KARST COLLAPSE HAZARD ASSESSMENT SYSTEM OF WUHAN CITY BASED ON GIS

Yiping Wu1*, Wei Jiang2, Hui Ye1

ABSTRACT

With the rapid construction, some geohazard took place with the strong human activity on geological environment in Wuhan. By using the karst collapse evaluating model and the advantages of GIS technology in image processing and space-analysis, Karst Collapse Assessment System of Wuhan City is built up in this paper. The research method and scheme of karst collapse prediction, which from information collection and management → evaluation data standardization → prediction model analysis → prediction result graphic processing and analysis , are materialized in the system. The system is mainly made up of three subsystems: Information management Subsystem, Hazard Assessment Subsystem, Information Issue Subsystem. According to analyzing the distributing condition of karst collapse, the main influence factors of karst collapse are pointed out. The dynamic change of karstic groundwater is the main trigger factor. Applied with fuzzy multidisciplinary assessment model, the karst collapse hazard evaluation of Wuhan is carried out. Zonation map of karst collapse susceptibility in Wuhan is achieved. This system provides an effective way for the karst collapse information management and hazard prediction of the city, where Carbonate Rock is widely distributed. The result of the assessment can be a gist and ensure for the city planning in Wuhan.

Key Words: Karst collapse assessment system, GIS technology, Trigger analysis, Fuzzy multidisciplinary assessment

INTRODUCTION

Karst collapse is a kind of environmental and geological phenomenon of surface deformation or collapse. In the cities, karst collapses caused by human activities, such as pumping groundwater for water supply and mine dewatering, are generally of large scale and paroxysmal. They can pose a serious threat to buildings and human safety.

Recently, there are many researchers taking up with the mechanism of karst collapse(Mowar S., 1996; Thomas., 1999; Roberto., 2002; He et al, 2003). Combining with numerical simulation, theory of mathematics and elasticity are applied to evaluate the stability of the soil hole(Huang et al, 1985; Jiang 1998; Wang 1998; Ketelle, et al, 2002; Deborah et al, 2002; Yang, 2002). At the same time, with the development of computer technology, the database and areal stability prediction of karst collapse is emphasized. Some semi-quantitative and quantitative method are applied into the areal karst collapse assessment based on GIS, such as frequency ratio Technique (İşık Yılmaz, 2007), Grey system statistics method (Jia et al., 1994),

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Fuzzy-Hierarchy prediction (Chen et al., 2000), Grey fuzzy synthetic assessment (Qiu, 2004), ANN Model (Bao 2002; Hu, 2003; Zhu, 2004; Chen, 2005). With the development of GIS technology, GIS is applied to evaluate Karst collapse. Such as analysis of the statistical relationships between sinkholes and the causal factors to produce the prediction models (Galve et al., 2008), calculation of stability coefficients by stress–strain state of the rock formations (Koutepov., 2007). Many methods are applied to evaluate Karst collapse, they are the probability method of logistic regression (Lamelas et al., 2008), Decision tree model (Bruno, 2007), monofactorial overlay analyst and dynamic-weighted calculation (Zang et al., 2009), PLS Path Model (Feng, 2008) et al.

Wuhan is one specially big city in middle of China. With the long action of natural factors and strong human activity, some karst surface collapse took place in the insidious carbonate rock. There had been recorded almost ten karst collapses since 1931. These collapses all took place in the Wuchang and Hanyang second bottom along Yangtze River, where insidious carbonate rock distributes (Fig. 1). There are dense population and many important constructions in these zones, such as Jingguang Railway, 107 National Highway and embankment of Yangtze River. So it is significant to study on the karst surface mechanism collapse and how to control the hazard.

![Carbonate rock contribution map of karst aquifer](image)

**Fig. 1** Carbonate rock contribution map of karst aquifer

**GEOLOGICAL SETTING**

In the study area, the insidious carbonate rock lie in the second bottom along Yangtze River and the south of Changjiang Bridge. Small part of study area belongs to third terrace, which has broken terrain. The carbonate rock (Fig. 1.) always lies underground, which locates in the axial region of the synclines, such as Daqiao Syncline, Lujiajie Syncline and Luxiang Syncline (Fig. 2.). The sediment age of carbonate rocks are Middle-Carboniferous, Early-Permian, Early-Triassic. The lithology of the carbonate rock are mainly limestone and dolomitic limestone, partly argillaceous limestone and argillaceous zebra limestone. In the carbonate rocks, calcite venation exists, which width is from 0.1m to 3.9m. Because of the structural function, there are compression faults in the carbonate rocks of the axial region of the synclines. So there the groundwater is active and karst phenomenon is developed. On the surface of the carbonate rock, there are loose deposit of Q3 to Q4. The lithology are sand,
gravel, mucky soil and clay. The thickness is 0 to 30 meters.

