Study on risk assessment method of Karst collapse
——Taking the Karst collapse in Linyi urban areas as an example

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Abstract: Karst collapse is one of main important geological disasters in Linyi city of Shandong Province. In this article, risk assessment of present and forecast situation of karst collapse have been done by the method of fuzzy comprehensive evaluation based on level analysis at the first time. The hazardous assessment, the vulnerability and the expected loss have been assessed, and then the risk assessment map of karst collapse at present is obtained and prevention and control work of karst collapse is expected to develop. It puts up availability exploration on prevention of the same geohazards, and provides a reference pattern.

1. Introduction
Karst collapse, a karst - cap - water system, is a macro performance on the systematic instability process under the influence of various factors at the surface [1]. There is a great randomness on its occurrence and a significant uncertainty on the loss of natural environment and human’s life. It can be said that karst collapse is a potential risk for karst area. Evaluating the possibility of karst collapse occurring and losses caused makes it more targeted and scientific to make the prevention and treatment decision. The risk assessment on karst collapse mainly includes three aspects: hazardous assessment, vulnerability assessment and expected loss assessment.

2. Assessment of karst collapse risk status
This evaluation, which adopts the method of fuzzy comprehensive judgement based on the analytic hierarchy process, makes the hazardous assessment on karst collapse in the evaluation area, and its major steps consist of making sure of evaluation factors and their weight values, rating classification, defining the membership function of evaluation unit and abstracting element attributes by GIS tools to make comprehensive evaluation.
2.1 Determination of evaluation factors

Karst collapse in the study area is mainly relative to karst conditions, groundwater conditions (distance between water level and interface, level change and distance to the center of cone of depression), capping conditions, environmental conditions (pumping strength and distance to pumping wells) and history conditions. Therefore, this evaluation regards above 5 conditions in a total of 8 factors as karst collapse risk evaluation factors, in order to build a hierarchical structure model on karst collapse hazardous assessment in the study area.

According to conditions and influencing factors of karst collapse, while combining with the expertise and using "1-9 scale" method [2-3], we regard the reasonable weight value as the final authority. Namely:

Final weights value of basic conditions layer:

\[ A_C = (0.2608, 0.3292, 0.1743, 0.1399, 0.0958) \]

Final weights value of evaluation factor layer:

\[ A_{CI} = (0.2608, 0.2097, 0.0850, 0.0345, 0.1743, 0.1399, 0.0575, 0.0383) \]

2.2 Classification and value of evaluation factors

We use hierarchical fuzzy evaluation method and divide its evaluation objectives A into the evaluation set for five levels [4-5] (see Table 1).

A = {stable region(1), basically stable region(2), secondary unstable region(3), unstable region(4), extremely unstable region(5)}

| factor                | grade                    | stable region (1) | basically stable region (2) | secondary unstable region (3) | unstable region (4) | extremely unstable region (5) |
|-----------------------|--------------------------|-------------------|----------------------------|-------------------------------|---------------------|-----------------------------|
| karst condition       | degree of karst           | no                | not well developed          | not developed                 | developed           | well developed              |
| underground water condition | distance between water level and interface(m) | >5 | 5-2 | 2-0 | 0-3 | <3
|                        | amplitude of ground water level(m) | <1 | 1-2 | 2-3 | 3-5 | >5
|                        | distance to center of depression(km) | >10 | 10-7 | 7-4 | 4-2 | <2
| cap rock condition    | thickness (m)             | <0.5 or >20       | 15-20                       | 10-15                        | 5-10               | 5-0.5                       |
| environmental condition | pumping strength          | <300              | 300-500                     | 500-1000                     | 1000-1500          | >1500                       |
|                        | distance to pumping well (m) | >500              | 500-200                     | 200-100                      | 100-50             | <50                         |
| historical condition  | distance to collapse site(km) | >10 | 10-5 | 5-3 | 3-1 | <1

Note: The property values of grating evaluation in this table are consistent with legend levels in the grading layers (Figs. 1 to 11)
2.3 Determination of the factors’ rating membership function
The evaluation in this article is to take hierarchical attribute values of all factors on the center of the grid cell as the ranking membership value of the entire unit[6].

