Development of a Decision Support System for Earthquake Risk Assessment and Loss Mitigation: The Hanoi Case Study

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Abstract

A powerful, GIS-based Decision Support System (DSS) was developed to assist users in managing earthquake risk for an urban area. The system consists of a spatial database and two main components. The first component is designed to assess the earthquake hazard caused by a predefined scenario earthquake for a chosen urban region and provides users with a set of ground shaking and ground failure maps. The second component is specialized on earthquake risk assessment, which resulting in a set of maps depicting level of damage and losses of various elements at risk within the community (people, buildings). The system's outputs, which are forecasts of damage and human impacts that may result from future earthquakes, can be used to manage effective earthquake disaster reduction measures including preparedness, emergency response activities and recovery actions and policies. As an illustration of the system, some results of the Hanoi case study are presented.

1. Introduction

The earthquake threat usually appears in places of high seismic activity and becomes catastrophic if such places are at the same time urban or industrial areas. In Vietnam, despite of the fact that events of magnitude 6.7 or higher have occurred in the northwestern part of the country, earthquakes have never been recognized as a disaster with highest priority. To some extent, earthquakes occurred in Vietnam up to now are not devastating partly because their epicenters are located far from the urban or industrial areas. Nevertheless, the earthquake risk exists and can not be ignored, particularly for many vulnerable areas of the country as the territory of North Vietnam, the coastal zones of Central Vietnam and the southeastern continental shelf of Vietnam. For such areas, the assessment of earthquake risk in order to help community in managing risk and reduce earthquake loss becomes not only actual problem, but an urgent need.

During the last five years, the use of GIS technology has significantly accelerated the progress of earthquake research. The GIS provides a powerful tool for solving specific and sophisticated problems in seismology. GIS applications allow users to display outputs and visualize the effects of different earthquake scenarios and assumptions and then make the sound decisions.

This paper describes the development of a GIS-based software, which can be used as a

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Decision Support System in earthquake risk assessment and loss estimation for the areas, vulnerable to earthquake threat in Vietnam.

2. Decision Support System and Its Application to Earthquake Risk Assessment

A Decision Support System (DSS) is an interactive computer based system which help decision makers utilize data and models to solve unstructured problems and make decisions, Sprague et al. (1986). In another words, DSS is essentially a means for involving a range of structured inputs to generate possible options leading to sound management decisions. Many sophisticated DSS are built using GIS technology, which provides a user-friendly graphical interface and allows for the decision maker's own insights.

A GIS based DSS for earthquake hazard assessment and loss estimation has been developed recently and has been pilot tested for an urban area of Hanoi, Phuong (2001; 2003), Phuong et al. (2003). Figure 1 shows the structure of an earthquake risk assessment procedure, where the numbered boxes correspond to 5 analysis modules of the system. As indicated by the arrows, the modules are interdependent, i.e. outputs of some modules are used as input to others.

The system is initiated by defining a study region. Then, a scenario earthquake, which is an earthquake with predefined magnitude and location is defined for the study region. On the basis of existing data and knowledge on seismicity, seismotectonics, ground condition, various methods are applied to assess the ground motion for the study region. The results of this assessment, also known as the seismic hazard of the region, are used as input for the next stage, where the ground failure is assessed. Finally, data on vulnerability such as census tracks, population density, landuse, infrastructure (buildings, transportation, lifelines etc.) is combined with the ground failure data to estimate loss and damage caused by the scenario earthquake in the study region.

3. ArcRisk: An Earthquake Risk Assessment Tool for Earthquake-Prone Areas in Vietnam

The whole system, methods and data have been coded into a user-friendly software (called ArcRisk), that can be run in the ArcView GIS environment. The Avenue programming language was used to link the main components of the system, including a spatial database, the analysis models and graphical user interface. The analysis modules of ArcRisk implement the steps of the risk assessment procedure described in Figure 1.

