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Procedia Earth and Planetary Science 2 (2011) 247 – 254
Procedia
Earth and Planetary Science

The Second International Conference on Mining Engineering and Metallurgical Technology

Real-time warning system of regional landslides supported by WEBGIS and its application in Zhejiang Province, China

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Abstract

As one of the provinces of highest economic growth in coastal China, Zhejiang Province is experiencing serious geological disasters during the past development of economy, which are mainly induced by intensive rainfall during typhoon season or by long-term rainfall from May to June every year. Thus, supported by WEBGIS, a real-time warning system of regional landslides is studied. According to the characteristic of rainfall in Zhejiang province, the study divides the province into typhoon region and non-typhoon region, using statistic approach to study the correlation of regional landslides hazards and rainfall, rainfall intensity of typhoon region and non-typhoon region. By correlation analysis, effective rainfall model is defined, and the thresholds of effective rainfall and rainfall intensity are obtained. Combining these thresholds with spatial prediction production of landslides hazards, predictive models for landslide warning of Zhejiang Province are established. Then a real-time warning system of regional landslides explored by WEBGIS software is successfully developed considering both regional geology and rainfall process information.

*Keywords:*landslide, prediction, real-time warning, effective rainfall, rainfall intensity, WEBGIS; typhoon;

1. Preface

Although landslide occurrence essentially depend on certain factors, such as topography, geological structure, lithology and so on, certain other exterior factors are also very important to slop instability, such as rainfall, earthquake, excavation, loading and water fluctuation. Rainfall, especially rainstorm, is an important and most frequent among these factors. 15 geo-hazards of 27 enumerative significant geo-hazards are induced by rainstorm in the paper of *Case study of significant geo-hazards in China*[1].

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1878–5220
doi:10.1016/j.proeps.2011.09.040

Above 95% of more than 90 landslides have close relation with rainfall or groundwater seepage, among which the majority occurs in rainy season [2]. In Zhejiang Province, about 90 % of sudden geo-hazards are triggered by rainfall. Thus, study on landslides prediction and warning supported by weather forecast is progressively regarded, and many countries and regions have developed this study.

As one of the provinces of highest economic growth, Zhejiang Province is experiencing serious geological disasters during past development of economy, such as landslides, debris-flows, rock falls, and so on. Geo-hazard occurrences have tight relation with the referred clime. During August to September every year, coastal southeast regions are swept by tropic storms frequently, and it causes rainstorm that easily brings numerous onset geo-hazards of landslides, rock falls and debris flows. Thus, it is essential to establish a real-time forecasting and warning system for sudden geo-hazards[3].

The key to this system is to integrate spatial prediction results with time forecast. When typhoon or rainstorm is coming, it can upload spatial prediction zonation map, monitored data of important geo-hazards and real-time rainfall to the warning system by Internet or other communication styles, and combining the warning models to issue the real-time warning information on Internet. One side, the system studies landslide warning models; on the other hand, it develops real-time warning system coupling regional geology and meteorological information for regional landslides based on WEBGIS. On the basis of landslide spatial prediction, combining real-time weather information, this system can predict spatial position and failure time of landslides.

2. Real-time landslide warning model coupling regional geology and meteorological information

The past studies of predicting landslide through rain were mostly from rain aspect, and hardly considered geological factors, so the reliability and accuracy of warning results would be greatly decreased undoubtedly. Landslide warning coupling regional geological and meteorological information is an effective method to warn the onset regional landslides.

In this system, based on historical landslide information of four demonstrated counties (Chun'an, Pan'an, Qingyuan and Yongjia in Zhejiang Province), according to rain traits of this province, the regions assaulted by typhoon are concentrated in southeast Zhejiang Province, and the areas affected by plum-rain are focused on the mid-west. Therefore, Qingyuan and Yongjia located in southeast are considered as the typhoon-affected regions, and Chun'an and Pan'an located in mid-west are deemed as non-typhoon–affected regions. Based on the information, the paper sets up the geological models for different areas and geological conditions, and analyzes the coupling relationship of regional geology and meteorological information through Stat. method.

