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Earthquake – Tsunami Hazard Assessment and Risk Mitigation in Vietnam using GIS

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The increase of damages and losses due to earthquake and tsunami is not a contingent phenomenon, but a indispensable consequence of population explosion, high speed industrial and infrastructure development, and other social-economical activities. High seismic risk exposure is particularly focused on megacities, industrial centers located in the areas, vulnerable to earthquake impacts, or coastal zones within radius of tsunamis affection. Therefore, planning and investment for strategies on reduce and mitigation of losses and damages due to earthquake and tsunami now become an urgent issue for many countries in the World. Moreover, these strategies have to be made and implemented before the occurrence of earthquake or tsunami in order to avoid much more expenses for the response and recovery activities.

This paper shows some examples of using GIS to assess seismic hazards at regional scale and to estimate losses for urban areas of several cities in Vietnam. The posibility of using a GIS to develop a database of pre-calculated tsunami scenarios and a DSS for tsunami risk analysis is also discussed. A fault-source model for deterministic seismic hazard assessment in Vietnam was developed based on a database of seismically active faults, Well and Coppersmith relation between earthquake magnitude and fault's parameters (1994) and 10 attenuation equations for regions with different seismotectonic settings. A GIS-based DSS was developed to help users in assessing hazard caused by a scenario earthquake assumed to be originated by a tectonic fault. The software allows automatic implementation of various stages in a seismic hazard assessment procedure, such as selection of study region and active fault, definition of a scenario earthquake, and hazard calculation.

Use of a GIS makes possible the convenient manipulation of loss estimation data concerning building stock and casualties. The results show a realistic picture of damage and loss that may result from future earthquakes in Vietnam. The estimates of damage and human impacts due to earthquakes and tsunamis can help the decision-makers at local, regional and national levels in:

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

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1. Introduction

The quantitative seismic hazard assessment is usually based on pre-developed source models, which simulate the process of energy release and seismic wave propagation of an earthquake from source to site. The seismic hazard models allow to calculate hazard at a given point and then to construct the hazard map for the entire study area.

Such seismic hazard models were first developed and used by Cornell (1968) and Milne and Davenport (1969). Implicit in all of these models is the assumption that the total energy released by earthquakes radiated from the focus of the earthquake, and therefore may be called "point-source models". The application of the point-source models would not be accurate in case of major earthquakes, when total energy released is distributed along the rupture zone that could be several hundred kilometers long or when the site is located very close to the fault. In general, the rupture length is a significant parameter in the determination of seismic hazard, and neglecting its effect would tend to underestimate the real risk to large-magnitude earthquakes.

To overcome the disadvantages of point-source models, Der Kiureghian and Ang (1977) at the same time with Douglas and Ryall (1977), proposed a fault-source model, which is based on the assumption that an earthquake originates at the focus and propagates as an intermitten series of fault ruptures or slips in the rupture zone of the Earth's crust, and that the maximum intensity of ground shaking at a site is determined by the slip that is closest to the site.

In this paper, development of a fault-source model for seismic hazard assessment and risk analysis in Vietnam is described. GIS technology was used to create powerfuls tools for calculating and maping hazard, then displaying outputs and permits users to "see" the effects of different earthquake scenarios and assumptions. Two examples of the use of fault-source model in seismic hazard assessment and risk analysis in Vietnam at regional as well as urban scales are given.

2. Database of seismically active fault systems in Vietnam

In order to develop a fault-source model for Vietnam, a database of 46 seismically active faults systems in the territory and continental shelf of Vietnam was created. Information of faults systems were taken from the studies, previously published by various authors (Nguyen Hong Phuong, 1991, Cao Dinh Trieu et al, 2002). The faults systems are grouped in two ranks, depending on their depth of active layers and magnitude thresholds. The faults systems are simplified and digitized as single polylines in a GIS environment, and linked with their attribute data. There are two types of faults attribute data stored in the database. The first type is the descriptive information, including fault name, fault rank, type of faulting, main direction, total length, etc... More important attribute type is the fault parameters, which can be used directly to the hazard calculation as maximum moment magnitude, surface and subsurface rupture sizes, dip angle, etc…

A scheme of seismically active faults systems in the territory and continental shelf of Vietnam is shown in Figure 1.

