GIS-based approach for evacuation safety place mapping in Da Nang city, Vietnam

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Abstract

Tsunami is a disaster which occurs in a short period of time but causes huge losses of life and property. Da Nang, a coastal city located by the East Sea of Vietnam is at risk of suffering from tsunamis. The city government built the first early warning system in 2015, functioning for citizens in the whole coastal region. However, there is a lack of an emergency evacuate plan for cases of warned disasters. This study aims to build an evacuation safety place map applying GIS-based approach to determine population distribution, transport system, and safety places. Results would be a useful tool to support to disaster risk management activities of Da Nang when a tsunami occurs.

Key words: GIS-based approach, evacuation, Da Nang city

Introduction

Coastal region is well-known as favorable living area for people since it provides economic sources such as tourism, fisheries, biodiversity… However, along with the mentioned benefits are the risks of disaster caused by existing tsunamis that result in serious damages for life and property.

Vietnam is located in the Southeast part of the Eurasian continent, between the Indian continent, the Philippines and the Australian continent. Vietnam is not on the boundary of any tectonic plate, thus seems to be less vulnerable from earthquake and tsunami than other countries in the region (Figure 1).

• Northern Vietnam is prone to seisms from low to medium level. This region has a number of discrete geologic fault systems, such as some around Red River, Ma River and Lai Chau – Dien Bien area.

• These discrete faults can be hundreds kilometers long with the slide speed about 0.5 to 2 millimeters per year (V. Tobyáš and R. Mittag, 1991). With such geologic fault of that length, in Northern areas there is likely to occur earthquakes of magnitude 5.7-7.0 Richter.

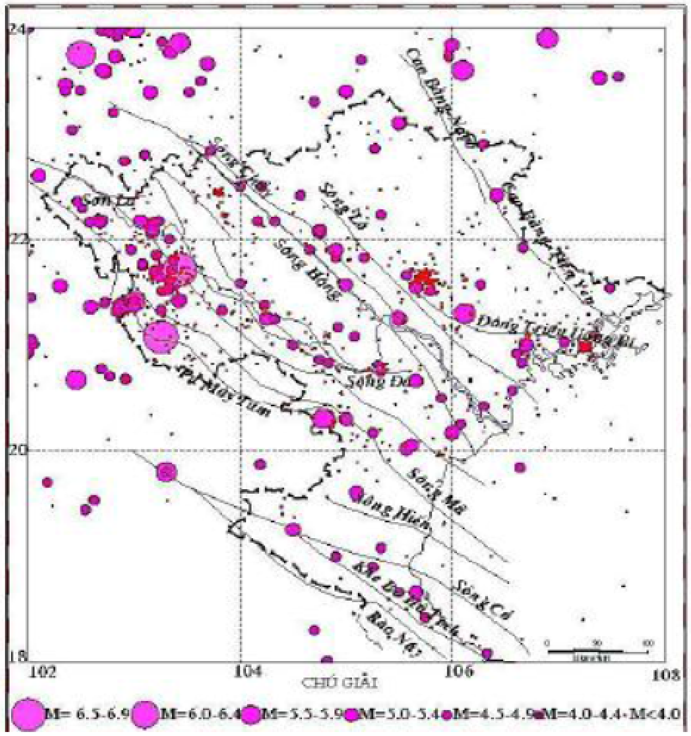

Figure 1: Map showing seismic history in Northern Vietnam with main discrete lines
(Source: Data provided by Institute of Geophysics - http://igp-vast.vn/)

The history shows that, from 1900s to 1995, in Vietnam there were 2 earthquakes of magnitude 6.7-6.8 and intensity VIII-IX (on MSK-64 scale), 2 ones of magnitude 5.6-6.0 and intensity VII-VII, 13 ones of magnitude 5.105.5 and intensity VII and over 100 ones of magnitude 4.6-5.0 and intensity VI-VII (IGP, 2011). The most recent earthquakes took place in Dien Bien Phu were of magnitude 6.7 Richter (November 1935) and of magnitude 6.8 in Tuan Giao (June 1983).

Da Nang city is the first to complete the coastal stations of tsunami warning system in Vietnam. Currently, Da Nang is testing these tsunami early warning stations. It is one of 10 tsunami warning stations in coastal Da Nang that are completed at the end of 2015. Nevertheless, the city has no scenario for emergency response once the tsunami reaches land. This research attempts to develop a method for selecting the most effective evacuation safety places applying GIS-base approach. Network analysis method and a variety of geographic information tools will determine safe evacuation places for people as well as effective instant evacuation routes. This research applies ArcGIS Network Analyst tool by ESRI. The outcome is expected to be a significant tool, highly applicable to reduce the losses of life and property in Da Nang city.

