

Investigation and Assessment of Landslides and Debris Flows in Sichuan Province of China by Remote Sensing Technique

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Abstract: Taking TM images, ETM images, SPOT images, aerial photos and other remote sensing data as fundamental sources, this research makes a thorough investigation on landslides and debris flows in Sichuan Province, China, using the method of manual interpretation and taking topography maps as references after the processes of terrain correction, spectral matching, and image mosaic. And then, the spatial characteristics of landslides and debris flows in the year of 2005 are assessed and made into figures. The environmental factors which induce landslides and debris flows such as slope, vegetation coverage, lithology, rainfall and so on are obtained by GIS spatial analysis method. Finally, the relationships of landslides or debris flows with some environmental factors are analyzed based on the grade of each environmental factor. The results indicate: 1) The landslides and debris flows are mainly in the eastern and southern area of Sichuan Province, however, there are few landslides and debris flows in the western particularly the northwestern Sichuan. 2) The landslides and debris flows of Sichuan Province are mostly located in the regions with small slope degree. The occurring rate of debris flow reduces with the increase of the vegetation coverage degree, but the vegetation coverage degree has little to do with the occurrence of landslide. The more rainfall a place has, the easier the landslides and debris flows take place.

Keywords: remote sensing technique; landslides and debris flows; Sichuan Province

1 Introduction

Sichuan Province, located in Southwest China, has vast territory, abundant resources and a long history of civilization. However, the special physical geography and geological environment make it one of the provinces in China with the highest occurrence rate, the largest scope, the most types, the highest frequency and the worst effect of landslides and debris flows. It is named “the land of abundance” as well as “geological disasters museum” (Dai, 2002; Yan and Yue, 2004). Therefore, it is significant to make good survey and assessment of landslides and debris flow disasters of this area. Remote sensing images contain a wealth of geological and geographical information, so remote sensing technique is one of the most economical and efficient techniques to obtain geological disasters information (Wen, 1994). In recent years, remote sensing technique has been widely applied to geological disasters survey, and a large number of results have been achieved (Li and Zhao, 1998; Joy and Lu, 2004; Yang et al., 2005; Sigrid et al., 2005; Zhang, 2005). Based on a variety of remote sensing images, the paper

interprets the landslides and debris flows with larger area after series of image enhancing processes, and evaluates their spatial distribution and relationships with the main environmental factors.

2 Study Area

Sichuan Province is located in 26°03'–34°19'N and 97°21'–108°31'E, and it is in the hinterland of Southwest China, with an area of 485,000km² and a population of about 87.5×10⁶ in the year 2005. It is situated in the upper reaches of the Changjiang (Yangtze) River, and surrounded by mountains. The terrain is complex with mountain and plateau area accounting for 78.82% of the region. The climate belongs to temperate and moist subtropics climate, and the annual average precipitation is about 1000mm. However, the climate of each place is obviously different, and the climate obviously changed in vertical direction in the plateau of western Sichuan, so Sichuan Province has the phenomenon of “different weather of each five kilometers”. The industry and agriculture are advanced, and the tourist resources are rich,

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so that it has been called “the land of abundance” since the old times because of its rich products and the elegant mountains and rivers.

3 Data Preparation

3.1 Data sources

The Data of the research include: 1) Remote sensing images: SPOT images (10m) of December 2004, TM images (30m) and ETM images (15m) of October 2005. 2) Topographic data: 1:250,000 topographic maps and the derived maps of DEM, slope and aspect. 3) Auxiliary data: 1:500,000 geological maps and soil maps.

3.2 Data processing

3.2.1 Terrain correction

Based on Digital Elevation Model (DEM) with the scale of 1:250,000, the research corrected the remote sensing images and the auxiliary data into the coordinates system of the DEM by the method of two-dimensional formula through ground control points. The coordinates system of the DEM use the national uniform central longitude of 105°E, the double standard latitude parallel of 25°N and 47°N respectively and the ellipse of spheroid Krasovsky. Terrain correction can not only guarantee the remote sensing image and the auxiliary data consistent in the horizontal spatial position, but also eliminate the distortion of remote sensing images induced by the undulation of landform.