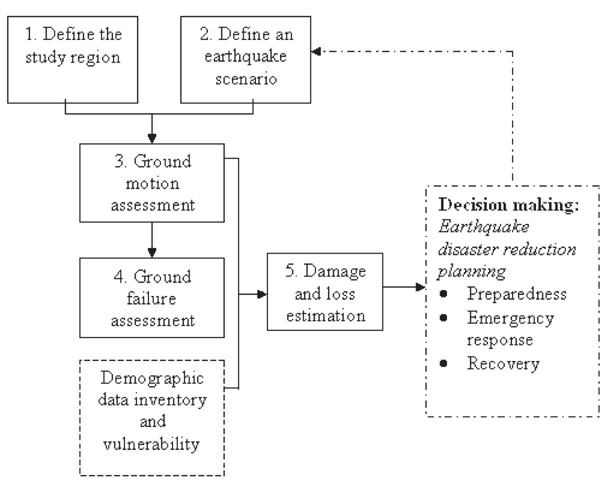

Figure 1: Earthquake risk assessment procedure by means of a DSS

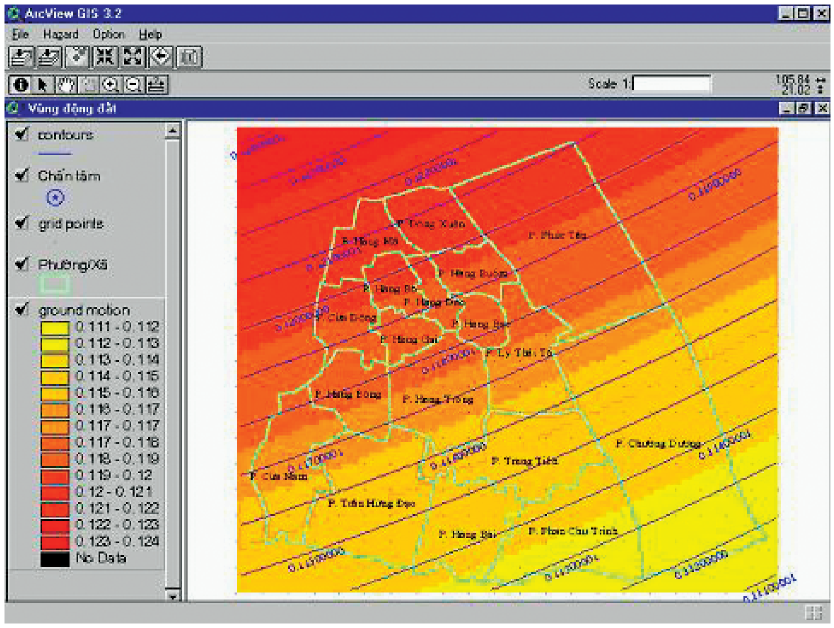

Figure 2: Sample ground shaking map: PGA map calculated for Hoan Kiem district, using Xiang Jianguang & Gao Dong (1994) attenuation function and a 6.2 magnitude scenario earthquake with epicenter coinciding the 1285 historical earthquake

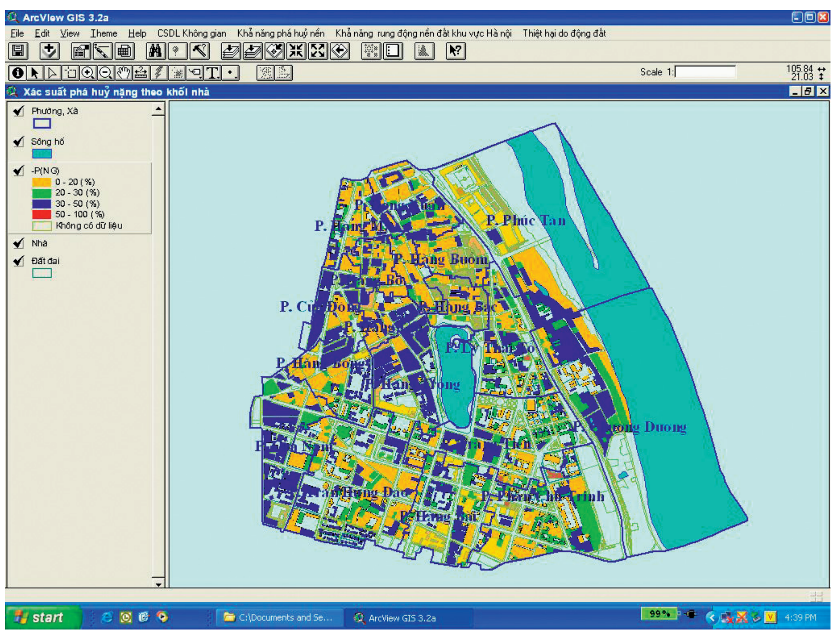

Figure 3: Estimation of building damage at Hoan Kiem District, Hanoi due to an arbitrary earthquake scenario

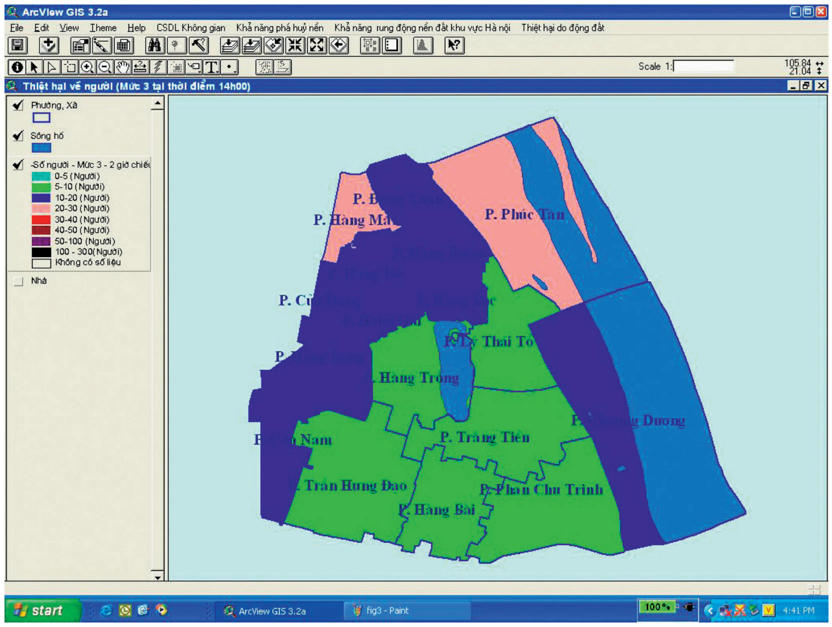

Figure 4: Estimation of casualties at Hoan Kiem District, Hanoi, due to an arbitrary earthquake scenario

ArcRisk gives the users options for selecting the scope and nature of the output of loss estimates. The extent and level of risk due to earthquake in the region are depicted in a variety of GIS maps, automatically generated by the software.

