METHODOLOGY ON GEOLOGICAL DISASTER INVESTIGATION AND RISK ASSESSMENT FOR HIGHWAY IN MOUNTAINOUS AREAS BASED ON REMOTE SENSING

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ABSTRACT: Problem: Owing to the geographical location of mountain highways, they are easy to be damaged by geological disasters such as debris flow and landslide, resulting in huge property losses and human casualties. Given the magnitude and complexity of transportation systems, near-real time field-based assessment is simply not an option. One technology, regarded as the most effective way in disaster investigation and warning, is remote sensing. **Methodology:** This paper reviews recent advances in geological disaster investigation and risk assessment for mountain highway based on remote sensing, and proposes the framework for geological disaster management. Firstly, in geological disaster detection, visual interpretation and image classification are the main methods based on the image characteristics including shape, tone, texture, and so forth. Additionally, object-oriented technology is a new method to extract thematic information from high resolution imageries. For improving the identification efficiency and precision, the knowledge base can be introduced to share interpretation knowledge. With the distribution of disasters, their relations with lithology, topography, and etc. can be studied to derive the spatial rules of geological disasters. Secondly, in risk assessment of geological disaster, weights of evaluation factor can be ascertained with analytic hierarchy process (AHP) method, and the risk levels can be evaluated quantificationally by multiple linear regression analysis, fuzzy integrate evaluation or other methods. Through the integration of database, analysis models and decision models, the disaster reduction decision support system against disasters along highways can be set up for estimation of the risk levels, and exercising appropriate control measures to reduce the risk. **Conclusions:** Remote sensing technology is an effective way in geological disaster investigation and risk assessment for highway in mountainous areas. The results can supply reference for hazards prevention and route selection of highway.

1. INTRODUCTION

The highway construction is gradually moving into high gear in recent years and has promoted the economic boom in China. Transportation, especially highway transportation has become the arteries of society. In particular, with the implementation of China's Great Western Development Strategy, lots of highways in Western mountainous regions are being constructed and the highway transportation plays the much more significant role in promoting economic growth. However, Owing to such contributing factors as rough terrain, rainfall and underground water, the regions in Western China, has always been exposed to a wide variety of geological disasters, like debris flow and landslide. These geological disasters can damage the highway, which is the lifeline, block the transportation and delay the distribution of relief supplies, resulting in huge property losses and human casualties. When a disaster like the 2008 Wenchuan earthquake strikes, for effective incident response, it demands a rapid overview of damage sustained by numerous elements spreading over a wide geographic area. Traditionally, the geological disaster information of highway in mountainous region is obtained through field-based investigation. Yet this way is costly and limited in monitoring range. Given the magnitude and complexity of transportation systems, near-real time field-based investigation for geological disaster along highway in mountainous region is simply not an option.

One technology which has had an enormous impact on disaster management has been remote sensing. In the past decade, this technology has been used extensively to explain the extent of impacts caused by earthquakes, tsunamis, hurricanes, floods and wildfires. Through high-resolution optical imagery and active sensors, remote sensing technologies have demonstrated significant efficacies in quantifying post-disaster damage, monitoring recovery and reconstruction progress after significant disasters. Remote sensing technology is regarded as the most effective way in disaster investigation and disaster warning with its rapid, direct, comprehensive, macroscopic features. Remote sensing provides a wealth of images support for disaster monitoring. With these images, it is possible for not only the rapid identification and monitoring of disasters in wide areas, but also risk assessment of geological disasters along highway. In recent years, the remote sensing technology is applied increasingly widely and deeply in highway hazard in China. Particularly, during disaster emergency response of natural disaster, such as Wenchuan earthquake and Yushu earthquake, multiple departments in China got multi-source remote sensing data before and after the disaster through, obtained a lot of disaster information based on data processing and analysis, and achieved disaster quick survey in large-scale range. The result helped the disaster relief workers quick access to macro-information of the disaster in order to make decision of disaster relief. It also facilitated to analyze a variety of causes of disasters and morphological characteristics. Besides, with the temporal characteristics, the remote sensing technology is avail to help researchers understand the development of disaster for preventing and controlling the highway disasters.

