A Stepwise, multi-parameter Debris Flow Monitoring and Warning System
分级多指标泥石流监测预警系统

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Main contents

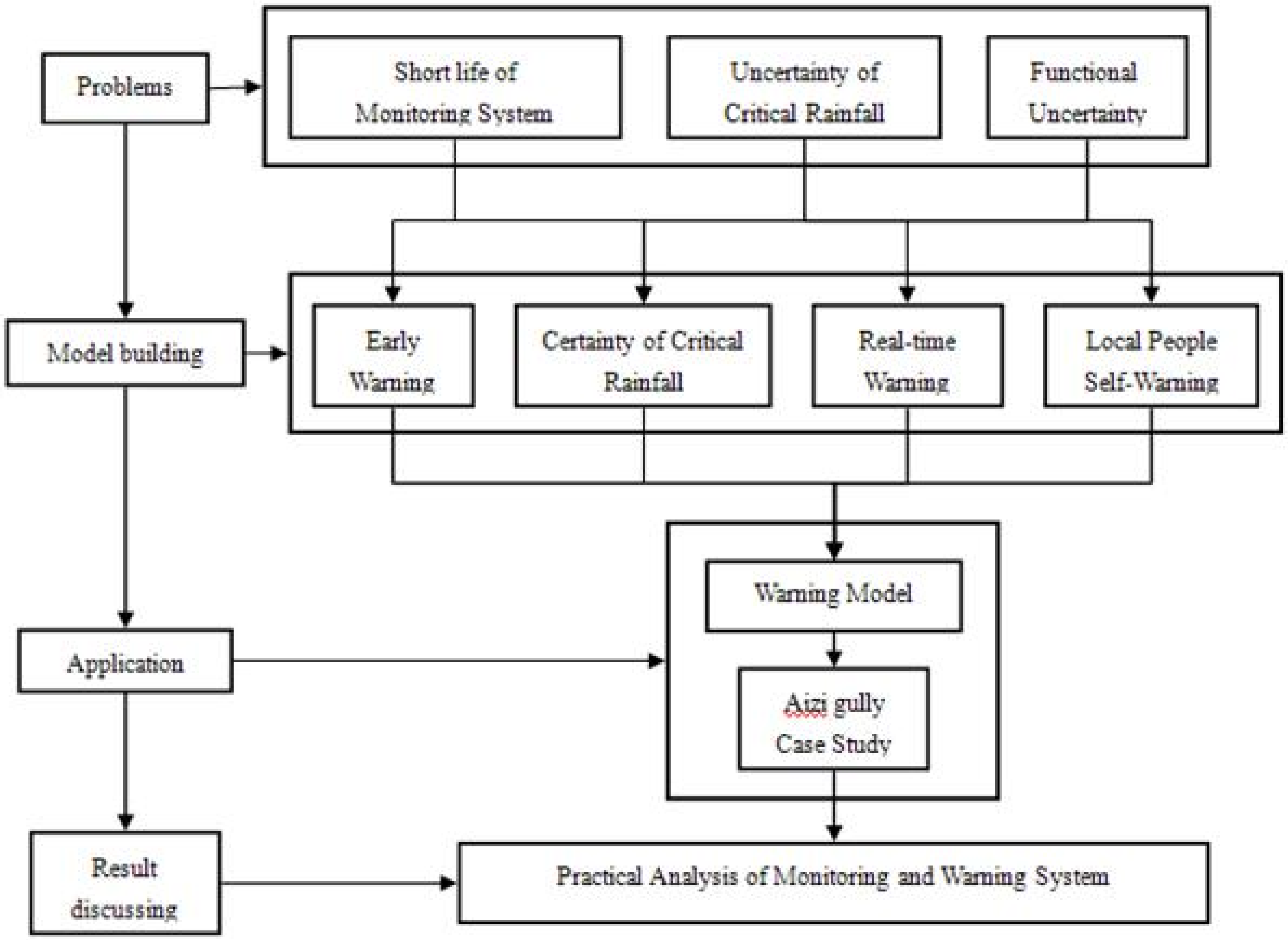
- The **imbalance** between limited lifespan of equipment and long period of hazard reoccurrence低频率泥石流与短寿命的监测系统存在矛盾
- The **critical rainfall** is difficult to check correctly 准确的临界雨量很难确定
- The **functionality problems** of monitoring and communication equipments 仪器的稳定性存在问题
- A comprehensive debris flow **warning system** working in various stages depending upon the critical rainfall threshold limits. 基于泥石流运动过程的3级警戒雨量的确定
- It works in **six** stages: **Early Warning, Near-warning, Triggering Warning, Movement process warning, Hazard Warning and Local people self-warning.** 包括6个子过程的综合监测预警系统
- **Aizi valley** is chosen as a case study. 矮子沟示范应用

Debris flow is heavy in China and also in the world

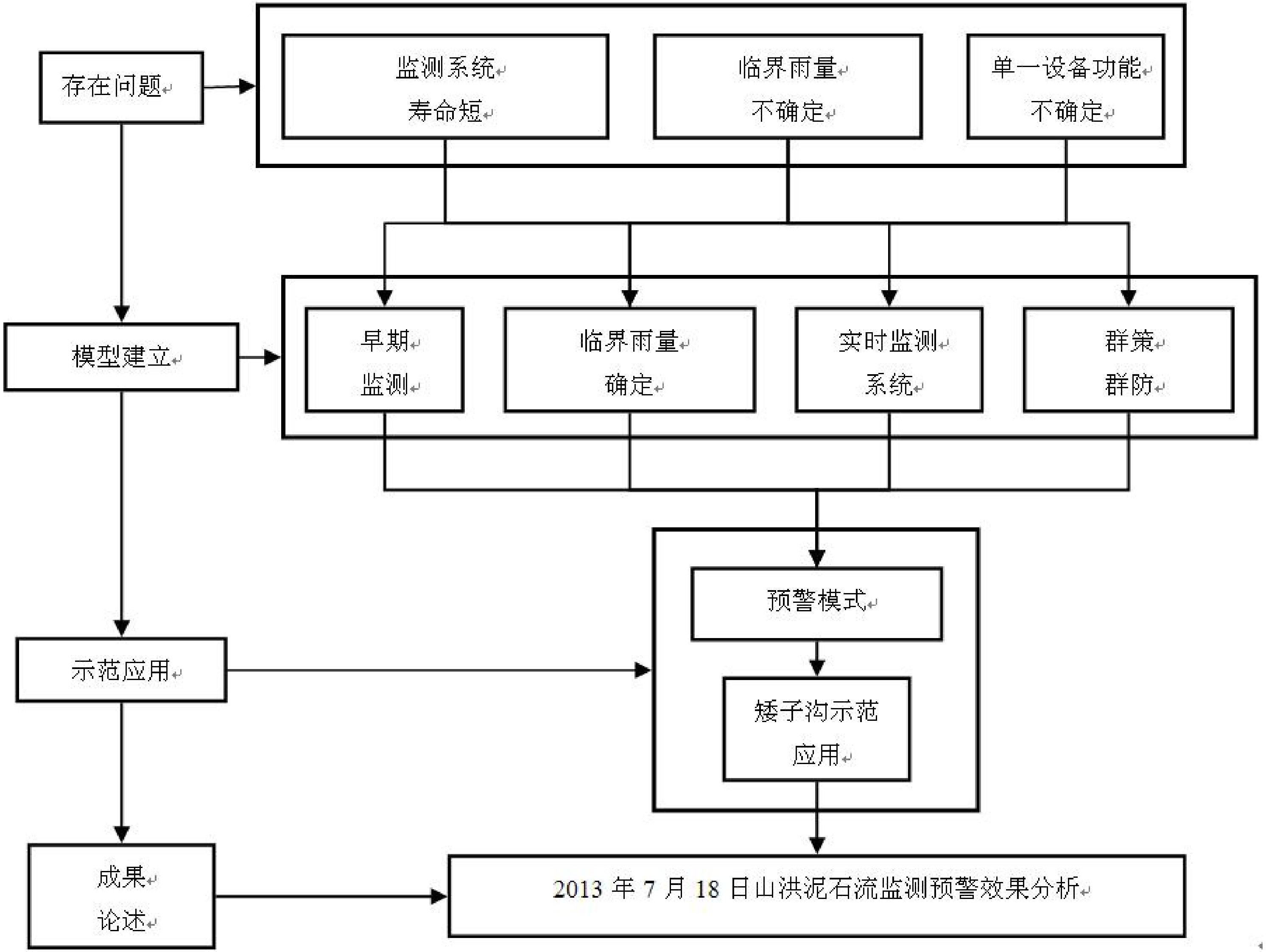
The successful warning is difficult by far

However, the **successful rate** of the current debris flow warning system is still **not high** after decades of efforts. For example, the error rate reached up to 72% in the debris flow warning of burned areas in southern California, USA (Restrepo et al. 2008).

Flow chart of proposed Warning system



研究技术路线图


存在问题
监测系统寿命短
临界雨量不确定
单一设备功能不确定
模型建立
早期监测
临界雨量确定
实时监测系统
群策群防
示范应用
预警模式
矮子沟示范应用
成果论述
2013 年 7 月 18 日山洪泥石流监测预警效果分析

Historical Record of debris flow catastrophe events throughout the world

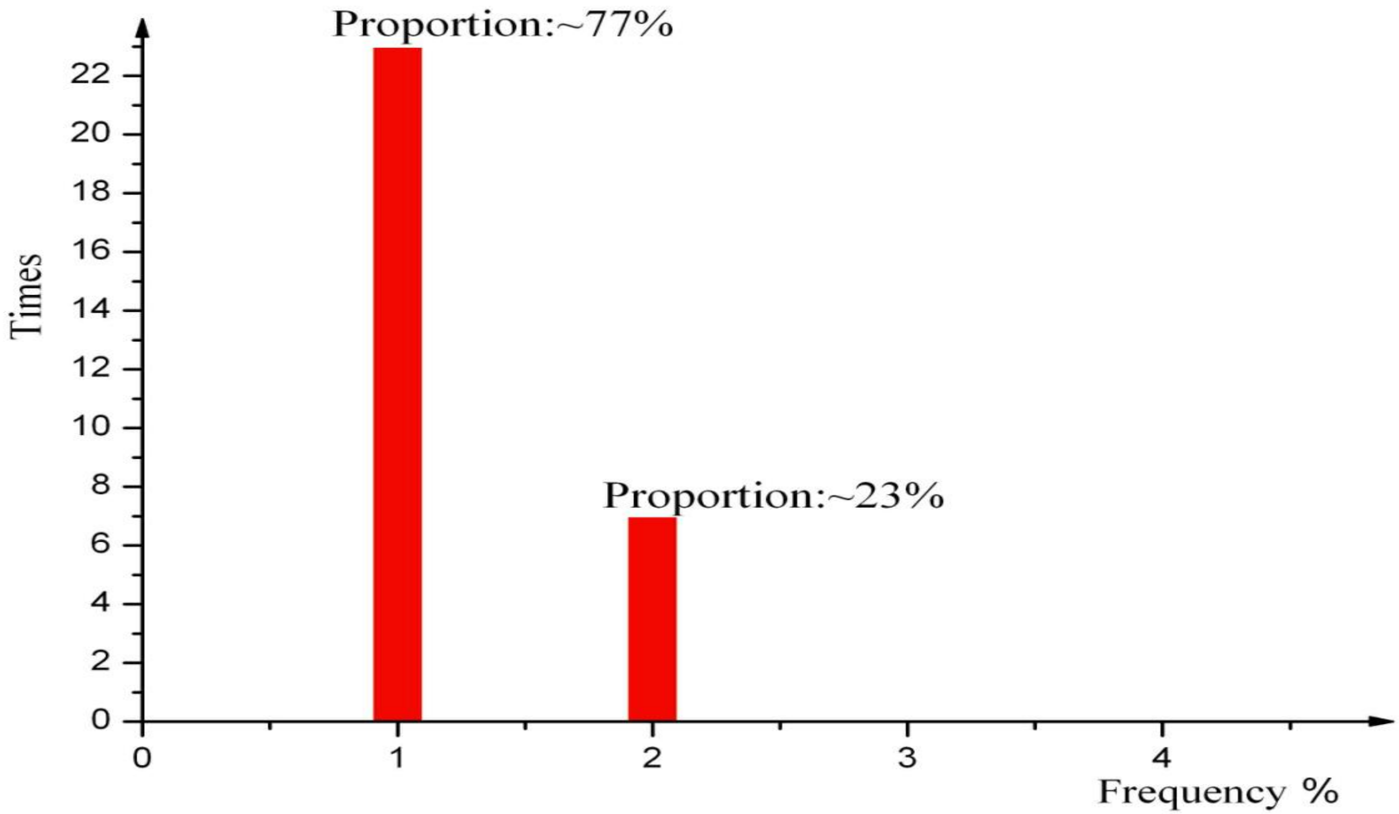
Table 1. Historical record of debris flow catastrophic events throughout the world