In the following sections, the description of main analysis modules of the system, their functions and outputs are given. As an illustration of the system, preliminary results of seismic risk estimation of the Hoan Kiem district, downtown of Hanoi are presented.

3.1 Defining the Study Region

In most cases, the study region can be defined as administrative boundaries such as city, district or ward limits. In fact, a study region can be any combination of administrative units, each of which comprises one or more smaller geographic units. Thus, defining the study region requires only that the user be able to identify the smallest geographic units that comprise the region.

The first module of the system has been developed for defining the study region. An example of the use of this model to extract the Hoan Kiem district from the base map of Hanoi city is shown in Figure 2. Note that the extracted region includes all its wards as the unit polygons. In ArcRisk, the study region selection is handle by means of a number of selection windows, Phuong (2003).

3.2 Defining an Earthquake Scenario

The second module allows users to specify the parameters of a scenario earthquake, predicted to occur in or near the study region. These parameters are: magnitude, epicenter's coordinates, focal depth. Besides, additional information on the shaking source (e.g. location of the faults or fault segments capable of originating earthquakes, fault rupture parameters such as fault type, depth, width, length, rake angle, slip rate etc.) can be extracted from the system's spatial database and used for defining earthquake scenario.

A scenario earthquake can either be a historical epicenter event, a source event, or an arbitrary event. ArcRisk provides a number of windows for users to manipulate in order to specify an earthquake scenario: select a variable, modify the parameters, etc.

3.3 Ground Shaking Assessment

Once the source and site have been identified on map, module 3 is used to solve the following problems:

a) To calculate the ground shaking for the study region using attenuation relationship and scenario earthquake selected from the previous module;
b) To compile seismic hazard maps in terms of one of the ground motion parameters for the chosen study region.

The default parameter used to compile ground shaking maps is Peak Ground Acceleration (PGA). Figure 2 illustrates a PGA map (a_{max}) compiled for the Hoan Kiem district, according to a predefined earthquake scenario. As can be seen from Figure 2, the ground shaking map is presented in both vector and raster formats.

3.4 Ground Failure Assessment

In the fourth module, the local site effect and ground failure are considered. Taking into account that the type of soil in the study region can affect the amplitude of the ground motion, a digitized soil map is supplied with the software to include the site effects. ArcRisk considers the following types of ground failure: liquefaction, landsliding and surface fault ruptures. Each of these types of ground failure are quantified by Permanent Ground Displacement (PGD) measured in meters.

The implementation of the module 4 results in a number of ground failure maps, automatically calculated and displayed for the study region. The typical thematic maps on ground failure are:

- Liquefaction susceptibility map;
- Landslide susceptibility map;
- Map of probability of liquefaction;
- Map of probability of landslide;
- Map of ground settlement due to liquefaction;
- Map of ground lateral spreading due to liquefaction;
- Map of ground lateral spreading due to landslide.

3.5 Loss Estimation

Information on ground motions and ground failure is used in combination with data on vulnerability to assess damage and loss for the study region in the Module 5 (Figure 1). ArcRisk assesses the damages and loss caused by the scenario earthquake for two elements at risk: the building stocks and the casualties. The examples below illustrate the application of ArcRisk to the Hoan Kiem district, downtown of Hanoi.

Structural damage caused by earthquake is assessed for 16 common model building types, classified according to their construction material and building height (FEMA, 1999). For each of these types, damage is described by five damage states: none, slight, moderate, extensive and complete. ArcRisk calculates the damage state probabilities for each model building types, and the results are used for casualty estimation. It should be noted that ArcRisk considers only the casualties due to damage or collapse of buildings. Casualties are estimated for 4 injury severity levels and at three times of the day: nighttime, daytime and commute time.

The results of this module can be presented in two forms: charts for calculation at points and maps for the whole study region. The maps presented in Figures 3 and 4 show the building damage and casualties for the Hoan Kiem district, downtown of Hanoi due to a close-to-reality scenario earthquake.

4. Conclusion

ArcRisk appears to be a powerful tool for earthquake hazard and risk assessment in Vietnam. The forecasting capability makes ArcRisk useful for many users with different needs. One of the important outcomes is that the application of ArcRisk can considerably raise the people's awareness of the earthquake threat in the country. Moreover, ArcRisk can be applied as a Decision Support System in order to help the decision-makers at local, regional and national levels in:

- Mitigating the possible consequences of earthquakes,
- Anticipating the possible nature and scope of the emergency response needed to cope with an earthquake-related disaster, and
- Developing plans for recovery and reconstruction following such a disaster.

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