Study area

Da Nang city includes the mainland and the Paracel Island in the East Sea. The mainland is located at $15^0$55' to $16^0$14' North latitude, $107^0$18' to $108^0$20' East longitude; it borders Thua Thien – Hue Province to the north, Quang Nam Province to the west and south, East Sea to the east. The sea includes Paracel Islands located at $15^{0}45'$ to $17^{0}15$ North latitude and 111^{0} to 113^{0} East longitude, about 120 sea miles to the south of Ly Son Island (Quang Ngai Province, Vietnam) (Figure 2).

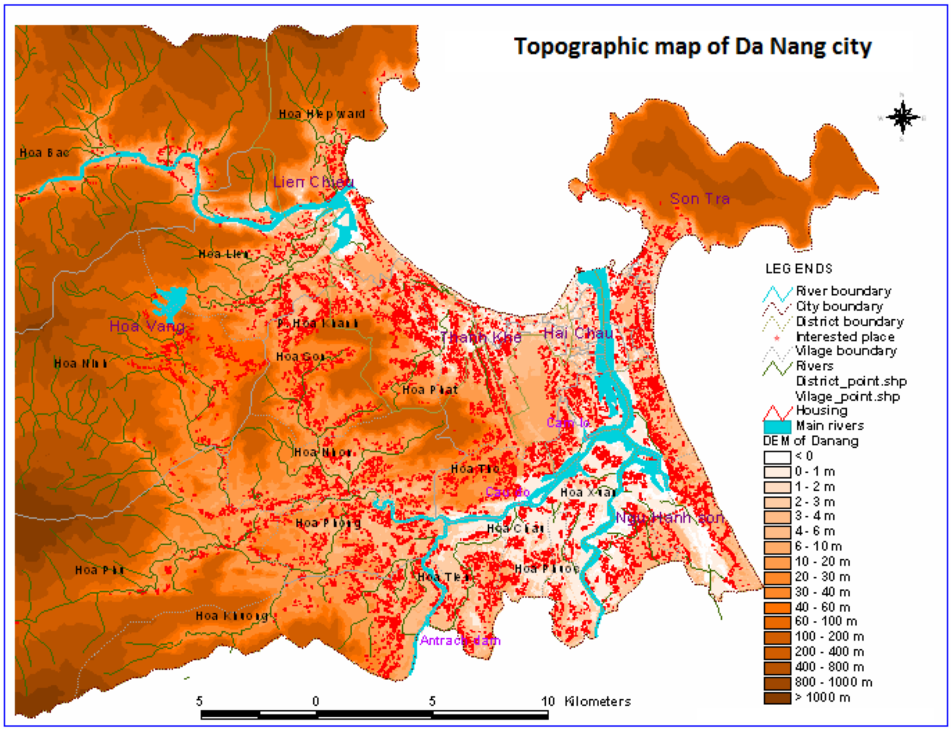

Figure 2: Topographic map of Da Nang city including resident areas

As reported by the Department of Health (2016), Da Nang City has the population of approximately 1,029,000 in 2015, mostly concentrates along the coastline and the banks of Han River (DOH, 2016). When a tsunami reaches, it is estimated that 85% of the city population will be affected.

Based on an earthquake along the fault of Manila, the height of tsunami is estimated corresponding to the level of earthquake in Vietnam as follow:

Table 1. Estimated of water rise when tsunami occurs

Level	Paracel Island	Spratly island	Hue Province – Da Nang city	Quang Nam – Quang Ngai	Binh Dinh – Ninh Thuan	Binh Thuan – Ba Ria Vung Tau
8 Richter	2.5 m	1 m	Below 3 m	1 -2 m	1 m	Below 1 m
8.4 Richter	4 m	2 m	Above 3 m	2- 4 m	1.5 – 2 m	1m
8.6 Richter	8-9 m	4 -6 m	6 – 9 m	7 – 10 m	3-5 m	1.5 m

(Source: http://www.monre.gov.vn/v35/default.aspx?tabid=675&CateID=57&ID=75126&Code=OZMDV75126)

