International Journal of Environmental Protection and Policy
2019; 7(2): 72-79
http://www.sciencepublishinggroup.com/j/ijepp
doi: 10.11648/j.ijepp.20190702.14
ISSN: 2330-7528 (Print); ISSN: 2330-7536 (Online)

Geo-environmental Quality Evaluation Based on GIS in Shiyan-Wudang Mountain Area

Bei Wang[1], Xiaomei Wang[1, *], Yongpeng Fu[2], Xueping Li[1], Wen Zhang[1], Yaobang Lu[1]

[1]Faculty of Engineering, China University of Geosciences, Wuhan, China

[2]Geological Survey Center in Wuhan, China Geological Survey, Wuhan, China

Email address:
1577353067@qq.com (Bei Wang), 984829886@qq.com (Xiaomei Wang), 4183896912@qq.com (Yongpeng Fu),
1422332187@qq.com (Xueping Li), 1201820280@cug.edu.cn (Wen Zhang), 450395123@qq.com (Yaobang Lu)
*Corresponding author

To cite this article:
Bei Wang, Xiaomei Wang, Yongpeng Fu, Xueping Li, Wen Zhang, Yaobang Lu. Geo-environmental Quality Evaluation Based on GIS in Shiyan-Wudang Mountain Area. *International Journal of Environmental Protection and Policy*. Vol. 7, No. 2, 2019, pp. 72-79. doi: 10.11648/j.ijepp.20190702.14

Received: April 14, 2019; **Accepted**: May 26, 2019; **Published**: June 15, 2019

Abstract: The Shiyan-Wudang Mountain area is located in the Danjiangkou Reservoir Area, the upper reaches of the Han River, the hinterland of the Qinba Mountain Range. The main geological environmental problems in the region include collapse, landslides, debris flow, ground collapses, and ground fissures, which seriously restrict local economic development. Based on the analysis and summary of the distribution, development characteristics, formation conditions and influencing factors of geological disasters in this area, the multiple comparisons is used to select the formation complex, slope, distance from the fault zone, water yield property, distance from surface water system, average annual rainfall, mountain disaster point density, soil erosion, and human engineering activity intensity as the evaluation indicators, the geological environment quality evaluation index system of Shiyan-Wudang Mountain area was established; Geographic information system (GIS) technology is used to carry out hierarchical management of basic maps, and establish a spatial database of geological environment conditions. The analytic hierarchy process is used to determine the weight of the index system. The evaluation module developed by MapGIS platform is used to evaluate the geological environment quality of the study area. Respectively, the area of geological environment with best quality, good, poor and worst areas accounted for 56.805%, 22.800%, 16.474%, and 3.921%. The results show that the geological environment quality of the study area is generally good, and some areas are poor, and very few are bad. The calculated evaluation map is compared with the current geological disaster points, and the results verify the accuracy and scientificity of the evaluation process and results. The research results of this paper can provide a basis for regional geological environment management, planning, disaster prevention and mitigation.

Keywords: Shiyan City-Wudang Mountain, Geological Environment Quality, Analytic Hierarchy Process, Evaluation

1. Introduction

With the development of human society, the space, scale and complexity of human activities have expanded rapidly at an unprecedented rate, which has largely changed the appearance of the Earth's surface. The imbalance of the relationship between "people and land" has led to a decline in the environmental quality of the lithosphere surface inhabited by humans, frequent occurrence of geological disasters, and significant loss of human life and property [1]. Therefore, it is necessary to evaluate the quality of the geological environment to understand the degree of the regional geological environment, so as to ensure the coordination of urban construction, economic development and geological environment protection.

In recent years, geological environment assessment has developed rapidly and achieved great results. For example, in 2011, Pilz, Marco and so on, taking Santiago, Chile as an example, studied the evaluation of urban seismic conditions and proposed the key factors for the evaluation of geological disasters [1]. In 2015, Jiang X et al. proposed a common comprehensive index method and a new support vector machine (SVM) model, and compared them to evaluate the geological environment quality of mining [2]. Kong C et al. presented an integrated technique using back-propagation neural network (BPNN) and geographic information system (GIS) to assess suitability for agricultural land based on geo-environmental factors in the rural-urban fringe [3]; Chen X et al. used the weights-of-evidence method based on ArcGIS to evaluate the sensitivity of debris flow in Kangding County [4]. In 2017, Du Qian et al. used a combination of Logistic regression and information model to evaluate the landslide susceptibility [5]. NIU Q et al. used Probability Index method, Information Method and Logistic Regression model to study the risk of geological disasters in Lanzhou area [6].

