

REMOTE SENSING FOR DISSASTER MITIGATION: CASE STUDY FOR TSUNAMI EVACUATION ROUTE MODELLING IN CILACAP-CENTRAL JAVA, INDONESIA

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ABSTRACT

Indonesian region is located in the interaction between three major plates, one of the most active subduction zones. This region has frequent earthquakes and tsunamis. Given its location, Indonesian region is very vulnerable to many disasters, including tsunami. The rapid growth of population in coastal areas makes Indonesia more vulnerable to tsunami occurrence since coastal areas have always been the most preferred location for settlements. This research was conducted in Cilacap Regency, Indonesia which was hit by tsunami on July 17th, 2006, caused many damages and casualties.

In the tsunami mitigation plan, evacuation plays a crucial measure for saving human lives. The primary strategy for saving lives immediately before tsunami waves arrives is to evacuate people from the hazard zone. Especially for communities who are living in a low-lying coastal area. Given their location, it would be impossible to evacuate these communities in time, which could result in significant loss of life.

This research tried to determine the suitable location for vertical evacuation and the capacity of suitable evacuation shelter buildings and also to develop a methodology to choose the most effective evacuation routes. For these purposes, some kind of spatial information are required such as the distribution pattern of settlements and detailed road network, in which for these study, can significantly be supported by using remote sensing technology. This paper will present the results of how remote sensing technologies were used to support provision of spatial information required for tsunami evacuation model in Cilacap, Central Java.

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1. INTRODUCTION

Coastal areas have always been the most preferred location for settlements. It is because the attractiveness of coastal areas and many economic opportunities providing by those areas. Because of these factors and also the long gaps between tsunami destructing events, coastal people tend to develop new housing, marine facilities, and resort developments. These make people and facilities are threatened by the destructiveness of tsunami. Additionally, given their location, it would be impossible to evacuate these communities in time, which could result in significant loss of life. In this condition, evacuation planning are considered as instrument for risk mitigation at the local scale, and it is commonly by choosing existing roads as suggested evacuation routes.

Based on the sources and time to travel, tsunami can be classified as local and distant. Local tsunami can arrive at nearby shores only within minutes, for example in 17 July 2006 tsunami occurrence in Cilacap, the first wave of tsunami struck its coastal area one hour after the earthquake and can have a huge damage resulting from triggering earthquake such as ground shaking, landslides and surface faulting, etc. On the other hand, distant tsunami can travel for hours before hitting a coastline. These types of tsunami will determine the time needed to respond and act on warnings. In Indonesia most of tsunami events are local so that the tsunami warning should be announced in a very short time. For this case, early warning system would be the critical point for evacuation route determination and evacuation planning as well.

In the case of buildings for evacuation, because tsunami has long period to be occurred, there are no certain buildings functioning only as evacuation shelter buildings. Finding the suitable buildings that can be used as evacuation shelter building is necessary due to high building construction cost and also efficiency in space occupation. A mosque, school, high floored-house and etc. can be used as evacuation shelter buildings. These evacuation shelter buildings should have certain design and configuration including size, shape and orientation (NTHMP, 2001).

It is important to identify to which evacuation building should people in a certain area go and how to get there in a fast and efficient way. It is important to identify the existing buildings that are potential to function as evacuation shelter building, and it should be integrated with the effort of finding new evacuation shelter building locations. Furthermore, the existence of evacuation shelter building should be included in spatial plan with regard to disaster mitigation aspects.

The objective in this study was to examine the potential of satellite remote sensing in supporting tsunami mitigation planning in the Central Java, Indonesia. Remote sensing data and methods were used to support the development of tsunami evacuation maps for the coastal areas of Cilacap such as for identifying buildings as the sources of evacuee, existing building for evacuation and also to improve the existing road network. Geographical Information Systems (GIS) was used to manage all spatial data and to create and use all components in the tsunami evacuation model.

