Evaluation and Function Zoning of Geological Environment Carrying Capacity in Changping District, Beijing

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Abstract. The carrying capacity of the geological environment to human activities is limited, and the maximum limit of this carrying capacity is the geological environment carrying capacity. It is necessary to scientifically understand the concept of geological environment carrying capacity from two dimensions: the geological environmental conditions (the carrier) and human activities (the load). Changping District, Beijing, is an important district north of the capital city, and it has conspicuous locational advantages in diverting non-capital functions and achieving high-quality development. By following Beijing's strategic positioning as the "four centers," Changping District will rationally define the regional functions, adhere to the constraint of resource and environment carrying capacity, impose district-wide control of the population, land use, and construction scale, promote development with reduced resource consumption, and optimize the regional spatial structure. In this context, it is urgent to carry out research on geological environment carrying capacity in the development planning activities under the new concepts in a new era. This paper evaluates the background carrying capacity and bearing state of the geological environment in Changping District of Beijing by using the hierarchical comprehensive index method. The evaluation has determined the degree of favorable geological environmental conditions as well as the degree of impact from human activities on the geological environment and resources. Based on this, geological environment function zoning is conducted, and recommendations on regional development and eco-environmental protection are presented.

Keywords: Geological environment, Evaluation of geological environment carrying capacity, Function zoning of geological environment, Changping District, Beijing.

1. Introduction

The geological environment is an independent and open environmental system, an important part of the natural environment, the most basic habitat and space of activities for human beings, and the fundamental carrier of materials needed for production and life [1]. The geological environment's carrying capacity for human activities is limited, and this maximum limit is the geological environment carrying capacity [2, 3]. Geological environment carrying capacity refers to the maximum potential for human activities to develop and transform the environment that the geological environment can withstand during a certain period and within a specific range, while the regional geological environment does not undergo qualitative changes, and the functions of the geological environment do not develop in a direction unfavorable to human society and economic activities [4, 5].

It is necessary to scientifically understand the concept of geological environment carrying capacity from two dimensions: the geological environment conditions (the carrier) [6, 7] and human activities (the load). The first is the supporting and limiting role of the geological environment. For the same scale and intensity of human activities, different geological environment conditions provide different supporting and limiting roles [8, 9]. The second is about the activity and transformation ability of the load. Under the same geological environment conditions, different ways and intensities of human activities will have different impacts on the geological environment. The concept of geological environment carrying capacity essentially interprets the dialectical relationship between the geological environment and human activities and can serve as a criterion for measuring the coordination between the two [10, 11].

The report of the 20th National Congress of the Communist Party of China pointed out the need to accelerate the construction of a new development landscape and strive to promote high-quality development. One of the important measures to accelerate the construction of a new development landscape is to conduct the evaluation and function zoning of resource and environment carrying capacity [12, 13]. This requirement fully reflects the important role and immense demand for the evaluation of geological environment carrying capacity in the sustainable development of the entire country, society, and economy.

Changping District, Beijing, is an important district north of the capital city, and it has conspicuous locational advantages in diverting non-capital functions and achieving high-quality development. According to the Zoning Plan (Land Spatial Planning) of Changping District (2017-2035), by following Beijing's strategic positioning as the "four centers," Changping District will rationally define the regional functions, adhere to the constraint of resource and environment carrying capacity, impose district-wide control of the population, land use, and construction scale, promote development with reduced resource consumption, and optimize the regional spatial structure. In this context, it is urgent to carry out research on geological environment carrying capacity in the development planning activities under the new concepts in a new era. Therefore, research on the evaluation and function zoning of geological environment carrying capacity is practically significant as it can provide scientific support for Changping District's land planning, urban layout programming, industrial structure adjustment, resource optimization and allocation, and ecological environmental protection.

2. Overview of the Study Area

Changping District is located in the northwest of Beijing, at the junction of the Yanshan Mountain and a branch of the Taihang mountain ranges. With geographic coordinates of the district being east longitude 115°50'17" - 116°29'49" and north latitude 40°2'18" - 40°23'13", Changping borders Yanqing County and Huairou District on the north, Shunyi District on the east, Haidian District and Chaoyang District on the south, and Mentougou District and Huailai County of Hebei Province on the west. The district takes up 1,342.7 km^2, of which about 60% is mountainous areas and 40% is plain areas (Figure 1).

