Abstract

Debris flow is a serious disaster that frequently happens in Sichuan province China. The relationship between precipitation and debris flow is one of the important components of prediction research. We chose the geographic information system (GIS) as a tool to estimate the precipitation of hazard point and used statistical techniques to calculate attenuation coefficient of effective antecedent precipitation. With such methodologies, the logistic regression model was used to comparatively analyze the contribution rate of two types precipitation combination: 1) intraday rainfall and 10-day previous rainfall, 2) intraday rainfall and effective antecedent rainfall. Our results indicate that the contribution rate of intraday rainfall is the highest and that the category coincidence rate of second type precipitation is 3% higher than the first.

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Keywords: debris flow; logistic regression; attenuation coefficient; effective antecedent rainfall

1. Introduction

Debris flow is a sudden natural hazard which is caused by precipitation and a large volume of loose debris torrent solid in valley. The precipitation is an important factor for debris flow. It provides a trigger condition and acts as transport media.
Previously, researches about relationship between precipitation and debris flow have been conducted, but the study areas mainly focused on small watershed and the prefecture-level cities, such as Ganzi, Liangshan, and Ya’an. The time span for such studies was as short as 10 years or below. Therefore, there have been insufficient information for analysis. Furthermore, the relation studies were conducted basing on sample statistical and qualitative descriptions [1-3] and researches method focused mostly on critical rainfall calculating. The conclusion of these researches is that debris flow was triggered by critical rainfall when it reached a certain value [4-6]. However, except for intraday rainfall, the occurrence of a hazard still depends on the antecedent precipitation. And because of the surface runoff, wind and other factors, antecedent precipitation would reduce along with time. So far, some researchers have calculated the attenuation coefficient by measuring the moisture content of soil [7]. Some used the empirical statistic value 0.84 as attenuation coefficient [8-9]. This method, however, was always employed in small watershed researches. While the third method was to calculate it by analyzing the relationship between occurrence time of debris flow and rainfall time [10].

In view of insufficiencies of the previous researches, e.g. short time span and limited study area, the mainly idea of this article is to analyze the relationship of regional rainfall and debris flow by a set of long time span precipitation data and debris flow data in large scale region.

2. Material And Method

2.1 Study Area

Sichuan Province is located in southwest of China, and is bounded by longitudes of 97°21'E and 108°31'E, latitudes of 26°03'N and 34°19'N. Topography is complex and diversified, including mountainous area, basin and plateau. The climate of study area belongs to warm temperature climate zone, characterized by abundant and concentrated rainfall. The debris flow historical records from the China Geological Environmental Monitoring Institute shows that there are a total of 467 disaster points with precise position in the region from 1951 to 2004.

2.2 Data

In this paper, daily precipitation data that comes from 54 meteorological stations is used to research the relationship between rainfall and debris flow. For sufficient observational data for our study, we used the daily precipitation records during the period of 1981-2004 extracted from the China Meteorological Data Sharing Service System and the corresponding disaster data from the China Institute of Geo-Environmental Monitoring. The analysis factors include intraday rainfall, 10-day previous rainfall and effective antecedent rainfall.

2.3 Methodology

GIS technology and Logistic regression model were used to research. In reality, it is difficult to measure the rainfall of disaster points when the debris flows happen. Therefore, a useful method spatial interpolation is use to estimate the precipitation of disaster points. Our method is: 1) estimate the precipitation of disaster points, 2) calculate the attenuation coefficient of effective antecedent rainfall by statistical method, 3) use logistic regression model to analyze the relationship between debris flow and two types of comparative rainfall which are intraday rainfall and 10-day previous rainfall, intraday rainfall and effective antecedent rainfall. Fig. 1 demonstrates the flow of research process.
1) **Kriging Interpolation**

Kriging is an interpolation based approximate meta-model. It is a widespread and high-accuracy spatial interpolation method used to estimate rainfall of disaster points [11]. This method is used here to estimate the intraday rainfall and 10-day previous rainfall of points at which the disaster has happened. The calculation is carried out by the geostatistical analyst functional model in software ArcGIS Map.

2) **Method of Calculating Effective Precipitation**

The effective antecedent rainfall is calculated as a summation of daily rainfall, multiplied by a decrease coefficient as presented as the following equation:

\[
R_a = \sum_{i=0}^{n} k_i R_i
\]  

Where \( R_a \) is effective antecedent Rainfall and \( R_i \) (i=0,1,2…n) is the previous “n day” of rainfall. And \( k \) is attenuation coefficient which calculated by a statistical method.

