Risk Control of Karst Collapse----A Case Study of Linyi City

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Abstract. Karst collapse is a common geological disaster, and groundwater level is the main influencing factor of karst collapse in Linyi City. This article uses the established groundwater flow model to propose a method for controlling karst collapse: to make the karst water level not lower than the control level. Based on this method, three different groundwater extraction schemes were designed in the study area, and calculation analysis was performed in conjunction with water level control points. The results show that in the future, the amount of karst water exploitation in the urban area of Linyi City will be reduced by 11.65×104m3/d compared with the current situation, The reduced groundwater volume will be solved by the surface water project of the Andi reservoir in Linyi City, which can control the danger of karst collapse.

1. Introduction

The urban area of Linyi City is located at the leading edge of the Linyi Monoclinal Hydrogeological Unit. The terrain is flat and the slope is small. It is a water-rich zone with karst fissure water. The main sources of groundwater recharge are atmospheric precipitation, river water leakage and irrigation infiltration. The principal drainage methods are artificial mining. The general flow direction of groundwater is from northwest to Southeast.

The western boundary of the study area includes the northern section of the rock slope fault in the north and the line of the underground watershed of the Julongshan-Woniu mountain, which is a water-impermeable boundary; the northern and eastern boundaries are composed of the Tanyi-Linyi fault structural combination zone, and are also water-impermeable boundaries; The lithology of the southern boundary is Middle Ordovician limestone, which is a permeable boundary. Therefore, the Linyi hydrogeological unit is a semi-open karst water system with three sides facing the east, north, and west, and the south permeable [1].

For a long time, karst groundwater has been the main source of water supply for living and industrial and agricultural production in the study area. Since the 1980s, the long-term exploitation of karst groundwater has caused 19 karst collapses in Linyi City, presenting a great threat to people's lives and property. Therefore, the evaluation and control of the karst collapse danger in the study area is of great significance to the social and economic stability and development of the area.
2. Influence of groundwater on karst collapse

The risk control of karst collapse mainly refers to the loss control, that is to take measures to minimize the cost of loss and reduce the possibility of the occurrence of karst collapse. The study finds that changes in groundwater conditions are the main influencing factors of karst collapse. Regarding the mechanism of karst collapse caused by changes in groundwater conditions, the common explanations at home and abroad include latent erosion theory [2], vacuum absorption theory [3], out-of-load loading effect [4], vibration effect [5], and osmotic pressure effect [6].

By analyzing the relationship between previous karst collapses in the study area and the spatial-temporal changes of groundwater levels, the following conclusions are drawn: (1) The greater the groundwater level change, the faster the lifting speed, and the higher the collapse frequency. (2) The number of karst collapse generally increases with the increase of the water level. (3) After the groundwater level lowers below the bedrock roof, it is particularly easy to cause collapse. Based on the hydrogeological conditions of the study area, the controlling water level of the karst collapse is determined to be between the bedrock roof elevation and 2m below the bedrock roof elevation. When the regional groundwater level is lower than this control water level for a long time, karst collapse is easily caused. On this basis, the well layout and volume of water wells in the study area are adjusted and designed to control the karst collapse.

3. Determination of control scheme

3.1. Method and technical route

In order to accurately describe the dynamic changes of groundwater level, a numerical model of karst groundwater flow is established [7]. The model is identified and verified using groundwater dynamic data, and relevant hydrogeological parameters are obtained. At the same time, based on the principle that the predicted water level of the selected control point is not lower than the controlled water level,
three different planned mining schemes are determined and substituted into the model for forecast evolution, and finally a reasonable groundwater mining scheme is determined.

3.2. Determination of the location of karst collapse control points
In order to reduce the threat of karst collapse to urban areas, efforts must be made to eliminate the presence of groundwater levels in urban areas below the bedrock roof. Among them, T1-T9 are existing subsidence points; Y1-Y4 are newly added control points to monitor the groundwater level in the southern Luozhuang area; 640, 602, 644 supplementary control points. See Table 1 for details of each control point.