According to the integrated survey data about hydrogeology and engineering geology in Wuhan, the deep karst is developed, mainly consist of karst caves, which max size is 20 to 30 meters and filled with clay and gravels partly. The shallow karst mainly consists of corroded fissure and karst caves, where NWW and NNE corroded fissure developed. In the drilling, there are many small karst cave, which is 0.10 to 0.30 meter high and filled with clay or gravel. In the study area, karst growth is mainly controlled by the geological structure and lithology. The Karst growth has the following characters:

1. It has the close relationship with the geological structure position. The closer to the axial region of the synclines and fault zone, the more karst growth.
2. It has the close relationship with lithology. The karst growth in limestone and bioclastic limestone is more than in dolomitic limestone. In argillaceous limestone there are no karst. Karst mostly occure in the limestone of Middle-Carboniferous and Early-Triassic. The Middle-Carboniferous karst phenomenons mainly are bigger karst cave. The Early-Triassic karst phenomenons are corroded fissure, the average karst rate is 6.57%.
3. On the plane, the karst is banded, and the connectivity of the corroded fissure is different. The geographic and drilling data has shown that the big strip is near Tujiagou Judicial School and Fenghuochun.
4. Karst growth has the vertical zonality. Normally it is divided into deep karst zone and shallow karst zone by underground 50 meters.

SYSTEM CONSTRUCTION

The recent karst collapse assessment has entered into a new stage. It is directed by new prediction theory and based on abundant data by advanced investigation technology. Its technological process is shown in figure 3. Even more and more data used in the process, the GIS computer disposal means provide effective approaches to deal with karst collapse assessment data.
The great number of information, complex data structure, excessive levels and angles put forward new command to the prediction system. To adapt the disparate demand, this Karst Collapse Assessment System adopts Windows XP as basic platform, MAPGIS as developing plat. With the MAPGIS spatial database structure, VISUAL C++ is applied by the object-oriented program method. Its merits are objective, visual and mutual, its interface is friendly, process is clear, and easy to use and develop.

The research method and scheme of karst collapse assessment, which from information collection and management → evaluation data standardization → prediction model analysis → prediction result graphic processing and analysis, are materialized in the system. The system is mainly made up three subsystems (Fig.4): Information Management Subsystem, Hazard Assessment Subsystem and Information Issue Subsystem.
Fig. 4 Karst Collapse Assessment System Structure

The Information Management Subsystem is the basis of the prediction. In this subsystem, the dynamic and scientific management of the relative information is realized. The main functions include: information-collecting, compiling, updating, inquiring and so on. The Hazard Assessment Subsystem is the core subsystem to predict. In this subsystem, some effective predict models are provided, such as Information Model, BP Model, Fuzzy Multidisciplinary Assessment Model and Gray-clustering model. The Information Issue Subsystem focus on the decision-making and information issue. The whole prediction proceeding, especially based on irregular unit, is realized automatically to fit the complexity of karst collapse assessment.

**KARST SURFACE COLLAPSE HAZARD ASSESSMENT IN WUHAN**

**Confirming evaluating factor**

The correct choice of evaluating factor depicted the formation essence of karst cover-collapse and affected the precision of prediction. In the literatures concerned cover-collapse prediction, different scholars advanced different types of factors and the number was diverse. In fact, karst cover-collapse is destabilization process that the system of karst-overlap-water presented under the function of all sorts of agents. Confirming the evaluating factors should be based on analyzing formation reasons and course of cover-collapse using engineering geology principle. By virtue of practical investigation data and the forefather’s research achievements, this paper indicated it were the four most elementary factors that characteristic of karst geology, characteristic of overlap, groundwater flow feature and human activity controlling cover-collapse in study area. The four factors respectively provided development space, material resource and dynamical condition for the formation of collapse. Therefore this paper chose eight evaluating factors (Table 1.).

