Design of GIS-based Monitoring and Early-warning System of Landslide Hazard in Diao Zhongba

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Abstract

To ensure the safety of village called Diao Zhongba, reduce the capital investment and prevent geological disasters, it is necessary to design a monitoring and warning system for it. GIS software ---MAPGIS is selected to be the base platform, whose basic functions are applied to manage the engineering geological information in Diao Zhongba, coupled with the research on the secondary development library based on MAPGIS, thus achieving the early-warning of landslide. This warning system conducts detailed analysis on various aspects, such as system requirements, system design, system environment selection, specific database design, warning function module design, etc. In this system, a total of 16 kinds of models are designed, which can be divided into three categories, long-term prediction, short-term prediction, critical-sliding prediction. Long-term prediction model includes the limit analysis method, golden section method, and dynamic fractal dimension model. Medium-range forecast model includes biological growth model, cusp catastrophic model, nonlinear regression analysis model, the gray GM (1, 1) model, BP neural network model, exponential smoothing, Kalman filtering method. Critical-sliding prediction model includes Zhaitengdixiao model, Su aijun model, sliding deformation power model, gray displacement vector angle method, collaborative model. The automation and information processing for landslide hazards in this system can provide basis for early warning of landslide in Diao Zhongba.

Keywords: landslide; monitoring; early-warning system; design; Diao Zhongba

1. Introduction

Landslide in Diao Zhongba, only 12km from the estuary of Yangtze River, is located in the Wangshui village in the south-west of Zhong county town. The landslide once deformed in 1962, 1982 and 1988 due

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to heavy rains and the deformation zone was gradually increasing. The storm in July in 1988 has led to a
greater range of surface deformation, resulting in the houses collapse and damage of 43 residents living there. Therefore, analysis on the landslide as well as the design of monitoring and early-warning system for it can provide security guarantee for Zhongba village, reduce capital investment, and achieve geological disasters prevention.

2. Theory and model of landslide hazard prediction

2.1. Theory and methods of landslide hazard prediction

Landslide prediction is the core issue of landslide researches, which was started in the 1960s. It includes special prediction and time prediction. The former is to determine the location of unstable slopes, while the latter is to determine the time of landslide based on the former one. Due to the complexity of landslide, the landslide time prediction is still a worldwide problem. Landslide hazard prediction theory has experienced long-term development, so it can be divided into three categories according to their different theoretical basis [1]:

(1) Regard the rock-soil mechanics as the basis

This theory aims to explore the prediction ways against the geological hazards causes and inducement mechanism as well as its kinetic process, and discuss the formation and evolution mechanism of geological hazard mainly based on the statics and dynamics of geological hazard’s formation and evolution. In other words, study the prediction approaches of linear and non-linear dynamics by constant revealing the formation mechanism of mudslides and landslides.

(2) Regard the statistics and applied mathematics as a theoretical basis of geological hazards prediction

Based on statistical theory, conduct statistical analysis on various signs, phenomena and variables of geological hazards, and establish the related prediction equation. One of the notable features is to use the deformation characteristics and signs of geological disasters as a prediction basis, regardless of the formation mechanism.

(3) Regard the information science and geographic information science as the theoretical basis of geological hazards prediction

Determine the development trend of geological hazards according to the relevant database and information content of geological hazards. Utilize the GIS theory and technology to build prediction platform and embed professional analysis of geological hazard to handle and predict early-warning modules.

2.2. Landslide prediction model

Researches on the landslide prediction techniques and methods have made great progress since the 1980s. The most commonly-used quantitative landslide hazard prediction models can be divided into the following types: deterministic prediction model, statistical forecasting models and non-linear prediction model [2].

(1) Deterministic model

Quantize the data determined by various parameters of landslide and its environment, use rigorous reasoning methods, especially mathematics and physical methods, to conduct accurate analysis and get the clear prediction judgments.

Common prediction methods are shown as follows: Satio method, HOCK method, K * KAWAWURA method, creep test prediction models, creep spline joint model, sliding deformation power method, limiting equilibrium method.
(2) Statistical prediction model

Utilize various statistical methods and theoretical models of modern mathematical statistics to carry out macro-surveys and analysis mainly on the existing landslide and the relationship of its geological environmental factors and the external forces to obtain the statistical laws, which will be used to fit the displacement-time curve of different landslide and conduct prediction according to the extrapolation of the model.