This study is supported by “major highway disaster monitoring and assessment technology research based on remote sensing (2009318221097)” in Western Transportation project of Ministry of Transport. It focuses on the methodology of information identification and risk assessment based on remote sensing and forms the management framework for mountain highway geological disasters, which is the technological foundation for mountain highway disaster management and highway route selection. The result of geological disaster investigation and risk assessment can also provide basis for decision making for the relevant departments to disaster prevention and relief work.

2. BACKGROUND

2.1 Type and Hazards of Mountain Highway Geological Disasters

Natural disasters are diverse in China. Analyzed and summarized the existing researches and literature, the natural disasters, which have a more serious impact on the highway, can be classified as meteorological disasters and geological disasters. For the highway, the hazards are mainly due to severe geological disasters, including landslide, debris flow, collapse, earthquake and so on (Hu, 2011). Geological disasters usually damage the highway in mountainous region and directly impact on highway traffic capacity and traffic safety. For example, the Wenchuan earthquake in 2008 and theYushu earthquake in 2010 directly induced a large number of landslides and other secondary geological disasters causing a very serious damage for the mountain towns, villages and a variety of transportation facilities, water conservancy and hydropower facilities, tourism landscapes, etc. Especially, the geological disasters caused fatal damage to the highway system, creating great difficulties for disaster relief and reconstruction. According to statistics, during "5.12" Wenchuan earthquake occurring in 2008, highways in Sichuan, Gansu and other surrounding provinces were badly damaged, including 19 expressways, 159 national and provincial highways, 7605 rural roads. The length of damage highways were up to 47,277 km, while 5560 bridges and 110 tunnels were destroyed at the same time. The Zhouqu debris flow occurring on August 7, 2010, blocked many parts of three national and provincial highways. In Zhouqu county, the main roads were flooded or buried.

2.2 Study of Highway Geological Disaster Based on Remote Sensing

Remote sensing technology, with the characteristics of systematic and macroscopic, is appropriate for study of geological disasters. In the 1970s, since the loss caused by destruction of geological disasters became more and more serious, some developed countries started to do disaster monitoring and assessment with remote sensing. After 1980s, the technology has begun to receive widespread national attention. Japan prepared the l: 50,000 national geological hazard maps with remote sensing images. European countries summarized systematically the remote sensing methods on the basis of landslide and debris flow survey, and demonstrated the required spatial resolution of remote sensing images for identification the landslide and debris flow in different size, different brightness and contrast (Wang, 2007). Mukherjee et al. (1998) identified the landslides by visual interpretation of remote sensing images before and after the landslide, put the interpretation results into geographic information systems (GIS) spatial analysis model, and finally got landslide risk maps. Saha et al. (2002) extracted land use/land cover information and other environmental information in landslide areas from a variety of remote sensing data, and then got landslide hazard index combined with GIS.

In China, geological disasters survey by remote sensing began in the late 1970s, when aerial photographs were used to determine the extent of landslide, topography, drainage, land cover, geological materials and the role of human impact on landscape and other factors. With the development of sensors and image processing technology, remote sensing, at home and abroad, has been widely used in investigation, monitoring and control of landslides, debris flow, collapse and other geological hazards, and gradually applied to highway geological disease research. Chen Chujiang et al. (2004) and Zhang Minghua(2005), accomplished a comprehensive interpretation of the debris flow, landslides, active faults and other geological disasters along the Medog highway, using processed remote sensing images of Landsat-ETM +, IKONOS-2, aerial and other data. Wang Lihong et al.(2006) carried out highway disease survey by visual interpretation on the Sichuan-Tibet Highway in Tibet based on remote sensing. This study focused on the trends of main disasters. Wang Zhihua (2007) taking Tiantai landslide as an example, analyzed the landslide boundary, sliding direction, sliding distance, sliding speed, and so on with remote sensing and GIS technology.

