Disaster Management Using GIS Technology :A Case Study in Taiwan

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Abstract: Due to the particular geographical location and geological condition, Taiwan suffers from many natural hazards, such as typhoons, flooding, landslides, land debris, and earthquakes, which often cause series property damages and even life losses. To reduce the damages and losses caused by the natural hazards, an integrated and complete disaster management information system is necessary. An ideal DMIS should integrate the GIS tools, internet technology, dynamic hazard models and graphical user interfaces (GUIs), and covers the operations through the four different phases which include mitigation, preparedness, response, and recovery. In the past, the relevant research fields for disaster prevention involving earthquakes, floods, debris flows, and hazard response system have been successfully studied in Taiwan. However, to better and faster manifest the results of those research fields to the real practices, an integrated information system is needed. In this paper, the framework of DMIS using GIS and internet technology is firstly described. Based on the framework of DMIS, a decision support system for emergency response (DSSER) or typhoon hazard has been developed by the Information Division of the National Science and Technology Center for Disaster Reduction (NCDR). This system is designed to integrate the real-time monitoring data, the dynamic hazard models and GUIs to provide disaster management decision support tools for emergency response. The results of disaster interpretation, analysis and prediction using this system are then provided to the National Emergency Operations Center (CEOC) for decision making and disaster management. The current framework and developing information systems of disaster management in Taiwan are also introduced briefly. Issues of system implementation and promotion and strategies to overcome the difficulties of disaster management will also be discussed. Conclusions of preliminary results and future works are also provided in this paper.

Keywords: GIS, Disaster Management, Decision Support, Hazard Models.

1. Introduction

Natural hazards have been perceived as random acts of nature, symbolized by extremes in physical processes [1]. Due to the particular geographical location and geological condition, Taiwan suffers from many natural hazards, such as typhoons, flooding, landslides, land debris, and earthquakes, which often cause series property damages and even life losses. Although it is almost impossible to avoid the occurrence of disasters and completely recoup the damage caused by the natural hazards, the sufferings and risks can be minimized by developing suitable strategies for disaster management, such as the developing of early warning systems, realizing of the pre-disaster developmental plans, implementing of disaster preparedness and emergency response, mobilizing of relief resources, and helping in rehabilitation and post-disaster reconstruction, etc. [2].

The general process of disaster management involves real-time disaster information collections, compilations, interpretations, analyses, predictions, illustrations and decision support. Monitors and detectors have to be installed to collect the disaster information real time. Databases and mathematical models are employed and integrated to process and analyze the hazards information. It may be observed that advancement of information technology in the form of internet, Geographic Information System (GIS), remote sensing and satellite communication can help a great deal in planning and implementation of disaster management [3, 4]. In the past, GIS has emerged as a powerful tool for effective disaster management through mitigation, preparedness, response and recovery phases [4, 5, 6]. In disaster prevention phase, GIS using a variety of modeling techniques is used to analyze the large volume of data needed for the hazard and risk assessment and awareness [7]. It can also allow making available the risk maps and carrying out some basic scenario analysis. In preparedness phase, GIS is a useful tool for the planning of evacuation routes and resources dispatching, and for the integration of hazard models with other relevant basic data in the design of disaster warning system [3, 6]. In the response phase, GIS can be used to making the detailed pictures of the event tracking, forecast of the affected regions and the evacuation plans [8]. In the disaster recovery phase, GIS can be used to organize the damage information and the post-disaster census information, and in the evaluation of sites for reconstruction [4].

Although the technique of GIS provides the basic ability for the disaster management, some researchers have noted that the current commercial GIS products are unable to facilitate real-time natural hazard risk management decision-making without significant modifications or integration with external hazard models [1]. This restriction is urging the next generation of Decision Support System (DSS) which integrates GIS, internet technology, dynamic hazard models and graphical user interfaces, to provide effective decision support tools for disaster management. In this paper, a Decision Support System for Emergency Response (DSSER) was developed for preparedness and response of typhoon hazards. This system is base on the Web-GIS framework that the disaster information can be distributed via internet technology. When typhoon is coming, the DSSER is used to integrate real-time monitoring information, hazard models and graphical user interfaces to analyze and manage the disaster information such as the current position and possible path of typhoon, the spatial distribution of rainfalls, and potential areas of flooding, landslides and debris flows [8]. The results of hazard analysis and warning messages are finally delivered to the National Emergency Operations Center (NEOC) and help the commander to make the right decisions in disaster preparedness and response phases.

This paper will first introduce the current framework and developing information systems of disaster management in Taiwan. A case study using the developing DSSER for typhoon hazard will be examined. Issues of system implementation and promotion and strategies to overcome the difficulties of disaster management will also be discussed.

