Geological hazard risk assessment based on GIS in Mianchi County

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Abstract: The probability of surface collapse, landslide, collapse and debris flow is very high in hilly and mountainous areas of Mianchi County of western Henan province. The article obtained geological hazard district of Mianchi County though the analytic hierarchy process (AHP) to carry on the geological hazard risk assessment in the study area. Eight disaster-inducing factors were selected the density of disasters, slope gradient, slope height, slope shape, rock-soil body types, vegetation index, rainfall index, and engineering activity intensity based on the GIS platform and combined with the field investigation result of geological disaster points.

1. Introduction
Mianchi County belongs to the remains of Qinling Mountains and is the hilly and mountainous regions in the western of Henan Province. The landform is divided into middle-mountain of tectonic geomorphology, denudational landform of the low mountains, hills of denudation landform, and terraces of valley geomorphology. The north is the middle and low mountainous area, and the south is the hilly area, which is rich in mineral resources and has strong mining activities. The special topography and character of the soil limited the mode of slope deformation-failure, controlled the characteristics of disasters consist of landslide, avalanche slide, debris flow, ground collapse and so on, and determined that Mianchi County was a high incidence area of geological disasters such as ground collapse, landslide, debris flow, mud rock flow. Ground collapse is mainly caused by underground mining, mainly located in the southern coal mining concentrated towns; landslide and debris flow are widely distributed in the area, mostly small soil or rock slopes, mainly due to the construction of industrial and civilian architecture and road construction; the hidden danger of debris flow is in the northern mountainous area, most of which belong to valley-shaped debris flow. In order to study the geological hazard risk zoning in Mianchi County, this paper employs the analytic hierarchy process and combined with GIS platform to establish the evaluation model, and get the results quickly.

2. Overview of the region
The research area in this paper is located in the west of Henan Province, is a hilly and mountainous area, with a total area of 1421 square kilometers. The jian river in the middle of the county as the boundary.
The elevation of this area gradually increases northward, from 500m to more than 1000m. Further north still, mountains after dozens of miles of steep drop into the Yellow River valley, only 200m above sea level. This area belongs to the stratigraphic division of western Henan in North China. The lithology of outcrops is mainly sedimentary rocks, followed by volcanic rocks. Stratigraphic ages are exposed from Proterozoic, Paleozoic, Mesozoic and Cenozoic, but the stratigraphic development of each age is not complete. Among them, the Quaternary is the most widely exposed. Sedimentary types of the strata in each epoch: Marine sediments before the Early Ordovician, interactive marine & terrestrial deposit during the Middle and Late Carboniferous, and continental deposit after the Permian. Mianchi is located in Mianchi - Queshan fault-fold structural belt in bundle of Huaxiong Platform margin depression of the North China Platform. The weak geological structures of magmatic activity are complicated, which mainly include some broad and gentle folds and small scale fault structures. Rivers in Mianchi belongs to the Yellow River basin, the Yellow River along the winding from the west to the east, narrow valley, steep bank, tributary of development. The average precipitation is 474mm in May to October of the calendar year, accounting for 82% of the annual precipitation, mostly rainstorm and continuous rain. Rainfall is one of the main inducing factors for the formation of geological disasters such as landslide, avalanche slide, debris flow, ground collapse and ground fissure. Therefore, the vast majority of geological disasters in the area occur in summer and autumn.

3. The risk evaluation indexes system

The geological hazard area refers to the area where the geological hazard is obviously likely to occur and may cause more casualties and serious economic loss [1]. Thus, the regional division should be based on the evolution tendency of geological hazards [2], using the geological disaster points causing losses, combining the formation conditions of geological hazards and the evolution trend of triggering factors and human engineering activities, so as to delineate the risk degree of geological hazards in different regions [3-5]. According to this principle, on the basis of the analysis of geological hazard formation conditions, the four-layer structure index system of geological hazard evaluation in Mianchi was established by using the method of target analysis [6].

![Geological disasters risk assessment indexes system](image)

(1) Historical calamities
Disaster history refers to the statistics of existing geological disaster groups, which mainly considers the number and scale of geological hazards that have caused losses. In view of the fact that landslides and collapses that have not been investigated by remote sensing interpretation, these are generally natural geological phenomena that cause no damage. The point density, surface density and volume
density are used to represent the point density and volume density based on the actual investigation of landslide and ground collapse and debris flow that have caused or have potential hazards.

(2) Basic factors
Basic factors refer to the background of geological environment conditions that control and affect the occurrence of geological hazards, such as slope gradient, slope height, slope type and rock soil mass types.

(3) Inducing factor
It refers to various external forces and human activity factors, including rainfall and human engineering activities, that induce (or trigger) the evolution of geological environment system to an unfavorable direction and even lead to geological disasters.

