Zoning and Evaluation of Geological Disaster Vulnerability Based on Multi-source Data Integration in Loess Area of East Gansu --Taking Xifeng District as an Example

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Abstract: Xifeng District, Qingyang City, Gansu Province is located in the hinterland of Dongzhi tableland in the East Gansu Loess Plateau. The common geological disasters in here are landslides, unstable slopes, and debris flows. From the multi-source data, 14 factors with obvious influence are selected to constitute the index system, and the weight of each factor is obtained by using the AHP method. Based on the multi-source data integration method, the 14 factors are superimposed to obtain the geological hazard-prone zoning and evaluation in this area. The evaluation results show that the area is divided into 3 areas prone to geological disasters, and 9 sub-areas. (1) The high-prone area accounts for 48.96% of the total area, and the geological disasters mainly are unstable slopes. (2) The medium-prone area accounts for 22.64% of the total area. (3) The low-prone area accounts for 28.4% of the total area. The results not only provide a theoretical and practical basis for the establishment of a geological hazard assessment system in the East Gansu Loess Region, but also provide an important basis for the urban planning development and environmental coordination in Qingyang City.

1. Introduction
Xifeng District of Qingyang City is located in the eastern part of Gansu Province, which is the Loess Plateau of East Gansu, the upper reaches of Jing River, and the heartland of Dongzhi tableland [1]. It has a temperate semi-arid continental climate. The main rivers in this area are the Malian River in the east and the Pu River in the west. The most part of this area is covered by quaternary loess, which is strongly eroded by flowing water. The geological environment is very fragile. In addition, human activities are frequent here, and geological disasters are relatively serious. Searched from the CNKI by keywords and found that there are few systematic geological disasters evaluations of the East Gansu Loess Plateau. Therefore, the results of the geological disasters zoning in Xifeng District were obtained, which can provide scientific geological basis and evaluation method guidance for the establishment of geological disaster information system, disaster prevention, and urban and rural planning.

2. Survey of Geological Hazards in Xifeng District
Based on small measuring scales in other regions, the large measuring scale 1:10,000 remote sensing interpretation was adopted in key investigation areas, and combined with field inspections, the types of geological disasters in this area are: unstable slopes, ground fissures, landslides, and debris flows. Therefore, in this paper, the main basis for evaluation is the common types of geological hazards.
The investigation found that the formation and development of geological disasters are closely related to the formation of rock and soil, terrain, human activities, and vegetation. At the same time, the time distribution law is highly correlated with precipitation and earthquake time. Therefore, the selection of evaluation factors is related to these above factors.

3. Multi-source data integration method and evaluation index establishment

3.1 Multi-source data integration method
The characteristic of GIS data collection is the source of the multi-source data integration method [2]. Due to the different sources of GIS data, when collecting data, different data types are stored in different layers, and the multi-source data maps collected are integrated in later period using the spatial overlay analysis function [2]. Due to the difference weights of different factors in the superposition process, the Analytical Hierarchy Process (AHP) [3] can be used to determine the weights of each factor. Finally, the multi-source data is used to obtain the final zoning result through the spatial superposition method.

3.2 Establishment of evaluation index system
As the occurrence and development of geological disasters are affected by a variety of factors, multiple factors should be fully considered in zoning. The survey found that this area is mainly affected by three major factors: development factor, basic factor, and inducing factor. Development factor determine the distribution and scope of geological hazards. The long-term effects of basic factor and inducing factor will increase the possibility of geological hazards, which is a long-term accumulation process. In order to highlight the comprehensiveness of the geological hazard regional evaluation factors and obtain the multi-source nature of the data, under the three major index factors, the multi-source data shown in Table 1 are selected for a total of 14 secondary factors.

| Main factors | Secondary factor |
|--------------|------------------|
| Development factor U1 | Geological hazard frequency ratio P1 |
| | Geo-hazard area modulus ratio P2 |
| | Geological hazard volume modulus ratio P3 |
| Basic factor U2 | Slope P4 |
| | Slope change rate P5 |
| | Slope type P6 |
| | Cutting depth P7 |
| | Gully density P8 |
| | Hydrogeological conditions P9 |
| | Geotechnical body type P10 |
| | Vegetation index P11 |
| Zoning of possibility V | Rainfall P12 |
| | Earthquake P13 |
| | Engineering activities P14 |

Combined with expert opinions, the AHP method was used to calculate 14 types of indicators, and the weight allocation table for the evaluation index of possibility to geological hazards was obtained, as shown in Table 2. It can be seen that the factors that have a greater impact on regional geological hazard zoning are P1, P2, and P9.
Table 2. Weight values for the evaluation factor of geological hazards

| Factor | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 | W9 | W10 | W11 | W12 | W13 | W14 |
|--------|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|------|
| Weight| 0.28 | 0.11 | 0.04 | 0.04 | 0.01 | 0.04 | 0.04 | 0.09 | 0.17 | 0.01 | 0.00 | 0.05 | 0.01 | 0.01 |