2.4 Fuzzy comprehensive evaluation
We extract the grading value of all the secondary factor from the hierarchical properties library of evaluation factors(Figure 1-5 correspond with the classification zones in Table 1), and determine the hierarchical membership risk values of each evaluation factor. Then we obtain the matrix Rc of membership function, which multiplies the weight set Ac of each evaluation factor. Hereafter, we calculate fuzzy evaluation set for each unit and get the maximum value. What the maximum corresponds to is the level where the unit is[7].

Fig.1 The distribution map of the distance to the funnel center

Fig.2 The distribution map of the distance to quaternary baseboard
As No. 8804 unit, the actual property value is (2, 4, 5, 2, 5, 1), corresponding fuzzy subset is:

\[
C_{8804} = \begin{bmatrix}
0,1,0,0,0 \\
0,0,0,1,0 \\
0,0,0,0,1 \\
0,0,0,1,0 \\
0,0,0,0,1 \\
0,1,0,0,0 \\
0,0,0,0,1 \\
1,0,0,0,0 \\
\end{bmatrix}
\]

According to the final calculated result, we get the result of the fuzzy hierarchy predicted partition of karst collapse area, namely the stable region 1, the basically stable region 2, the secondary unstable region 3, the unstable region 4, the extremely unstable region 5 (see Figure 5).
3. Evaluation of vulnerability and expected loss
In the light of 1:50000 actual material map of study area, street map, railway and highway map as well as water distribution map, etc., generated the distribution map on social economy and basic conditions of the study area (see Figure 6) while there are 10-meter-wide buffer zone of railway, 20-meter-wide buffer of high-speed State Road, 15-meter-wide main street buffer and 5-meter-wide buffer is set near river. And then, evaluate the vulnerability and the expected loss of these elements\cite{8}. 

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Fig.6 The distribution map of social base infrastructure
1-Highway of Beijing-Shanghai 2-Railway 3-General highway 4-State Road 5-Main street 6-Site of government 7-Industrial land 8-Agricultural land 9-Village 10-Urban Resident
3.1 socio-economic vulnerability assessment
Socio-economic vulnerability assessment (V-social) evaluates that karst collapse could bring potential odds to the socio-economic losses, mainly considering several aspects as the density of population, the level of economic development, the ability and the importance for the whole society to overcome the disaster and so on. Its assignment range is between 0 and 1: the higher value indicates the greater vulnerability (see Table 2, next page).

| Type                              | V-social | V-stru | V-eco (million yuan) | V-loss (million yuan) | Rank |
|-----------------------------------|----------|--------|----------------------|-----------------------|------|
| Agricultural Areas                | 0.4      | 1      | 0.05                 | 0.02                  |      |
| Main Street                       | 0.8      | 0.6    | 0.1                  | 0.048                 | 1    |
| General Highway                   | 0.6      | 0.5    | 0.35                 | 0.105                 |      |
| State Road                        | 0.8      | 0.4    | 0.5                  | 0.16                  |      |
| River                             | 0.2      | 1      | 1                    | 0.2                   |      |
| General Highway, Main Street      | 0.9      | 0.5    | 0.5                  | 0.225                 |      |
| Highway                           | 0.9      | 0.4    | 0.7                  | 0.252                 |      |
| State Road, Main Street           | 0.9      | 0.5    | 0.7                  | 0.315                 |      |
| Village                           | 0.8      | 0.9    | 0.45                 | 0.324                 | 2    |
| State Road, General Highway       | 0.9      | 0.5    | 0.8                  | 0.36                  |      |
| General Highway and Highway       | 0.9      | 0.5    | 1                    | 0.45                  |      |
| Industrial land                   | 0.6      | 0.2    | 5                    | 0.6                   | 3    |
| State Road, River, Main Street    | 0.9      | 1      | 0.8                  | 0.72                  |      |
| Railway                           | 0.7      | 0.6    | 2                    | 0.84                  |      |
| River, Main Street                | 0.8      | 1      | 1.2                  | 0.96                  |      |
| State Road, Railway               | 0.8      | 0.5    | 2.5                  | 1                     |      |
| Railway, General Highway          | 0.8      | 0.6    | 2.2                  | 1.056                 |      |
| General Highway, River            | 0.9      | 1      | 1.2                  | 1.08                  |      |
| Seat of government                | 0.9      | 0.3    | 4                    | 1.08                  |      |
| Railway, Highway                  | 0.9      | 0.5    | 2.5                  | 1.125                 |      |
| General Highway, River, Main Street| 0.9     | 1      | 1.5                  | 1.35                  | 5    |
| State Road, River                 | 0.9      | 1      | 1.5                  | 1.35                  |      |
| Urban area                        | 1        | 0.9    | 1.75                 | 1.575                 |      |
| Railway, River                    | 0.8      | 1      | 2.5                  | 2                     |      |

3.2 Structural Vulnerability Assessment
Structural vulnerability assessment (V-stru) was designed to evaluate the anti-collapse capabilities of the different land use elements from the perspective of infrastructure, which is denoted by the possibility of collapse occurring and values in 0 – 1.