Method

The GIS-based approach included determining the population distribution, assessing the road network and transportation system, modeling flows to safety places (high buildings, hills, mountains..), and identifying restricted allocation areas and other constraints. The steps used to determine safety place locations including a two-tiered process. The first involves applying the data and methods to the existing safety places by defining service areas for safety places based on travel time or distance. A network service area is a region that encompasses all accessible streets that are streets that lie within a specified impedance based on either a distance or a time cost. For instance, the 20-minute service area for a safety place includes all the streets that can be reached within 20 minutes from that safety place. The second level focuses on additional safety places beyond the four existing buildings. Results of the modeling include proposed locations of additional escape buildings, capacity and service area of each building, and the evacuation route to the safety place for each center of population. The proposed locations for additional safety places were again determined through network analysis. The capacities of additional safety places were adjusted to meet the surplus demand. Accessibility analysis and network models were used to optimize spatial distribution of safety place locations. Evacuation routes can be further developed and refined for each service area. Tsunami travel time is an essential concept since it will limit the movement of evacuees in the evacuation process (Budiarjo A., 2006).

Tsunami travel time is defined as the time for tsunami waves to travel from the source (epicenter) to a particular location in the coastal area (3). The International Tsunami Survey Team (ITST) surveyed the 2004 tsunami wave on Miyagi, Fukushima and Iwate of Japan, and their analysis showed that the wave arrived in Miyagi and Iwate and some parts of Fukushima coast within 30-40 minutes (Yalciner, A.C. et al, 2013) of the earthquake. Safety places need to be located within walking or running distance from population locations in tsunami hazard zones. The National Department of Disaster Prevention and Control master plan of rehabilitation and reconstruction defines the reachable distance of 500m, 1000m, 1500m, and 2000m corresponding to the shortest travel time of 5, 10, 15, and 20 minutes respectively by the elderly, women and children (Bappenas, 2005). The time parameters are decided through evacuee walking speed. For safety reasons, it is preferable that the speed should be adjusted to the velocity of the elderly or the disabled in areas where many such residents live. A walking speed for the elderly of 0.751 m/s is used in this analysis (Bappenas, 2005).

Dewi (2012) identifies three components of evacuation time which consist of: (i) decision time between event detection and the official decision to warrant an evacuation; (ii) evacuation warning, preparation time or the reaction time of the population (RT); (iii) and response time or actual response time (TTime) which is the time required for respondents to physically evacuate to safer areas. Additionally, the technical or natural warning signs (ToNW) will be determined by official decision time (IDT) and notification time (INT). Generally, human response can be based on natural or technical warning signs. It requires knowledge of tsunami warning signs like earthquake or sudden drop of sea level and the knowledge of what to do such as evacuation by the community.

The evacuation time (ET) or response time of the population (TTime) can be calculated based on the following modified formula (Dewi, 2012):

TTime = ETA – ToNW – RT (I)

ToNW = IDT + INT (II)

where
TTime = Time required for people to evacuate;
ETA = Estimated Tsunami Arrival (40 minutes);
ToNW = Technical or Natural Warning (8 minutes);
RT = Reaction Time of Population (10 minutes);
IDT = Institutional Decision Time (Issuance from INA-TEWS, 5 minutes);
INT = Institutional Notification Time (Issuance by local government, 3 minutes).

These elements were incorporated to determine the coverage area of safety places based on the evacuation time. The estimated time of tsunami arrival of 40 minutes refers to the experience in 2004. It took 8 minutes for the early warning system to sound, and 10 minutes as the reaction time, which leaves 20 minutes to travel to the shelter building. Based on the evacuation process, this 20 minute evacuation time was split into 15 minutes to travel along the network to the shelter buildings and 10 minutes to get to the upper floor.

