A GIS-Based Approach to the Selection of Evacuation Shelter Buildings and Routes for Tsunami Risk Reduction

a Case Study of Cilacap Coastal Area, Indonesia

by :

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Thesis submitted to the Double Degree MSc. Programme, Gadjah Mada University and
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Thesis

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Disclaimer

This document describes work undertaken as part of a programme of study at the Double Degree International Programme of Geo-Information for Spatial Planning and Risk Management, a Joint Program of Faculty of Geo-Information Science and Earth Observation - University of Twente - The Netherlands and Gadjah Mada University - Indonesia. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute.

Abstract

Coastal areas have always been the most preferred location for settlements, since they provide the attractiveness and many economic opportunities, such as tourism, small-scale industries and fishery. 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.

Cilacap is the only coastal city which is located in the southern part of Java Island which has been hit by tsunami on July 17, 2006. The region occupies a flat area and has become one of industrial center supported by many international sea ports, fish markets and many tourist destinations. Besides occupying low-lying areas near the coast, Cilacap lies in tsunami hazard zone and it is always possible to be struck by tsunami again.

Based on this condition, this research tried to develop a method to choose the most effective evacuation routes using GIS tools in a tsunami-prone area, case of Cilacap coastal area. Network analyst and many GI techniques were used to determine the location and capacity of potential suitable evacuation shelter buildings and also the most effective evacuation route for tsunami. Since ArcGIS Network Analyst software incorporates an advanced connectivity model to accurately characterize real-world multimodal networks.

Population distribution is estimated by houses and facilities occupants' estimation by using population data, space requirements, as well as field observation. Center of population become the source of origin and QuickBird image was used as basis to identify the existing shelter buildings as target of evacuations. The evacuation process was simulated that the residents of the inundation area will be encouraged to walk to safe areas in certain of time. In order to perform analysis, a network datasets must be developed on the detailed road network including setting the travel time for each segment of the road, defining direction, and one-way streets. Travel time was derived from July 17, 2006 tsunami and the development of tsunami early warning system in study areas.

Results of the modeling include proposed location of additional ESBs, capacity and service area of each building, and also evacuation route for each center of population to reach escape buildings. There were 14 proposed additional ESBs that should be built in study area #1 for day population scenario. Meanwhile for night-time scenario, there were 18 additional ESBs that proposed to be build. In the second area, for daytime and time, three additional ESB is proposed due to limited occupancy in that areas. For daytime scenario, the shortest travel time (TT) is 0.198 minutes for 76 meters and the longest TT for 579.7 meters is 14.98 minutes. For night-time scenario, the shortest TT is 0.08 minutes for 3.32 meters and the longest TT is 14.94 minutes for 577.57 meters. Meanwhile, in the second area, the shortest TT is 0.07 minutes for 2.7 meters and the longest TT is 14.5 minutes for 270.7 meters.

Keywords: Evacuation shelter building, evacuation routes, Cilacap, network analyst.

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Abbreviations

ADPC	Asian Disaster Preparedness Centre
ARC	American Red Cross
BAKORNAS PBP	National Coordinating Board for the Management of Disaster
BAPPENAS	National Development Planning Agency
BAKOSURTANAL	National Coordinating Agency for Survey and Mapping
BPS	Central Bureau of Statistics
ETA	Estimated Tsunami Arrival
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GITEWS	German-Indonesian Tsunami Early Warning System
IOC	Intergovernmental Oceanographic Commission
JTIC	Jakarta Tsunami Information Center
NGDC	National Geophysical Data Center
NOAA	National Oceanic Atmospheric and Administration
NTHMP	National Tsunami Hazard Mitigation Program
RW	Rukun Warga
RT	Rukun Tetangga
TT	Travel Time

Chapter 1. General Introduction

This chapter describes the background of the research, research problems, research objectives, research questions and research structure.

1.1 Background of the Study

Tsunami is a wave or series of ocean waves created by sudden, large disturbances of the deep ocean-water mass (2004). There are many factors which cause tsunami such as: earthquakes, volcanic eruption, landslides, slumps, and meteor impacts. Tsunami is most commonly generated by subsea fault movements with prominent vertical dislocation of the sea floor that disturbed the deep ocean-water mass which is often triggered by earthquakes along deep ocean trenches and convergent plate boundaries. Indonesia southern coastlines are located along the convergent boundary of Eurasian and Indo – Australian plates which result those areas prone to tsunami hazard triggering by major earthquake.

The destruction due to tsunami impact is various depending on the source, the distance from the epicenter and also the intensity of the trigger factors which cause tsunami. Mostly, the coastal areas which are densely populated will have severely damages because of high concentration of population, building, infrastructure and socio-economic facilities. Furthermore, tsunami can cause a huge number of fatalities, damages, and cause considerable economic and business losses. For instances, tsunami caused by Krakatau eruption in Sunda Straits - Indonesia in 1883 is one of the disasters which has destroyed the nearby coastal areas. It killed more than 36.000 people and caused hundreds of houses were completely damage (Bryant, 2008). The most recent tsunami which hit South coast of Java, Indonesia on July 17th, 2006 brought the massive damages to the coastal area of many provinces i.e. West Java, Central Java and Yogyakarta Special Province. More than 600 people died and a number of destruction to coastal villages and towns such as Pangandaran, Batukaras, Ciamis and Cilacap (Lavigne et al., 2007) .

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 1.1.). 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).

In the tsunami mitigation plan, evacuation plays a crucial measure for saving human live. NTHMP (2001) stated that the primary strategy for saving lives immediately before tsunami waves arrives is to evacuate people from the hazard zone. Especially for communities who are very vulnerable to tsunami and 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 (FEMA, 2008b). In the south Java tsunami occurrence on July 17th, 2006, many people run to higher places in the northern part of the city after the earthquake occurred or as soon as they saw the tsunami approaching. Cilacap lies in the tsunami hazard area and it is possible to be struck by tsunami again, so it is important to improve measures to support evacuation of residents, tourists and others. Supporting measures includes, increasing local awareness of tsunami disasters, providing a national tsunami warning system which reaches local communities to trigger evacuation of the residents and tourists, and providing evacuation routes in case of tsunami occurrence, constructing tsunami shelters, etc.

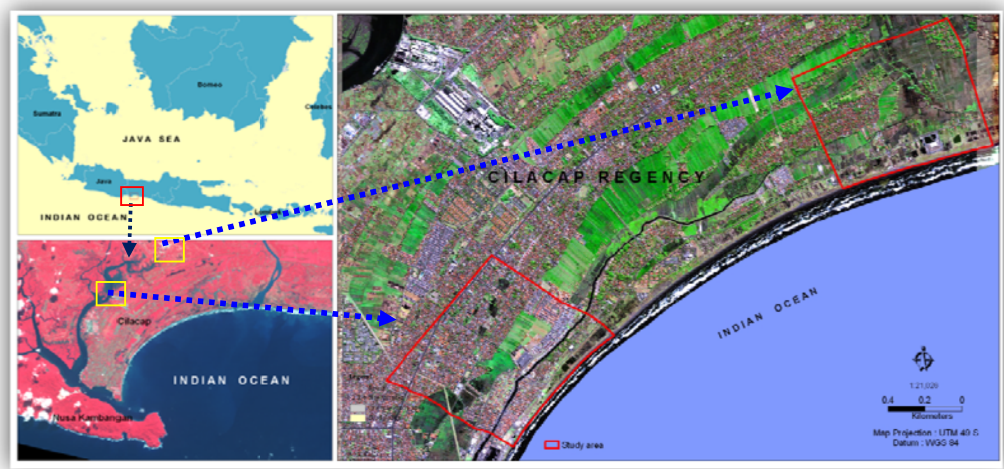


Figure 1. 1. Location of the research

The main issue of this research is tsunami evacuation planning, with the focus on the selection of the effective tsunami evacuation route and identification of potential suitable location for additional evacuation shelter buildings (ESB) as pre-tsunami evacuation destination.

1.2 Research Problems

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 coastal 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. 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. To determine the best evacuation route from a given point we have to identify the fastest path from that point to the assembly point. This fastest path is not always the shortest path, because in fact this line could intersect natural barriers, buildings, rivers, lakes, sandy areas, or have a very high slope that will reduce the speed of evacuee or even block it completely (Laghi, et.al., 2007).

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, landslide 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). Moreover, it is necessary to determine the capacity, spatial distribution and accessibility of evacuation shelter building within a region. Besides, 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.

Based on the problems mentioned above, the research problems of this study are formulated as follows:

1. How to identify the suitable location for additional evacuation shelter buildings for tsunami;
2. How to determine the evacuation route in tsunami occurrence;
3. How to optimize evacuation of coastal communities in a tsunami-prone area to evacuation shelter buildings in a very limited time;
4. How to develop a methodology to choose the most effective route for tsunami evacuation and suitable location for additional shelter building.

1.3 Research Objectives

The main objectives of this research are to determine the location and capacity of potential suitable evacuation shelter buildings and to develop a methodology to choose the most effective evacuation routes using GIS tools in a tsunami-prone area, case of Cilacap coastal area.

To reach the main objectives, the following specific objectives have to be achieved:

1) To identify the most suitable building types that can function as evacuation shelter buildings for tsunami, based on literature studies and field observations;
2) To identify existing buildings in Cilacap – Indonesia that can function as evacuation shelter buildings based on high resolution satellite images and field observations;
3) To generate day-time and night-time population density map of the area prone to tsunami inundation;
4) To identify suitable locations of additional evacuation shelter buildings based on the most effective evacuation route for tsunami and day-time and night-time population densities.

1.4 Research Questions

The following research questions were addressed in order to achieve the objectives that have been mentioned above.

Table 1. 1. Research Objectives and Research Questions

No	Research Objectives	Research Questions
1.	To identify the most suitable building types that can function as evacuation shelter buildings for tsunami, based on literature studies and field observations	a. What are the most appropriate characteristics of existing evacuation shelter buildings? b. What are the already-known design requirements for existing ESBs?
2.	To identify existing buildings in Cilacap that can function as evacuation shelter buildings based on high resolution satellite image and field observations	a. Which buildings can be functioned as evacuation shelter buildings? b. How to identify evacuation shelter buildings using high resolution image? c. What are the alternative functions of additional evacuation shelter buildings for tsunami based on literatures and field observations?
3.	To generate day-time and night-time population density map of the area prone to tsunami inundation	a. How many people need to be evacuated? b. How is their spatial distribution during daytime and night-time?
4.	To identify suitable locations of additional evacuation shelter buildings based on the most effective evacuation route for tsunami and day-time and night-time population densities	a. How many additional evacuation shelter buildings needed and what are the capacities needed? b. How to locate the evacuation shelter buildings? c. How to optimize their spatial distribution? d. What is the evacuation time to be assumed? e. How is evacuation of people after tsunami warning? f. How do people reach the temporary evacuation shelter buildings? g. What is the walking speed of people to be applied?
5.	To assess the utility of geo-information technique to identify the most effective evacuation route and suitable location for additional ESB	a. Is GI techniques helpful to identify the suitable location of ESB and the most effective evacuation route?

1.5 The Benefit of the Study

The results may give benefits to the government and society and also those who have an interest in tsunami risk management, such as:

1. It could be used as consideration in mitigation plan for tsunami,
2. It can be one of key elements of preparedness.
3. The safe route and safe zones for tsunami evacuation would help the government during and after disaster, in order to evacuate population and also to provide logistic.
4. Finding the multi-function buildings that can be used as ESBs is necessary due to high building construction cost and also efficiency in space occupation.

1.6 Research Structure

The thesis proposal writing is organized as follows:

- **Chapter 1** is about general introduction and justification of the research includes the background, research problems, research objectives, research questions, benefit of the research and research structure;
- **Chapter 2** discusses the literature studies that explain tsunami (its source and generation, propagation, run-up, inundation, its temporal probability, tsunami hazard assessment, and tsunami model), concept and model of evacuation plan, and two examples of tsunami evacuation model. Further this chapter also figures out network analyst software, network datasets creation, and characteristics of evacuation shelter building for tsunami. Short description regarding hexagonal tessellation and speed of evacuees end this chapter.
- **Chapter 3** explains Tsunami Early Warning System including estimated tsunami arrival and evacuation time.
- **Chapter 4** describes the study area of Cilacap comprises geographic and nature condition, land use type, population data and also geomorphology condition.
- **Chapter 5** illustrates the research design, pre-fieldwork, fieldwork and post-fieldwork activities, and description of the method which were used in this research for further analysis.
- **Chapter 6** presents the results of the process that have been carried out. The description comprises two parts; the model input consists of the result of building assessment, road network assessment and population estimation. The second part is other data which are supported the model, including tsunami inundation map and land cover maps.
- **Chapter 7** discusses the evacuation model including service area of existing ESB, additional ESB location and evacuation route selected.
- **Chapter 8** gives conclusions and recommendations of this research, including recommendation to the future research, to the community and to the government of Cilacap.

1.7 Research Timeframe

This research was conducted based on the research time frame in table below:

Table 1. 2. The Timeframe of the Research

No	Activities	May	June	July	Aug	Sept	Oct	Nov	Dec
1.	Pre-fieldwork								
	a. Literature review								
	b. Checking data availability								
	c. Study area selection								
	d. Fieldwork preparation								
2.	Fieldwork								
	a. Primary data collection								
	b. Secondary data collection								
3.	Post-fieldwork								
	a. Data analysis								
	b. Thesis writing								
	c. Report finalizing								

Chapter 2. Literature Review

This chapter mainly explains the concept of tsunami, its sources and generation, tsunami propagation, tsunami inundation and also the concept of tsunami hazard assessment. Further explanation related to evacuation planning, evacuation model, tsunami evacuation model and evacuation shelter buildings also includes in this chapter. The general description of the network analyst and the concept of tessellation ends this chapter.

2.1 Tsunami

2.1.1 Tsunami sources and its generation

Tsunami is among the most destructive natural disaster. It has been damaging to coastal community, wiping out the entire populations with very little warnings or very often striking without warning. The word "tsunami" is originated from the Japanese term *harbor wave*, because it can generate large wave oscillation in harbors and enclosed water bodies. It is also called tidal wave, although it is improper term because tsunami has nothing to do with tides (Kusky, 2003; Fernando et al., 2008). Tsunami is commonly used for describing a giant ocean wave, generated by vertical displacement of a column of water and also created by sudden, large disturbances of the deep ocean-water mass (NERC, 2000; Abbott, 2004).

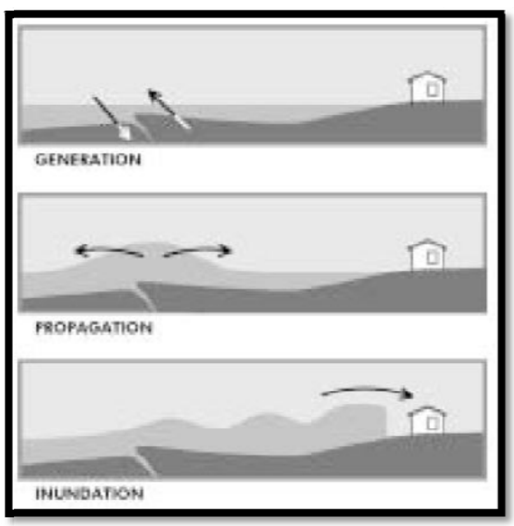


Figure 2. 1. Tsunami generation, propagation and inundation (NTHMP, 2001)

Tsunami sources could be generated by subsea fault movements with vertical dislocation of the sea floor that disturbed the deep ocean-water mass. This provides the initial perturbation and energy for the generation of tsunami (Fernando et al., 2008). This vertical displacement or dislocation can be generated by five main processes which can occur together in the same event. Those five main processes generated tsunami are earthquakes, volcanic eruptions, landslide, extra-terrestrial object (asteroids or comets) and anthropogenic tsunami (explosions). The energy associated with landslide or volcanic eruption is less than those produced by vertical submarine faulting (Kusky, 2003; Fernando et al., 2008). It is because earthquakes with vertical displacements can push large volumes of water upward or downward generating tsunami.

Most tsunami are generated by earthquakes, particularly the one which strike offshore or near the coast (Kusky, 2003). When the earthquakes occur beneath the sea, the water will be displaced from its equilibrium relating to the gravity field and try to regain its equilibrium. The number of waves resulted can vary depending on the nature of the earthquakes. As they propagate, waves can change into two or more larger wave (Heitner, 1969; Fernando et al., 2008). In addition, tsunami triggered by earthquake can generate ocean floor movements or landslide which is spread to the coastal area and possibly results in serious fatalities (Heitner, 1969; Mardiatno, 2008). There are many example of earthquake triggering tsunami and most of those events occur in Pacific Rim and South East Asia specifically Indonesia (Table 2.1). This concentration of earthquake in Pacific Rim and Indonesia represent all tsunami in historic record due to their position in the circum-Pacific belt or the Ring of Fire (NERC, 2000).

Table 2. 1. Historical Record of Earthquakes-Generated Tsunami

Year (A.D)	Location	Source Location (If Different)	Maximum Run-up	Deaths
1700	Sanriku coast, Japan	-	?	~100 000?
1737	Kamchatka	-	64 m?	>50
1755	Lisbon, Cadiz, Tangier Madeira	Gorringe Bank, Atlantic Ocean*	25 m+	>25 000***
1863	Eastern Philippines	-	?	~30 000?
1868	Pacific Rim (Chile, Peru)	North Chile trench	20 m	~25 000
1896	Sanriku Coast, Japan	**	24 m	~26 000
1908	Messina, Italy	-	8 m	~6 000***
1933	Sanriku Coast, Japan	-	20 m	~3 000
1946	Pacific rim (especially Hawaii)	Aleutian arc, Alaska**	35 m	~200
1960	Pacific rim (especially Chile, Hawaii, Japan)	Central Chile trench	20 m	~2 500
1964	Alaska, California	Alaska	20 m	115
1976	Eastern Philippines	-	?	~3 000?
1983	Hokkaido, Japan	Sea of Japan	15 m	103
1992	Nicaragua	**	10 m	170
1992	**Flores, Indonesia**	**-**	**26 m**	**~1 000**
1993	Honshu, Japan	Sea of Japan	20 m	230
1994	**Java, Indonesia**	**Java trench**	**14 m**	**230**
1996	**Irian Jaya, Indonesia**	**North Irian Jaya**	**11 m**	**160**
1998	Sissano, Papua New Guinea	*	20 m	~2000
2004	**Aceh, Indonesia**	**Off west coast of Sumatra**	**50.9 m**	**300.000**
2006	**Java, Indonesia**	**Off South coast of Java**	**10 m**	**~664**

* *Source locations and types uncertain; submarine landslides triggered by earthquakes have also been implicated in these events*

** *Probable "tsunami earthquakes"*

*** *Death tolls uncertain because of confusion between deaths caused by earthquakes and deaths caused by tsunamis.* Source : (NERC, 2000; NGDC, 2009)

The second trigger for tsunami is volcanic eruption which is associated with the collapse of volcanic slopes, debris and ash flows that displace large amount of water above the volcano. Although a volcanic eruption rarely produces a large tsunami, it can generate a huge destructive of tsunami occurrence also (Bryant, 2008). Krakatau was the most famous eruption causing the huge destructive tsunami in 1883. The waves reached run-up heights of 35 m and killed more than 36.000 people (NERC, 2000; Kusky, 2003). In contrast, Tambora eruption in 1815 only produced a local tsunami 2- 4 m high because it lays 15 km inland (Bryant, 2008).

Landslides that displace large amount of water can also generate tsunami. There are two recognizable tsunami generation mechanisms. The first mechanism is the movement of sub-seafloor material from one place to another, generating a reverse flow of water. The second mechanism is sub-aerial landslides entering the sea pushing water laterally as they do so and generate a reverse flow once after completely submerge (NERC, 2000). Kusky (2003) explained that many sub-marine landslides are earthquake-induced, but tsunami are considered to be landslides-induced if the earthquakes is not large enough to generate tsunami. Furthermore landslides along the steep continental slope that flanks the most coastlines are also the source of tsunami as a result of submarine earthquake (Bryant, 2008). A 1720-foot-high tsunami in Lituya bay - Alaska was one of the extraordinary tsunami caused by landslides specifically by avalanche (Kusky, 2003).

The other triggering factor for tsunami is meteorite impacts. Even though there has been no known historical data about them, this does not mean that they are not cataclysmic (Kusky, 2003; Bryant, 2008). The concept on how tsunami can be generated by the impact of extraterrestrial objects is less understood. In addition, tsunami of unknown source in historical catalogues may have been produced by small impacts far out at sea, but it is not possible to be proved (NERC, 2000).

2.1.3 Tsunami propagation

Tsunamis are different from usual short waves in the ocean which are generated by wind over deep water (Figure 2.2). They differ in term of wavelength, period, velocity and amplitude. Wavelength is the distance between crest of successive waves, meanwhile period is the time required for two successive wave crests to pass a fixed point. Most ocean waves have wavelengths of 100 meters or less and 10 seconds of period, but tsunami are exceptional in that they have 200 km wavelength or greater and one hour period (NERC, 2000; Kusky, 2003). Generally, tsunami wave train has several superimposed wave with different period. One or two waves will dominate leading to the perception in the impact area of a series of separate wave (ESS, 2005).

Because tsunami has a very huge wave length, very little energy could be lost as they propagate. They travel very fast in the deep water at high speeds and travel great transoceanic distances with limited energy loss (Kusky, 2003; ESS, 2005; NOAA, 2009). Imamura (2005) explained that the deeper the water and the longer the wave the faster tsunami will propagate. In addition, the tsunami wave speed depends upon wavelength and the water depth (Table 2.2). Normal oceans wave travel at less than 90 km per hour, where as many tsunami travel for about 800 – 950 km per hour (Bolt *et al.*, 1977; Kusky, 2003). As waves enter shallow water, they slow down, grow taller and change shape. Tsunami change significantly as they propagate due to water depth variations (Figure 2.3).

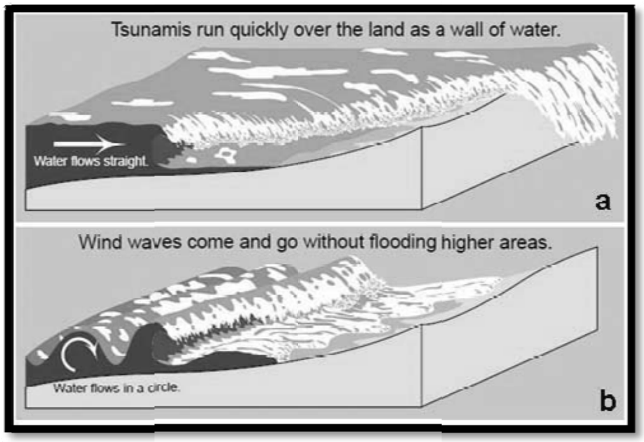


Figure 2. 2. The Difference between Wind-Waves and Tsunami-Waves (ESS, 2005)

When tsunami breaks on the beach, they emerge as flooding, or form a 'bore' as they move up a river or stream. When the water height increase, water from the shore line will be recede to give volume flux for the growing wave. It becomes the first sign of the generating of tsunami to coastal community (ESS, 2005; NGDC, 2009). If water recede, it expose sea life and ocean bottom. Fatalities will be occurred when people try to explore the strange landscape of the ocean bottom and gather fish. It is because the wave will return to cover the exposed coastal areas. Even though, there may be an interval time between the arriving of waves, usually the later waves can be more destructive than the first (Figure 2.3).