2.1 Regional landslide spatial prediction of Yongjia

Regional landslide hazard analysis requires knowing the hazard probability or intensity of occurrence in a research region during a specific period. If landslides occurrence is regarded as a random event, the task of hazard analysis is to estimate the probability or return period of hazard occurrence with various possible intensities. From the aspect of qualitative analysis, higher degree landslide activities are, more hazardous landslides are. But from the aspect of quantitative analysis, hazardous degree should be reflected from detailed indexes. This article discusses semi-quantitative analysis of regional landslide hazards, which has been expatiated in the part of spatial prediction. In terms of regional background, environmental factors and triggered factors of landslide, adopting some approved predictive models (Information value model, Expert graded model, Neutral net model, and so on), landslide spatial prediction can be developed, and the predictive production can predict spatial location.

2.1.1 Factors and categories

Located in southeast coast in Zhejiang province, Yongjia mainly suffers rain-induced landslides. In this region, landslides are dominated by lithologic formation, topography and geological structure, and triggered by human activities and high intensity rain.

Considering lithologic formation, topography and geomorphology, hydro-geological condition, vegetation, and so on, according to historical landslides, Information value model is applied to predict landslide potential site of Yongjia. In this study, nine factors are selected at first. By using correlation analysis, two factors (relative difference in elevation and elevation of slope toe) are eliminated, being relatively high correlation with other factors. So, five environmental and two triggered factors, slope gradient, lithologic formation, faults distribution, water system, land-use types, annual rainstorm days and human activities (road distribution is mainly considered), are selected for modeling.

2.1.2 Procedures of landslide hazard mapping and superposing mapping

According to selected factors, landslide distribution map and seven factor maps are compiled on the same scale of 1:100 000. Furthermore, these maps are digitized on GIS platform. And these digitized factors maps are respectively superposed with the landslide distribution map to create quantitatively factor information maps and compute the information values in terms of GIS analysis function and its customization. The bigger the information value is, the more favorable landslide hazard of the category occurs. Theoretically, negative information means unfavorable action for reducing uncertainly. Forecasting equation can be founded by single information value (Formula 1).

$$I_i = 0.572x_1 + 1.599x_2 + \ldots + 1.485x_{24} \qquad (1)$$

Then, seven individual information maps are further superposed to generate sum information map that presents comprehensive contributions by all factors and their categories, and it is the basic quantitative map for hazard zonation.

2.1.3 Grading landslide hazard

Sum information value for each unit is computed by formula 1 and then critical values confirmed. Critical values, abstract forecasting numbers whether landslides occur, are the most important evidence for landslide hazards zonation. In the paper, two methods, stat. method according to landslide density and Fast clustering method[4,5], are adopted to decide critical values, which can insure reasonable grading[6]. Then landslide hazard zonation map that indicates different hazard levels compiled (Figure 1).

2.2 Landslide prediction and warning combined with rainfall

Determination of thresholds of rainfall intensity and effective rainfall are based on the analysis of historical rainfall associated with landslide occurrences during the period of 1980-2001 in Zhejiang Province, and 263 rainfall-induced landslides is collected with detail information in the study. According to landslide scale, 246 as small-scale. In terms of the material of slopes, there are 257 soil and detritus landslides. And in the research, 17530 records of daily rainfall data between 1980 and 2001 are collected. From the information, it concludes that landslide occurrences concentrate on June-September each year [7].

2.2.1 Effective rainfall model

Considering that one rain process not always induce landslide occurrences and only part rainfall of one rain process influences landslide, cumulative rainfall can't be deemed as critical rainfall obviously. Hence, effective rainfall is recognized, which could be obtained by using this day's rainfall in some time multiplying effective rainfall coefficient [8]. While deciding effective rainfall coefficient, it intends to adopt power exponent form (Formula 2).

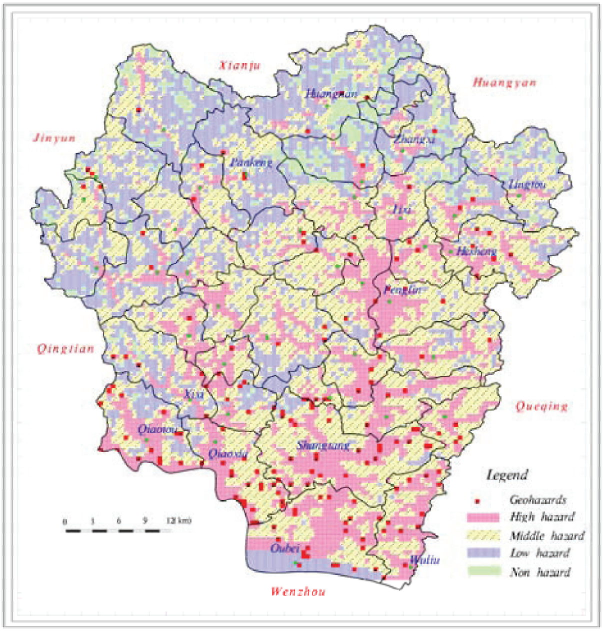

Figure 1. Geological disasters hazard grading map of Yongjia County based on Information value model