Common prediction methods are shown as follows: gray GM (1,1) model (including the traditional GM (1,1) model, unequal interval sequence GM (1,1) model, Metro metabolic GM (1,1) model, optimizing GM (1,1) model, gradual iterative GM (1,1) model), biological growth model (Pearl model, Verhulst model, Verhulst inverse model), curve regression model, multiple non-linear correlation analysis, time series prediction model, the Kalman filter, Markov chain forecasting, fuzzy mathematical method, dynamic tracking method, slope creep prediction model, the gradient-sine prediction model, gray displacement vector angle method, golden section method and so on.

(3) Non-linear prediction model

It is a kind of landslide prediction model utilizing the non-linear scientific theory which is effective to solve the complex issues.

Common-used prediction methods are shown as follows: BP neural network model, collaborative prediction model, BP-GA hybrid prediction method, collaborative - bifurcated prediction model, the dynamic fractal dimension tracking prediction model, nonlinear dynamic model and displacement dynamic analysis method, etc.

3. Monitoring program of landslide hazard in Diao Zhongba and its prediction model

3.1. Monitoring program of landslide in Diao Zhongba

Arrange the monitoring cross-section for the main sliding body and the residential area within the influence area by landslide analysis. Four sections are numbered as I, II, III, IV, 16 GPS monitoring points, 8 inclined holes, 8 thrust holes and 8 hydrological holes are arranged in the sliding body, in addition, hydrological holes can complete monitoring automatically[3][4]. Meanwhile, lay out 2 GPS datum points on the stable strata outside of the sliding body.

3.2. Prediction model of landslide hazard in Diao Zhongba

According to the characteristics of landslide in Diao Zhongba and the maturity of various models, a total of 15 kinds of models are designed, which can be divided into three categories, long-term prediction, medium-short-term prediction, critical-sliding prediction. Long-term prediction models include: limit analysis method, golden section method and dynamic fractal dimension model. Medium-term prediction models include: biological growth model, cusp catastrophe model, nonlinear regression analysis model, the gray GM (1,1) model, BP neural network model, exponential smoothing method and Kalman filtering method. Critical-sliding prediction models include: Saito model, Suaijun model, sliding deformation power model, gray displacement vector angle method and collaborative model.
4. System analysis

4.1. Analysis of system requirements

The available data shows that the indirect loss caused by landslides in China has been up to 200 billion every year, and the overhead costs are even higher. Therefore, landslide prediction has become a research hotspot in our country. Landslide monitoring and early-warning is to predict the landslide trend by a variety of means and sound a warning by various means, which can provide basis as well as evaluation for the landslide abatement. Real-time monitoring for landslide is a comprehensive high-tech, which covers electronics, computers, communication, measurement and other fields, so it is the multi-disciplinary product.

One of the important features of landslide monitoring information is its rich data source, large data volume, numerous data types and complex data structures, which are the so-called multi-source, large amounts, multi-class and multi-dimensional; the second feature is that the landslide monitoring data is related with geographic location and time. Traditional database technology cannot perfectly describe and analyze these data and the development of GIS technology has provided us a solution.

4.2. Analysis of system data sources

The vector data in this system mainly derives from the digitization of engineering geological maps by MAPGis interactive vectorization module. In this system, the vector map elements into three categories can be divided into three categories according to the basic geometrical characteristics by using the MAPGIS vector data organization method: point data, linear data and area data (that is, surface data). Correspondingly, the file types can also be divided into three categories: point files (*.WT), linear files (*.WL) and zone files (*.WP).

4.3. System Design

4.3.1 System Target

The landslide monitoring and early-warning system based on GIS is the software system regarding the dynamic monitoring data as the basis, critical-sliding forecast as the core and GIS technology as support, which is established to achieve the accurate landslide forecasting. Specific objectives are shown as follows:

(1) To achieve landslide information management, including basic information and dynamic monitoring information of landslide.