Since geological environment assessment is a comprehensive analysis of complex geological processes, the traditional method is not easy to achieve this process. The GIS technology can be used to simulate spatial geological entities reliably, and the evaluation results are relatively real and reliable [7-14]. In this paper, the analytic hierarchy process is used to determine the weight of the index system, and the evaluation module developed by MapGIS platform is used to evaluate the regional geological environment quality.

2. Overview of the Study Area

2.1. Study Area

The Shiyan-Wudang Mountain area is located in the Danjiangkou Reservoir Area, the upper reaches of the Han River, the hinterland of the Qinba Mountain Range, The study area belongs to northern subtropics monsoon climate region, moderate climate, and distinctive four seasons. the weather in spring and autumn is complex and changeable. The surface water resources are abundant, the river network is dense, and the annual average runoff is 1,151.6 million m^3.

2.2. Engineering Geological Conditions

2.2.1. Topography

The study area is located in the mountainous area of northwest Hubei. It belongs to the eastern extension of the Qinling and Daba Mountains, and the north of the Wudang Mountains. The terrain slopes from south to north. On the whole, the topography in the south is high while in the north is low. The northern part is a low hilly area, and the south is a low mountain area. The statistics of various landform areas (except the water system area) in the study area are shown in Table 1.

Table 1. *Statistical Table of Landform Types in the Study Area.*

Landform type	Database code	Elevation (m)	Area (km^2)	Percentage
Plains	1	<200	118.27	13.94%
hills	2	200~500	549.49	64.95%
Low mountain	3	500~1000	65.4	7.73%
Middle mountain	4	1000~3500	1.53	1.8%

2.2.2. Stratum

The exposed strata in the study area include the Middle-Early Proterozoic Era Wudangshan rock group, the Cretaceous Sigou Formation and the Quaternary loose sediments. The Wudang Mountain Group is a metamorphic volcanic-sedimentary rock system that undergoes a metamorphism in the middle and high-pressure region and a multi-period deformation. The pleats of the inner rock layers are developed. The contact interfaces between different rock layers are mostly composed of early shearing or bedding ductile shear bands, which generally show complex structural stratigraphic stacking characteristics. The rock (structure)-stratigraphic sequence of the study area is shown in Table 2 below:

Table 2. *Rock (structure) - stratigraphic unit sequence table.*

Geological Time			stratigraphic unit			symbol	thickness (m)	description
Era	Period	epoch	Group	Formation	Member			
Cenozoic Era	Quaternary Period	Holocene				Qh^{al}	＞8.0	loam, silty sand and fine sand, gravel
Mesozoic				Sigou Formation	Second Member	Ks^2	＞442	Purple Sand-earth Rock, Fine-sandstone, argillaceous sandstone
					First Member	Ks^1	189.1	Purple Sand-earth Rock, Sandy conglomerate
Proterozoic Era			Wudangshan Group	Third group		PtW_3	＞493	quartz schist
				Second group		PtW_2^2	＞1247	sericite schist

2.2.3. Geological Formation

The study area is located in the Yangtze plate, which belongs to the South Qinling orogenic belt in the geotectonics. The regional structure is located in the central strike-slip shear deformation zone of the Wudang Mountain two-way orogenic belt, consisting of the lower tectonic layer (the middle-early Proterozoic Wudangshan group) and the upper sedimentary caprock (the Late Cretaceous Sigou Formation). There are a large number of Late Proterozoic basic rock beddings. The early lower tectonic layer stretch shear deformation, medium-term thrust nappe shear and strike-slip shear deformation and late extension collapse are the most important tectonic deformation events in the study area. The deformations of each period are superimposed, resulting in the current basic structural contours of the study area: linear strong strain zones (the strike-slip ductile shear zone) and the weakly strained geological bodies sandwiched are regularly arranged in the south-central part. It forms a parallel strip-like structure between strong and weak; the northern part is the

Late Cretaceous red basin structure, whose material composition is mainly a set of sediments with superimposed brittle faults in different directions.