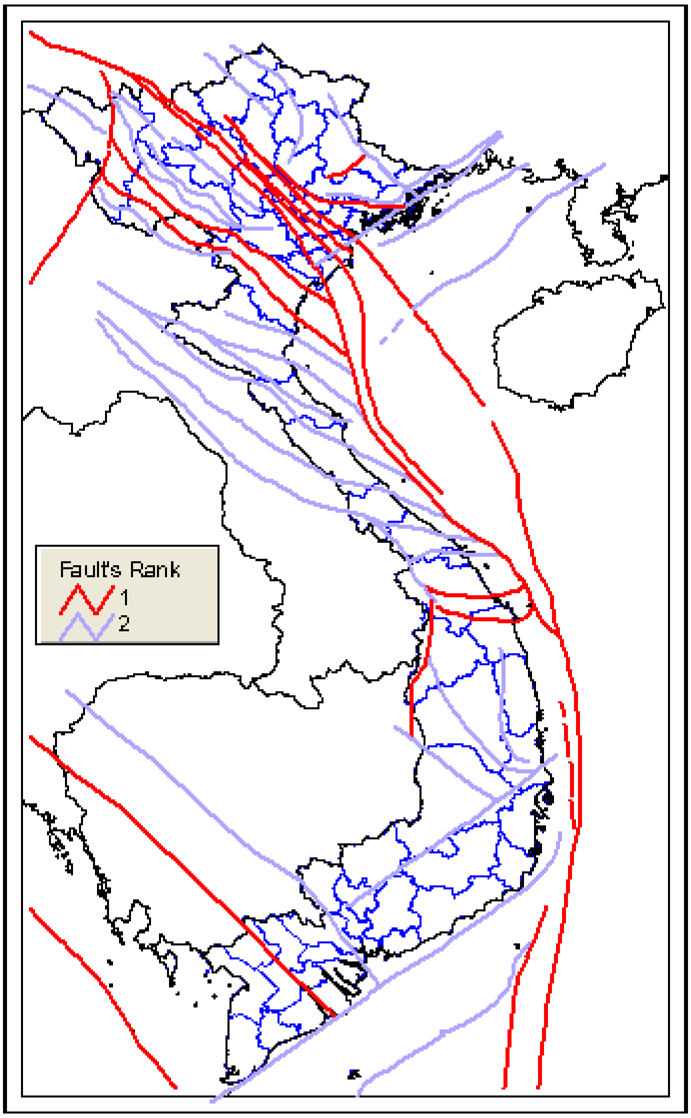

Figure 1. Scheme of seismically active faults systems in the territory and continental shelf of Vietnam.

3. Development of a fault-source model

The relationship between earthquake magnitude M and rupture length L has been investigated by many authors. A fault-source model of Vietnam was developed, using the relationship of Wells and Coppersmith (1994) given below:

$$\mathrm{Log10}(L) = a + b.\ M \qquad (1)$$

where L is the rupture length (km) and M is the moment magnitude of the earthquake; a and b are regression coefficient, determined for different types of faults and given in Table 1.

Relationship between ground motion parameters Y, the earthquake magnitude M and the focal distance R, also known as the attenuation equation, can be express as follows:

$$Y = c_1 \exp(c_2 M) Rc_3 \quad (2)$$

where Y is one of the peak ground motion values (acceleration, velocity, or displacement). c_1, c_2 and c_3 are spatial dependent constants.

Table 1. Regression coefficients of fault rupture relationship of Wells and Coppersmith (1994)

Rupture type	***Fault type***	***a***	***B***
Surface	Strike slip	-3,55	0,74
	Reverse	-2,86	0,63
	All	-3,22	0,69
Subsurface	Strike slip	-2,57	0,62
	Reverse	-2,42	0,58
	All	-2,44	0,59

In this case, two ground motion parameters are used to express seismic hazard. The first parameter is Peak Ground Acceleration (PGA), in units of gals, and the other one is shaking intensity I, characterizing the strength of shaking on the earth's surface, reported on non-instrumental MSK-64 scale.

For the PGA values, many attenuation equations have been defined by various investigators for regions with different geological and geo-dynamical condition in the world. Table 2 lists 10 most characteristic attenuation equations used for the application of fault-source model of Vietnam.

The relationship between intensity I and the values of PGA is given in table 3. The conversion is not implemented in the cases, when I is less than level V, and when I exceeds level X, for there is no practical meaning in engineering seismology.

Table 2. The attenuation equations used for the fault-source model of Vietnam

No	***Reference***	***Purpose***
1	Nguyen Dinh Xuyen and Tran Thi My Thanh (1999)	Vietnam earthquakes.
2	Xiang Jianguang and Gao Dong (1998)	Yunnan earthquakes (PGA only).
3	Boore, Joyner & Fumal (1993, 1994a, 1994b)	Shallow crustal earthquakes.
4	Sadigh, Chang, Abrahamson, Chiou, and Power (1993)	Shallow crustal earthquakes.
5	Campbell and Bozorgnia (1994)	Shallow crustal earthquakes (PGA only).
6	Munson and Thurber (1997)	Hawaiian earthquakes (PGA only).
7	Youngs, Chiou, Silva and Humphrey (1997)	Deep and subduction zone earthquakes.
8	Frankel et al. (1996)	The central and Eastern U.S.
9	Toro, Abrahamson and Schneider (1997)	The central and Eastern U.S.
10	Lawrence Livermore National Laboratory (Sayv, 1998)	The central and Eastern U.S.

Table 3. Relationship between values PGA and shaking intensity I (MSK-64 scale)

PGA (gals)	***Intesity I***
0.015-0.03	V
0.03-0.06	VI
0.06-0.12	VII
0.12-0.24	VIII
0.24-0.49	IX
> 0.49	X

4. Development of GIS tools

Fault-source model was applied to define scenario earthquakes to be used in seismic hazard and risk assessment procedures in Vietnam at two levels: regional and urban. A scenario earthquake is the event, most likely to have occurred, and with predefined parameters. In another words, scenario earthquake is a simulation of an event in the past for predicting the effects of a future event.

A simple algorithm of seismic hazard assessment for Vietnam using a fault-source model is shown in figure 2. As can be seen from the figure, this is a four steps procedure, resulting in the ground shaking maps for the study area. The procedure starts with definition of a study area. Then follows the selection of a fault from GIS database, which is capable for an earthquake in the selected area. The fault parameters are used to describe a source of the scenario earthquake assumed to be originated on the chosen fault. Finally, a proper attenuation equation is chosen for computation of seismic hazard of the study area, according to the given scenario. Two layers denoting shaking maps of the study area in terms of PGA and I values are automatically displayed in the end. A GIS-based software called F-Hazard was created to help users with their various options.

