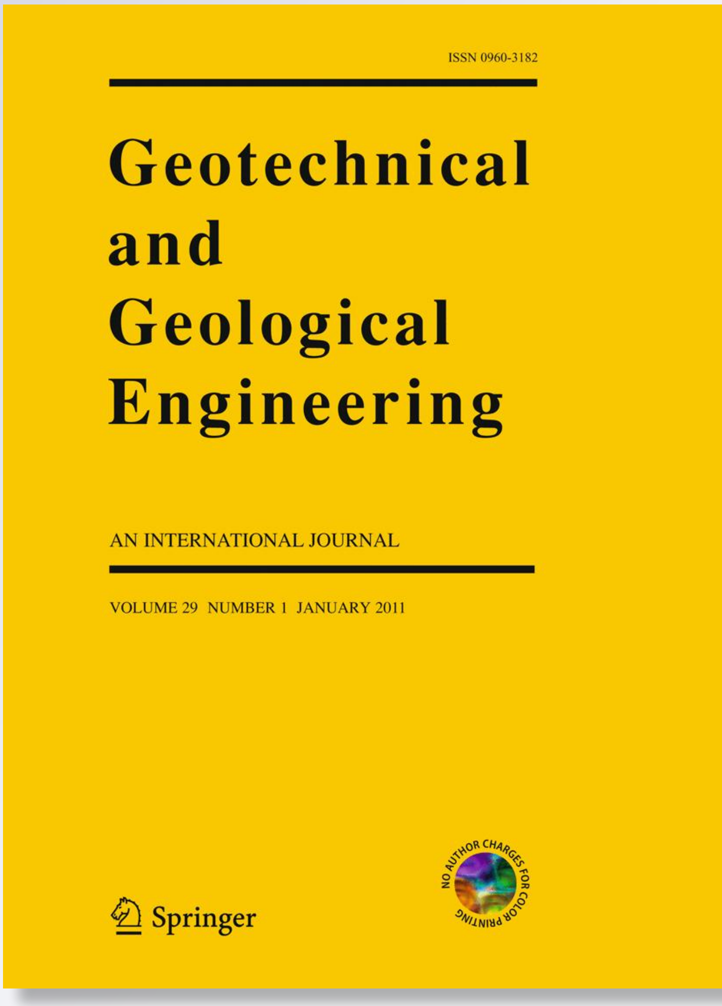
A GIS-based Decision Support System for Typhoon Emergency Response in Taiwan

Geotechnical and Geological Engineering
An International Journal

ISSN 0960-3182
Volume 29
Number 1

Geotech Geol Eng (2010)
29:7-12
DOI 10.1007/
s10706-010-9362-0



Geotech Geol Eng (2011) 29:7–12
DOI 10.1007/s10706-010-9362-0

ORIGINAL PAPER

A GIS-based Decision Support System for Typhoon Emergency Response in Taiwan

Ming-Hsi Hsu · Albert S. Chen · Liang-Chun Chen · Cheng-Shang Lee · Feng-Tyan Lin · Chen-Jia Huang

Received: 15 July 2005 / Accepted: 30 August 2009 / Published online: 30 October 2010

Abstract The effective response actions can significantly reduce the damage caused by disasters, but the emergency managers require plenty of information before setting up appropriate strategies. The data gathering and analyzing processes are complex and the time is constrained during emergency. A GIS-based decision support system was developed to enhance the emergency operations during typhoon attacks in Taiwan. The system integrates the real time rainfall monitor and forecast information, the hazard potential, and the basic spatial database to help the emergency managers making decisions efficiently.

Keywords Emergency response · Decision support system · GIS · Hazard potential

M.-H. Hsu (✉) · L.-C. Chen · C.-J. Huang
National Science & Technology Center for Disaster Reduction, 9F., No.200, Sec. 3, Beisin Rd, Sindian City, Taipei County 231, Taiwan
e-mail: mhhsu@ntu.edu.tw

M.-H. Hsu
Department of Bioenvironmental Systems Engineering, National Taiwan University, No. 1, Sec. 4, Roosevelt Rd, Taipei 10617, Taiwan

A. S. Chen
Centre for Water Systems, College of Engineering, Mathematics and Physical Sciences, University of Exeter, Harrison Building, North Park Rd, EX4 4QF Exeter, UK

L.-C. Chen · F.-T. Lin
Graduate Institute of Building and Planning, National Taiwan University, No. 1, Sec. 4, Roosevelt Rd, Taipei 10617, Taiwan

C.-S. Lee
Department of Atmospheric Sciences, National Taiwan University, No. 1, Sec. 4, Roosevelt Rd, Taipei 10617, Taiwan

1 Introduction

Taiwan is located at the intersection of Eurasian and Philippine sea plates as well as in the path of warm ocean currents. The environmental features result in frequent natural catastrophes, tremendous casualties and severe economic losses. The official statistics show that Taiwan suffers 6.6 natural hazards per year in the last decade. Earthquakes, flooding and typhoons are the major natural disasters. Typhoons are the most frequent events and amount for 65% of the natural hazards.

