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# An Early Warning System for Regional Rain-Induced Landslide Hazard

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## ABSTRACT

Landslide in alpine regions often causes heavy losses of both human lives and properties, most of the landslides are induced by heavy rainfall. In this paper, we put forward an early warning system of rain-induced landslide. From 2002, we carried on the demonstrative work of landslide monitoring and early warning in Yaan, Sichuan Province, China, and constructed the first county-scale landslide monitoring and early warning region. Yucheng District of Yaan City is located in the west of the Sichuan Basin, right in the intersection of SichuanBasin and the Tibetan Plateau. The slopes are made of Mesozoic sedimentary rock, sandstone inter-bedded with mudstone. Yucheng District has the title "sky funnel" because of the high precipitation, the annual precipitation is about 1750 mm. We carried out detailed landslide survey, and obtained the location, scale, characteristics, influence and triggering factors of the landslides. Then we assessed the regional landslide susceptibility. Based on the evolution law of the landslides, we selected ten factors to study the relationship between the factors and landslide. Using the bi-variate statistics method, we calculated the contribution to landslide from each factor, classified the susceptibility into four categories. We set up the regional rainfall monitoring network with 13 automatic CAWS600R rain gauges. Using the landslide survey data, we studied the rainfall influencing of the regional landslides. The one-day and three-day rainfall controls the occurrence of regional landslide. We also classified the triggering effect of rainfall into four categories. We presented a method to calculate the landslide danger degree using the susceptibility and triggering category. Utilizing the predicted rainfall data and real-time monitored rainfall data, together with the landslide susceptibility map, we developed a WebGIS-based landslide warning system, which greatly strengthened the capability for geohazard control.

**Keywords:** Landslide; Early-Warning; Monitoring; WebGIS; Yaan

## 1. Introduction

Rain-induced landslides often occur in almost all alpine regions, and always resulted in serious human life and economic losses. To mitigate the loss of landslide, there is only two measures: one is stabiles the landslides and potential landslides, or move the people and infrastructures out of landslide-influence area, the other measure is strengthen the awareness of people live in danger regions, so that when rainfall-induced landslides do occur, people know how to save their lives very well, thus the potential landslide loss was reduced. So, to tell in what conditions the elements will be at risk is an efficient way to mitigate the landslide hazard [1].

As a natural phenomenon, the occurrence of landslide is controlled basically by geological conditions, morphological conditions, land cover conditions, etc. The landslide susceptibility analysis can give a clue of the dangerous degree site by site. A lot of methods of regional landslide susceptibility evaluations have been studied and developed [2,3]. The triggering factored was studied by the 66 landslide samples already occurred with detailed investigation, and then the threshold of landslide-trigger values was suggested.

So, an automatic landslide early warning system based on real-time rainfall monitor data was put forward in Yucheng District, Sichuan, China.

The study area is located in the west of the Sichuan Basin, right in the intersection of Sichuan Basin and the Tibetan Plateau. The coordinate is 102˚51' - 103˚12'E, 29˚40' - 30˚14'N. The area is about 1067 km$^2$, 91% of which is mountainous region. Its population is about 330 thousand. The area is covered with the sedimentary rocks of Mesozoic and Cenozic ages, sandstone inter-bedded with mudstone, which is easy to slide. Yucheng District

has a sub-tropical monsoonal climate, and it is titled "sky funnel" because of the high precipitation. The annual precipitation is about 1750 mm. Most of the rain falls during May to October, especially in July and August.

Landslide is one of the most serious hazard endangering the lives and properties in Yaan. Landslide and debris flow have caused 185 deaths, and the direct economic loss is over 2 million CNY.

## 2. Landslide Survey and Susceptibility Assessment

We carried out detailed landslide survey, and obtained the location, scale, characteristics, influence and triggering factors of the landslides. Then we made the regional landslide susceptibility assessment.

Based on the evolution law of the landslides, we select ten factors to study the relationship between the factors and landslide (**Table 1**).

Using the bi-variate statistics method [4,5], we calculated the contribution to landslide of every factor, also shown in **Table 1**. Then the contributions were summed up, and classified into four categories. So, we obtained the regional landslide susceptibility map. The accuracy of this method was shown in **Figure 1**. The landslide susceptibility map is reasonable and sound.

## 3. Rainfall-Induced Landslide Warning System

We set up the regional rainfall monitoring network with 13 automatic CAWS600R rain gauges in Yucheng District in 2005. From then on, the real-time rainfall is monitored. Using the landslide survey data, we studied the rainfall influencing of the regional landslides (**Figures 2** and **3**, **Table 2**). The one-day and three-day rainfall controls the occurrence of regional landslide. We also classified the triggering effect of rainfall into four categories [6].

**Table 1. The 10 factors used in landslide susceptibility assessment.**

| No. | Factor | Wight |
|---|---|---|
| 1 | Slope gradient | 0.10 |
| 2 | Slope aspect | 0.03 |
| 3 | Rock type | 0.15 |
| 4 | Plant cover | 0.04 |
| 5 | Altitude | 0.06 |
| 6 | Structural geology | 0.06 |
| 7 | Slope type | 0.07 |
| 8 | River influence | 0.07 |
| 9 | Road influence | 0.10 |
| 10 | Annual precipitation | 0.10 |