No	Gully Name	Location	Basin Area (Km^2)	Date	Deaths and Missing (Persons)	Rainfall (mm)	Discharge (m^3/s)	Deposits Volume (m^3)	Frequency (Per 100 Years)	Reference
1	Qiongshan Gully	Danba County, Sichuan province	32.3	Jul.11, 2003	51	35mm/24h	4836	--	2	Chen et al. 2004
2	Elang Gully	Danba County, Sichuan province	18.75	Jun.26, 2003	14	--	--	5 x10^5	1	Liu 2010
3	Guxiang Gully	Bomi County,Tibet	25.2	Sep,1953	140	140mm/24h	28600	1.1 x10^7	1	Zhu et al. 1997
4	Aizi Gully	Ningnan County, Sichuan province	65.55	Jun.28, 2012	41	78.3mm/24h 23.3mm/1h	903.12	5.74 x10^5	1	Hu et al. 2012
5	Sanyanyu Gully	Zhouqu County, Gansu province	25.75	Aug.8, 2010	1765	96.77mm/1h 77.3mm/30min	1219.8	1.5 x10^6	1	Liu et al. 2011
6	Wenjia Gully	Mianzhu shi, Sichuan province	7.81	Aug.18, 2010	12	227mm/12h; 90mm/h	1530	1.98 x10^6	1	You et al. 2011
7	Caiju Gully	Puge County, Sichuan province	5.2	Jun.20, 2003	10	157.9mm/24h	500-600	7 x10^5	1	Liu et al. 2003

8	Caiyuan Gully	Wenchuan County, Sichuan province	19.4	Aug.9, 2003	11	39.3mm/24h 25mm/4h	999	5 x10^5	2	Liu et al. 2004
9	Dongyuege Gully	Gongshan County, Yunnan province	46.9	Aug.18, 2010	92	11mm/h	--	3.5 x10^6	1	Su et al. 2012
10	Hefan Gully	Linxiang shi, Hunan province	1.8	Jun.10, 2011	19	55mm/h; 162.6mm/24h		9 x10^4	--	Lu et al. 2013
11	Glen Ogle-1, Glen Ogle-2	--	209 and 476	Aug.18, 2004	No Deaths (57 Rescued)	15-20mm/h, 89mm/24h	8500	8500 and 3200	1	Milne et al 2009
12	Antofagasta, Chile	--	43	June.18, 1991	119	24mm/h	7-8 x 10^5	--	1	Sepulveda et al. 2006
13	Santiago ,Chile	--	38	May.3, 1993	34	--	2 x 10^6	--	1	Sepulveda et al. 2006
14	Venezuela	Central coast of Venezuela	--	Dec. 15-16, 1999	30,000	72mm/h, 380.7-410.4 mm/24h	--	1.9 Million	1 or 2	Pe´rez 2001
15	Campania Southern Italy	Sarno Area	--	May.5-6, 1998	161	-	0.6x10^3-3.4x 10^3	1.42x10^6	2	Zanchetta et al. 2004
16	Tuscany Italy	--	150	June.19, 1996	14	158mm/h, 474mm/12h	-	1,360,000	1	Giacomo et al. 2004

17	Santiago Atitlan	Panabaj, Guatemala	180,000	October.5, 2005	1000	--	1280-1680	360,000	1	Sheridan et al. 2007
18	Izumi city, Harihara Japan	Kagoshima prefecture	15.2	July.9, 1997	21	365mm/24h, 62mm/h		13 x 10^4	1	Sassa et al. 1997
19	Otari Village Gamahara, Japan	Nagano Prefecture	--	Dec.6, 1996	14	48mm/h, 376mm/24h	--	--	1	Sassa et al. 1997
20	Hida River Japan	Hida River, Gero	--	August.18, 1968	104	--	--	--	1	Takahashi 2007
21	Los Angeles	--	--	Jan.1, 1934	45	--	--	--	2	Jakob & Hungr 2005
22	Los Angeles	--	--	Mar.3-4, 1978	30	--	--	--	2	Jakob & Hungr 2005
23	Tomeasa village Romania	Hunedoara county	--	Jul.11-12, 1999	13	136mm/2h	--	--	1	Lessons learnt from Landslide disasters in Europe 2003 Javier Hervas
24	Herb, Taiwan	Herb	--	Aug.1,1996	73	--	--	--	1	Lin & Jeng 2000
25	Ofelia Taiwan	Ofelia	--	Jun.23, 1990	39	--	--	--	1	Lin & Jeng 2000
26	Toraji Taiwan	Toraji	--	Jul.30, 2001	200	--		402585	1	Chang et al. 2011
27	Morakot Taiwan	Morakot	--	Aug.8, 2009	673	--	--	326,0001	1	Chang et al. 2011
28	Nelson County	Virginia USA	--	Aug.19-20,1969	150	710mm/8h	--	--	1	Simpson and Simpson, 1970, Camp and Miller, 1970
29	Larcha	Bhotekoshi valley Nepal	--	Jul.22, 1996	54	100mm		104000	1	Adhikari & Koshimizu 2005
30	Casita Volcano	Nicaragua	--	Oct.30, 1998	2513	1000mm	--	--	1	Scott 2000

The frequency of hazards with people died more than 10 persons
大于10人灾害的频率



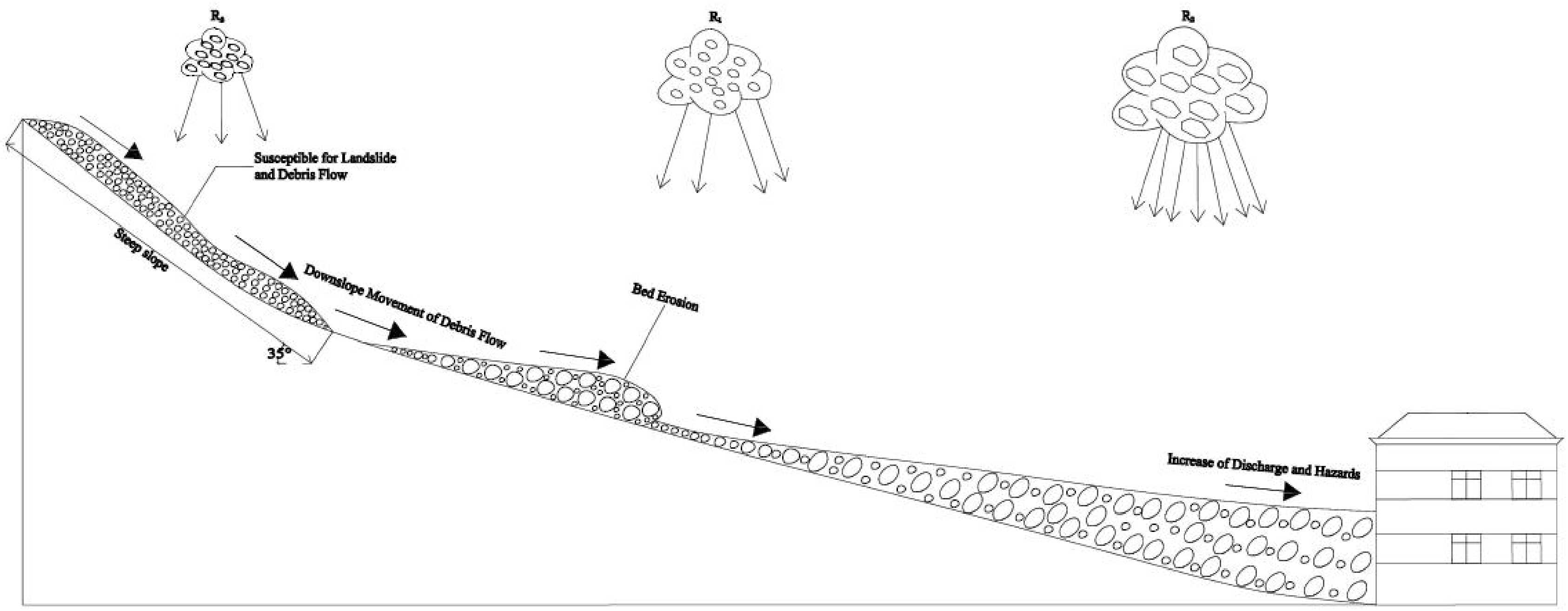
From historic records of debris flow catastrophic events which resulted in more than 10 casualties throughout the world it is estimated that 23 % of the events happened once in 50 years. However, the recurrence intervals of the others (77 %) were greater than or equal to 100 years.

The raining

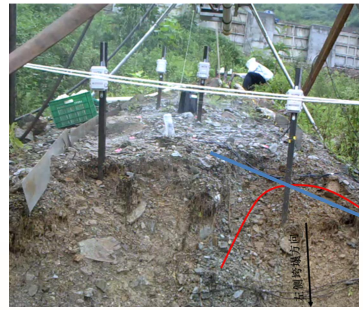
- For example, the threshold of critical rainfalls of two different debris flow cases in Senet basin of Spain that occurred in 7 August, 2009 and 25 March, 2010 were 6mm/5min, 30mm/h and 2mm/5min, 8.7mm/h, respectively. The variable extent 5min rainfall is 66.7 %, while that of 1h rainfall is 71.0 % (Hurlimann et al. 2011). In another example, the threshold of critical rainfall of Jiangjiagou debris flow in 1981 varied from 2mm/10min to 7mm/10min, and the variable extent reached up to 71.0 % (Wu et al. 1990).

Rainfall thresholds R_0, R_1 and R_2 for debris flow initiation, movement and hazard process

泥石流三级雨量



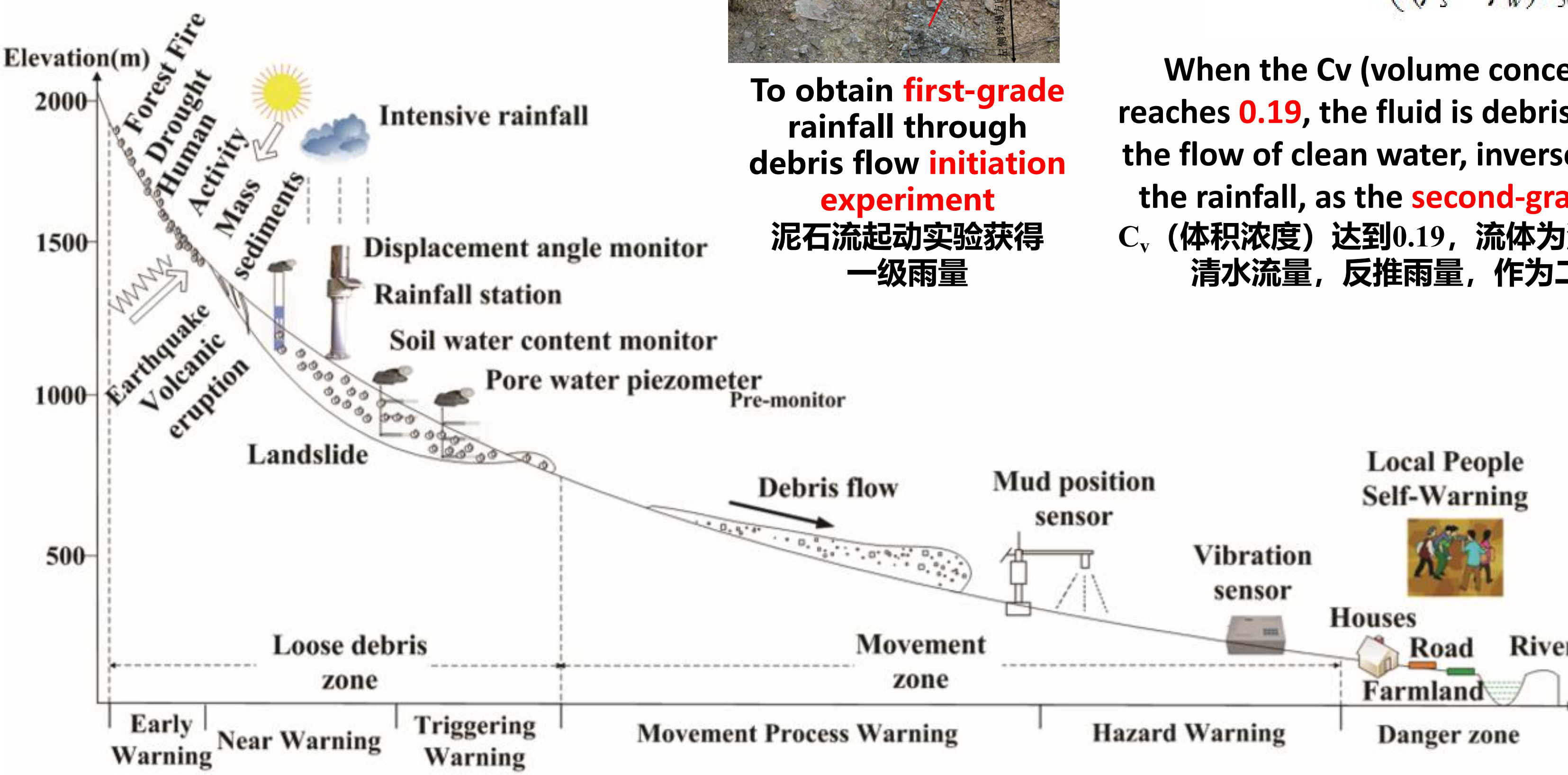
The three grades of raining is determined by field experiments, model calculation and historical data analysis
三级雨量通过现场实验、模型计算和历史数据分析确定



To obtain first-grade rainfall through debris flow initiation experiment
泥石流起动实验获得一级雨量