2. TSUNAMI EVACUATION MODEL

The principle function of evacuation is to make sure that people move from a relatively danger place to a safer place via a route that is itself free from significant danger (Webb, 2005). Furthermore, the main strategy of evacuation is to save lives. NTHMP (2001) explained that there are two methods of how to evacuate people from tsunami hazard zones to the safer place, as follows; a). Horizontal evacuation; people move from the hazard zones to the safer areas in a distant locations or higher ground such as hills; b). Vertical evacuation; this method will evacuate people to the higher floors of a tsunami-resistant building nearby.

Applications that can create an efficient evacuation plan are needed to help evacuate community to safer areas in case of disaster. Huang *et. al.* (2005) stated that evacuation planning tools can be categorized into simulation-based approaches to which describes the responses and route behaviour of evacuees including estimating the clearance time, etc and the second one is analytical approaches which can optimize the evacuation process including roads, shelters, rescue points, etc. Further, many researcher try to combine both approaches.

Silva *et. al.* (2003) explained that to study an evacuation system, two technologies are used namely, simulation modeling and Geographical Information Systems (GIS). A GIS is able to store spatially referenced data and information and provide sophisticated mapping and display facilities. Many existing GIS come with built-in analysis tools in addition to their data storage, manipulation and representation tools. The problem and decision making scenario provide an interacting elements that have a spatial dimension which can be associated to geographical coordinates of the Earth's surface. For illustration, location elements such as shelters, population generation points (houses, workplaces, schools, hospitals, etc), hazard locations, etc., and directional elements such as travelling vehicles, wind and other meteorological features, etc. all can be linked to a spatial dimension.

Despite providing a helpful mechanism to deal with problem which have spatial dimension, a GIS cannot provide the complex decision model required to overcome real-world problem (Church *et. al.* (2000) *after* Silva *et. al.* (2003)). In this case, simulation modeling is essential to develop an appropriate tool to handle the spatial decision making aspects of the evacuation planning process. Church and Sexton (2002) concluded that most of the research has been concentrated on two distinct problems, evacuation of buildings and evacuation of large areas, like entire cities or coastal plains.

Figure 1 from FEMA (2008b) explains the process of decision making and design of vertical evacuation in particular area. In fact, vertical evacuation is needed when there is not enough time between warning and tsunami inundation to allow a community to evacuate inundation zone or to higher ground. In most cases this will be communities at risk for near-source-generated tsunamis.

The implementation of those methods in the prone area to tsunami depends upon the characteristic of tsunami and location, topography, existing facilities and evacuation time.

There are many factors to be considered in selecting suitable method in tsunami evacuation, as follows:

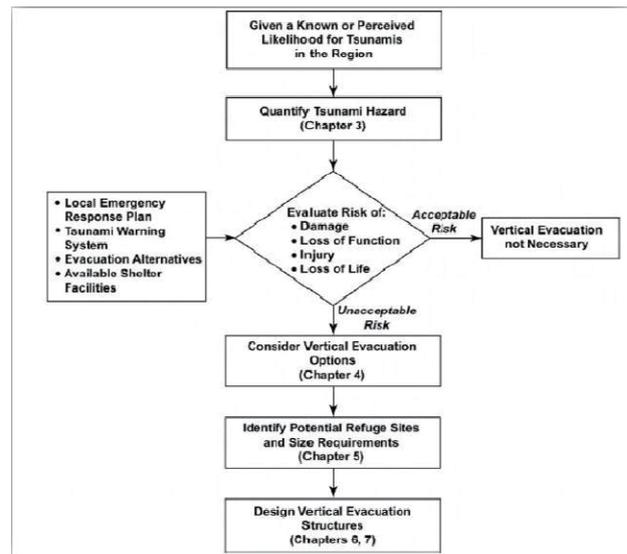


Figure 1. Decision-making and design process for vertical evacuation structure (Source : FEMA, (2008b))

a) Evacuation time

The available time for evacuation mostly depend on the remaining time between tsunami warning alarms to the arrival of tsunami wave. The evacuation time can vary according to the type of tsunami. It varies from several minutes to hours. After an earthquake generated tsunami, early warning system will take several minutes to analyze and decide whether this earthquake will cause tsunami and disseminate the information to the authority. Horizontal evacuation is better applied in the area which is prone to distant tsunami due to longer tsunami arrival time, so that there will be more time to move to the safer place in a distant or higher ground. On the other hand, vertical evacuation will be suitable for the area exposed to local tsunami. It is because the tsunami waves will arrive on shore in a shorter time.