2. Current Framework of Disaster Management in Taiwan

Learning from historical disasters, the National Disaster Prevention and Protection Commission (NDPPC) in Taiwan realizes that it is necessary to coordinate relevant governmental and non-governmental organizations (NGOs) together through mitigation, preparedness, response and recovery phases. The Fig.1 shows the current framework for disaster information in Taiwan. For examples, in the preparedness and response phases, the National Fire Agency (NFA), Ministry of the Interior, who is the executive organization of the National Emergency Operations Center (NEOC), should not only tightly work with fire departments of local governments but also many other organizations who are in charge of related affairs, such as the meteorological information from the Central Weather Bureau (CWB), the water resources and sewerage management from the Water Resources Agency (WRA), the transportation and community services from the Ministry of Communications, and so on. In the recovery and mitigation phases, organizations involving civil engineering, construction, land management, zoning control, health, environment, social work, economics, finance, and insurance need tense cooperation.

To increase the capabilities of disaster prevention and response, the NDPPC, central and local governments not only improve their equipments, manpower, drills, institutions, and regulations, but also employ advanced telecommunications and information technologies to enhance their capabilities to collect and analyze information about hazards and distribute timely instructions. Under the framework shown in Fig.1, many governmental organizations in Taiwan have their own information systems for disaster prevention or rescue operations [9]. Some of them are: (1) National Fire Agency and local fire departments are establishing information systems for emergency response and dispatching, (2) Taipei city government has developed a decision support system for disaster response, (3) NCDR has developed a program to predict possible damaged areas according weather prediction and potential disaster maps, (4) National Center for Research on Earthquake Engineering has developed TELES to estimate potential losses based on different earthquake scenarios, (5) Central Weather Bureau has information systems for weather prediction and earthquake monitoring, (6) Soil and Water Conservation Bureau has a web-based Geographical Information System (GIS) to provide the locations of potential landslide areas and dangerous creeks, (7) The web site of Water Resources Agency provides real-time information of water levels of important reservoirs and rivers, drought areas, and subsiding areas, (8) Central Geological Survey has maps indicating fault lines.

Although many agencies or departments may have their own professional affairs and operations for disaster prevention, it is necessary to coordinate relevant agencies together when hazards occur. To accomplish such a complicated interagency coordination, the National Science Council (NSC) launched a National Science and Technology Project for Hazard Mitigation (NAPHM) in 1997. The purpose of NAPHM is to initiate and integrate research works concerning disaster reduction, protection and response in various fields. The NAPHM also asks the research results to be implemented and practiced in the real world. In 2003, based on the Disaster Prevention and Relief Act, the executive office of NAPHM was upgraded to the National Science and Technology Center for Disaster Reduction (NCDR). In addition to carrying out the NAPHM project, NCDR clarifies her missions including scientific researches, technical supports, implementation and promotion. The goal of NCDR is to provide consultative advices, based on scientific knowledge, for the administrative and executive organizations to make their decisions. To achieve the goal, the information division of NCDR is responsible for developing necessary information technologies (IT) to mitigate disasters. Furthermore, the issue of information exchange, sharing and integration among various relevant organizations through the Internet becomes one of the most essential tasks to deal with nowadays [10].