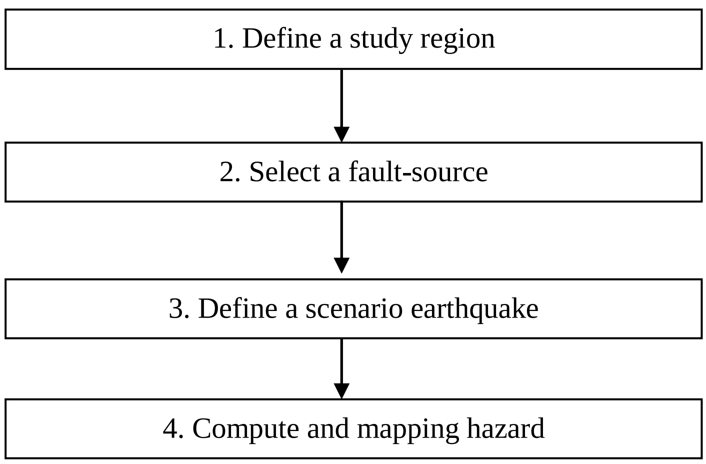

Figure 2. A procedure for seismic hazard assessment using a fault-source model

With more sophisticate algorithm, the fault-source model was also applied to seismic risk analysis and loss estimation in Vietnam at urban scale. Additional calculation modules were developed to enable the use of a combination of datasets reflecting local site conditions as well as the elements at risk in the study area. A GIS tool called ArcRisk was developed for the urban case, with function of a decision support system (Nguyen Hong Phuong, 2002, 2007, Nguyen Hong Phuong et al, 2003).

A procedure for urban risk analysis and loss estimation is shown in figure 3 with 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 first two steps are similar to the ones described in the hazard assessment procedure (see figure 2), however in this case the chosen study area follows administrative boundaries such as city, district(s) or ward(s) limits. On the basis of existing data on seismicity, seismotectonics, engineering geology and local site conditions, the ground motion is assessed for the study area. The ground motion characteristics obtained then are used as input data for assessment of ground failure due to liquefaction and landslides during earthquake. Finally, information on vulnerability of elements at risk such as demographic and infrastructure data can be used in combination of ground failure outputs to evaluate risk and estimate losses for the study area.

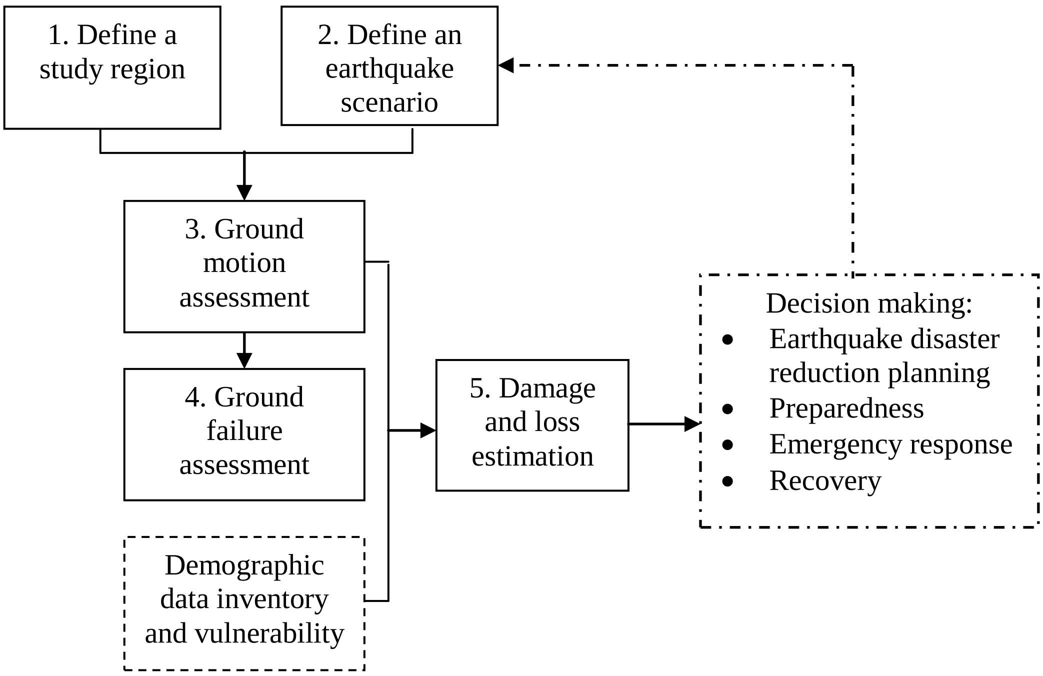

Figure 3. A procedure for urban risk analysis and loss estimation

5. Applications

GIS tools developed on the basis of fault-source model are used in simulating the significant events, observed in the past, and to assess the urban risk caused by future earthquakes. Pre-calculated scenarios can be stored in a database for any hazard assessment and risk management purpose. Two examples given below show the use of the fault-source model in seismic hazard assessment and risk analysis in Vietnam at regional and urban scales.