b) Topography

Topography characteristics such as elevation will determine also the method of evacuation to be implemented. High elevation of land which is higher than tsunami waves like hill or high inland is required by horizontal evacuation. Meanwhile, coastal area which has low-lying area and maybe there is no hill nearby will require vertical evacuation.

c) Wave run-up and tsunami inundation

Coastal characteristics, source of tsunami, magnitude and the existing of coastal feature such as mangrove and coastal forest will determine the height of run-up and the extent of inundation area. Vertical evacuation is required when run-up and inundation level grow faster due to for example the bigger magnitude of earthquake, whilst, horizontal evacuation is needed when run-up and inundation level grow slowly.

d) Supporting facilities and infrastructure

Roads, bridges and evacuation route are needed to support the movement of huge number of population within the same time period. In addition, a public room in the evacuation place and also mode of transportation are necessary to be considered. Moreover, vertical evacuation needs buildings which are adequate in terms of capacity, strength, utility and also capability. For those methods of evacuation (Table 1), an

effective warning systems and public information, notification, and training program are critical to the success of all evacuation measures.

Table 1. Suitability of tsunami evacuation method

Evacuation Method	Horizontal	Vertical
Tsunami travel time	Long (hours)	Short (minutes)
Location & Topography	Close to hills or higher elevation ground	Flat, low-lying land
Wave run-up & inundation level	Slow run-up, inundation <1 m	Fast run-up, inundation >1 m
Required facilities & infrastructure	Evacuation route, road & bridges, mode of transport	Multi-storey building, escape hill

Source : Budiarjo (2006)

In this research, the focus will be on the building for vertical evacuation of tsunami. Evacuation is not a new concept for emergency planners. Even though, the purpose of evacuation is to move people away from an actual or potential danger to a safer place, it is not an easy option and may not be the safest option as well (HMG, 2006). So evacuation should not be automatically to be adopted. Simulation can be define as *the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and /or evaluating various strategies for the operation of the system* (Shannon, 1998). These assumption falls into two categories: structural assumptions which involve simplification and abstraction of reality on issues involving the operation and the processes of the system, and the data assumption which are based on the collection of reliable data and its proper analysis.

3. DESIGN OF REMOTE SENSING DATA TO SUPPORT EVACUATION MODEL

Remote sensing is one of the most important tools in risk management, from modeling and vulnerability analysis, from early warning, to damage assessment. It is very useful in the planning process in general, and also valuable in detecting and mapping many types of natural hazards when detailed descriptions of their effects do not exist. The development of remote sensing technologies has improved the mapping abilities and increased its applications. Some examples of remote sensing application in three phases of risk management are presented in Table 2.

It is very essential to know what types of remote sensing information are suitable for identifying and assessing particular natural hazards. Furthermore, an effective utilization of remote sensing data depends on the capability of the users in accurately interpreting photographs, images, graphs or statistics which are derived from remotely sensed data. There are many factors which determine the uses of remote sensing data in natural hazard assessment, such as scale, resolution, and tone or color contrast. Moreover, coverage, frequency, data cost and availability are also incorporated.

In case of tsunami evacuation model, more detail data regarding buildings are needed, since the evacuation model is started from the concentration of evacuees. From building maps we can have building footprints represented the residential of evacuees. The

building maps can be derived from high resolution images such as IKONOS, QuickBird, etc. High resolution images are needed when the more detail data regarding population for each building are required. In fact, building inventories for tsunami evacuation model can be carried out at various scale levels, depending on the requirements of the tsunami evacuation model. There are many different scales have been identified, ranging from small scale to detailed scale (Table 3).