The topography of Changping District is complex. The northern and western mountainous areas are mainly uplifted by the Yanshan Movement, with the highest peak being Huanglongwa (1439.8m above sea level) in the northwest. The lowest point is to the east of Nanqijia in the south (27m above sea level). Gently sloping alluvial plains form in the central and southern parts. In the transitional zones between plain and mountainous areas, there are contiguous mountainous platforms in the piedmont zones due to the joint action of erosion and accumulation. Along valley mouths, the sediment and gravel carried by the flood accumulate with the overflow to form diluvial cones and proluvial fans with varying widths. At the contact zones between the proluvial fans and the alluvial plains, the terrain is relatively low, and depressions of varying sizes form between the alluvial fans.

Changping District has a warm temperate continental semi-humid monsoon climate with distinct four seasons, the rainy season also being the hot season, and dramatic changes in dryness, wetness, coldness, and warmth. Affected by atmospheric circulation, topography, and other factors, precipitation and heat conditions vary significantly from year to year, season to season, and area to area. The average annual temperature in the district is 12.6°C, and the average annual precipitation is 512.1mm. Affected by climate, the precipitation is unevenly distributed between seasons, with rainfall concentrated in the four months from June to September, amounting to 411.6 mm, accounting for 80.4% of the annual precipitation.

Figure 1. Geographical location of the study area

3. Evaluation Method and Indicator System

3.1. Evaluation Method

Geological environment carrying capacity is subject to various influencing factors, and each factor exists objectively and independently. Some factors are difficult to quantify, so evaluating geological environment carrying capacity involves a comprehensive analysis of this scattered and difficult-to-quantify information [14]. The hierarchical comprehensive index method is a comprehensive evaluation method that combines quantitative and qualitative analysis. It expresses the evaluation of scattered matters using mathematical models and scales information that is difficult to quantify through pairwise comparisons, making the evaluation results of geological environment carrying capacity more reliable and reasonable [15].

The indicator layers of the hierarchical comprehensive index method can be divided into the following three layers:

(1) Goal layer: This layer has only one element and is the preset goal or expected result for a complex problem.

(2) Criteria layer: This layer is an intermediate level for achieving the goal and criteria that need to be considered and can be composed of several sub-levels.

(3) Indicator layer: This layer provides support for the elements of the criteria layer and the specific measures and schemes taken to achieve the ultimate goal.

The geological environmental elements at the criteria layer and indicator layer have been comprehensively evaluated based on the evaluation indicator system of geological environment established with an analytic hierarchy framework. The comprehensive evaluation adopts the comprehensive index method with the following evaluation model:

$$M_i = \sum_{j=1}^{n} Z_j \times W_j = \sum_{j=1}^{n} (\sum P_{ji} \times W_i) \tag{1}$$

Where: M_i - Comprehensive evaluation index of geological environment carrying capacity;

Z_j - The evaluation index value of the j-th criteria layer;

W_j - The weight of the j-th criteria layers, i=1, 2, …, n;
P_{ji} - The score of the i-th indicator of the indicator layer corresponding to the j-th criteria layer;
W_i - The weight of the i-th indicator, i=1, 2, …, n.

There are five background levels of geological environment carrying capacity: low, relatively low, moderate, relatively high, and high, and there are three geological environmental carrying states: surplus, balanced, and overloaded.

3.2. Construction of Evaluation Indicator System

Constructing a complete indicator system is a necessary condition for objective and accurate evaluation. The selection of evaluation indicators should follow the principles of scientific validity, representativeness, operability, and sustainability, fully considering the static and dynamic characteristics of the geological environment. The indicator system should reflect the background levels and carrying state of the geological environment in the study area. Therefore, it is necessary to build a background evaluation system and a state evaluation system for the evaluation of geological environment carrying capacity (Table 1 and 2).

In this evaluation, attributes are assigned to each indicator of the indicator layer. A positive attribute indicates that the indicator used in background evaluation has a positive correlation with carrying capacity as a supporting factor, while a negative attribute indicates a negative correlation as an inhibiting effect.