Table 2. 2. The Speed at which Tsunami Travel in Certain Ocean Depth

Depth (m)	Phase Speed (m/s)	Phase Speed (km/hr)
50	22	80
100	31	113
500	70	252
1,000	99	356
2,000	140	504
3,000	171	617
4,000	198	713
5,000	221	797
6,000	242	873

Source : (Mofjeld et al., 2004)

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 and can have a huge damage resulting from triggering earthquake such as ground shaking, landslide and surface faulting, etc. On the other hand, distant tsunami can travel for hours before hitting a coastline. Tsunami at the coast of Chile in 1960 is one of example of long distant tsunami, as can be seen in Figure 2.4 which shows the estimated time for tsunami waves to travel across Pacific Ocean from Alaska and Chile (EWRC, 2007). It hit Hilo shore of Hawaii after travelling more than 12.000 km in less than 15 hour with 804 km/hour in velocity. Then it struck Japanese coastline generating higher wave than any other outside Chile itself 22 hours after the shock and spreading around the Pacific Ocean (Bolt *et al.*, 1977; NERC, 2000).

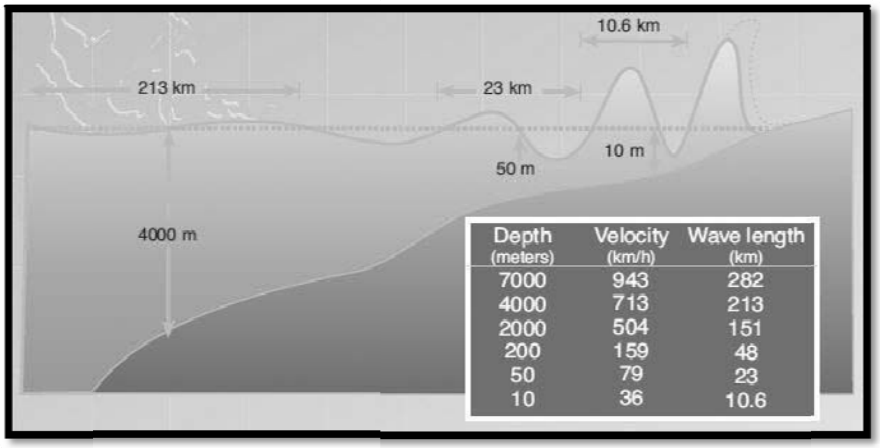


Figure 2. 3. The Tsunami Wave on the Coastlines (As the tsunami attacks the coastline, the wave energy is compressed into a much shorter distance and a much shallower depth, creating destructive tsunami wave (Martin-Neira and Buck, 2005; IOC, 2008b)

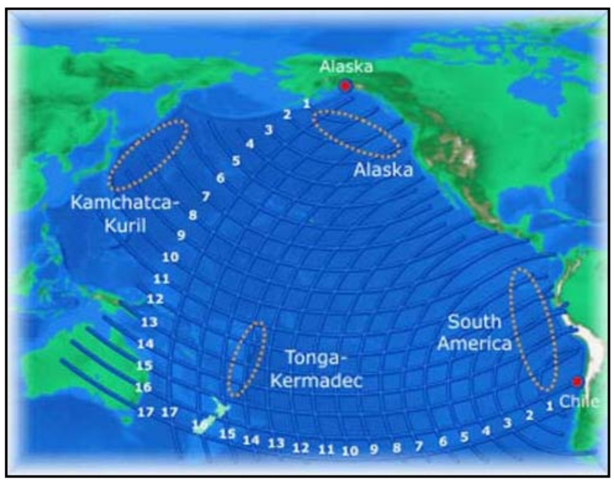


Figure 2. 4. Long Distance Tsunami

In Indonesia most of tsunami events are local, such as tsunami in Aceh on 26th December 2004 took 30-40 minutes to reach Meulaboh (Yalciner, et. al, 2005). In the case of 17 July 2006 tsunami in Southern coast of Java, it is categorize as local tsunami, because the tsunami travel time only took less than 60 minutes (Lavigne *et al.*, 2007).

2.1.4 Tsunami run-up

Run-up is the height of the tsunami above sea level at the farthest point it reaches on the shore (NERC, 2000; Fernando et al., 2008). Bolt *et.al* (1977) and Bryant (2008) stated that the run-up of tsunami may be significantly different from the height of the wave where it first hits the shore. The size of the additional height depends on the inclination of the slope over which it is moving. For example, for natural hillside of around 20 degrees the run up height is about twice the value of H0, whilst in the case of vertical cliffs or walls the run up height can be as 5 times H0. Furthermore, the maximum run-up is usually recorded and used to express the tsunami magnitudes (NERC, 2000). Based on Iida and others (1976) after (NGDC, 2009) there are two terms may be determined from the run up value, i.e. tsunami magnitude and tsunami intensity, which are defined as :

$$m = \log_2 H$$

$$I = \log_2 (2^{1/2} * H)$$

where m is the magnitude, I is the intensity and H is the maximum run up height of the wave. The maximum run-up height of a solitary wave can be calculated using the following formula(Bryant, 2008):

$$H_{r\max} = 2.83(\cot \beta)^{0.5} H_t^{1.25}$$

where H_{max} is maximum run-up height of a tsunami above sea level (m), H_t is wave height at shore or the toe of a beach (meter) and β is slope of the seabed (degrees).

Tsunami run up can also in the complex form which is approaching shore in the form of one or more bores. A bore is a certain waveform in which the mass of water propagates to the shore with the wave and the leading edge of the wave is often turbulent. These tsunami bores are particularly damaging as they cross a shoreline. Because the bore pushes a small wedge-shapes body of water which transfer momentum to the wedge, it increase the water velocity and turbulence by a factor of two (Bryant, 2008).

There are many factor which influence the run up of tsunami, including the size of wave, the configuration of shorelines, the profile of the water depths, diffraction, and other irregularities particular to certain areas (Kusky, 2003). Hence, run-up height were spatially very variables, and the protected sites will have the higher run-ups. Because of refraction effect, every promontory experienced large run-up as well. On the other hand, steep coastlines were hardest hit because the waves could approach shore with minimal energy dissipation.

2.1.5 Tsunami inundation

Inundation is the maximum horizontal distance that is reached by a tsunami (Fernando et al., 2008). NERC (2000) explained that on a flat coastal area (with slope of around 0.1 to 0.05 or less), the extent of the inundated area by the tsunami is limited not by the maximum height it can reach. It is limited by the dissipation of the wave by drag forces as it flows over the more or less rough surface of the land (Figure 2.5).

The extent of the region covered by the tsunami varies according to the height and wavelength of the wave as they arrive in the near shore areas, and with the local topography (NERC, 2000). In addition, Heller, et. al (2005); Kaistrenko et.al. (1991) *after* (Fernando et al., 2008) stated that the inundation areas not only depend on the local topography but also bathymetry as well as the orientation with respect to the incoming wave, tide level and magnitude of the tsunami.

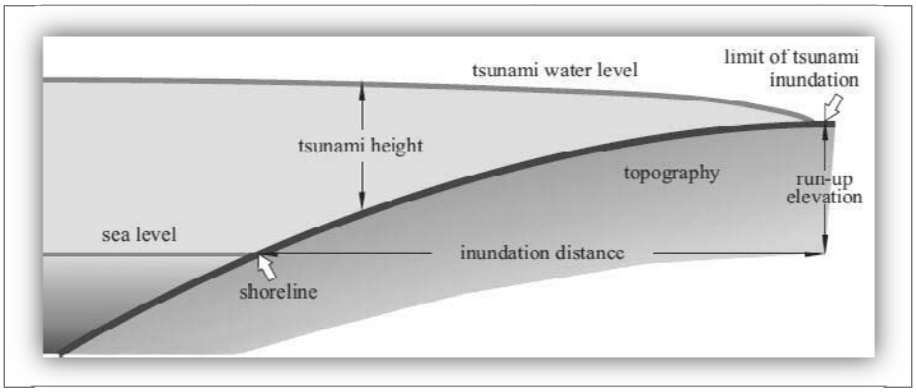


Figure 2. 5. Measurement of Inundation Distances and Run-Up Elevation (Source : USGS after (Chandrasekar et al., 2007)

Furthermore, NERC (2000) explained that on relatively flat coastal area, the extent of the tsunami inundated zone depends less upon the topography. It depends more upon the properties of terrain, i.e. sizes, numbers and other characteristic of objects upon it which exert drag upon the base of surges or bores flowing rapidly across the landscape. These features are expressed in terms of roughness coefficient that is related to the inundation distance or "run in" X_{max} resulted by a tsunami of given height H_0 at the coast. The maximum distance that run-up can penetrate inland (X_{max}) on a flat coast can be calculated using the following formula:

$$X_{\max} = 0.06 \frac{H_0^{4/3}}{n^2}$$

where H_0 is the wave height at coast and n is surface roughness coefficient. Table 2.3 shows the value of n for different terrain types.

Table 2. 3. The Typical Value of Roughness Coefficient for Different Terrain Types

Terrain type	Roughness coefficient	Inundation distance	
		10 m tsunami	50 m tsunami
Mud flats, ice, open fields without crops	0.015	5700 m	48.5 km
Built - up areas (typical)	0.035	1050 m	8.9 km
Built - up areas (city centers with high rise buildings)	0.03	100 m	1 km
Forests, jungle, rough lava flows	0.07	260 m	2.2 km

Source : (NERC, 2000; Bryant, 2008)

The roughness coefficient shows an effective decrease for waves that are large in relation to the size of the obstacles in their paths. This could be the reason why the value given in the table above is sometimes different with the real tsunami occurrence. This may however also reflect that the first tsunami wave in a series removes most of the obstruction in its path, reducing surface roughness for the later waves in the series (NERC, 2000; Bryant, 2008).

Bryant (2008) stated that the cross-sectional area of coastline inundated by a tsunami is equal to the cross-sectional area of water under the wave crest to shore as illustrated in following figure. The bigger the tsunami or the longer the wave period, the greater the volume of water carried onshore and the greater the extent of flooding (Figure 2.6).

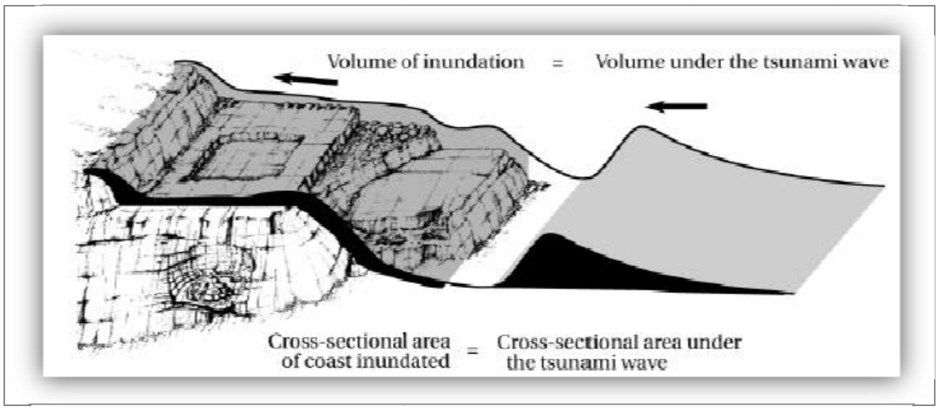


Figure 2. 6. The cross-sectional of the area of coastline flooded and volume of inundation by a tsunami is equal to the cross-sectional area and volume of water under the tsunami waves crest (Bryant, 2008)

2.1.6 Temporal tsunami probability

Temporal tsunami probability means the probability of tsunami of a particular magnitude occur in a certain area in a given period of time (Papathoma *et al.*, 2002). It is a key point to learn the probability occurrence of tsunami in the future. Historical data of former tsunami have particular value as they can provide information on the frequency and magnitude of events for the time period for which historical records are available. The analysis of these data allows scientists to understand when a certain tsunami with a certain magnitude is likely to occur in a given area. Dominey-Howes et al., (2007) after (Heidarzadeh *et al.*, 2008) stated that compilation and analysis of historical data of tsunamis is of primary importance for tsunami hazard assessment. The compiled data yield important information about the return period of tsunamis, the different types of potential tsunamis in the region, the possible tsunami wave heights, and the most vulnerable coastlines to the impact of tsunamis.

The processes by which tsunami are generated mean that major damaging events are relatively rare, but the damage they cause can be great. They are very low probability, but very high consequence events. Because of that, the analysis of tsunami is very important, especially for the area where tsunami has not been struck after long period or never struck by tsunami but it is potential to be struck.

In most of the cases there is a fixed relation between magnitude and frequency for natural events, including tsunami. The frequency of events with a low magnitude is high, while the frequency of events with great magnitude is low (Figure 2.7).

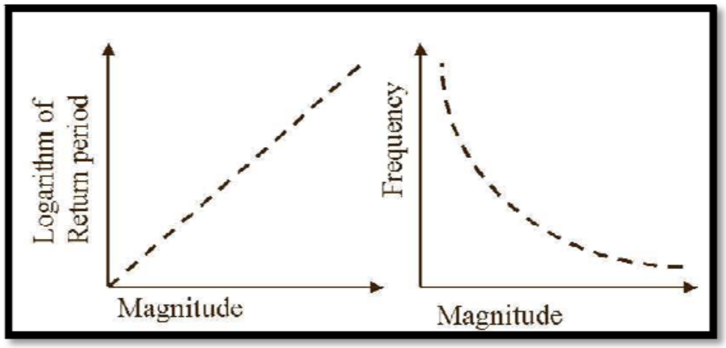


Figure 2. 7. Graphs showing the magnitude – frequency relation (Alkema *et al.*, 2009)

For coastal location which has a complete historical data of tsunami occurrence, it has been possible to calculate the probability (return periods) for different magnitude tsunami (Papathoma *et al.*, 2002). Meanwhile for other coastal locations, there is insufficient data to determine tsunami probability. In this case, the probability of tsunami is calculated using a combination of source specifications and numerical propagation models (Geist and Parsons, 2006).

Indonesian region is prone to earthquake and tsunami disasters. Although the region is prone to tsunami disaster, tsunami activity is not well understood. This is partly because of very limited available information on historical tsunami activity.

Latief *et.al.* (2000) divided Indonesia region into 6 zones by considering the tectonic setting and its seismicity (see Figure 2.8), as follows:

1. Zone A : The west Sunda arc includes the northwest Sunda Strait; i.e. Sumatra and the Andaman Islands.
2. Zone B : The east Sunda arc includes the area in the region in the east Sunda Strait to Sumba, i.e. Java, Bali, Lombok, Sumbawa, and Sumba.
3. Zone C : The Banda arc covers the area of the Banda Sea, i.e. Flores, Timor and Banda Islands, Tanimbar islands, and Ceram and Buru.
4. Zone D : Makassar Strait.
5. Zone E : Molucca Sea, Sangihe and Halmahera.
6. Zone F : North Irian Jaya.

Latief *et al*., (2000) also compiled historical tsunami data of Indonesia from 1600 to 1998 from many literatures (Table 2.4). 105 tsunamis have struck Indonesia region, and 95% have been generated by earthquakes, 9 by volcanic eruptions and 1 by a landslide.

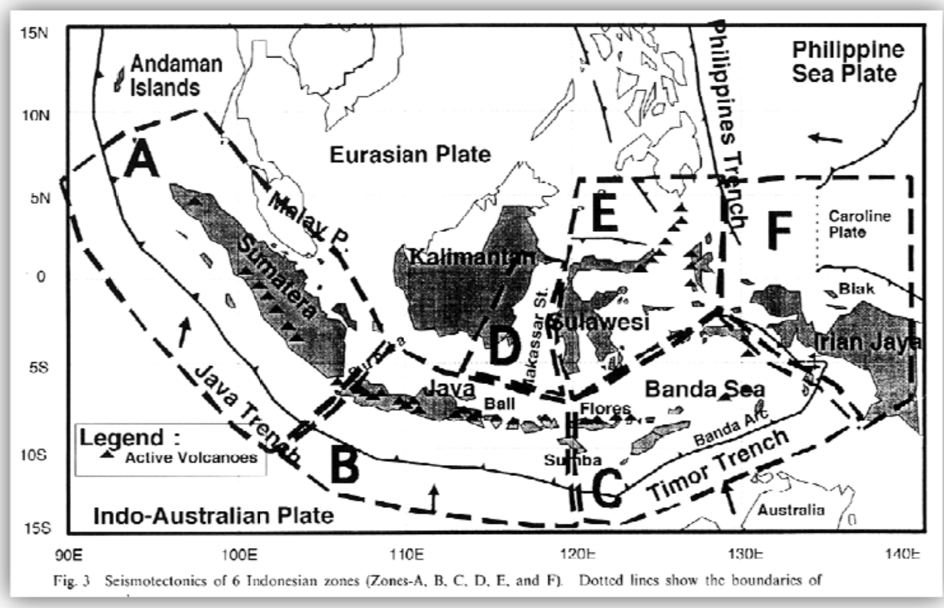


Figure 2. 8. Seismo-tectonics of Six Indonesian Zones (Latief *et al.*, 2000)

Table 2. 4. Tsunami Activity in Indonesia

Zone	Region	Number of Tsunami	Percentage of Occurrence	Number of Fatalities	Percentage of Fatalities
A	West Sunda arc	16	15.3%	36.360	67.7%
B	**East Sunda arc**	**10**	**9.5%**	**3.261**	**6.0%**
C	Banda arc	35	32.3%	5.570	10.3%
D	Makassar Strait	9	8.6%	1.023	1.9%
E	Molucca Sea	32	30.8%	7.576	13.9%
F	North Irian Jaya	3	2.9%	357	0.7%
	Total	105	100%	54.147	100%

Source : Latief et al., (2000)

Temporal tsunami probability in Cilacap can be derived from this historical tsunami occurrence. Cilacap is located in Zone B (East Sunda arc region). According to Latief *et al*. (2000), there were 82 destructive earthquake in this region with time interval about 2 – 3 years indicating extremely high activity. There were 10 tsunami occurrence, 9 were generated by earthquake and 1 by volcanic eruption. The average interval between tsunami is estimated to be about 10 – 15 years.

The earthquake that generates tsunami – known as tsunamigenic earthquake – usually has special characteristics. The tsunamigenic earthquakes have characteristics as (a) the epicenter is located in the sea, (b) the earthquake focal depth less than 60 km so that could be classified as shallow earthquake, (c) the earthquake magnitude (Ms) greater than 6.0, and (d) the earthquake focal mechanism are dip-slip type of thrusting or normal faulting (Puspito, 2002).

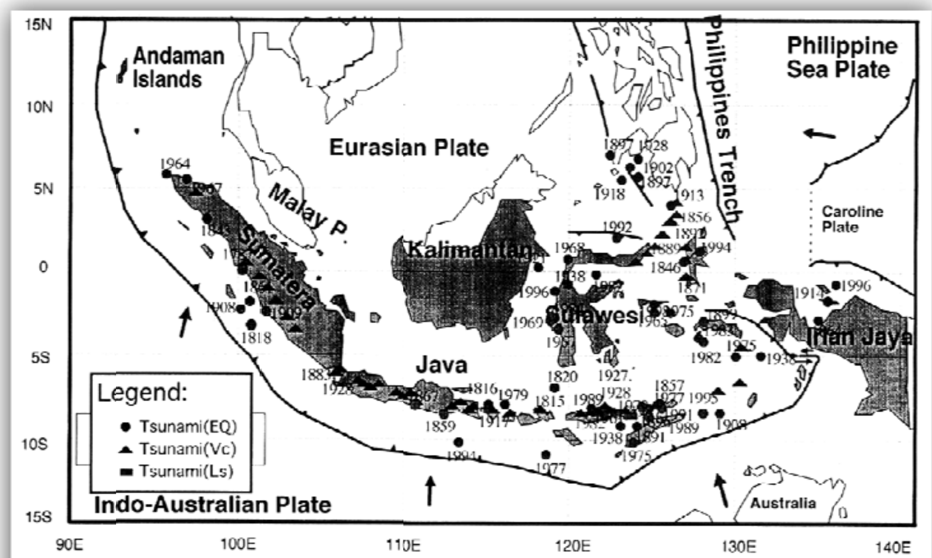


Fig. 4 Location of tsunami and year of their occurrence. Solid circles, triangles and a square respectively indicate tsunamigenic earthquakes, volcanoes and a landslides.

Figure 2. 9. Location of Tsunami Occurrence in Indonesia (Latief *et al.*, 2000)

2.1.7 Tsunami hazard assessment

The aim of hazard assessment is to assess how probably hazardous events are and how large their effects might be. Heidarzadeh *et.al.,* (2008) explained that different methods have been employed by researchers to assess tsunami hazards in various tsunamigenic zones around the world including: (1) analysis of historical tsunami, (2) deterministic modeling, and (3) probabilistic modeling.

Papathoma *et.al.,* (2002) calculate the probability (return periods) for different magnitude tsunami from a complete historical data of tsunami occurrence in Greece. When data of historical tsunamis for a particular site are insufficient, tsunami hazard can be calculated using a deterministic method. This method takes into account characteristic scenarios considering the largest event known to have hit the area of interest and to simulate this event through numerical modeling (Geist and Parsons, 2006). This technique has been used to assess tsunami hazards in some vulnerable coastlines e.g., Okal *et. al.* (2006) and Tinti iet.al., (2005b).

A further level of improvement in tsunami hazard assessment considers not only how large a tsunami affecting a particular community may be, but also how likely the occurrence of a tsunami of a given magnitude is. This is known as probabilistic tsunami hazard assessment, and its implementation is similar in concept to that of Probabilistic Seismic Hazard Assessment. This method uses a combination of probability analysis for offshore earthquake occurrence and numerical modeling of tsunamis to determine the probability of having a tsunami whose maximum water elevation exceeds a certain value at a coastal site. The method has been employed by some authors e.g. Burbridge (2008) and Geist and Parsons (2006).

Burbridge *et. al.,* (2008) and Geist and Parsons (2006) described that deterministic approach is normally used for developing inundation maps and evacuation based on the maximum credible tsunami for a given region. Because they contain little or no information about likelihood, however, scenario-based methods are of limited usefulness for broader policy and planning decisions including insurance applications. For these purpose, probabilistic approach is considered. Probabilistic Tsunami Hazard Analysis was rarely considered until recently—i.e., since the occurrence of the 2004 Indian Ocean Tsunami.

Tinti and Armigliato (2003) *after* (Geist and Parsons, 2006) stated in detailed, deterministic modeling based on a particular source scenario best serves the purposes of coastal engineers to develop effective tsunami counter-measures. It seems that for multiple mitigation objectives, both deterministic and probabilistic analyses are needed. In a multi-objective hazard analysis, de-aggregation of probabilistic results is an effective tool for developing scenarios for deterministic modeling.

2.1.8 Tsunami Model

Tsunami model tries to simulate many processes of tsunami, i.e. tsunami generation, tsunami propagation and also tsunami run-up and inundation by using mathematical model approaches (Diposaptono and Budiman, 2008). Berryman (2006) stated that the process of numerical tsunami modeling can considered as three stages: 1) Source modeling, in which the generation of the tsunami, either by earthquake, landslide, volcano or bolide impact, is simulated; 2) Propagation modeling, in which the dispersal of the tsunami waves around the ocean, sea, or lake, is simulated; 3) Inundation modeling, in which the water flow over dry land is simulated.

Further, these tsunami models use the energy released, the size of the deformed area, the mean displacement at the surface, and the dip, strike and slip angle to infer a seafloor displacement pattern (FEMA, 2005).

After having established initial wave condition, tsunami models estimate the movement of tsunami from its source to the target coastline, over the seafloor. When the simulated wave arrives at the coastline, tsunami models become inundation models and calculate the propagation of the tsunami as it moves inland. In this case, tsunami models are the combination of earthquake, wave propagation to the impact zone and inundation models (FEMA, 2005).