Table 2. Examples of remote sensing application in each risk management phase

	Prevention	Preparedness (warning)	Relief
Earthquake	Mapping global lineaments and landuse	Geodynamic measurements of strain accumulation	<i>Locate stricken areas, map damage</i>
Volcanic eruptions	Topographic and landuse maps	Detection/measurement of gaseous emission	Mapping lava flows, ashfalls and lahars, <i>map damage</i>
Land-slides	Topographic and landuse maps	Soil porosity: rainfall, slope stability	<i>Mapping slide area</i>
Flash floods	Landuse maps	Local rainfall measurements	<i>Map flood damage</i>
Major floods	Flood plain maps, landuse maps	Regional rainfall, evapo-transpiration	Map extent of floods
Storm surge	Landuse and land cover maps	Sea state, ocean surface wind velocities	<i>Map extent of damage</i>
Hurricanes		Synoptic weather forecast	<i>Map extent of damage</i>
Tornadoes		Now casts, local weather observations	<i>Map amount, extent of damage</i>
Drought		Long-ranged climate model	Monitoring vegetative biomass; station communication
Tsunami	Inundation map, hazard maps and landuse map	Evacuation route maps	<i>Map extent of damage</i>

Source: Walter (2008)

Note:

- Normal : Operational or needs very little research
- Underlined : Research and development required
- Bold** : Requires improved observation capability
- Italics* : Requires improved spatial or temporal resolution

Table 3. Building inventory versus mapping scale

Scale of analysis	Building inventory
Small : < 1:100.000	By Municipality <ul style="list-style-type: none"> • Nr. Buildings
Medium : 25-50.000	Mapping units <ul style="list-style-type: none"> • Predominant type (e.g. residential, commercial, industrial) • Nr. Buildings
Large : 10.000	Building footprints <ul style="list-style-type: none"> • Generalized use • Height • Building types
Detailed : >1:10.000	Building footprints <ul style="list-style-type: none"> • Detailed use • Height • Building types • Construction type • Quality / Age • Foundation

Modified from (Alkema *et. al.*, 2009)

4. DATA AND METHOD

4.1 Study Area

Cilacap is one of the regencies in Central Java Province, Indonesia. Some part of its region is protected by Nusa (island) Kambangan and the others are directly facing the Indian Ocean (Figure 2).



Figure 2. Overview of study areas

Some areas in Cilacap have become industrial centers and sea ports which by its nature making these areas highly populated. Many buildings are situated on the coastal plain just a few meters away from the present shoreline since the region occupies a flat area, some of which are fishing village forming squatter areas. Although some parts of Cilacap are protected by Nusa Kambangan but there have been many damages and casualties due to south Java tsunami occurrence on July 17th, 2006. The disaster took hundreds of lives, devastated the beach, damaged hundreds of fishing boats and houses, etc (BAKORNAS PBP, 2006; Mori *et. al.*, 2007).

4.2 Method

Building Identification; Tsunami inundation of supplied model from worst scenario was used as a basis in selecting the locations which require vertical tsunami evacuation. The building map was extracted from 0.6 m resolution of Quick-Bird image. The buildings serve as the source of evacuees. The building maps were then classified based on their building uses. Heads up digitizing method was used to delineate each building block by using visual interpretation. In this case, professional knowledge and experience combined with the interpretation element were needed in interpreting the image. The large buildings could be orange to brown (depending on roof style) and their locations in relatively easy-accessed areas. In detailed, Budiarto (2006) and Janssen (2004) stated that the identification of the facilities can be illustrated as follows (Figure 3).

- A U shape building or L shape building with open field can be school because of its location near settlement.
- The offices are identified through their building mass typology.
- The existence of certain facilities such as market building, port, bus station can be easily identified from field observation and from image.