4. Zoning and Evaluation of Geological Hazards in Xifeng District

4.1 Quantification of evaluation indicators

Due to the 14 factors involved in the evaluation are not all quantitative statistics, in order to reduce the difference in values and dimensions, the 14 factors are firstly converted into quantitative expressions (Table 3), and finally normalized (Between 0 to 1) by the linear threshold method formula (1) [4]. Due to the need for overlay analysis in the later period, considering that the raster data has certain advantages when performing the overlay analysis, all the data obtained are converted into a raster structure, in which the development factor U1 uses a raster data processing method [5]. With a cell size of 2.5km × 2.5km, the study area was discretized into 20 rows × 15 columns, a total of 170 cell grids, and other factors were performed according to this method.

\[ Y_i = \frac{x_i - x_{\text{min}}}{x_{\text{max}} - x_{\text{min}}} \quad (\text{Formula 1}) \]

Table 3. Quantitative methods of evaluation factors and normalization method table

| Evaluation factor | Factor quantization ways |
|-------------------|--------------------------|
| P1                | Calculate the ratio of disaster frequency density to total frequency density in each unit. |
| P2                | Calculate the ratio of the disaster area modulus of each unit to the total area modulus. |
| P3                | The ratio of the volume modulus to the total area modulus of the disaster in the unit. |
| P4                | The 1:50000 DEM data was used to calculate the slope gradient data of the whole area by using ARCGIS surface analysis [4]. When assigning a value, the area slope gradient larger than 60° is defined as 1, and the area with slope gradient smaller than 10° is defined as 0 [6] [7]. |
| P5                | The DEM was used to extract the slope change rate data of the whole area. |
| P6                | The ArcGIS platform extracts the surface curvature information of the survey area from the DEM data, and uses the curvature to express the slope type. |
| P7                | Find the DEM average and minimum, and then use the grid calculator to find the difference between the average and minimum. |
| P8                | The ratio of the total length and area of the valleys in each watershed was calculated by taking the final collection thresholds of the hydrological network and the gully watershed network. |
| P9                | According to the mechanical strength properties of the loess, the loess samples were obtained in the field. When the moisture content is less than 18%, the stability is high and the value is 1. The moisture content is greater than 20%, and the stability is reduced. |
| P10               | Assigned with Table 4 |
| P11               | 2014 ETM + remote sensing data of Xifeng District, calculation of vegetation index NDVI [7]. |
| P12               | Based on the multi-year average rainfall obtained by the station, interpolation is used to obtain the precipitation in the region. |
The calculation of the grid is performed mainly through the results of seismic intensity zoning. Take the city, village and town as the center, and make a three-layer buffer zone with an interval of 250m. The maximum value after rasterization is 3.

Table 4. List of classification and assignment of geotechnical types in Xifeng District

| Engineering Geological Rock Group Code | Engineering Geological Rock Formation | Assignment | Proportion (%) | Area (km²) |
|----------------------------------------|--------------------------------------|------------|---------------|------------|
| Q_3^{eol}                              | Maran Loess                          | 4          | 50.46%        | 505.08     |
| Q_2                                    | Lishi Loess                          | 3          | 17.61%        | 176.28     |
| Q_1                                    | Wucheng Loess                        | 2          | 28.75%        | 287.8      |
| K_{1h}, k_{1h}                         | Mainly rock formations of sandstone, mudstone and siltstone | 1          | 3.18%         | 31.76     |

4.2 Evaluation model establishment

After the above evaluation factors are quantified, using the grid calculation function in ArcGIS software, the information of the study area is calculated in the form of a weighted sum of 14 factors (Formula 2), and the results of the geological hazard possibility map of Xifeng District in Figure 1 are obtained. Compare the calculation results of the evaluation with the rules of the development of geological hazards in this area, find the appropriate critical point of the boundary of possibility, and divide the entire area into three levels in Table 5: low, medium and high possibility areas.

Calculation formula: \( F = \sum W_i \times I F_i \) (Formula 2), where \( F \) is the value of the geological disaster possibility of the evaluation unit, \( W_i \) is the weight of the evaluation factors in Table 2, and \( I F_i \) is the value of the evaluation factors in Table 3 after normalization.