Tsunami models could estimate the height of tsunami and their arrival times based on certain tsunami source, including earthquakes, sub-aerial and submarine landslides, volcanic eruptions, etc. There are various hydrodynamic numerical models for calculating tsunami inundation, such as the MOST (Method of Splitting Tsunami), the TUNAMI-N2, ADCIRC model, SIMs (Standing Inundation Models), etc. Anunnziato (2005) and NOAA (2009) stated that all the models however need to be set in an appropriate value so that the more realistic model could be developed. Since the characteristics of the generating earthquakes and other triggering factors are not fully known, the models need to be initialized in a rather subjective way. Tsunami modeling can be useful in a tsunami early warning system in two ways; 1) Real-time monitoring of the tsunami propagation and prediction of coastal effects; 2) Support the evacuation plans and community preparedness by means of inundation (run-up) calculations of historic or hypothetical events (JTIC, 2009).

2.2 Evacuation Plan

2.2.1 Concept of evacuation plan

ADPC (2008) defined risk as the expectation value of losses including death, injuries, properties, etc., that would be caused by a hazard. Further, ADPC stated that disaster risk can be seen as a function of the hazard, exposure and vulnerability. So, in that case, to reduce disaster risk, it is necessary to decrease the level of vulnerability and to keep exposure as far away from hazards as possible by relocating populations and property.

Risk management cycle consist of four phases, i.e., preparation/mitigation and preparedness in the pre-disaster stage and response and rehabilitation/reconstruction in the post-disaster stage. Examples of measures taken in each phase are described in Table 2.5.

Table 2. 5. Example of Measures in Each Disaster Risk Management Phase

Disaster / Phase	Earthquake	Flood	Storm (cyclone, typhoon, Hurricane)	Landslide
Prevention / Mitigation	▪ Seismic design ▪ Retrofitting of vulnerable buildings ▪ Installation of seismic isolation/seismic response control systems	▪ Construction of dike ▪ Building of dam ▪ Forestation ▪ Construction of flood control basins/reservoirs	▪ Construction of tide wall ▪ Establishment of forests to protect against storms	▪ Construction of erosion control dams ▪ Construction of retaining walls
Preparedness	▪ Construction and operation of earthquake observation	▪ Construction and operation of meteorological observation systems	▪ Construction of shelter ▪ Construction and operation of meteorological observation systems	▪ Construction and operation meteorological observation systems
	▪ Preparation of hazard maps ▪ Food & material stockpiling ▪ Emergency drills ▪ Construction of early warning systems ▪ Preparation of emergency kits			
Response	▪ Preparation of hazard maps ▪ Food & material stockpiling ▪ Emergency drills ▪ Construction of early warning systems ▪ Preparation of emergency kits			
Rehabilitation / Reconstruction	▪ Disaster resistant reconstruction ▪ Appropriate land use planning ▪ Livelihood support ▪ Industrial rehabilitation planning ▪			

Source: ADPC (2008)

Evacuation is a risk management strategy which may be used as a means of mitigating the effects of an emergency or disaster on a community. It involves the movement of people to a safer location (EMA, 2005).

In many hazardous situations, the best option is to relocate at-risk population to a safe place. This is a complex problem with many behavioral and management facets. For instance, selection of zone to evacuate, designation of shelters and exits, selection of routes for evacuees so that safety evacuation under dynamic hazard and traffic condition can be conducted (Cova and Johnson, 2002). However, to be effective it must be correctly planned and executed.

Bustamante and Wolf (2007) said that evacuation planning is a key role of emergency management and homeland defense preparation. It is also a critical component in emergency management. Further, Huang *et.al.,* (2005) declared that the objective of evacuation planning is to take full advantage of the implementation of the emergency management system which is responsible for evacuating communities in the danger areas.

In addition, many structural and non-structural mitigation measures addressed at civil protection are used currently. Structural mitigation measures include measures such as sabo-dams, dikes and other protection constructions. Nevertheless, the advantages of these measures are not significant, mainly because of excessive cost of construction and inadequate spatial/temporal reliability of prediction. The development of these facilities requires alternate non-structural mitigation measures. Emergency evacuation along with advanced forecasting, monitoring and warning are becoming important to counteract the insignificant success of structural measures (Kumar, K. *et al.*, 1996).

2.2.2 Concept of Accessibility

There are many definition of accessibility in the literature. Social Exclusion Unit of UK Government (2003) *after* Poole (2003) defines accessibility as “the ability of people to get to key services at reasonable cost, in reasonable time and with reasonable ease’. Meanwhile Goodall (1987) *after* Farrow and Nelson (2001) defines accessibility as ‘the ease with which a location may be reached from other locations’. (Jong and Eck, 1996) stated that a location to be accessible if the effort it takes to go to certain location is acceptable to the target group, so in this case the concept of accessibility includes not only the transport link between origin and destination and the ability for travelling by the target group, but also the characteristics of the destination and the objective of the trip.

Poole (2003) stated that there are four component for determining the accessibility: (1) a transport component reflecting the effort between an origin and destination location, (2) a landuse component reflecting the spatial distribution of supplied activities at destinations and demand for those activities, (3) a temporal component which is reflecting the time restrictions of individuals and destinations, and (4) an individual component, reflecting the needs, abilities and opportunities of individuals.

HSRC (2008) *after* Widyaningrum (2009) stated that accessibility modeling includes not only calculating access, but also the calculation of capacity constraint per-location, distance to closest facility, improved access for the population and various optimum location. Poole (2003) noted that accessibility measures can be considered with reference to opportunity and deterrence function. Opportunities can be considered in terms of those available to an individual (origin accessibility), or the catchment areas for a specific destination. Deterrence functions aim to represent the cost of reaching destinations in term of distance or time.

In this research, accessibility modeling tried to calculate the capacity and service area of destination location. Service area defines as a region that encompasses all accessible streets especially streets that are within a specified impedance. In this case, travel time is assigned as cost attribute of the impedance.

2.2.3 Evacuation Model

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 and analytical approaches. Further, many researcher try to combine both approaches. Figure 2.10 below describes the different concept of both approaches.

Silva *et.al.* explained that (2003) 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 provides 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 (house, workplace, schools, hospitals, etc), hazard location, etc., and directional elements such as travelling vehicle, 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, Murray, Figuerosa, and Barber (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.

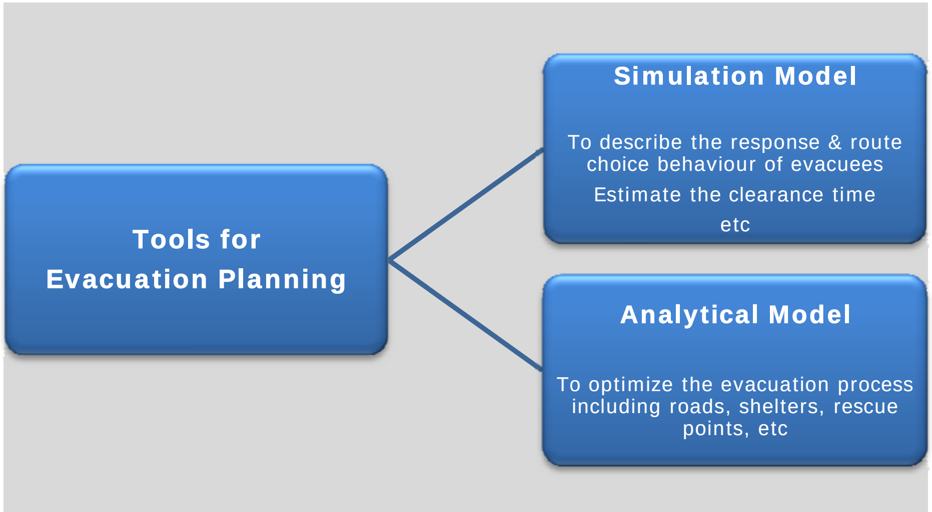


Figure 2. 10. Different Approach of Evacuation planning studies (Huang *et al.*, 2005)

Santos and Aquirre (2004) declared in detailed that there are four types of simulation models in building evacuation including :

(1) Flow based (for example EVACNET4 and EGRESSPRO). This model employs a flow-based approach which enables the user to construct a simulated physical environment *as a network of nodes*. It is a completed network model which can determine an optimal plan to evacuate the building in a "minimum" amount of time.
(2) Cellular automata (for example EGRESS, Pathfinder, TIMTEX). This program discrete space and model the node density in individual floor cell. Evacuees are modeled as individual on a grid. It is capable to execute comparative analysis of how the flow of toxic substances inhibits the timing and rate of egress.
(3) Agent-based (for example SIMULEX, EXIT89, GridFlow). This model fixes certain set of attributes to each person, so that the walking speed of each person is assessed independently of the average density of a group in a defined area.
(4) Activity-based models that incorporate social scientific processes, ie. FIRESCAP, EXODUS, and the Multi-Agent Simulation for Crisis Management (MASCM). The programs include a set of social physiological attributes and characteristics for each agent such as age, name, sex, breathing rate, running speed, dead/alive, among others. The agents also possess a fixed degree of familiarity with the building, agility, and patience.

Evacuation modeling applied to large areas has involved the use of similar approaches. Southworth (1991), Kumar *et. al.,* (1996) and Church and Sexton (2002) described in their paper that most researchers now have developed a computer simulation model and have attempted to estimate evacuation times, notable among them being I-DYNEV, IEMIS/I-DYNEV, EVAS, MASSVAC, etc. These models focus on disasters that affect wide area such as nuclear discharge, chemical release, dam failure flooding and have used car as transportation mode in their evacuation.

2.2.4 Evacuation Route Model

Evacuation routes correspond to spatio-temporal networks. For example in transportation networks, these networks contain a specific collection of points (nodes) with location information, line segments (edges) connecting the points and time-varying attributes attached to elements. The characteristic of these networks is dynamic, in other words the network topology changes with time (e.g. in a road network it might be possible for some road segments to be unavailable due to road repair or damage caused by disasters). New routing algorithms must be developed to address dynamically changing networks (Bustamante and Wolff, 2007).

Kim *et.al.,* (2007) explained that evacuation route planning will find out routes to minimize the time to evacuate the vulnerable population. It is a main component of efforts by civil authorities to prepare for both natural and man-made disaster. To support the evacuation and aid efforts, the planning for the effective evacuation route is required.

Defining the effective evacuation route from a given point should consider that the fastest path sometimes is not the shortest path. Hence, in calculating the distance between two points (i.e. between source and destination) we have to consider not only the geometric distance but also the cost in term of time, energy, etc. which are needed to move along the given path (Laghi, M. *et al.*, 2007). Evacuation route identification should always consider the travel component, such as travel path, travel time and travel impedance. Travel paths refer to the existing roads and also virtual roads or passable paths (for example in public park or green belt). Travel time refers to the available time for evacuation and travel impedance means the evacuees' speed or walking speed of people.

Southworth (1991) noted that route selection models are applied to estimate the movement of evacuees over a transportation network, over time. They are also the fundamental tool around which to develop plans for the utilization of road space during an emergency. Route selection models are principal to get a good estimation of just how long it will take a population to safe areas, and which roads to use. Based on time it takes to evacuate all communities from an area, the evacuation must begin as early as possible, to stagger the timing of community movement or in case of shutting down of traffic, to propose other forms of protective action.

Bustamante and Wolf (2007) divided evacuation route planners into two categories, the micro-scale based planners that assign traffic to a road network and simulate traffic at a high level of fidelity (e. g. AIMSUN, PARAMICS, VISSIM, DYNASMART), and the meso-scale planners, that use a lower level of fidelity route planning approach, but have a more efficient runtime (Figure 2.11).

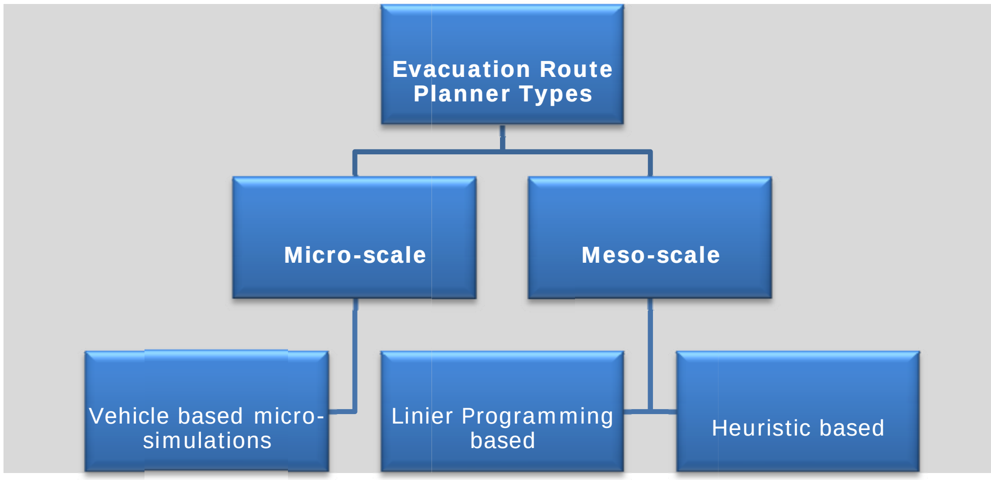


Figure 2. 11. Types of Evacuation Route Planners (Bustamante and Wolff, 2007)

In addition, Southworth (1991) explained the characteristics of selected evacuation models, as can be seen in following table (Table 2.5). The more detailed explanation of each model can be found in that reference.

Table 2. 6. The Characteristics of Selected Evacuation Models

Model	**Type of Traffic Stream Simulation**			**Type of Traffic Assignment**		
	Micro	**Meso**	**Macro**	**Simple**	**Static**	**Dynamic**
CLEAR	X			X		
DYNEV		X			X	
DYMOD			X			X
EVACD			X			X
MASSVAC			X			X
NETVAC			X			X
NETSIM*	X			X		
SNEM	X			X		
TWEEDIE ET AL	X			X		
UTPS-BASED**			X		X	

* *NETSIM is a micro-traffic simulation program not a full evacuation model*
** *UTPS is a transportation planning package, not an evacuation modeling package*
Source : Southworth (1991)

2.3 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;

1) Horizontal evacuation; people move from the hazard zones to the safer areas in a distant locations or higher ground such as hills.
2) Vertical evacuation; this method will evacuate people to the higher floors of a tsunami-resistant building nearby.

The following figure (Figure 2.12) 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.

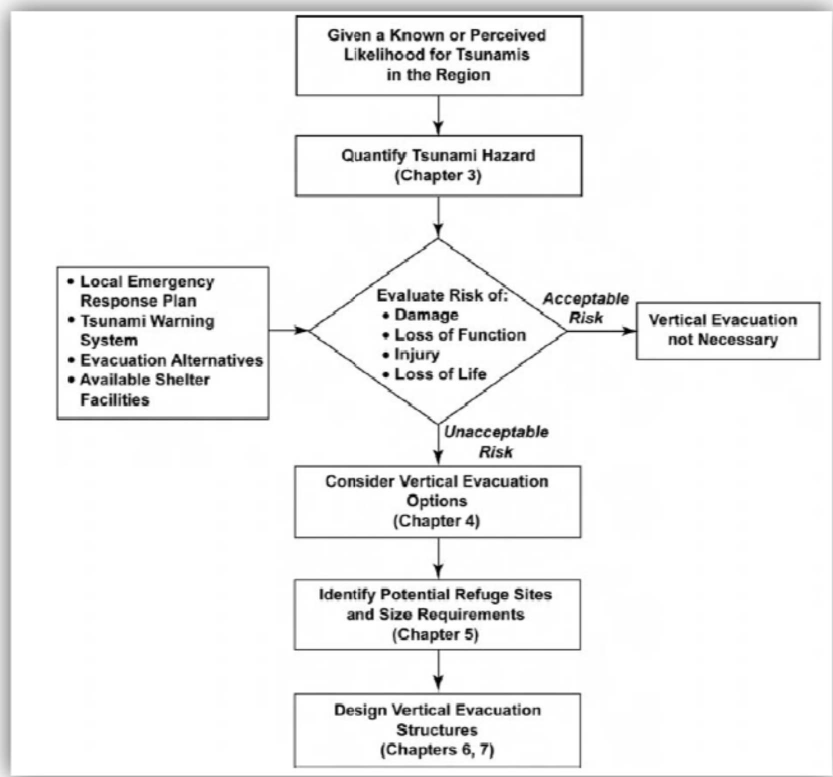


Figure 2. 12. Decision-making and Design Process for Vertical Evacuation Structure (FEMA, 2008b)

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:

1) 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 (Figure 2.13). 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.

2) 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.

3) 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.

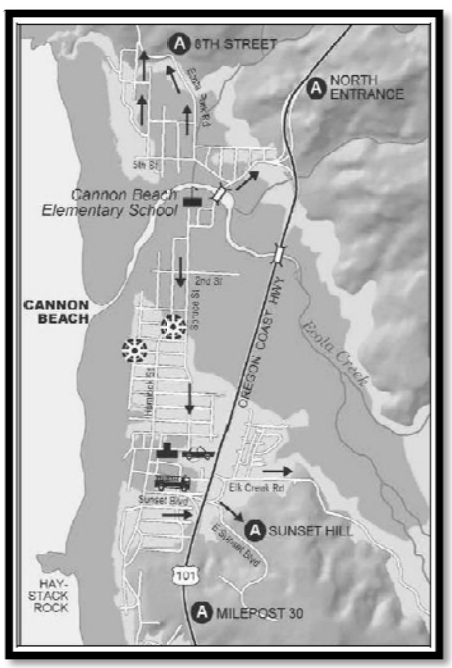


Figure 2. 13. Map of Horizontal Evacuation Shows the Inundation Zone and Evacuation Route (Raskin et al., 2009)

4) 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.
(ADPC, 2008)

For those methods of evacuation (Table 2.6), an effective warning systems and public information, notification, and training program are critical to the success of all evacuation measures.

Table 2. 7. 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.

The following illustrations are models which are incorporated GIS and simulation package in conducting evacuation models of tsunami. Evacuation simulation models for tsunami hazardous area aims as disaster risk reduction by providing information associated with safer routes to evacuate and time needed. This tsunami evacuation modeling incorporates utilization of GIS approach and run the simulation under many assumptions, such as the community evacuee themselves on foot at the uniform speed, evacuees live concentrated at the centre of hexagonal tessellation, therefore center of population is a point, each road is bi-directional and take the same time to move on both direction, etc.

a. Evacuation Routes Tools ArcGIS® toolbox

   This toolbox in ArcGIS is tsunami evacuation model developed by CRATER (Coastal Risk Analysis of Tsunamis and Environmental Remediation) and ADPC (Asian Disaster Preparedness Center) (CRATER, 2007a).

   This project developed a model performing minor cost path calculation to reach an assembly point. It gives the population a mechanism to find the shortest (not simply in terms of physical distance) and safer evacuation route. Assembly points were analyzed by calculating the maximum necessary time to reach them. The model is utilized ArcGIS algorithm such as cost function, cost distance on the spatial analysis process of raster datasets. Tools used to identify the shortest way option include spatial analysis, hydrological models and tri-dimensional analysis (Laghi, Mario *et al.*, 2007b; Widyaningrum, 2009)

Generally speaking, this model gives value to each cell describing evacuation speed, and the cost weighted value will be obtained, defined as the time needed to walk from each cell to the 'best' shelter.

Figure 2. 14. Evacuation Map of Kamala Beach generated by using Evacuation Routes Tools ArcGIS® toolbox

b. Flowmap

This software was developed at the Faculty of Geosciences of the Utrecht University in the Netherlands. This software packages can analyze and display interaction of flow data. For instance, commuting and migration flows, accessibility analysis, network analysis and interaction modeling (Universiteit Utrecht, 2009). Flowmap works with three kinds of data, i.e. maps, flow data and distance table. Maps consist of base map, map of point of origins and map of point of destinations. Flow data supply observed interaction like the size of evacuee flows from particular origin to destination, whereas distance tables is a matrix which have distances for all combinations of interaction between origin and destination (Breukelman *et al.*, 2009).

Strictly speaking, this software works with special type of data in the sense that there are two different geographic locations connected to each data item. The flow data itself can be people (e.g. commuters, shoppers, hospital visitors), goods, usage of agricultural services or telecommunication and so on. Budiarjo (2006) used this software package for location-allocation modeling to determine suitable optimized location of ESB in Meulaboh. In this case, map of point of origins represents source of evacuees and map of point of destinations represents shelter buildings or assembly points.

2.4 ArcGIS Network Analyst

ESRI (2007) stated that a network is a system of interconnections of elements, such as lines connecting points. Highways connecting to cities, streets interconnected to each other at street intersections, and sewer and water lines that connect to houses are some examples of networks. To travel over the network, connectivity is necessary. In addition, network elements like lines and points must be linked so that navigation can be conducted on the network. These elements have properties that control navigation as well.

There are two types of network modeling i.e transportation and utility network modeling. Transportation networks are indirect networks meaning that even though an edge (lines) on a network may have a direction allocated to it, the agent (person or object being transported) is free to decide the direction, speed and destination of traversal. Restrictions imposed on a network are guidelines for agents to follow such as one-way streets or no U-turn allowed, etc. These networks are modeled using network dataset.

Whereas, utility network is directed, meaning that the agent (water, sewage, or electricity) moves along the network based upon certain rules built into the network. The path is established in advance. It can be changed by the engineer, but not by the agent by opening some valves and closing others to change the direction of the network. Utility networks are modeled using geometric networks.

ArcGIS Network Analyst software incorporates an advanced connectivity model to accurately characterize real-world multimodal networks. This extension provides network-based spatial analysis including routing, travel directions, closest facility, service area, origin-destination cost matrix, and vehicle routing problem-solving analysis (Lynch, 2009).

This extension allows for dynamically modeling realistic network condition including turn restrictions, speed limits, height restrictions, and traffic conditions, at different times of the day. Network Analyst mainly allows users to perform network analysis for all kinds of applications, such as transportation planning, finding the best route across city, finding the closest emergency facility, identifying a service area around a location, or servicing a set of orders with a fleet or vehicle (ESRI, 2008).

Network Analyst can be very useful in a variety of sections, as can be described below (ESRI, 2006) after (Karadimas *et al.*, 2007):

1. Business, scheduling deliveries and installations while including time window restrictions, or calculating drive time to determine customer base, taking into account rush hour versus midday traffic volumes.
2. Education, generating school bus routes honoring curb approach and no U-turn rules.
3. Environmental Health, determining effective routes for county health inspectors.
4. Public Safety, routing emergency response crews to incidents, or calculating drive time for first responder planning.
5. Public Works, determining the optimal route for point-to-point pickups of massive trash items or routing of repair crews.
6. Retail, finding the closest store based on a customer's location including the ability to return the closest ranked by distance.
7. Transportation, calculating accessibility for mass transit systems by using a complex network dataset.

Recently, Network Analyst is also useful for evacuation modeling. It helps evacuation planners to find out the most effective route to evacuate communities to a safer place and to determine the most suitable location for additional shelters by considering the accessibility of location and travel time.