(4) The vulnerability of the hazard-affected body of geological hazards
The formation of geological hazards is the result of the coupling action of disaster body and disaster bearing body in time and space. The vulnerability of the hazard-affected body is an important part of the risk of geological hazard.

The methods to determine the weight mainly include expert scoring method, survey statistics method, sequence synthesis method, formula method, mathematical statistics method, analytic hierarchy process and complexity analysis method. Among them, the analytic hierarchy process (AHP) is a more reasonable and feasible system analysis method, which is determined by the experience judgment of several experts and combined with the appropriate mathematical model and further operation to determine the weight. This study uses this method to fill in the importance comparison matrix of geological disasters.

The weight obtained by the root method based on the importance degree comparison matrix.

Table 1. Comparison matrix of importance degree of comprehensive evaluation index system of regional geological hazard degree.

|    | A   | A1      | A2      | A3      |
|----|-----|---------|---------|---------|
| A1 | 1   | 2       | 1       |         |
| A2 | 1/2 | 1       | 2       |         |
| A3 | 1   | 1/2     | 1       |         |
| A11|     | A11     | A12     | A13     |
| A12|     | A12     | 1       |         |
| A13|     | A13     | 1       |         |
| A21|     | A21     | A22     | A23     | A24     | A25     |
| A22|     | A22     | 1/2     | 3       | 4       | 5       |
| A23|     | 1/3     | 2       | 1       | 3       | 2       |
| A24|     | 1/5     | 1/3     | 1/4     | 1       | 1       |
| A25|     | 1/5     | 1/3     | 1/2     | 1       | 1       |
| A31|     | A31     | A32     |         |
| A32|     | A32     |         |         |
| A31|     | A31     | 1/4     |         |         |
| A32|     |         | 1      |         |         |
| A33|     | A33     | 4      | 1       |         |

\[ A = (0.4,0.2,0.4); \]
\[ A1 = (0.60,0.20,0.20); \]
\[ A2 = (0.48,0.18,0.20,0.06,0.08); \]
\[ A3 = (0.2,0.8) \]
Pass consistency check:
CRA < 0.1, CRA1 < 0.1, CRA2 < 0.1, CRA3 < 0.1
The weight is reasonable according to satisfy consistency in each judgment matrix.
4. The evolution of geological disaster risk

(1) An area of great danger
The areas are mainly distributed along the S247 highway in the north of the coal mining area in the west and south of Mianchi. The total area is about 253.20 km², accounting for 17.82% of the total area of the region. It can be divided into two subregions, described as follows:

① Yinghao - Chen Cun - Zhang Cun - Po Tou - Yangshao - Rencun - Hongyang - S247 along the Sub-area
The total area is about 177.07 km², accounting for 69.93 of the large risk area. The collapse and landslide in the area are relatively developed. There are 93 geological disasters in the area, including 24 landslides, 59 collapses, 3 debris flows and 7 ground collapse.

② Orchard - Tianchi Sub-area
The total area is about 76.13 km², accounting for 30.07 of the large risk area. Ground collapse is most developed in the area. There are altogether 48 geological disasters of various kinds, including 6 landslides, 4 collapse points and 38 ground collapse.

(2) Medium fatalness region
The medium fatalness region is relatively scattered, involving each township, with a total area of about 935.30 km², accounting for 65.82 area of the whole district. The speed of urbanization construction is fast, and important engineering facilities such as roads, towns, buildings and reservoirs are relatively complete. The southern orchard and Tianchi is dominated by industry and agriculture, with coal industry as its pillar industry and tobacco and pepper as its main agricultural products. In the north, Nan Cun, Duan Cun, Potou, Yangshao, Ren cun Hongyang and other places mainly focus on agriculture and tourism, while in the west, Zhang cun and Chen cun focus on mineral development. There are 88 geological disasters and 48 landslides in this area, among which 47 are of low risk and 1 is of medium risk. The risk of 35 developmental collapse sites and 5 ground collapse sites is small. The whole region is divided into 5 subregions, which are described respectively:

① Zhang Cun-Chen Cun – Po Tou - Duan Cun Sub-area
It covers an area of 375.68 km², accounting for 40.17% of the area with moderate risk. Mainly distributed in Mianchi west of the low mountain area and along the Yellow River. Transportation in the area is not very convenient, the residents are relatively scattered, most of the residents have moved. There is Danxia scenic spot Yellow River, which is under construction. Landslides are the most developed in this area, with a total of 24 geological disasters, including 15 landslides, 8 collapse points and 1 ground collapse.

