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Design and Implementation of a Mountain Torrent Disaster Warning System Based on the Distributed Hydrological Model

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Mountain torrent disaster warning system is a significant non-engineering flood prevention measure for achieving the goals of flood prevention and disaster reduction in the related small rivers. After analyzing the design principle and objective of the system, we proposed a mountain torrent disaster warning system based on WEB GIS technology and the distributed hydrological model (DHM) of the river basin. The system includes multiple subsystems, namely, system management, 2D/3D Web GIS, rainfall and water information management, mountain torrent disaster prevention and control information management, flood forecasting, mountain flood forecasting and response, flood control project information management, duty and flood control business management, data synchronism, system auto-update and operating condition monitoring. The proposed DHM-based mountain torrent disaster warning system can help the users to master the water and rainfall information in first time, analyze the flood evolution, make the forecasting and display the forecasting results via the terminal. Accordingly, the administrative departments in charge of water conservancy can rapidly issue the mountain torrent forecasting messages and make timely flood-control and rescuing deployments, with the aims of effectively enhancing the timeliness of warning and reducing the induced casualties and property losses.

1. Introduction

Mountain torrent disaster is a kind of natural disasters induced by heavy rainfall events and irrational human activities in special natural geographic environments with special terrain conditions (Liu (2012)). The core of a mountain torrent disaster warning system is to collect, pool, analyze and display the related data to various kinds of mountain torrent disasters with the use of the modern computer information process technology (Liang and Liu (2010)). The system aims to provide the flood control and command departments with the applications such as information acquisition, monitoring & warning and command & dispatching, enhance the warning and command efficiency, change China’s backward situation in mountain torrent disaster prevention and reduce the casualties and property losses. Under the background of global climate change, the frequency, strength and distribution of extreme weather and climate events have become much more complex and difficult to predict (He et al (2012), Liu et al (2014)). In some small river basins of mountainous areas, the geological and geomorphologic characteristics are complex but the flood storage and detention capacity is quite limited (Chen et al (2010), Guo et al (2007)). Faced with increasingly severe mountain torrent disasters, many countries have already investigated or are working on the high-efficiency mountain torrent disaster warning and forecasting system and flood management methods, with the aim of reducing the induced damages to minimum. U.S. Hydrological Research Center has developed the Flash Flood Guidance System, which has been widely applied in Central America, Korea, the four countries along the Mekong River Basin, South Africa, Romania and the other countries. University of Maryland collaborated with U.S. National River Forecasting Center to develop a mountain torrent forecasting system based on distributed hydrological model (HEC-DHM). Japan International Cooperation Agency (JICA) developed a community-based mountain torrent early warning system for the Caribbean region. World Meteorological Organization (WMO) has also been engaging in the active promotion of integrated flood management, and successfully built the demonstration project titled Community-participated Flood Early Warning and Management in Bangladesh, India and Nepal in South Asia (Georgakakos et al (2006), USACE (2001), Jia (2009), Sabahattin (2013)). To construct a set of DHM-based mountain torrent disaster warning system is not only very necessary but also extremely urgent.

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The DHM-based mountain torrent disaster warning system is an important non-engineering flood control measure for achieving the goals of flood control and disaster reduction, which also can be considered as the lifeline in flood prevention work (Naulin (2013), Balica (2013), Hernan (2012), Mazzorana (2013)). A smooth and reliable mountain torrent disaster warning system for the small river basins in hilly regions can provide the flood prevention and command departments at different levels with timely information of water, rain and flood control engineering and help them rapidly and scientifically make decisions. Accordingly, the related departments can carry out the scientific and reasonable dispatching for flood prevention and disaster relief so as to reduce the losses induced by flood disasters to the lowest.

2. System requirements and design

2.1 Design principle

To design a mountain torrent disaster warning system, we should adhere to the following principles.