At present, traditional artificial visual interpretation methods are still the main methods for geological disasters identification. Although the visual interpretation is done under expert guidance to ensure the high accuracy of disaster identification, the low efficiency of this method is not fit for post-disaster emergency monitoring of highway disasters in wide range. The characteristics of geological disasters on images vary greatly in pattern, spectrum and scale. Thus, automatic or semi-automatic methods for geological disasters extraction in large area have many difficulties. However, domestic and foreign scientists have carried out a number of attempts. K. Oštir et al. (2003) did principal component analysis and Brovey fusion with radar and optical remote sensing data, and then determined the relationship between land use and soil moisture when the landslide occurred. According to the body-specific material composition and activity characteristics of debris flow and landslide, Su Fenghuan et al. (2008), built a rapid extraction model of mountain hazards, such as debris flow and landslide, through humidity index and greenness index extraction, Tasseled Cap transformation, image difference enhancement, density slicing and masking techniques. This model has successfully applied to landslides investigation after Wenchuan earthquake. Although remote sensing images carry abundant information of environment, it is still very difficult to acquire sufficient accurate disaster information using just images. Generally, the usual practice is to obtain the thematic information from remote sensing images, and then take the information as input parameters to spatial models, like GIS, for integration.

The researches on remote sensing applications in highway disaster focus on investigation and risk assessment of geological hazards. The data used in these studies are mostly visible/ near-infrared images, including Landsat, SPOT, IKONOS, aerial imagery and other high-resolution images. In addition, there are attempts to use radar data and thermal infrared data for disaster information directly or auxiliary interpretation and extraction.

3. METHODOLOGY FRAMEWORK

The task for geological disaster mitigation along mountain highway is composed of four aspects: disaster formative environment investigation, disaster situation investigation and monitoring, disaster risk prediction and evaluation and project management of high-risk body. Remote sensing technology can be directly used for the investigation and dynamic monitoring of disasters and their formative environment. Combined with statistics, GIS and other disciplines, remote sensing can be applied to geological disaster risk analysis, evaluation and prediction. It is the framework of mountain highway geological disaster management in figure 1.