**Table 1 Selected factors for prediction of regional cover-collapse susceptibility**

<table>
<thead>
<tr>
<th>Evaluating Factor</th>
<th>Characteristic of Overlap</th>
<th>Characteristic of Karst Geology</th>
<th>Dynamic Characteristic of Groundwater</th>
<th>Human Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Thickness $I_1$ (m)</td>
<td>Origin type $I_2$</td>
<td>Lithologic Characters of Bedrock $I_3$</td>
<td>Geological Structure $I_4$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Type $I_5$</td>
<td>Topomorphy $I_6$</td>
<td>Groundwater Type $I_7$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Groundwater Quantity $I_8$</td>
<td>Groundwater Activity Intensity $I_9$</td>
</tr>
</tbody>
</table>
Dividing prediction grid and preparing data

The acreage of 29.13 km\(^2\) of the unconsolidated rock coverage area in study region was partitioned into 11644 square grids—prediction grid with size 50×50 m\(^2\) by making use of the raster manipulation function of GIS software. At the same time, using different space interpolation technologies to make all discrete dots and lines systemic in GIS environment formed the regional parameter plot. Consequently values of all evaluating factors in prediction grid were acquired according to the regional parameter plot. The new data as the input of prediction model was obtained by using extremum method to normalize all aforementioned values.

Building up of fuzzy multidisciplinary assessment model

1 Judge rule determination of single factor

According to the judge aim, judge unit is \(v=\) \{ high susceptibility zone, medium susceptibility zone, low susceptibility zone \}. Based on three grade of judge unit, each judge factor is divided into I,II,III grade according to certain rule. The grade limit (Table 2) is synthetically decided by site investigation and recent relative criterion. In Table 2, the karst collapse susceptibility of I,II,III grade varies from high to low.

2 Dataset of factor weight

Because of the complexity and influence degree of evaluate factors, it is difficult to quantify all factors by uniform rule directly. In this paper, the binary factor comparison method and dephimethod are applied to confirm the weight of the second grade factor. If A is more important than B, the weight of A is 1, the weight of B is 0. If the importance of A is equal to B, the weight of A and B both are 0.5. All factors are compared pairwisely, total weight of each factor is received. With the father normalization, each factor weight is gained. The weight of No.1 factor unit is \(a_i=\{0.2, 0.5, 0.2, 0.1\}\). The general weight of No.2 factor unit is \(a_i=\{0.10,0.10,0.30,0.10,0.10,0.10,0.10,0.10\}\).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Single factor judge rule of karst collapse susceptibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluating factor</td>
<td>Grade</td>
</tr>
<tr>
<td>Origin of overlap</td>
<td>Loose deposit</td>
</tr>
<tr>
<td>Thickness of overlap</td>
<td>&lt;10m</td>
</tr>
<tr>
<td>Lithology of bedrock</td>
<td>Hard soluble carbonate rock (karst growth)</td>
</tr>
<tr>
<td>Geomorphy</td>
<td>Accumulation plain of denudation</td>
</tr>
<tr>
<td>Geological structure effect</td>
<td>Strong</td>
</tr>
<tr>
<td>Groundwater type</td>
<td>pore confined water in loose carbonate rock</td>
</tr>
<tr>
<td>Groundwater quantity</td>
<td>Abundant water quantity (single well water yield more than 500m(^3)/d)</td>
</tr>
<tr>
<td>Human activity intensity</td>
<td>intensive</td>
</tr>
</tbody>
</table>
3 Determination of evaluation factor’s subordinate

Evaluation factors are divided into two types: qualitative and quantitative indices. The qualitative indices’ values are assigned values discretely and their subordinate functions are their respective classes. The quantitative indices’ values are assigned values continuously and there are transitional states although each class has its own limit value. The subordinate functions of the quantitative indices are gotten through the following rule (Table 3.): dividing each interval area into four equal parts and assigning the two parts close to the class limit value as the transitional function, which is possessed by the neighbored classes; the other two parts belong to the respective class.

Thus the relative Fuzzy multidisciplinary assessment matrix of each unit is set up, and the subordinate of each unit is calculated. According to the Maximal Subordinate Principle, karst collapse susceptibility grade of each unit is determined. With the automatic processing of computer, the zonation map of karst collapse susceptibility (Fig.5) is made out.