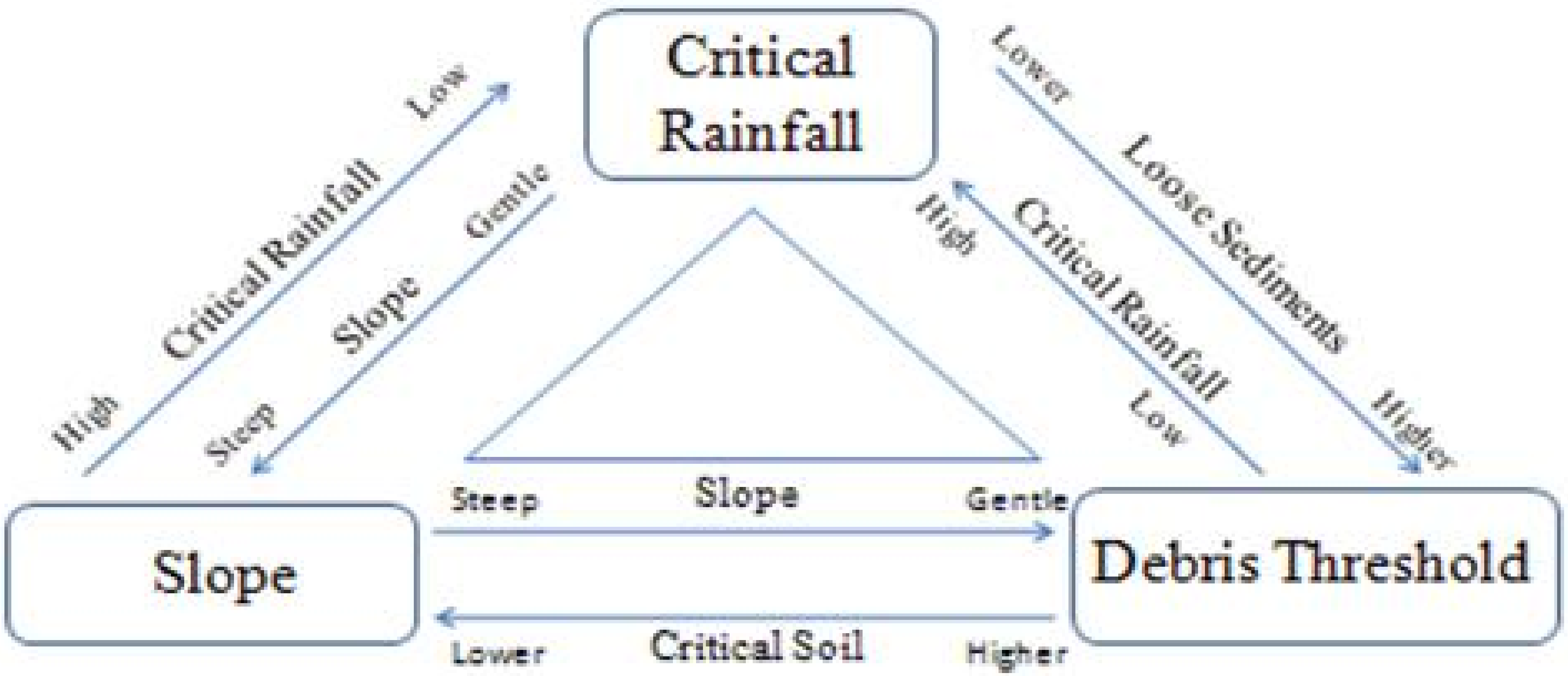
$$Cv = 0.223\left(\frac{\gamma_w hj}{(\gamma_s - \gamma_w)d_{50}}\right)^{0.48}$$

When the Cv (volume concentration) reaches 0.19, the fluid is debris flow. To get the flow of clean water, inversely calculate the rainfall, as the second-grade rainfall.
C_v（体积浓度）达到0.19，流体为泥石流。计算清水流量，反推雨量，作为二级雨量



Sketch of the stepwise multi-parameter debris flow warning system. Initial triggering from a susceptible site proceeds to later stages of monitoring and warning when critical rainfall limits are reached.

Three main factors responsible for debris flow initiation

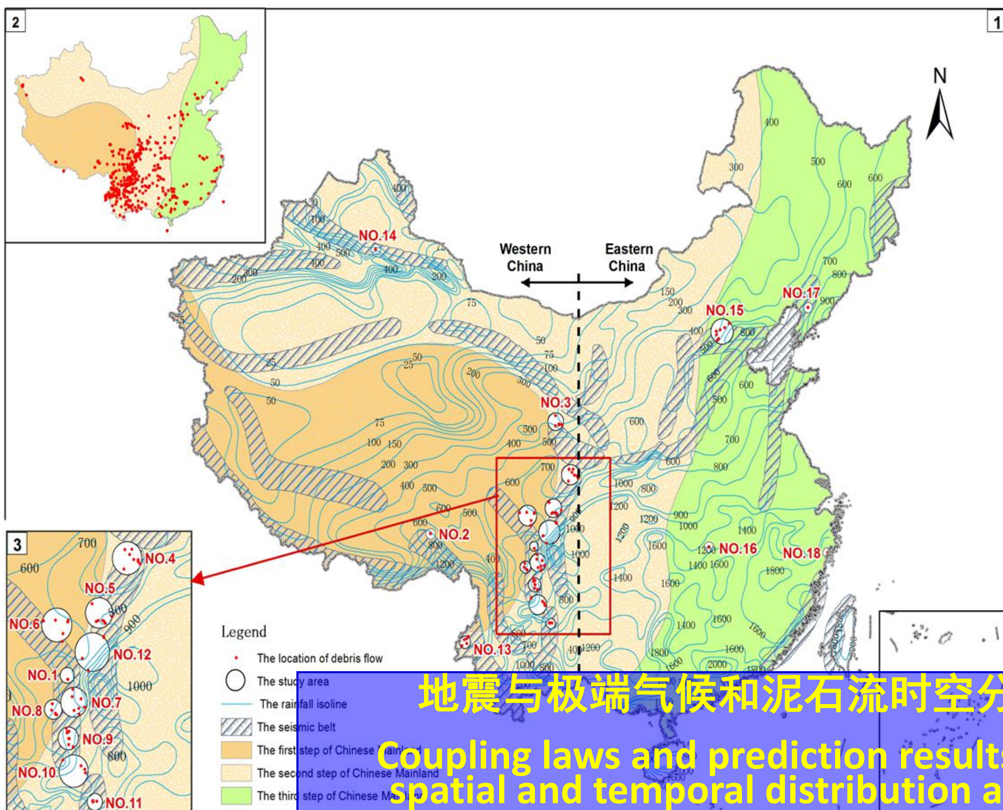


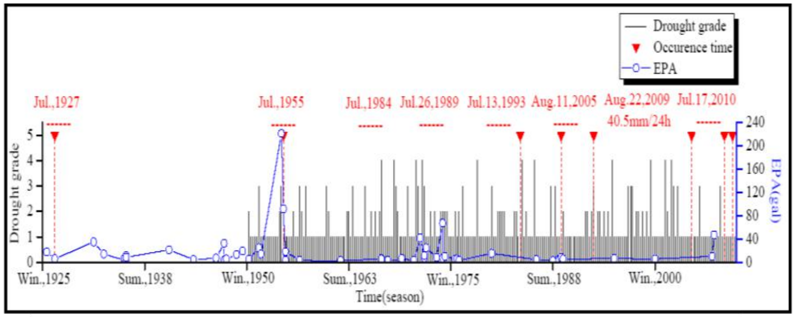
Early warning based on earthquake and drought

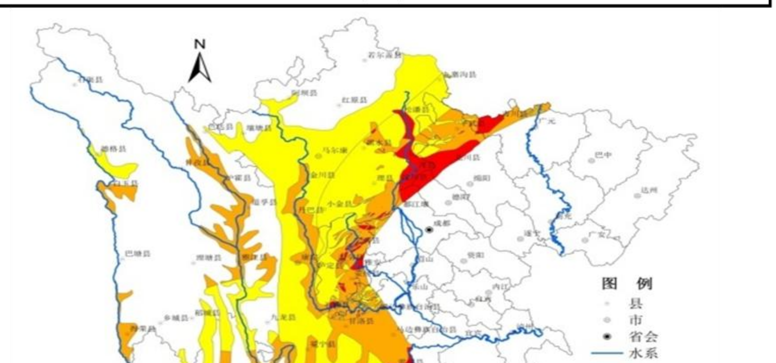
区域泥石流早期预测研究与应用

在对国内18个灾害性泥石流事件进行深入分析的基础上，课题组采用地震有效峰值加速度（EPA）和标准化降水指标（SPI）对地震与干旱的影响进行量化对比分析。研究表明，地震活动与干旱事件联合促进中国山区灾害性泥石流的发育。

On the basis of an in-depth analysis of 18 catastrophic debris flow events in China, we used seismic effective peak acceleration (EPA) and standardized precipitation index (SPI) to quantify and analyze the impact of earthquake and drought. The results show that the combination of seismic activity and drought events promotes the development of catastrophic debris flows in mountainous regions of China.



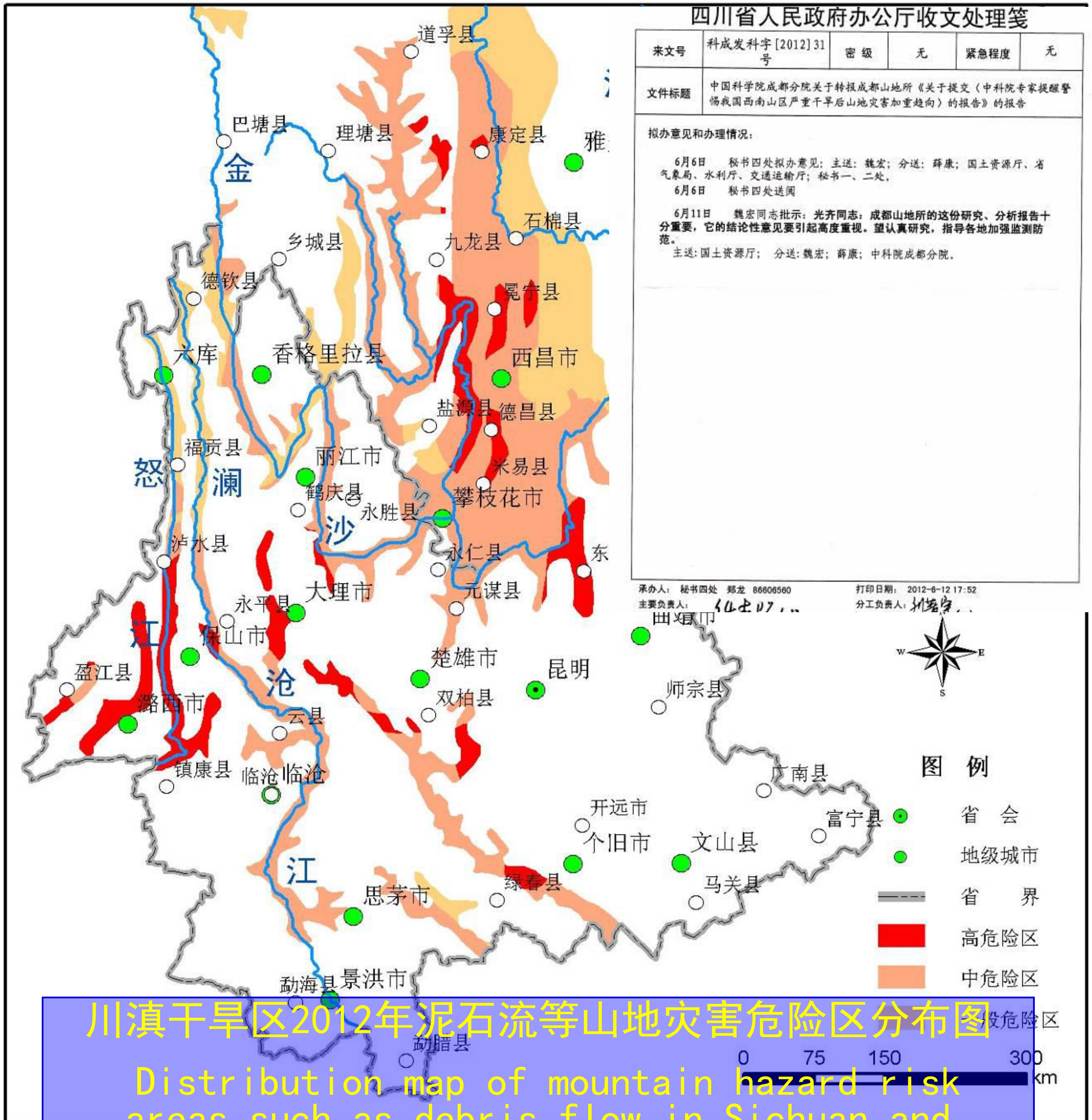




地震与极端气候和泥石流时空分布及规模频率的耦合规律与预测结果

Coupling laws and prediction results of earthquakes and extreme climate, the spatial and temporal distribution and the scale and frequency of debris flow

Early warning of debris flow disasters in **2012**: Based on the study of the impact of drought and earthquake on debris flow, landslides and other mountain hazards, based on the dynamic hazard zones and dangerous events of mountain disasters in 2010 and 2012, combined factors such as historical events, topography and geology, we complete the **traditional mountain disaster risk zoning**, predict the **possibility of frequent regional mountain disasters**, and put forward. **suggestions for regional mountain disaster prevention**