② Section of the Duan Cun east of the sub-area
It covers an area of 74.31 km², accounting for 7.95 of the area with moderate risk. It is mainly distributed in the middle and low mountain areas in the east of Duancun. Landslides are most developed in this area. There are 5 kinds of geological disasters, including 4 landslides and 1 collapse.

③ Ren Cun – HongYang Sub-area
Including two subregions, the area of 161.05 km², accounting for 17.22 of the middle risk area. Mainly distributed in Rencun Township and Hongyang Town. Landslide and collapse is most developed in the area. There are 26 kinds of geological disasters in the area, including 17 landslides and 9 collapses.

④ ChenCun – YangShao – ChengGuan - Orchard – TianChi Sub-area
The area is 324.26 km², accounting for 34.67 of the middle risk area. Mainly distributed in the southern Mianchi County hilly area. The sub-area has convenient transportation and a large population, mainly based on agricultural production. Landslide and collapse is most developed in the area. There are 33 geological disasters in the area, including 12 landslides, 17 collapses and 4 ground subsidence.

(3) An area of low risk
The area of low risk are distributed in some areas except the large and medium dangerous areas, covering an area of about 232.50 km², accounting for 16.36% of the total area. Human engineering
activity is minimal in this area. There are 2 geological disasters, including 1 landslide and 1 collapse. It is divided into three categories according to topographic and geomorphic conditions.

① Yinghao – ZhangCun – ChenCun Sub-area
It covers an area of 76.50 km², accounting for 32.90% of the area of low risk. It is mainly distributed in Mianchi in the southwest of the low hilly area. The terrain in the area is relatively flat, and there is a collapse in the subarea.

② DunCun – RenCun Sub-area
It covers an area of 23.01 km², accounting for 9.90% of the area of low risk. It is mainly distributed in the southeast of Duancun Township and Rencun Township in the north of the mountain area. The sub-area is uninhabited under current conditions, and there are basically no human activities.

③ NanCun Sub-area

It covers an area of 96.69 km², accounting for 41.59% of the area of low risk. It is mainly distributed along the Yellow River and in the mountainous area of Nancun Township. A landslide was found in this area.

④ Orchard – TianChi Sub-area

It covers an area of 36.30 km², accounting for 15.61% of the area of low risk. It is mainly distributed in the southeast of Orchard Township and the east of Tianchi Town. The topography of this area is less undulating. No geological hazards were found in this survey.

5. Conclusion

The following conclusions could be drawn by using GIS platform to analyze the survey data in the research area.

(1) Combined with the field investigation result of geological disaster points, this paper has selected the density of disasters, grade of side slope, slope height, shape of slope, rock soil mass types, vegetation index, critical precipitation index, and engineering activity intensity such as the eight factors that lead to disasters. Analytic Hierarchy Process (AHP) is used to evaluate the geological hazard risk in the study area.

The area of large risk area (Ⅰ), medium risk area (Ⅱ), and dangerous area (Ⅲ) is 253.2 km², 935.3 km², 232.5 km², accounting for 17.82%, 65.82% and 16.36% of the total area of the study area, respectively.

(2) In the study area, there are 77 disaster sites with low landslide risk and 2 disaster sites with medium landslide risk; ninety-nine of the collapse sites are hazardous, and there are two small and one medium risk debris flow; there were 9 sites with high ground collapse risk, 18 sites with medium ground collapse risk and 23 sites with low ground collapse risk; a total of 203 disaster sites have been investigated.

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References

[1] LIU L, YANG Z, SUN J, LIU Q, PENG P, DUAN J. (2021) Study on risk assessment of geological hazards in Huizhou District, Huangshan City, Anhui Province. The Chinese Journal of Geological Hazard and Control. 32(02):110-116.
[2] LAI B, LIU J, JIANG J. (2021) EVALUATION OF THE SUSCEPTIBILITY OF GEOLOGICAL DISASTERS IN ZHUHAI CITY BASED ON GIS. Journal of Geological Hazards and Environment Preservation. 32(01):31-36.
[3] DUAN S, LI Y, LI C. (2021) Geological hazard risk assessment based on GIS and analytical hierarchy process in Gande County, Qinghai Province. Mineral Exploration. 12(02):453-460.
[4] FENG J. (2021) Evaluation of Geological Disaster Hazard Zoning in Luoyang County, Shaanxi Province. Geospatial Information. 19(02), 78-82+120+7.
[5] SHI L, FAN W, LI P, CAO Y. (2020) Development Regularity and Risk Assessment of Geohazards in Zhenba County. Journal of Hebei University of Engineering (Natural Science Edition). 37(03):98-106.
[6] PENG Q, YANG J, CAO K. (2020) Development characteristics and risk assessment of geological hazards in xifeng county, guizhou province. 42(02):134-136+145.