2.2.4. Hydrogeological Conditions

The Shiyan -Wudang Mountain in the study area is mainly characterized by tectonic denudation of low-middle mountains and tectonic denudation of low hilly landforms. The lithology is mainly shallow metamorphic rocks and magmatic rocks, tectonic fractures and weathering fissures are very developed, due to mica schist, quartz schist, etc. It consists of flake minerals and shale components. The weathering is muddy and filled with various cracks, which is not conducive to the infiltration of atmospheric precipitation. Therefore, most of the atmospheric precipitation forms surface runoff and flows into the adjacent valleys, with only a small amount of infiltration. In the underground, fissure water is formed locally, but the amount of water is extremely small.

In the north of the Shiyan fault, along the Maota River, the Weihe River, the Baier River, the Danjiang River and the Tianhu Lake, the floodplain and the I-level terrace loosely deposited. The upper part of the lithology is sub-sand and the local silty clay. The lower part is composed of sand pebbles. The sand pebble layer has good water permeability, and the groundwater changes with the seasons. It is complementary to the river water. At the same time, it accepts the bedrock weathering fissure water and the residual slope layer, and the lateral infiltration of the groundwater in the slope alluvial layer. The water-rich water is relatively good. It is the main aquifer of groundwater in the territory.

3. AHP-based Geological Environment Quality Assessment Steps

Analytic Hierarchy Process (AHP) is a common method in geological environment quality evaluation [15-19]. This paper determines the weight of each evaluation factor by expert scoring, and uses the evaluation module developed by MapGIS platform to make the geological environment quality evaluation result more scientific and reasonable. The steps of geological environmental quality assessment based on AHP are as follows:

3.1. Division of Evaluation Units

The division of the evaluation unit grid mainly includes two types, one is the rule shape division, and the other is the irregular unit division. Generally, the rule unit grid is generally selected for the convenience and speed of computer calculation. However, in practice, there are often some problems in the accuracy of partitioning. For example, when dividing a unit grid, if the mesh is too large, the accuracy of the calculation result will be insufficient. If the meshing is too small, the amount of data will be too large and the calculation will be problematic. When dividing the evaluation unit, refer to the following empirical formula:

$$Gs = 7.49 + 0.0006S - 2\times10^{-9}S^2 + 2.9\times10^{-15}S^3 \quad (1)$$

Where: Gs—the size of the appropriate mesh; S—the denominator of the accuracy of the original data.

3.2. Establish Structure Model and Select Indicators to Determine the Evaluation System

In the geological environment quality evaluation system, there is generally a hierarchical structure. In this paper, the evaluation system is divided into three layers, namely: target layer, criterion layer and indicator layer.

The target layer (A) is the geological environment assessment of the Shiyan-Wudangshan area;

The criterion layer (B) is the nature of the evaluation index selected for the geological environment quality evaluation, such as environmental geological problems, geological conditions, hydrological conditions, etc.;

The index layer (C) is a specific factor that directly affects the evaluation in the evaluation system, such as stratum lithology, rainfall, groundwater enrichment, etc.;

According to the evaluation requirements, the geological environment quality evaluation index system of the study area is reasonably determined.

3.3. Evaluation Index Weight Determination

(1) Establish a judgment matrix $P=(p_{ij})_{n\times n}$. Where p_{ij} is the ratio of the importance of the i-th evaluation factor to the j-th evaluation factor, and its relative importance is determined by the scale method proposed by T.L. Satty [20].

(2) The feature vector and the maximum eigenvector λmax are calculated according to the judgment matrix, and the calculated feature vector is normalized, and the result is the weight value W of the level index.

(3) According to formula (2) and formula (3), the consistency test is performed to verify the rationality of the judgment matrix.

$$CI = (\lambda_{max} - n)/RI \quad (2)$$

$$CR = CI/RI \quad (3)$$

Among them, CI is the consistency index of the judgment matrix; CR is the random consistency ratio of the judgment matrix; RI is the average random consistency index of the judgment matrix, and T.L. Satty gives the value of RI (Table 3).