5.1. Seismic hazard assessment at regional scale

Program F-Hazard was used to simulate the Tuan Giao earthquake of June 24th, 1983, the one of the largest events ever observed and instrumentally recorded in the territory of Vietnam. Information on this earthquake was taken from previous publications. With the assumption of the earthquake origination on Son La fault, the parameters of scenario earthquake were defined as follows:

1) The fault-source is stretching in NW-SE direction, with a normal, right-lateral strike slip mechanism. The fault surface plunged north-eastward with a dip angle of $\gamma=75^0$;
2) Epicentre coordinates are φ= 103.43; λ= 21.71;
3) M_W = 6.77 (converted from M_S = 6.7);
4) Focal depth H = 23 km.

Figure 4 shows a PGA map calculated from Tuan Giao scenario, using the attenuation equation developed for Yunnan region, China by Xiang Jianguang and Gao Dong (1994). Spatial query tool allows displaying the shaking value calculated at any point on map in the small top-right corner window. Within the territory of Vietnam, while the maximum intensity of VIII-IX (and the value of PGA_{max} = 0,1409 gals accordingly) is observed in Lai Chau and Son La provinces, the attenuating shaking with intensity VII also affects the adjacent Yen Bai and Lao Cai provinces. The query for Hanoi city results in the intensity IV on MSK-64 scale.

The results obtained from the fault-source application show a good accordance with the observation data. Thus, the fault rupture length calculated by the Wells and Coppersmith equation is 26.27 km, which is coincident with what was described from the witnesses at epicentral area (Institute of Geophysics, 1990). On the other hand, the maximum PGA value calculated from the scenario is also in good accordance with the previously published hazard value, defined for the North-western region of Vietnam by probabilistic method (Nguyen Hong Phuong, 1997).

It should be noted that calculated hazard is clearly influenced by the fault's parameters used. For instant, modification of the dip angle values can lead to the changes in geometry of shaking contours. As can be seen from figure 4, the maximum isoseismic zone is located asymmetrically on the source fault, unlike the isoseismic maps published earlier (Institute of Geophysics, 1990). This fact emphasizes the advantages of the fault-source models over the point-source ones.

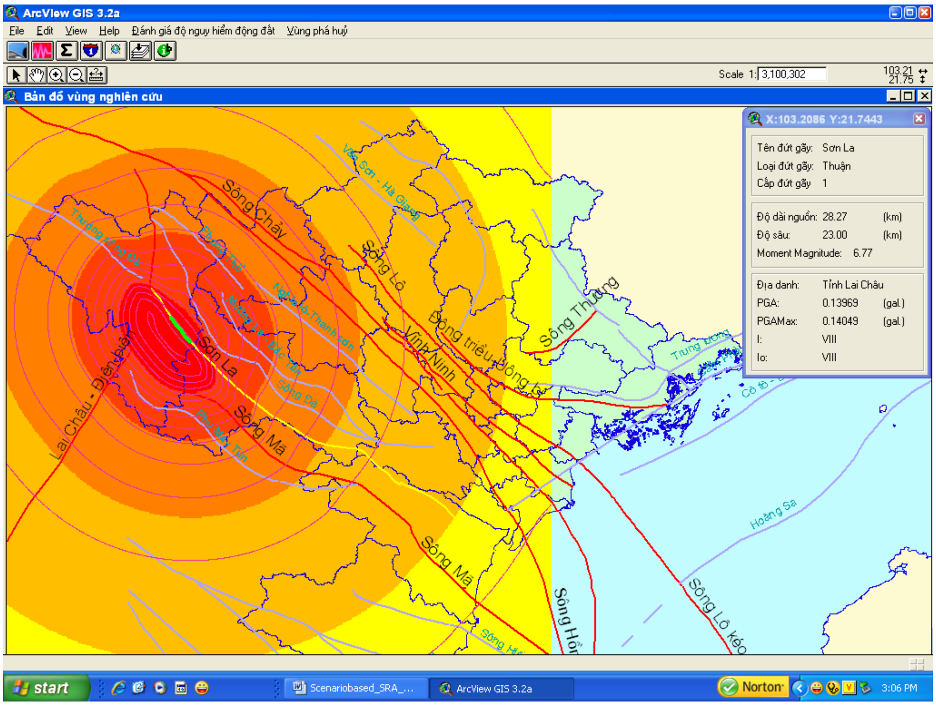

Figure 4. Application of a fault-source model in simulating the Tuan Giao earthquake of June, 24th, 1983 on the Son la fault

5.2. Seismic hazard assessment at urban scale

Since the year 2000, many researches on urban seismic risk assessment have been implemented in Vietnam. A methodology suitable for Vietnam was developed and pilot tested for some megacities of Vietnam as Hanoi, Ho Chi Minh and Nha Trang. The example below shows the application of fault-source model to seismic risk assessment and loss estimation for downtown area of Hanoi. Building damage and casualties caused by one of the scenario earthquakes, assumed to be originated on Chay River active fault, crossing the territory of the city were calculated using program ArcRisk (Nguyen Hong Phuong, 2007). The results obtained for the Ba Dinh district are illustrated.

The parameters of the Chay River source fault were defined as follows:

1) The fault-source is stretching in NW-SE direction, with a normal, right-lateral strike slip mechanism. The fault surface plunged north-eastward with a dip angle of $\gamma=70^0$;
2) Epicentre coordinates are $\varphi= 105.34$; $\lambda = 20.99$;
3) $M_W = 6.6$;
4) Focal depth H = 15 km.

