Research on Surface Debris Flow Sensitivity Evaluation Based on RS and GIS

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Abstract. Sensitivity analysis about small watershed is an important way to objectively understand the development characteristics of debris flow ditches. With the support of Remote Sensing and Geographic Information System technologies, Dongchuan County with frequent debris flow development in Kunming, Yunnan Province, southwest China was selected as the research object, the Landsat image and Digital Elevation Model were used to interpret the small watersheds on both sides of the Xiaojiang River. By selecting four indicators of fault zone, slope, gully density and land use as the impact factors, the sensitivity coefficients were quantitatively calculated. The following research results were obtained: The distribution feature of debris flow small watersheds was that, the Dongchuan fault zone was the axis which small watersheds were symmetrically distributed on; the sensitivity of the Dongchuan fault zone was the highest in the buffer distance of 5-10 km, which was prone to debris flow disasters; the debris flow was most sensitive in the slope range of 40°-50°; the debris flow was most sensitive to the gully density of 0.6-0.9 km/km² with broken surface; three types of land use such as bare land, water and construction land had high sensitivity coefficient and were easy to cause mountain disasters. According to the sensitivity coefficients of the above impact factors, the stacking method superposition analysis was carried out to obtain the sensitivity distribution of debris flow disasters in Dongchuan County. The medium sensitive area accounted for 53.84% of the total area, and the high sensitive area accounted for 27.02% of the total area. The medium sensitive area and the high sensitive area were the main areas where debris flow occurred. This study has certain reference significance for disaster prevention, soil and water conservation by quantitative calculation and comparison of debris flow disaster sensitivity.

Keywords. Debris flow, sensitivity, fault zone, slope, gully density, land use, Dongchuan County

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1. Introduction

China is a country with frequent debris flow disasters, and the occurrence frequency of debris flow disasters is higher in the southwest region due to the influence of geological structure. The Xiaojiang debris flow in Yunnan Province is a typical representative of debris flow in the southwestern mountainous area. The strong debris flow activity not only brought huge losses to the local people, but also destroyed the local ecological environment. It is known as the “Debris Flow Museum” in China, even in the world. According to statistics, since the 1950s, more than 300 people have been killed or injured in Dongchuan County due to debris flow, and the direct economic loss has reached more than 370 million yuan [1]. With the rapid development of RS and GIS technology and the rise of aerospace technology, the data sources for debris flow disaster investigation are extensive, and the data accuracy is greatly improved. Due to the continuous research on debris flow disasters by scholars from all over the world, human beings have a deeper understanding of the sensitivity of debris flow.

Sensitivity is defined as the magnitude and speed of changes in the system's internal response to external stimuli when the system encounters interference from other factors. It is an objectively existing property originating from the inside of the system which is used to describe that changes in one part of the system accumulate to a certain amount, causing other parts to burst into huge energy. This property only manifests when the system is perturbed [2]. Many scholars have conducted relevant investigations and studies on the sensitivity of mountain disasters. In 2004, Tang Chuan combined GIS spatial analysis technology and conditional probability model to evaluate the sensitivity of debris flow in the Nujiang River Basin in Yunnan Province [3]. In 2005, He Yiping selected the Xiaojiang River Basin as the research area, and calculated the secondary land types sensitivity on different slope grades to collapse, landslide and debris flow disasters [4]. In 2011, Tangchuan team applied the Strahler area-elevation analysis method, and used the principle of geomorphological information entropy combined with the geomorphological development stage to classify the sensitivity of 209 sub-basins in the Wenchuan area [5]. In 2015, Ding Mingtao improved the sensitivity model according to the probability statistical model and the seasonality of remote sensing images, and revised the model parameters in autumn and winter [6]. At the same time, on the basis of the sensitivity of debris flow, Shi Mingyuan fully considered the disaster-causing factors of torrents in Beijing Mountains, divided the comprehensive evaluation grades by K-means clustering method [7]. On this basis, Ruan Yunkai introduced the relative difference function in variable fuzzy theory, and selected 7 influencing factors to evaluate the sensitivity of 11 debris flow trenches in Chifeng City [8]. Ni Shubin calculated point sensitivity calculations for three types of mountain disasters such as collapse, landslide and debris flow, and obtained the sensitivity distribution map of the three types of disasters in Beijing mountainous areas [9]. Throughout the research on debris flow sensitivity, the focus is on the selection of mathematical models and variation factors [3-17].