- Mosques are identified from building orientation to Qiblat direction that differs from surrounding buildings and also by rectangular shape of the roof.
- Warehouse is identified through large roof plane and large open space surrounded by commercial facilities

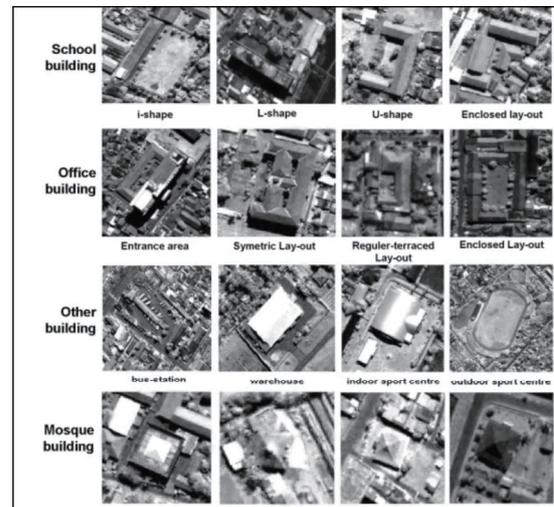


Figure 3. Building identification from QuickBird image (modified from Budiarto, 2006)

Ruko (“rumah-toko”, shop in ground floor and residential use at the upper floor) is identified from the rectangular multi-storey building mass with short flank heading the main road. The roof of ruko is mostly concrete flat deck with small part covered with tile or corrugated metal sheet.

Further, field observation was conducted to validate the building use maps and to assess buildings for ESB. The sampling design was determined based on tsunami run-up and inundated area. Hence the building site was classified into: sea-front site, river/canal-front site, and tsunami reached inland site. Buildings to be checked were selected purposively based on their uses in each building site and also based on preliminary survey having conducted. Despite based on their building sites, the selection of building samples were also determined by the diversity of building uses. The sites which have a high diversity of building uses had more building samples taken. For example, the area which has many facilities such as office, school, or other type of building uses, will have more samples to be observed. Buildings were classified based on their uses by knowing the characteristic of the objects in the image. For these purposes, buildings were classified into several classes, such as house, office, mosque, church, school, shop, hotel, sport-center, factory, and fishing market.

Several requirements of building resistance for tsunami to conduct building assessment were as follows: 1) Located at a distance of more than 200 m from shoreline or 100 m from a river near the coast; 2) Located near the population concentration; 3) Having alternate function as mosque, school, parliament building, government office, market, shopping centre, convention centre, sport hall, hotel, and parking building; 4) Building floor reserved for evacuation located above tsunami wave height in the area; 5) Well-planned and designed; 6) Good quality construction (tsunami and earthquake resistant building).

Road Network Identification: The other component for tsunami evacuation model is road network. It is one of the main components of the model since network analyst is used for generating the evacuation route. The network model is made up of arc segments with appropriate network connectivity settings and attributes defined. Networks typically have rules about how objects move through them.

In order to perform analysis, a network datasets must be developed on the available road network, otherwise it can be derived from high resolution image also. The available road network sometimes are not detailed enough to support the model. In this case, high resolution images and field survey are required to have a detailed road network include setting the travel impedance for each segment, defining directions and one-way streets, and also managing restricted turns.

The existing road networks were from topographic map of BAKOSURTANAL scale 1:25.000. This data was in shape file format. The road networks from Topographic map are less detailed than that is needed for this research. Consequently, the more detailed road networks were added from high resolution image.

The overall processes were as follows:

- 1). Geometric correction of Quick-Bird image using topographic map scale 1:25.000.
- 2). Overlaying the rectified image with existing road network data (shape file of topographic map).
- 3). Adding the missing road using heads up digitizing method in ArcGIS to make the available road networks more detailed.
- 4). Giving attributes to the road data and classifying the road into five classes based on the road width, i.e. arterial road, collector road, local road, other road and pathway.

These road networks were also added during fieldwork by using mobile PDA and GPS. During fieldwork, many missing roads were identified. Usually they were categorized as path and were located in the middle of settlements and covered by trees, making difficult to identify them from the image.