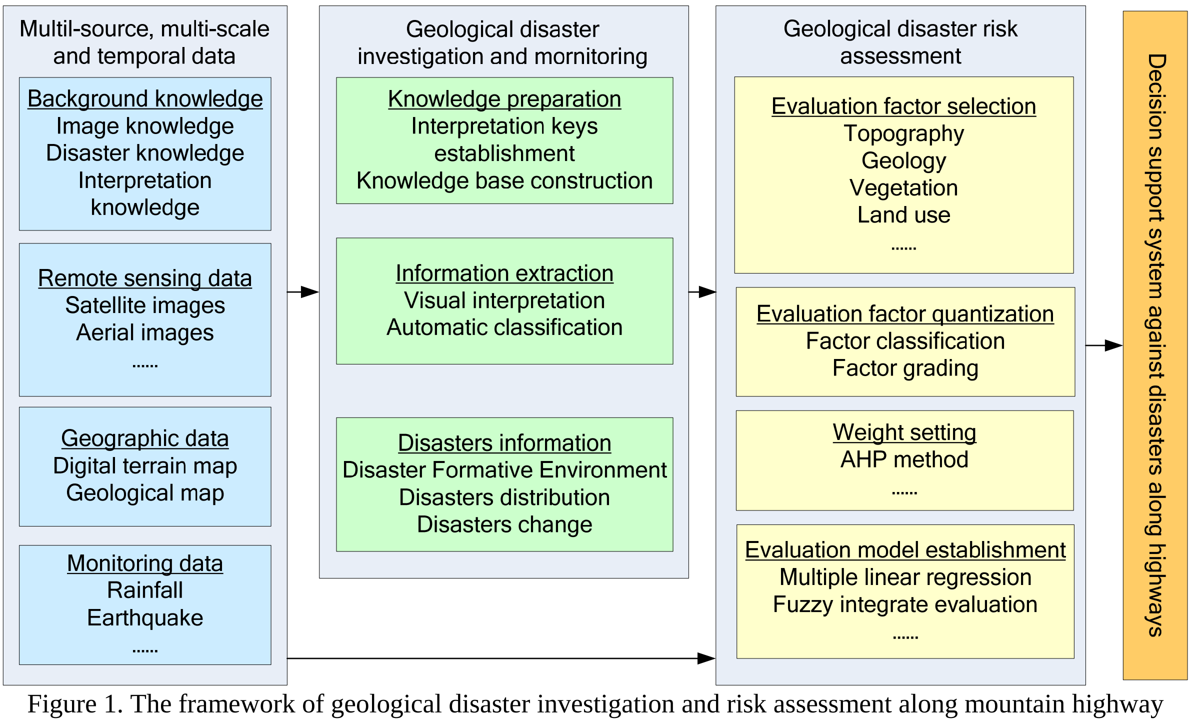

Figure 1. The framework of geological disaster investigation and risk assessment along mountain highway

3.1 Data and Data Processing

For identification and risk assessment of geological disasters along mountain highway, the required data include: remote sensing images in appropriate resolution, digital terrain maps, geological maps, and so on. Remote sensing images are mainly used for extraction of geological disasters and land cover. Digital terrain map is used to extract basic geographic features, such as water and roads, as well as digital elevation model (DEM). With DEM, the data describing the land surface morphology can be acquired, for example slope, aspect and so on. Geological maps include geological structure map, lithology map and so on, which are linked to geological disaster risk assessment. For convenience of research, all data are generally processed to types of point, line, polygon or grid with GIS software.

3.2 Disaster Formative Environment Investigation

Studies have shown that geological disaster-inducing conditions include eight types of environmental factors: (1) time precipitation, (2)annual average precipitation, (3)ground slope, (4)thickness and distribution of loose deposits, (5)development degree of geological structure, (6)growth of vegetation, (7) rock and soil structure and (8) level of human engineering activities. The meteorological satellites can monitor rainfall intensity in real-time. Land resources satellites can not only investigate the land surface comprehensively, but also have the capacity for investigation and analysis features of the shallow underground with infrared and microwave bands. Thus, among above 8 disaster-inducing factors, the first two factors can be surveyed by meteorological satellites and ground hydrological observation stations, and other factors can be obtained by land resources satellite combined with field-based survey. It is the most basic and important task for research the background of geological disasters.

3.3 Investigation and Monitoring of Geological Disaster

The applications of remote sensing technology for geological disaster investigation mainly refer to the use of remote sensing images for geological disasters recognition (Xu, et al, 2009). As a special hazardous geological phenomena, both individual and combined geological disasters, such as landslides, debris flow and collapse, present quite different from surrounding environment in shape, color, shadow, textures etc. in remote sensing images. Thus, we can extract the number, type, distribution, formation age and other qualitative characteristics of geological disasters. Utilizing remote sensing as well as GIS and GPS, we can obtain the quantitative characteristics of geological disasters, such as slope, aspect, elevation and size of disaster body and material displacement through the establishment of DEM of the target area.

At present, in the geological disaster detection, stereoscopic images interpretation and computer-human interactive interpretation are the main methods based on the establishment of interpretation keys according to diagnostic characteristics including shape, tone, texture, terrain, geomorphology, and so on. However, the spectral information in remote sensing images is not made full use of in these visual interpretation methods. Supervised and unsupervised classification methods can also be used according to the spectral and textural characteristics of geological disasters (Wan, et al.,2009). The image classification function removes some useless information and helps geological disaster identification by classifying the images into different classes (Chen, et al., 2004). Object-oriented technology is one of the methodologies to extract thematic information of geological disasters from high resolution remote sensing imageries (Hu, et al.,2008). The whole detection procedure includes multi-scale image object segmentation to construct multiple-level object hierarchy network and the knowledge rule construction of geological disaster with image object characteristics, environmental context and object topological relationship.