After comprehensively considering the geological characteristics of the Dongchuan area of the Xiaojiang River Basin, this paper uses Landsat images and DEM data to divide the spatial distribution of each small watershed, and the sensitivity calculation model was used to calculate the debris flow disasters sensitivity by adopting four influencing factors such as fault zone, slope, gully density and land use. The purpose of this study is to further understand the distribution law of debris flow in Dongchuan County, and to provide a basis for reducing disaster losses and rationally planning land.

2. Data and Methods

2.1. Study Area

Xiaojiang, which is a first-class tributary of the Jinsha River, is located in the northeastern part of Yunnan Province. It originated from the Yunnan-Guizhou Plateau and flows from south to north.
into the Jinsha River. Xiaojiang is a typical structural river valley with deep dissection. It has towering peaks and deep valleys. Most of mountains are at an altitude of 2000-3000 m above sea level. The small watershed is a tributary gully formed by special geological structure on both sides of Xiaojiang River. Xiaojiang has a total length of 141.9 km, a basin area of about 344.3 km², and a natural drop of about 2860 m. There are many gullies in the basin, and the distribution density of debris flow gully is 37.8 pieces/1000 km², which is a famous area with frequent debris flow outbreaks [18]. The Xiaojiang main fault zone runs through the entire Dongchuan County from north to south, which has a great impact on the formation of debris flows in Dongchuan County.

Dongchuan County is located at the northern of Kunming City, Yunnan Province, at 102°47′-103°20′E and 25°42′-26°31′N. The highest elevation in Dongchuan County is 4282 m, the lowest is 658 m, and the elevation difference is 3624 m, which total area is about 2023 km² [18]. The geographical location of Dongchuan County is shown in Figure 1.

2.2. Data source and Preprocessing

Land use types were interpreted using Landsat8 OLI multispectral remote sensing images in March 2018. First, geometric correction was performed, and then the panchromatic band and the multispectral band were fused, and the resolution was increased from 30 meters to 15 meters. After that, spectral enhancement processing was performed, and the spectral enhancement feature processing method adopted was principal component analysis (PCA). The processed images were rich in ground objects, which is conducive to the interpretation of ground information.

The 30-meter DEM was used for elevation processing, and the spatial reference coordinate system was set to the WGS_84 projection coordinate system, which provided basic data for extracting the river network and calculating the slope of the small watershed.

2.3. Research Methods

Firstly, the Landsat8 OLI remote sensing image combined with DEM was used to interpret the small watershed in the Dongchuan County, and the area of the debris flow was counted. The sensitivity calculation model was used to quantify the sensitivity of debris flow disasters to internal factors such as fault zones, slopes, gully density, and land use. Finally, the spatial distribution of sensitivity was obtained by using the layer overlay model.

The paper selected Dongchuan County as the study area, and adopted the area analysis method after considering the debris flow disaster as a planar disaster. The sensitivity calculation model is as follows:

$$ SC_i = \ln \frac{N_i/A_i}{N/A} $$

where $SC_i$ is the sensitivity value of debris flow disaster under the influence of the i-th type of factors; $N_i$ is the area of debris flow under the influence of the i-th factors; $N$ is the total area of debris flow; $A_i$ is the total area of the region under the influence of the i-th factors; $A$ is the total area of the region. The larger the value of $SC_i$, the higher the sensitivity, and the easier it is to lead to the occurrence of debris flow disasters.
3. Results analysis

3.1. Spatial Distribution of Small Watersheds

As shown in Figure 2, it was interpreted that there were 61 small debris flow watersheds in Dongchuan County by referring to Landsat8 OLI remote sensing images, DEM and river data vector. The total area of these watersheds was 745.58 km², accounting for 36.85% of the total area of Dongchuan County.

The small watershed in Dongchuan were mainly distributed on both sides of the Xiaojiang River Valley and the right bank of the Jinsha River. The main feature was that the Dongchuan fault zone was the axis, which was symmetrically distributed on both sides of the Xiaojiang River Valley in a string-like distribution. There were 61 watersheds in total, which were widely distributed. The development of debris flow in the upper reaches of the Xiaojiang River was strong and the area was widely distributed, while the development of debris flow in the area where the Jinsha River meet the mouth of the Xiaojiang River was weak and the area was small.