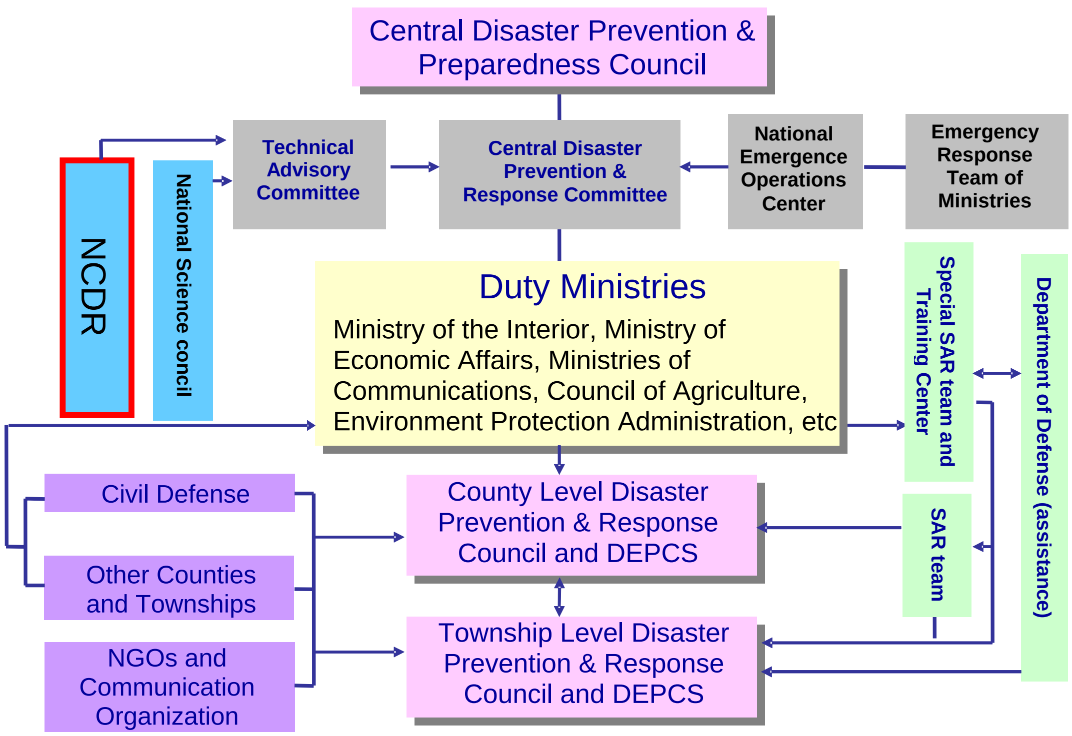


Fig. 1, Framework of Current Disaster Management Organizations in Taiwan

3. Case Study: Decision Support System for Emergence Response for Typhoon Hazards

Under the NAPHM project, NCDR has developed a Decision Support System for Emergency Response (DSSER) for typhoon hazards. This system is base on the Web-GIS framework that the disaster information can be distributed via the internet technology. The DSSER is designed to integrate the real-time monitoring data, the dynamic hazard models and graphical user interfaces (GUIs) to provide disaster management decision support tools for emergency response. The input data of this system includes the basic maps, the real-time information of typhoon and rainfall issued by the Central Weather Bureau, the real-time water information form the Water Resources Agency, and the hazard maps indicating areas of potential landslide, debris flow and flooding made by NCDR herself to estimate endangered areas under the current typhoon. Fig. 2 illustrates the data flow of the DSSER system. There are four main modules integrated into the DSSER including the rainfall monitoring and forecasting, the estimation of potential inundation areas, the estimation of potential landslide and debris flows, and the management of disaster information. With the coming of typhoon its future track is estimated according to the meteorological information provided by the CWB. When typhoon is approaching and the NEOC is activated, NCDR staff will estimate the hourly and accumulated rainfall distribution in the entire Taiwan over the next 24 hours. The results of rainfall forecasting will be fed into the DSSER system to analyze the possible occurrence of extreme disaster events including the flooding and debris flows over the next 24 hours. The results of analysis and warning messages are finally delivered to the National Emergency Operations Center (NEOC) and help the commander to make the right decisions in disaster preparedness and response phases. The functions of these four modules of DSSER will be described briefly in this section.

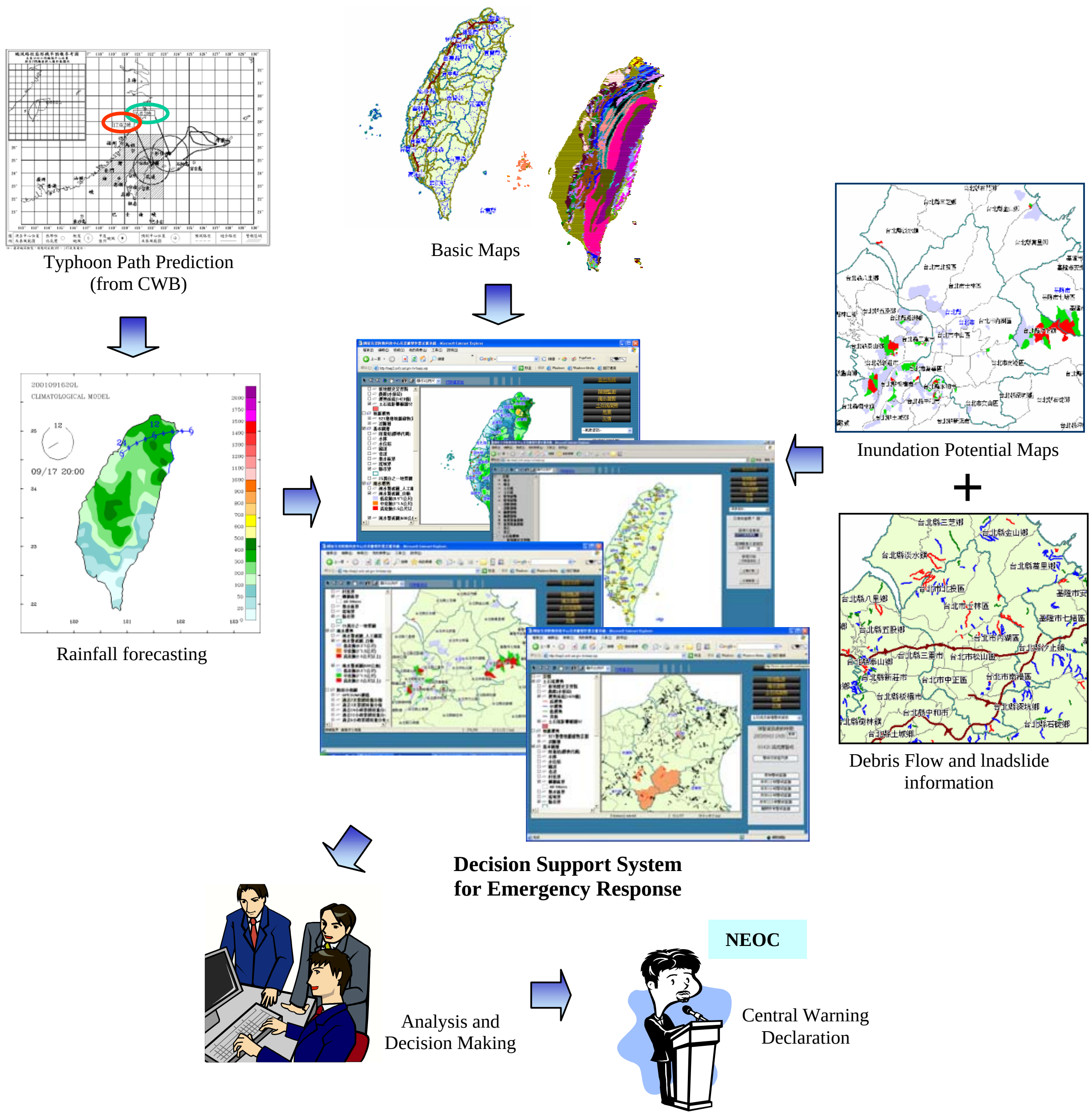
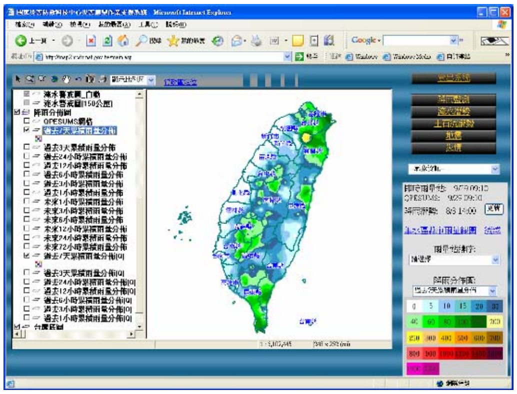