Table 3. *Mean random consistency index RI.*

Matrix ordern	RI	Matrix ordern	RI
1	0.00	7	1.32
2	0.00	8	1.41
3	0.58	9	1.45
4	0.90	10	1.49
5	1.12	11	1.51
6	1.24		

When CR≤0.10, the judgment matrix meets the requirements;

When CR>0.10, the judgment matrix does not meet the consistency requirement, and the judgment matrix needs to be reconstructed.

Perform a weighting calculation according to the weight value of the calculated index layer (C).

3.4. Evaluation Result Output

Based on the module developed by GIS, the evaluation index layer is superimposed and the scores of each unit are calculated. According to the evaluation model, each cell score is obtained and the geological environment quality is divided. The geological environment quality of the study area is divided into four grades: good, better, poor, and bad.

4. Evaluation of Geological Environment Quality in the Study Area

4.1. Evaluation Cell Division

According to the actual area of the study area, the standard square evaluation unit grid method is used to divide the study area into the same size unit grid. According to the previous empirical formula, the size of the evaluation grid is set to 500m×500m discrete grid units, a total of 3 384 unit grid.

4.2. Geological Environment Evaluation Index System

In this paper, the two-two comparison method is used to screen and optimize the evaluation indicators, and the geological environment quality evaluation index system of the study area is established. as shown in picture 1.

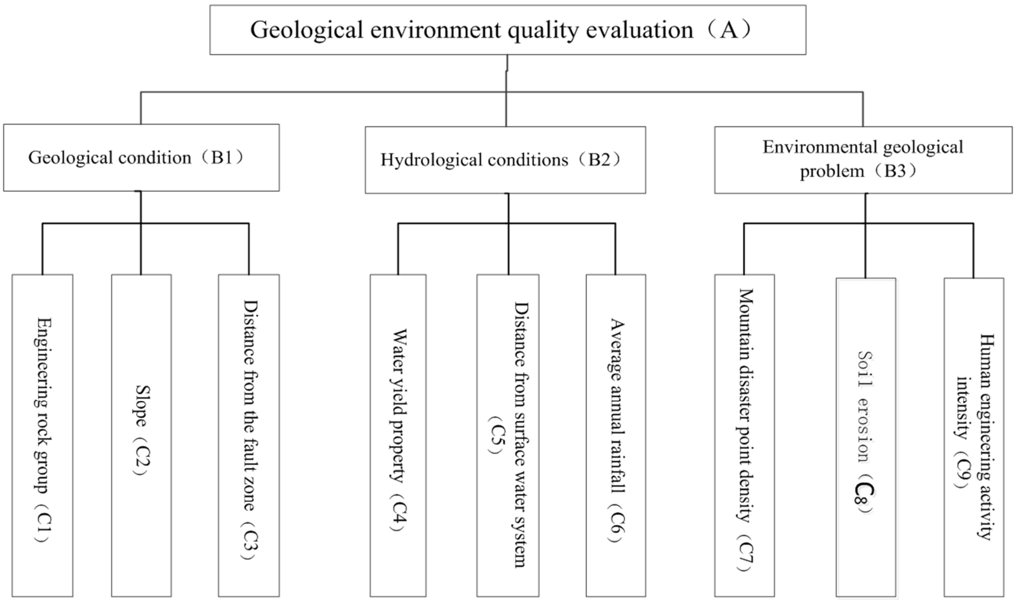

Figure 1. *Geological environment quality evaluation index system diagram.*

4.3. Evaluation Index Quantitative Classification

(1) Engineering rock group indicators

Combined with the exposure of study area, it is divided into four grades according to the rock group factor division: granular igneous rocks, flaky metamorphic rocks, sedimentary clastic rocks, and loose soils.

(2) Slope index

According to the topography and geomorphology conditions of the study area, the slope of each unit grid is used as the evaluation index, and the slope of the study area is divided into four grades: ≤10°, 10°~20°, 20°~30°, ≥30°.