$$R_c = R_0 + \alpha R_1 + \alpha^2 R_2 + \cdots \alpha^n R_n \quad (2)$$

R_c : effective rainfall; R_0 : this day's rainfall; R_n : rainfall before n days; α : effective rainfall coefficient; n: the passing days. According to Stat. analysis of historic information, for non-typhoon region, α =0.8; for typhoon region, α =0.7.

2.2.2 Confirmation of critical rainfall

According to the information of rainfall and historical landslides, whether in typhoon or non-typhoon region, landslide intensity is low at any rainfall to non-susceptive area of geo-hazard; to low susceptive area, when rainfall is quite a bit big, landslide intensity just increases and the increment is small; to high susceptive area, landslide intensity is the most, and with increase of rainfall, landslide intensity increases obviously (Figure 2). In the curve, vertical presents the frequency of landslides, and horizontal presents accumulative effective precipitation from past 30 years data.

2.2.3 Confirmation of critical rainfall considering geology and weather

Among 263 landslides with detail information, considering large-scale and moderate-scale landslides as one type, and small-scale as one type, critical rainfall of two kinds are confirmed respectively in terms of landslide scale. For small-scale landslides, the curves of figure 3 presents two critical rainfall values where the gradient is steep are found out which caused obvious increase in landslide increasing: 175 mm and 250 mm, For large-scale and moderate-scale landslides, when effective rainfall reaches 200 mm and 300 mm respectively, landslide numbers will increase obviously. Thus, these values are deemed as critical values [9].

According to the above statistic results, rainfall hazard level is divided into three grades: low hazard, moderate hazard and high hazard, which correspond to two thresholds respectively (Table 1 and Table 2).

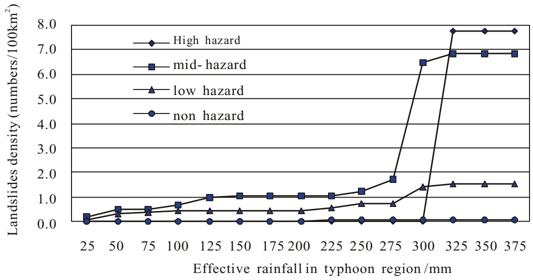

Figure 2. Curve of effective rainfall in typhoon zone

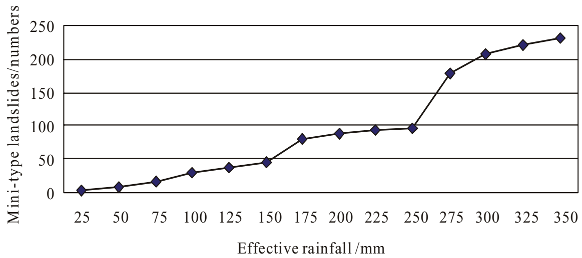

Figure 3. Curve of effective rainfall and small-scale landslide

Table 1. The thresholds and hazard grades of rainfall triggering different zones of landslides

	Low hazard		Medium hazard		High hazard	
	non-typhoon region	typhoon region	non-typhoon region	typhoon region	non-typhoon region	typhoon region
Rainfall intensity (mm)	0~50	0~90	50~130	90~150	≥130	≥150
Effective rainfall(mm)	0~150	0~125	50~225	125~275	≥225	≥275

Table 2. The thresholds and danger grades of rainfall triggering different scales of landslides

	Low hazard		Medium hazard		High hazard	
	Small landslide	Large and moderate landslide	Small landslide	Large and moderate landslide	Small landslide	Large and moderate landslide
Effective rainfall (mm)	0~150	0~200	150~250	200~300	≥250	≥300

2.3 Landslide warning coupling regional geology and weather

After receiving real-time precipitation value or regional precipitation contour from weather forecast department, spatial landslide zonation map can overlap precipitation distribution map to get the warning area in terms of mathematical model analysis. Table 3 displays the result of superposing the hazard grades of rainfall and landslide.