The methods for visual interpretation and automatic classification of geological disasters both have their own advantages. With automatic methods, the geological disasters information can be extracted very quickly and automatically. Visual interpretation is more difficult than automatic extraction methods, because it requires abundant professional background knowledge and it is time-consuming. However, its results are more accurate than that of automatic methods. Therefore, visual interpretation results can be used to verify results of automatic identification. Generally, these two types of geological disaster information extraction methods are suitable for remote sensing data in different resolution. For high spatial resolution satellite remote sensing data and aerial photographs, the method of artificial visual interpretation is more suitable, while automatic classification method is better for low and middle spatial resolution images.

There are two procedures, interpretation keys establishment and knowledge base construction, which we should pay attention to in the geological disasters investigation. Firstly, interpretation keys are composed of a set of image features, with which one type of surface objects can be distinguished from other types of surface objects in remote sensing images. Interpretation keys establishment is a key procedure of disaster identification, which directly determines the accuracy of the recognition results. As the differences of remote sensors, image acquisition time and disasters characteristics in different regions, the interpretation keys of geological disasters along mountain highway are quite different. Secondly, for interpretation of geological disasters, we need the background knowledge of both geological disaster and remote sensing image. All this knowledge can be obtained from experts, but the experts cannot always be contacted. Therefore, this is a new study field to store experts’ knowledge in the knowledge base (Hu, 2011). As a result, the users can share the geological disaster knowledge and improve the identification efficiency and precision.

With the distribution of geological disasters, the relations between geological disaster for highway in mountain areas and lithology, geological structure, topography, hydrogeology, atmospheric rainfall, vegetation, human activities, and so on can be studied.

3.4 Risk Assessment of Geological Disaster

In general, geological disaster risk assessment approaches can be divided into qualitative and quantitative methods. Qualitative methods mainly describe the risk of geological disasters qualitatively based on subjective experience, while quantitative models estimate the potential for geological disasters. Typically, there are two types of quantitative models of geological disaster risk assessment. The first type determines the method based on physical models and engineering geology. According to the physical mechanism of geological disaster, it evaluates the geological stability with mathematical models. However, this model needs to collect large amounts of data in geology, hydrogeology and other aspects. Hence, it is suitable for a special geological disaster monitoring, evaluation and prediction, but large-scale geological disaster risk assessment and prediction is difficult to achieve. The second type of model, based on statistical analysis theory, does not need to collect a large number of physical characteristics data. It predicts the future trend of geological disasters by analyzing characteristics of geology instability during the historical geological disasters. Therefore, this method has obvious advantage of regional disaster forecasting in wide range and has been widely used and accepted. Geological hazard evaluation process includes evaluation factor selection, evaluation factor classification and grading, weight setting and evaluation model establishment.

The development of geological disasters is controlled by many factors, such as topography, lithology, geological structure, valley cutting density, and so on. Considering these factors, the risk assessment value for geological disaster can be derived with the risk assessment models. The weights of evaluation factor can be ascertained with the analytic hierarchy process (AHP) method (Xu, et al.,2009). AHP is a multi-indicator analysis and evaluation method easily accessible with high precision feature. In this method, experts estimate the relationship between impact factors by pairwise comparison method to structure relationship matrix, resulting in a certain degree of subjectivity but avoid individual unreasonable weight. Consequently, it is reasonable for the AHP method used in weight setting for geological disaster-prone evaluation.

The risk of geological disaster can be evaluated quantificationally by multiple linear regression analysis or fuzzy integrate evaluation method. For the latter, there need one more step to deduce the estimate result about fatalness with principle of maximal feudatory to every section (Zhao, et al.,2007). A research result of debris flow risk assessment in Wenchuan is shown in figure 2 (Liu, et al., 2011). The dependability of evaluation result depends mainly on the degree of factors representation and the rationality of the factor weight and the models.