Fig. 2, The dataflow of Decision Support System for Emergence Response

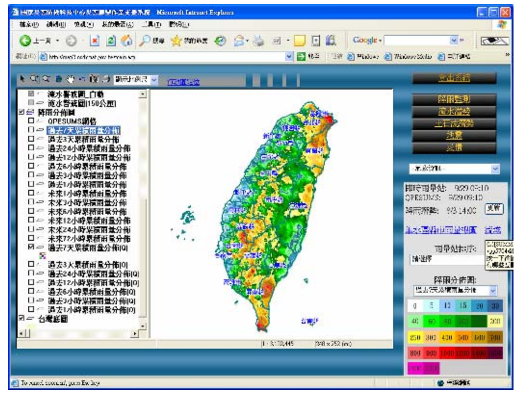
1) Rainfall Monitoring and Forecasting

During the monitoring stage when a typhoon was still far away from Taiwan, the NCDR staff collects the typhoon information and performed preliminary estimate of its future track. After the CWB issued sea and land warning, the motion of typhoon will be analyzed using the WINS system. The real-time observations of rainfall data from 374 precipitation stations which are irregularly distributed over Taiwan will be interpolated to the regular GRID data. The method of Inverse Distance Weighted (IDW) is used here as the interpolator. The accumulated rainfall distribution in the past 7 days is also calculated as the GIS layer which can be overlapped with other GIS layers such as the basic maps and potential hazard maps for further analysis. The result of the interpolation is shown in Fig.3(a). In addition, the rainfall amount of the typhoon can also be monitored using the Quantitative Precipitation Estimation and Segregation Using Multiple Sensors (QPE-SUMS) radar system [11]. The results is shown in Fig.3(b).

In the rainfall forecasting, the hourly and accumulated rainfall distribution in the entire Taiwan over the next 24 hours will be estimated using the climatological-persistence (CLIPER) model and QPE-SUMS radar system.



(b) Estimation of accumulated rainfall distribution using CLIPER model



(c) Estimation of accumulated rainfall distribution using QPE-SUMS radar system

Fig. 3, Rainfall Forecasting using the CLIPER and QPE-SUMS radar system

2) Estimation of Inundation Area

In order to reduce the disaster of flooding appropriately, an inundation monitoring model and an exact database of inundation potential maps are established by the Flood and Drought Disaster Reduction Division of NCDR. The surface inundation potential maps of urban regions in Taiwan have been simulated using the inundation model under the 24-hour design rainfalls of 150, 300, 450, and 600 mm. The results are stored as the GIS layers into the database in advance. When a typhoon attacks Taiwan, the inundation potential maps can be used to analyze the possible inundated areas and time of duration under the different raining condition. Fig. 4 shows the inundation potential map with different danger levels and warning districts queried using the user interface of the DSSER.

When typhoon is coming, the procedure which is integrated into DSSER automatically selects the inundation potential layers which indicate the possible flooding areas and disaster level every 10 minutes from the database according to the forecasting rainfall. The estimated results can also be modified manually via the user interface of DSSER according to the real rainfall situation. The information of inundation potential areas will be very helpful for the decision supports for emergency operations for typhoon and flooding disasters. It also assists the authorities concerned in proposing strategies for flood mitigation plans.