3.2. Buffer Zone of Fault Zone and Sensitivity

As far as plate tectonics is concerned, Yunnan Province is located at the junction of the Eurasian plate and the Indian Ocean plate, with frequent geological activities. Fault zones play an important role in controlling the development of debris flow disasters. There are seven major fault zones in Yunnan and the Xiaojiang fault zone is one of the areas where serious mountain disasters break out. The Xiaojiang fault zone starts from Qiaojiang County in the north, whose total length from north to south is about 500 km. Affected by this, debris flow disasters occurred frequently in the Dongchuan area, causing serious losses in history [1]. In this study, the fault zone of Xiaojiang in Dongchuan was selected as the index. For the convenience of distinguishing, this section was called "Dongchuan fault zone". Centered on Dongchuan fault zone, buffer zones were established at equidistant intervals of 5 km until the entire Dongchuan area was covered. Statistics on the distribution of debris flow hazards among different buffer zones were shown in Figure 3.
The total area of debris flow in Dongchuan County was 745.58 km$^2$. It can be seen from Figure 3, Figure 4 and Table 1 that 38.94% of the debris flows were distributed in the range of 0-5 km from the Dongchuan fault zone, and nearly 76.73% of the debris flow were distributed in the buffer distance of 0-10 km from the Dongchuan fault zone. The area of debris flow decreased sharply within 10-15 km. The buffer distance of 35 km covered the entire Dongchuan County and the distribution of debris flow gradually decreased with the distance increased. It can be seen that the geological activities of the fault zone provided extremely favorable conditions for the development and formation of debris flow. The closer the distance to the fault zone, the stronger the geological tectonic activity, and the easier it was to form debris flow.

According to the sensitivity calculation model, the sensitivity coefficients in different buffer distance were calculated. The sensitivity coefficient of debris flow was positive in the areas 0-5 km and 5-10 km away from the Dongchuan fault zone, which were 0.14 and 0.32 respectively. In the areas of 10-15 km, 15-20 km, 20-25 km, 25-30 km, and 30-35 km, all $S_C$ were negative, which showed that the fault zone had no significant influence on the debris flow disaster in this interval. In general, the sensitivity of debris flow disasters to the buffer distance of the fault zone was like that: 5-10 km > 0-5 km > 25-30 km > 10-15 km > 20-25 km > 15-20 km > 30-35 km.

![Figure 3](image3.png)

**Figure 3.** The relationship between the area and percentage and the buffer distance of the fault zone.

![Figure 4](image4.png)

**Figure 4.** Schematic diagram of buffer distance and debris flow small watershed.
Table 1. Disaster sensitivity coefficient of different buffer distance

<table>
<thead>
<tr>
<th>Buffer distance (km)</th>
<th>0-5</th>
<th>5-10</th>
<th>10-15</th>
<th>15-20</th>
<th>20-25</th>
<th>25-30</th>
<th>30-35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Debris flow density (km$^2$/km$^2$)</td>
<td>0.42</td>
<td>0.51</td>
<td>0.26</td>
<td>0.16</td>
<td>0.21</td>
<td>0.28</td>
<td>0.06</td>
</tr>
<tr>
<td>Sensitivity coefficients</td>
<td>0.14</td>
<td>0.32</td>
<td>-0.34</td>
<td>-0.82</td>
<td>-0.56</td>
<td>-0.27</td>
<td>-1.90</td>
</tr>
</tbody>
</table>

3.3. Slope and sensitivity

Slope provides potential energy for provenance area and precipitation, and it is an important dynamic factor affecting the development and formation of debris flow. Under normal circumstances, within a certain range, the steeper the slope, the easier it is for loose solid materials to slide down under the influence of gravity, and the probability of landslides will increase. Therefore, it is one of the important indicators affecting sensitivity. The distribution of debris flow with different slope grades was counted, and the sensitivity coefficient shall be calculated.