Table 3. Early-warning grades

		Hazard grade for rainfall		
		Low hazard	Moderate hazard	High hazard
Spatial hazard grading for landslide	High hazard	2nd warning region	4th warning region	5th warning region
	Moderate hazard	1st warning region	3rd warning region	4th warning region
	Low hazard	1st warning region	3rd warning region	3rd warning region
	Flat	1st warning region	1st warning region	2nd warning region

Corresponding to four landslide hazard grades, warning level is divided into five grades. In the first warning region, geo-hazards may occur hardly within 24-h; geo-hazards may slightly arise within 24-h in the second warning region; in the third warning region, monitoring work of geo-hazards should be strengthened and some prevention measures adopted; geo-hazards should be monitored whole day, field work near the geo-hazards stopped temporarily and rainfall change cared closely in the fourth warning region; in the fifth warning region, geo-hazards probably occurs within 24-h and should be monitored whole day, and it is essential to give an alarm [10,11].

3. Real-time landslide warning system based on WEBGIS

The system is mainly composed of two models, including rainfall processing, warning information processing and message releasing.

A mesoscale numerical forecasting mode, the well-known MM5, is localized to forecast accumulated rainfall within 48-h. The rainfall is forecasted and output by 6-h、12-h、24-h and 48-h, which present convenient for landslide forecasting. The trials in plum rain from 2003 to 2004 displayed the localized MM5 had a good forecasting capability and satisfied the practical demand for landslide real-time warning.

Considering there is not many rain data in the system, SQL database is selected to build rainfall database, which is operated by ODBC and ADO. By making use of special program compiled, the provincial rain data is processed and input into the database in bathes.

Real-time rainfall records of rain gauge stations distributed in Zhejiang Province are obtained via Zhejiang Provincial Meteorological Observatory and the information are gathered and processed timely. On this basis, needed data styles (pictures, texts, data) are generated and then uploaded to Server (Figure 4). Rain information mainly includes continuous practical rain and continuous predictive rain (Figure 5).

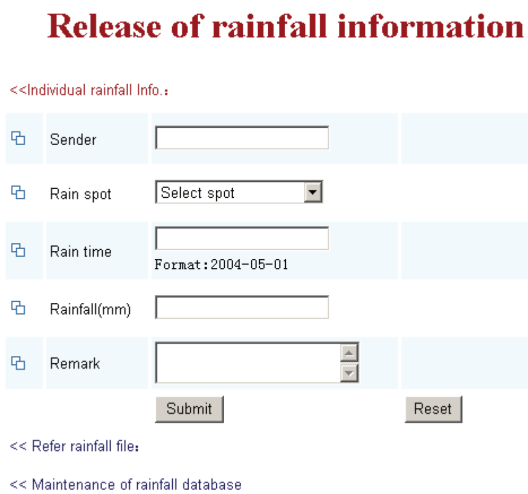

Figure 4. Upload interface of observatory's rain data

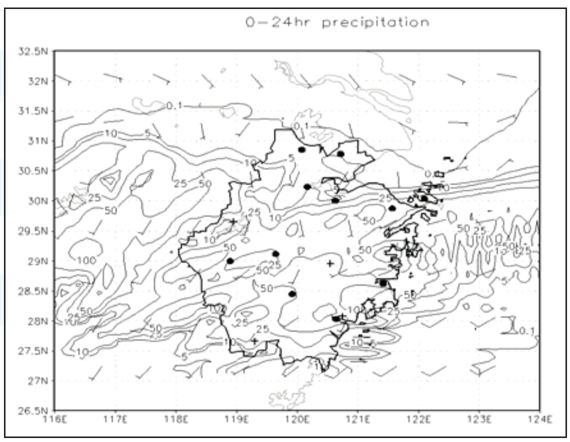

Figure 5. Predictive rainfall of Zhejiang province

After obtaining the data from rainfall database, Server processes the information quickly. Via rainfall processing module, effective rainfall is calculated and hazard rain-graph gained, and this map is superposed by landslide hazard zonation map, then warning map is obtained(Figure 6). According to these results, the government releases warning messages on Internet.