The annual-average precipitation is 2,500 mm, whereas the average in mountainous regions may reach 3,000–5,000 mm. About 80% of the rainfall, mainly brought by typhoons, concentrates between May and October. The total area of Taiwan is 36,000km^2, in which the mountainous area above 1,000 m occupies 32%, hills and plateaus between 100 m and 1,000 m cover 31%, and the rest is plains with elevation below 100 m. The topographical condition makes the 129 rivers in Taiwan are short and steep with small drainage basins. The intense rainfall and geographical characteristics often result in high peak flow discharge and short concentration time during typhoon events, which leaves insufficient time for emergency response and induce serious flooding in urban areas. The damages were often exacerbated in early years due to poor emergency response mechanism. Consequently, the Legislative Yuan in Taiwan passed the Disaster Prevention and Rescue Law (DPRL) in 2000 to strengthen the disaster emergency response of governments. In the DPRL, all government levels are required to set up Emergency Operation Center (EOC) for hazard mitigations. The Central Emergency Operation Center (CEOC) is organized at the national level for coordinating the departments of central government during emergency.

The emergency responses were focused on rescuing during disasters in early years. The emergency managers of CEOC provided the imperative resources and supports according to the requests from local governments. The mechanism reduced the damages of small disasters successfully, but the causalities and economic loss remained huge during catastrophes due to the insufficient relief resources and response time. The experiences forced the government to adopt more active hazard mitigating measures, i.e., if the probable hazard locations were highlighted earlier, the more response time and better preparedness could have been achieved.

Nevertheless, the administrative departments had limited studies and information to identify these hotspots. On the other hand, the National Science and Technology Center for Disaster Reduction (NCDR) had done many disaster-related researches and built the island-wide hazard potential databases, including inundation, landslide and debris disasters. Hence, the NCDR was assigned to identify the high hazard potential areas for the CEOC during emergencies.

The emergency actions for flash floods are usually time-constrained and the measures, such as resident evacuation and traffic closure, are expensive and inconvenient. False alarms have to be avoided to reduce the efforts and costs. Therefore, the emergency managers must be able to foresee the consequences of the flash flood events and to take certain actions appropriately. Different approaches were conducted to predict the accurate flood potential for decision supports. An integrated hydrological and hydraulic modeling approach was used for flood risk assessment in Italy (Anselmo et al. 1996). A real time hydrological model was applied for flood prediction with geographic information system (GIS) and WWW interfaces (Al-Sabhan et al. 2003) in U.S.

2 The Decision Support System

In Taiwan, the NCDR developed a GIS-based decision support system (DSS) to help the emergency managers setting up the response strategies efficiently. The DSS consists of the basic geographical database, the real time monitor and forecast rainfall database, the inundation potential database, and the debris and landslide potential database. The details of the databases are described as followings.

2.1 The Basic Spatial Database

The spatial database includes the administrative divisions, rivers, basins, watersheds, traffic networks, major public facilities, etc. The fundamental information can be overlapped with rainfall and hazard potential information to help emergency managers to understand the possible hazard scenarios and find available resources in the neighbourhoods. The emergency managers can easily obtain the required information and evaluate the applicable response measures via the DSS for making decisions.

2.2 The Rainfall Monitor and Forecast Database

The Central Weather Bureau (CWB) has built a rainfall observation network in Taiwan, which contains 43 weather stations and 406 automatic rain gauges. The precipitation records are automatically transmitted to the CWB by wireless radios with a 10-minutes frequency. The CWB collects the records, generates an observation report and forwards a copy to the NCDR via internet.

Besides the rainfall monitor records, the rainfall forecast information is also essential for the emergency managers to evaluate the rainfall tendency. During typhoons, the NCDR uses a Typhoon Rainfall Climatological Statistical Model (TRCSM) to estimate the possible precipitations during typhoons. The model uses the typhoon path predicted by the CWB to forecast the rainfall could be produced in during a typhoon event. The forecasted rainfall is integrated into the DSS to demonstrate the spatial and temporal distribution trends of rainfall.