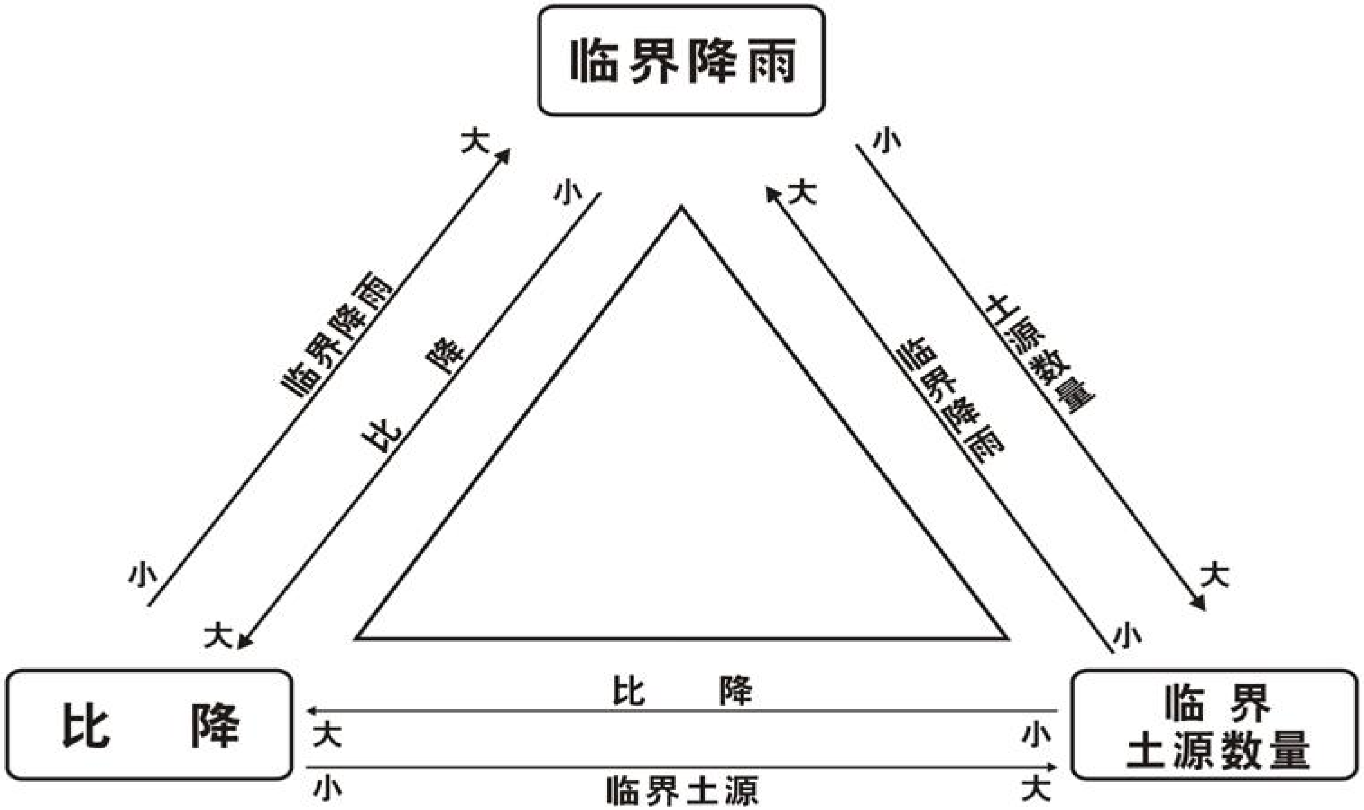


川滇干旱区2012年泥石流等山地灾害危险区分布图

Distribution map of mountain hazard risk areas such as debris flow in Sichuan and Yunnan arid area in 2012

基于泥石流形成主控条件的早期动态预警系统

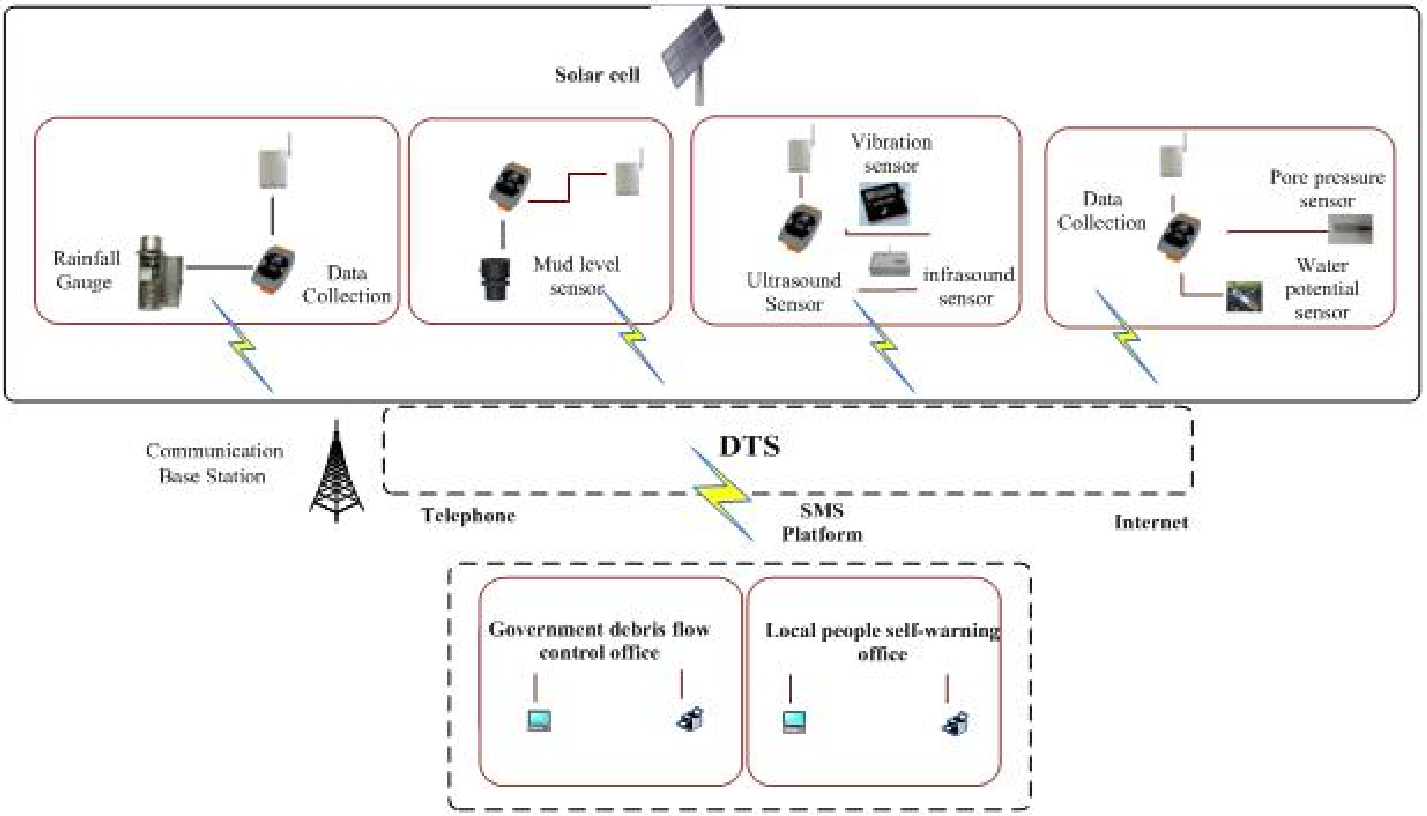
Early dynamic early warning system based on main control condition of debris flow



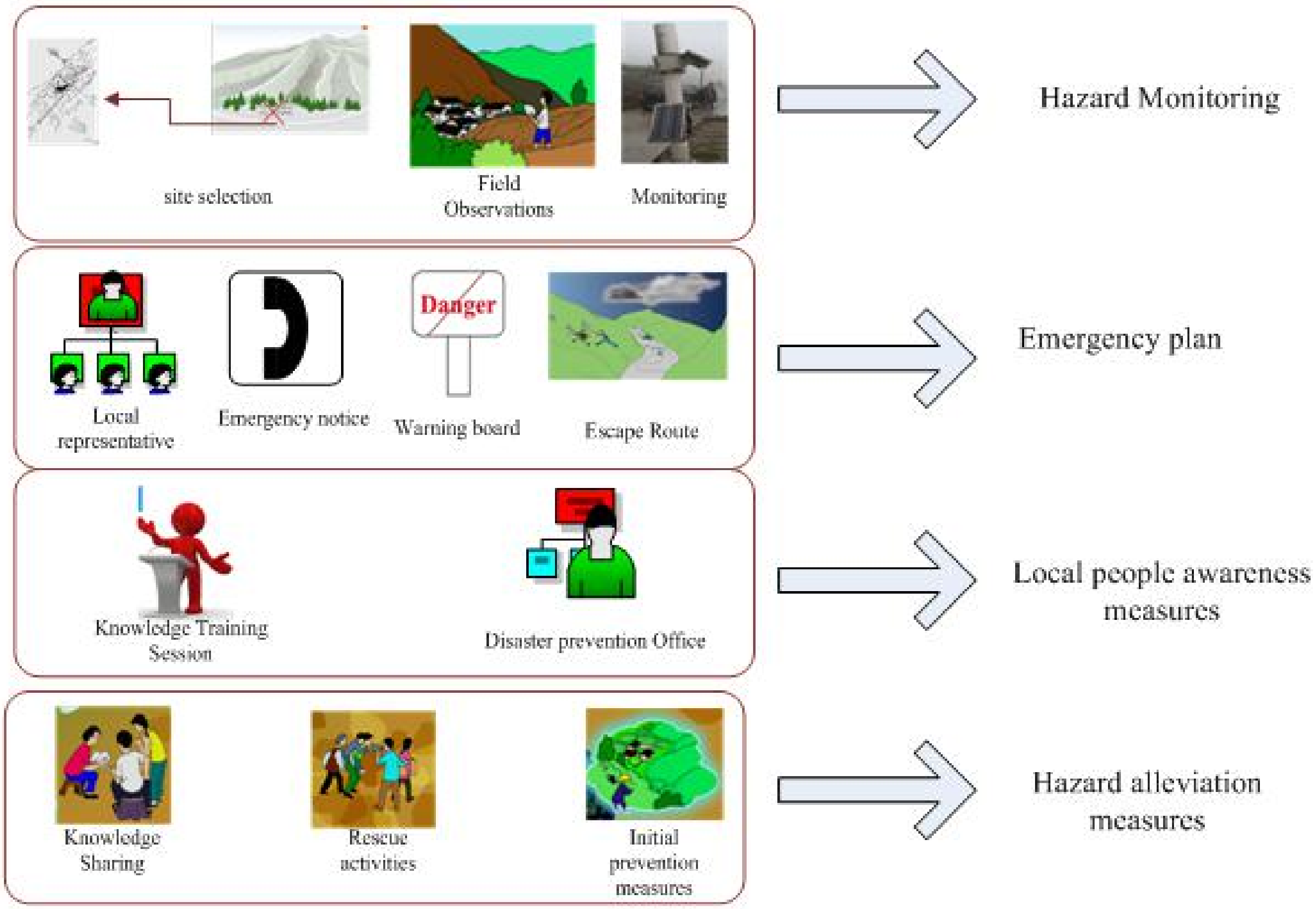
泥石流形成主控因素关系

The relationship of main controlling factors of debris flow

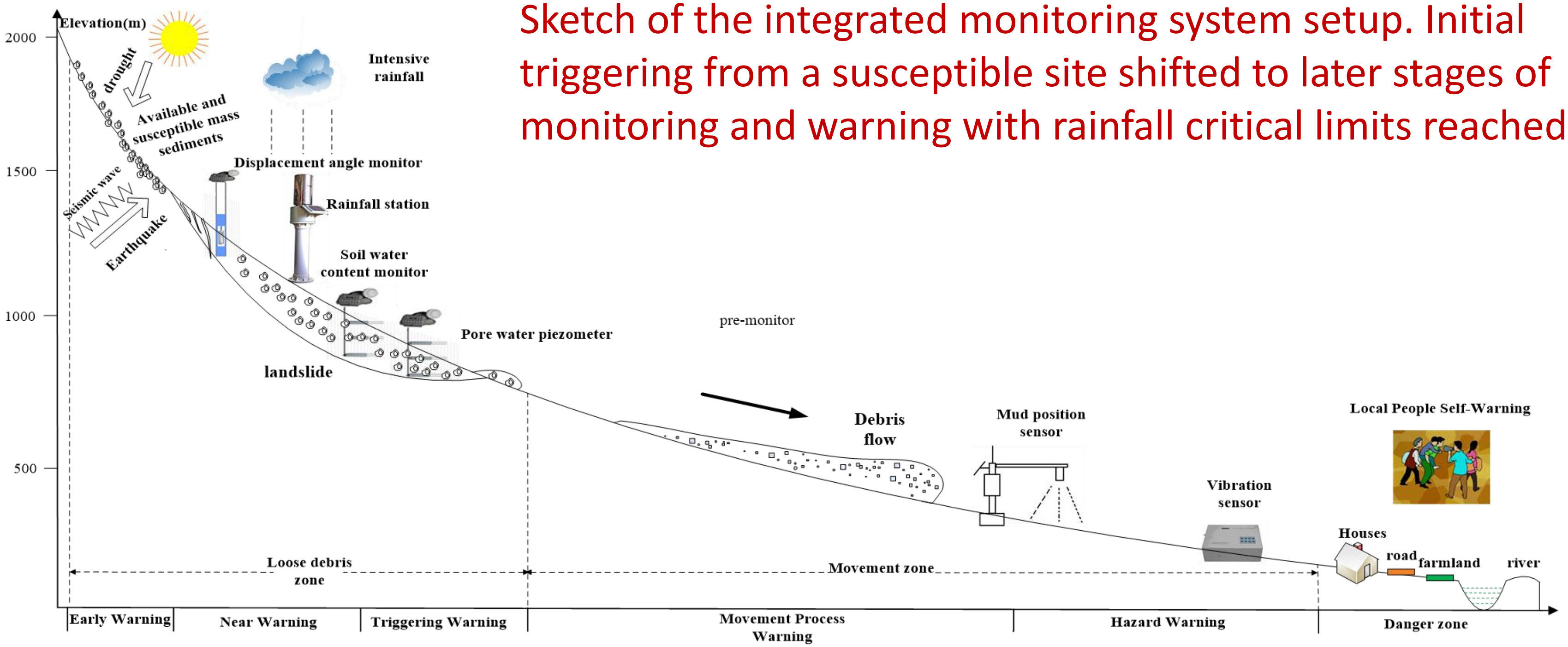
Technical scheme of flow monitoring and communication system

