecological sensitivity for Beijing. *Acta Ecologica Sinica*, 29(6): 3117–3125. (in Chinese)

Ye Yuyao, Zhang Hongou, Li Bin, 2008. An ecologically based technique for the Principal Function Zoning. *Progress in Geography*, 27(1): 39–45. (in Chinese)

Yeh A G O, Chow M H, 1996. An integrated GIS and location-allocation approach to public facilities planning: an example of open space planning. *Computer*, *Environment and Urban System*, 20(4–5): 339–350. doi: 10.1016/S0198-9715(97)00010-0

Yu Jianhui, Zhang Wenzhong, Wang Dai, 2011. The transformation path of China's resource-exhausted cities. *World Regional Studies*, 20(3): 62–72. (in Chinese)

Yu Kaisheng, 2007. *The Analysis about the Minerals Resource Type City* (*Area*) *Industrial Promotion of Competition Ability in China*. Beijing: Northeast Forestry University. (in Chinese)

Zhang Mingdong, Lu Yuqi, 2009. Theory study evolvement of national Major Function Oriented Zoning. *Areal Research and Development*, 28(3): 7–11. (in Chinese)

Zhang Yongshuang, Sun Ping, Shi Jusong *et al.*, 2010. Investigation of rupture influence zones and their corresponding safe distances for reconstruction after 5.12 Wenchuan earthquake. *Journal of Engineering Geology*, 18(3): 312–319. (in Chinese)

Zhao Wanmin, 2008. Some Thoughts on theoretical research about adaptation of planning of mountainous cities in Southwest China. *South Architecture*, (4): 34–37. (in Chinese)

Zhou Jianfei, Zeng Guangming, Huang Guohe *et al*., 2007. The ecological suitability evaluation on urban expansion land based on uncertainties. *Acta Ecologica Sinica*, 27(2): 774–783. (in Chinese)

Zhou Qing, Xu Xiwei, Yu Guihua *et al.*, 2008. Investigation on widths of surface rupture zones of the M 8.0 Wenchuan earthquake, Sichuan Province, China. *Seismology and Geology*, 30(3): 778–788. (in Chinese)

Zhu Chasong, Luo Zhendong, Hu Jiyuan, 2008. The research of urban non-construction land's classification based on ecological sensitivity analysis. *Urban Studies*, 15(4): 30–35. (in Chinese)

Zong Yueguang, Wang Rong, Wang Chenggang *et al*., 2007. Ecological suitability assessment on land use based on potential-constrain approach: the case of urbanized areas in Dalian City, China. *Geographical Research*, 26(6): 1117–1127. (in Chinese)