2.3 The Inundation Potential Database

The inundation potential database (IPDB) was built by the National Science and Technology Program for Hazards Mitigation (NAPHM, the former NCDR) in 2001. The NAPHM launched the project for building the IPDB of Taiwan since 1998. The IPDB was simulated by watershed divisions individually with four different total daily rainfall conditions, 150, 300, 450 and 600 mm.

The detailed IPDB requires a 2-D distributed watershed model to estimate inundation depths. Each watershed was divided into upstream mountainous catchments and a downstream alluvial plain with the assistance of GIS. The HEC-1 model was applied to compute the discharges of the mountainous catchments flowing into the alluvial plain. A 1-D dynamic channel-flow routing was performed for main channel flows computing (Hsu 1992), whereas a 2-D overland-flow routing was used for surface inundation simulation of the alluvial plain (Hsu 1998). For the urban regions with detailed sewer drainage system information (Hsu et al. 2000; Hsu et al. 2002), the Storm Water Management Model (Huber 1975; Huber and Dickinson 1988) was applied for sewer flows routing.

2.4 The Debris Flow Potential Database

The debris flow potential database was built according to historical records, numerical modeling and field investigations. There are 1,420 creeks and their corresponding downstream areas were identified prone to debris flow. The Soil and Water Conservation Bureau (SWCB) categorized those creeks into three grades as low, medium, and high potential, based on their mitigating engineering facilities and natural environmental characteristics. SWCB also installed monitoring system at high potential spots and set up emergency evacuation plans for the threatened communities. The historical landslide hazard locations were also added to the database because landslides often repeat at same locations.

3 Case Study

Figure 1 illustrates the operating procedures of the DSS. Once the system receives the real-time rainfall monitor and typhoon path forecasting information, the DSS immediately analyzes the tendency of rainfall and predicts the following development. The DSS generates the rainfall distribution maps of the latest 1, 3, 6, 12 and 24 h to display the overall rainfall situations. Figure 2 shows the 24-hour rainfall distribution at the early stage brought by Typhoon Nock-ten in 2004. The typhoon was still a distance from Taiwan at the time and was expected to make a landfall in the northeast area within several hours. The rainfall observation showed that the typhoon had started affecting Taiwan. The most important information at the time being were the forecast of the rainfall intensity, scale and the concentration areas for evaluating the damages. Figure 3 shows the forecasted rainfall distribution that analyzed by the TRCSM, which indicated that the rainfall would be up to 500 mm in the mountain areas in northern Taiwan.

The results were combined with the hazard potential database for finding the hotspots from the databases. For non-professional users, the procedures are too complex to integrate the information for selecting the suitable map. The DSS contains a series of automatic programs scheduled for data collecting, integrating and user-friendly interfaces for demonstration. For example, the DSS compares the near-real-time rainfall monitor and forecast conditions to the rainfall patterns that were used for establishing the IPDB. Then, the inundation potential maps with the most similar scenarios were selected from the IPDB and displayed. The DSS further overlapped the hazard information with the basic spatial database to help the decision makers setting up response strategies. Figure 4 shows the combination of the inundation potential and the traffic network in the area to be affected by Typhoon Nock-ten.

Once the areas with disaster potential were identified, the emergency managers can evaluate the damage and take certain actions to lessen damages. The inundation potential was categorised into three levels. Level 3 represents the average flood depth would be more than 1.5 m, which was the priority for hazard mitigation. Therefore, the managers issued early warnings to the residents living in the highlighted