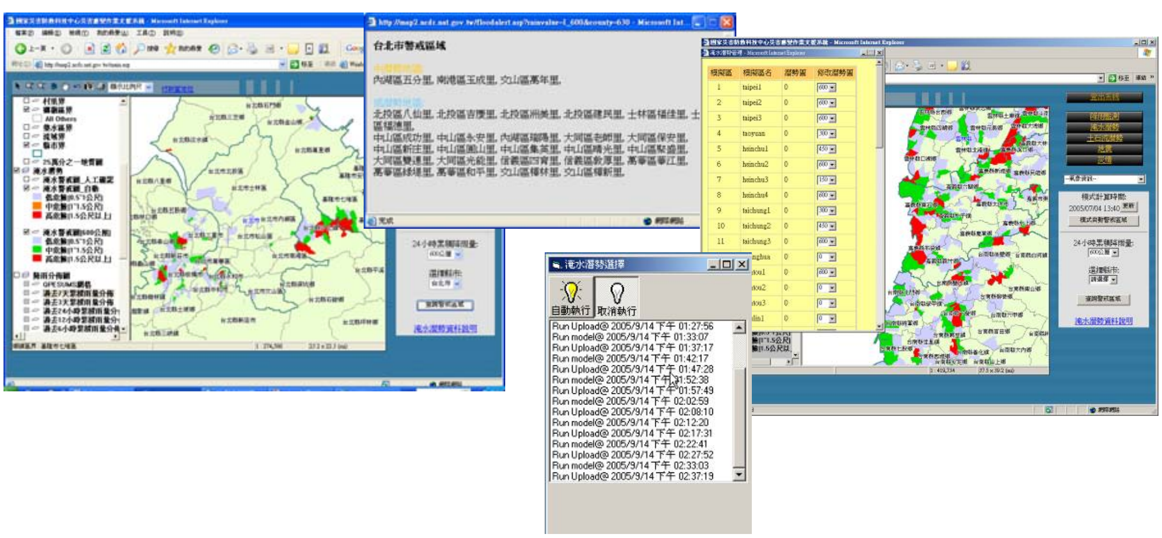
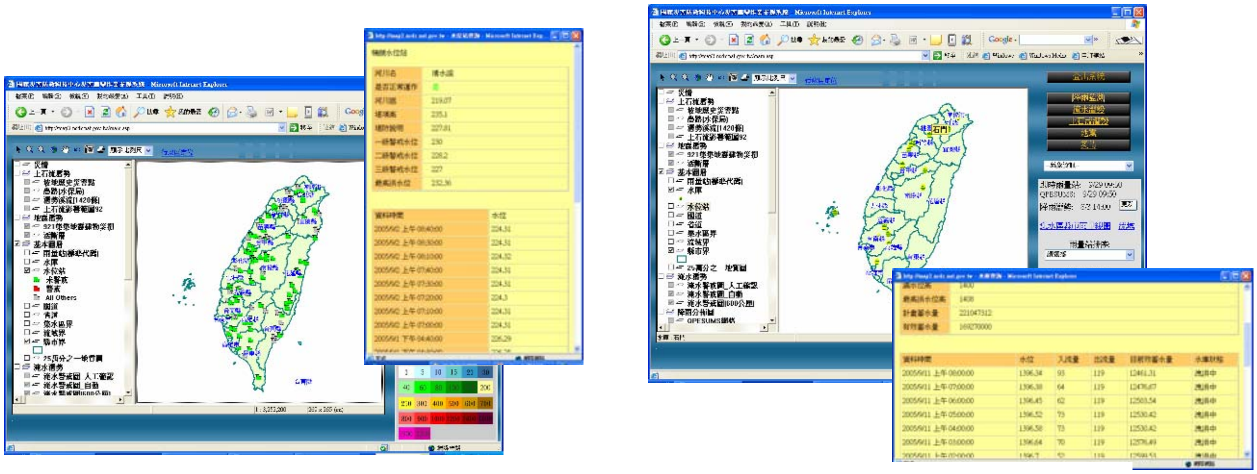


Fig. 4, The inundation potential map shows different danger levels and warning districts

In order to increase the estimation accuracy of the potential inundation areas, the real-time monitoring water information from the Water Resources Agency is also integrated into the DSSER system. Fig. 5 shows the distributions of the observation stations for real-time water information monitoring including the water level and current of rivers and reservoirs. The water information is recorded as XML format and transmitted into the DSSER via web services technologies real time.



(a) Water informationl of river

(b) Water information of reservoirs

Fig. 5, Real-time water information of rivers and reservoirs

3) Estimation of the potential hazards caused by Debris Flows and Landslides

The development of slope land in Taiwan is rapidly growing, so is the potential hazard for debris flow. Debris flow hazard has become one of the major reasons for slope land disaster. To reduce the damage of debris flow hazard, there are 1420 debris flow rivers investigated in advance by the Soil and Water Conservation Bureau, Council of Agriculture. In addition, the Slopeland Disaster Reduction Division of NCDR has also recorded 3,629 historical debris flows and landslides which are stored in the database. Fig. 6 shows the distribution of potential debris flows queried by the DSSER system. Utilizing the database, a critical isopleth map for debris flow threshold was setting up over the whole Taiwan.

When typhoon attacks Taiwan, the procedure which is integrated into DSSER system automatically identifies the potential areas of debris flow and landslide every one hour according to the isopleth map, averaged rainfall intensity and duration for pre-warning. The estimated results can also be modified manually via the user interface of DSSER according to the real disaster situation, shown in Fig. 7. By integrating the hazard analysis and simulation models of debris flow with the basic maps, the warning districts are distinguished as useful information that can assist the commander in making decision on hazard mitigation and salvage.