3.2.2 Spectral matching

In the process of acquiring information, the spectral brightness features of the same object generate value deviations because of weather, environmental conditions of underlying surface, the sensor sensitivity and other factors. As a result, the landslides and debris flows exhibit various characteristics in different scenes. Therefore, the spectral data of different scenes need to be matched to be consistent. The spectral matching between neighboring images of different phases is more complex, so the study only matches the spectra between neighboring images in near phases. Firstly, the cloudy and fog zones in source images and matching images are marked out through the method of drawing artificial lines. Then the look-up tables' conversion model is developed after correlation analysis between histograms of source images and matching images. The histogram of source images is converted to the histogram of similar matching images, ignoring cloudy and fog zones marked. Some information may be lost in the process of spectral matching, so the matching image selection in the spectral matching is particularly important and the matching spectra should be chosen from the images whose histogram shape, mean and variance are similar, and the images whose mean is in center, preventing image data brightness value excessively compressing and expanding.

3.2.3 Images mosaic

Sichuan Province involves SPOT images of more than 70

scenes, so that the entire covering work needs the mosaic of many scenes of images. The mosaic between scenes should select appropriate places, because there are great errors at the sides of each scene. The mosaic chooses curves to correct, and the choosing principles are as follows: 1) Taking up more accurate and good quality images of ortho-correction. 2) Avoiding cutting linear surface features. 3) Avoiding cutting important features such as cities. Normal margin will left a clear sideline, so eclosion is needed to dilute the segment, namely, making a weighed ambiguous handling in the overlapping zones. The image spectrum in the middle overlapping zone is contributed by the two scenes respectively by 50%. However, in the 10% of marginal area of image, 90% of the spectral information is contributed by the neighboring image, and 10% by another scene. Finally, the spectrum forms a transition zone, but not a spectral escarp in the overlap area.

4 Information Acquisition

4.1 Field investigation

Firstly, the research collected the previous researches on geological disasters of Sichuan Province extensively so as to fully understand the distribution of landslides and debris flows. Secondly, the field investigation was made by taking the topographical map with the scale of 1:250,000 as base map, and takes handset GPS as the main tool to locate the positions of landslides and debris flows. The investigation focused on the construction area and the active place of human. And the investigation results were input into database of the landslides and debris flows, which include the type, location (longitude and latitude), distribution scope, size and area, the time of occurrence of landslides and debris flows.

4.2 Image interpretation

The indoor interpretation of landslides and debris flows disasters was based on the SPOT images, combined with TM images and ETM images. Firstly, the research understood macro-element information of landslides and debris flows on remote sensing images, such as geomorphic feature, geological environment, vegetation conditions, and the artificial environment. And then, the interpretation marked the area where landslides and debris flows were easy to take place. Secondly, the database of field investigation was linked with the remote sensing images, so that the pictures can be easily located on the remote sensing images. According to the field pictures and the performance of landslides and debris flows on the remote sensing images (Eyers et al., 1998), the interpretation got the location and distribution of each landslide and debris flow in the light of topographical maps.

4.2.1 Landslides

Based on the morphological and structural characteristics of landslides on the pseudo-color images made by ETM4, ETM3 and ETM2 (Fig. 1), the research used the synthetic method of geography to identify the landslides

combining the reference of the geological environments of landslides (Zhang, 2005; Sui et al., 2005). The landslides had the following morphological characteristics: 1) Landslides are mainly located at the two sides of rivers, the headstream and junctions of the main and branch rivers with changeable controls of erosion. 2) The back wall of landslide generally took up the shape of an encircling chair. The micro-physiognomy of the tongue or the mesa of landslides was generally clear. Some landslides had obvious cracks at their backs. The bodies of landslides and their around rocks differed greatly in the aspect of image tone, with clear boundary. 3) Although some old landslides had smooth surfaces with trees, the natural ditches of the two sides of landslides were very deep and displayed sudden transition. As a result, those kinds of landslides were easier to be distinguished.