- Principle of high-efficiency responsiveness
- Principle of reliability
- Principle of safety
- Principle of standardization
- Principle of the compatible scalability
- Principle of parameterization
- Principle of friendly interface

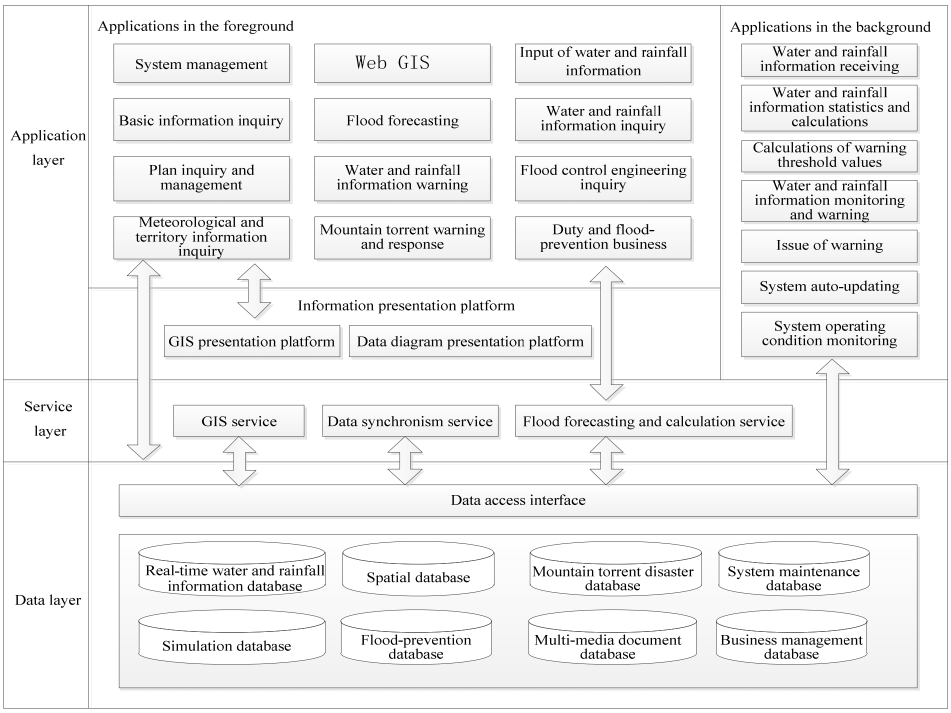

Figure 1: Framework of the constructed mountain torrent warning system based on DHM

2.2 System objective

Based on the distributed hydrological model (DHM) and WEB GIS technology, the system framework using the idea of structured design was proposed, as presented in Fig. 1.

This system is a three-layer structure consisting of data layer, service layer and application layer, and includes multiple subsystems such as system management, 2D/3D Web GIS, rainfall and water information management, mountain torrent disaster prevention and control information management, flood forecasting, mountain flood forecasting and response, flood control project information management, duty and flood control business management, data synchronism, system auto-update and operating condition monitoring. The system can acquire the rainfall and water information in first time, thereby conduct the calculations of flood forecasting and timely display the forecasting results on the terminal. Accordingly, using this system, the flood control commanders can quickly release the mountain torrent warning information and make some appropriate deployments through various means and channels, which can significantly enhance the timeliness of warnings and reduce casualties and property losses.

2.3 System development environment

(1) Hardware

Client	Server
CPU: 4-core CPU or more, with the main frequency of over 2GHz	CPU: 4-way 8-core CPU or more, with the main frequency of over 3GHz
Hard drive capacity: over 500G	Hard drive capacity: over 5T
Internal storage: over 8G	Internal storage: over 32G

(2) Software

Development tool	Microsoft Visual Studio 2010
Client	Server
Operating system: Microsoft Windows 7	Operating system: Microsoft Windows Server 2012 Datacenter
Software environment: Arcgis10.1, Intel MPICH2	Software environment: SQL Server 2012 Enterprise Core, Microsoft Visual Studio Team Foundation Server 2012 Microsoft SharePoint Server 2013

2.4 Implementation of the design

2.4.1 System management subsystem

This subsystem adopts the strategy of grouping users and endow the manage users with access rights. The subsystem has classified the users into the normal users, the system staffs, the flood-prevention watchkeepers, the flood-prevention experts, the data maintenance staffs and the system administrators, and set various access permissions with different functional modules for the users in different groups.