In this scenario, the maximum earthquake magnitude, predicted for the whole Hanoi region and the Yunnan attenuation equation were used. ArcRisk allows applying a comprehensive procedure including seismic hazard assessment (through the ground motion and ground failure evaluation) and seismic risk analysis (through the building damage and casualties estimation) for chosen area.

For each chosen area, the ground motion assessment results in the following:

1) A set of Peak Ground Acceleration maps, compiled for different time period and exceedance probabilities;
2) A set of Spectral Acceleration maps, compiled for different time and vibration periods.

Similarly, the ground failure assessment results in the following:

1) Liquefaction susceptibility map;
2) Landslide susceptibility map;
3) Map of probability of liquefaction;
4) Map of probability of landslide;
5) Map of ground settlement due to liquefaction;
6) Map of ground lateral spreading due to liquefaction;
7) Map of ground lateral spreading due to landslide.

Urban loss is evaluated for two elements at risk, namely the buildings and people. Accordingly, the outputs are presented in the form of two map sets. The first one is a set of maps, showing building damage in different state of damage, such as slight, moderate, extensive and complete. The second one is a set of maps, showing number of casualties in every ward, at four severity levels and at three different daytimes.

Some main results obtained from the Song Chay scenario are illustrated in this paper. Figure 5 shows the shaking map of Ba Dinh district, in terms of PGA (gals). In figures 6 and 7 (a, b, c) the distribution of extensive building damage and casualties at 2nd severity level are shown.

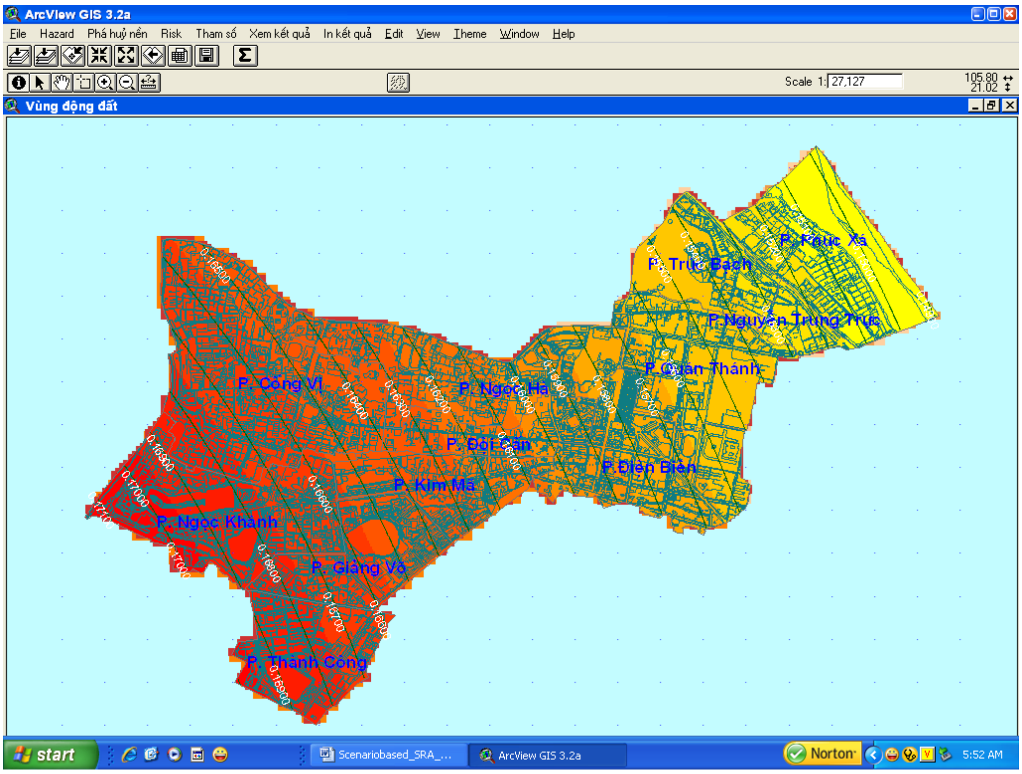

Figure 5. Peak Ground Acceleration map for the Ba Dinh district, Hanoi (Chay River scenario, M_W = 6,6, h=15 km).