4.2.2 Debris flows

The morphological characteristics of debris flows or their ditches were quite clear on the true-color images made by ETM1, ETM2 and ETM3 (Fig. 2), which are the base-ments of the recognition of debris flows. In addition, the background of the basin where debris flows occur and

their texture characteristics of eroding-depositing physiognomy were beneficial for recognition of debris flows. The debris flows could be divided into two types according to their shapes: sloping debris flows and ditch debris flows. The former was generally located in sloping bodies with steep slope, cracked rocks and thick accumulations. The forming and spreading areas could be seen clearly in the color infrared images with the shape of spindle, sliver and tadpole, and the color of iron grey or shallow bright (pseudo-color images). The latter had obvious forming area, spreading area and the depositing area on the remote sensing images. The forming areas were mainly the bigger valley of dipper shape, and the colors on the images were mainly iron grey or light bright because there were lots of solid materials of landslips, landslides, sloping flows and moraines. The spreading area took on the shape of “V”, and there were different scales of landslides, landslips and sloping flows in the shape of “fishbone” or “scolopendra”. The depositing area was located in the mouth of ditches with the accumulated bodies in the shape of fan. Although, there was vegetation in the depositing area, the shape could still be easily distinguished.

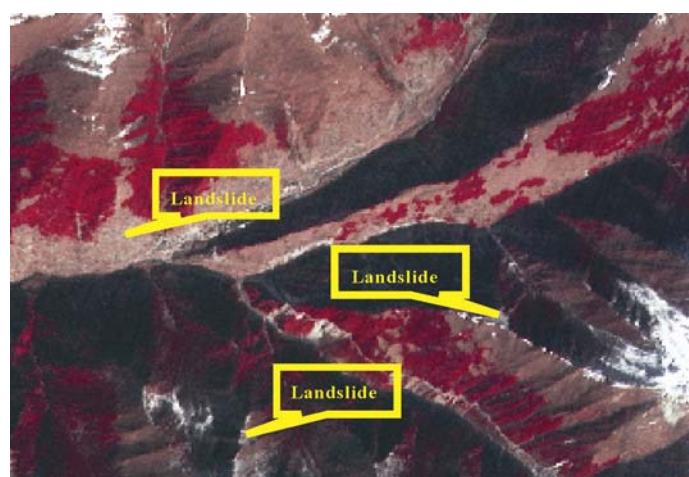


Fig. 1 Landslides in pseudo-color image

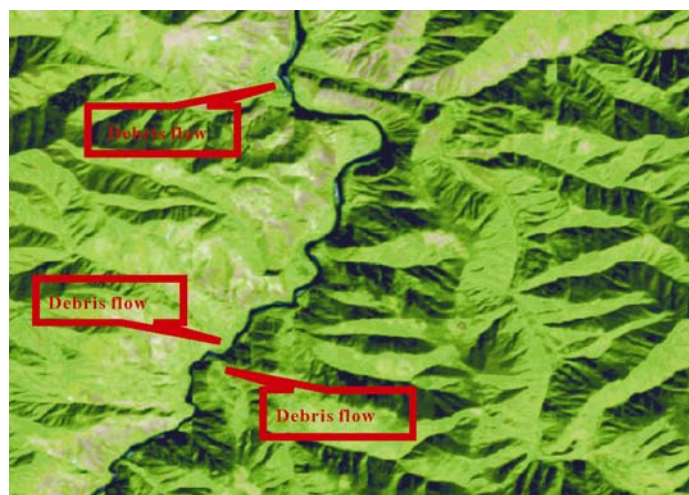


Fig. 2 Debris flows in true-color image

4.3 Verification

The recorded landslides and debris flows points in the field investigation and the recorded materials in recent 5 years were used to confirm the precision of the interpretation on landslides and debris flows.

The number of verified points of debris flows was 64, and the number of actual points was 60, accounting for 93.8%, at the same time, there were 3 debris flow points that we could not mark out and there was one debris flows point that was wrongly interpreted. The number of verified points of landslides was 56, and the number of actual points is 53, accounting for 94.6%, at the same time, there were 3 landslide points that we could not mark out and none of the landslide point is wrongly interpreted.