Table 1. List of control points.

| Serial number | Well number | Elevation of bedrock roof /m | Predict initial water level /m | Control water level /m |
|---------------|-------------|------------------------------|-------------------------------|------------------------|
| 1             | T1          | 59.11                        | 64.53                         | 59.11                  |
| 2             | T2          | 63.38                        | 64.57                         | 61.61                  |
| 3             | T3          | 62.84                        | 62.54                         | 61.11                  |
| 4             | T4          | 61.75                        | 61.31                         | 59.75                  |
| 5             | T5          | 61.23                        | 61.31                         | 59.45                  |
| 6             | T6          | 60.27                        | 60.38                         | 58.37                  |
| 7             | T7          | 60.12                        | 60.02                         | 58.67                  |
| 8             | T8          | 65.39                        | 64.43                         | 63.39                  |
| 9             | T9          | 62.27                        | 61.23                         | 61.27                  |
| 10            | Y1          | 62.8                         | 60.78                         | 61.59                  |
| 11            | Y2          | 62.6                         | 59                            | 60.60                  |
| 12            | Y3          | 62.11                        | 61.69                         | 60.11                  |
| 13            | Y4          | 61.82                        | 60.38                         | 59.80                  |
| 14            | 640         | 62.7                         | 60.99                         | 60.70                  |
| 15            | 602         | 59                           | 62.5                          | 59.00                  |
| 16            | 644         | 60.13                        | 59.59                         | 58.13                  |

3.3. Determination of the mining volume of the forecast scheme
Through calculation, three different groundwater extraction schemes are intended to control the water level in the karst collapse area.

Option 1: The amount of karst water extracted in the urban area is reduced by $1.165 \times 10^4$ m$^3$/d, and the water gap is solved by surface water (Andi Reservoir in Linyi City); see Figure 2 for adjusting the position of mining wells, and see Table 2 for adjusting the amount of mining.

Option 2: The amount of karst water exploitation in the urban area is reduced by $1.165 \times 10^4$ m$^3$/d, and the water shortage is solved by non-urban water supply sources; the total volume of well extraction is increased by 4315 m$^3$/d, and the amount of urban mining adjustment is adjusted according to the solution 1.

Option 3: The amount of karst water extracted in the urban area is reduced by $1.165 \times 10^4$ m$^3$/d, and half of the water shortage is solved by surface water. The other half is settled by non-urban water sources. Each mining well added an additional 2157 m$^3$/d of mining volume on the original basis; the urban mining volume was adjusted according to plan one, and other mining volume data remained unchanged. See Figure 3 for adjusting the position of mining wells, and see Table 3 for adjusting the amount of mining.
Table 2. Adjustment plan of mining volume in urban area of Option 1.

| Well number | Exploitation quantity / (m$^3$/d) | Well number | Exploitation quantity / (m$^3$/d) |
|-------------|-----------------------------------|-------------|-----------------------------------|
|             | Original mining volume | Option 1 | Original mining volume | Option 1 |
| 5594        | 3000 | 2000 | 6689 | 3000 | 0 |
| 8163        | 3000 | 2000 | 5878 | 4000 | 0 |
| 5961        | 4000 | 2000 | 6879 | 20000 | 0 |
| 6335        | 3000 | 1000 | 7418 | 20000 | 0 |
| 5000        | 2000 | 5000 | 6779 | 25000 | 0 |
| 6979        | 15000 | 12000 | 5682 | 500 | 10000 |
| 7251        | 3000 | 0 | 5599 | 3000 | 4000 |
| 7701        | 40000 | 0 |  |  | 

Figure 2. Plan 1 adjustment of mining point location.

Figure 3. Plan 2 and plan 3 adjust the location of mining points.
Table 3. Adjustment of non-urban mining volume for Option 2 and Option 3.

| Well number | Exploitation quantity / (m$^3$/d) | Well number | Exploitation quantity / (m$^3$/d) |
|-------------|------------------------------------|-------------|------------------------------------|
|             | Original mining volume             | Option 2    | Option 3                            |
| 924         | 300                                | 4615        | 2457                               |
| 1949        | 50                                 | 4365        | 2207                               |
| 2153        | 220                                | 4535        | 2377                               |
| 2423        | 150                                | 4465        | 2307                               |
| 2495        | 50                                 | 4365        | 2207                               |
| 2888        | 200                                | 4515        | 2357                               |
| 3063        | 200                                | 4515        | 2357                               |
| 3078        | 500                                | 4815        | 2657                               |
| 3085        | 130                                | 4445        | 2287                               |
| 3546        | 200                                | 4515        | 2357                               |
| 3606        | 1500                               | 5815        | 3657                               |
| 3708        | 200                                | 4515        | 2357                               |
| 3809        | 100                                | 4415        | 2257                               |