(3) Distance from the fault zone

According to the difference between the cell grid and the fault zone in the study area, the distance factor between the study area and the fault is divided into four grades: ≥5 km, 2-5 km, 0.5-2 km and 0-0.5 km.

(4) Water yield property

According to the water-richness of various strata in the study area, the water yield propertyis divided into four grades: loose soil pore water, clastic rock pore water, bedrock fissure water, and aquifer.

(5) Distance from surface water system

According to the difference of the distance between the unit grid and the surface water system in the study area, the distance factor between the study area and the surface water system is divided into four levels: 0~0.5km, 0.5~2km, 2~5km and ≥5km.

(6) Average annual rainfall

Precipitation is an important factor in causing environmental and geological problems such as soil erosion and geological disasters. Therefore, annual precipitation is also an important factor in geological environmental quality assessment. According to the field survey and precipitation contour map, the spatial distribution of annual precipitation in the study area is divided into four grades of <800mm, 800mm-900mm, 900mm-1000mm, and >1000mm.

(7) Mountain disaster point density index

According to the results of the on-site investigation, the density of disaster points in the study area (that is, the number of disaster points in each evaluation unit grid) is divided into four levels: 0, 0-1, 1-2, > 2 points / 0.25 km^2.

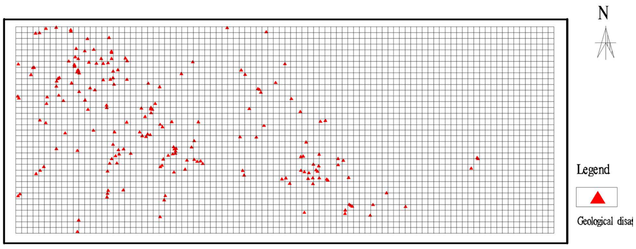

Figure 2. *Density factor map of mountain disaster points in the study area.*

(8) Soil erosion

In the periphery of the study area, there are mostly metamorphic rocks, mudstones, siltstones, etc. The surface of the rock mass is severely weathered, the rock mass is broken, and the weathered layer is loose and easily eroded by surface water bodies such as rainwater. Soil erosion is very common. According to the on-site investigation of the study area, the soil erosion is divided into four categories: non-occurrence, small scale, medium scale and large scale.

(9) Human engineering activity intensity index

Human engineering activities are often accompanied by damage to the geological environment. According to the general situation of the study area, residential areas, mine sites, quarries, and large highways are used as reference objects, and the activity center spreads around to represent the intensity of human activities. The activity intensity is divided into non-occurrence, small scale, medium scale and large scale four levels.

The results of quantifying and grading the evaluation indicators are organized as shown in Table 4.

Table 4. *Classification table of geological environment quality evaluation indicators.*

Factor Quality level	Best	Good	Poor	Worst
Engineering rock group	Granular igneous rock	Flaky metamorphic rock	Sedimentary debris	Loose soil
Slope	≤10°	10°~20°	20°~30°	≥30°
Distance from the fault zone	≥5 km	2~5km	0.5~2km	0~0.5 km
Water yield property	Loose soil pore water	Clastic rock pore water	Bedrock fissure water	Water barrier
Distance from surface water system	0~0.5 km	0.5~2 km	2~5 km	≥5 km
Average annual rainfall (mm)	<800	800~900	900~1000	＞1000
Mountain disaster point density (point/0.25km2)	0	0-1	1-2	＞2
Soil erosion	None	week	strong	stronger
Human engineering activity intensity	None	week	Strong	Stronger

4.4. Evaluation Index Weight Determination

Using the above principles and formulas, determine the judgment matrix (Table 5, Table 6), calculate the weight, and perform consistency test according to formula (2) and formula (3).

Table 5. *Guidelines layer indicator matrix and weights.*

Geological environment quality evaluation (A)	Geological condition (B1)	Hydrological conditions (B2)	Environmental geological problem (B3)	Weight (Wi)
Geological condition (B1)	1	1/2	2	0.2970
Hydrological conditions (B2)	2	1	3	0.5396
Environmental geological problem (B3)	1/2	1/3	1	0.1634
CR=0.0088<0.1 λmax=3.0092				

Judgment matrix consistency test: $CR = 0.0086 < 0.1$, conforms to the consistency test.