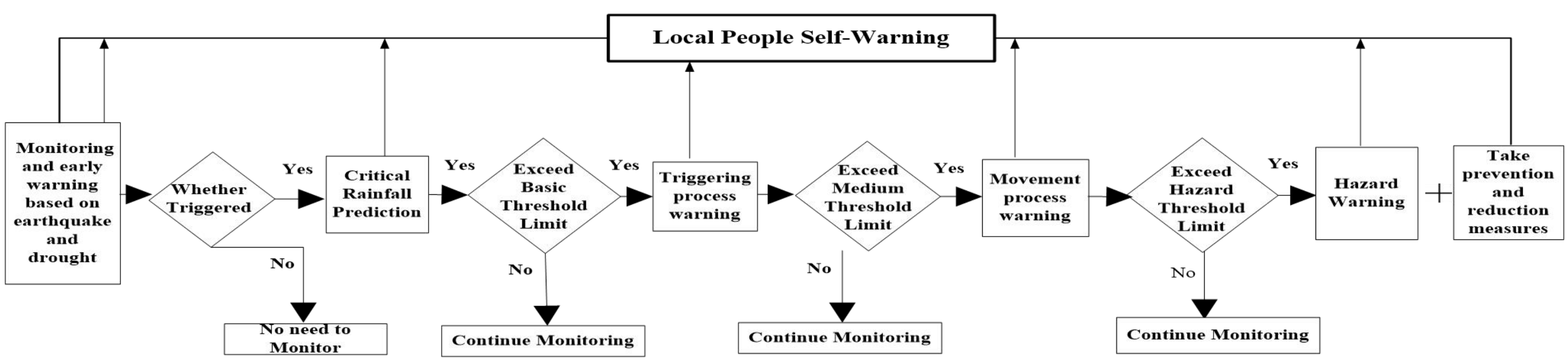


Local people Self-warning System



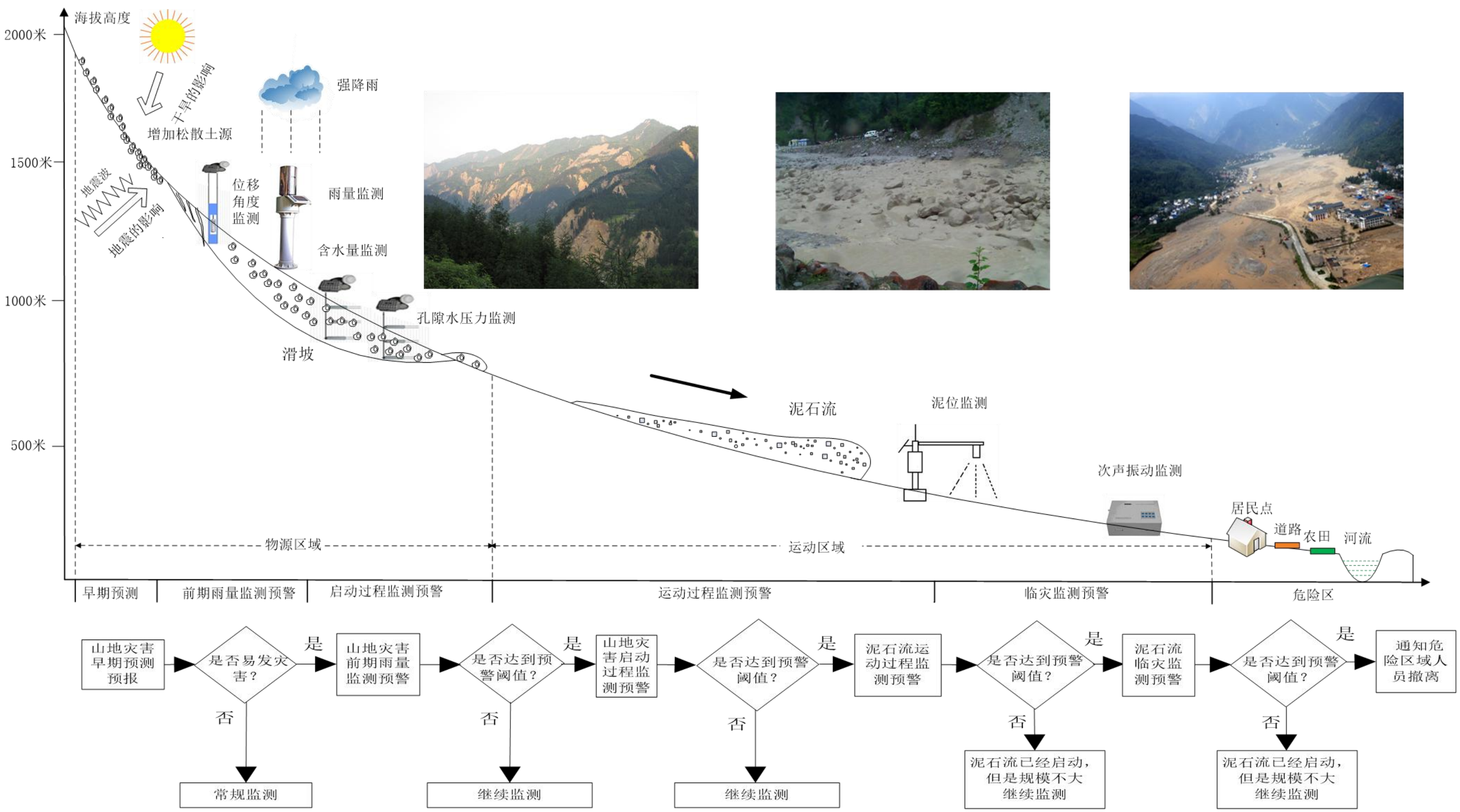
Sketch of the integrated monitoring system setup. Initial triggering from a susceptible site shifted to later stages of monitoring and warning with rainfall critical limits reached.





基于动态过程的泥石流监测预警技术体系

Monitoring and early warning technology system of debris flow based on dynamic process



灾害案例1

The heaviest debris flow hazards in 2012

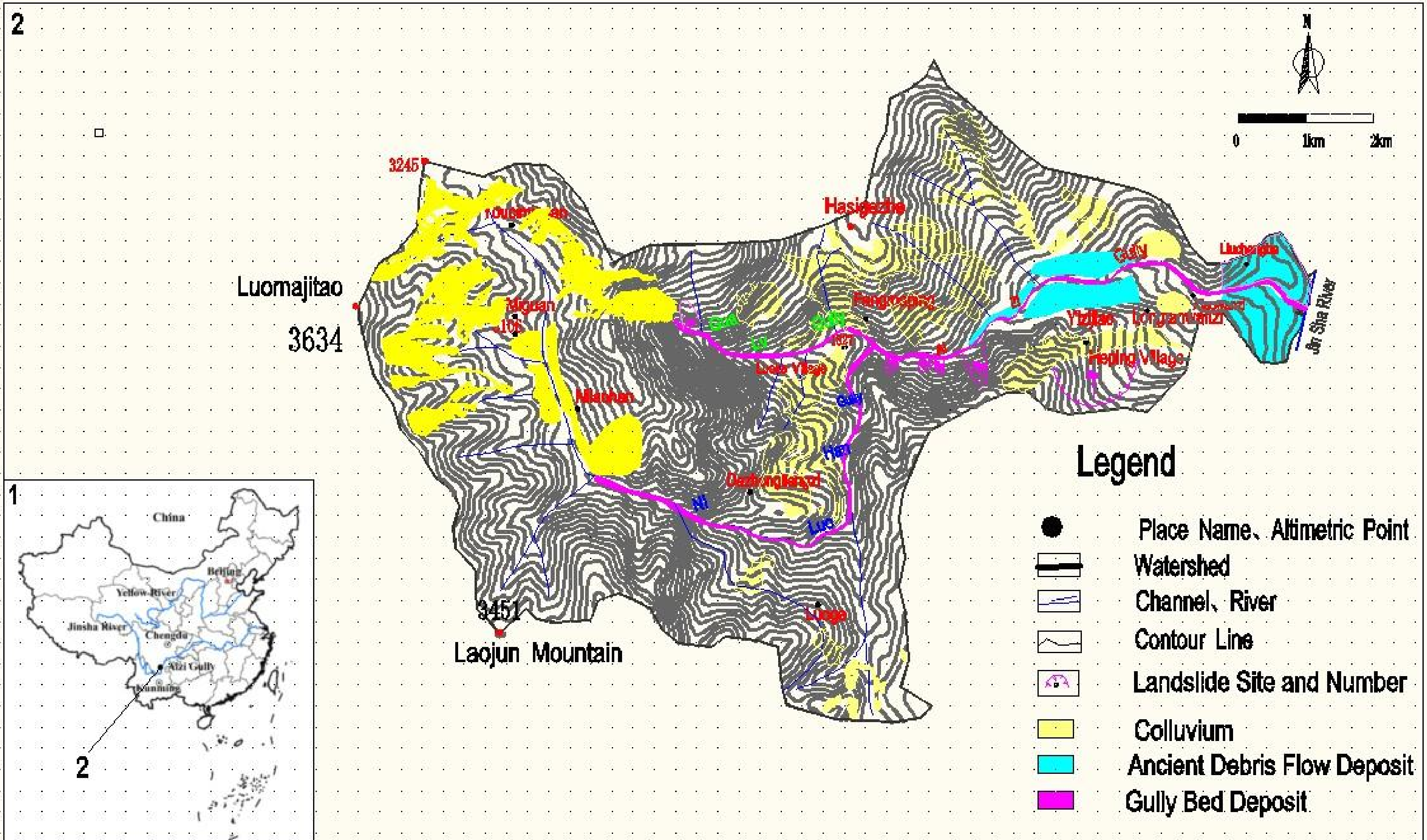
2012年6月28日，凉山州一工地发生特大泥石流灾害，造成40人死亡和失踪。

On June 28, 2012, a huge debris flow disaster occurred at a construction site in Liangshan, causing 40 deaths and disappearances.

CASE STUDY

- Aizi Valley is chosen as a case study which lies near the region of Baihetan Hydropower Station having capacity of 15 million kW.
- The local climate is of subtropical monsoon which is warm and slightly dry.
- The annual average temperature is 19.0 °C
- The average annual rainfall is 960.5 mm
- The drainage area of Aizi valley Basin is 65.55 km^2
- The average longitudinal slope of the main channel is 155 ‰
- The highest altitude is 3646 m while the lowest altitude is 604 m
- There are 10 villages and 577 residents in the basin.

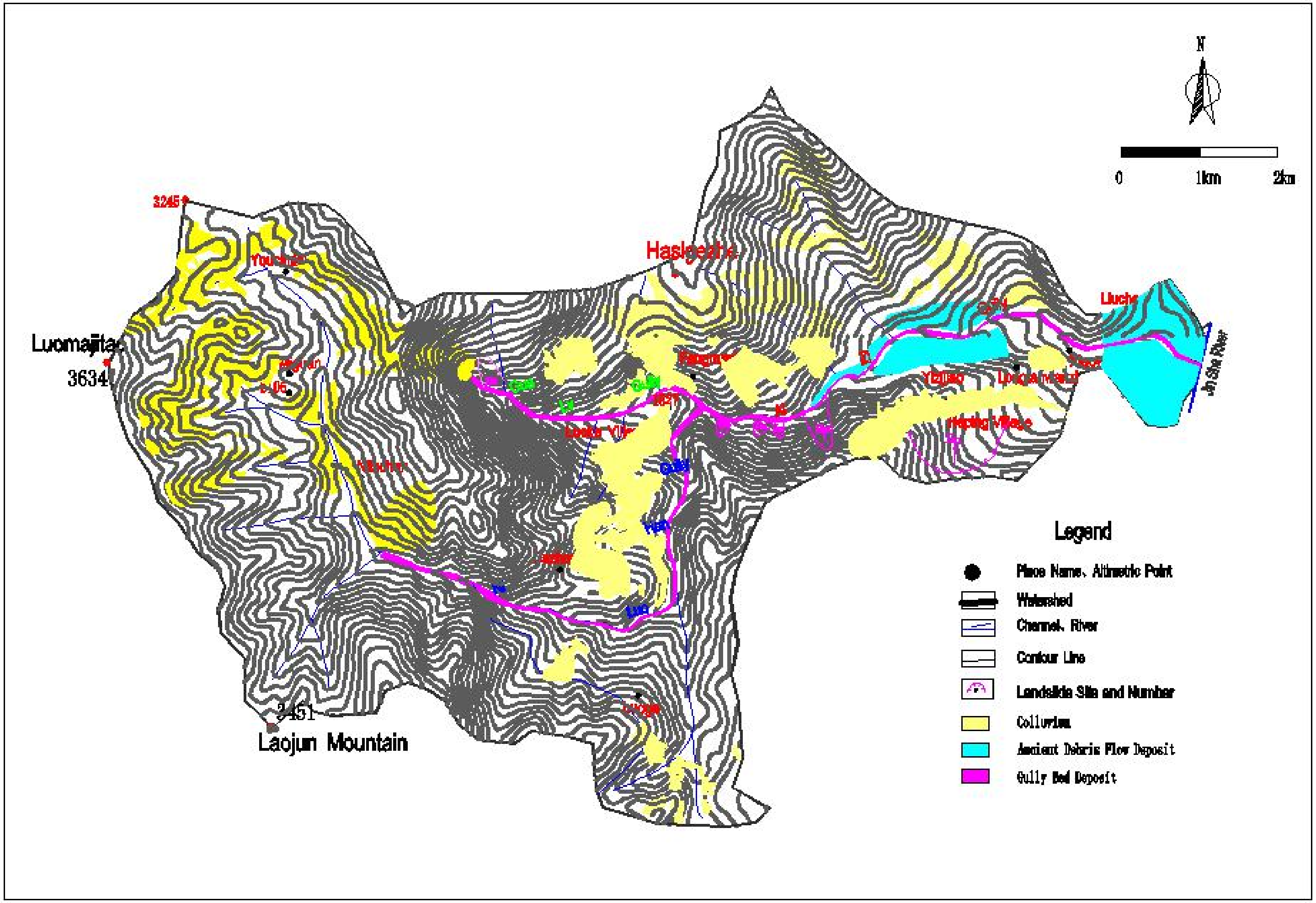
Distribution of loose mass within Aizi valley