3) **Logistic Regression**

Logistic regression model is a logarithmic model that describes the relationship between one or more variables and binary dependent variables. The binary logistic model is as follows:

\[
P = \frac{e^{\beta_0 + \beta_1 x_1 + \ldots + \beta_m x_m}}{1 + e^{\beta_0 + \beta_1 x_1 + \ldots + \beta_m x_m}}
\]  

Where \( P \) is the probability of an events occurring, \( \beta_0 \) is the constant of the equation, \( x_1, x_2, \ldots, x_m \) are the values of the independent variables and \( \beta_1, \beta_2, \ldots, \beta_m \) are the coefficient calculated for independent variables. Actually, the following simpler format is always used:

\[
P = \frac{1}{1 + e^{-B}}
\]

\[
B = \beta_0 + \beta_1 x_1 + \ldots + \beta_m x_m
\]

Here, the presence or absence of debris flow is used as dependent variable, which takes a value of 0 and 1 (for) to represent the absence and presence of disaster respectively. The intraday rainfall, 10-day previous rainfall and effective antecedent rainfall are used as independent variables to establish the equation.
3. Results

3.1 Spatial and Temporal Distribution

At the Temporal distribution, 93.8% of debris flows occur in summer from June to September. In this flood season of Sichuan Province, the rainfall accounts for 70% of annual precipitation. Fig. 2 shows the relationship among occurrence of time, frequency and rainfall which from 1981 to 2004 in Sichuan Province. It can be seen that rainfall increases the risk and frequency of the disasters.

![Fig. 2 Relationship among time, frequency and rainfall](image)

At the Spatial distribution, hazards are all located in the heavy rain areas. The distribution structure is along the south-north direction, with obvious regionalization (see Fig. 3). In the eastern part, disasters occurred in the biggest rainfall area with low frequency. Heavy rainfall is the dominant factor in this part. The average annual rainfall around the Sichuan Basin and south is lower than eastern part, while the occurrence frequency is the highest in the study area. Except for the precipitation, debris flow is also affected by other factors such as geological features and other factors.

![Fig. 3 Relationship Between space, Frequency and rainfall](image)

3.2 Analysis of Antecedent Precipitation

As for the occurrence of debris flow, precipitation is a dynamic factor. Continuous rainfall makes the soil moisture, and decrease the shear strength of soil. Intraday rainfall and 10-day previous rainfall are used as independent variables. Regression result is as follows:
\[ P = \frac{1}{1 + e^{-B}}. \]  
\[ B = -0.528 + 0.024r_0 - 0.002r_1 + 0.001r_2 - 0.001r_3 + 0.002r_4 - 0.001r_5 + 0.002r_6 + 0.001r_7 - 0.001r_8 \]  

Where \( r_0 \) represents the intraday rainfall which debris flow occurred, \( r_1 \rightarrow r_{10} \) respectively 10 days before the debris flow rainfall. Category coincidence rate was 70%. It can be seen from the regression equation, the coefficient of intraday rainfall is the highest, 0.024. That means the contribution rate of intraday rainfall to debris flow is the biggest.

### 3.3 Analysis of Effective Antecedent Precipitation

The frequency of debris flow after the day with heavy rain has been counted. For example, “one day before” means the rainy event happened is one day earlier than the disaster (see Table I).

<table>
<thead>
<tr>
<th>Rainy time</th>
<th>Total</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intraday</td>
<td>275</td>
<td>83.586</td>
</tr>
<tr>
<td>One day before</td>
<td>29</td>
<td>8.814</td>
</tr>
<tr>
<td>Two days before</td>
<td>10</td>
<td>3.039</td>
</tr>
<tr>
<td>Three days before</td>
<td>10</td>
<td>3.039</td>
</tr>
<tr>
<td>Four days before</td>
<td>5</td>
<td>1.522</td>
</tr>
<tr>
<td>Five days before</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Six days before</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Seven days before</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Eight days before</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nine days before</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ten days before</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

As can be seen from Table I, there are 83.6% of the debris flow occurred after intraday rainfall. The following exponential relationship can be built by fitting a curve with the total frequency. As shown in Fig. 4 and (4), the fitting accuracy is as high as 99%.

\[ f(x) = 83.5526 \exp(-2.1869x). \]  

Where \( x \) is the day before debris flow occurred. For example, when \( x=0 \), it means the intraday when disaster happened, \( x=1 \), it means the previous one day. \( f(x) \) is the attenuation coefficient.

The intraday rainfall and effective antecedent rainfall are used as independent variables. Result equation is as follows:

\[ P = \frac{1}{1 + e^{-B}} \]  

\[ P = 1/1 + e^{-B}. \]
\[ B = -0.411 + 0.044r_0 - 0.024r_a \]

Where, \( r_0 \) is the intraday rainfall, \( r_a \) is effective antecedent rainfall. Category coincidence rate of this group is 73%. And the contribution of intraday rainfall, which is still larger than other rainfall’s, is 0.044.

4. Conclusion

The location of debris flow disasters and the distribution of rainfall are factors interrelated. At the Temporal distribution, debris flow occurs mainly in summer, the rainy season. At the Spatial distribution, the locations of debris flows are also within the rainy region. As a result, rainfall is the dominant factor of debris flows.

The expression of the relationship between rainfall and the two types of comparative rainfall, i.e. intraday rainfall and 10-day previous rainfall, intraday rainfall and effective antecedent rainfall, comes out by Logistic regression analysis. The results indicate the coefficient of intraday rainfall is the highest. It means that intraday rainfall contribute most to the debris flow. According to comparison of the category coincidence rate between two types of rainfall, the second type is 3% higher than the first. It indicates that effective antecedent rainfall is more significantly related to debris flow.

Acknowledgment

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References