Table 6. *Geological conditions B1 - indicator layer matrix and weight.*

Geological condition (B1)	Engineering rock group (C1)	Slope (C2)	Distance from the fault zone (C3)	Weight (Wi)
Engineering rock group (C1)	1	3	3	0.5936
Slope (C2)	1/3	1	1/2	0.1571
Distance from the fault zone (C3)	1/3	2	1	0.2493
CR=0.0516<0.1 λmax=3.0536				

Judgment matrix consistency test: $CR = 0.0516 < 0.1$, conforms to the consistency test.

Similarly, the B_2-C and B_3-C weights are calculated. Finally, the total hierarchical weight of A-C is calculated (Table 7). According to the evaluation factors, the degree of impact on each geological environment is scored separately. The score range is [0,100], where the score of 0 indicates the worst quality for the geological environment, and the score of 100 indicates that the geological environment quality is the best under the grading conditions.

Table 7. *Geological environmental quality assessment - indicator layer weighted comprehensive weight.*

Weight Factor	Geological condition (B1)	Hydrological conditions (B2)	Environmental geological problem (B3)	Comprehensive weight
	0.2970	**0.5396**	**0.1634**	**(i=1,⋯9)**
Engineering rock group (C1)	0.5936			0.1763
Slope (C2)	0.1571			0.0466
Distance from the fault zone (C3)	0.2493			0.0740
Water yield property (C4)		0.5278		0.2848
Distance from surface water system (C5)		0.1396		0.0754
Average annual rainfall (C6)		0.3325		0.1794
Mountain disaster point density (C7)			0.1429	0.0233
Soil erosion (C8)			0.2857	0.0467
Human engineering activity intensity (C9)			0.5714	0.0934

4.5. Results and Discussion

4.5.1. Results

The study area was evaluated according to the geological environment quality evaluation index system. According to the evaluation model, each cell score is obtained, and the comprehensive information threshold of all grids is obtained [0,78]. According to the geological environment quality grades of the previous study area, there are 4 grades of best, good, poor, and worst zones, which are divided into [0,10), [10,30), [30, 50) and [50, 78]. According to the geological environment quality level interval corresponding to the score of each grid, the geological environment quality map of the study area is finally formed. As shown in Table 8, the results of geological environment quality evaluation in the study area are shown in Figure 3.

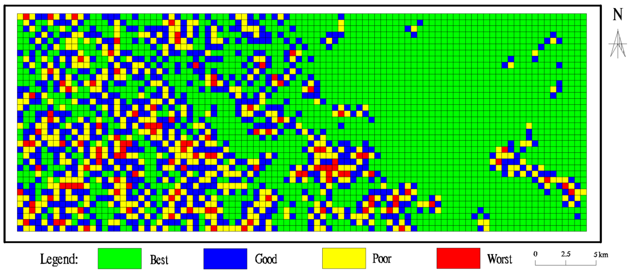

Figure 3. *Results of geological environment quality evaluation in the study area [insert evaluation results on 3D geographic map].*

Table 8. *Grid unit score.*

Interval	Start	End	Environmental quality level	Number of units	Area (km2)	Proportion
1	50	78	best	1 923	480.75	56.805%
2	30	50	good	772	193.00	22.800%
3	10	30	poor	557	139.25	16.474%
4	0	10	worst	132	33.00	3.921%
Total	0	78		3 384	846.00	100 %

(1) Best quality area of geological environment

In the study area, except for the distribution area of some human engineering activities, the rest is a good quality geological environment, mainly distributed around the Wudang Mountain Scenic Areas. The sub-area covers an area of approximately 480.75km2, accounting for approximately 56.805% of the study area. The area is mainly far from the fault and is a plain and a hill area. The rainfall is less, the groundwater enrichment level is lower, the geological disasters are less, and the phenomenon of soil erosion is less obvious, and the geological environment is of better quality.