矮子沟流域松散物源分布图

Distribution of loose mass within Aizi valley

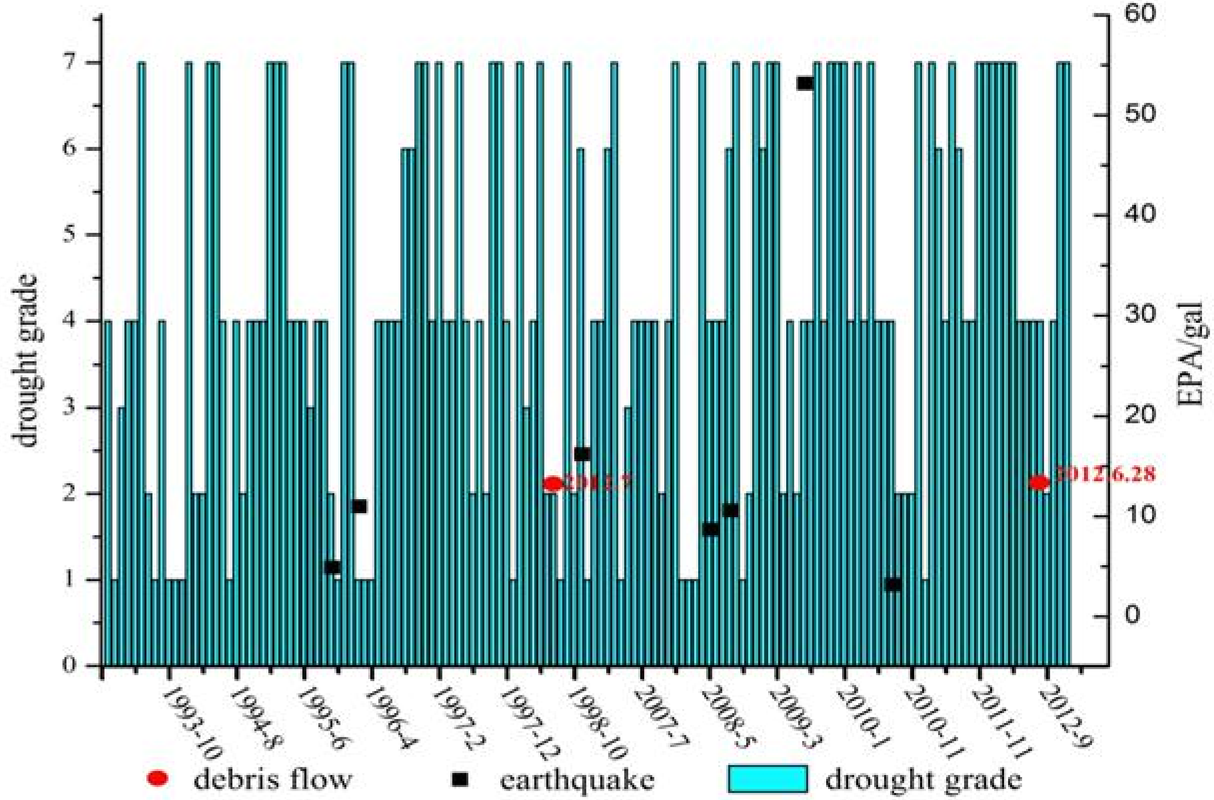
汇水面积：65.55km
主沟比降：155‰



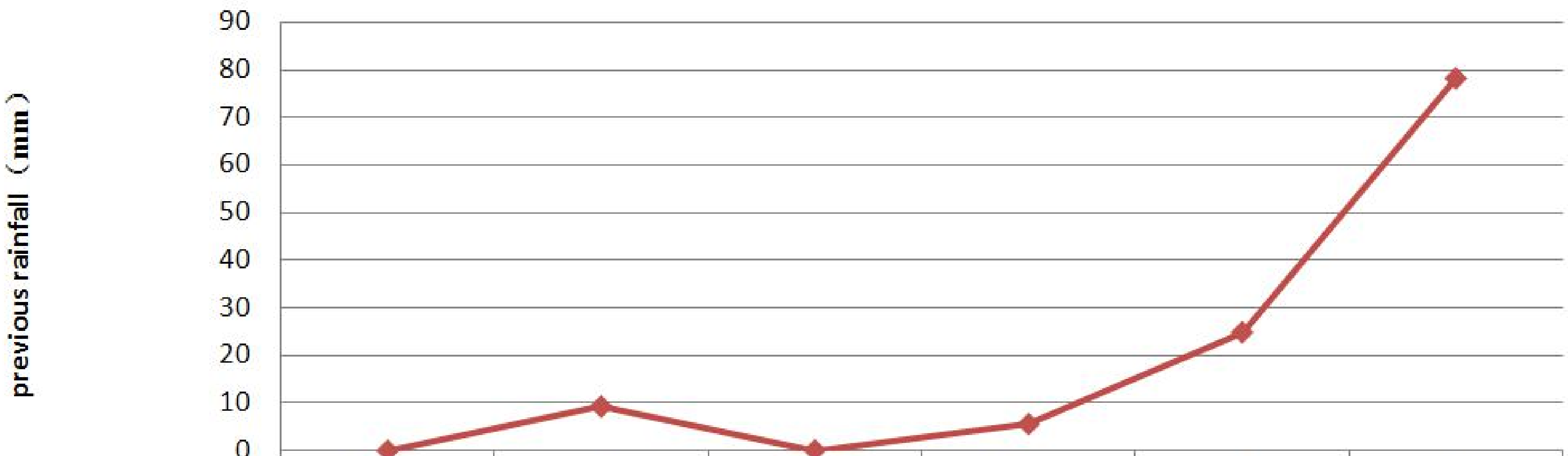
物源方量统计表（万m³）

流域沟段	残积物	崩坡积物	滑坡堆积	老泥石流堆积	总计
泥罗汉沟	407.09	445.24	90.10		
瓜绿沟	940.18	158.50			
矮子沟	1041.54	554.60	765.00	411.00	
总计	2388.81	1158.34	855.1	411.00	4813.25

Earthquakes, Drought and Debris Flow increase the loose solid materials in Aizi valley. Data presented from 1993-2012



Graph showing five day cumulative precipitation at Xintian Metrological Station



	6.23	6.24	6.25	6.26	6.27	6.28
Xintian Station	0	9.3	0.1	5.6	24.9	78.3

矮子沟泥石流的前期降雨量

Previous rainfall

Critical rainfall threshold calculation in field

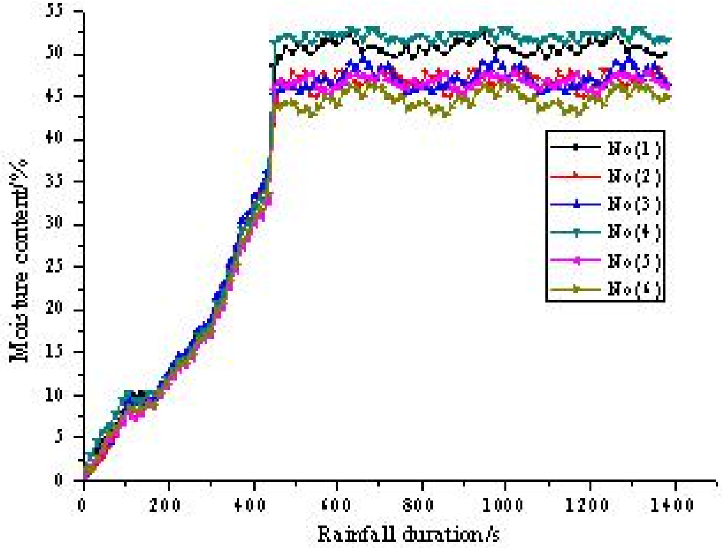
Table 2. Critical rainfall thresholds on the basis of experiment and model calculation

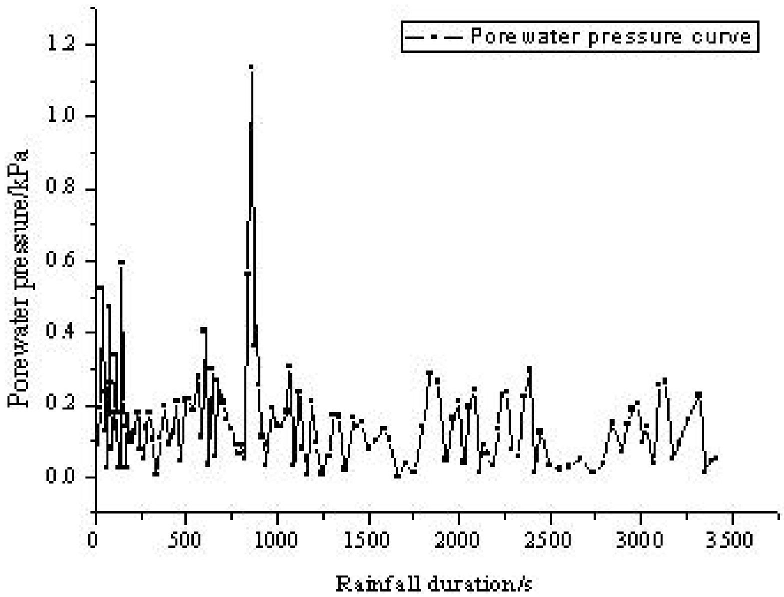
Rainfall Thresholds	Confirmation basis	Rainfall (mm)
Initiation rainfall R_0	Experiment	20.3
Confluent rainfall R_1	Model calculation	25.3
Hazard rainfall R_2	Model calculation	30.4

a. Experimental process

b. Data collection system

Moisture content and pore water pressure variation curves during rainfall





临界指标的确定

Determination of critical indicators

- **Critical precipitation index**

bed initiation corrected model: $q = 4\frac{d_{90}^{1.5}}{(\tan\theta)^{1.17}}$

中铁西南院对中小流域暴雨洪水计算方法： $Q = 0.278 r_p i_B \eta F$

降水量	确定依据	雨量结果
启动雨量 R_0	试验方法	20.3
汇流雨量 R_1	模型计算	25.3
成灾雨量 R_2	模型计算	30.4

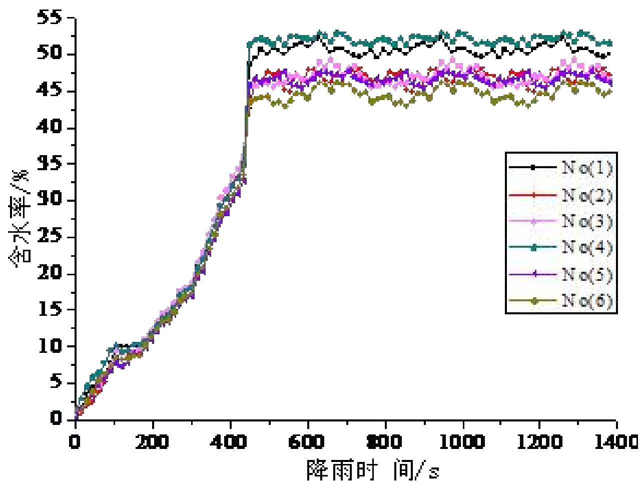
泥石流发生频率和暴雨频率计算泥石流临界雨量的方程:

The equation to calculate debris flow critical rainfall:

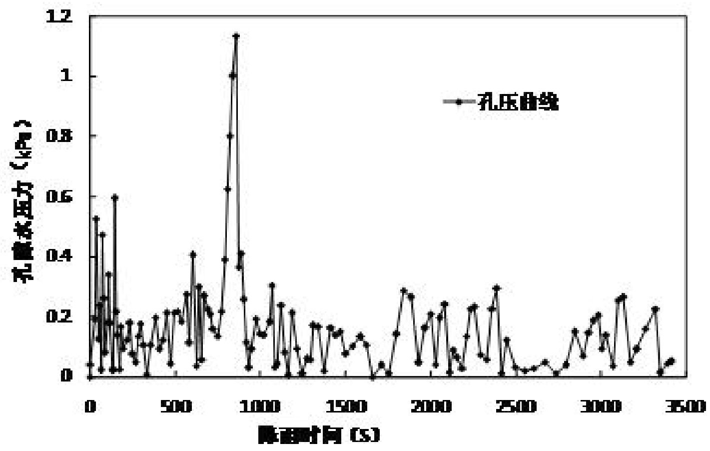
$$k = -0.1 \times x_1 + 0.073 \times x_2 + 0.6$$

临界指标的确定
Determination of critical indicators

- **Pore pressure and water content index**



a. Curve of water content change



b. Curve of pore pressure change

When the water content does not reach the peak value, the soil begins to **creep**. The corresponding **water content** at the beginning of the creep deformation of the soil body is about **30%**, and after the water content reaches the **peak**, the soil body quickly destabilizes and slides under the action of rainfall to form a debris flow. The corresponding peak value is about **46%**. Therefore, the **threshold value** of water content is the range value, and the range is **30% ~ 46%.**

The **pore pressure** from sudden increase to fall lasts about **1** minute, and the average value of pore pressure in this period is taken as the threshold value of pore pressure, which is **1.31kPa**.