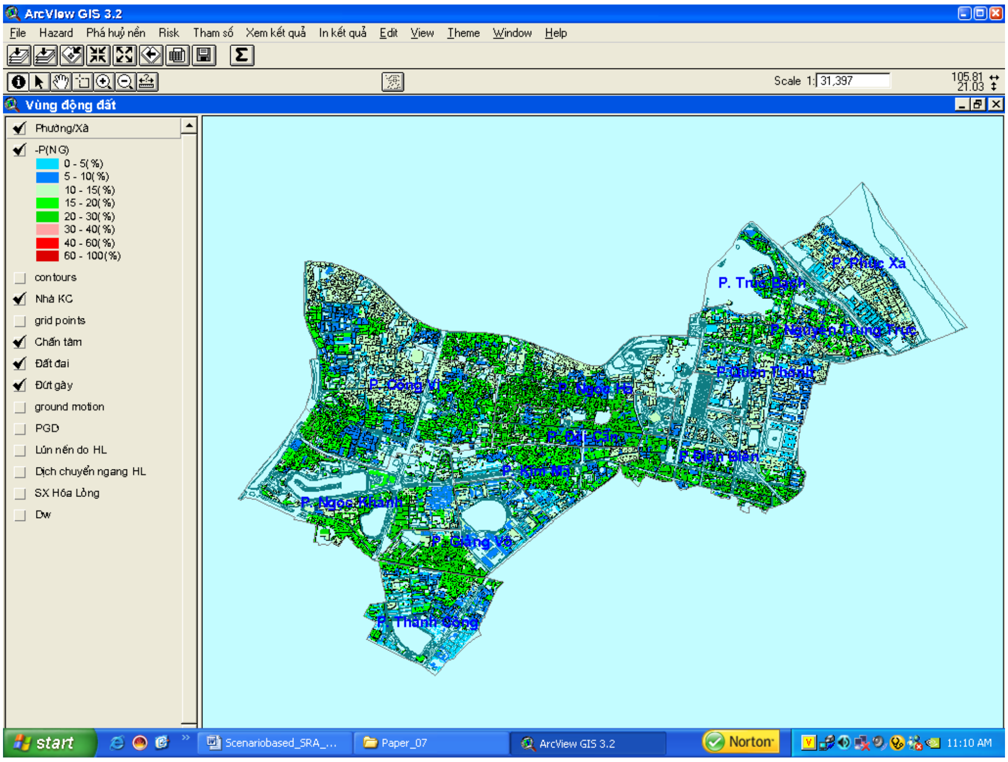

Figure 6. Map showing extensive building damage in Ba Dinh district, Hanoi (Chay River scenario, M_W = 6,6, h=15 km).

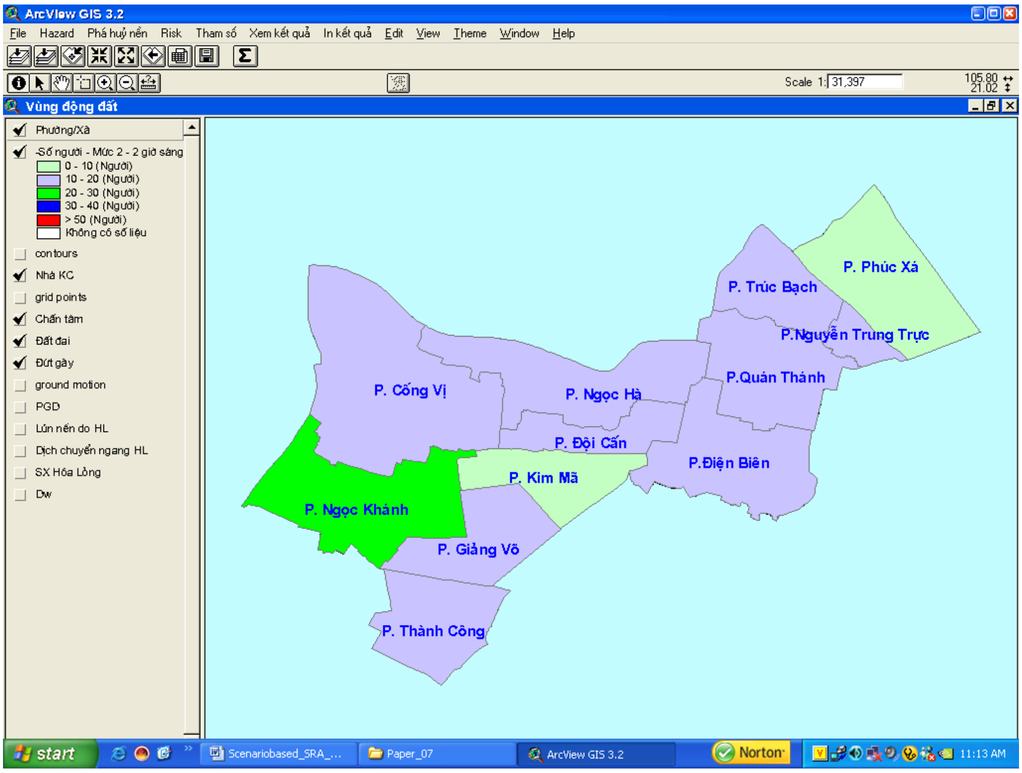

Figure 7a. Casualties of 2nd severity level in Ba Dinh district, Hanoi at 2 a.m. (Chay River scenario, M_W = 6,6, h=15 km).