There are five kinds of network analysis layers, as follows (ESRI, 2008)

1. Finding the Best Route
   This extension can find efficient travel routes from one location to another or the best way to visit several locations. Strictly speaking, it can be concluded that any valid network cost attributes can be used as the impedance when determining the best route.
2. Finding the Closest Facility
   This command allows us to determine which facility or vehicle is closest, for instance the closest hospital to accident, the closest store to customer's address, the closest school to residential houses, etc. Further, this command also can give the best route to the facility.
3. Finding Service Area
   A network service area is a region that covers all accessible streets that lie within a particular impedance. User can generate service areas around a site on a network. This command can provide information of how accessible an area is. It is measured in term of travel time, distance, or any other impedance on the network. For this research, this tool can find the area which can be reached within certain evacuation time from source of population. In addition this command also can fine the best route from source of population to the specified shelter.
4. Creating an OD cost matrix
   OD cost matrix is a table that contains the network impedance from each origin to each destination. Based on the minimum network impedance required to travel, this command ranks the destinations that each origin connects to in ascending order. The OD cost matrix solver is designed for quickly solving large problems and it doesn't contain information that can be used to generate true shapes of routes and driving directions. These kinds of information can be generated using the closest facility solver. The best network path is determined for each pair (origin-destination), and the cost is stored in the attribute table of the output lines, which are straight lines. Generally speaking, this tool allows us to generate travel direction.
5. Solving a vehicle routing problem
   This tool tries to solve such vehicle routing problem. The objectives are to give a high level of customer service by honoring any time windows while keeping the overall operating and investment cost for each route as low as possible. The constraints are to complete the routes with available resources and within the time limits imposed by driver work shifts, driving speeds and customer commitments.

Network Analyst software determines the best route by using an algorithm which finds the shortest path, developed by Edgar Dijkstra (1959). Dijkstra's Algorithm is used to calculate the shortest path from a starting node to all other nodes of a graph (directed or undirected). The algorithm strikes a balance by calculating a path which is close to the optimal path that is computationally manageable (Olivera 2002) after (Karadimas et al., 2007).

The following description illustrates the step for each iteration of the algorithm. The initial node is the starting point where we start to move. Distance of a node Y will be the distance from the initial node to it. Djikstra' algorithm will assign some initial distance values and will try to improve them step-by-step, as can be seen Figure 2.14. The shortest path from node 1 to the other nodes can be found by tracing back predecessors (bold arrows), while the path's cost is noted above the node. Figure 2.14 is an example of Dijkstra's algorithm (Orlin, 2003) after (Karadimas *et al.*, 2007) which can be illustrated as follows.

1. Assign to every node a distance value. Set it to zero for our initial node and to infinity for all other nodes.
2. Mark all nodes as unvisited. Set initial node as current.
3. For current node, consider all its unvisited neighbors and calculate their distance (from the initial node).
4. If this distance is less than the previously recorded distance (infinity in the beginning, zero for the initial node), overwrite the distance.
5. When we are done considering all neighbors of the current node, mark it as visited. A visited node will not be checked ever again; its distance recorded now is final and minimal.
6. Set the unvisited node with the smallest distance (from the initial node) as the next "current node" and continue from step 3.

Each node is processed exactly once according to an order that is being specified above. Node 1 (i.e. starting node) is processed first. A record of the nodes that were processed is kept, called it as Queue (Table 2.7). So initially Queue=. When node k is processed the following task is performed: If the path's cost from the starting node to j could be improved including the vertex (k,j) in the path then, an update follows both of Distance[j] with the new cost and Predecessors[j] with k, where j is any of the unprocessed nodes and Distance[] is the path's cost from the origin node to j. The next node to be processed is the one with the minimum Distance[]. In other words it is the nearest to the origin node among all the nodes that are yet to be processed. The shortest route is found by tracing back predecessors.

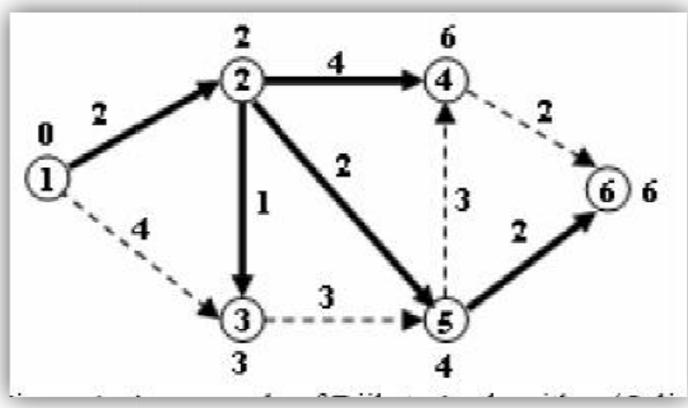


Figure 2. 15. An Example of Djikstra's Algoritm (Orlin, 2003) after (Karadimas *et al.*, 2007)

Table 2. 8. A Record (Queue) with All Processed Nodes

		Distance						Predecessors				
Queue	**Next Node**	**1**	**2**	**3**	**4**	**5**	**6**	**2**	**3**	**4**	**5**	**6**
1	2	-	2	4	∞	∞	∞					
1,2	3	-	-	3	6	4	∞		2	2	2	
1,2,3	5	-	-	-	6	4	∞					
1,2,3,5	4	-	-	-	6	-	6					5
1,2,3,5,4	6	-	-	-	-	-	6					
1,2,3,4,5,6	-	-	-	-	-	-	-					

Source : (Karadimas *et al.*, 2007)

2.5 Network Dataset

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 improved road network obtained from the previous stage. These include setting the travel impedance for each segment, defining directions and one-way streets, and also managing restricted turns. This network datasets should indicate that the corresponding roads connect to each other. They must also have poly-line geometry in which the line features connect to other line features at coincident endpoints or at all coincident vertices (ESRI, 2005).

1. Travel Impedance

The impedance represents the cost of travelling over the link or the measure of resistance to movement of people through the link. This travel impedance can be expressed in term of distance, time, fuel consumption, cost, etc. (ESRI, 2005). In vertical evacuation simulation, the impedance is expressed in time since the evacuation is strongly related with the limited evacuation time.

For this research, the travel impedance is expresses by time that it takes to travel on a certain road based on the speed along the road. It is assumed that the evacuation process is done by walking, since mass evacuation on-foot very often is the only means for community to quickly escape from sudden natural disaster. It is also to overcome the problem dealing with the shutting down of roads and transport system.

The speed of walking which is used in this research is from Institute of Fire Safety and Disaster Preparedness - Japan (Sugimoto et al., 2003). The walking velocity of a group of elderly people is 0.751 m/sec which is the slowest evacuee speed. It is assumed that if the evacuees with the slowest speed can reach the evacuation destination, other evacuees that move faster can reach the ESB consequently.

In building the network, different value was given to each network segments especially for sea-ward and inland-ward direction. For inland-ward direction, the time needed to travel each network was assigned as 'segment length/0.751 m/sec' (in seconds). It means that in time of evacuation, people will move away from the coastal areas to the northwest of the city. The same values were given to the network that are more or less parallel to the shorelines or where people tend to move to both end segment directions. Meanwhile, to forbid people to go to sea-ward direction, the negative value was given to the network.

2. Restriction

As mentioned before, the network datasets have rules about how objects travel through them. Directions and turns can be set to create an appropriate flow of network. Turns hold information on which turns are allowed or not, and whether there is any impedance when using a turn. In order to set directions, other attribute called one-way or two-way streets are needed.

3. Evacuation Time

Knowing the evacuation time is necessary in order to provide a tool for pre-planning and also intended for decision making. Dotson and Jones (2005) stated that evacuation tsunami estimation can identify challenges to efficient evacuation which allows mitigation measures to be pre-planned.

There five main steps to creating a network datasets, as follows (ESRI, 2008):

1. Preparing the feature dataset and sources
   To arrange all feature classes participating as sources in one feature datasets.

2. Preparing the sources for appropriate roles inside the network dataset.
   To add field attributes that represent impedance values i.e. distance, travel time, and so on. It is better to name the attributes based on the impedance unit.
   a) For example, if the impedance is in time unit so give MINUTES as the name of the field attribute. If the impedance values are different based on direction of travel, the field attributes are then split into two and the names can be FT_Minutes or TF_Minutes (FT refers to From To and vice versa, it is based on the direction of digitizing).

   b) If one-way street is include as a role, the edge sources should have a field specifying one-way street information, and the name of field attribute can be 'One_Way' or 'Oneway'.

3. Preparing turn feature classes and adding turn information.
   It contains fields containing information that will be used in the network attributes, such as turn impedances. For example how much time needed to turn in a certain location, or turn restriction for certain vehicle to pass.

4. Create the network dataset
   It will create network dataset by naming the network, identifying the network sources, setting up the connectivity, identifying elevation data, etc.

5. Build the network dataset.
   The process includes creating network elements, establishing connectivity, and assigning values to the defined attributes.

2.6 Evacuation Shelter Building

FEMA (2008b) defined a vertical evacuation from tsunami as a building or earthen mound that has sufficient height to elevate evacuees above the level of tsunami inundation, and is designed and constructed with the strength and resiliency needed to resist the effects of tsunami waves.

In some location, higher ground may not exist or local tsunami make it not possible for community to evacuate to a distant location due to short warning time. Thus, a probable solution is vertical evacuation into the upper level of buildings or structures design to resist the effects of tsunami (FEMA, 2008b).

There are many characteristic of buildings designed required for a buildings to be allocated as evacuation shelter building. Mostly, these characteristics associate with building performance regarding to evacuation process, as follows.

1) Structure

The buildings for ESBs should be earthquake and tsunami-resistant. It is expected that those buildings could survive after tsunami occurrence. Structural system selection and configuration (from foundation to roof framing) will determine the strength of those buildings to withstand anticipated tsunami and earthquakes.

FEMA (FEMA, 2008b; 2008c) stated that the following structural attributes that have proofed good behaviour in past tsunami include: (a) strong systems with reserve capacity to resist extreme forces; (b) open systems that allow water to flow through with minimal resistance; (c) ductile systems that resist extreme forces without failure; and (4) redundant systems that can experience partial failure without progressive collapse.

Systems showing these attributes include reinforced concrete and steel moment frame system, and reinforced concrete shear wall systems, as can be seen in the figure below (FEMA, 2008b; 2008c).

2) Evacuation floor

In ESBs, the floor elevation should be higher than the wave height. Usually, the building is multi-storey in which people can evacuate to the first or second floor or to other designated upper floor. The flat concrete roof of a building could also be an evacuation area.

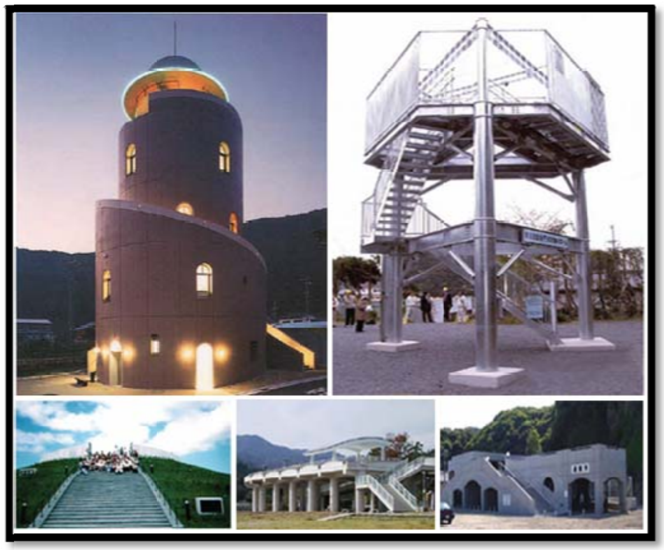


Figure 2. 16. Vertical Evacuation Structure, examples from Japan (FEMA, 2008b; 2008c)

3) Design Function
Since tsunami have long period to be occurred, there is no such buildings which only function as ESBs. In addition to the reason is that for efficiency in urban space and cost. The alternative building for evacuation purposes mainly are public facilities or public service oriented function, multi-storey building, reserve space for additional capacity, well planned and have a good construction quality. Figure 2.16 shows many examples of evacuation shelter buildings for tsunami, mostly from Japan. These buildings could be mosque, school, parliament building, government office, market, shopping centre, convention centre, sport hall, hotel, and parking building (FEMA, 2008b).

4) Design and Capacity
Sufficient space is needed for ESBs so that they can load more people or evacuees. FEMA (2008b) stated that, the recommended minimum square footage per occupant for a tsunami refuge is 10 square feet per person. It is equal to 0.93 square meters per person and it is supported by space requirement given by Planning Agency of Indonesia (BAPPENAS), which stated for evacuation purposes the design of ESB must designate a place which designate space of 1 m^2/person (BAPPENAS, 2005). Further, ARC (2002) for hurricane shelter stated that on a short-term basis, shelter requirements should be determined no less than 15 square feet per person. Enough space must be set aside for registration, health services, and safety and fire considerations.

5) Horizontal accessibility
ESBs structures should be located such that all persons designated to take refuge can reach the structure within the time available between tsunami warning and tsunami inundation(FEMA, 2008b).

6) Vertical accessibility
ESB must have an adequate stairs, or ramp which are designed to meet the building safety requirement. It is necessary to consider the width of the stairs to support the movement of people for evacuation.

2.7 Hexagonal Tessellation

Tessellation, according to Laurini and Thompson (1992) is defined as sets of connected discrete two-dimensional units (Figure 2.16). This cellular decomposition implies that every point in space is assigned to only one cell. An irregular tessellation is an extending configuration of polygons of polyhedral of varied shape and size.

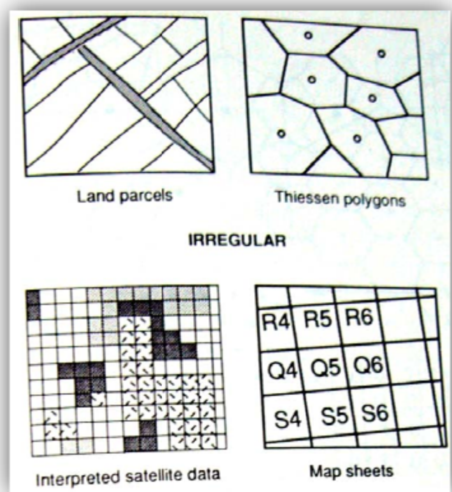


Figure 2. 17. Regular and Irregular Tessellation Source: Laurini and Thompson (1992)

A tessellation provides a way to deal with the occupancy of space, in contrast to dealing with identifiable entities like lakes or towns. However, some person made phenomena occurs as tessellation, for instance land ownership parcels. Irregular tessellation are used in areas such as, zonal for social, economic and demographic data, administrative or political unit, surface modeling triangles, etc. Whereas regular tessellations are encountered in image data remote sensing, data compilation from maps by grid squares, organization of map libraries, etc (Laurini and Thompson, 1992).

The basic spatial units of a tessellation can vary in size, shape, orientation and spacing. The basic unit may vary in size for a given theme for a given scale. Regular tessellations with variable size units for one theme have to be produced from the smallest scale by subdivision, as is seen in the process of creating quad-trees by hierarchical decomposition. Tessellation is not only to be seen as spatial units for recording data, but also as devices for facilitating access to databases for continuous space.

Regular grids or lattices are frequently used to study ecosystems, for observations, experiments and simulations and are frequently used by ecologists in various ways. Regular patterns are the most efficient in several respects for surveys, sampling and experimental planting arrangements (Olea, 1984; Dale, 1998) after (Birch *et al.*, 2007). Further Jenness (2009) stated that researchers and land managers often require a way to systematically divide the landscape into equal-sized portions.

Breaking up the landscape this way simplifies monitoring plans, and is an essential step in developing systematic sampling design.

For this research, the evacuation model is started from the concentration of evacuees. By using Network Analyst, both shelter destination and center of evacuee were expressed in term of point. From building map we can see that there were 3,937 building blocks represented the residential of evacuees. Due to the time constraint, the author tried to make the simplification for the model. The population distribution will be systematically divided into equal-sized portion by using tessellation or grid.

For this purpose hexagonal tessellation was used because of several reasons. Hexagon shape has a shorter perimeter than a square of equal area, which potentially reduces bias due to edge effects (Krebs, 1989) after (Birch *et al.*, 2007). Further, it is said that the hexagon tessellation is attractive because it minimises spatial distortion and, if constructed on an equal-area map projection, provides an equal-area sample. Furthermore, hexagonal tessellation is suitable for modeling which incorporate connectivity and movement paths.

To generate the hexagonal tessellation over the study area, an extension of repeating shape for ArcGIS was used (Jenness, 2009). This tool generates array of repeating shapes over a user-specified area. These shapes can be hexagon, squares, triangles, circle or points and they can be generated with any directional of the display. Shapes can be generated over all selected records of a feature theme, over the entire rectangular extent of a theme, over the rectangular extent of all themes in the view, or over the visual extent of the display.

2.8 Speed of Evacuees

Based on Guide Book for Tsunami Preparedness in Local Hazard Mitigation Planning from Government of Japan, Ventura County and IOC (NLA *et al.*, 1998; VC OES, 2006; IOC, 2008c), to guarantee a safe and smooth evacuation, local hazard programs generally forbid residents from evacuating by personal vehicles during at any type of disaster. During tsunami emergency, time is limited and escaping vehicles not only obstruct the roads, they pose a threat to life.

For that reason, for local tsunami, the residents of the inundation area will be encouraged to walk to safe areas. The majority of residents should be able to move to high ground or artificial high ground on foot in less than one hour (VC OES, 2006).

Actually, for distant tsunami, there may be sufficient time to escape by vehicles, thus it is not necessary to prohibit it. Even during a local tsunami event, in case where roads and pedestrian evacuation routes do not intersect, prohibition of vehicle evacuation is not necessary. Further, US Department of Transportation (2007) explained in their document that in Conceptual Approaches for Managing Pedestrian Evacuation in Metropolitan Areas, it is important to designate and manage separate evacuation corridors for outbound vehicles and for pedestrians by minimize the number of points where pedestrians and vehicles are in close proximity.

Based on the explanation above, the evacuation in this research was assumed to be performed by walking. Thus the speed of evacuees in this case was the speed of walking of evacuees.

There are many research have been conducted related with the speed of walking of people. Most of them measured pedestrian speed of walking in the crosswalk or at signal intersections in urban areas (LaPlante and Kaeser, 2007). The latest research by Millazo II *et.al.,* (1999) conducted in United States stated that the speed of walking for crosswalks was 1.2 m/sec for most areas, and 1.0 m/sec for crosswalk which served large number of older pedestrian. The other research held by Knoblauch *et.al.,* (1996) indicated that younger pedestrian walking speed is 1.22 m/sec and 0.91 m/sec for older pedestrians.

Kumar (1996) for their research in Kami-furano - Hokkaido used a walking speed of 1.2 m/sec to simulate evacuation by walk, based on the result of a walking experiment undertaken during evacuation training at Kami-furano. Meanwhile, Takashi *et.al.* after (Kumar, K. *et al.*, 1996) have used 1.4 m/sec in their simulation of Kami-furano town's evacuation model.

Another research related with the speed of walking was conducted in disaster approach gave different results. The Japan Institute for Fire Safety and Disaster Preparedness (1987) *after* Sugimoto *et.al.,* (2003) gave an overview of the speed of walking in disaster evacuation as can be seen in table below.

Table 2. 9. Evacuee Walking Speed

Walking condition	Average walking speed
A person pushing a perambulator	1.070 m/s
A person with a child	1.020 m/s
A independent walking elderly person	0.948 m/s
A group of walking elderly people	0.751 m/s

Source: Institute for Fire Safety & Disaster Preparedness (1987) after Sugimoto et.al., (2003)

National Land Agency of Japan (1998) suggested that the time required to evacuate is set at human walking speed. For safety reason, it is preferable that the speed be adjusted to the velocity of the elderly or disabled in areas where many such residents live.

Based on that, the speed of walking of evacuee which is used for the model is 0.751 m/s. It is assumed that if the evacuees with the slowest speed can reach the evacuation destination, other evacuees that move faster can reach the ESB consequently.

Chapter 3.Early Warning System

This chapter gives some explanations regarding the concept of tsunami early warning system (TEWS). Further this chapter also describes Indonesia TEWS, its condition and development in southern part of Java. In addition, description related with estimated tsunami arrival time and evacuation time are also presented.

3.1 Tsunami Early Warning System

A tsunami warning system (TWS) is a system to detect tsunami and to announce warning to prevent loss of life and property. Generally, it comprises two main components, i.e. a network of sensors to detect tsunami and a communications infrastructure to issue timely alarms to permit evacuation of coastal areas.

Tsunami warning systems are able to save lives by alerting populations of coastal areas that tsunami is moving toward their location. Tsunami warning system, principally works on the record of a series of tidal gauges placed around the ocean. The gauges will monitor the route of any tsunami through their location. If these stations detect a tsunami, warnings are issued quickly for local and regional areas likely to be affected. The warning will include the predicted tsunami arrival time at selected communities within the geographic area defined by the maximum distance the tsunami could travel (Kusky, 2003; Budiarjo, 2006). Since analyzing all of information takes time, however, these systems are most effective for areas located far from the earthquake source. For example the area located more than 750 km, or one hour away from the source region of the tsunami, but may also prove effective for saving lives in closer area (Kusky, 2003).

The effectiveness of tsunami warning system varies based on the lead time available to effect an evacuation. For distant-source tsunami, the warning system is more effective due to the available time to implement an appropriate response that can reduce or eliminate the risk (Webb, 2005). On the other hand, for local-source tsunami there is barely enough time to issue warning. There are two problems with a warning system. One is to give too many alerts in which no major wave is noticeable to the population. If a warning is given too often, people become unconcerned and take no proper action. The second danger is that once tsunami alerts are given some of the population will go down to the shore curiously to watch the wave come in (Bolt *et al.*, 1977).

Doi (2003) stated that it is also important to educate people to provide them with basic knowledge on earthquakes and tsunamis, and on the warning and information system. So, they can obtain warning and information without misunderstanding and, in turn, to use this information effectively. Because an effective evacuation is thus dependent on pre-planning and public education as there will be no time for an organized evacuation.

3.2 Indonesia TEWS

The Indonesian region areas have very complicated plate-convergences consisting of subduction, collision, back-arc thrusting and back-arc (Latief *et al.*, 2000). Given its location, the Indonesian region is prone to earthquake and tsunami disasters, especially after Aceh tsunami of December, 2004, Nias earthquake of March, 2005, Java earthquake of May, 2006 and Java tsunami of July, 2006. Additionally, earthquake in the Indian Ocean off the coast of Indonesia occur along a subduction zone – the Sunda Arc – which extends from the north western corner of Sumatra to Flores in the east of Indonesia (Figure 3.1). So if tsunamis occur in this region, the waves will hit in an extreme case and will reach the coast within 20 minutes. There is only little time remain to warn local community to evacuate. This condition will form the basis when developing the concept for the entire warning system(GITEWS, 2009).

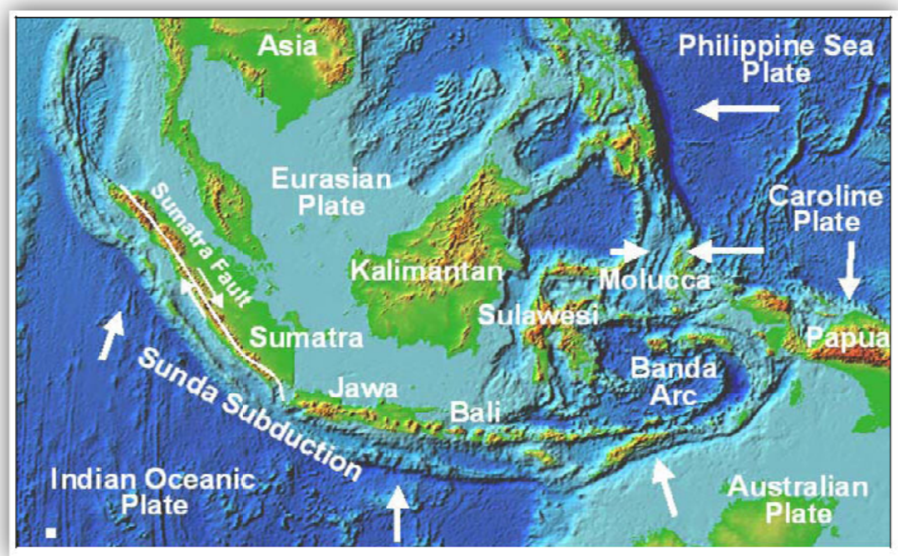


Figure 3. 1. Tectonic Pattern in Indonesia (JTIC, 2009)

Indonesian government has committed to establish the Indonesian Tsunami Early Warning System (Indonesia TEWS) and launched this system on November 2008. The development of the system has been supported by several foreign countries i.e. Germany, Japan, China, France and the United States (JTIC, 2009).