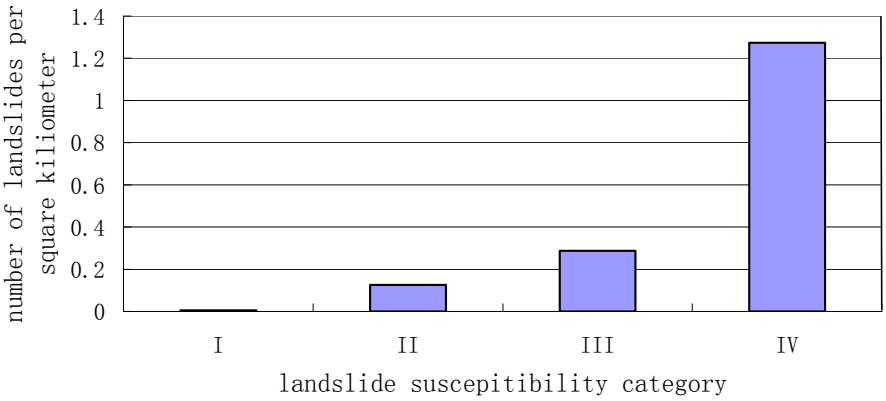


**Figure 1. Evaluation of the landslide susceptibility assessment.**

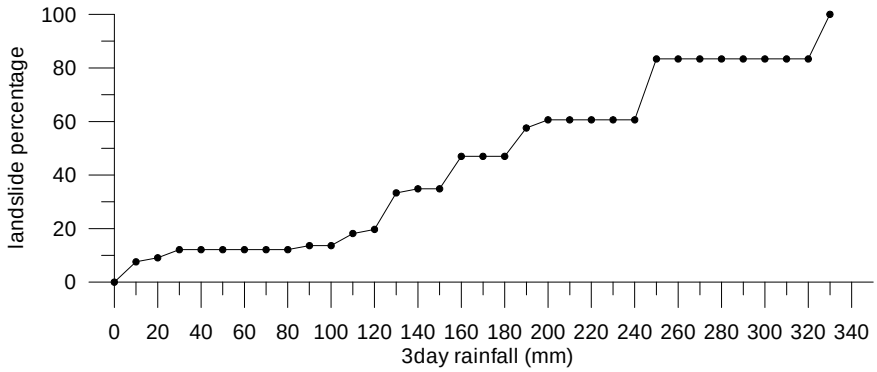


**Figure 2. The relationship between 3-day rainfall and landslide.**

 

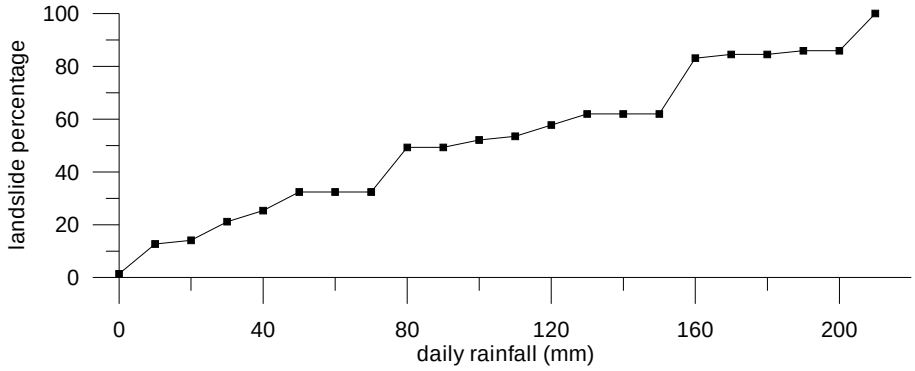


**Figure 3. The relationship between 1-day rainfall and landslide.**

**Table 2. Rainfall trigging category to landslide.**

| Trigging category | 3-day rainfall (mm) | 1-day rainfall (mm) |
|---|---|---|
| 1 | 0 - 100 | 0 - 20 |
| 2 | 100 - 150 | 20 - 50 |
| 3 | 150 - 240 | 50 - 100 |
| 4 | 240+ | 100+ |

**Table 3. Calculation table of landslide dangerous category.**

| | Landslide susceptibility category | | | |
|---|---|---|---|---|
| | **I** | **II** | **III** | **IV** |
| **Trigging category 1** | ONE | ONE | ONE | TWO |
| **Trigging category 2** | ONE | TWO | TWO | THREE |
| **Trigging category 3** | ONE | TWO | THREE | FOUR |
| **Trigging category 4** | TWO | THREE | FOUR | FOUR |

We present a method to calculate the landslide dangerous degree using the susceptibility and triggering category, shown in **Table 3**. The forecasting dangerous level is also classified into four categories: most serious (FOUR); serious (THREE); medium (TWO) and pretty safe (ONE).

The GIS-based landslide warning software was developed and put into use. The early warning system has been carried on by the collaboration of Bureau of Land and Resources and Meteorological Bureau of local government during the rainy season since 2005 [7]. The Meteorological Bureau provides the weather forecasting information, the professional staff of Bureau of Land and Resources calculate the landslide dangerous degree, and then put forward to the people in potential hazard zone. These measures greatly strengthened the awareness of the coming hazard.

## 4. Conclusion

The landslide warning system research work has been carried on for about 10 years. We successfully set up the warning system, and the result is pretty good. The landslide warning system is built on the basis of the following work: 1) Detailed landslide mapping is carried on by professionals. The distribution, characteristic, controlling factor is studied. The landslide susceptibility map is produced qualitatively; 2) Triggering factors are studied and properly selected in the usage of early warning system; 3) Rainfall monitoring network is constructed. The coverage of each rain gauge is about 10 square kilometers; 4) GIS-based landslide warning software is developed. The implantation of the landslide warning system greatly strengthened the hazard mitigation work of local government.

## 5. Acknowledgements

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