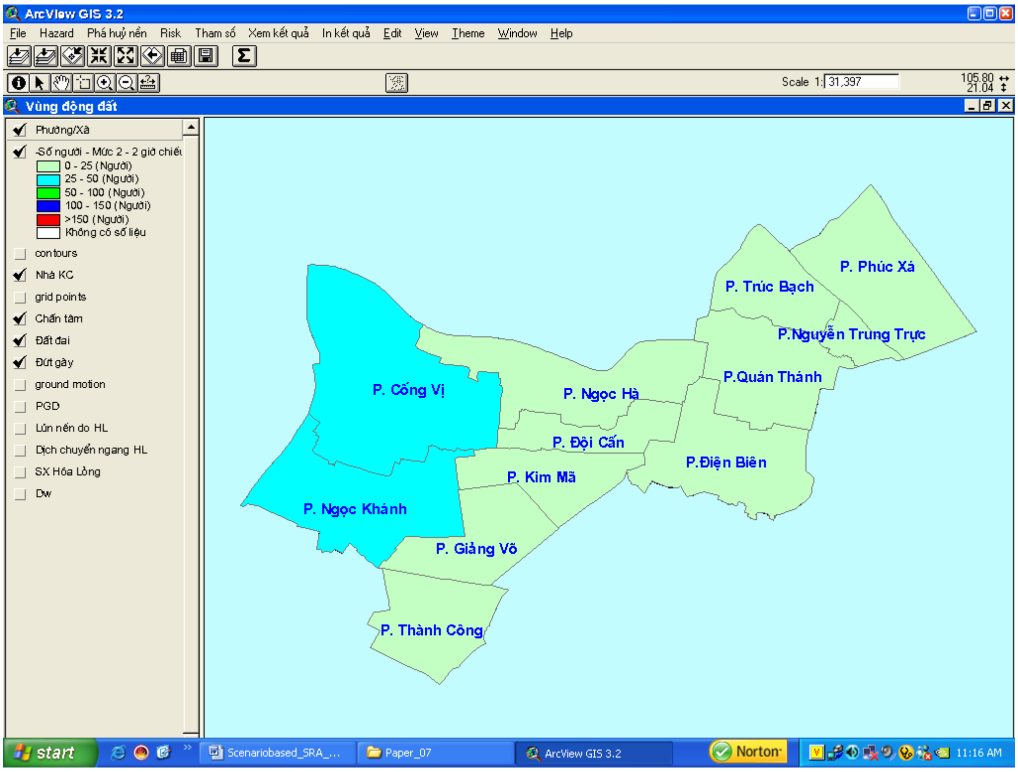

Figure 7b. Casualties of 2nd severity level in Ba Dinh district, Hanoi at 2 p.m. (Chay River scenario, M_W = 6,6, h=15 km).

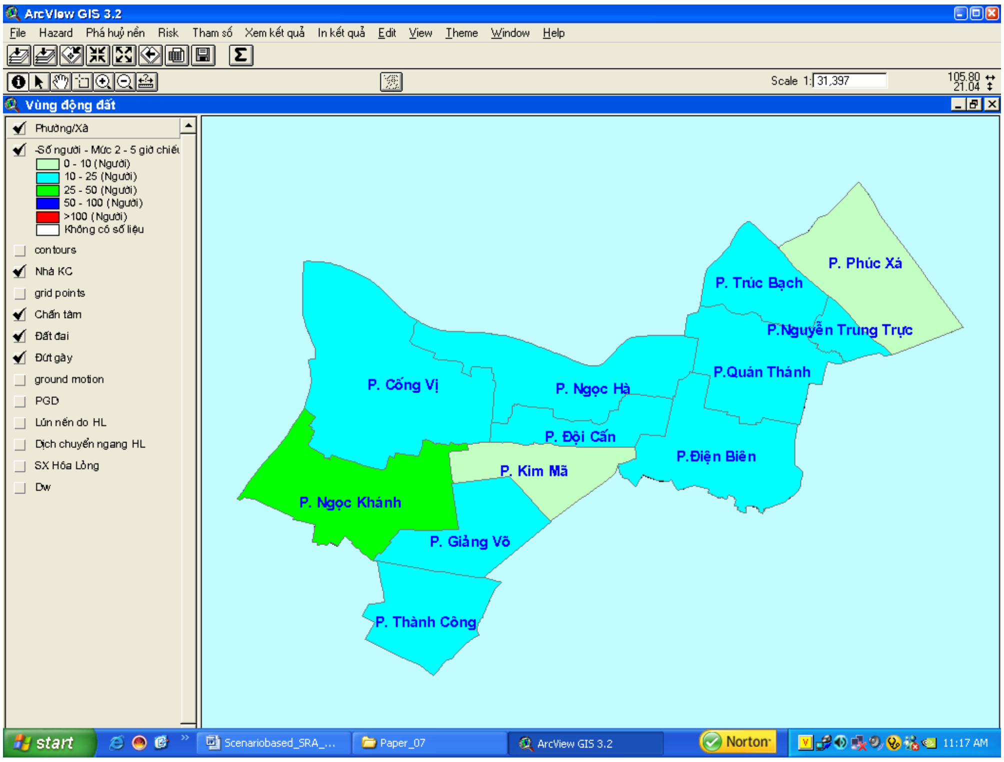

Figure 7c. Casualties of 2nd severity level in Ba Dinh district, Hanoi at 5 p.m. (Chay River scenario, M_W = 6,6, h=15 km).

6. Tsunami hazard assessment using a GIS

In Vietnam, after most destructive in recorded history Sumatra-Andaman of December 26, 2004 and Sendai, Japan of March 11, 2011 tsunamis, given the change in the nation's acknowledgement of this horrific natural disaster, a new era started in tsunami research. Up to now, several projects have been done in terms of tsunami risk assessment using a GIS. Vu Thanh Ca et al (2008) calculated 25 tsunami scenarios generated in the South China sea in order to investigate the impact to the Vietnamese coasts. Nguyen Hong Phuong et al (2010) developed a new methodology for tsunami vulnerability assessment for urban area of Vietnam based on Multi-Criteria analysis technique. Figure 8 shows a map of bulding vulnerability exposed to tsunami hazards, compiled for a downtown area of Nha Trang, a coastal city in Central Vietnam. However, up to now there is no GIS based DSS developed so far for the case of tsunami.