The establishment of Indonesian TEWS is under coordination of Ministry of Research and Technology (MENRISTEK). The design of this instrument was adopted from PTWC (Pacific Tsunami Warning Center), Hawaii and the JMA (Japan Meteorological Agency), Japan. To be able to alert the population quickly and reliably, the early warning system in the Indian Ocean is therefore based on a combination of several components, as can be seen in Figure 3.2 (GITEWS, 2007). The components comprise as follows:

1) The land-supported observation network
   Seismometers equipped with Global Positioning System (GPS) receivers can monitor and detect tsunamigenic earthquake near-real-time and locate the location and magnitude within few minutes.

2) The marine measuring network
The measuring instruments which are installed in, at or near the ocean, consist of: a) ocean bottom unit, i.e. pressure sensors and/or ocean bottom seismometers, b). a series of buoys equipped with GPS technology and meteorological instruments, c) tide gauges measuring water level along the coastlines and on island.
3) Modeling wave propagation
The model estimates which part of the coasts are in danger due to tsunami and estimate arrival time of the giant waves. The calculated scenarios will be used for real time f in the case of an earthquake in Sunda Trench.
4) The national warning centre
The data from all components of the TEWS are received and analyzed by warning center in Jakarta. Those responsible at national level analyses the risk and send out a warning if a tsunami has been generated, where and when it is to be expected and which height the wave might reach. This warning will be delivered via predetermined communication channels to governmental institutions, local disaster management, action forces and media.
5) Alerting the inhabitants, education and organization
As part of this "Capacity Building", the inhabitants are also educated on the dangers of tsunamis and the proper procedures, a process that begins at school and finishes with evacuation exercises.

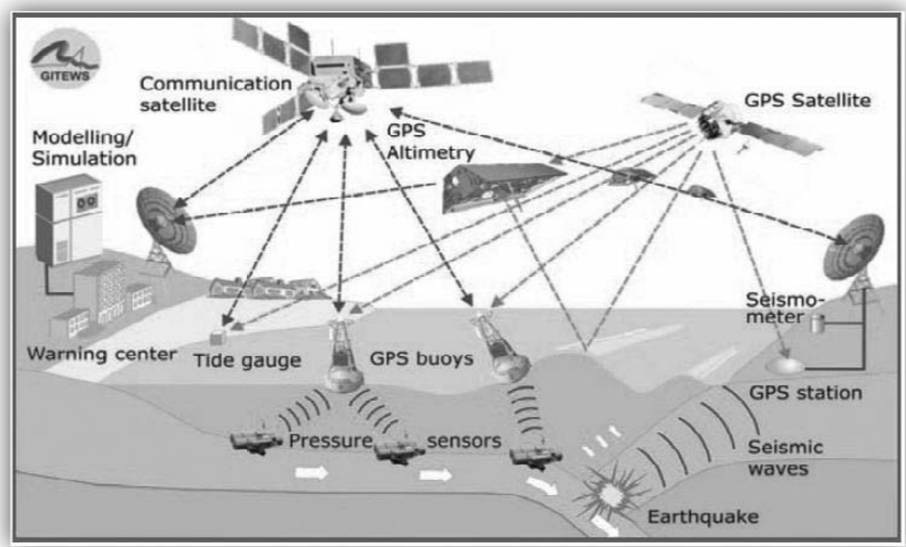


Figure 3. 2. The components of Tsunami Early Warning System in Indian Ocean (GITEWS, 2007; JTIC, 2009)

The tsunami warning should be issued within 5 minutes after the earthquake to the authorities, media, and communities at regional level (Figure 3.3). Meanwhile at national level, tsunami warning should be disseminated 10 minutes after the earthquake.

Then, the system is waiting for the confirmation of the sea level monitoring from tide gauge or buoy station. When tsunami occurrence is confirmed by sea level monitoring, then the tsunami warning dissemination will be confirmed as well. On the contrary, if the sea level does not confirmed, the cancellation of the tsunami warning should be issued.

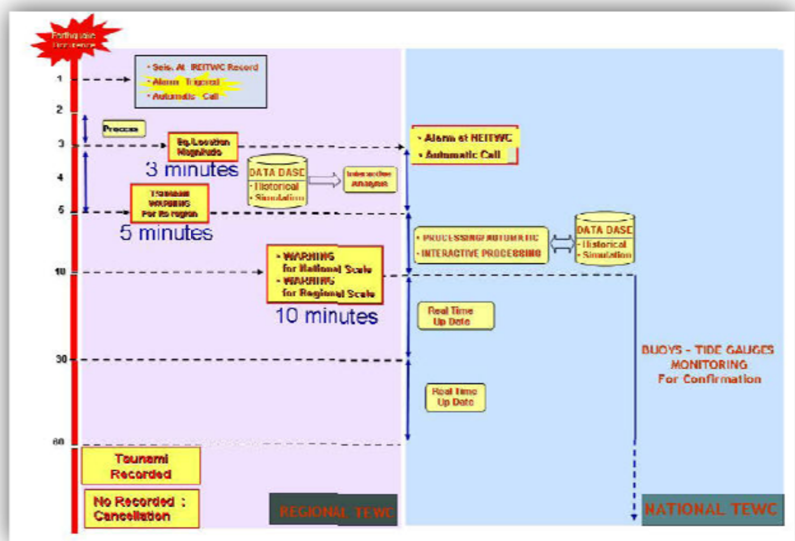


Figure 3. 3. Time Sequence of the Tsunami Warning Issuance
BMG (2006) after JTIC (2009)

According to (JTIC, 2009), the proposed Indonesian TEWS will consist of 10 regional centers and one national center. The national center will be located in Jakarta, while the regional centers will be located at Medan, Padang, Ciputat, Yogyakarta, Denpasar, Kupang, Makassar, Manado, Ambon and Jayapura. Figure 3.4 shows location of the regional centers and national center of the Indonesian TEWS.

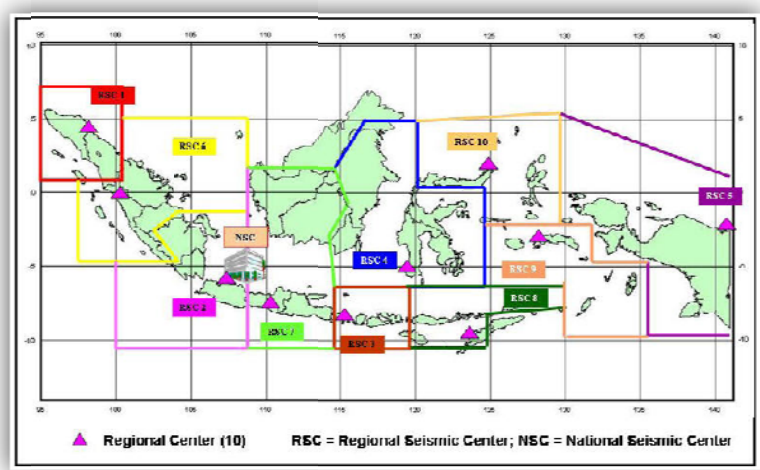


Figure 3. 4. National and Regional Centers of the Indonesian TEWS
Source : BMG (2006) after JTIC (2009)

3.3 Estimated Tsunami Arrival

The estimated time arrival of tsunami (ETA) is time required for the first tsunami wave to propagate from its source to a given point on coastline (IOC, 2008a). It is identified by the time lasting from the end of earthquake to the time of the first huge destructive wave arrived at the shore, so that travel time is considered as arrival time. Tsunami travel time will depend on the types of tsunami. It can take in minutes or even hours (Figure 3.5). The relatively long time available to conduct an appropriate response means that the risk can be reduced or eliminated with an effective warning system (Webb, 2005).

In tsunami mitigation especially for tsunami evacuation planning, the tsunami travel time is necessary to define the available time for evacuation of population in tsunami hazard zones. After an earthquake, it takes several minutes for the tsunami early warning to analyze and decide whether the earthquake will cause tsunami. If it does, then the system will needs more minutes to alarm coastal population to evacuate. The remaining time after the decision-making and alarming process is then considered as evacuation time.

The estimation of ETA in Cilacap coastal area is referred to the estimated time arrival from Global Scale Tsunami Hazard Response map produce by GITEWS project. The first wave of tsunami will reach Cilacap coastal area in 40 minutes after the end of the earthquake (Widyaningrum, 2009). Post *et.al.* (2009) explained that the calculation of representative ETA is based on a set of 761 tsunami scenarios covering the range of potentially possible tsunami events provided by the German Research Centre for Geosciences (GFZ Potsdam) within the GITEWS project.

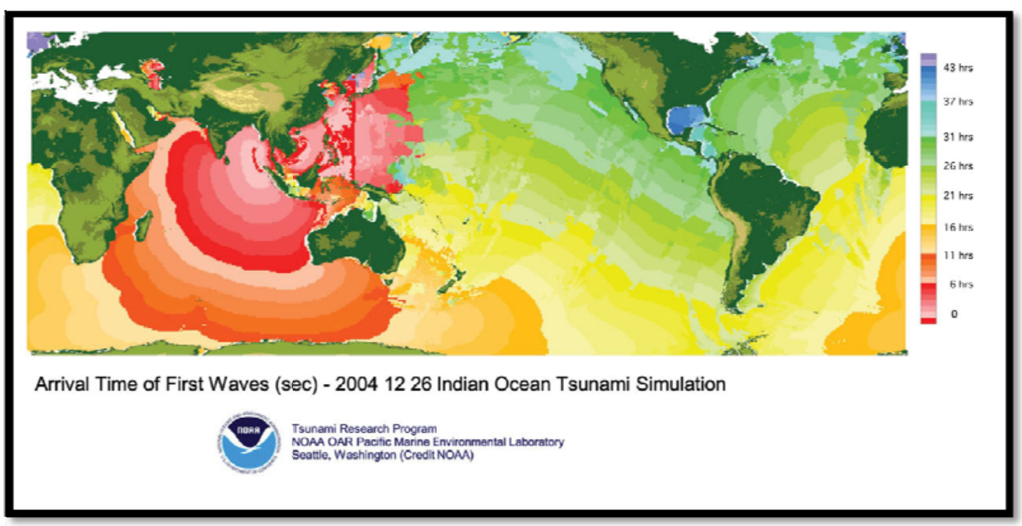


Figure 3. 5. The December 26 Tsunami Travel Time and Arrival Time Worldwide (NOAA-PMEL, 2005)

3.4 Evacuation Time

Evacuation time is the available time for evacuation. It is defined by knowing the remaining time after the issuance of tsunami warning to the arrival of tsunami waves. Charnokol and Tanaboriboon (2006) and Post *et.al.* (2009) explained that there are four components of evacuation time (Figure 3.6 and 3.7) which consists of decision time (time between event detection and official/institutional decision to warrant an evacuation), notification time (evacuation warning), preparation time or the reaction time of population (RT), and response time or actual response time (RsT) which is the time required for respondents to physically evacuate to safer area. Additionally, Post *et.al.*, (2009) stated that institutional/official decision time (IDT) and notification time (INT) will determine the time at which technical or natural warning signs (ToNW). 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 community.

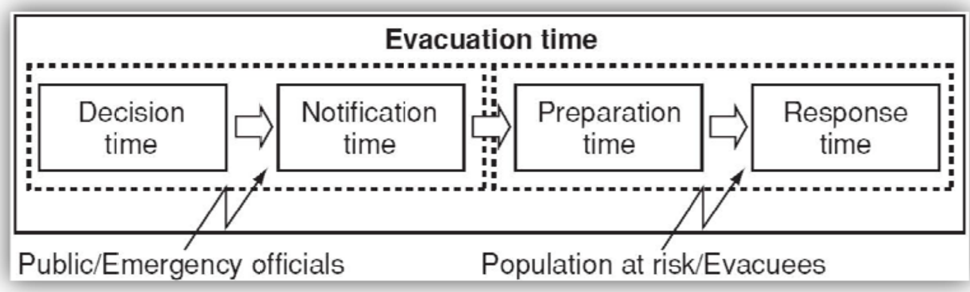


Figure 3. 6. Four Components of Evacuation Time
(Charnkol and Tanaboriboon, 2006)

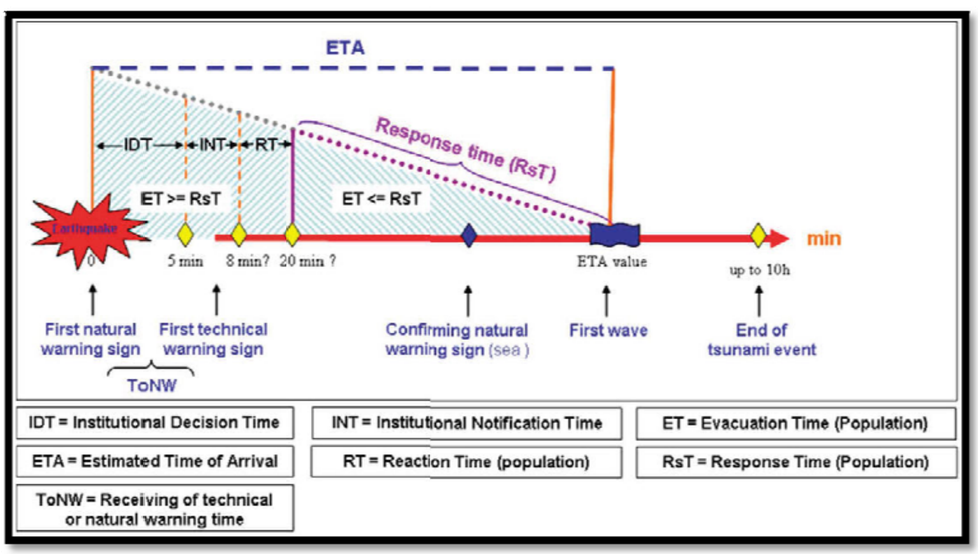


Figure 3. 7. Assigned Time Component for The Assessment of Human Response Capability To Tsunami Warning (Post *et al.*, 2009)

JTIC (2009) stated that the Indonesian Tsunami Early Warning System (INA-TEWS) is design to issue the tsunami warning at regional level within 5 minutes after the earthquake occurred in local level and 10 minutes in the national level. The same statement was also given by Post *et. al.* (2009) stated that values of a sudden sea-level retreat before tsunami hit the coast can be assumed approximately 5 – 10 minutes. Further, Post *et. al.* (2009) noted that 5 minutes can be assumed as Institutional Decision Time (IDT) and adopted 3 minutes as institutional notification time (INT). Consequently, 8 minutes is assigned in for the time of natural warning signs (ToNW). This value is taken also for this research since it represents the optimum duration needed for giving information to the local community regarding tsunami height and its arrival time.

The next unknown information is the reaction time of population (RT) when they hear warning sign. Warning system helps people at risk from forthcoming disaster. Warning system has two distribution functions, i.e. to alert the public that something unusual could happen and the second is to notify people of what that unusual event is and what to do to protect themselves. Sorensen (1993) described that the former function can be served by audio or visual signal such as siren or alarm; the later, in most cases, requires verbal communications.

Mileti and Sorensen after Sorensen (1993) noted that there are sequential process of warning response of people, such as: 1) Hearing the warning, 2) Understanding the contents of the warning message, 3) Believing the warning is credible and accurate; 4) Personalizing the warning to oneself, and 5) Responding by taking a protective action. Charnkol and Tanaboriboon (2006) noted that there is individual variation in response to warning such as the timing of response. This variation makes travel demand for evacuation is different from everyday travel needs.

Recent findings by Charnkol and Tanaboriboon (2006) suggested reaction times depending on available response times. Based on household surveys for selected regions in Thailand impacted by the tsunami 2004, they found for certain response times (RsT) of 60, 45, 30 and 15 minutes respective reaction times of 15 to 30, 13 to 25, 10 to 20 and 5 to 10 minutes (Figure 3.8).

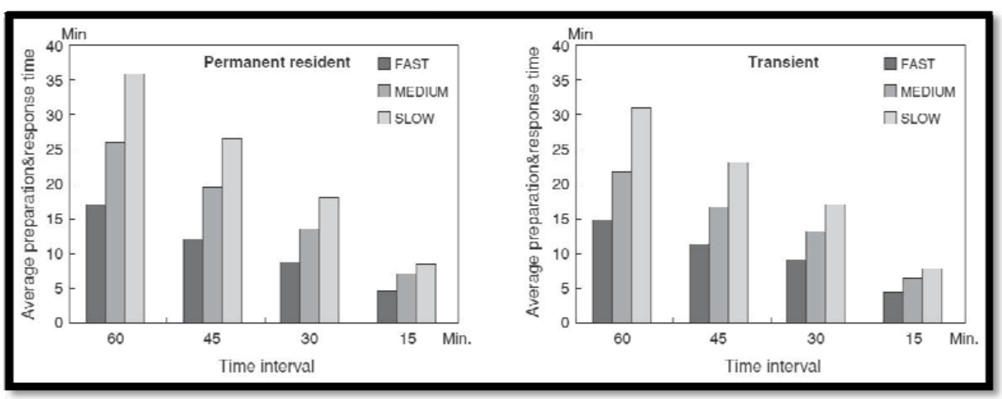


Figure 3. 8. Average Preparation (Reaction Time) and Response Time (Evacuation Time) of Permanent Residence and Transients (Charnkol and Tanaboriboon, 2006)

For this research 10 minutes was taken as time needed for people to react and 22 minutes for people to go to shelter buildings. Regarding evacuation process, this 22 minute-evacuation time was split into 17 minutes travelling on the network to shelter building and 5 minutes climbing up to the upper floor. FEMA (2008b) stated that increased travel times may need to be considered if obstructions exist, could occur, along the travel or ingress route. Unstable or poorly secured structural or architectural elements that collapse in and around the entrance, or the presence of contents associated with the non-refuge uses of a structure, could potentially impede ingress.

The evacuation time (ET) or response time of population (RsT) was then can be calculated based on the following formula modified from Post *et.al.* (2009):

RsT = ETA – ToNW - RT
ToNW = IDT + INT

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

From the formula above, the evacuation time (response time) in Cilacap coastal area was 22 minutes which was split into 17 minutes to reach the shelter buildings and 5 minutes to climb up to the upper floor (Figure 3.9).

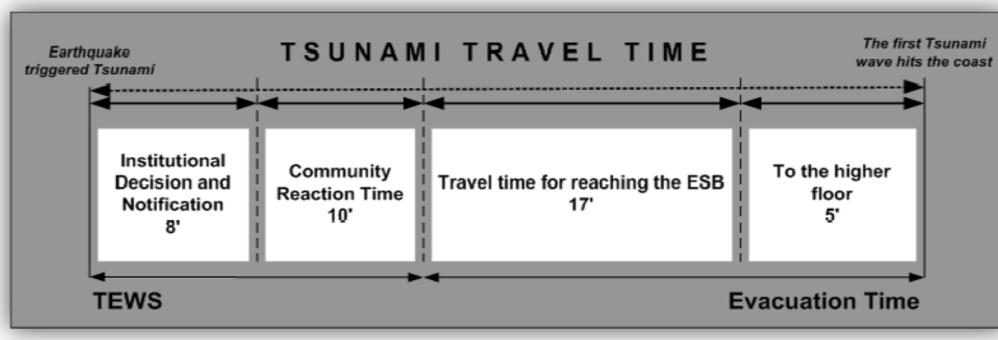


Figure 3. 9. Time Allocated for Tsunami Evacuation in Cilacap
(Charnkol and Tanaboriboon, 2006; Post *et al.*, 2009; Widyaningrum, 2009)

Chapter 4.Overview of Study Area

This chapter illustrates the research areas of the study. It explains about the overview of location including geographic and nature condition, population data and description regarding geomorphology of the areas.

This research is located in southern part of Java coastal areas which have been hit by tsunami on July,17 2006. Cilacap is the only coastal city which is located in the southern part of Java Island. The region occupies a flat area and has become one of industrial center supported by many international sea ports, fish markets and many tourist destinations. Besides occupying low-lying areas near the coast, Cilacap lies in tsunami hazard zone and it is always possible to be struck by tsunami again.

4.1 Geographic and Nature Condition

Cilacap is a regency in the southwestern part of Central Java province in Indonesia. Its capital city is Cilacap. It is a very important region for its marine fishery resources and also the site of many industrial plants, a geothermal power plant, and one of Pertamina (Indonesia's national petroleum company) processing units in Indonesia. The site has the largest production capacity, producing the most diverse kinds of products among other Pertamina units. In addition, Cilacap is also a sea port on the southern coast of the island of Java that can service shipping of reasonable tonnage. Even though Cilacap is called an industrial center, Cilacap is also an agricultural area where there exist paddy fields, mix crops and other plantations.

Cilacap regency lies from 07^{o}30’00" - 07^{o}45’20” S and 108^{o}04’30” - 109^{o}30’30” E. Administratively, it shares its border with Banyumas, Brebes, and Kuningan Regency at the northern side, with Kebumen at the eastern side, with Ciamis Regency and Banjar city at the western side (PEMKAB-Cilacap, 2010).

Cilacap city is situated between 4-12 m above sea level. It has a flat-to-gentle topography, and exposes to any tsunami sources. The terrain elevation in the lowland area is higher in the northern and north-eastern part and becomes lower in the western and south-western part. The surface water flows mainly from north-east to south-west (Sutikno, 1981; Mardiatno, 2008).

There are three main rivers in Cilacap city i.e. Donan River, Yasa River and Sabuk River. The last two rivers are located in study area #1 and #2 respectively. Many big ships, especially those from the oil companies and cement factory, and small boats sail on these rivers. Actually, Yasa river is a man made channel to support transportation from remote areas to Cilacap port which was developed in the seventeenth century (Zuhdi, 2002). Yasa river consists of brackish to salt water due to the influence of the tide. It is also used as a water-way for fishing boats. Meanwhile the Sabuk River, located in the eastern part, is a river which is functioned as an irrigation channel (Sutikno, 1981).

This city harbor is facing the Hindia Ocean and is protected by Nusa Kambangan Island. This island sheltered Cilacap from worst of the 2004 tsunami. On the other hand, the disaster took more than 600 lives and a number of destruction to coastal villages and towns such as Pangandaran, Batukaras, Ciamis and Cilacap (Lavigne et al., 2007).

4.2 Land use Type

The land use types in Cilacap city are dominated by the mixing of crops and buildings, since these areas are densely populated. The buildings comprise settlements, schools, offices, shops, industries, etc. Some villages are dominated by paddy fields, for instance in Mertasinga , and Menganti. Type of land use Cilacap city from Central Bureau of Statistics of Cilacap can be seen in the following table (Table 4.1).

Table 4. 1. Type of land use in study area

Village	Paddy fields	Settlement	Garden	Others	Total
Sidakaya	35,000	92,110	-	3,757	130,867
Tegalkamulyan	57,000	98,300	10,500	23,179	293,297
Gunung simping	64,000	264,898	-	8,841	273,739
Sidanegara	25,000	173,100	-	18,726	191,826
Mertasinga	231.20	142.43	66.00	53.37	261.40
Menganti	395,536	92,799	128,332	38,376	259,507
Total	576,559	721,349	138,898	92,932	1,149,497

Source: BPS (2007)

From the table above, it can be seen that, paddy fields are dominant agriculture in Menganti village, followed by garden. Mostly, in every village paddy fields exist even in relatively small areas. Gunung simping and Sidanegara have more settlements among others. Spatial distribution of land cover types in Cilacap city could be figure out in the following satellite image of QuickBird (Figure 4.1). The dark green smooth texture refers to paddy fields which are surrounding by many buildings. Buildings are represented by brown or orange rough texture. The grey straight lines refer to road network which connected many places. The white circle shapes (at upper left of the image) refer to petroleum company complex.