临界指标的确定
Determination of critical indicators

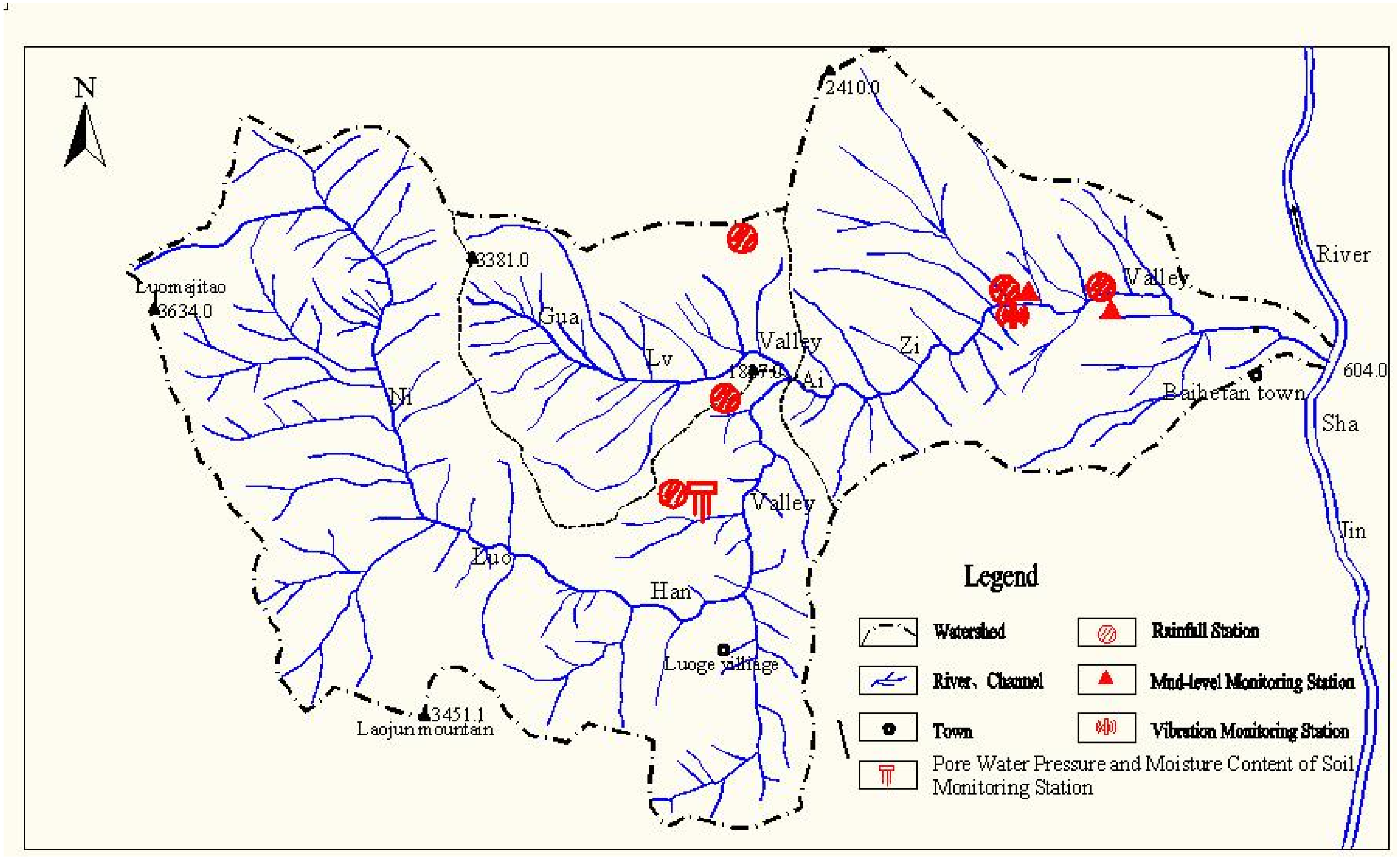
- **Flow stage index**

The analysis of the monitoring data of the flow stage index in the Aizigou watershed showed that when the mud level reached **1.73m**, multiple debris flows of varying slopes in the watershed **broke out**. Large-scale debris flows are easy to break out, so the **flow stage index** is set to **1.73m**.

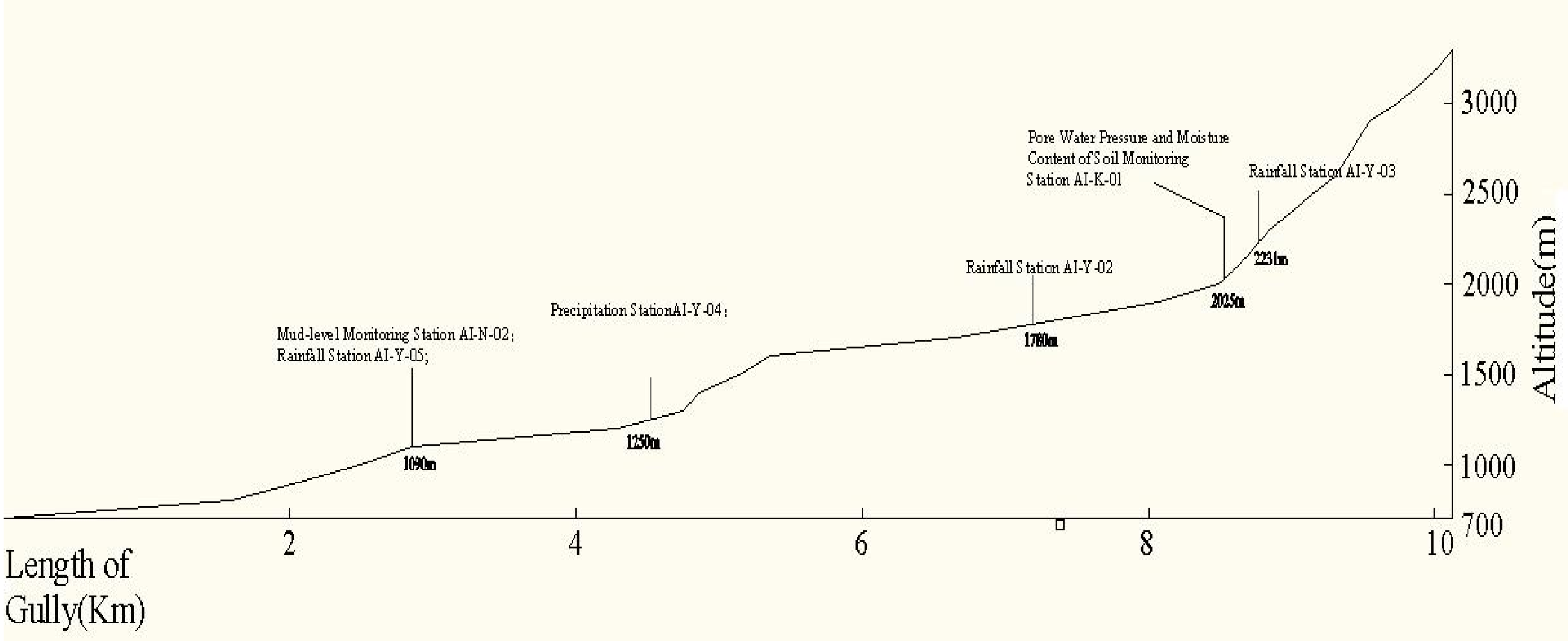
临界指标的确定
Determination of critical indicators

- **Vibration index**
- Jiangjia Gully in Dongchuan, Yunnan, has relatively complete vibration observation data. It has been found through years of observation and statistics that when the vibration acceleration value is 100 gal, it is very likely that a debris flow will **occur**. Based on this, the seismic index is determined to be **100 gal**.

The distribution of debris flow monitoring stations in Aizi valley



The distributing profile of debris flow monitoring stations in Aizi valley



金沙江白鹤滩水电站矮子沟泥石流监测站点剖面分布图

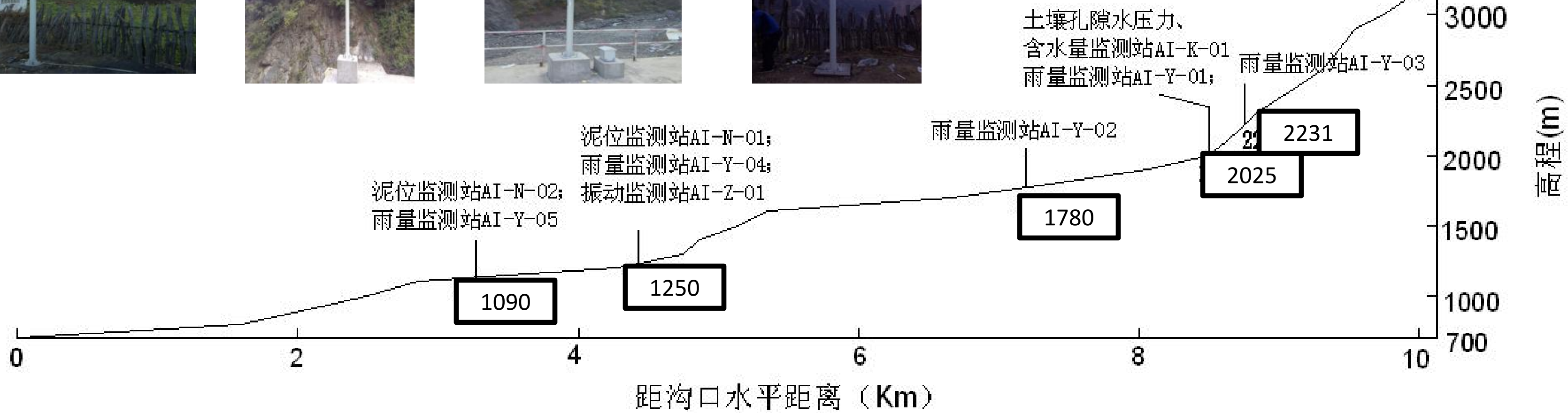
Profile distribution of the debris flow monitoring site of the Aizi Gully in Baihetan Hydropower Station on Jinsha River

矮子沟杉木箐村雨量站

矮子沟1号坝泥位站

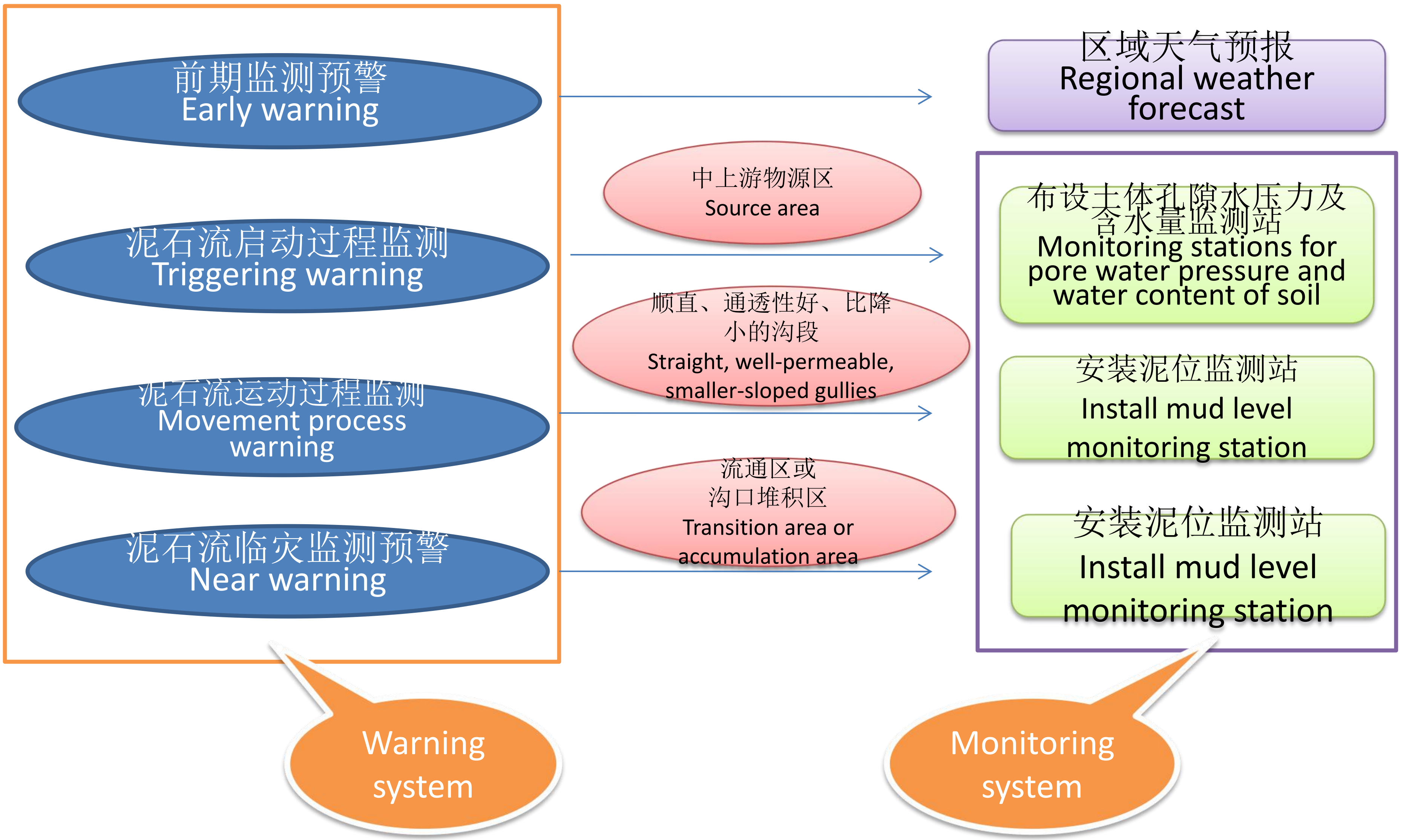
矮子沟1号坝振动站

矮子沟1号孔压含水站



序号	站点编号	所属流域	泥石流流量(m^3/s)				泥石流警戒泥位（m）			
			P=1%	P=2%	P=5%	P=10%	P=1%	P=2%	P=5%	P=10%
1	AI-N-01	矮子沟	940.91	877.43	708.24	571.99	3.62	3.02	2.46	1.98
2	AI-N-02	矮子沟	963.13	897.93	724.09	584.10	7.46	6.84	5.27	4.38