It can be seen from Figure 5, Figure 6 and Table 2 that 27.67% of debris flows were distributed in the slope range of 30°-40°, and 25.90% of debris flows were distributed in the slope range of 20°-30°. With the increase of slope, the distribution area of debris flow showed a trend of increasing firstly and then decreasing. Therefore, the development and formation of debris flow required certain topographic conditions, and the slope conditions of 30°-40° were conducive to the development of debris flow. Generally speaking, the greater the slope of the ditch bed, the more favorable it is for the formation and movement of debris flow. However, if the slope exceeds a certain limit, it is not conducive to the accumulation of loose solid matter. Therefore, a suitable slope is an important dynamic condition for the formation of debris flow. With the increase of slope, the density of debris flow also showed a trend of increasing firstly and then decreasing. The debris flow density was the largest in the slope range of 40°-50°, which was 0.57 km$^2$/km$^2$. Followed by the slope range of 30°-40°, and the debris flow density was 0.45 km$^2$/km$^2$.

The sensitivity coefficient results were basically consistent with the density distribution of debris flow, and the sensitivity coefficient was the largest in the slope range of 40°-50°, which was 0.44, followed by 30°-40° and greater than 50°. In the slope range of 0°-10°, 10°-20°, and 20°-30°, the sensitivity of debris flow to slope was weak, and the sensitivity coefficient was negative, which are -0.32, -0.31, and -0.05, respectively. In general, the sensitivity of debris flow to slope was 40°-50°>30°-40°> greater than 50°> 20°-30°>10°-20°>0°.

Figure 5. The relationship between the area and percentage of debris flow and the slope.
Table 2. Disaster sensitivity coefficient of different slope

<table>
<thead>
<tr>
<th>Slope</th>
<th>0°-10°</th>
<th>10°-20°</th>
<th>20°-30°</th>
<th>30°-40°</th>
<th>40°-50°</th>
<th>&gt;50°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Debris flow density (km²/km²)</td>
<td>0.27</td>
<td>0.27</td>
<td>0.35</td>
<td>0.45</td>
<td>0.57</td>
<td>0.42</td>
</tr>
<tr>
<td>Sensitivity coefficients</td>
<td>-0.32</td>
<td>-0.31</td>
<td>-0.05</td>
<td>0.21</td>
<td>0.44</td>
<td>0.13</td>
</tr>
</tbody>
</table>

3.4. Gully density and sensitivity

Gully density is the total length of gullies in unit area, which is used to describe the degree of ground fragmentation by watercourses and reflects the characteristics of surface runoff. The value of the gully density is related to the vegetation, slope, soil, lithology and other factors in the small watershed. The gully density is an important index in the hydrological analysis, which can reflect the soil erosion to a certain extent, and is an indispensable index in the research on the sensitivity of debris flow disasters [19]. The research area was divided into 10 km × 10 km cells by using the fishnet function, so as to calculate the gully density in each cell. Finally, the gully density in each cell was calculated using the gully density model.

\[
\text{Gully density (km/km²) = Gully length(km) / Sample area(km²)}
\]  

(2)

It can be seen from Figure 7, Figure 8 and Table 3 that 86.48% of the debris flows were distributed in the area with a gully density of 0.6-0.9 km/km², while the distribution of debris flow in other areas was very few, and the percentage of debris flows was distributed in a mountain peak. It can be seen that too small or too large gully density was not conducive to the formation and occurrence of debris flow. If the gully density was too small, there will be a lack of hydrodynamic factors. If the gully density was too large, the soil erosion will be serious, which was not conducive to the accumulation of provenance. The distribution of debris flow density was similar to the percentage distribution.

In the gully density range of 0.6-0.9 km/km², the sensitivity coefficient was the largest, which was 0.07. The sensitivity coefficient gradually decreased from the middle to both sides. All of them except the range of 0.6-0.9 km/km² were negative, showing a normal distribution trend. In general, the sensitivity of debris flow to gully density was 0.6-0.9 km/km² > 0.9-1.2 km/km² > 0.3-0.6 km/km² > greater than 1.2 km/km² > 0-0.3 km/km².
Figure 7. The relationship between the area and percentage of debris flow and the gully density.