Figure 4. 1. Overview of land cover type of study area #1 from QuickBird Image
(Source: GITEWS Project)

4.3 Population data

The study area covers four sub-districts that are located in the city region. These are South Cilacap, Central Cilacap, North Cilacap, and Kesugihan. Each of this sub district has a number of villages. There are six villages includes as research locations, namely: Sidakaya, Tegal Kamulyan, Gunung Simping, Sidanegara, Mertasinga and Menganti. Among those villages, Sidakaya and Sidanegara are the densest populated areas with the density 9.198 and 9.064 square km respectively. The following table (Table 4.2) explains the population data of the study area.

Table 4. 2. Population Data of the Study Area

District	Name of village	Area (km2)	Household	Number of population	Average number of people per household	Density per km2
South Cilacap	Sidakaya	1.31	2.556	12.049	4,71	9,198
	Tegal kamulyan	2.94	3.160	13.927	4,30	4,737
Central Cilacap	Sidanegara	3.38	7.743	30.638	3,96	9,064
	Gunung Simping	2.17	3.397	14.541	4,28	6,701
North Cilacap	Mertasinga	4,93	3.788	15.493	4,09	3,077
Kesugihan	Menganti	6.55	2.598	10.002	3,85	1,527

Source : BPS (2007)

Table 4. 3. The number of population based on occupation

Name of village	Agricultural labor	Fishermen	Industrial workers	Construction workers	Government officer	Entrepreneur
Sidakaya	96	782	412	664	644	698
Tegal kamulyan	145	1,311	216	346	248	19
Sidanegara	201	177	1,425	1,299	1,740	47
Gunung Simping	131	51	671	602	932	21
Mertasinga	1,172	1,279	401	881	354	188
Menganti	1,895	226	229	242	174	12

Source : BPS (2007)

Table 4.3 shows the number of population based on their occupation. From the table, it can be seen that in Tegal kamulyan, the occupation is dominated by fisherman due to its location near shorelines. This is a fishing village. Meanwhile, Menganti is an agricultural village. Mostly, the occupation of its residents is agricultural labors. For other areas, the occupation of their residents is mixing of many occupations, such as industrial workers, construction workers and entrepreneur, etc.

4.4 Geomorphology condition

Cilacap occupied a low-lying coastal area which is ranging up to 12 meter above sea level. Cilacap has a unique geomorphology pattern of low ridges and shallow depressions parallel to the coast (see Figure 4.2). The red smooth texture refers to shallow depressions which are used for agriculture, mainly paddy fields. Meanwhile, the red rough texture refers to low ridges which are nowadays used as settlements areas.

Figure 4. 2. Overview of geomorphological pattern of low ridges and shallow depressions parallel to the coast from SPOT image (Source: Tsunarisque Project)

According to Sutikno (1981), Cilacap city was a coastal alluvium plain which can be classified into smaller landform units, as follows:

a. Sand dune units

These units are parallel to the coast with elevation approximately 7 m above sea level. Due to the exploitation of iron-rich sands, the natural forms of sand dunes which are 100 m wide are no longer existed. Sand dunes material comprise of coarse un-weathered, dark colored sands of volcanic origin.

b. Beach ridge units

Remnants of the beach ridges are now occupied by settlement. The pattern of beach ridges is parallel to the coast. The width is various from 0.2 – 1.0 km. The feature of beach ridges can only be observed in Gumilir village to the eastward region whilst in the town areas the ridges features no longer exist. The material of this location consists of sand, but with a quite fine texture compare to the rides near then ridges.

c. Lagoon unit

Lagoon units are relatively lower than ridges to form depressions. The pattern of the lagoons alternates with that of beach ridges with various width ranging from 0.2 – 3.9 km. These areas were usually function as paddy field due to its fine-textured even clay which possibly originated from weathering processes of the ridges and from the suspended loam of the Serayu River brought by irrigation channel.

d. Alluvial plains unit

These unit consists of the alluvial plain and the flood plain which was developed under the influence of Serayu and Donan river. Material in the banks of Donan River bank is clayey, whilst that in the Serayu River banks consists of sandy materials.

The geomorphology unit of Cilacap can be seen in the following figure (Figure 4.3). From figure 4.3, Mardiatno (2008) explained that the lowland area is mostly influenced by the combination of marine and fluvial processes. The landforms in Cilacap can be classified as abandoned valley, alluvial plain, backswamp, beach, coastal plain (former beach), colluvial footslope, colluvio-alluvial footslope, floodplain, karst hills, mature beachridge, mature swale, mudflat, old beachridge, old swale, saltmarsh, spit, swamp (former swale), young beachridge and young swale. According to the morphochronology, the landform developments in the lowland area are in a chronological series (from the oldest to the youngest): alluvial plain/floodplain - old beachridge/swale - mature beachridge/swale - young beachridge/swale - beach.

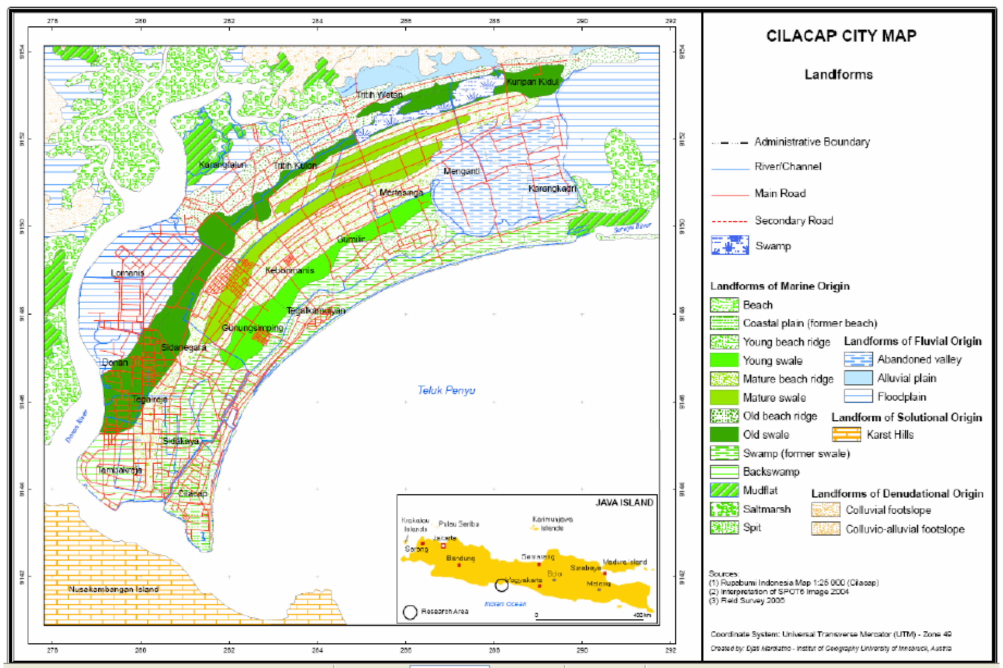


Figure 4. 3. Geomorphology condition of Cilacap
Source: Mardiatno (2008)

Chapter 5.Research Methodology

This chapter illustrates the research design of the study, data involved in the research and also method description which are conducted in the research. The description begins with the explanation related with research design, data used in this research, how to develop model inputs and ends by how to conduct the model.

5.1 Research Design

The aim of this research is to develop an evacuation planning for tsunami mitigation plan. This research tried to develop a method in determining the most effective evacuation routes using GIS tools and also the location of additional shelter building. The framework of the research can be seen in Figure 5.1.

In general, there were five parts of the studies that were conducted during the research process, as follows.

1. Identification of evacuation shelter buildings as tsunami evacuation destinations using high resolution image. Tsunami inundation zone in worst scenarios from supplied model was used as a basis in selecting the locations which require vertical tsunami evacuation.
2. Estimation of building capacity for evacuation purposes using space requirement approach and field observation.
3. Estimation of population number for day and night scenarios using population data in RW level collected using PGIS approach.
4. Establishing of road network datasets.
5. Generating evacuation model for tsunami evacuation to find location for additional shelters and finding the most effective route. Land cover map was used to check the suitability of proposed location as additional shelters.

5.2 Data Availability

The data which were used in this research consists of images, maps and demographic data. The data were collected in the preparation phase and also during fieldwork. For more detailed, the list of the data can be seen in the following table.

Table 5. 1. List of Data Used

Type	Specification	Format	Source
Quick-Bird image, 23 June 2006	60 cm	Digital	GITEWS Project
Topographic Map	1:25.000	Hardcopy	BAKOSURTANAL
Road Network	1:10.000	Digital	BAKOSURTANAL
Tsunami Model	1:9.000	Digital	Mardiatno (2008)
Population Data	Village level	Text	Statistics Board of Cilacap Regency

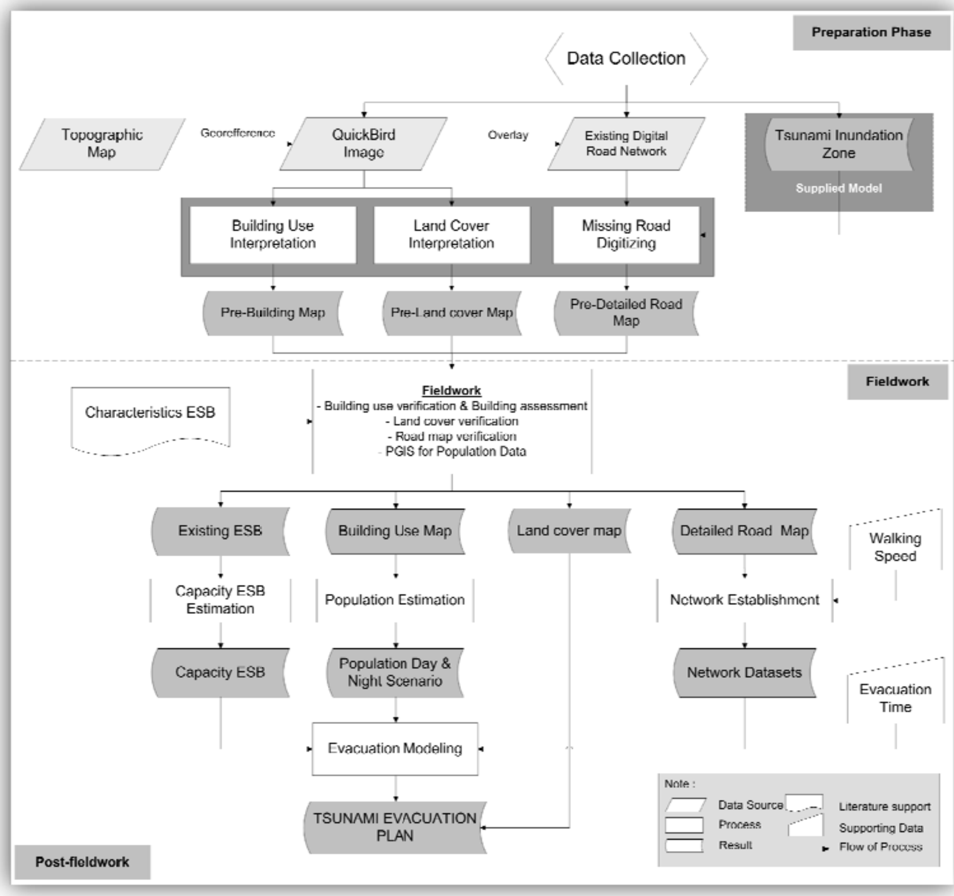


Figure 5. 1. Framework of the Research

5.3 Preparation Phase

This research began with the preparation phase comprised of such literature review through previous studies, relevant journals, books and other sources to obtain more understanding and information regarding data needs, methods and software that will be used for this research. Further, preliminary site observation and fieldwork preparation were also conducted.

Preliminary site observation was conducted for getting general overview of study areas. It helped in data preparation such as image interpretation. Before fieldwork was conducted, the sampling design was created, and pre-processing of data including image interpretation and image digitizing were also performed.

Another step which was also important was preparation of equipment, such as mobile PDA (*Personal Data Assistance*), hardcopy of maps to be checked (building map, road map, land cover map), fieldwork form, camera, voice recorder, etc.

5.3.1 Identification of Tsunami Inundation & Safe Areas

In the tsunami mitigation plan, especially for establishing evacuation zones and routes, the impact of tsunami over an area should be known. Moreover, the communities should understand the areas which are at risk, the water height and flow velocities, and also how tsunamis interact with the built and natural environment (Bernard et al., 2007).

For this purpose, tsunami inundation maps were used as a basic to derive tsunami evacuation maps since they give prediction regarding the potential inundated and safe areas. Guillande *et. al*. (2009) also stated that at local level, tsunami hazard is usually described by inundations maps providing inundation depths and extension. According to Immamura (2009) the other tsunami hazards which can be compiled on a map including arrival time, velocity, and wave force. Further, Kumar *et. al.* (2008) stated that inundation maps are depictions of coastal areas that identify regions, populations, and facilities that are at risk from tsunami attack, which could be used by emergency planners for disaster response and mitigation.

In this research, the available tsunami hazard maps were used. These maps were developed by Mardiatno (2008). Those tsunami hazard maps were derived by using TUNAMI model developed by Fumihiko Imamura from Disaster Control Research Centre (DCRC) - Tohoku University, Japan. Tsunami wave model using TUNAMI provides a comprehensive analysis of hazard. The model starts from the tsunami source (initial condition), tsunami propagation and inundation.

5.3.2 Land Cover Classification

The land cover map was developed from Quick-Bird image which was interpreted visually. It was done based on object recognition including various target identification in an image using interpretation elements. The interpretation was conducting based on local knowledge of the areas as well. The interpretation elements are the characteristic of picture used to define the interpretation keys, which supply guidance on how to identify certain object. For example, a U shape building with open field could be school because of its location near settlement (Bakker et al., 2004).

Generally, there were seven classes consist of river, ponds, paddy, road, built-up area, open area, mix crop. The processes were as follows:

1. Geometric correction of Quick-Bird image using topographic map scale 1:25.000;
2. The rectified image was then interpreted visually in ArcGIS;
3. Land cover verification during fieldwork.

5.3.3 Building Map Interpretation

The building map was extracted from 0.6 m resolution of Quick-Bird image. The visual interpretation method was used for generating the building map of the study area. In this case, professional knowledge and experience combined with the interpretation element are needed in interpreting the image. The large buildings can be identified from their rectangle shape, their size from medium to large, their tone from orange to brown (depend on roof style) and their location in relatively easy-accessed area. For example, a U shape building or L shape building with open field can be school because of its location near settlement. This visual interpretation was validated by field observation.

Buildings were classified based on their uses by knowing the characteristic of the objects in the image. For these purposes, buildings were classified into house, office, mosque, church, school, shop, hotel, sport-center, factory, and fishing port.

5.3.4 Road Network Identification

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 route itself.

The existing road network was from topographic map of BAKOSURTANAL scale 1:25.000. This data was in shape file format. The road network from topographic map is less detailed than that is needed for this research. Consequently, the more detailed road network will be 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 network more detailed.
4). Giving attributes to the road data and classified the road into five classes based on the road width, i.e. arterial road, collector road, local road, other road and pathway.

The following figures (Figure 5.2) give illustration on how to improve the road network from existing road data from topographic map.

Figure 5. 2. The process to improve the existing road network data from topographic map. The road data were overlaid with the rectified QuickBird image #(1). The blue lines refer to the road data from digital topographic map and the black lines in figure #(2) refer to the missing roads which were digitized visually in ArcGIS

5.4 Fieldwork and Data Collection

Fieldwork was conducted in three phases from July up to September 2009. In this phase, some data and information from related institutions were collected such as population data from Central Bureau of Statistics. The verification of building map, road map and land cover map were also conducted. Open interview without questionnaire was also carried out to find out more about what local people view on tsunami signs, places for evacuation, evacuation routes, etc. The main activities during fieldwork were as follows:

1. Land cover verification.
2. Building inventory and building assessment, including collecting data of occupant number.
3. Road network verification including measuring the width of the road.
4. PGIS for developing the boundary map of RW and population data (household number) per RW (Rukun Warga/neighborhood).

5.4.1 Land Cover verification

The aim of this process was to validate land cover maps which were created based on visual interpretation. The purposive sampling scheme was used to derive the accuracy of classification. The classification accuracy would test the land cover maps created from QuickBird image against the existing land cover from field observation.

The process begin with the determining the building site due to tsunami impact on coastal areas. Building sites in this case were classified into sea-front site, river/canal-front site, and tsunami reached inland site. Sample to be checked was selected purposively by considering the accessibility to the area and also by considering the distribution of sample over the polygon class. The author tried to make sure that certain objects which are the main priorities for additional shelters (such as open areas, built-up areas in term of facilities, and mix crops) were checked properly. Further, it is important that for every site of (sea-front, river-front and tsunami further reached inland sites), there were enough samples to be observed.

Congalton and Green (1999) stated that majority researchers have used an equation based on the binomial distribution or the normal approximation to the binomial distribution to compute the required sample size. Another approach could be made on a balance between what is statistically sound and what is practically attainable. Congalton and Green (1999) also stated that based on their experience, a general guideline or “rule of thumb” seems to be collecting a minimum of 50 samples for each vegetation or land cover category in the error matrix. For this research approximately 50 samples were taken for each land cover class, but it really depended upon the areas of polygon of land cover classes, if it is wider more samples were taken and if it is narrower lesser samples were taken. Spatial distribution of land cover samples is presented in Figure 5.3 and 5.4.

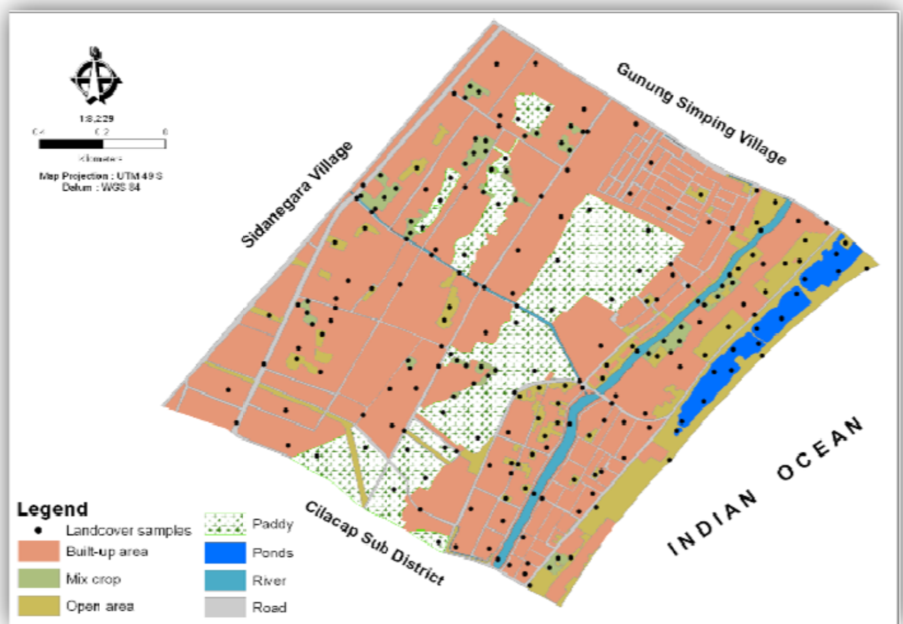


Figure 5. 3. Spatial Distribution of Land cover Samples in Site #1

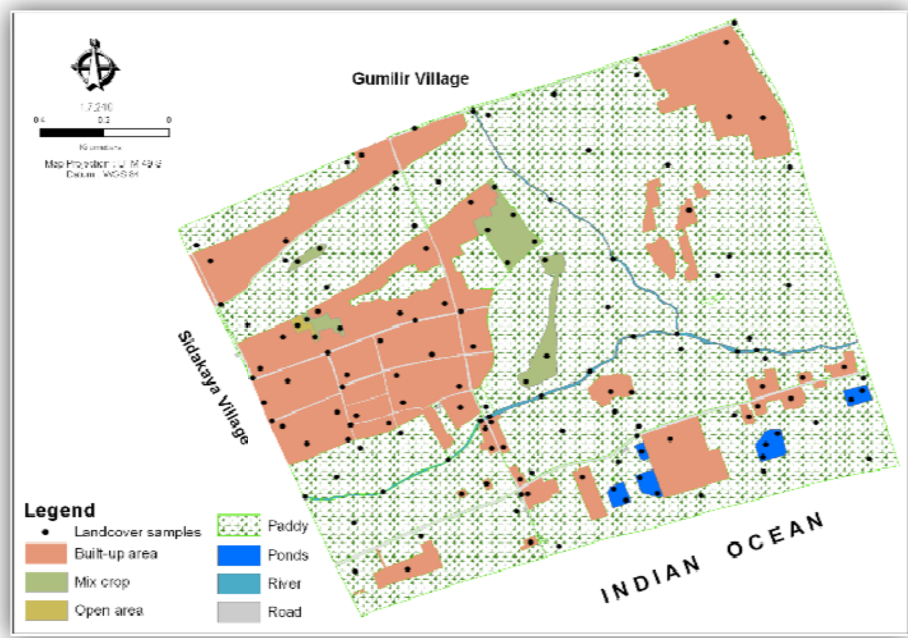


Figure 5. 4. Spatial Distribution of Land cover Samples in Site #2

For each site visited, pictures were taken and coordinate were recorded by using the field recording sheet (it can be seen in Appendix 1).

5.4.2 Building Inventory

The purpose of building inventory in this research was to obtain information regarding the use of the buildings, number of occupants during daytime and night-time. The sampling design was determined as follows:

1. Determining the building site
   Based on tsunami run-up and inundated area, the building site was classified into: sea-front site, river/canal-front site, and tsunami reached inland site.
2. Building selection
   Buildings to be checked were selected purposively based on their uses in each building site and also based on preliminary survey having conducted.

There were 141 buildings taken for field observation in location #1 and 54 samples for location #2 (Figure 5.5 and 5.6). The samples were taken from all building sites comprise of 29 buildings of sea-front site, 25 buildings of river-front site, and 87 of tsunami-reached inland site. Meanwhile for the second area, there were 21 buildings of sea-front site, 4 buildings of river-front site, and 29 of tsunami-reached inland site.

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.