2.4.2 Web GIS subsystem

The Web GIS subsystem is the basis for the presentation of system platform information and can present the 2D/3D geographic data and the flood torrent monitoring and warning information via Internet Explorer (IE). In addition to the general functions including GIS platform map zooming, map-layer control, spatial measuring and information inquiry, this subsystem has the following functions:

- Web GIS map marking and plotting
- Web GIS 3D virtual reality
- Web GIS information inquiry and analysis
- Web GIS analysis charts output and saving

2.4.3 Water and rainfall information management subsystem

(1) Real-time water and rainfall information reception and storage

The system platform can receive the precipitation data collected from the automatic rainfall stations every ten minutes and write the data into the standard real-time water and rainfall database.

(2) Real-time water and rainfall data processing

The system can conduct the real-time statistical analyses and calculations on the precipitation data in the background and generate the precipitation results of each administrative division and small watershed. The system will monitor the precipitation data in real time and judge whether they exceed the warning threshold values of the administrative divisions and small watersheds.

(3) Rainfall information query and analysis

The rainfall information query and analysis subsystem includes rainfall monitoring and precipitation analysis, mainly in the form of Web GIS and sheets.

2.4.4 Mountain torrent disaster prevention information management subsystem

(1) Basic information inquiry

The basic information mainly includes the basic information of the related counties, towns and villages, the small watersheds, the monitoring stations, the historical disasters, the duty officers and the mass measurement and prevention systems.

(2) Plan inquiry management

The system can help the users to inquire the flood-prevention plans of the related counties, towns and villages, the industrial and mining enterprises and the schools.

(3) Weather and national territory information inquiry

The system can receive the weather and national territory information and can provide the users with the related inquiries of real-time weather forecasting, real-time satellite cloud pictures and geological disasters.

2.4.5 Flood forecasting subsystem

(1) Real-time precipitation warning

For the flood forecasting system, the real-time precipitation data collected by the rainfall observation stations are input while the discharge processes and the hydrologic processes at all river basin outlets are output. Through real-time simulations on the runoff processes in the river sections when the warning occurs, the warning flow or water level indexes can be directly used for mountain torrent disaster warning.

(2) Distributed hydrological model (DHM)

In DHM, the river basin is divided into several hydrological simulation units according to different terrains, soils, vegetation, land utilizations and precipitations in this region. In each unit, a group of parameters can be used to reflect the basin characteristics. By means of remote sensing (RS) and geographic information system (GIS) technologies, the runoff yield and runoff confluence/concentration parameters with spatial distribution characteristics, which are necessary in DHM and related to soil, vegetation and land utilization type, can be acquired.

(3) Distributed geomorphologic unit hydrograph

Since most of small watersheds lack of hydrologic data, the traditional unit hydrograph calculation methods based on hydrologic data are inapplicable. A new method directly based on the tomographic, geomorphologic and vegetation features is proposed, in which the probability distribution function of the water particle concentration time is theoretically equal to the unit hydrograph.

1) Calculation of water flow velocity

The water flow velocity on the slope is connected with both tomographic gradient and water volume. According to Manning's formula, by taking the slope gradient and rainfall intensity into account, the water flow velocity at a certain location along the river basin can be calculated by:

$$V = KS^{0.5}i^{0.4} \tag{1}$$

in which V denotes the water flow velocity (m/s), S denotes the gradient at a certain location in the river basin along the flow direction, i denotes the rainfall intensity (m/s), and K denotes the velocity coefficient.

2) Calculation of concentration time

As to any point in a small watershed, there is a fixed confluence path to reach the outlet. In DEM, the runoff in a certain grid will flow to the adjacent grids around it along the direction of maximum gradient, and accordingly, the confluence path of the runoff in this grid towards the outlet can be acquired. According to the grid size and the water flow velocity in the grid, the detention time of the runoff in each grid can be calculated by:

$$\Delta\tau = L/V \text{ or } \Delta\tau = \sqrt{2}L/V \tag{2}$$

in which $\Delta\tau$ denotes the runoff time in a grid and L denotes the side length of the network. Along the confluence path, the concentration time of the runoff from each grid to the outlet can be written as:

$$\tau = \sum_{i=1}^{m} \Delta\tau_i \qquad (3)$$

in which τ denotes the concentration time of the runoff from a certain grid to the outlet and m denotes the number of the grids along the runoff path.