Table 1. Background evaluation indicator system of geological environment carrying capacity

Goal layer	Criteria layer	Indicator layer	Indicator attribute
Background level of geological environment carrying capacity (A)	Topographic and geological conditions (C_1)	Topography (P_1)	−
		Ground slope (P_2)	−
		Tectonic stability (P_3)	−
	Hydrogeological conditions (C_2)	Groundwater resources (P_4)	+
		Groundwater depth (P_5)	+
		Groundwater quality (P_6)	−
	Environmental geological conditions (C_3)	Engineering construction suitability (P_7)	+
	Environmental geological conditions (C_4)	Geological hazard susceptibility (P_8)	−
	Resource conditions (C_5)	Mineral resources (P_9)	+
		Land resources (P_{10})	+
		Land resources (P_{11})	+

Table 2. Evaluation indicator system of geological environment carrying state

Goal layer	Criteria layer	Indicator layer	Indicator attribute
Level of geological environment carrying state (B)	Current state of environmental geology (D_1)	Geological disaster risk (U_1)	−
		Current state of groundwater pollution (U_2)	−
		Current state of soil pollution (U_3)	−
	Current state of resource development (D_2)	Current state of mineral development (U_4)	−
		Current state of land use (U_5)	−
		Current state of surface water development (U_6)	−
		Current state of groundwater development (U_7)	−

4. Evaluation Process

4.1. Background Evaluation of Geological Environment Carrying Capacity

4.1.1. Determine weights of background evaluation indicators

The Analytic Hierarchy Process (AHP) is used to determine the weight of each evaluation indicator, and the importance of the background evaluation indicator system of geological environment carrying capacity is compared and determined. The importance of each indicator assigned by experts is statistically analyzed to exclude results with large differences; the arithmetic mean of the pairwise comparative importance of each indicator is calculated. The judgment matrices at different levels are constructed after rounding.

First, a judgment matrix of the criteria layer (A) to the goal layer (C) is constructed (Table 3):

Table 3. Judgment matrix of order A-C

A	C_1	C_2	C_3	C_4	C_5
C_1	1	2	3	2	2
C_2	1/2	1	1	2	1
C_3	1/3	1	1	2	1/2
C_4	1/2	1/2	1/2	1	1/2
C_5	1/2	1	2	2	1

The yaahp AHP software is used to calculate the weight of each indicator in the criteria layer; W_j= (C_1, C_2, C_3, C_4, C_5) = (0.349, 0.185, 0.148, 0.106, 0.212); the calculated maximum eigenvalue λ_{max} is 5.137; CR is 0.03 < 0.1. Therefore, it meets the consistency test conditions.

Next, the judgment matrix of the indicator layer (P) to the criteria layer (C) is constructed respectively, and the weight of each index (W_{ji}) is calculated. All meet the consistency test conditions, indicating that the weight calculation of each indicator layer is appropriate. Finally, the overall ranking weight (comprehensive weight W_i) of each indicator layer element to the goal layer is determined. The four indicators with a relatively high impact on the background levels of geological environmental carrying capacity in the study area are tectonic stability, engineering construction suitability, land resources, ground slope, and geological hazard susceptibility. The three indicators that have a moderate impact are groundwater resources, surface water resources, and groundwater quality. The three indicators that have a relatively low impact are ground elevation, mineral resources, and groundwater depth. The weights of indicators are shown in Table 4.

Table 4. Weights of indicators for comprehensive background evaluation

Goal layer	Criteria layer	Weight (W_j)	Indicator layer	Weight (W_{ji})	Comprehensive weight (W_i)
Background level of geological environment carrying capacity (A)	Topographic and geological conditions (C_1)	0.349	Topography (P_1)	0.109	0.038
			Ground slope (P_2)	0.309	0.108
			Tectonic stability (P_3)	0.582	0.203
	Hydrogeological conditions (C_2)	0.185	Groundwater resources (P_4)	0.540	0.100
			Groundwater depth (P_5)	0.163	0.030
			Groundwater quality (P_6)	0.297	0.055
	Engineering geological conditions (C_3)	0.148	Engineering construction suitability (P_7)	1	0.148
	Environmental geological conditions (C_4)	0.106	Geological hazard susceptibility (P_8)	1	0.106
	Resource conditions (C_5)	0.212	Mineral resources (P_9)	0.163	0.035
			Land resources (P_{10})	0.540	0.114
			Land resources (P_{11})	0.297	0.063

4.1.2. Quantification of background evaluation indicators of carrying capacity

Table 5 for the quantitative assignment and scoring criteria of comprehensive background evaluation indicators.