Table 3. Disaster sensitivity coefficient of different gully density

<table>
<thead>
<tr>
<th>Gully density (km/km²)</th>
<th>0-0.3</th>
<th>0.3-0.6</th>
<th>0.6-0.9</th>
<th>0.9-1.2</th>
<th>&gt;1.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Debris flow density (km²/km²)</td>
<td>0.00</td>
<td>0.26</td>
<td>0.40</td>
<td>0.27</td>
<td>0.21</td>
</tr>
<tr>
<td>Sensitivity coefficients</td>
<td>-6.61</td>
<td>-0.33</td>
<td>0.07</td>
<td>-0.30</td>
<td>-0.55</td>
</tr>
</tbody>
</table>

3.5. Land use and sensitivity

The unreasonable way of human land use aggravates the sensitivity of debris flow disasters. Land use is an important factor affecting the sensitivity [4,19,20]. Principal Component Analysis (PCA) can obtain components from large to small signal-to-noise ratios after orthogonal linear transformation, and the first few components can be used to represent the original image. The basic
idea is to keep the original information as much as possible. Through principal component analysis, the difference between ground objects is enhanced, which is beneficial to the classification.

Support vector machine (SVM) is a classifier in supervised classification. It is a machine learning method based on statistical learning theory which can automatically find those support vectors that have greater discriminating ability for classification. According to that, SVM has better classification accuracy. In recent years, support vector machine classification has achieved remarkable results in change monitoring, urban expansion, landscape change due to its high classification accuracy. Therefore, this paper used SVM classification method based on PCA processing to classify Dongchuan County. Due to the small width of the river, it was difficult to extract the boundary accurately, so the river was extracted by visual interpretation method. According to the classification result, there were six main types of land in Dongchuan. The largest area of grassland was 725.42 km$^2$, accounting for 35.86% of the overall area, followed by forest land, accounting for 32.01%. The area of water area was the smallest, accounting for only 15.83 km$^2$. The area statistics of each category were shown in Table 4. The distribution of debris flow in different land use types was counted, and the sensitivity coefficient was also calculated.

It can be seen from Figure 9, Figure 10 and Table 5 that 33.74% of the debris flows in Dongchuan were distributed in grassland, accounting for the highest proportion, while only 1.14% of the debris flows were distributed in water, accounting for the lowest proportion. However, the density of debris flow in bare land and water area was very high. The density of debris flow in cultivated land was the lowest, which was 0.28 km$^{-2}$/km$^2$. As far as the sensitivity coefficient was concerned, the sensitivity coefficient of bare land was the largest, which was 0.39. The sensitivity coefficients of cultivated land, forest land, and grassland were negative, so the impact on disasters was not obvious. In general, the sensitivity of debris flow disasters to land use types was as follows: bare land > water > construction land > grassland > forest land > cultivated land.

### 3.6. Spatial distribution of sensitivity

According to the above sensitivity coefficient results, the layer overlay model was used to conduct overlay analysis [21-24] to evaluate disaster sensitivity. The four indicators of fault zone distance, slope, gully density and land use were selected as evaluation factors [25]. The elements were transformed into grids, and the values were assigned according to the importance degree of the nine-bit scale matrix by using the principle of analytic hierarchy process. The weights of the four indicators were determined to be 0.4230, 0.2274, 0.2274 and 0.1222 respectively, $\lambda_{max} = 4.0104, CR = 0.0035 < 0.1$, which passed the consistency test [26-28]. According to the sensitivity coefficient of each factor, the quantitative score of the evaluation unit was calculated by weighted iterative calculation, as shown in Table 6, so as to carried out the sensitivity evaluation of the small watershed of debris flow, and finally obtained the sensitivity zone of debris flow in the Dongchuan. The results were reclassified into 6 grades: extremely insensitive, insensitive, mildly sensitive, moderately sensitive, highly sensitive, and severely sensitive. Due to the low overall sensitivity coefficient of gully density, the quantitative score was 1-5.

According to Figure 11 and Table 7, the entire study area was divided into six areas: extremely insensitive, insensitive, mildly sensitive, moderately sensitive, highly sensitive, and severely sensitive. 53.84% of Dongchuan County was moderately sensitive area, mainly distributed in Jiangjiaigou, Dabainigou and Dongchuan urban area, 10-15 km away from the left bank of Xiaojiang River; 27.02% of the area was highly sensitive area, mainly distributed in the small watershed within 0-10 km on both sides of the Xiaojiang River. Tuobuka Town, Tangdan Town, Houshan, Dabainigou and Xiaobainigou in Dongchuan City were all highly sensitive, which protection and management should be strengthened.
Figure 9. The relationship between the area and percentage of debris flow and the land use.