3) Calculation of unit hydrograph

To make the statistical calculations on the concentration time, we can obtain the probability density distribution of the concentration time of the small river basin. The base width of the probability density distribution of the concentration time can then be adopted as the concentration time of this small watershed.

Then, to do unit conversion on the probability density distribution of the concentration time and linear reservoir regulation and storage, we can obtain the unit hydrograph of the small river basin.

4) Forecasting results

The forecasting results include the flow process chart of the outlet section of a certain basin and the forecasting runoff of the control section at a certain moment. Moreover, the users can query the forecasting results of river sections through direct searching, the screening of the administrative divisions, the clicking on the map and the classification of basins.

2.4.6 Mountain torrent warning and response subsystem

(1) Warning index and the related classifications

The warning index is a significant parameter for mountain torrent disaster forecasting and the determination of the warning levels. It means that, in a river basin or a region, when the precipitation or the water level reaches or exceed a certain level, the mountain torrent disasters such as river floods, debris flows and landslides may occur in this river or region. Once the warning index is achieved, the watchkeepers should issue the warning signals and thereby the related departments and institutions should make the emergency responses.

(2) Determination of warning index

To determine the warning index is essentially for sending the warning measure timely and reasonably, so that the masses in risky areas can timely transfer without any losses of life and property. There are two indexes affecting the determination of warning index--the precipitation amount and the water level value, in which the determination of the former index is crucial for mountain torrent disaster warning.

2.4.7 Flood-prevention project information management subsystem

The flood-prevention project information management subsystem consists of three parts, input, maintenance and inquiry of the involved data in flood-prevention project database.

2.4.8 Duty and flood control business management

The system has a series of functions, including the flood-prevention duty records, the daily office document management, news pushing, E-mail, file sharing, sending and receiving of SMS messages and faxes and etc. The system can endow the staffs on flood-prevention duty with the rights to manage various multimedia documents (or files) through a lot of modules such as image management module, picture management module, the engineering drawing data management module, the fax archiving management module and video data management module.

2.4.9 Data synchronism subsystem

Data synchronism subsystem includes two modes--uplink synchronization (i.e., from county to city to province) and downlink synchronization (i.e., from province to city to county), in which the downlink synchronization mode can be further divided into one-to-one and one-to-many modes.

2.4.10 System auto-updating subsystem

If a new version of software is detected, the system will be automatically updated to the newest version without interrupting the system's normal operating.

2.4.11 Operating condition monitoring subsystem

This function is applied to monitor the modules running in system's background (such as the water and rainfall information receiving module and the warning massage sending module). If these modules are out of service or crashes, the subsystem first try to restore the modules to normal operation; if the modules' normal operations cannot be achieved, the subsystem will send the warning message of system wrongs to the monitoring center of the system construction units and prompt the system maintenance personnel to manually recover the system. Similarly, this operating condition monitoring system is also monitored by the poller of the monitoring center so as to find some faults such as crashes, network interruption, and etc.

3. Conclusions

The construction of mountain torrent disaster warning systems for the small river basins can further improve the prevention and control measures for various mountain torrents and geological disasters, so that the warning information can be timely and accurately sent to the risky regions and the related persons can adopt the precautionary measures in time according to the flood prevention plans. These mountain torrent disaster systems are significant and can contribute to minimizing the casualties, guiding the flood-prevention works and finally construing the harmonious society. In the present work, based on the information and forecasting decisions provided by the hydrologic monitoring system, we made the best of the advantages of WEB GIS technology and DHM in hydrological forecasting, and proposed a set of scientific and comprehensive mountain torrent forecasting system integrating information acquisition, network transmission, decision support and warnings & precautions. The principle of design, method, content and use of the system were explicitly presented in this article. The constructed warning system can remotely monitor the mountain-torrent-disaster-prone zones and automatically sent the warning information for the emergency. The system has powerful functions and abundant information and is convenient to use, with significant promoting and application values.

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