(2) Good quality area of geological environment

The areas with good geological environment quality are mainly distributed near the rivers in the study area and the weaker areas of human engineering activities, mainly distributed around Dachuan Town and Maota Town. The sub-area covers an area of approximately 193 km2, accounting for approximately 22.8% of the study area. Compared with the geological environment poor area and bad area, the slopes are slower, the height difference is smaller, the mountain disasters are less, relatively safe and far from the fault zone, and the groundwater is rich. Therefore, it is divided into areas with good geological environment quality.

(3) Poor geological environment quality area

The poor geological environment is mainly distributed in hilly and low-mountain areas and areas with strong human engineering activities. At the same time, The water yield property level is mainly Class III, with a large amount of rainfall. It is located in the vicinity of the main fault zone and in areas with strong human activities. The sub-area covers an area of approximately 139.25 km^2, accounting for approximately 16.474% of the study area.

(4) Worst geological environment quality

The geological environment with poor quality in the study area is mainly located at geological disaster points and fault zones as well as areas with strong human engineering activities. The sub-area covers an area of approximately 33 km2, accounting for approximately 3.921% of the study area. There are many large faults in this area, the geological background conditions are relatively complicated, and the possibility of mountain disasters is relatively large. Rainfall and human activities are one of the main factors inducing mountain disasters.

(5) Geological environment quality assessment division and geological disaster point verification

The geological environment quality sub-area obtained by the GIS evaluation module is compared with the mountain geological hazard point to verify whether the evaluation process is correct, as shown in Table 9 below:

Table 9. *Geological disaster point verification table.*

	Number of grids	Number of disaster points	Proportion
Best area	1 923	0	0
Good area	772	2	0.01%
Poor area	557	42	22.22%
Worst area	132	147	77.77%
Total	3 384	189	100%

It can be obtained from Table 8 above that there are 147 mountain geological disasters in the bad area, accounting for 77.77% of all geological disaster points; The number of geological disasters in the geological environment with poor quality is 42, accounting for 22.22% of the total number of geological disasters; only 2 disaster points fall in the good geological environment, accounting for 0.01%; there are no geological disaster points in the geological environment with better quality. By comparing with the disaster points in the field geological survey, it can be concluded that the evaluation process and results are reasonable and meet the requirements of geological environment quality evaluation.

4.5.2. Discussion

Geological environment quality evaluation has experienced a process from qualitative to semi-quantitative. The evaluation methods mainly include traditional qualitative analysis method, neural network analysis method and geographic information system. However, traditional qualitative evaluation methods cannot carry out a complex geological process. Comprehensive comprehensive analysis of multiple information can not reveal the quality of geological environment. For neural network model analysis, the selection of training sample database is very important, which is directly related to the accuracy of our evaluation results. Due to data data limitations, The sample data is not easy to obtain; for the GIS method, we use the GIS platform to construct a quantitative evaluation model and a weighted model to quantitatively evaluate the geological environment, which can simulate the spatial geological entity very intuitively. Based on the above analysis, we choose the GIS method as our evaluation method.

5. Conclusions and Recommendations

5.1. Conclusions

The membership degrees of the Best, good, poor and worst areas in the geological environment evaluation of the study area were 56.805%, 22.800%, 16.474%, and 3.921%, respectively. Through the GIS technology, the data of the research area evaluation index was built. Based on the evaluation module of MapGIS, the geological environment quality map of the study area is obtained. According to the geological environment quality map, the best area accounts for 1,923 unit grids, the good area has 772 grids, and the poor area has 557 grids. There are 132 grids in the worst area; the geological environment quality assessment area map is compared with the geological disaster points of the field field investigation, and the results verify that the evaluation process and results are accurate and scientific. The evaluation results generally indicate that the geological environment quality in the study area is generally good.

5.2. Recommendations

The verification of the evaluation results is mainly based on the degree of coincidence between the distribution of disaster points and the evaluation results, which can reflect the rationality of the evaluation results to some extent. However, due to data limitations, the type and scale of the disasters are not considered in this evaluation. In the subsequent research, it is possible to consider the nature of the type of disaster, and assign different weights to each disaster point according to certain criteria, so as to reflect the attributes of the disaster point itself, so that the evaluation results can be better tested.