Table 5. Quantitative score table of comprehensive background evaluation indicators

Code	Evaluation indicator	Quantification criteria (0-1 points)				
P_1	Ground elevation (m)	≥800	[600, 800)	[400, 600)	[200, 400)	[0, 200)
	Score value	0.1	0.2	0.5	0.7	0.9
P_2	Ground slope	≥ 25°	[15°, 25°)	[8°, 15°)	[3°, 8°)	[0°, 3°)
	Score value	0.1	0.3	0.5	0.7	0.9
P_3	Structural buffer zone (km)	[0, 1)	[1, 2)	[2, 4)	[4, 8)	≥8
	Score value	0.1	0.3	0.5	0.7	0.9
P_4	Exploitable modulus of groundwater (10^4 m^3/ a·km^2)	[0.5, 1)	[1, 2)	[2, 4)	[4, 8)	[8, 12)
	Score value	0.1	0.3	0.5	0.7	0.9
P_5	Groundwater depth (m)	[0, 1)	[1, 2)	[2, 3)	[3, 5)	≥5
	Score value	0.1	0.2	0.4	0.6	0.8
P_6	Groundwater quality	Category V	Category IV	Class III	Class II	Class I
	Score value	0.1	0.3	0.5	0.7	0.9
P_7	Engineering construction suitability	[1, 0.7]	[0.5, 0.7)	[0.3, 0.5)	[0.1, 0.3)	[0, 0.1)
	Score value	0.1	0.3	0.5	0.7	0.9
P_8	Geological hazard susceptibility	[0, 0.1)	[0.1, 0.3)	[0.3, 0.5)	[0.5, 0.8)	[1, 0.8]
	Score value	0.1	0.3	0.5	0.7	0.9
P_9	Available mineral resources	Inadequate	Relatively inadequate	Moderate	Relative abundant	Abundant
	Score value	0.1	0.3	0.5	0.7	0.9
P_{10}	Proportion of available land resources	[0, 5%)	[5%, 10%)	[10%, 20%)	[20%, 30%)	≥ 30%
	Score value	0.1	0.3	0.5	0.7	0.9
P_{11}	Average surface water runoff ($10^4 m^3$/ a)	[0, 500)	[500, 1000)	[1000, 2000)	[2000, 3000)	[3000, 5000)
	Score value	0.1	0.3	0.5	0.7	0.9

4.1.3. Classification of background evaluation of geological environment carrying capacity

The comprehensive background evaluation of the geological environment carrying capacity is conducted on a GIS platform using the comprehensive evaluation model to calculate the comprehensive background evaluation index. The background levels of carrying capacity are then classified based on the criteria (Table 6).

Table 6. Classification of comprehensive background evaluation of geological environment carrying capacity

Classification of carrying capacity	Low	Relatively low	Moderate	Relatively high	High
Comprehensive background evaluation index	[0.1, 0.25)	[0.25, 0.4)	[0.4, 0.6)	[0.6, 0.8)	[0.8, 1]

4.2.Evaluation of Geological Environment Carrying State

4.2.1. Determine weights of state evaluation indicators

The AHP method is also used to determine the weight of the comprehensive state evaluation indicators. First, the judgment matrix of the criteria layer (B) to the goal layer (D) is constructed as follows (Table 7):

Table 7. Judgment matrix of order B-D

B	D_1	D_2
D_1	1	5/7
D_2	7/5	1

The yaahp AHP software is used to calculate the weight of each indicator in the criteria layer; W_j= (D_1, D_2) = (0.417, 0.583). Therefore, it meets the consistency test conditions.

Next, the judgment matrix of indicator layer (U) to criteria layer (D) is constructed respectively, and the calculation results meet the consistency test conditions. Finally, the overall ranking weight (comprehensive weight Wi) of each indicator layer element to the goal layer is determined. According to the comprehensive weights of the indicator layer elements to the goal layer in evaluating the geological environmental carrying state, the four indicators that have a relatively high impact on the geological environment carrying state are the current state of land use, geological hazard risk, current state of surface water development, and current state of groundwater development. The current state of groundwater pollution has a moderate impact, while the current state of soil pollution and the current state of mineral development have a relatively low impact. The weights of indicators are shown in Table 8.