(2) To critical-sliding forecasting and early warning. On the basis of dynamic monitoring, compare the prediction models and critical-sliding criterion to carry out landslide warning.

4.3.2 System environment selection

MAPGIS system is a tool-based GIS developed by China University of Geosciences (Wuhan). MAPGIS provides a complete library of secondary development and the secondary development interface is commonly known as the API (Application Program Interface), a set of function command available for application programs, with which users can establish the application-oriented GIS in some specific areas in the programming environment such as BORLAND C, VISUAL C and VISUAL BASIC, etc. In addition, MAPGIS secondary development library also provides lots of reusable base classes for MFC-
based users, which packages the basic functions for the application programs, making the development more convenient and flexible.

4.3.3 System function design

(1) Input of monitoring dynamic information and module management: input the field collected and indoor processed data, and conduct sort management to obtain various result charts.

(2) Monitoring information and visualization modules: display the information such as point distribution of landslide monitoring, network structure, the overall displacement of landslide, groundwater monitoring, single-point deformation curve, subsidence curve, etc, using digital graphics.

(3) Pre-processing module of monitoring data: due to the unequal time interval of the monitoring data, it is necessary to solve the problem in order to improve prediction accuracy. If the monitoring data is largely influenced by external random factors in the monitoring process, its time series trace shows unsmooth, so it is necessary to conduct filtering and smoothing for the monitoring data to remove the interference of random factors as far as possible. Therefore, the pre-processing modules of monitoring data must be provided in order to meet the requirements of predictive models.

(4) Module of landslide prediction model: use the multi-angle and multi-data integration approach such as surface displacement model, underground displacement model, groundwater model, rainfall and rainfall intensity model, and the integrated model combined with two or more prediction parameters to conduct critical-sliding forecast for landslide.

(5) Researches and modules of critical-sliding prediction: when the displacement model, groundwater model and integrated model are in critical early-warning period, the dereference problem of critical-sliding point, that is, the threshold value. The rationality of threshold value will directly affect the accuracy of prediction results, so this module is designed as dynamic module, which can be adjusted according to the on-site monitoring data.

(6) The parameter setting module: provide the function of various parameter settings.

(7) Results viewer module: provide the function to browse the data of generating results.

The monitoring and early-warning system of landslide in Diao Zhongba is as shown in Figure 1.

![Fig. 1. Structure of landslide early warning system](image-url)
4.3.4 Database Design

(1) Spatial database design

System data classification: ① location information: topography, humanity, geological boundaries, faults, fold axes, drilling location; ② description of geographical features: stratigraphic unit, the type of geological boundaries, drilling names, etc.; ③ descriptive information of geological map: Map name, scale, legend, etc.; ④ other information: diagrammatize the relationship between rocks and profile, etc.

Spatial data layers can be divided into: geology (geological boundary), faults, mineral deposits, drilling, rock samples, field location, topography, hydrogeology, etc.

(2) Attribute database design

The attribute database of basic information includes: integrated engineering geological conditions in landslide area, the basic structure of landslide, the existing achievement and so on. The attribute database of monitoring information includes: absolute displacement monitoring information by telluric method, monitoring information by borehole tilt-meter, underground water level monitoring information and surface flow monitoring information.

4.4. The process to achieve the landslide early-warning

On the platform of landslide prediction database formed by basic data and real-time monitoring data, select the obtained data for each model and carry out calculation. Then compare the calculated results of model and the corresponding critical-sliding criterion to conduct landslide prediction. The results will be reported to upper-level unit and step into the stage of early-warning such as public release, etc.

5. Conclusions

The application of GIS technology in geological disaster prediction and early-warning is an effective way in disaster studies and now the potential of GIS in geological hazard study is constantly expanding. Regarding the prediction model as the core, the basic geological information database and dynamic monitoring database as the basis, the GIS as the technology platform, landslide prediction and early-warning system in Diao Zhongbaachieve achieves the process from input and management to model calculations and automatic evaluation of geological hazard data.

By the specific design of landslide monitoring and warning system in Diao Zhongba, we propose that the high-grade monitoring equipment, in-depth geological analysis and danger release platform based on Web_GIS are the most effective means to avoid danger and ensure safety.

References