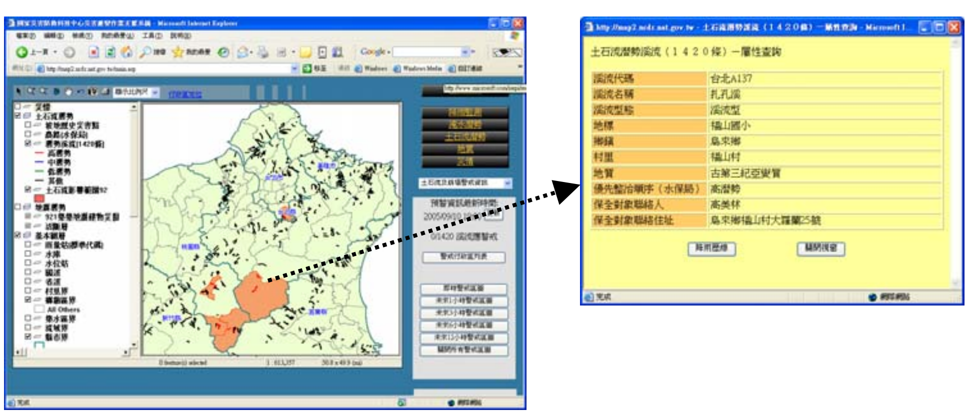


Fig. 6, The potential areas of debris flow rivers and the relevant information

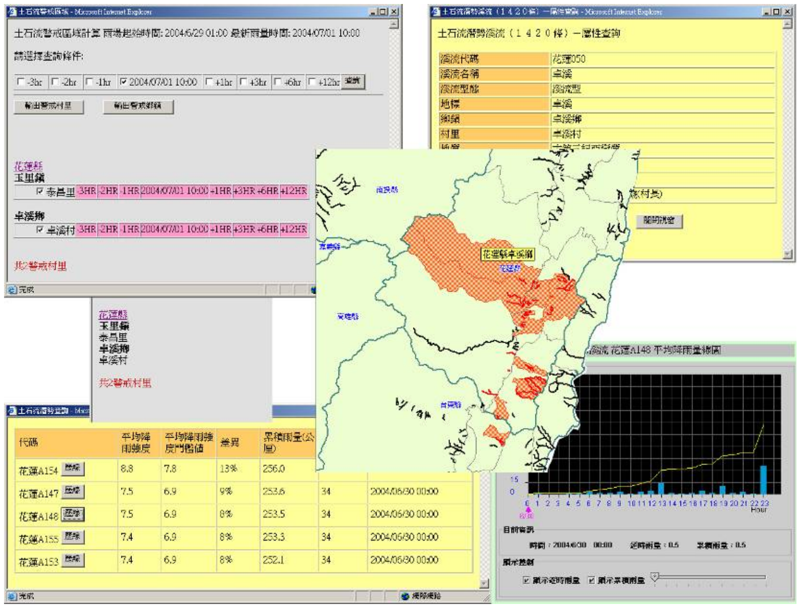


Fig.7, The user interface for the identification of warning districts of debris flows

4) Management of Disaster Information

Real time and correct information for the disaster situation is very important to the decision makers in relief and rescue phase. The collection of the disaster information usually affects the results of rescue actions. How to collect accurate real-time disaster information effectively and input this information to an appropriate database for further utilization are the important issues for the activity of disaster rescue. Using the powerful database to handle and analyze data, the decision makers can make the best decision for the emergency response immediately. The purpose of this module is to establish the mechanism of real-time disaster information collection for the disaster decision making. The DSSER can be improved effectively after integrating these disaster information.

In fig. 8, the disaster information is illustrated as a GIS distribution layer that enables the decision maker to understand the disaster distribution at a glance and do an appropriate emergency response. The location of a disaster can be determined by the digitization function of GIS, and the disaster information can be inputted or re-edited via the GUI tools of the DSSER.