Result

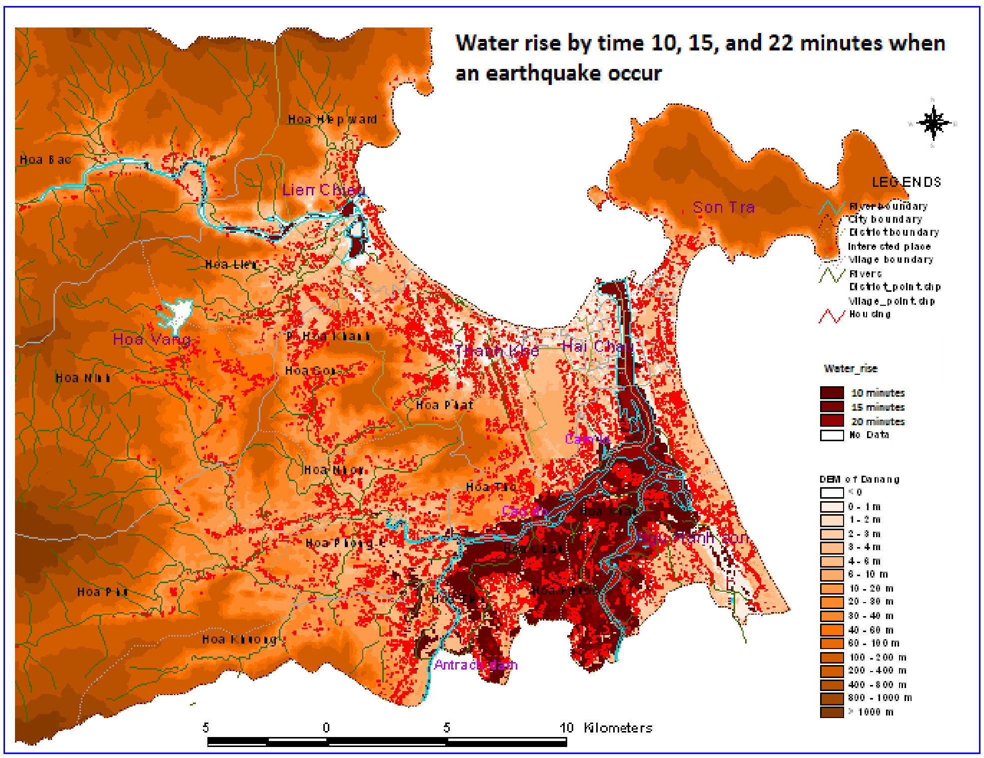

Figure 3. Water rise when tsunami occurs

The safety place is defined as the capacity of travel time along a street network. During an evacuation, people will move away from their existing buildings to the safety places. In general, evacuees will move in directions away from the direction of the tsunami movement. Safety places, therefore, need to be accessed by people who come from the coastal, but also allow people from the opposite direction to be evacuated if their distance was within 20 minutes. GIS tools were used to develop service areas based on the evacuation times to a safety place. The three different coverage areas included 10-minute, 15 minute, and 20 minute service area to access the safety place mapped. Next, people accessing existing buildings were determined using GIS Network Analyst. Figure 4, "Existing safety place Service," shows the coverage area for the existing four safety places. The analysis showed that most of the potentially affected people would not have time to access the building even within 22-minute maximum time available for evacuation.

Based on the analysis of existing safety places, an estimated 545,098 people or approximately 62.3 % of the total population are exposed to the tsunami threat.

The next step was to estimate additional safety places to be added and identify the populations to be evacuated from existing buildings. Data such as building footprints, inundation areas, roads, village areas, district borders were collected from the Da Nang Department of Natural Resources and Environment – DONRE (2015). ArcGIS Network Analyst was used to allocate additional safety places for high population density areas. The service areas were then developed by considering the 10, 15, and 20 minute travel times and two-way rule. Travel time ranges were used to determine the coverage areas for each safety place, and how many people would evacuate within the time range. Proposed safety places were evaluated for suitability using land use maps and local knowledge of the community.