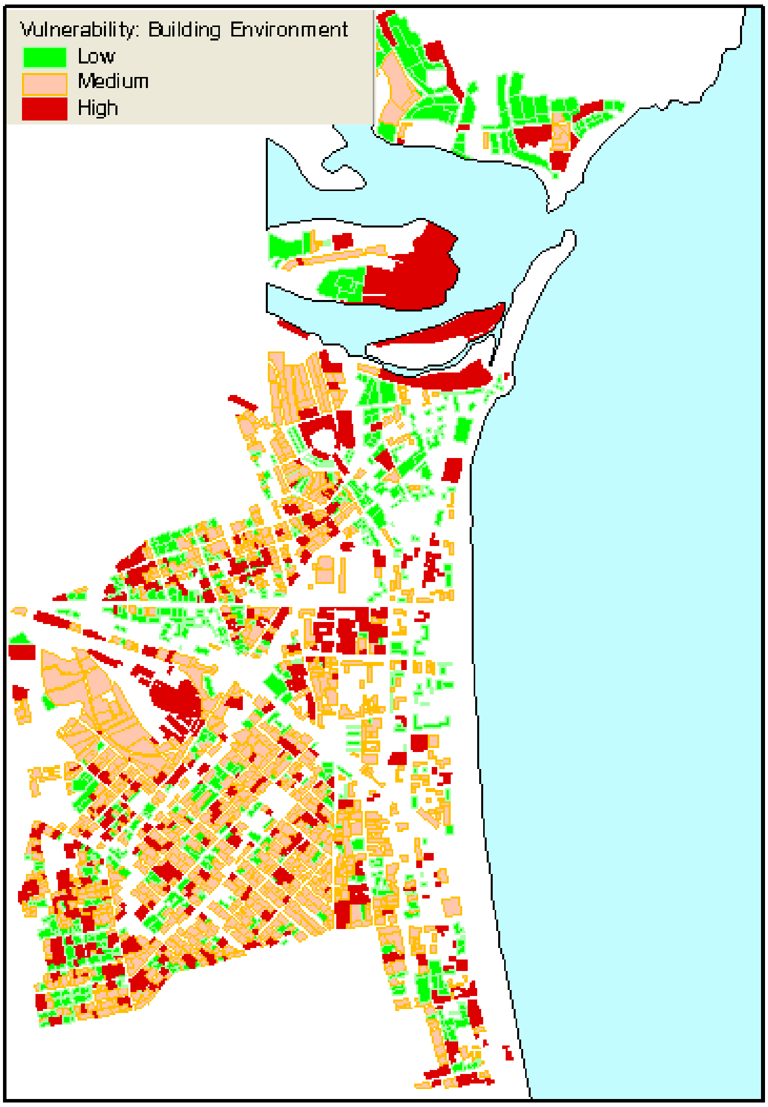

Figure 8. Map of building vulnerability due to tsunami for a coastal urban area of Nha Trang city.

A Decision Support System applied to tsunami risk assessment for a coastal zone is being developed by inheritance of the experience, tools and some modules of above described ArcRisk software. However, there are some differences between the two systems due to the nature of occurrence, propagation and impacts of these phenomena. A comparison is given here refering to a scheme presented in Fig. 3. The difference between earthquake and tsunami risk assessment procedures starts in the Module 3, where calculation models are applied to assess the sea's bottom and the sea's surface deformation, which yields the wave's type at the moment earthquake occurred at the epicentral point. In Module 4, hydro-dynamical models can be applied to compute the transoceanic propagation of the scenario tsunami. The results of the Module 4 are presented in terms of animation pictures, simulating the tsunami propagation from epicentre to the study coastal zone, with time and intensity indicated. The module 5 has the same function as in case of inland earthquake, but emphasizes on loss and damages caused by inundation. Obviously, the new system, particularly the simulation module will require much longer run time and much higher perfomance of computing facility.

7. Conclusion

In this paper, the development of a fault-source model for deterministic seismic hazard assessment in Vietnam was described. The model was developed on the basis of a dataset on seismically active faults defined and published for the whole territory and the continental shelf of Vietnam, with assumption that earthquakes are originated on seismically active tectonic faults. Well and Coppersmith equation on the relation between earthquake and fault's parameters (1994) and 10 attenuation equations for regions with different seismotectonic regimes were included in the model.

Based on the model, two GIS-based tools are created, allowing for seismic risk analysis in Vietnam at various scales, from regional to urban. The specific functions of these tools also give the users options for selecting the study area, source parameters and attenuation law for risk calculation. The extent and level of risk due to scenario earthquake are depicted in a variety of GIS maps, automatically generated in a GIS environment.

The model was applied to a scenario of Tuan Giao earthquake of June, 24th, 1983 to investigate the effect of fault source model on the calculated hazards at regional scale. The good accordance between calculated results and observation data shows advantage of the fault-source model over the point-source one in seismic hazard assessment.

Another application of the model is to assess risk and estimate losses from scenario earthquakes at urban scale. The results obtained from a scenario applied to megacities show the advantages of the methodology and technique used. Application of deterministic seismic risk analysis based on earthquake scenarios can have important contribution in seismic zoning, urban planning and risk management for high priority areas and mega cities of Vietnam.

The methodology can be extended to develop a Decision Support System for tsunami risk analysis. Also, it is worth emphasizing the urgent need of using high-perfomance computing facility to develop a pre-calculated tsunami scenarios database for the warning purpose in Vietnam.

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