5 Results and Analysis

5.1 Distributing characteristics of landslides and debris flows

The paper only interpreted landslides with area bigger than 900m^2 due to the resolution limit of ETM images, and the numbers of landslides and debris flows interpreted were 516 and 915 respectively (Fig. 3). From Fig. 3, we can know that landslides and debris flows are mainly in the eastern and southern area of Sichuan Province, accounting for 80% or more. On the contrary, in the western particularly in the northwestern Sichuan, there are few landslides and debris flows. The east of Sichuan Province is the plain region with low elevation and plain relief, but there are much more landslides and

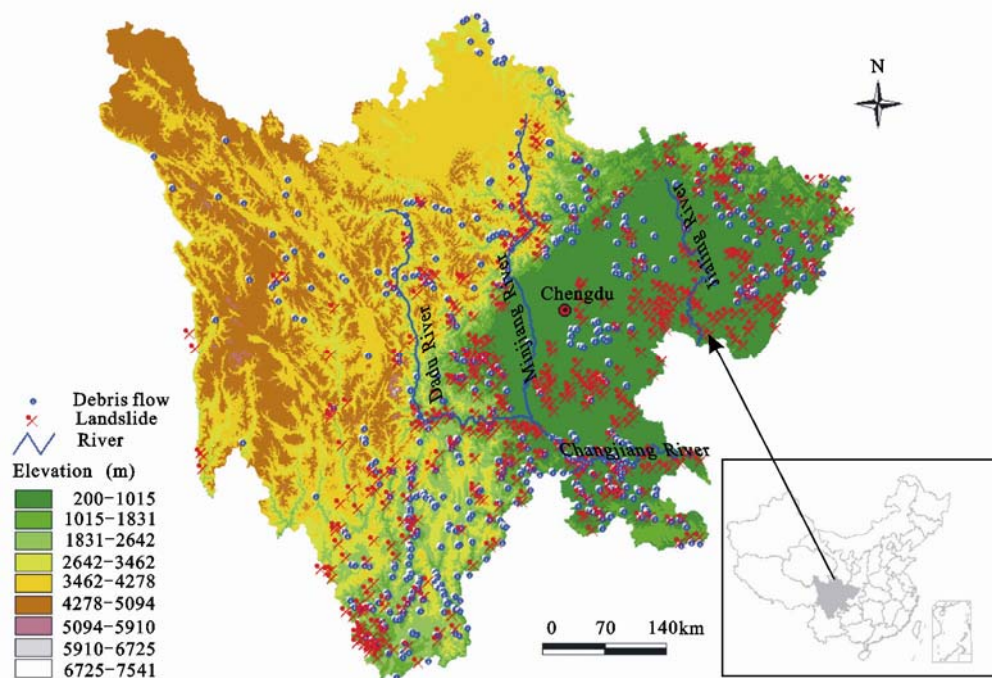


Fig. 3 Distribution of landslides and debris flows in Sichuan Province

Debris flows. The reason is that the region belongs to the plain planting area with enough material sources and feasible rainfall conditions for the forming of landslides and debris flows. However, in the west especially northwest of Sichuan Province, there are mainly mountains with better vegetation cover and rare interference of human being.

5.2 Relationships of landslides and debris flows with environmental factors

The research chooses some typical environmental factors such as the slope, the lithological character, the vegetation coverage, the precipitation and the human activity, etc. to appraise landslides and debris flows.

(1) Relationship of landslides and debris flows with slope. The slope grades are divided in 4 ranks: $<10^\circ$, $10^\circ\text{--}25^\circ$, $25^\circ\text{--}40^\circ$ and $>40^\circ$. The points of landslides and

debris flows are overlaid on the slope grade maps and the results (Fig. 4) indicate: there are 241 landslides located in the scope grade of between $10^\circ\text{--}25^\circ$, accounting for 46.7% of total landslides, 104 landslides in the slope grade above 25° , accounting for 20.2%, but only 16 landslides in the slope grade $>40^\circ$, accounting for 3.1%. The debris flows are mainly distributed in the slope scope smaller than 40° , and the number of debris flows decreases with the increase of slope value. There are 866 debris flows with a slope scope below 40° , accounting for 94.6% of total landslides; and there are 420 debris flows in the slope scope below 10° , accounting for 45.9% of total landslides.