监测系统与应用
Monitoring system and application



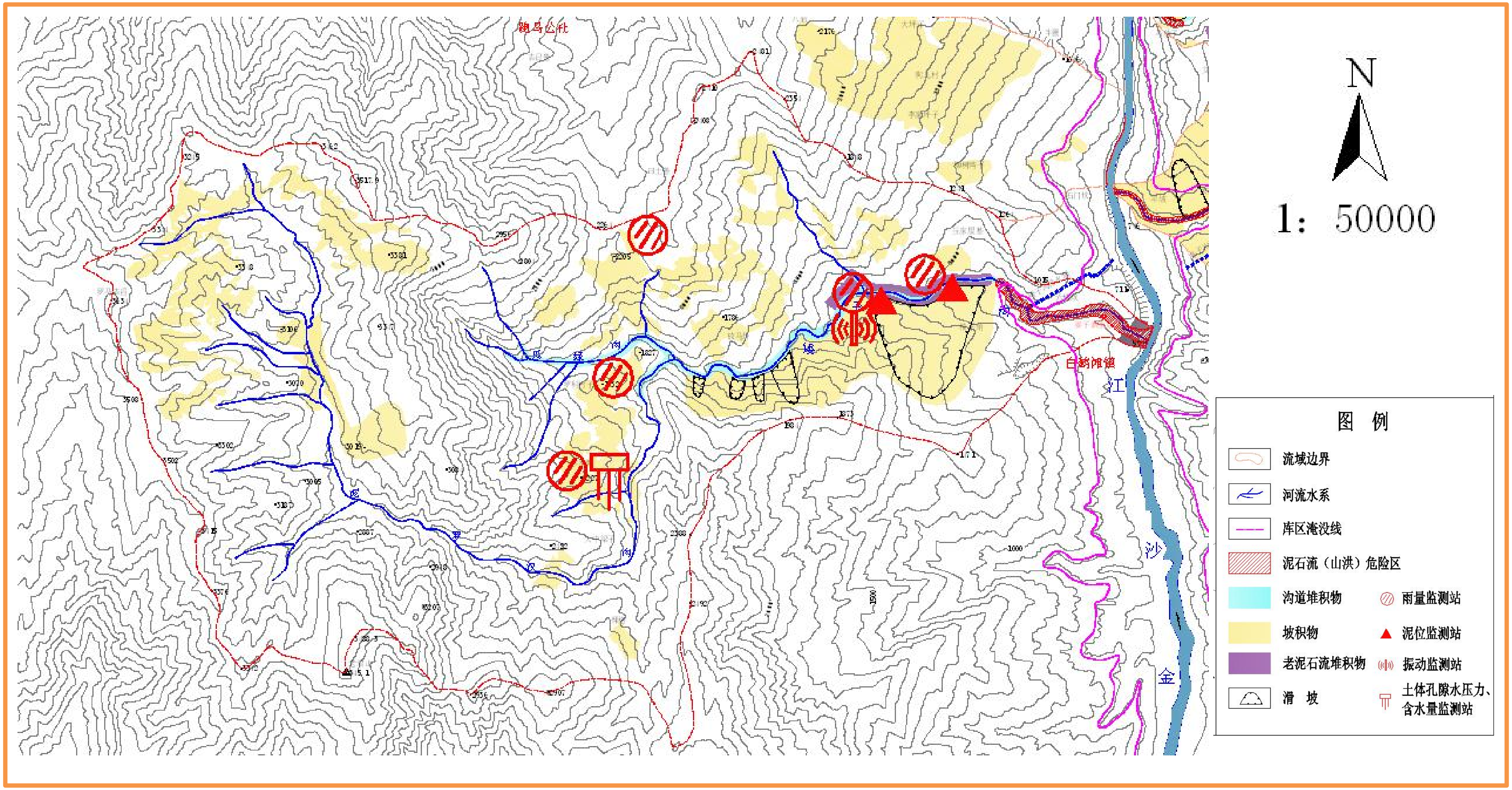
矮子沟泥石流监测站点分布表

Distribution table of debris flow monitoring stations in Aizi Gully

流域	流域面积（km^2）	站点类别	数量（个）	安装地点	布设高程（m）
矮子沟	65.55	雨量站	5	倮格乡杉木箐村村委会（小学）空地	2025
				倮格乡罗科村子安置点	1780
				跑马乡放马坪垭口	2231
				矮子沟泥石流防治工程 1 号拦挡坝	1250
				矮子沟泥石流防治工程 2 号拦挡坝	1090
		泥位站	2	矮子沟泥石流防治工程 1 号拦挡坝	1250
				矮子沟泥石流防治工程 2 号拦挡坝	1090
		孔压含水站	1	倮格乡杉木箐村村委会坡地	2025
		振动站	1	矮子沟泥石流防治工程 1 号拦挡坝	1250

矮子沟泥石流监测站点平面分布图

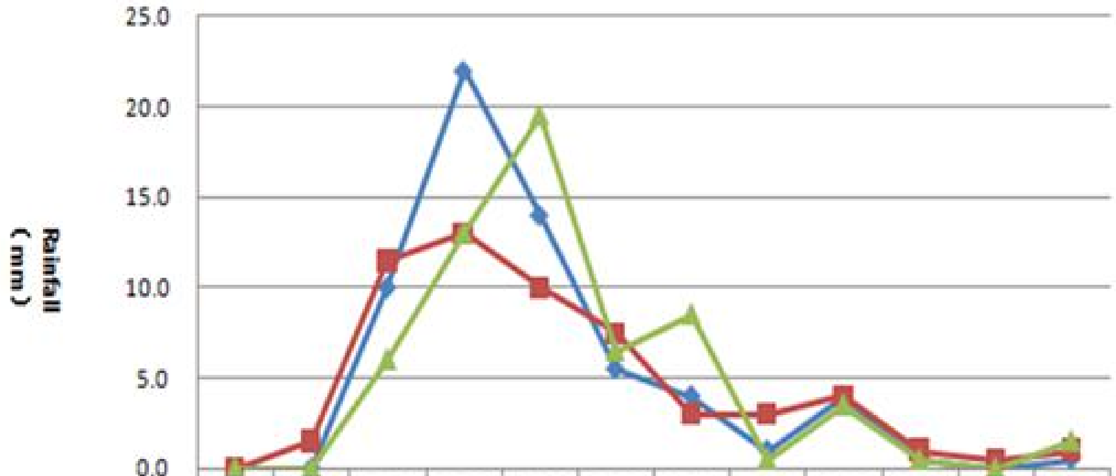
Distribution map of debris flow monitoring station in Aizi Gully



Debris flow monitoring stations in Aizi valley

Basin	Basin area (km^2)	Site category	Number of stations	installation site	Height (m)
Aizi valley	65.55	Rainfall station	5	Opening space of Shanmuqing village committee (primary school) in Luoge Town	2025
				Luokecunzi site in Luoge Town	1780
				Bealock of Fangmaping in Paoma Town	2231
				NO. 1 check dam of Aizi gully debris flow prevention projects	1250
				NO. 2 check dam of Aizi gully debris flow prevention projects	1090
		Mud level station	2	NO. 1 check dam of Aizi gully debris flow prevention projects	1250
				NO. 2 check dam of Aizi gully debris flow prevention projects	1090
		Pore pressure and water potential station	1	Sloping fields of Shanmuqing village committee in Luoge Town	2025
		Vibration station	1	NO. 1 check dam of Aizi gully debris flow prevention projects	1250

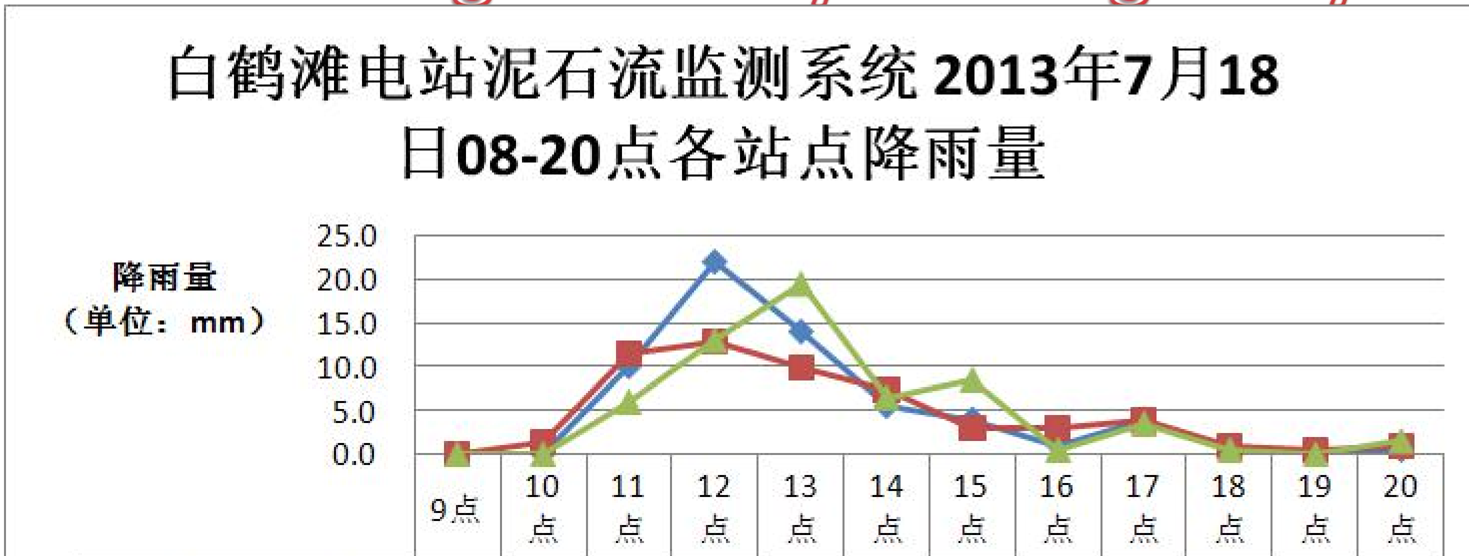
Rainfall stations data on July 18, 2013.



	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
Aizi Gully 2# dam	0.0	0.0	10.0	22.0	14.0	5.5	4.0	1.0	4.0	0.5	0	0.5
Yakou in Aizi gully	0.0	1.5	11.5	13.0	10.0	7.5	3.0	3.0	4.0	1	0.5	1
Chepingyizhai in dazhai gully	0.0	0.0	6.0	13.0	19.5	6.5	8.5	0.5	3.5	0.5	0	1.5

监测预警实践分析

Monitoring and early warning analysis



	9点	10点	11点	12点	13点	14点	15点	16点	17点	18点	19点	20点
矮子沟2号坝	0.0	0.0	10.	22.	14.	5.5	4.0	1.0	4.0	0.5	0	0.5
矮子沟垭口	0.0	1.5	11.	13.	10.	7.5	3.0	3.0	4.0	1	0.5	1
大寨沟车坪彝寨	0.0	0.0	6.0	13.	19.	6.5	8.5	0.5	3.5	0.5	0	1.5

In May 2013, the Aizi Gully was monitored. On July 18, heavy rain occurred in the region. According to the characteristics of the regional rainstorm. It was determined that its rain intensity reached 22mm in one hour, and the early warning system issued a level 1 warning.

As a result, it was found that only the slope soil in the watershed collapsed, the main gully had no debris flow confluence, and only high-sand flow occurred with a flow rate of $5m^3/s$.

Conclusions

- This warning system consists of 6 parts i.e. Early warning, Near warning, Triggering warning, Movement process warning, Hazard warning and Local people self-warning.
- In this warning system various thresholds have been defined based on the initial triggering, movement process and hazard triggering stages of debris flow.
- Although the empirical thresholds described in current research are a fundamental constituent for a comprehensive warning system, yet there are several questions that need to be answered; the mismatch between the short lifespan of monitoring systems and the low frequency of disasters, restriction in the accurate prediction of critical rainfall and the unreliability of the monitoring equipments.
- Early warning of debris flow is based on the quantity and distribution of these loose solid materials that are influenced by earthquake, volcanic eruption, human engineering activities.

Continued…….

- The critical rainfall scale for debris flow varies significantly within a basin. Based on debris flow initiation, movement and hazard process, some triggering experiments, bed erosion model and statistical analysis are applied to check the threshold of critical raining.
- Local people self warning system is divided into four parts which includes the guidance from the government, local people precautionary measures, knowledge sharing and early escape practice.
- This system provided successful results in Aizi gulley debris flow warning


Welcome to your cooperative research!
Thank you!