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Geological Environmental Adaptability of Qingdao Rural Urbanization Based on Fuzzy Mathematical Method

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Abstract Fuzzy mathematics comprehensive evaluation method is used to evaluate the geological environment suitability of rural urbanization in Qingdao City, China. A total of 5 first-level evaluation factors are selected, including environmental geological condition, geological resources, engineering geological condition, geological disaster and environmental geological problem, and human engineering activity. And there are 27 second-level evaluation factors, such as topography, land type and vegetation, nature reserve, water source protection area, groundwater quality division, and major engineering project. Qingdao City is divided into four districts of suitable area, relatively suitable area, moderately suitable area and relatively unsuitable area of ecological environment. And their characteristics are introduced. Suggestions for the developing direction of urban construction are put forward. Region of Laoshan District lying to the west of the Shilaoren is suitable to set up high-rise building; west Hongshiya may establish a waste landfill site; Jiaozhou Bay, the downstream of Dagu River, and Jihongtan Reservoir should be built as the key geological environment protection area and water source protection area. And the north Hongdao should be strictly monitored in order to control the expansion of urban construction to Jihongtan Reservoir. Mocheng District and the area north of it, Jiaozhou District and the area east of it are the ideal urban construction development areas in Qingdao City in the future.

Key words Rural urbanization, Qingdao, Fuzzy mathematical method, Geological environment, Adaptability, China

Qingdao is a leading city of Shandong Peninsula during the construction of urban agglomeration, as well as an important economic center and port city in the east coast of China, national historical city and a famous tourist site with rapid economic development. Qingdao has jurisdiction over 7 districts and 5 cities. Since the reform and opening up, its urbanization level has been improved. Therefore, Qingdao City puts forward a modern "Big Qingdao" international urban strategy, aiming to construct a national key central city and a world famous characteristic city. Process of urbanization is significantly accelerated in rural areas, but the contradiction between urban construction and geological environment has become increasingly prominent. Geological environment restricts the site selection, layout and development of city, while development of city further causes the environmental and geological problems[1-3]. Therefore, it is of great importance to carry out geological environmental adaptability in Qingdao City.

1 Geological environment condition in Qingdao City, China

Qingdao City has the topography and geomorphology of mainly plain, hill and low mountain, with five landform types of low mountain, hill, denudation plain, alluvial diluvial plain and alluvial marine plain. Its major peaks are Lao Mountain, Daze Mountain, Xiaozhu Mountain, and Dazhu Mountain with the main peak of Lao Mountain being 1 133 meters high.

According to the physical and mechanical properties of rock and soil mass, Qingdao City can be classified into eight engineering geological zones, such as hard block instrusive rock, hard block—stratiform-like extrusive rock, hard metamorphic rock, hard—relatively hard metamorphic rock with marble—limestone, relatively hard clastic rock—extrusive rock, hard—relatively hard limestone, loose soil, and soft soil.

Area of agricultural land takes the first place in the land resources. Among them, two thirds of the farmland is distributed in the valley, piedmont plain and intermontane basin. At present, acceleration of urbanization has reduced the area of arable land. Unused land in Qingdao City mainly includes grassland, saline land, marsh, sandy land, bare land, and bare rock land. Dagu River is an important water source of Qingdao, which is at a status of exploitation-supplement balance. Allowable exploitation quantity of groundwater and waste water discharge in Qingdao reach 6.34×10^8 m^3/a and 3×10^8 m^3/a, respectively. Water is seriously polluted and most of the rivers have become sewage ditches[4].

Seawater intrusion, coastal erosion and deposition, collapse, landslide, debris flow, and ground fissure occur in Qingdao City. And various environmental geological problems have brought adverse impact on the development of urbanization,

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such as muddy soil, saturated liquefied sandy soil, expansive soil, water and soil loss, soil salinization, soil desertification and soil pollution.

2 Suitability evaluation method for geological environment during urbanization construction

Geological environment is the basic condition for rural urbanization development[5]. Suitability evaluation method for geological environment during urbanization construction is one of the basic foundations for functional divisions of urban construction and urban plan.