Table 4. Area statistics of different land use types

<table>
<thead>
<tr>
<th>Land use</th>
<th>Bare land</th>
<th>Cultivated land</th>
<th>Forest land</th>
<th>Grassland</th>
<th>Building land</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (km²)</td>
<td>315.08</td>
<td>247.03</td>
<td>647.72</td>
<td>725.42</td>
<td>72.27</td>
<td>15.83</td>
</tr>
<tr>
<td>Percentage</td>
<td>15.57%</td>
<td>12.21%</td>
<td>32.01%</td>
<td>35.86%</td>
<td>3.57%</td>
<td>0.78%</td>
</tr>
</tbody>
</table>

Table 5. Disaster sensitivity coefficient of different land use

<table>
<thead>
<tr>
<th>Land use</th>
<th>Bare land</th>
<th>Cultivated land</th>
<th>Forest land</th>
<th>Grassland</th>
<th>Building land</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Debris flow density (km²/km²)</td>
<td>0.54</td>
<td>0.28</td>
<td>0.33</td>
<td>0.35</td>
<td>0.42</td>
<td>0.54</td>
</tr>
<tr>
<td>Sensitivity coefficients</td>
<td>0.39</td>
<td>-0.29</td>
<td>-0.10</td>
<td>-0.06</td>
<td>0.12</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Table 6. Quantitative scores and weights of each evaluation index

<table>
<thead>
<tr>
<th>Indexes</th>
<th>Quantitative scores</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buffer distance of fault zone (km)</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>5-10</td>
<td>0-5</td>
<td>10-15, 25-30</td>
</tr>
<tr>
<td>Slope (°)</td>
<td>0-10°</td>
<td>10°-20°</td>
</tr>
<tr>
<td>Gully density (km/km²)</td>
<td>0-0.3</td>
<td>&gt;1.2</td>
</tr>
<tr>
<td>Land use</td>
<td>Bare land</td>
<td>Cultivated land</td>
</tr>
</tbody>
</table>

Table 7. Sensitivity grading result

<table>
<thead>
<tr>
<th>Partition</th>
<th>Area (km²)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely insensitive</td>
<td>2.27</td>
<td>0.11%</td>
</tr>
<tr>
<td>Insensitive</td>
<td>26.99</td>
<td>1.33%</td>
</tr>
<tr>
<td>Mildly sensitive</td>
<td>325.88</td>
<td>16.11%</td>
</tr>
<tr>
<td>Moderately sensitive</td>
<td>1089.37</td>
<td>53.84%</td>
</tr>
<tr>
<td>Highly sensitive</td>
<td>546.67</td>
<td>27.02%</td>
</tr>
<tr>
<td>Severely sensitive</td>
<td>32.16</td>
<td>1.59%</td>
</tr>
</tbody>
</table>
4. Conclusions

This study comprehensively used RS and GIS technology to explore the spatial distribution characteristics of the small watershed of the Dongchuan debris flow, and the sensitivity coefficients of four types of indicators was calculated with the sensitivity model. Corresponding conclusions were drawn from the research:

(1) The small watershed in Dongchuan were mainly distributed on both sides of the Xiaojiang River Valley and the right bank of the Jinsha River, and there were more on both sides of the Xiaojiang River Valley. The main feature was that the Dongchuan fault zone was the axis, which was symmetrically distributed on both sides of the Xiaojiang River Valley in a string-like distribution.

(2) The sensitivity of debris flow to the fault zone was that: 5-10 km > 0-5 km > 25-30 km > 10-15 km > 20-25 km > 15-20 km > 30-35 km; The sensitivity of different slopes was 40°-50°>30°-40°> greater than 50°> 20°-30°>10°-20°>0°-10°; The sensitivity of gully density was 0.6-0.9 km/km² > 0.9-1.2 km/km² > 0.3-0.6 km/km² > 1.2 km/km² above > 0-0.3 km/km²; The sensitivity of land use was that: bare land>water>construction land>barren grassland>forest land>cultivated land.

(3) According to the sensitivity level, the moderately sensitive area accounted for 53.84% of the total area, and the highly sensitive area accounted for 27.02%.

(4) This study used the former sensitivity calculation model to evaluate the sensitivity of small watersheds only through four types of indicators. The selected indicators were simple and limited. In the future research, the calculation model should be improved according to the actual environment, and more index factors reflecting the internal characteristics of the system such as lithology and geological structure should be introduced to improve the accuracy of the evaluation.

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