Table 8. Weights of indicators for comprehensive state evaluation

<table>
<tr><th>Goal layer</th><th>Criteria layer</th><th>Weight (W_j)</th><th>Indicator layer</th><th>Weight (W_{ji})</th><th>Comprehensive weight (W_i)</th></tr>
<tr><td rowspan="7">Level of geological environment carrying state (B)</td><td rowspan="3">Current state of environmental geology (D_1)</td><td rowspan="3">0.417</td><td>Geological disaster risk (U_1)</td><td>0.595</td><td>0.248</td></tr>
<tr><td>Current state of groundwater pollution (U_2)</td><td>0.276</td><td>0.115</td></tr>
<tr><td>Current state of soil pollution (U_3)</td><td>0.128</td><td>0.053</td></tr>
<tr><td rowspan="4">Current state of resource development (D_2)</td><td rowspan="4">0.583</td><td>Current state of mineral development (U_4)</td><td>0.054</td><td>0.031</td></tr>
<tr><td>Current state of land use (U_5)</td><td>0.452</td><td>0.264</td></tr>
<tr><td>Current state of surface water development (U_6)</td><td>0.247</td><td>0.144</td></tr>
<tr><td>Current state of groundwater development (U_7)</td><td>0.247</td><td>0.144</td></tr>
</table>

4.2.2. Quantification of evaluation indicators of geological environment carrying state

See Table 9 for the quantitative assignment and scoring criteria of comprehensive state evaluation indicators.

Table 9. Quantitative score table of comprehensive state evaluation indicators

Code	Evaluation indicator	Quantification criteria (0-1 points)		
U_1	Geological hazard risk index	[0, 0.2)	[0.2, 0.5)	[0.5, 1]
	Score value	0.3	0.5	0.9
U_2	Comprehensive standard pollution index of groundwater	[0, 0.6)	[0.6, 1)	≥1.0
	Score value	0.3	0.5	0.9
U_3	Soil pollution carrying state index	[0.7, 1]	[0.3, 0.7)	[0, 0.3)
	Score value	0.3	0.5	0.8
U_4	Mineral resources development index	[0, 30]	(30, 60]	(60, 100]
	Score value	0.3	0.5	0.9
U_5	Land pressure state index	<0	0	>0
	Score value	0.3	0.4	0.9
U_6	Surface water relative carrying index (RCI)	[0, 0.8)	[0.8, 1.2)	>1.2
	Score value	0.3	0.5	0.8
U_7	Degree of groundwater development (%)	[0, 70]	(70, 100]	>100
	Score value	0.3	0.5	0.8

4.2.3. Classification of carrying state evaluation

See Table 10 for the state evaluation criteria of the geological environment carrying capacity.

Table 10. Classification of comprehensive state evaluation of geological environment carrying capacity

Carrying state classification	Surplus	Balanced	Overloaded
Comprehensive state evaluation index	[0.3, 0.5)	[0.5, 0.7)	[0.7, 1]

5. Evaluation Results and Analysis

5.1. Background Evaluation of Geological Environment Carrying Capacity

The background carrying capacity of the geological environment in the study area is mainly divided into five levels. In terms of distribution, the areas with low and relatively low carrying capacity are concentrated, mainly distributed in the north, northwest, and southwest, accounting for 34.49% of the study area. These areas are characterized by relatively high ground elevation, large slopes, significant tectonic effects, relatively small to moderate groundwater resources, poor engineering construction suitability, high geological hazard susceptibility, limited usable land resources, and lack of mineral resources, resulting in a poor development potential (Figure 2).

The areas with moderate carrying capacity include Xingshou Town-Cuicun Town-Shisanling in the east, Nankou Town-Liucun Town-Yangfang Town in the central and west part, and the area west of Gaoyakou in the southwest, accounting for 20.78% of the study area. The Xingshou Town-Cuicun Town-Ming Tombs area is characterized by low elevation, moderate slope, moderate tectonic effect, good engineering construction suitability, relatively abundant underground water resources, low geological hazard susceptibility, and abundant available land resources. However, this area has limited mineral resource reserves, moderate groundwater quality, and moderate-relatively low surface water resources. Therefore, the background carrying capacity of this area is moderate, with a moderate development potential.