3.3 Evaluation of expected loss
Expected loss evaluation is to calculate and assess the expected loss of karst collapse. For reference with collapse losses of other parts of the country, this article dose it from the national economy and people's property losses when the collapse occurred, which is expressed as V-eco and united by
ten-thousand RMB. Finally, gain the expected loss value ($V_{\text{loss}}$) through the values of the vulnerability and the economic loss and grade it.

Taking comprehensive treatment and analysis on the assessment results of vulnerability (social vulnerability and structural vulnerability) and economic loss, we receive the assessment results of expected loss ($V_{\text{loss}}$). In this, adopt the method of direct multiplication multiply directly, namely:

$$V_{\text{loss}} = V_{\text{social}} \times V_{\text{stru}} \times V_{\text{eco}}$$

By 5-13, the final loss value of each land use unit can be calculated when the collapse occurs, and then we rank losses artificially following the size, which are divided into five grades (5 level represents maximum loss while 1 level means the minimum). At last, we get the distribution map of expectation loss (see Figure 7).

![Fig7 The distribution map of expectation loss](image)

### 4. Risk Assessment

#### 4.1 Methods of Risk Assessment

Karst collapse risk ($R$) is a function of the potential risk of collapse ($Q$) and the expected loss ($V$) \cite{9}, namely:

$$R = f(Q, V)$$

In this evaluation, the following model is selected:

$$R = Q \times V$$

In the actual operation, multiply the property of the distribution map of dangerous evaluation of karst collapse by that of the distribution map of expectation loss under the corresponding unit to generate an initial risk grade (see Table 3). Later, reclassify this grade and determine the level of risk karst collapse for five in which the highest risk is located at 1 grade while the lowest lies in 5.

| Initial Value $R$ | Reclassified Value | Risk Grade |
|-------------------|--------------------|------------|
| >20               | 1                  | one-grade  |
| 16-20             | 2                  | two-grade  |
| 7-15              | 3                  | three-grade|
| 4-6               | 4                  | four-grade |
| 1-3               | 5                  | five-grade |

#### 4.2 Results of Risk Assessment

There are all 5 grades risk zones in the evaluation area (see Figure 8). The one-grade risk zone with the area of about 12.7 km$^2$ is located in the center of Linyi City and the northwestern of LuoZhuang
District, as well as along some vital traffic arteries. These areas are densely populated, so a great social risk loss will be apt to generate once karst collapse occurs. The distribution of two-grade risk zone is in the eastern and southern of evaluation area whose area is about 24.15km² and it is composed of the large areas of the central city as well as Zhuchen - Panlongzhuang areas and Hunan– Dabaiyizhuang areas. The two-grade risk zone is high risk karst collapse district. The 22.82km²-area of the three-grade in the eastern and northeastern part of the vast evaluation region is viewed as middle risk district. The four-grade risk zone is located in the mid-western, with area of about 47.79km², and it is viewed as low risk district. The karst collapse risk of five-grade district in the western, northwest and northern area with the area of about 61.58km² is viewed as lower risk district.

5. Conclusions
The highest hazardous region of Karst collapse is located near the cone of depression of water level and the northeastern with high degree of karst development and subsidence areas in total of about 23.6 km². Make the evaluation of vulnerability and expected loss on the basis of the hazardous assessment, and then obtain classification results after comprehensive risk assessment that the one-grade risk regions with an area of about 12.7 km² are located in some residential areas and other places of the center of Linyi Town and the northwestern of LuoZhuang District. Because of the higher degree of karst development, the high frequency collapse occurs in history and the dense urban neighborhoods in this area, a great loss will be caused easily once the collapse happens. Therefore, some targeted preventions and treatments need to be taken urgently.

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