References

[1] Pilz M, Parolai S, Picozzi M, Zschau J. Evaluation of proxies for seismic site conditions in large urban areas: The example of Santiago de Chile [J]. Physics and Chemistry of the Earth 2011 36 (16): 1259-1266.

[2] Jiang X, Lu W, Zhao H, et al. Quantitative evaluation of mining geo-environmental quality in Northeast China: comprehensive index method and support vector machine models [J]. Environmental earth sciences, 2015, 73 (12): 7945-7955.

[3] Kong C, Lan H, Yang G, et al. Geo-environmental suitability assessment for agricultural land in the rural–urban fringe using BPNN and GIS: a case study of Hangzhou [J]. Environmental Earth Sciences, 2016, 75 (15): 1136.

[4] Chen X, Chen H, You Y, et al. Weights-of-evidence method based on GIS for assessing susceptibility to debris flows in Kangding County, Sichuan Province, China [J]. Environmental Earth Sciences, 2016, 75 (1): 70.

[5] Du Qian F W, Kai L. Geohazard susceptibility assessment by using binary logical regression and Information value model [J]. Journal of Catastrophology, 2017, 32 (2): 220-226.

[6] NIU Q, FENG Z, ZHANG Y, et al. Susceptibility Assessment of Disaster Environment for Landslide Hazard based on GIS in Lanzhou Area [J]. Journal of Catastrophology, 2017 (3): 6.

[7] Zheng, M., S. Niu and H. Zheng, A GIS-based Research on Triggering Factors of Erosive Landslide and Collapse in Yanhe River Basin. 2016. 36 (2): p. 156-160.

[8] Meng, X., et al., GIS-Based susceptibility assessment of geological hazards along the road from Dujiangyan to Wenchuan by factor analysis. 2016. 27 (3): p. 106-115.

[9] Shi, C., X. Lu and Z. Liu, GIS-based zoning of geological hazards susceptibility in Huizhou district of Huangshan city of Anhui province. 2016. 27 (1): p. 136-140.

[10] Niu, Q., et al., Susceptibility Assessment of Disaster Environment for Landslide Hazard based on GIS in Lanzhou Area. 2017. 32 (3): p. 29-35.

[11] Zheng, M., S. Niu and H. Zheng, A GIS-based Research on Triggering Factors of Erosive Landslide and Collapse in Yanhe River Basin. 2016. 36 (2): p. 156-160.

[12] Zhao, B., et al., GIS analysis on seismic geological disasters susceptibility of Wenchuan. 2013. 38 (6): p. 70-72.

[13] Meng, X., et al., GIS-Based susceptibility assessment of geological hazards along the road from Dujiangyan to Wenchuan by factor analysis. 2016. 27 (3): p. 106-115.

[14] Wang, N., et al., Quantitative evaluation of geological disaster liability based on RS & GIS analysis: A case study of Wufeng County, Hubei Province. 2012. 19 (6): p. 221-229.

[15] Kazakis N, Kougias I, Patsialis T. Assessment of flood hazard areas at a regional scale using an index-based approach and Analytical Hierarchy Process: Application in Rhodope–Evros region, Greece [J]. Science of the Total Environment, 2015, 538: 555-563.

[16] Sahoo S, Dhar A, Kar A. Environmental vulnerability assessment using Grey Analytic Hierarchy Process based model [J]. Environmental Impact Assessment Review, 2016, 56: 145-154.

[17] Fan W, Wei X, Cao Y, et al. Landslide susceptibility assessment using the certainty factor and analytic hierarchy process [J]. Journal of Mountain Science, 2017, 14 (5): 906-925.

[18] Wang X, Wang T, Wang Q, et al. Evaluation of floor water inrush based on fractal theory and an improved analytic hierarchy process [J]. Mine Water and the Environment, 2017, 36 (1): 87-95.

[19] Lyu H M, Shen J, Arulrajah A. Assessment of geohazards and preventative countermeasures using AHP incorporated with GIS in Lanzhou, China [J]. Sustainability, 2018, 10 (2): 304.

[20] Saaty T L. The analytical hierarchy process. New York: Mc Craw-Hill, 1980: 30—75.