Table 5. Grading table for zoning evaluation of geological hazard possibility

| No. | Grade                  | Grading range F | Number of cells | proportion (%) | Area (km²) |
|-----|------------------------|-----------------|----------------|----------------|------------|
| 1   | Low-prone area         | 0.043986~0.302565 | 48             | 28.4%          | 282.94     |
| 2   | Central vulnerable area| 0.302565~0.492158 | 39             | 22.64%         | 225.6      |
| 3   | High-prone area        | 0.492158~0.712534 | 83             | 48.96%         | 487.81     |
|     | Total                  |                 | 170            | 100%           | 996.35     |

4.3 Geological disaster-prone zoning results and zoning evaluation

According to the basis and method for the division of geological hazard-prone areas and the distribution of geological hazards in the previous survey, the survey area is divided into 3 large areas as shown in Figure 1, and further divided into 9 sub-areas.

(1) High-prone areas of geological hazards (A)

As the large population in the area where high risk area is located, in addition to the influence of topography, rainfall, and vegetation control, it is also related to human engineering activities. It is mainly distributed in the west and southeast of Xifeng district, the loess gully regions and the gully margins of loess tableland with frequent human engineering activities, which is mainly the eroded zone of the Pu river, Gaijia basin, and Yingwa basin branch ditch, with a total area of 487.81 km², accounting for 48.96% of the total area in this district. The geological environment in the area is harsh. The strata are mainly covered by loess, the gully is well developed, the vegetation coverage is low, human activities are frequent. The density of hidden danger points of geological disasters reached 71, and the main failure types of unstable slopes were up to 61. There have been many landslide and mudslide disasters in history. According to statistics, the number of people threatened reached 1771, and the value of property was...
147.8835 million yuan. This area will be a key prevention area. Based on development characteristics and administrative divisions, this area is divided into 4 sub-areas, which are:

1) Western Pengyuan unstable slope high-prone sub-area (A1);
2) Pengyuan-Urban area - Hot Spring Huoxiang gully unstable slope high-prone sub-area (A2);
3) Dongzhi—Xiaojin—Xiansheng mudslides, unstable slopes, and landslides high-prone sub-area (A3);
4) Xiaojin—Dongzhi—Chenhu—Shishe unstable slopes and ground fissures are high-prone to sub-area (A4).

Figure 1. Zoning map of geological hazard susceptibility in Xifeng District

(2) Medium-prone areas of geological disasters (B)
This area is located in the east of Pengyuan, Houguan village, and the east of Hot Springs—the northeast of Shishe, with a total area of 225.6km², accounting for 22.64% of the total area of Xifeng District. The geological environment in this area is relatively fragile. The unstable slope, ground fissure and other geological hazards are moderately developed, with 7 hidden dangers, which are mainly unstable slopes. Compared with Grade A, the population is relatively less, but the impact of geological hazards will gradually increase with the expansion of cities. Based on development characteristics and administrative divisions, this area is divided into three sub-areas, which are:

1) Eastern Pengyuan unstable slope medium-prone sub-area (B1);
2) Southwest of Pengyuan Township-Houguan village unstable slope medium-prone sub-area (B2);
3) East of Hot Springs—northeast of Shishe unstable slope medium-prone sub-area (B3).

(3) Low-prone area of geological hazards (C)
This area is located in the central and south-eastern loess tableland and loess residue tableland of Xifeng District, with an area of 282.94 km², accounting for 28.4% of the total area of Xifeng District. It is mainly loess loaches eroded by the Pu river and Malian River. This area is located in the hinterland of Loess Plateau. With a relatively large population density, it is the main population area in the area. The ravines and gullies here are not developed and the terrain is relatively flat. The geological conditions are relatively good. According to historical statistics, there are fewer hidden danger points and low incidence. However, with the damage of human engineering construction and gully trace erosion, it will gradually cause soil erosion and related problems, and further promote the grade of geological disasters, so it should be paid attention in the later stage. Based on development characteristics and administrative divisions, this area is divided into two sub-areas, which are:

1) Central Pengyuan—Urban area—Western Hot Springs—Central Dongzhi—Northern Xiaojin—Xiansheng low-prone sub-area (C1);
2) Central and southern Shishe low-prone sub-area (C2).

5. Conclusion
In this paper, 14 influence factors are selected from the multi-source data, and the multi-source data are integrated through spatial overlay analysis to obtain the disaster zoning of the Xifeng District. This method can guide the selection of geological hazard indicators and zoning methods in the East Gansu Loess Region. However, the impact of human factors is still limited to distance factors. With the expansion of human activities, the impact of human factors will be much greater than natural factors. Therefore, future research should focus on the direction of subdividing the impact of human factors on the geological environment.

Acknowledgments
I would like to express my gratitude to technical guidance and experimental equipment provided by the Key Laboratory of loess engineering properties and engineering applications of Colleges and Universities in Gansu Province, and financial support from Gansu Provincial Department of Industry and Information Technology Project (GGLD-2019-055, GGLD-2019-053).

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