2.1 Selection of evaluation method and evaluation factor

Suitability evaluation on geological environment during urbanization construction is a spatial comprehensive decision-making problem involving multi-levels and multi-factors. Thus, this research fully considers the various geological environment affecting urban construction[6]. According to the comprehensive analysis on environmental geological condition, engineering geological condition, development degree of geological disaster and environmental geological problem, status of geological resources, and human engineering activity in Qingdao City, 5 first-level evaluation factors and 27 second-level evaluation factors are selected for suitability evaluation on geological environment, from the angle of coordinated development between urban construction and geological environment. Fuzzy mathematical method is adopted to evaluate the suitability of geological environment of urban construction.

2.2 Quantization of evaluation factor and determination of weight

2.2.1 Quantization of evaluation factor. According to the characteristics of urban construction, the second-level evaluation factors for suitability evaluation on geological environment in urbanization construction can be divided into 5 grades, that is suitable, relatively suitable, moderately suitable, relatively unsuitable, and unsuitable (Table 1).

Table 1 Classification standard for second-level evaluation factor

Grade	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ
Score	90	70	50	30	10
Evaluation grade	Suitable	Relatively suitable	Moderately suitable	Relatively unsuitable	Unsuitable

2.2.2 Weight determination of evaluation factor. Weight of evaluation factor is determined by experts in environmental geology, engineering geology, urban construction and environmental engineering. Table 2 reports the calculation result of weight of evaluation factor.

Table 2 Weight of second-level evaluation factor

Weight of first-level evaluation factor	Second-level evaluation factor	Weight
Environmental geological condition	Topography	0.478 8
0.253 9	Land type and vegetation	0.089 0
	Nature reserve	0.171 6
	Water source protection area	0.171 6
	Groundwater quality division	0.089 0
Engineering geological condition	Regional crustal stability	0.250 0
0.253 9	Engineering-geological classification of rock and soil masses (including adverse soil mass)	0.750 0
Geological disaster and environmental	Land subsidence	0.145 5
geological problem	Landslide	0.181 8
0.320 5	Land collapse and ground fissure	0.163 6
	Sewage and wast water, garbage emission (including surface water pollution)	0.090 9
	Seawater intrusion	0.127 3
	Coastal erosion and deposition	0.018 2
	Endemic disease	0.054 5
	Water and soil loss	0.054 5
	Soil pollution	0.036 4
	Soil salinization and soil desertification	0.090 9
	Over-exploitation cone of groundwater	0.036 4
Geological resource	Groundwater resource	0.235 2
0.062 3	Surface water resource	0.131 1
	Geothermal resource	0.077 4
	Oil and gas resource	0.045 1
	Solid mineral resource	0.045 1
	Geological tourism resource	0.466 1
	Human engineering activity	0.109 4
Human engineering activity	Major engineering project	0.257 4
0.109 4	Main road and port	0.371 3
	Mining	0.371 3

Table 2 indicates that geological disaster and environmental geological problem is the most important evaluation factor among the first-level evaluation factors, having the maximum weight, followed by environmental geological condition and engineering geological condition. And human engineering activity and geological resource have the minimum weights, which are consistent with the actual situation of Qingdao City. As for environmental geological condition, topography is the most important factor. And engineering-geological classification of rock and soil masses is the most import factor for environmental geological condition. Landslide, land collapse, ground fissure, and land subsidence have the maximum weight in geological disaster and environmental geological problems. Geological tourism resource is the main factor for geological resource; and mining and main road and port are the main factors for human engineering activity. Weight values of the factors mentioned above are rational and are consistent with the actual situation of Qingdao during suitability evaluation on geological environment during urbanization construction.

2.3 Introduction of evaluation method The basic principles of fuzzy mathematics comprehensive evaluation method are the fuzzy varying principle and the maximum membership degree law. And the following model is selected to carry out the fuzzy evaluation:

$$f(z_1, z_2, \cdots, z_n) = \sum_{j=1}^{n} c_j z_j \qquad c_j \geqslant 0, \tag{1}$$

where z is the basic score of a given evaluation factor, and c is the weight of a given evaluation factor. The influence index set and evaluation set are established, which are

$$U = \{\mu_1, \mu_2, \cdots, \mu_n\}, \tag{2}$$

and $V = \{v_1, v_2, \cdots, v_n\}$, respectively, (3)

where U is the evaluation factor set, μ is a certain evaluation factor, V is the evaluation result set, and v is the evaluation result of a certain evaluation factor. The element $v_j (j = 1, 2, \cdots, n)$ represents the possible evaluation results.