(2) Relationship of landslides and debris flows with lithology. The lithological map is obtained by digitizing and evaluating the geological maps with the scale of 1:500,000. Landslides and debris flows are easy to take

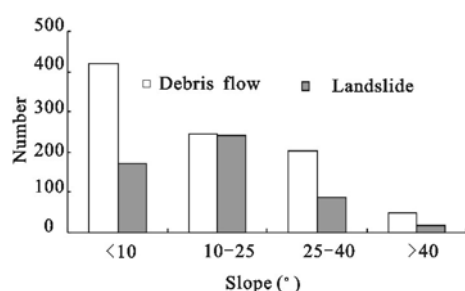


Fig. 4 Distribution of debris flows and landslides with slope

place in sediment-based and loose-soil region, where the numbers of landslides and debris flows are 866 and 484, accounting for 94.6% and 93.8% respectively. The field investigation showed that the main material sources of debris flows are broken rock and mudstone, and other stones in debris flows come mainly from the soil surface layer. Moreover, in the field investigation, we can also see that the majority compositions of the landslides are clastic sedimentary rock or metamorphic rock, and landslide is easy to take place in these regions where there is igneous rock or granite as the first floor, and sedimentary rock or metamorphic rock as the band.

(3) Relationship of landslides and debris flows with vegetation coverage. The degree of vegetation coverage (F_{cover}) is calculated from the remote sensing images and the formulae are as follows (Zhang, 1994):

$$NDVI = \frac{TM_4 - TM_3}{TM_4 + TM_3} \quad (1)$$

$$F_{\text{cover}} = aNDVI + b \quad (2)$$

where $NDVI$ is the normalized vegetation index, TM_4 and TM_3 are luminance values of the 4th and the 3rd wave band of the TM images; F_{cover} is the coverage vegetation degree; a , b is the empirical coefficient. The vegetation coverage is divided into 4 scopes: >25%, 25%–40%, 40%–65%, and >65%. The vegetation coverage map is overlaid with the maps of landslides and debris flows, and the results indicate (Table 1): the better the vegetation coverage is, the less the number of debris flows is, which shows that the vegetation coverage has great impact on the distribution of debris flows. The number of landslides in each grade of vegetation coverage has little distinction, which shows that the vegetation coverage has small effect on the distribution of landslides and it is not indispensable condition but necessary condition for the occurrence of landslides.

Table 1 Relationships of vegetation coverage with landslides and debris flows

Vegetation coverage (%)	<25	25–40	40–65	>65
Landslide	139	127	134	116
Debris flow	441	282	139	53

(4) Relationship of landslides and debris flows with precipitation. The annual precipitation is interpolated into the grid of 500m×500m by reverse weighed average method using the 1915 weather stations' data (Zhang et al., 2006). The map of annual precipitation is overlaid with the maps of landslides and debris flows respectively, and the results show that (Fig. 5): the more the precipitation, the more the number of landslides and debris flows.

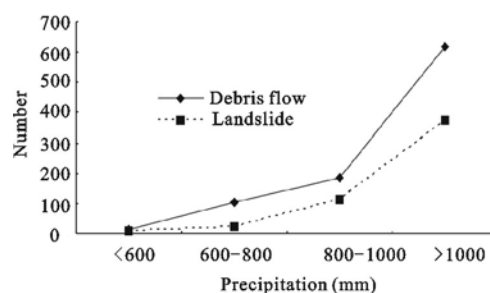


Fig. 5 Distribution of debris flows and landslides with precipitation

6 Conclusions

(1) It is macro, fast, accurate to use remote sensing method to obtain the information of landslides and debris flows. The remote sensing technology is one of the effective means to appraise geological hazards.

(2) In 2005, the numbers of landslides and debris flows with area bigger than 1000m² are 516 and 915 respectively. The landslides and debris flows are mainly distributed in the eastern and southern area, accounting for 80% or more. On the contrary, in the western area particularly in the northwest, there are few landslides and debris flows.

(3) The landslides and debris flows of Sichuan Province are mostly located in the regions with small slope degree. The landslides and debris flows are easy to take place in sediment-based regions. Sichuan's landslide, debris flow disasters are mostly located in the area with small slope. The occurring rate of debris flows reduces with the increase of the vegetation coverage, but the vegetation coverage has little to do with the occurrence of landslide. The occurrence of landslides and debris flows has close relationship with the distribution of annual precipitation, namely, the more the precipitation is, the easier the landslides and debris flows take place.

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