5. RESULTS AND DISCUSSIONS

The building use classification is needed to be determined because it gives contribution in evacuation process since it will serve as target point of evacuations. The uses of the buildings will determine the number of people who present in the buildings in the different periods of time. For these purposes, building classes were classified into house, office, mosque, church, school, shop, hotel, sport-center, factory, and fish market (Figure 4). From this classified building maps, there were two objectives could be achieved. First, facilities location could be identified. By knowing the location of facilities, the estimation of population during daytime and night-time could be made since the number of population in offices, schools and other facilities could be estimated. In this case, a high resolution image is needed to identify the type of the building uses. Further this information is required to estimate the number of population in each building. Second, from these building maps, the potential existing shelter buildings for tsunami evacuation could be recognized.

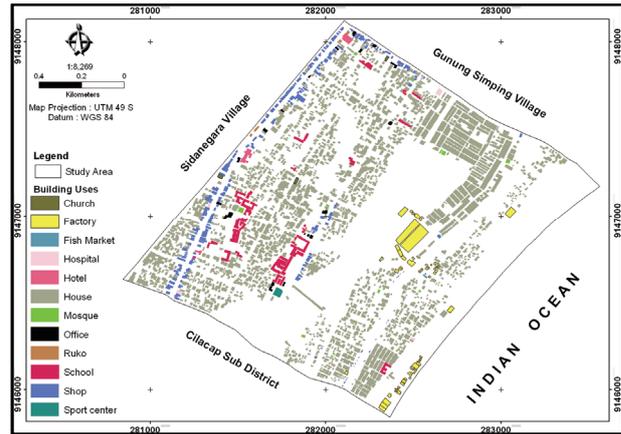


Figure 4. The results of building identification using high resolution image and field observation

The detailed road network is necessary to be implemented in the network modeling. Road network is very essential for evacuation purposes since it will determine the movement of evacuees. It also serves as connection to the shelters and provides the evacuation routes itself. The accessibility to an ESB will require sufficient evacuation route so that evacuees can reach the ESBs in time.

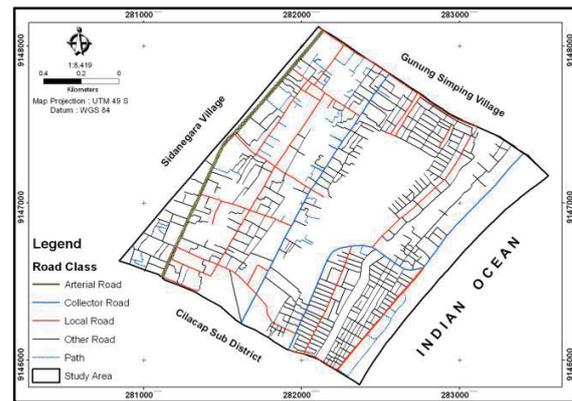


Figure 5. The improved road network

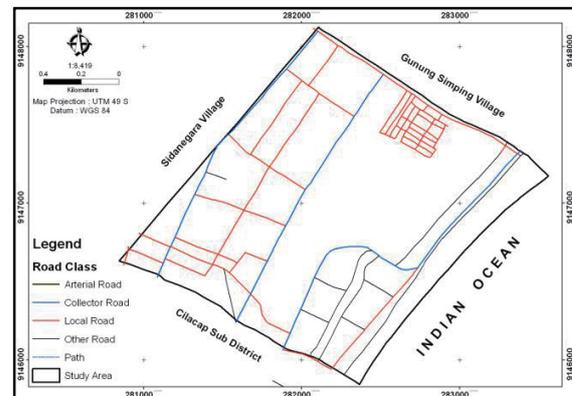


Figure 6. The available road network from topographic map

6. CONCLUSION

The realistic model from tsunami evacuation model is determined by the detailed input data of road network, network attributes and population data. The detailed road network will enhance the model since the travel will be carried on from the centroids of tessellations (point of origin) to the closest network. In line with developing more detailed road network, more detailed network attributes will result in a better evacuation model. Other thing which is important to improve is source of evacuees. In this case the detailed building type is necessary so that the number of evacuees could be estimated.

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