Real-time warning system of regional landslides supported by WEGISB in Zhejiang province had been developed at 2004, and launched into test-run in May.During Typhoon Rananim hitting Zhejing province in August , the system undertook the landslide warning work, and obtained good economy and social benefits.

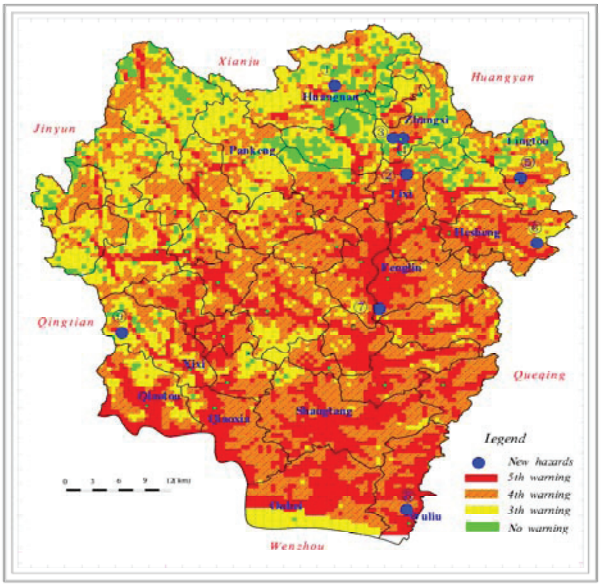

Figure 6. The geo-hazards distribution in geo-hazard predictive map of Yongjia

3. Real-time warning instance based on WEBGIS

Typhoon Rananim made landfall at Shitang town, Wenling city of Zhejiang province at 0:20am on August 12, 2004, and the strongest wind at its center reached above level 12 (45 m/s). It arrived with extremely strong wind and large amounts of rainfall. In Zhejiang Province, from 8:00am August 11 to 8:00am August 14, there were 275 hydrological observation stations at which rainfall exceeded 100 mm, 79 stations with rainfall exceeding 200 mm and 36 stations with rainfall over 300 mm. The biggest rainfall reached 916 mm at Futou station, Yueqing city, Wenzhou district, among which rainfall was 661.8mm within 12-h and 874.7mm within 24-h. All data broke the highest historical records of Zhejiang Province. Heavy rains triggered many landslides and debris flows in the northern part of Yueqing, and neighboring cities (Yongjia, Xianju, Pan’an) also encountered landslides and debris flows. Rananim caused tremendous economic losses in Zhejiang Province, and damage bill is likely to reach 18 billions RMB (US$2.16-billion). A total of 115 people were killed and more than 1,600 injured by typhoon, floodwater and landslides.

During typhoon Rananim, the warning system started up timely and developed the landslide real-time warning in studied area Yongjia. Before Rananim landing, from 10 to 11 August 2004, according to its possible landing location and strength, the system was applied to release two suggestive landslide forecasts respectively. Since 8:00am August 12, in terms of diverse track of Rananim and rainfall, combining landslide spatial prediction result of Yongjia, the system released newly real-time warning information every 4-h, and notified the most likely hazardous region prone to landslide occurrences, which provided timely and reliable information for local government.

8 landslides are located in 5th warning region and 1 located in 4th warning region among 9 newly landslides((Figure 6)). According to the released warning map on Internet, Bureau of Land and Resources of Yongjia organized evacuation timely, and there were no casualties caused by landslides in this county.

4. Conclusions

Regional landslide hazard prediction and warning is still a problem and focus in the research of landslide hazards. In this article, a real-time warning system of regional landslide hazards was set up, with the development on WEBGIS platform. Taking landslides during the period of typhoon Rananim of 2004 in Yongjia county of Zhejiang province as examples, basic theories were discussed from two aspects in the article: spatial prediction and time warning.

In this system, by analyzing the relationship between historical landslides and rainfall, the rainfall thresholds of studied area were obtained. In rainy season, local weather service station presents day rainfall and predictive rainfall within 24-h for this system on Internet or through other communication approaches, and the system forecasts the likelihood of landslide occurrences and grades the warning level through the warning model, then timely releases the warning message on Internet. In terms of the feedback analysis of practical occurred landslides, such landslide predictive mode based on regional geology and rainfall process can improve the accuracy and real time of landslide warning.

Acknowledgements

This study was supported by the National Natural Science Foundation of China (Grant No. 51009097).

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