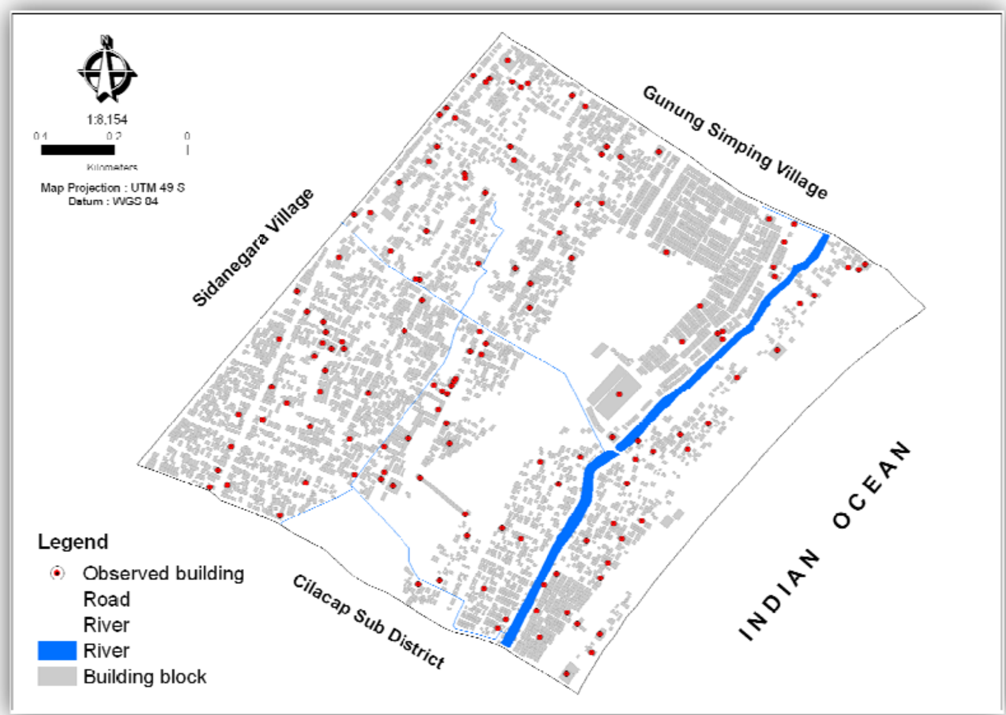


Figure 5. 5. Spatial Distribution of Building Samples in Site #1

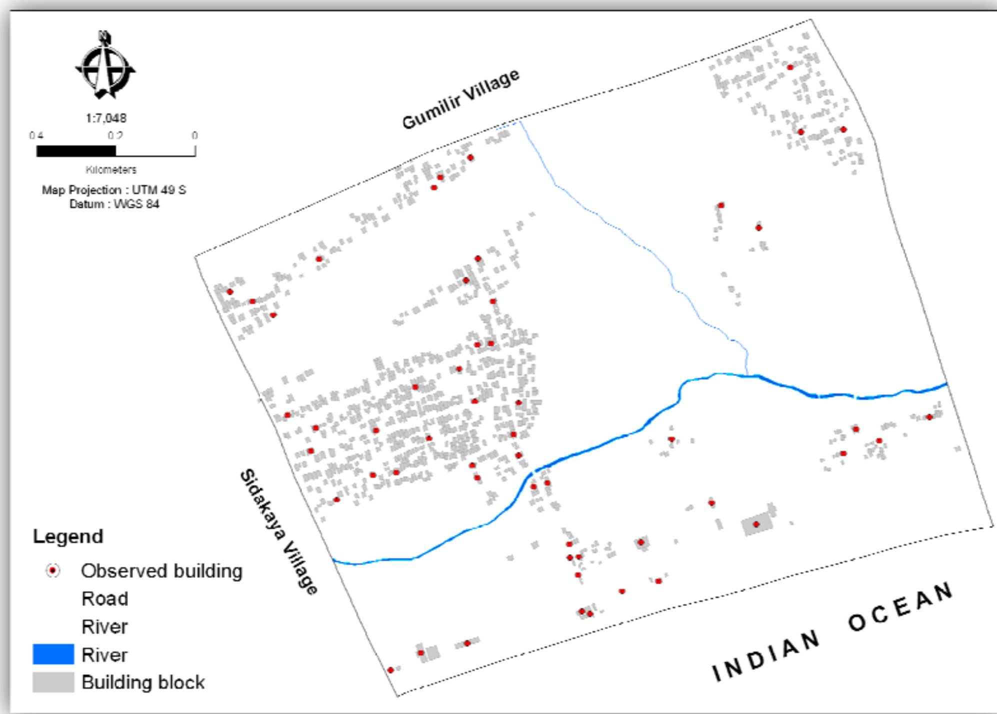


Figure 5. 6. Spatial Distribution of Building Samples in Site #2

For each building visited, pictures were taken and open interview was also conducted. Several questions related with their perception regarding tsunami and evacuation were asked. Additionally, the information such as the use of the buildings were taken, also other information, e.g. the number of workers, the number of student, the possibility of building as tsunami evacuation point, etc. All of such information regarding building uses verification was recorded on the field recording sheet (Appendix 2). Further, this information was used not only for validating the building map based on their uses but also for estimating the population in different scenarios (day and night-time).

5.4.3 Buildings Assessment

After conducting building inventory, then building assessment for selected buildings which were predicted potential as evacuation shelter buildings was performed. Budiarjo (2006) and Widyaningrum (2009) listed several requirements of building resistance for tsunami to conduct building assessment 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).

Despite the criteria related to design and construction of the building, there were many other criteria which are necessary to be assessed. FEMA (2008c) stated that emergency provisions will include food and water, sanitation management, emergency supplies, and communications equipment.

There were 13 buildings which were predicted potential as existing shelter buildings. Their spatial distributions can be seen in Figure 5.7. Besides performing building assessment, key persons were interviewed in order to gain such information related with number of people in the buildings and their daily activities. This information is necessary to know their occupancy during day and night for generating population scenarios over the day.

Further, field recording sheet was designed to record the characteristics of structural design of buildings. Information of building locations, coordinates and photo documentations were included in the sheet (Appendix 3).

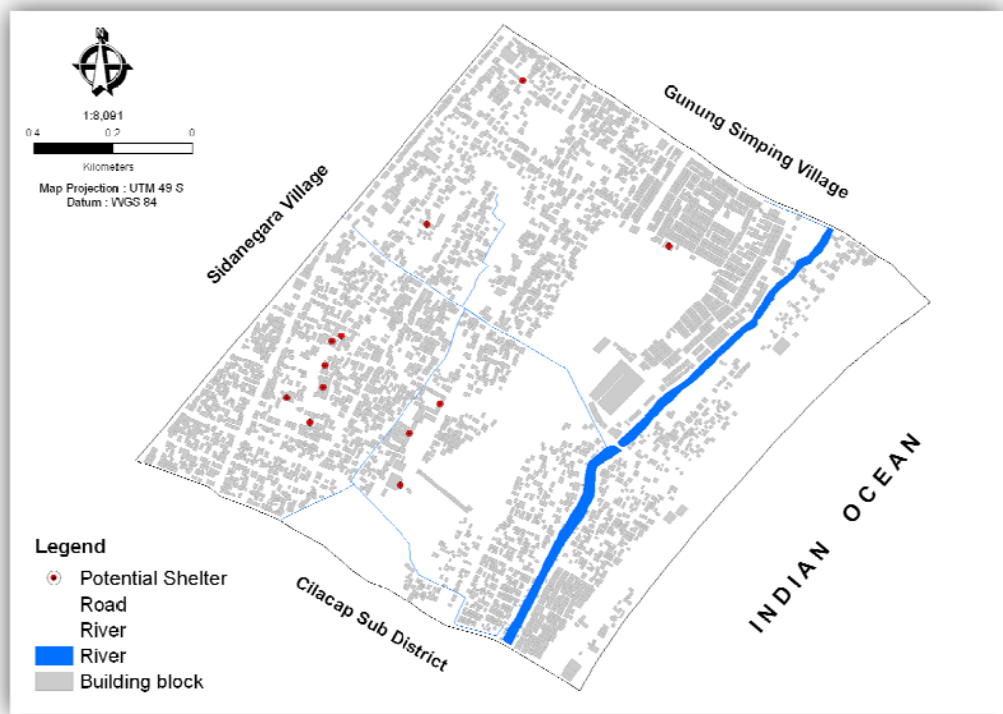


Figure 5. 7. The spatial distribution of potential existing shelters in study area #1

5.4.4 Identification of Detailed Road Network

Road map from topographic map was created based on 1993/1994 aerial photo and 1998 field survey. So, there will be many changes in the field regarding the development of the new roads. This field observation tried to find out the missing roads and also classified them based on their width.

Due to time constraint and cost effectiveness, the locations of road samples were the same as building samples. The field survey for building use and road network were made in the same time by using PDA, GPS, digital camera, topographic map and printed Quick-Bird which was completed with basic information such as administrative boundary, road network, and river. This mobile PDA used ArcPad6 software to store and retrieves digital data. The map projection on mobile PDA was set into UTM Zone 48S and coordinate system WGS 1984. Some digital data such as Quick-Bird image, digital base map and digital road map in shape file stored in mobile PDA as well.

PDA and GPS will be used to get accurate position of the roads. This equipment was also used to add the new roads and their attributes. For each road segment, the width was measured and the surface condition was noted. Pictures were also taken as documentation and the data will be input to the road attributes. The following figure (Figure 5.8) gives illustration of how the missing road added by PDA Tracking and GPS.

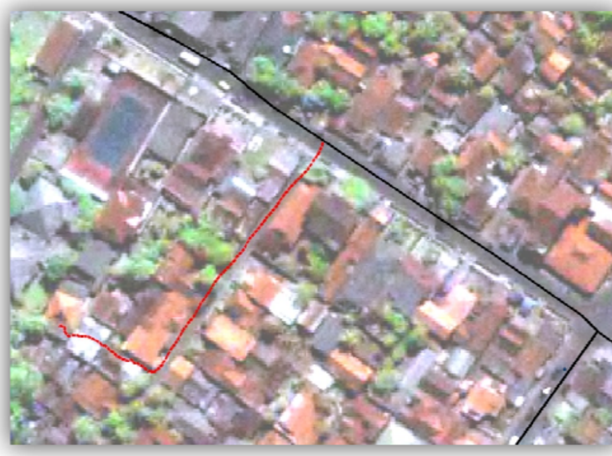


Figure 5. 8. Adding Missing Road (The black line was the existing road map which was stored already in PDA, whilst the red line was the missing road which was added using PDA Tracking during fieldwork)

5.4.5 PGIS for Population Data in RW Level

The objective of this activity was to obtain the RW boundary and the number of households per RW. Since RW were not a government administrative division, the RW maps were not available. So in this case, the author developed the RW maps using PGIS (Participatory GIS) approach. PGIS is one of the powerful methods to obtain unrecorded information.

As can be seen in Figure 5.9, during fieldwork, the printed Quick Bird image in A3 format completed with additional information such as road network, river and topographic map were used to do map generation of RW boundary. The respondents for PGIS were the key persons of RW. Those key persons were asked to map the RW boundary by using the printed map which has been prepared. Further, population data (household number per RW) were also recorded.

Interview was conducting mostly in Bahasa Indonesia. In some occasions, interview was conducting in Javaness language. In this case, author was accompanied by local guide who translates the conversation into Bahasa Indonesia. Local guide is a local citizen who knows the characteristics of study areas. During the fieldwork, the local guide also helped author in accepting information from key persons related with the boundaries of RW which are in term of name of roads, rivers, agriculture areas, etc.

Figure 5. 9. PGIS for obtaining RW map (Figure 5.13.1: cyan dash lines refer to RW boundaries)

Figure 5.9. #(1, 4, 5) shows the result of RW boundary mapping by using PGIS methods. Whilst figure 5.9. #(2, 3, 6) shows the process of interviewing the key persons of RW related to RW boundaries and households number. In general, all respondents seemed to have a good response during the interview, and it was not difficult to communicate and interact with local people in study areas.

5.5 Post-Fieldwork

All data obtaining during field work were then processed and analyzed using ArcGIS Ver.9.3. The description of each process can be seen in the following sub-chapter.

5.5.1 Land Cover Classification

Land cover comprises several classes, such as ponds, paddy field, mix crop, open area, road, and built-up area which were then classified based on building uses. Land cover in this research was not part of the model inputs. It was utilized in the process to ascertain whether certain location which was suggested by the model was suitable as additional shelter. It is because the network analyst in finding the suitable location for additional shelter was only based on the fast route. It was measured in term of travel time on the network. Hence, in this case land cover map was needed to check the suitability of particular location as additional shelter locations.

The land cover map was interpreted visually and heads up digitizing method was used to process the image (see Figure 5.10 for the workflow of image processing). The classification error matrix or confusion matrix (or contingency table) was performed to derive the classification accuracy. Congalton (1991) defined that an error matrix is a square array of numbers set out in rows and columns which express the number of sample units assigned to a particular category relative to the actual category as verified on the ground. The concept of the error matrix can be seen in Figure 5.11.

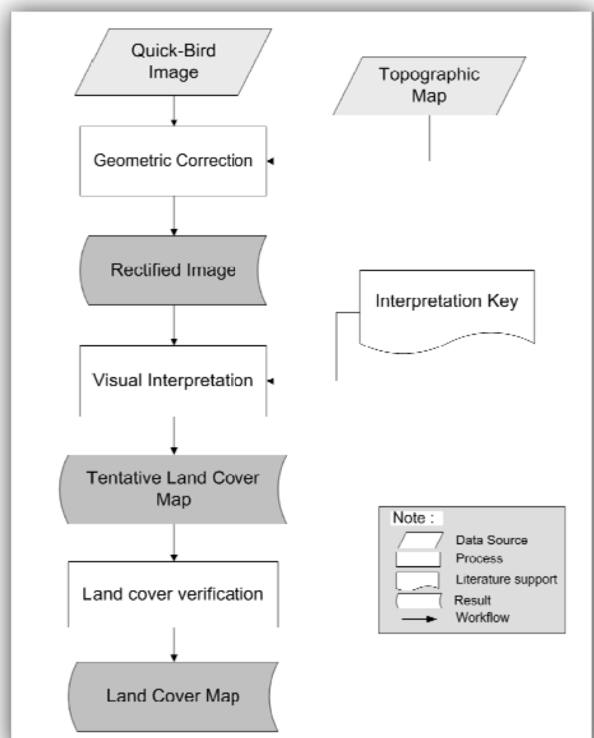
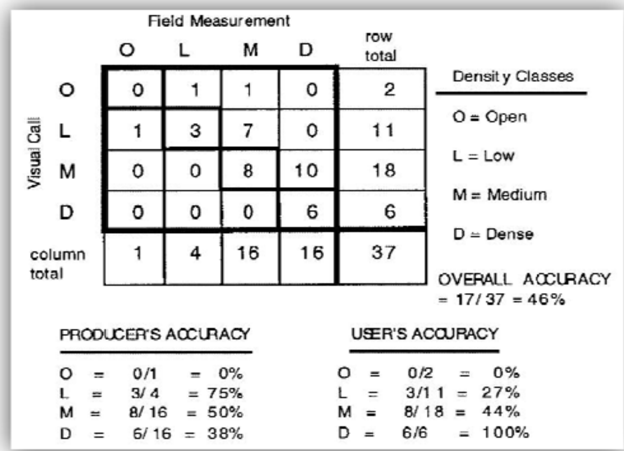


Figure 5. 10. Workflow of image interpretation for land cover



Field Measurement

Visual Call	O	L	M	D	row total
O	0	1	1	0	2
L	1	3	7	0	11
M	0	0	8	10	18
D	0	0	0	6	6
column total	1	4	16	16	37

Density Classes

O = Open

L = Low

M = Medium

D = Dense

OVERALL ACCURACY = 17/37 = 46%

PRODUCER'S ACCURACY

O = 0/1 = 0%

L = 3/4 = 75%

M = 8/16 = 50%

D = 6/16 = 38%

USER'S ACCURACY

O = 0/2 = 0%

L = 3/11 = 27%

M = 8/18 = 44%

D = 6/6 = 100%

Figure 5. 11. Example of error matrix (Congalton and Green, 1999)

To ascertain the most suitable locations as shelter buildings in this case, there were many factors to be considered as follows.

1. The first priority was open area.
   It was the most suitable location for additional shelters for this research since it has not been occupied yet.
2. The second priority to be considered would be the existing facilities in the surroundings. Those facilities could be schools, government offices, community centers, recreational facilities, sports complexes, libraries, museums, police or fire stations, mosque, etc. Retrofitting of public facilities was other alternatives for additional shelters.
3. The next alternative was mix crops. Mix crops are usually located near settlements and consist of various plants such as mango trees, banana trees, coconut trees, etc. These areas were less economical compare to paddy field.
4. Paddy, ponds, and river were not suitable for additional shelters regarding the unsafe condition when these areas hit by tsunami waves. Paddy were not suitable for additional shelter because it is located in low-lying areas and the soils have less bearing capacity. Bearing capacity is the capacity of soil to support the loads applied to the ground. Meanwhile, tsunami can enter the river with destructive waves caused more destruction to the area surrounding. It makes river was not recommended for shelter building locations.

5.5.2 Building Assessment

The purpose of building assessment was to provide the input for the model. Buildings in this case were source of people to be evacuated. The process in building assessment can be seen in Figure 5.12.

5.5.2.1 Identification Building Use & Evacuation Shelters

The building use classification is needed to be determined because it gives contribution in evacuation process since it will serve as target point of evacuation. The use of the buildings will determine the number of people present in the buildings in 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.

From this classified building map, there are two objectives could be achieved. First, facilities location could be identified. By knowing the location of facilities, the estimation of population during day and night-time could be made since the number of population in office, school and other facilities could be estimate. Second, from these building maps, the potential existing shelter buildings for tsunami evacuation could be recognized.

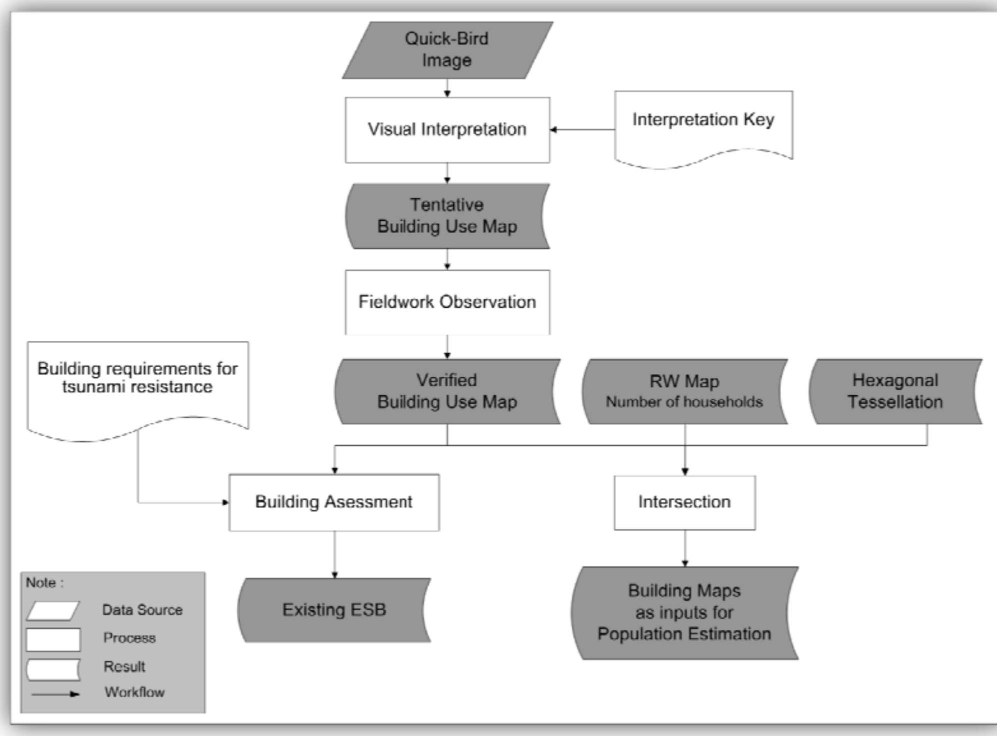


Figure 5. 12. Workflow of building assessment

After conducting field observation, the next step was completing all the attributes of building data with the number of occupants during day and night-time based on data which collected in the field. Besides, from field survey the number of occupants was also can be calculated by using architectural approach.

5.5.2.2 Creating Hexagonal Tessellation

The evacuation model was started from the concentration of evacuees. By using Network Analyst, both shelter destinations and center of evacuees are expressed in term of points. From building maps we can see that there were 3,937 building blocks represented the source of evacuees. Due to the time constraint, the author tried to make the simplification for the model input. The population distribution will be systematically divided into equal-sized portion by using tessellation or grid. It was assumed that residents live concentrated at its center (the center of this tessellation will be called centroid). Otherwise, model should be started from 3,937 point of origins which will take longer time to be conducted. Ideally, people will evacuate from every building block and try to find out the nearest network.

In this case, hexagonal tessellation was chosen since hexagon has a shorter perimeter than a square of equal area, which potentially reduces bias due to edge effects (Krebs, 1989) after (Birch *et al.*, 2007). Further, it is said that the hexagon tessellation is attractive because it minimises spatial distortion and, if constructed on an equal-area map projection, provides an equal-area sample. Furthermore, hexagonal tessellation is suitable for modeling which incorporate connectivity and movement paths.

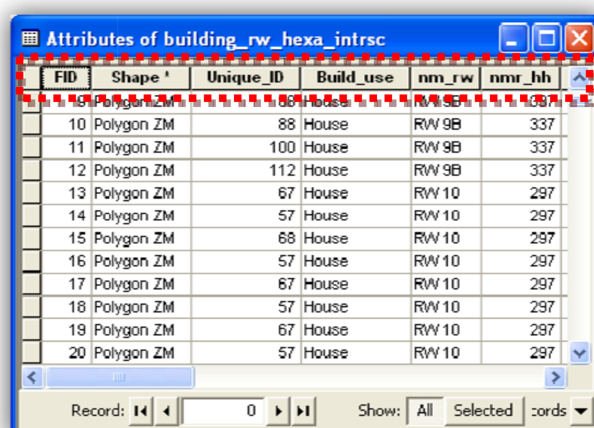
By this simplification, the number of points of origin will be decrease in number since a group of buildings will be represented by the centroid of hexagonal tessellation as center of evacuee (point of origin). For this purpose, one hectare hexagonal tessellation was used; the each side is 62.04 m in length. The area of 1 hectare is manageable extent of detail level spatial planning and building design.

To generate the hexagonal tessellation over the study area, an extension of ArcGIS so called Repeating Shape for ArcGIS was used (Jenness, 2009). The steps were as follows:

1. Choose the region of interest with selected feature in feature layer. This option will allow us to generate shapes that will completely cover all the selected features in some point, polygon or line.
2. Choose the shape type to create, in this case hexagonal shape.
3. Set shape parameter. All options in this case have several parameters relating to size, spacing and orientation shapes.
4. Generating the process.
5. Overlaying the hexagonal tessellation with building maps and RW maps using intersection command in ArcGIS software.

The final result of this process was building maps which were completed with all data regarding name of RW, the number of households in each building, and hexagonal ID, as can be seen in Figure 5.13. So, each building in building maps will have such kind of information, as follows:

1. Numeric field **Unique_ID** refers to certain hexagonal label in which the building attached.
2. String field **Building_use** refers to the usage of the building.
3. String field **nm_rw** refers to the name of RW in which the building located.
4. Numeric field **nmr_hh** refers to number of households in certain building.


Attributes of building_rw_hexa_intrsc

FID	Shape *	Unique_ID	Build_use	nm_rw	nmr_hh
9	Polygon ZM	88	House	RW 9B	337
10	Polygon ZM	88	House	RW 9B	337
11	Polygon ZM	100	House	RW 9B	337
12	Polygon ZM	112	House	RW 9B	337
13	Polygon ZM	67	House	RW 10	297
14	Polygon ZM	57	House	RW 10	297
15	Polygon ZM	68	House	RW 10	297
16	Polygon ZM	57	House	RW 10	297
17	Polygon ZM	67	House	RW 10	297
18	Polygon ZM	57	House	RW 10	297
19	Polygon ZM	67	House	RW 10	297
20	Polygon ZM	57	House	RW 10	297

Record: 0 Show: All Selected :cords

Figure 5. 13. The attribute result of intersection between building maps, RW maps and hexagonal tessellation

5.5.2.3 Building Capacity Estimation

It was necessary to determine the capacity of existing shelter buildings so that the number of population to be evacuated in the buildings could be estimated. Furthermore, the capacity of the existing buildings was important for knowing how many additional shelters should be added. In this case, when the evacuees meet the maximum capacity of an existing shelter, the rest of evacuees should find the other additional shelters.