| Well number | Exploitation quantity / (m$^3$/d) | Well number | Exploitation quantity / (m$^3$/d) |
|-------------|------------------------------------|-------------|------------------------------------|
|             | Original mining volume             | Option 2    | Option 3                            |
| 924         | 4533                               | 100         | 4415                               |
| 1949        | 4815                               | 50          | 4365                               |
| 2153        | 4829                               | 80          | 4395                               |
| 2423        | 5009                               | 100         | 4415                               |
| 2495        | 5176                               | 80          | 4395                               |
| 2888        | 5735                               | 340         | 4655                               |
| 3063        | 5748                               | 1400        | 5715                               |
| 3078        | 6469                               | 130         | 4445                               |
| 3085        | 6853                               | 110         | 4425                               |
| 3546        | 7215                               | 466         | 4781                               |
| 3606        | 7772                               | 1000        | 5315                               |
| 3708        | 8040                               | 750         | 5065                               |
| 3809        | 8325                               | 450         | 4765                               |

4. Control results analysis

In the prediction calculation, the following objective functions are used: the objective function A, which calculates the sum of the squares of the water level and the control water level difference at each comparison point of each control point (unit: m$^2$); the objective function B, which calculates the maximum absolute value of the difference between the water level and the control water level (unit: m). By adjusting the amount of groundwater extraction, the objective function value of the prediction calculation is minimized.

$$A = \sum_{i=1}^{n} (h_i - h_i')^2, \quad B = \text{MAX}\{|h_i - h_i'|\}$$

$h_i$: Calculate water level at the end of the month in the forecast period.

Table 4. Comparison table of objective function values of various schemes.

|                 | Objective function A | Objective function B |
|-----------------|----------------------|----------------------|
| Option1         | 0.591                | 0.434                |
| Option2         | 5.996                | 1.097                |
| Option3         | 1.960                | 0.485                |

It can be known from Table 4 that the two target values of the first scheme are the smallest and the targets are the best. It can be seen that through the reduction of groundwater in urban areas, the reduction of the amount of recovery from surface water can control the occurrence and development of karst collapse. Increasing the amount of water supplied by non-urban water sources can achieve the same goal, but the result is not as effective as Option 1. At the same time, issues such as the amount of water available from non-urban water sources and the possibility of transferring water to urban areas must also be considered.
Figure 4. 640 control point water level process line during forecast period.

Figure 5. Flow field at the end of prediction period.

Figure 6. Difference between predicted water level and control water level.
The predicted water level process line for the representative control point, the groundwater flow field at the end of the forecast period, and the comparison chart between the predicted water level and the controlled water level, are selected to illustrate the results of karst collapse risk control. Figure 4 is the predicted water level process line for the representative control point No. 640. It can be seen from Figure 4 that the predicted water level at the control point is still lower than the control water level in the first year of the forecast period, but the water level is gradually increasing due to reduced production, and the subsequent groundwater level mainly changes with the change of precipitation. Figure 5 is the groundwater flow field at the end of the forecast period. From Figure 5, it can be seen that the water level in the urban area is basically stable near 62m, and the decline in the northwest at each period is about 2m. Figure 6 is the difference between the predicted water level and the controlled water level at the end of the forecast period. It can be seen from Figure 6 that the predicted water level in the southeast of the study area is lower than the control water level of 0-2 m, because this area is a concentrated groundwater exploitation area. The predicted water level in the north and northeast is 4m higher than the controlled water level, and the predicted water level in the western and central regions are 0-4m higher than the controlled water level.

It can be known that by rationally adjusting the layout of groundwater mining, the occurrence and development of karst collapse can be controlled to a certain extent. After adjusting the mining according to Option 1, the water level in most areas would be higher than the karst collapse control water level, resulting in reducing the danger of groundwater levels to karst collapse.

5. Conclusion

The karst is developed in Linyi City, and the thickness of Quaternary system is relatively thin. Due to unreasonable exploitation of groundwater, the local groundwater level in the urban area continues to drop, and the danger of karst collapse near the landing funnel is very high.

The risk control method is tantamount to select several representative water level control points to control the water level to remain above 2m below the bedrock roof. Based on the principle that the predicted water level is not lower than the controlled water level, three different planned mining schemes are predicted using the groundwater flow model, and finally a reasonable groundwater mining scheme is determined: the amount of karst water mining in the future urban area will be reduced by 1.165×10^4 m^3/d. The reduced water volume is solved by surface water engineering (Andi banks) outside the study area, which can control the danger of karst collapse to a certain extent.

Acknowledgments

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