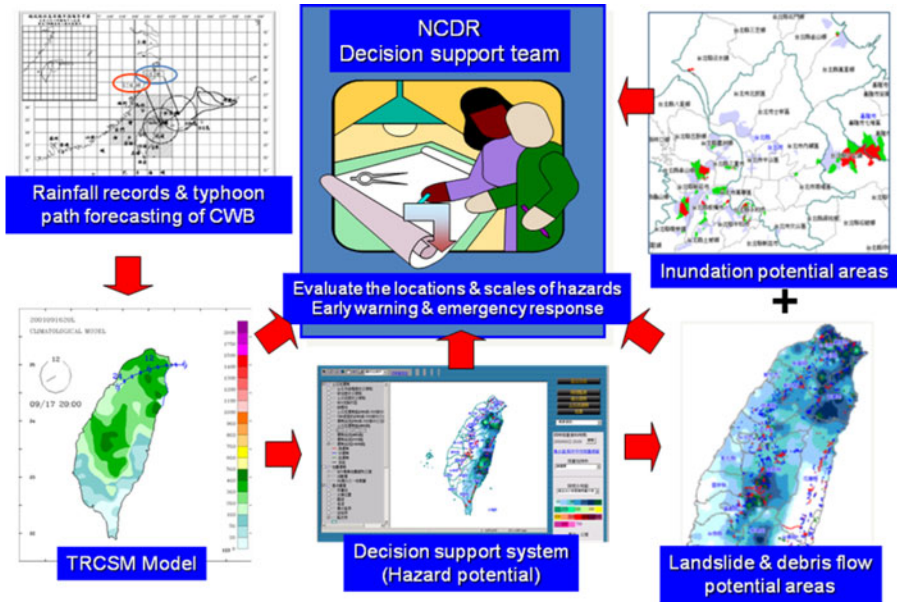


Fig. 1 The operation procedure of DSS

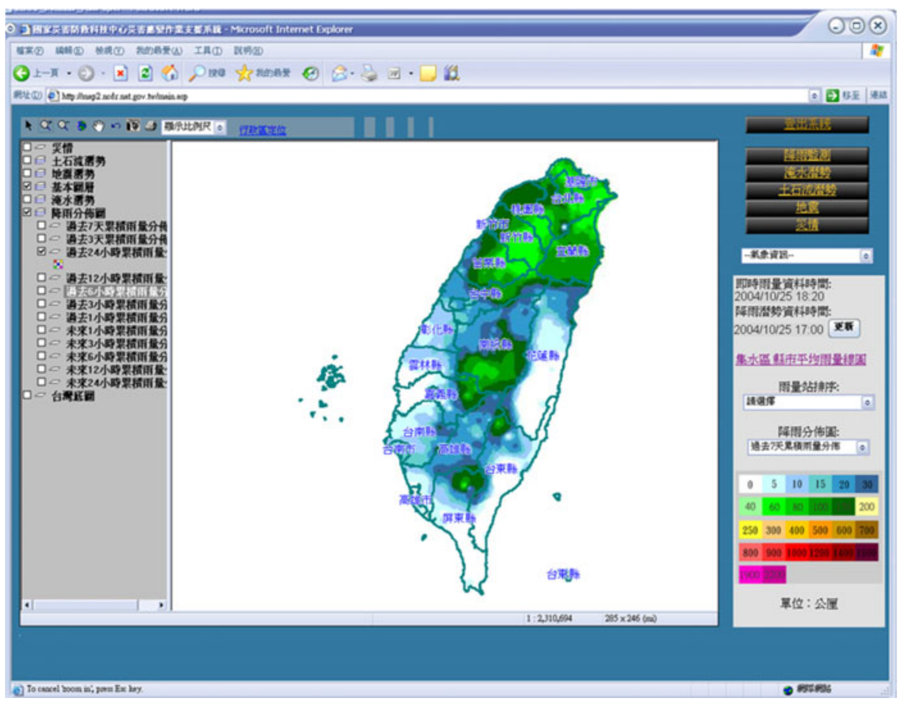


Fig. 2 The monitor rainfall distribution map before the landfall of Typhoon Nockten event

areas and set up the evacuating plans based on the relationships among the inundation extents and depths, the community locations, the traffic networks, and the sites and capacities of shelters. The authorities also allocated rescuing resources, such as temporary flood-defense walls, sand bags and pumps, to reduce the impact of inundation.

4 Conclusions

The DSS successfully helped the emergency response operations, however, the reliability of the DSS relies on the accurate modelling results. The TRSCM is statistical-based such that the model is limited for predicting extreme event conditions. Similar restrictions apply to