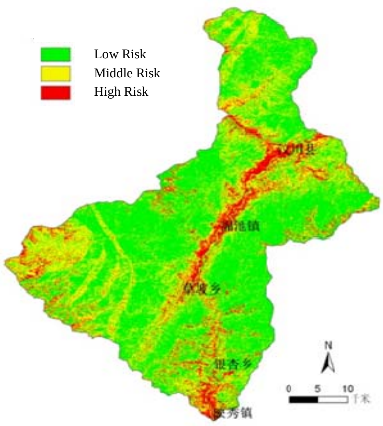

Figure.2 Distribution for hazard level of debris flow in Yingxiu-Wenchuan

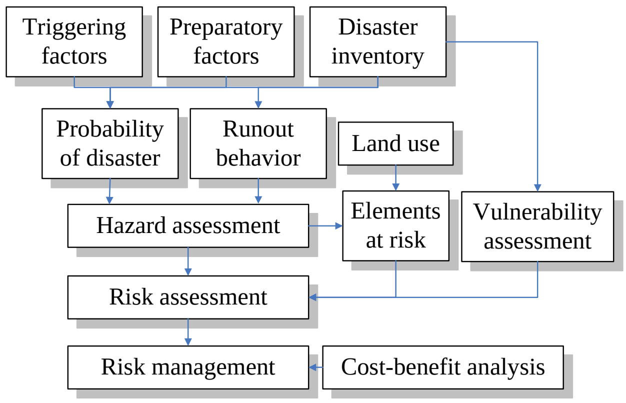

Figure 3. A framework for geological disaster risk assessment and management

With the results of geological hazard evaluation, we can do regional planning of geological disasters, identify the geological disaster-prone area and evaluate the degree of risk in order to prevent geological disasters and decrease losses. The results can also provide basic information for establishment of geological hazard monitoring network.

Furthermore, in order to offer a solid technical infrastructure, the disaster reduction decision support system against disasters along highways in mountainous area can be set up through the integration of database, analysis models and decision models. It requires the following issues to be addressed: (a) probability of geological disasters, (b) runout behavior of geological disasters, (c) vulnerability of property and people to geological disasters, (d) geological disasters risk to property and people, and (e) management strategies and decision-making. The framework of geological disasters risk assessment and management is shown in Figure 3 (Dai, et al. 2002). The system can be used for estimation of the level of risk, deciding whether or not it is acceptable, and exercising appropriate control measures to reduce the risk when the risk level cannot be accepted.

4. CONCLUSIONS

Remote sensing is an emerging high technology. It is not only necessary but also feasible for carrying out geological hazard investigation with this technology. Remote sensing plays an important role through all the process of geological disasters investigation, monitoring and risk evaluation. This paper states methodologies for investigation and risk assessment of geological disasters for mountain highway based on remote sensing images in order to mitigate the harm and loss. The extraction of geological disaster along mountainous highway has great significance for relief assessment on bearing capacity of disaster area and reconstruction work after the disaster. It can provide more advantageous basis for preventing landslide and for the disaster evaluation. The risk evaluate results can supply reference in the work of geological hazards prevention along the highway, and it will lay the foundation for further study, the practical application and dissemination of assessment techniques.

Certainly, for the constraints of lack of standards and so on, the methodologies in this study still have some restrictions. First, there is not a standard for evaluation factor system of risk assessment. So it is difficult to determine the evaluation factors and there will inevitably be omissions and weaknesses for the established evaluation factor system. Second, there are no uniform standards internationally for the grading methods of the results of geological disaster risk assessment at present. There are only a handful of relevant literatures, in which researches mainly grading the result of hazard assessment in accordance with personal experiences, resulting in the lack of credibility. Therefore, in the near future, we should pay more attention to the formulation of national standards for geological disaster management.

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