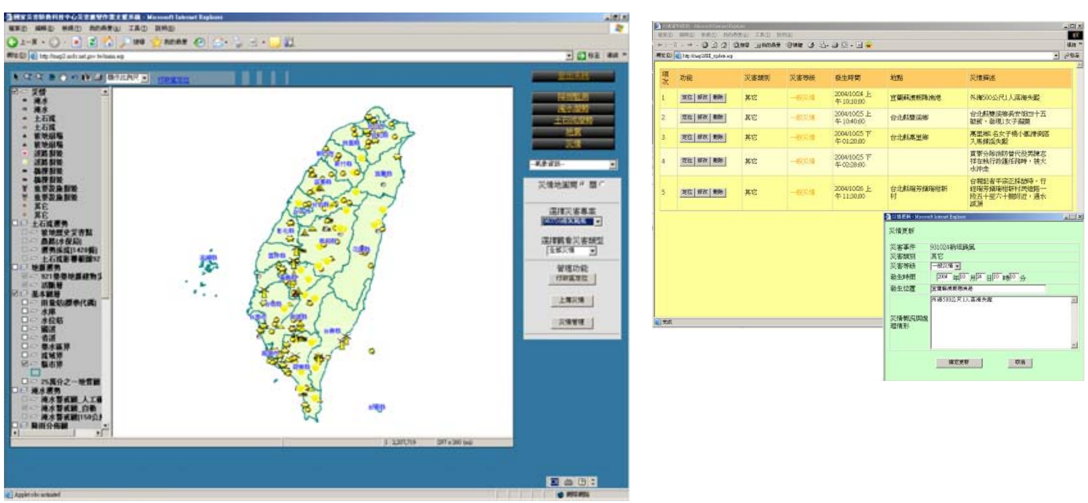


Fig. 8, The management of the disaster information and the GUI for information input

4. Strategies of Developing Disaster Management Information Systems

Disaster management is an interagency and interdisciplinary task. It involves many governmental agencies and departments. In particular, due to the nature of different kinds of disasters, the content and process of management information systems for different disasters in different phases may vary. In other words, the broad concept of disaster management system can be further classified into subsystems or modules. Sun et al. [12] proposed a framework of disaster management system in terms of the four phases of disaster management, namely mitigation, preparedness, response, and recovery. According to the framework, NCDR is prompting the development of an integrated Disaster Management Information System (DMIS) which is expected to be able to coordinate different levels of governmental agencies or departments in a smooth way during the period of disaster management. The DSSER system mentioned in Section 3 is one of the sub-systems of the DMIS. Since the disaster management system is very comprehensive, it is necessary to adopt some strategies to assure the success of the system development.

1) Taking the advantage of National GIS Program

The data base of DMIS consists of basic data and hazard data. Basic data include topographical maps, water systems, road systems, etc., while hazard data refer to sensed data concerning current rainfall and water level, or maps of faults, potential flooding, land slide, and debris, etc. When basic data are overlaid with hazard data within a GIS environment, it can not only show the spatial distribution of emergency events, but also perform further spatial analyses to assist decision makings. However, data collection is a huge and complicate work. To reduce the effort, it is necessary to have tight connection with the National Geographical Information System (NGIS) Program.

The purpose of the NGIS program, which has been carrying out more than 10 years in Taiwan, is to coordinate nation-wide GIS projects and establish a common standard for spatial databases [13]. The NGIS program has spend a lot of efforts on clarifying the responsibilities of GIS-related organizations. In other words, the NGIS program is establishing a general purpose, sound and nation-wide data base. DMIS is one of the most potential users of the NGIS program. Many GIS data which DMIS need may be available through the NGIS program. DMIS do not have to duplicate the same digitization work.

2) Teaming up the Information Divisions of Associate Centers of NCDR

While providing technical support to local governments is one of NCDR's missions, NCDR selects disaster prevention research centers of six major universities located in northern, central, and southern Taiwan as associate research centers to assist local governments. These associate research centers have strong information divisions with local data and capable of developing advanced information systems. Thus, teaming up the information divisions of these associate research centers becomes an important strategy to elevate and promote information technology for disaster management.

3) Establishing data exchange standard and common platform

Although many agencies or departments may have their own fruitful data bases, it is not unusual to find that the data items, definitions, formats, and degrees of precision and accuracy among these various data bases are incompatible. The incompatibility among data bases brings a lot of difficulty for having an integrated DMIS. However, this difficulty is not DMIS's own problem. It can be found in almost every inter- organization information systems. To overcome this problem, the Department of Information Management, Research, Development, and Evaluation Commission, Executive Yuan, have announced an XML-based official documents exchange standard guidelines in an e-government project. DMIS has to take the advantage of this standard. Following the exchange standard guidelines, DMIS can set up practical exchange standards, such as GML-based hazard maps exchange standards, for emergency management organizations can share data and information systems smoothly. Furthermore, DMIS should use web-based technology to establish her own data warehouse as a common platform. The idea of data warehouse of DMIS is shown in Fig. 9.

As city, state and national governments deploy Internet based GIS technology, there will be demand for a comprehensive, integrated approach to managing the entire range of spatial, as well as non-spatial data used in carrying out various governmental responsibilities and services. Data exchange at local, regional, city, state and national levels can be a continuous and cohesive process, resulting in better management and control of resources.