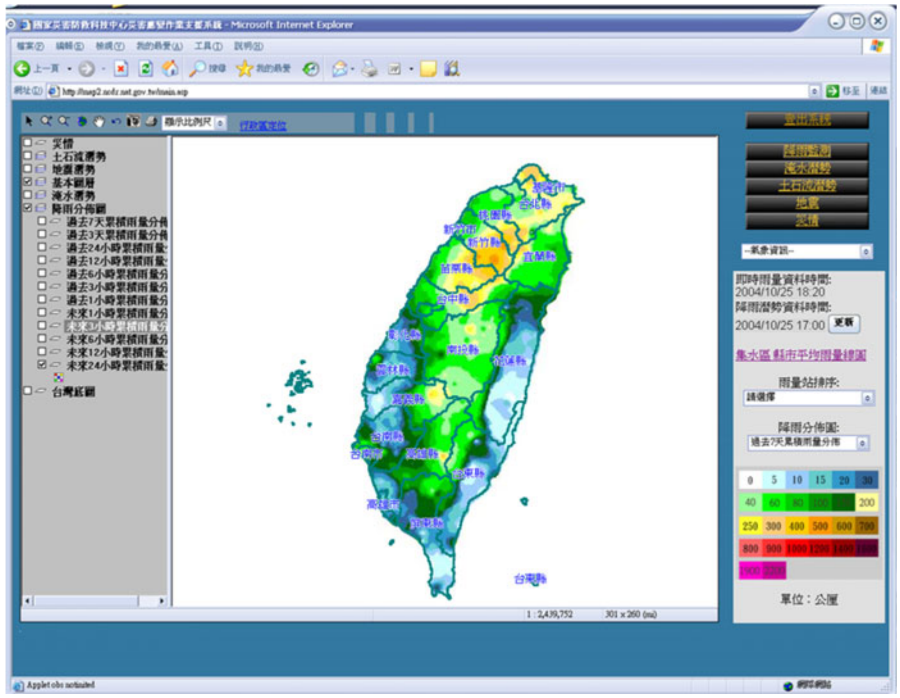


Fig. 3 The forecasted rainfall distribution before the landfall of Typhoon Nock-ten event

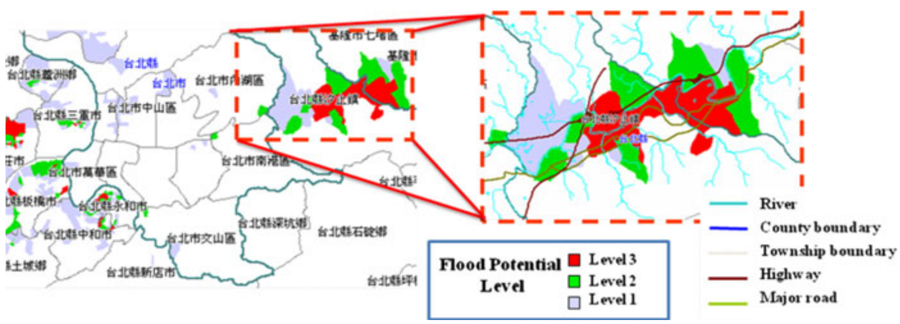


Fig. 4 The highlighted inundation potential areas (*left*) and the overlapped map with spatial information layers (*right*) for setting response actions

the hazard potential estimations. Accompanying with the climate change, the extreme rainfall events are expected to increase in the future. The enhancement of TRSCM and hazard potential databases would be necessary to ensure the DSS for providing creditable services.

The DSS collects the timely information via the internet connection and matches the event conditions with the scenarios in the hazard databases. Thus, the DSS provides not only the integrated observation records, but also the hazard potential and the additional geographical information. The user-friendly interface simplifies the complex efforts and time for data collecting, integrating and matching. The decision makers can easily query the integrated information during emergency and take response actions with the assistance of the application.

Acknowledgements The authors thank the National Disaster Prevention and Protection Council, the National Science Council, the National Fire Agency, the Central Weather Bureau, and the Water Resource Agency, for providing the valuable information and support.

References

Al-Sabhan W, Mulligan M, Blackburn GA (2003) A real-time hydrological model for flood prediction using GIS and the WWW. Comput Environ Urban Syst 27:9–32

Anselmo V, Galeati G, Palmieri S, Rossi U, Todini E (1996) Flood risk assessment using an integrated hydrological and hydraulic modelling approach: a case study. J Hydrol 175:533–554

Hsu MH (1992) Simulation of inundation with overflow on Levee along Keelung River. The CCNAA-AIT joint seminar on prediction and damage mitigation of meteorologically induced natural disasters, Taipei, Taiwan

Hsu MH (1998) Inundation study for stations and depots of Taiwan High Speed Rail. Hydraulic research laboratory. National Taiwan University, Taipei, Taiwan

Hsu MH, Chen SH, Chang TJ (2000) Inundation simulation for urban drainage basin with storm sewer system. J Hydrol 234(1–2):21–37

Hsu MH, Chen SH, Chang TJ (2002) Dynamic inundation simulation of storm water interaction between sewer system and overland flows. J china Inst Eng 25(2):171–177

Huber WC (1975) Model for storm water strategies. APWA Reporter

Huber WC, Dickinson RE (1988) Storm water management model. User's manual verson IV. Environmental Protection Agency, US