The areas with relatively high carrying capacity are mainly the urban area of Changping, Nanshao Town, Machikou Town in the central part, the area east of Nankou Town and Liucun Town, and the large area of Shahe-Huilongguan-Dongxiaokou-Beiqijia in the southeast, accounting for 28.61% of the study area. Among them, the urban area of Changping, Nanshao Town, Machikou Town, and the areas east of Nankou Town and Liucun Town have relatively low elevations, gentle slopes, small-moderate tectonic effects, good engineering construction suitability, adequate groundwater resources, low-moderate geological hazard susceptibility, and sufficient usable land resources. However, the groundwater quality is relatively poor-moderate, the groundwater burial depth is relatively shallow, and mineral resources are relatively scarce. The large area of Shahe-Huilongguan-Dongxiaokou-Beiqijia has inadequate surface water resources, poor-moderate groundwater quality, and scarce mineral resources, but it has low ground elevations, gentle slopes, good engineering construction suitability, sufficient usable land resources, and low geological hazard susceptibility. Therefore, the background carrying capacity of this area is relatively high, with a good development potential.

The areas with high carrying capacity are distributed in the southeast of the study area in Shahe Town, as well as Xingshou Town-Xiaotangshan-Lvgezhuang-Beiqijia Town, accounting for 16.12% of the study area. Although affected by relatively poor groundwater quality, shallow burial depth, and moderate surface water resources, these areas have the advantages of low ground elevations, gentle slopes, low tectonic effects, abundant groundwater resources, low geological hazard susceptibility, good engineering construction suitability, and sufficient usable land resources. The overall background carrying capacity is high in these areas, which can accommodate a greater intensity of human activities developing and transforming the geological environment and thus have a good development potential.