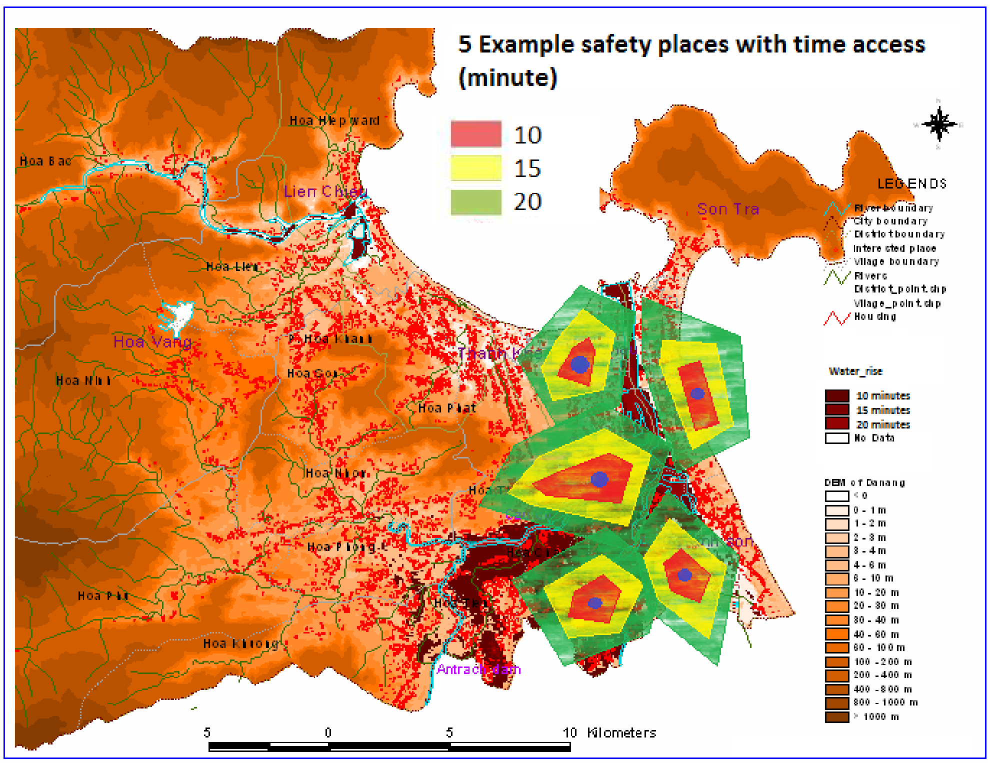

Figure 4. Some example of safety places

A first cut analysis identified new safety places based on under-served population clusters. These sites were evaluated and adjusted. After several iterations, the best locations to cover the at-risk population were determined.

The final selection of safety places included 26 new buildings (almost all hotels) to cover the total population exposed to tsunami threats. The needed capacity of the new proposed safety places were based on the number of people in these service areas and the travel times based on movements from existing buildings to the new proposed safety places. The largest space was calculated for safety place which could accommodate 5,764 people (Da Nang PPC's Tower). On the other hand, the lowest capacity building was safety place 2 which could hold approximately 1,432 people. With the proposed and existing safety place, all at-risk population would theoretically be able to evacuate to the closest shelters within the expected arrival time of tsunami generated by a near shore earthquake, comparable to that of the 2011 tsunami. The combined analysis of existing with additional safety places showed a reconfiguration of evacuation destinations. The remain existing safety places will accommodate 3,435 to 4,752 people and the 12 additional safety places will accommodate 144,582 people.

Conclusion

All across the world, there are opportunities to study disasters such as the earthquakes and tsunami in Japan in 2011 and learn from the responses to tragedy. The survivors have important lessons in response, recovery, mitigation and adaptation to ongoing risks. The lessons are important to both Japan and others around the world facing tsunamis and other hazards. Effective mitigation planning and preparedness needs to safeguard communities and the livelihoods of residents. Future development will be at risk if communities fail to address disaster risks with appropriate mitigation measures. Tools and approaches such as safety places and understanding of evacuation behavior helps to build resilience.

This study identifies the need for evacuation and proposed additional evacuation buildings which could be reached using existing roads and pathways. While evacuation sites are important, residents, emergency managers, organizational and community leaders, and government agencies need to collectively manage needs, assets, capacities, and interests to build resilient communities. This study uses spatial information and pedestrian routes to evaluate and site evacuation locations and increase preparedness for future tsunamis.

The Da Nang disaster prevention and control Plan 2015-2020 identified mitigation measures to minimize potential future disasters. Many measures emphasize structural solutions such as escape buildings, breakwaters and evacuation routes in the event of a tsunami. While non-structural measures such as zoning to restrict new development in hazard prone areas were identified, these have been difficult to design and implement. Non-structural measures are less visible and rely on government and other stakeholders to plan, zone, regulate, inspect, enforce, and maintain land use laws and building codes. Another tactic is to encourage best practices in designing tsunami resilient buildings and communities. Towards this end, the Department of Natural resources and Environment, should develop training courses to build capacity in disaster risk reduction. Training and capacity building plays a significant role in reducing risks. There is need for continued research on integrating urban planning and evacuation from flooding and other hazards (Da Nang PPC, 2015). There are important knowledge and practical experience in urban planning, emergency management and transport engineering relevant to resilience. There needs to be both continuous learning and sharing of knowledge across disciplines to minimize the loss and impact of future disasters.

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