The evaluation result set can be divided into five grades, that is, V = {suitable, relatively suitable, moderately suitable, relatively unsuitable, unsuitable}. Table 3 reports the result of evaluation.

Table 3 Classification standard of fuzzy mathematics comprehensive evaluation

Suitability classification	Suitable	Relatively suitable	Moderately suitable	Relatively unsuitable	Unsuitable
	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ
Classification standard	>75	70 – 75	65 – 70	60 – 65	<60

Membership degree function is used to evaluate a single factor, so as to establish a fuzzy subset R_i of evaluation set V, which is

$$R_i = \{r_{i1}, r_{i2}, r_{i3}, r_{i4}, r_{i5}\}. \tag{4}$$

Then, evaluation matrix with single factor is established, which is a fuzzy subset of evaluation set V. R_i is the evaluation matrix of a evaluation factor, and r_{ij} is the jth evaluation value of the corresponding evaluation set of the ith index in factor U. $i = 1, 2, \cdots, 27$; $j = 1, 2, 3, 4, 5$ is the influence factor in evaluation factor index set according to the data distribution characteristics of evaluation factor.

Index weight set is established, which is

$$A = \{\alpha_1, \alpha_2, \cdots, \alpha_5\}. \tag{5}$$

Weight $\alpha_i (i = 1, 2, \cdots, m)$ should satisfy the normalization and nonnegative condition, that is, $\sum_{i=1}^{m} \alpha_i = 1, \alpha_i \geqslant 0 (i = 1, 2, \cdots, m)$. Finally, fuzzy comprehensive evaluation is carried out, which can be represented by

$$B = A \times R, \tag{6}$$

where A is the factor weight set, α_i is the weight of a certain factor, R is the single factor evaluation matrix, and B is the fuzzy comprehensive evaluation set. Thus, evaluation result of the factor evaluated can be determined.

3 Result of suitability evaluation

Qingdao City is divided into 117 element meshes with the area of 10 km ×10 km each. Areas with more complex conditions can be subdivided by quartering method. After obtaining the score of each unit grid, computer program is adopted to calculate the data and MAPGIS is used to generate a contour map. Then, necessary amendment is carried out according to the actual investigation result.

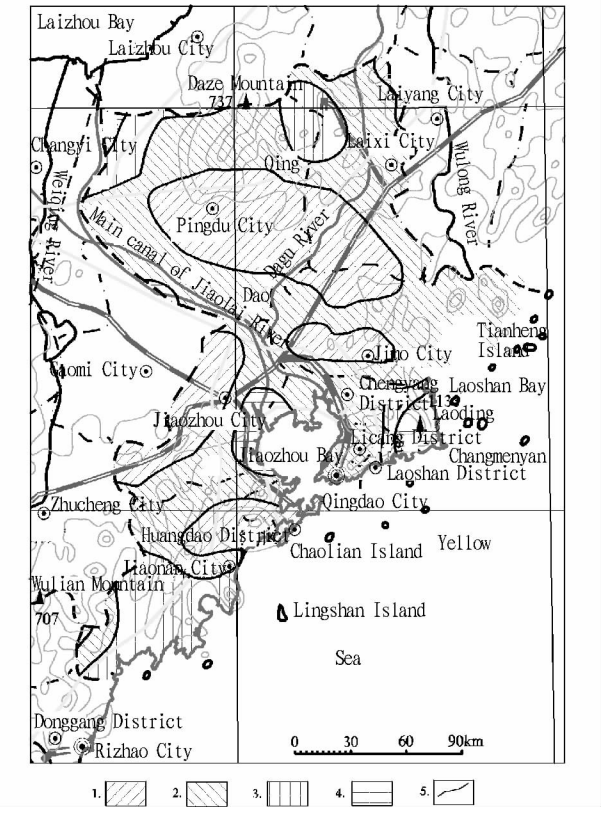
According to the suitability evaluation result of geological environment in urban construction, Qingdao City can be divided into four districts of suitable area, relatively suitable area, moderately suitable area and relatively unsuitable area of ecological environment. Both Table 4 and Fig. 1 report the distributed rules and characteristics of each district.