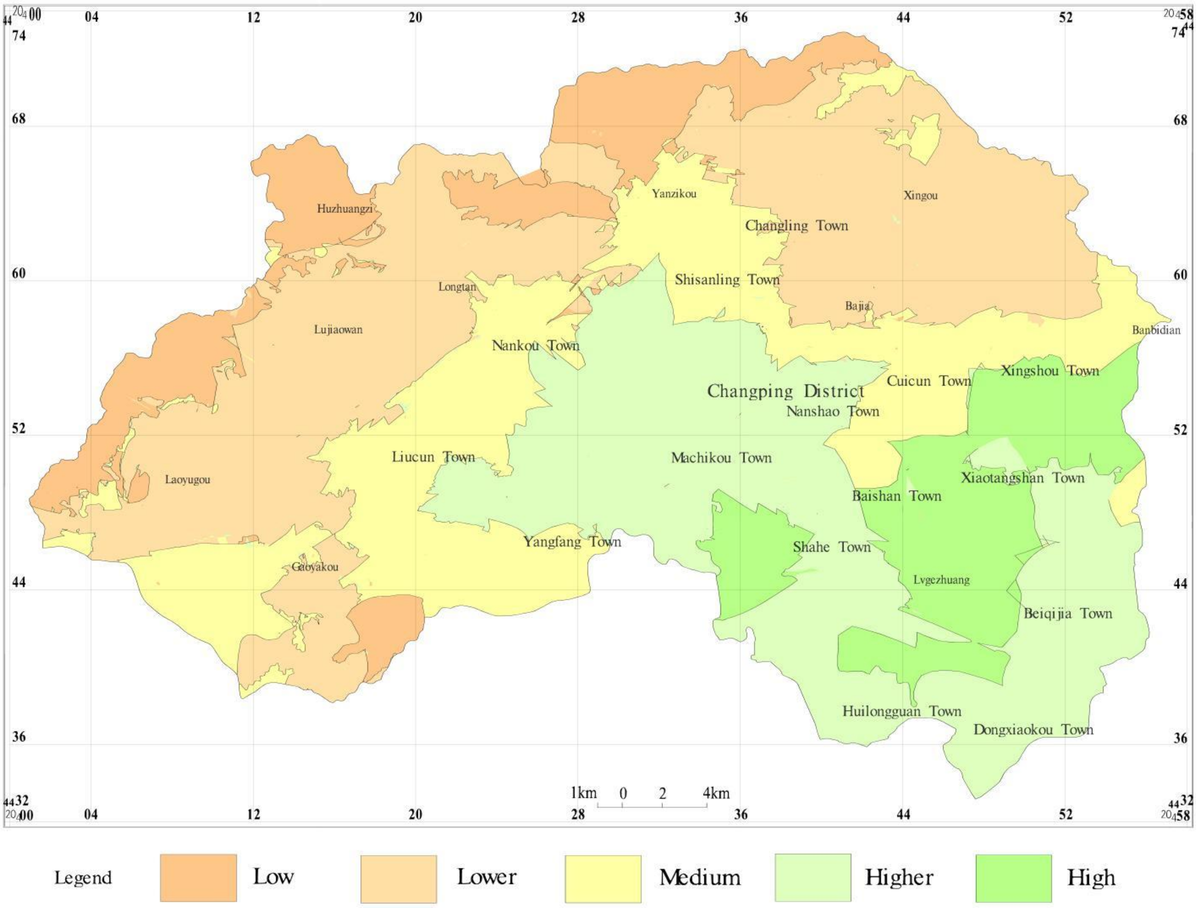

Figure 2. Levels of background carrying capacity of geological environment

5.2. Evaluation of Geological Environment Carrying State

According to the evaluation results, the carrying capacity state of the geological environment in the study area is mainly divided into three levels. In terms of distribution, the areas in a surplus state are distributed in the northeast, northwest, and southwest of the study area, accounting for 38.72% of the study area. These areas have relatively few geological environmental issues, a low degree of resource development and utilization, and a low impact caused by human activities. Overall, they are in a surplus state (Figure 3).

The balanced areas are distributed in the central, north-central, and eastern areas of the study area, mainly with relatively concentrated populations, accounting for 43.67% of the study area. These areas have a certain development potential, but caution should be taken to prevent an overloaded state. These areas are significantly impacted by human activities. Among them, the area of Shisanling-Nankou Town-Liucun Town-Yangfang Town has moderate-high geological hazard risks, balanced-overloaded groundwater pollution, surplus-balanced development and utilization of groundwater and surface water, balanced land resource utilization, and surplus-balanced mineral resources. The area of Shahe-Baishan-Xiaotangshan-Beiqijia-Xingshou Town has overloaded groundwater development, balanced-overloaded surface water development, balanced-overloaded groundwater pollution, but it has surplus geological hazard risks, surplus mineral development, and generally surplus soil pollution, so it overall evaluation result is being balanced. The balanced areas have a certain development potential, but it is necessary to monitor geological environment elements, release early warnings, and take caution to prevent an overloaded state.

The overloaded areas are concentrated in the urban area of Changping, areas east of Nanshao Town, Xiaotangshan Town, as well as Huilongguan-Dongxiaokou and Beiqijia Town in the southeast, accounting for 17.61% of the study area. This area has the highest population concentration and intensity of human activities. Although the geological hazard risks, soil pollution, and mineral development are low in these areas, land use is mostly overloaded or close to overloaded, groundwater is polluted to a certain extent, and surface water and groundwater are partially overloaded. The overall carrying state is overloaded. It is necessary to monitor key geological environmental elements in these areas, release early warnings, and formulate corresponding countermeasures to alleviate the carrying state.