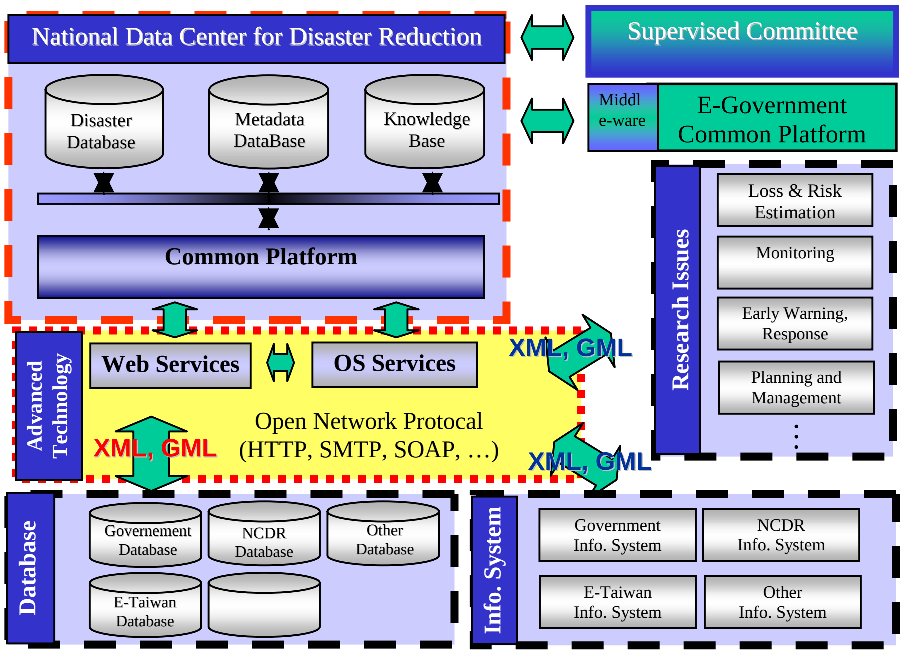


Fig. 9, The framework of DMIS data warehouse

4) Participating International Information Cooperation Projects

Many countries have already developed many successful DMISs. Taiwan's DMIS project can learn a lot of experiences from them. In particular, Taiwan should actively participate in international emergency response actions. It is not only a return for the help which the international community gave to Taiwan in the Chi-Chi earthquake in 1999, but also a good chance to learn and exchange experiences, including information management, each other.

5. Conclusions

This paper first introduced the current framework and developing information systems of disaster management in Taiwan. A decision support system for emergency response of typhoon hazard is developed for the case study. Issues of system implementation and promotion and strategies to overcome the difficulties of disaster management in Taiwan are also be discussed.

Information system is an essential component for disaster reduction and emergency management. Many organizations, including fire, weather, water, and soil agencies, in different levels of governments in Taiwan have had their own emergency information management systems. The further step for having an integrated DMIS is to tightly work with the NGIS program, team up the information divisions of associate research centers, establish a data warehouse as a common platform with an XML/GML-based data exchange standards, and join international cooperation projects. In the future, the disaster management information system will be upgraded to be a real decision support system, where more intelligent reasoning and prediction models should be installed together.

It is highly expected that we will have a more successful emergency response and disaster reduction system if we are able to fully employ the powerful capability of computer systems, web-based technology, and telecommunications device.

References

[1] Zerger, A., and Smith, D. I., 2003. Impediments to using GIS for real-time disaster decision support, *Computers, Environment and Urban Systems*, 27:123-141.

[2] Rao, D. P., 2000. Disaster Management, *Proc. Map* India *2000*, New Delhi, India. Available at: http://www.gisdevelopment.net/application/natural_hazards/overview/nho0004.htm

[3] Gupta, A., 2000. Information Technology and Natural Disaster Management in India, *Proc. ACRS'2000*, Taipei, Taiwan, pp. 346-351.
[4] Banger, S. K., Remote Sensing and Geographical Information System for Natural Disaster Management, *Proc. of Map India 2002*, New Delhi, India, Available at: http://www.gisdevelopment.net/application/natural_hazards/overview/nho0011.htm
[5] **URL:** The Introduction to FEMA's Strategic Plan, Available at http://www.fema.gov/library/pp2intro.shtm
[6] Carrara, A. and Guzzetti, F. (eds), 1995. Geographical Information Systems in Assessing Natural Hazards, Kluwer Academic Publishers, Dordrecht, The Netherlands.
[7] Raheja, N., 2003. GIS-based Software Applications for Environmental Risk Management, *Proc. of Map India 2003*, New Delhi, India, Available at: http://www.gisdevelopment.net/application/natural_hazards/overview/mi03080.htm
[8] Lin, F.T. 2004. Disaster Reduction Decision Support Systems in Taiwan, International Conference on Earthquake Hazard Preparedness, Rescue and Recovery, Taipei, Taiwan, pp.273-300.
[9] Lin, F. T., Hsu, P. H., 2005. The Development of Disaster Management Information Systems in Taiwan, *The 1st International Conference on Urban Disaster Reduction*, Kobe, Japan, 18-20 January.
[10] Sun, C.-H., Lee, P. J., Tang, K. T., and Tao, Y. H., 2004. Integrated Disaster Management Information System Based on Web Services Technology, *International Conference on Earthquake Hazard Preparedness, Rescue and Recovery*, Taipei, Taiwan, pp.99-133.
[11] **URL:** Quantitative Precipitation Estimation and Segregation Using Multiple Sensors, Available at http://www.nssl.noaa.gov/western/qpe/
[12] Sun, C.-H. et al., 2000. Developing a disaster management decision support system, *The Press of National Geographical Information Systems*, 34 (in Chinese)
[13] Lin, F. T., 2004. A Study on National GIS Master Plan, a research report sponsored by the Computer Center, Ministry of the Interior, Taiwan.