Table 3 Determination of evaluation factor’s subordinate

<table>
<thead>
<tr>
<th>Interval</th>
<th>Class I</th>
<th>Class II</th>
<th>Class III</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x \leq a_1 )</td>
<td>( 1 - \frac{x}{2a_1} )</td>
<td>( \frac{x}{2a_1} )</td>
<td>0</td>
</tr>
<tr>
<td>( a_1 &lt; x \leq \frac{a_1 + a_2}{2} )</td>
<td>( \frac{(a_1 + a_2) - 2x}{2(a_2 - a_1)} )</td>
<td>( 1 - \frac{(a_1 + a_2) - 2x}{2(a_2 - a_1)} )</td>
<td>0</td>
</tr>
<tr>
<td>( \frac{a_1 + a_2}{2} &lt; x \leq a_2 )</td>
<td>0</td>
<td>( 1 - \frac{2x - (a_1 + a_2)}{2(a_2 - a_1)} )</td>
<td>( \frac{2x - (a_1 + a_2)}{2(a_2 - a_1)} )</td>
</tr>
<tr>
<td>( x &gt; a_2 )</td>
<td>0</td>
<td>( \frac{a_2}{2x} )</td>
<td>( 1 - \frac{a_2}{2x} )</td>
</tr>
</tbody>
</table>

Fig. 5 Zonation map of karst collapse susceptibility in Wuhan

Analysis of assessment result

Zone I: In this zone, there is high susceptibility of karst surface collapse. There are karst zone covered with loose deposit, which contains abundant pore confined water. The karst water has close hydraulic connection with pore water. There are some amount of karst cave in
the carbonate rock. There are some soil holes developed in the overlap, which is not too thick. So in the zone, all condition is propitious to cause karst surface collapse. There have been already several karst surface collapses in the history. This zone will be the key control zone for karst surface collapse. To the location, where insidious soil hole has been discovered, many method should be adopted to control their development. For instance, air hole is get through to remove the negative pressure for the soil hole in the cohesive soil, drilling is needed to fill in the hole or reinforce for the soil hole in the sandy soil. To the other location, soil hole location should be found out firstly. At the same time, the hydraulic condition, which could cause strong groundwater vertical seepage, should be eliminated. For example, the karst channels are blocked up, the pump and drainage of relative groundwater activity should be stopped, and so on. At last the dynamic character of groundwater and Yangtze River should be monitored attentively.

Zone II: In this zone, karst surface collapse is possible to take place under the suitable condition. There are karst zone covered with loose deposit, which contains abundant pore confined water. There are no water insulation course, so there are closer hydraulic connection between karst water and pore water. With the suitable condition, it is easier to cause karst surface collapse. But in the carbonate rock of this zone, there are a little growth of shallow karst cave. With the development of soil hole existed, it is still possible to cause karst surface collapse.

Zone III: In this zone, karst surface collapse doesn’t take place generally. This zone includes the following two conditions. The one is karst zone covered with old clay, which is relative water insulation course. The other is covered karst zone covered with red sandstone. On the upper, pore confined water is abundant in the loose sand, which has the complementary relationship with Yangtze River in the high or low water period of Yangtze River. Because of the obstruction of red sandstone, there are no hydraulic connection between karst water and pore water or Yangtze River.

CONCLUSION

Based on GIS, karst collapse assessment system is established in Wuhan to realize karst collapse information management and analysis. Favorable results and important effects are gained. The main results and conclusion are as following:

(1) Wuhan Karst growth has the close relationship with the geological structure position, and lithology. And it has the obvious vertical zonality.
(2) The exist of karst cave in the carbonate rock is the basic condition of karst collapse. And the triggers are complex, the main induced factors include surface load and the quick alteration of groundwater level caused by different reasons, such as rainfall, Yangtze River and pump water.
(3) By applying the fuzzy multidisciplinary assessment model, karst collapse high susceptibility zone is figured out. Based on the result, the following attention of controlling karst surface collapse is put forward. Some effective measurement should be carried out to find out and control the soil hole. At the same time, the action of strong groundwater vertical seepage should be prohibited. And the relative monitoring work of groundwater and Yangtze River must be executed.
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