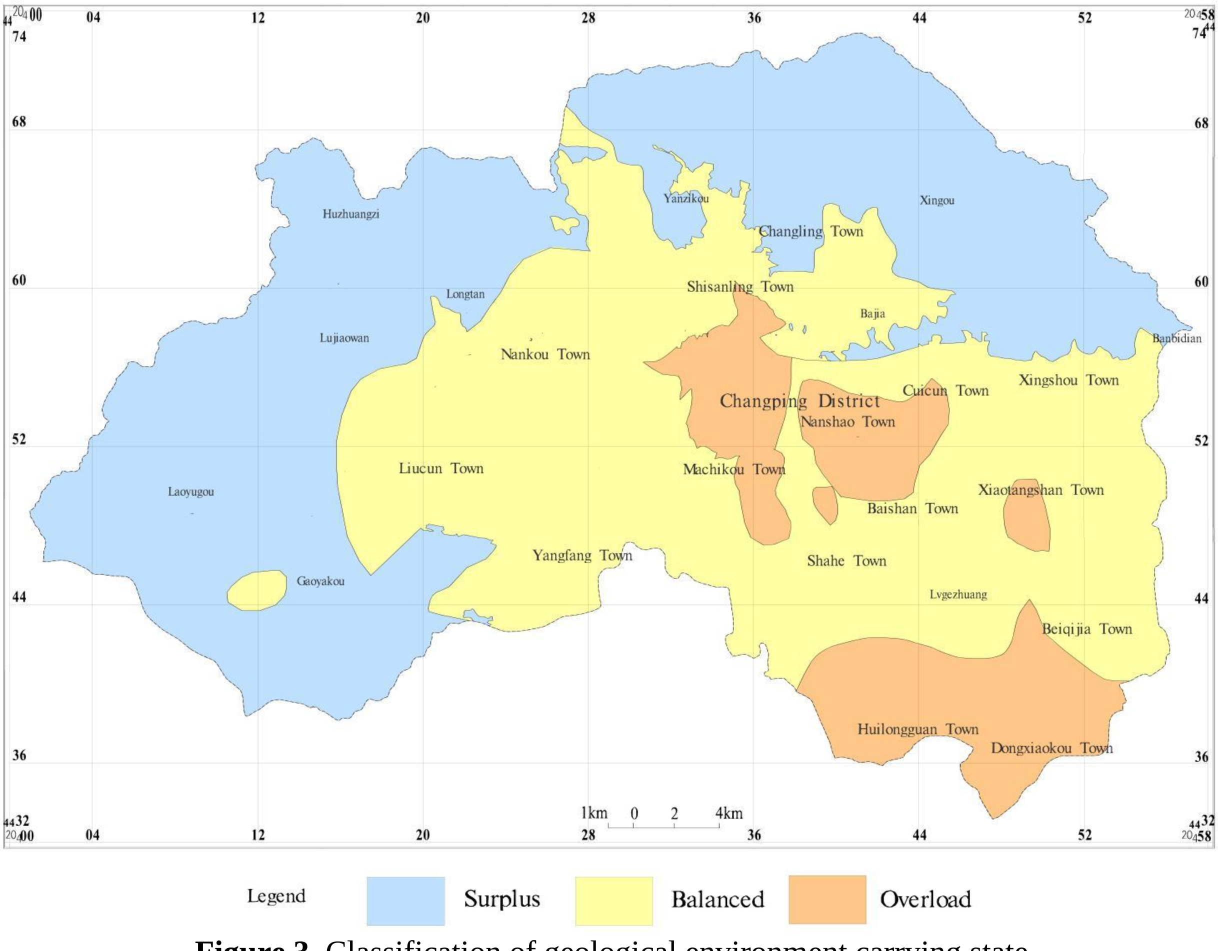

Figure 3. Classification of geological environment carrying state

6. Conclusion

(1) In the study area, the background carrying capacity of the geological environment is divided into 5 levels. The areas with high carrying capacity are distributed in the southeast of the study area

in Shahe Town, as well as Xingshou Town-Xiaotangshan-Lvgezhuang-Beiqijia Town, accounting for 16.12% of the study area, with a good development potential. The areas with relatively high carrying capacity are mainly distributed in the central part and the southeast, accounting for 28.61% of the study area, with a relatively good development potential. The areas with moderate carrying capacity include Xingshou Town-Cuicun Town-Shisanling in the east, Nankou Town-Liucun Town-Yangfang Town in the central and west part, and the area west of Gaoyakou in the southwest, accounting for 20.78% of the study area, with a moderate development potential. The areas with low and relatively low carrying capacity are concentrated, mainly distributed in the north, northwest, and southwest, accounting for 34.49% of the study area, with a poor development potential.

(2) The carrying capacity state of the geological environment in the study area is mainly divided into three levels. The areas in a surplus state are distributed in the northeast, northwest, and southwest of the study area, accounting for 38.72% of the study area. The balanced areas are distributed in the central, north-central, and eastern areas of the study area, mainly with relatively concentrated populations, accounting for 43.67% of the entire study area with a certain development potential. The overloaded areas are concentrated in the urban area of Changping, areas east of Nanshao Town, Xiaotangshan Town, as well as Huilongguan-Dongxiaokou and Beiqijia Town in the southeast, accounting for 17.61% of the study area, and corresponding measures should be formulated for these areas.

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