Table 4 Division of geological environmental adaptability in urban construction

Name	Area // km^2	Distribution scope	Characteristics
Suitable area of ecological environment(Ⅰ)	3 042.83 (accounting for 28.56%)	Pingdu, Jimo, Jiaozhou, Huangdao and so on	Flat terrain; mainly the eluvium talus, denudation plan, alluvial diluvial plain; better engineering geological condition; better regional stability; no serious geological disaster or environmental geological problem; no large-scale mining; no natural reserve; no water source protection area; abundant natural building materials; developed traffic; the geological environment conditions suitable for urban construction
Relatively suitable area of ecological environment(Ⅱ)	5 731.36 (accounting for 53.80%)	Most parts of Qingdao City	Mainly the hill and alluvial diluvial plain; better engineering geological condition; better regional stability; geological disaster in only a few areas; less environmental geological problem; less mining; abundant natural building materials; developed traffic; the conditions suitable for urban construction

Continued (Table 4)

Name	Area//km^2	Distribution scope	Characteristics
Moderately suitable area of ecological environment(Ⅲ)	1 448.84 (accounting for 13.60%)	South Jiaonan, north Pingdu, peripheral Laoshan and so on	Some ups and downs in terrain, including hill, coastal plain and alluvial diluvial plain; general regional stability; poor engineering geological condition in some areas; geological disaster and environmental geological problems; some natural reserves and water source protection areas; relatively concentrated mining; the geological environment conditions moderately suitable for urban construction
Relatively unsuitable area of ecological environment(Ⅳ)	430.98 (accounting for 4.05%)	Lapshan, area around Jiaozhou Bay, Pingdu Xinhe and so on	Mainly the hill, coastal plain and middle-low mountain; poor regional stability; landslide in middle-low mountain; land collapse and landslide in mining area; many national natural reserves; intense exploration of mining; greater density of mining mountain; relatively poor suitability of geological environment in urbanization construction



1. Suitable area; 2. Relatively suitable area; 3. Moderately suitable area; 4. Relatively unsuitable area; 5. Suitability boundary of ecological environment.

Fig. 1 Suitability evaluation division of ecological environment in urban construction

4 Suggestions for the developing direction of urban construction

(1) According to the suitability evaluation result on geological environment during rural urbanization in Qingdao City, the main city of Qingdao has better infrastructure in urban construction and is suitable to establish all types of buildings. Therefore, it is feasible to let the main city become an integrated area of city administration, culture, business office, tourism and housing. Region of Laoshan District lying to the west of the Shilaoren has better geological condition and is suitable for high-rise building. Therefore, it is feasible to be planned as a high-tech industrial zone. But it is better to establish high-rise house or office building, which can effectively ease the shortage of urban land. It is also feasible to take Huangdao as a business center and a comprehensive logistic zone. After the establishment of Qingdao Bay Bridge, the distance from the main city of Qingdao to the Hongshiya will be shortened. Thus, there may establish a waste landfill site in west Hongshiya.

(2) South Hongdao is the mouth of Jiaozhou Bay with weak eco-geological environment. Therefore, geological environment of areas along Jiaozhou Bay should be further protected during urban construction in order to prevent the deterioration of ecological environment. It is suggested to take Jiaozhou Bay, the downstream of Dagu River, and Jihongtan Reservoir as the key geological environment protection area and water source protection area. And the north Hongdao should be strictly monitored in order to control the expansion of urban construction to Jihongtan Reservoir.

(3) In the long run, Mocheng District and the area north of it, Jiaozhou District and the area east of it are suitable to establish various buildings, due to their flat terrain, better geological condition, abundant groundwater resources, less geological disaster and environmental geological problems, better road, railway and other infrastructure. Therefore, these areas are the ideal urban construction development areas in Qingdao City in the future.

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