A vertical evacuation structure is typically expected to provide a temporary place of evacuees during tsunami event. For short-term evacuation shelter, FEMA (2008b) noted that the stay duration should be expected to last between 8 to 12 hours, as a minimum. In addition, since tsunami can include a series of waves, it is recommended that evacuees should remain in shelters at least until the second high wave which could occur up to 24 hours later.

The space requirement needed per refugee can vary depend on the length of occupancy and type of hazard. The longer the duration of occupancy, the greater the minimum space requirement per occupant for comfort requirements, for building infrastructure, systems, and services needed when housing people on an extended basis. There are many different source giving values for the minimum space requirement per occupant. FEMA (2008b) stated that, the recommended minimum square footage per occupant for a tsunami refuge is 10 square feet per person. It is equal to 0.93 square meter per person. Further, the National Development Agency of Indonesia (BAPPENAS, 2005) noted that the space needed for accommodating one person is 1 square meter. Meanwhile, ARC (2002) for hurricane shelter stated that on a short-term basis, shelter requirements should be determined no less than 15 square feet per person.

The calculation of tsunami evacuation building capacity (TEBC) is using the following equation (Budiarjo, 2006; Widyaningrum, 2009):

$$TEBC = (CS \times BA \times NrF) / (SpP) \quad \text{.......................} \quad (1)$$

TEBC	=	Tsunami Evacuation Building Capacity (number of person)
CS	=	Capacity Score (%)
BA	=	Building Area (m^2)
NrF	=	Number of Floors
SpP	=	Space needed for one person (m^2)

For this research, the minimum space requirement per occupant is 1 square meter. It is anticipated that this density will allow evacuee to sit down without feeling overly crowded for a relatively short period of time. This space of 1 square meter would not be considered appropriate for longer stays that included sleeping arrangements. It should be adjust up for longer stay. Hence the above formula could also be expressed as follows:

$$TEBC = (CS \times BA \times NrF) / (1\ m^2) \quad \text{.......................} \quad (2)$$

The building area is the total floor area of the building for evacuation. Especially, when there are more than one floors used for evacuation purposes. The capacity score depend on the type of building since each building type will have different condition of free space available. The formulas used can be seen in Table 5.2 as follows:

Table 5. 2. The TEBC for each building types

Type of Building	Tsunami Evacuation Building Capacity
Mosque/worship	78% * BA / 1 .... (3)
School	30% * BA / 1 .... (4)
Office	23,6% * BA / 1 .... (5)
Market building/Mall	23% * BA / 1 .... (6)
Hotel	26,3% * BA / 1 .... (7)
Hall/Gallery	100% * BA / 1 .... (8)

Source : (Budiarjo, 2006; Widyaningrum, 2009)

The calculation of ESB capacity in this case is important since it will determine the number of evacuees that can be served for tsunami evacuation. If more space needed per person, it means that less people which can be sheltered and more ESB required.

5.5.3 Creating Network Dataset

After conducting field observation of road network, all information regarding road classes and the road width were then input to the attributes of road data using ArcGIS version 9.3. The overall procedures of network datasets preparation can be seen in Figure 5.14. The next step describes the creating of network datasets.

The steps in creating network dataset comprised as followings:

1. Preparing the feature dataset and sources
   Since the data were in shape files format, all the feature classes were put in the same directory.
2. Preparing the sources for appropriate roles inside the network dataset.
   There were two attributes added to the road data, i.e. time impedance and one way street.
   a) The time impedance was determined by time required to move over the network by considering speed of walking of evacuee which was affected by width of the road. The names of the fields were FT_MINUTES and TF_MINUTES, since the impedance values differ based on travel direction. The descriptions below are the explanations on how the travel time over the network can be calculated.

      Knoblauch (1996) stated that walking rates are influenced by a variety of factor including the width of the roads, road density, the number of pedestrian in a group, etc. For this research due to the time constraint in conducting the research, the speed of walking in a particular road is only influenced by the walking speed of evacuees and the width of the roads. In this case, the speed of walking in a particular road is calculated using the following formula:

$C_0 = W / S$ ………. (9)	$V = (C_0 / C_1) * V_s$ ……… (11)
$C_1 = W / S$ ………. (10)	

Note:

V	=	Actual Speed of walking during disaster (m/sec)
C_0	=	Base capacity of the road (round-in value)
C1	=	Actual capacity of the road during disaster (round-up value)
Vs	=	Speed of walking during disaster by a group of elderly person 0.751 m/sec (Sugimoto *et al.*, 2003)
W	=	Width of the road (m)
S	=	Space requirement of person 0.625 sq meter (Neufert, 1999)

b) For modeling one-way street, a string field called ONEWAY was added. It restricted the movement of evacuees to the shoreline direction. Then create evaluators that interpret its value as follow:
   1). "FT" or "F" indicates a one-way street only permitting travel in the digitized direction of the edge.
   2). "TF" or "T" indicates one-way street only permitting travel against the digitized direction of edge.
   3). "N" indicates a street that does not permit travel in either direction.
   4). Any other value (in this research "B" is used) indicates a street that permit travel in either direction.

3. Create the network dataset
   This stage includes naming the datasets, identifying the network sources, setting up connectivity, etc. For this research, turn was not include in the process since the data were not available. It needs further research for knowing how much time needed to turn at certain places in a certain condition of road.

4. Build the network dataset.
   This step was required before the network datasets is performed, not only if we make a new datasets but also when the network datasets is edited. Building is a process of creating network elements, establishing connectivity, and assigning values to the defined attributes.

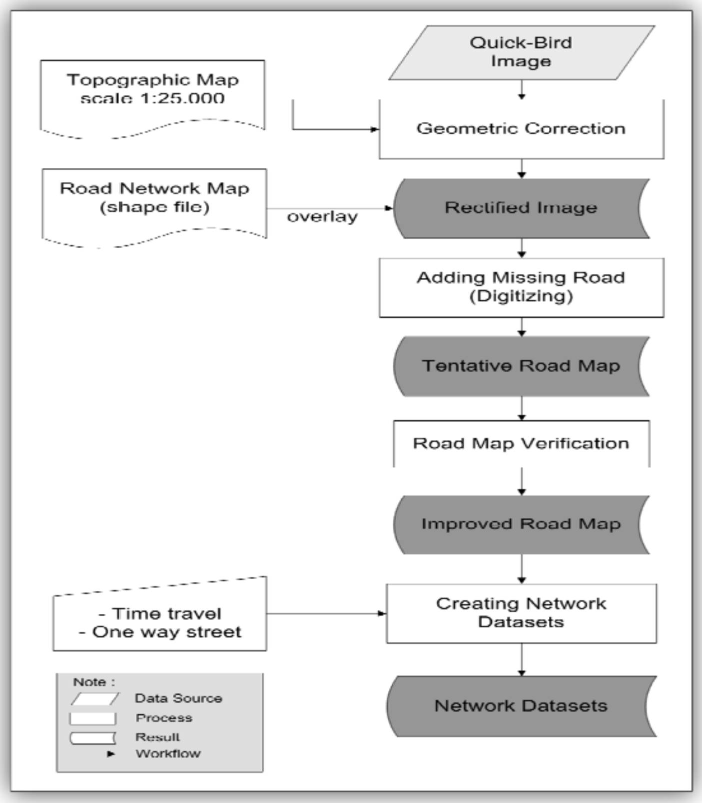


Figure 5. 14. Overall procedures of road network identification and network dataset creation

5.5.4 Population Estimation

5.5.4.1 Pre-processing Population Data

Estimation of population to be evacuated and their distribution are crucial to be known in evacuation planning. By knowing the number of populations to be sheltered and their distribution, the evacuation shelter buildings can be allocated properly.

For this research, the number of occupants per building was necessary in order to develop scenarios of day population and night population. So far, the available population data from Central Bureau of Statistics of Cilacap Regency is in village level with the average number of people in each household. The problem in many cities in Indonesia which are densely populated and also in Cilacap is that one house (a building) can consist of more than one household. So, if population data from village level was used for evacuation modeling, there will be underestimate number of population that should be evacuated. To overcome such problem, the more detailed population data is needed. In this case, author tried to improve the population data in village level by using the household number per neighborhood (RW). By knowing the number of households per RW and the number of buildings per RW, we can estimate the number of household per building and further this value will be used to calculate the number of occupants per building.

Rukun warga (neighborhood/RW) is the area division within the village. It is not the government administrative division but the establishment of the RW is based on the agreement among the people for community service purposes. Each RW consists of several blocks or RT (*Rukun Tetangga*) and each RT consists of several households. The RW areas are separated by roads, rivers, agricultural areas or even certain buildings.

The number of households was collected in the field by interviewing the key persons of each RW. Not only information related to the number of households was collected but also the boundaries of the area. The following equations were used to calculate the number of occupants in a house.

HsPH = HPR / BPR	.... (12)
OPB = HsPH x OPHs	…………………….. (13)

Note:

HsPH	=	Number of Household per House
HPR	=	Number of Houses per RW
BPR	=	Number of Buildings per RW
OPB	=	Number of Occupants per Building
OPHs	=	Number of Occupants per Household

5.5.4.2 Day and Night Population Scenario

Concentration and distribution of population are dynamic over the day due to the concentration of business establishment, offices, and settlement. For example, in a commercially used market areas or buildings, there will be a high population during daytime and the number of people will be decrease significantly during the night-time. The dynamic spatial shift of population will result in a short time relocation of the vulnerability indicator ‘population’ (Taubenböck *et al.*, 2008).

In this research, the scenarios of day and night-time are used to run the evacuation model. The difference in population distribution over the day through the study area will result in different ESB allocations. Estimation of population during day and night was then conducted in each tessellation and was assigned as the origin of people to be evacuated to the shelters.

There are two kinds of population estimation involved, population number in the house and population number in facilities, such as in the school, office, commercial area, etc. The more detailed description on how to calculate the number of population in each is given in the following sub-chapters.

5.5.4.3 Estimation of Population in the House

The calculation of population in the houses was conducted by calculating the number of the houses per tessellation and multiplying the result with the number of population per household. For each scenario, the population in the houses were calculated using the following formula (Budiarjo, 2006):

Daytime	50% (occupants) * (nr_houses) * (nr_occupants/house)	…….(14)
Night-time	100% (occupants) * (nr_houses) * (nr_occupants/house)	…….(15)

It is assumed that 50% of the occupants were at home and the rest were being outside the house conducting their activities. For example, if the family consists of four people (father, mother, and two children), the mother and 1 child stay at home during the day while father and 1 child are at work or school. In night-time scenario, the assumption is that all of family members are at home.

The value 50% used in this research was only an assumption. It needs further research or existing data related the number of people who remain at home during daytime and number of people at work, school, or elsewhere in that region. These detailed data are not available in the population data from Central Bureau of Statistics. Further research is needed to know such kind of information regarding percentage of people in certain locations over the day.

5.5.4.4 Estimation of Population in the Facilities

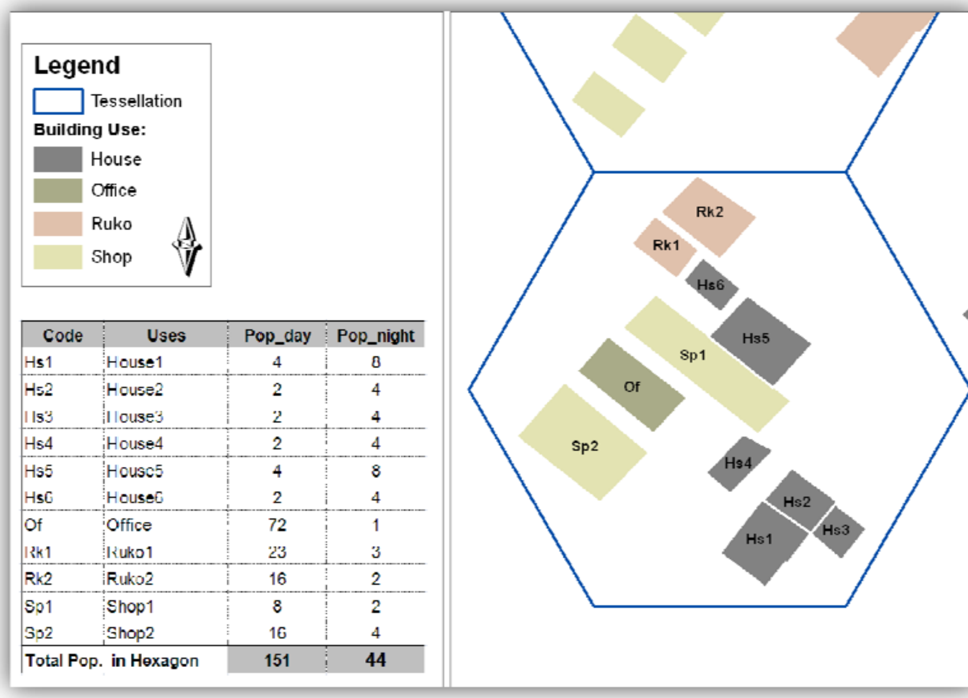
For calculating the number of population in the facilities, the primary data from field work were used. For example, if the number of occupants at school were known (i.e. students, and teacher) from fieldwork, this data would be used in the calculation (110% * number of occupant at school), otherwise space requirement approach would be used in calculation. Some information related with the number of students and workers were collected during fieldwork. The formulae which were used for estimating the number of population in facilities are as follows: The following description show the concept to calculate the number of population in each hexagonal tessellation based on the formula above (Figure 5.15).

Table 5. 3. Population estimation for day and night-time scenarios

Facility (1)	**Formula (2)**
Mosque	
Day scenario	10% (capacity) * building area / 1.8 (space requirement) ...... (16)
Night scenario	1 person
	Only one security guard is available during the night
School	
Day scenario	110% (capacity) * building area / 4 (space requirement) or 110% (capacity) * number of occupants ...... (17)
	10% for other occupants i.e. teacher, officer, food & merchandise seller
Night scenario	1 person
Boarding house	
Day scenario	1 person
Night scenario	100% (capacity) * building area / 4.6 (space requirement) ...... (18)
	It is assumed only 2 person stay at the building (cleaning service & security)
Office	
Day scenario	100% (capacity) * building area / 8.5 (space requirement) ...... (19)
Night scenario	1 person
Shop	
Day scenario	4 person (employee and/or visitor)
Night scenario	1 person
	................*continued to the next page*...................

Facility	Formula
Ruko (shop & house)	
Day scenario	(50% (family member) * population/household) + 4 (employee and/or visitor) ...... (20)
Night scenario	100% (family member) * population/household
	The owner (mostly) also lives in the building
Hotel	
Day scenario	50% (capacity) * building area / 16 (space requirement) ...... (21)
Night scenario	80% (capacity) * building area / 16 (space requirement) ...... (22)
Factory	
Day scenario	Total people in the whole facility area
	It is assumed that the area contain its regular occupant
	Based on field observation, estimation is conducted by knowing the number of people in factory (workers, security, cleaning service, etc)
Night scenario	2 person (security guard)
Fish Market	
Day scenario	Total people in the whole facility area
	It is assumed that the area contain its regular occupant
	Based on field observation, estimation is conducted by knowing the number of people in fish market (fisherman, officer, buyer, cleaning service, etc)
Night scenario	2 person (security guard)

Source: modified from (Budiarjo, 2006)



Code	Uses	Pop_day	Pop_night
Hs1	House1	4	8
Hs2	House2	2	4
Hs3	House3	2	4
Hs4	House4	2	4
Hs5	House5	4	8
Hs6	House6	2	4
Of	Office	72	1
Rk1	Ruko1	23	3
Rk2	Ruko2	16	2
Sp1	Shop1	8	2
Sp2	Shop2	16	4
Total Pop. in Hexagon		151	44

Figure 5. 15. The step in calculating population in hexagonal tessellation

5.6 Evacuation Modeling

Evacuation is a main protecting action in disaster occurrence such as floods, landslides, tsunami, volcanic eruption, etc. It defines as the act of evacuating or leaving a place because of a real or anticipated threat or hazard (Sorensen, J. and Vogt, 2006). Those evacuation efforts consider road capacity and evacuation times calculated by comparing estimated traffic demand to capacity. In this research, evacuation modeling took into account the capacity and accessibility of the evacuation shelters.

Network Analyst –an extension of ArcGIS Desktop- is utilized for evacuation modeling including determining the effective route and suitable location for additional evacuation shelter buildings. An optimal evacuation route out of a risk area was determined using network flow approach. The goal of the network flow evacuation problem is to route people from a certain original location to a safe area outside the risk zone in the most effective time.

5.6.1 Accessibility Model

HSRC (2008) *after* Widyaningrum (2009) stated that accessibility modeling includes not only calculating access, but also the calculation of capacity constraint per-location, distance to closest facility, improved access for the population and various optimum location. Poole (2003) noted that accessibility measures can be considered with reference to opportunity and deterrence function. Opportunities can be considered in terms of those available to an individual (origin accessibility), or the catchment areas for a specific destination. Deterrence functions aim to represent the cost of reaching destinations in term of distance or time.

In this research, accessibility modeling tried to calculate the capacity and service area of destination location using two scenarios -daytime and night-time-. Service area defines as a region that encompasses all accessible streets especially streets that are within a specified impedance. In this case, travel time was assigned as cost attribute of the impedance (Figure 5.16).

The results of this model were time calculation for determining the service area of each ESB and the calculation of capacity-constraint per location. There were two maps generated by this process, as follows: 1) service area of ESB in daytime; 2). service area of ESB in night-time.

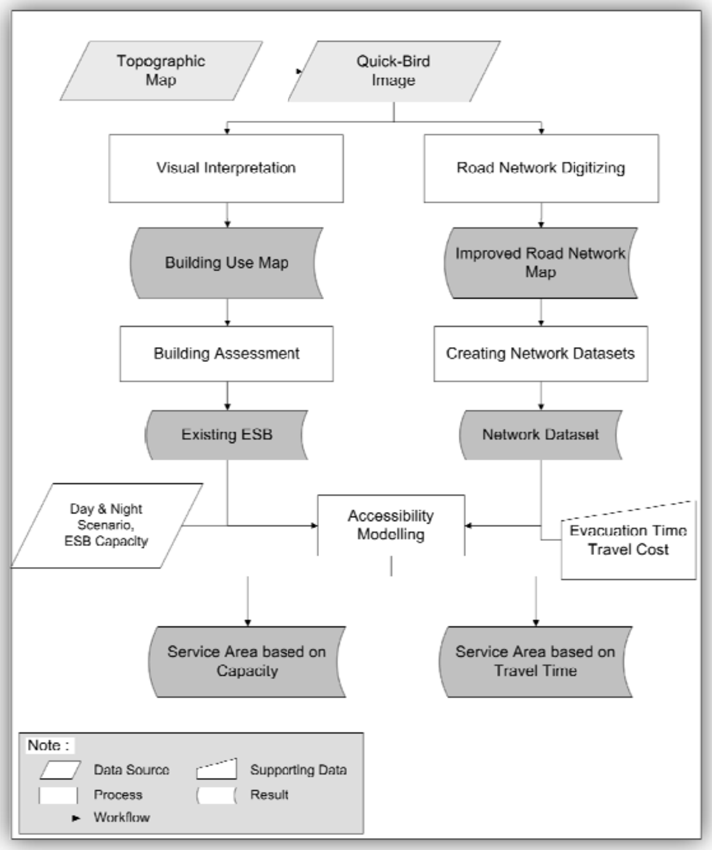


Figure 5. 16. Flowchart of accessibility modeling

5.6.2 Service Area of ESB

ESB service areas refer to the service areas which were developed by considering capacity and travel time (TT). The calculation and estimation of ESB capacity and time area is essential to be done in accessibility modeling. Since, it is possible that not all the population in the time area can be sheltered in the nearest evacuation shelter building.

During evacuation, people will move away from the coastline which is represented also in performing the time area of the shelters. The evacuation buildings can only be accessed by people who come from the coastal direction, but it still allows the people from the contrary direction to be sheltered if their distance is within 17 minutes to reach the building. There were two processes of calculation in this stage, as follows:

1. The estimation of total population in those areas who can reach the ESB during evacuation time.
2. The estimation of ratio of population in certain areas which can be sheltered in the ESB.

The following descriptions describe the different concept of service area based on time travel and based on the capacity of building. The service area means the area which can be served by a particular shelter building as a target of evacuation by considering TT and number of population.

1. Service area based on evacuation time (time area)
   It defines the total number of people in certain areas who are able to reach the evacuation building in a given time. To develop service area based on evacuation time to ESB, the function of New Service Area tools of Network Analyst is incorporated. In this case, a 17-minute service area for a point includes all the streets that can be reached within 17 minute from that point.
2. Service area based on capacity
   It defines the number of people in certain area who can be sheltered in shelter building in a given time. It derives from tsunami evacuation building capacity calculation (TEBC). Service area based on number of population who can be sheltered in ESB was developed by using GIS techniques. It was done by calculating number of population in the nearest tessellation. The coverage of this service area was created by joining the tessellation which participated in the calculation. The shortest TT and the number of population in each tessellation were parameters in creating the service area based on capacity.

The following figure (Figure 5.17) describes the different approach between service area based on evacuation time and capacity. The final coverage which was the coverage based on capacity will be assigned as the service area of shelter building. There were two maps result in this process, i.e. ESB service area using daytime scenario and night-time scenario.

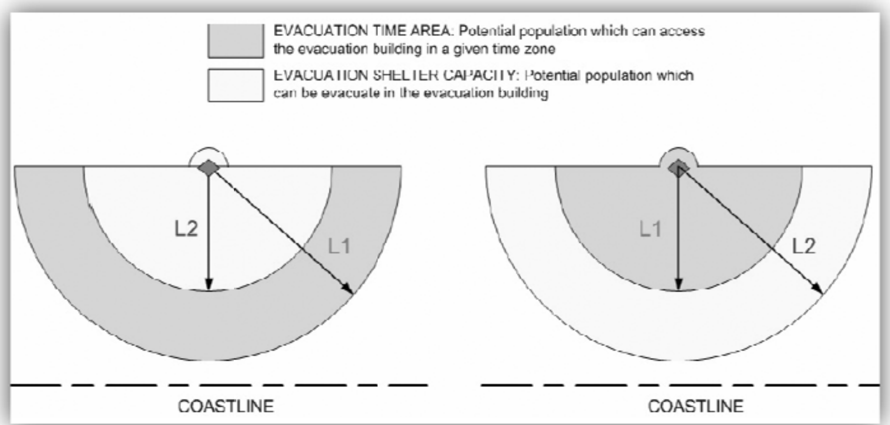


Figure 5. 17. Evacuation Shelter Capacity and Service Area Approach
(Source : Tsunami Mitigation Guidelines for Evacuation Building - Japan, 2005) *after* Widyaningrum (2009)

The following illustrations show the concept in creating the service area based on time area and capacity of ESB. For example, a service area of certain ESB will be created based on 10 minutes TT. The capacity of this ESB is 350 evacuees. The steps that should be performed are as follows:

1. By using Service area command of Network Analyst, service area of ESB is created based on 10 minute travel time. The result is like in Figure 5.18 (a).
2. In Figure 5.18 (a), the blue coverage refers to the service area of ESB based on travel time. The red cross refers to ESB.

3. Using this service area as a basis, Find Closest Facility command of Network Analyst was used to find the ESB from centroid (source of evacuees) which are located inside service area based on time. The result can be seen in Figure 5.18 (b). The dark blue lines in Figure 5.18 (b) show the routes from each tessellation (dark blue dot) to ESB (red cross).

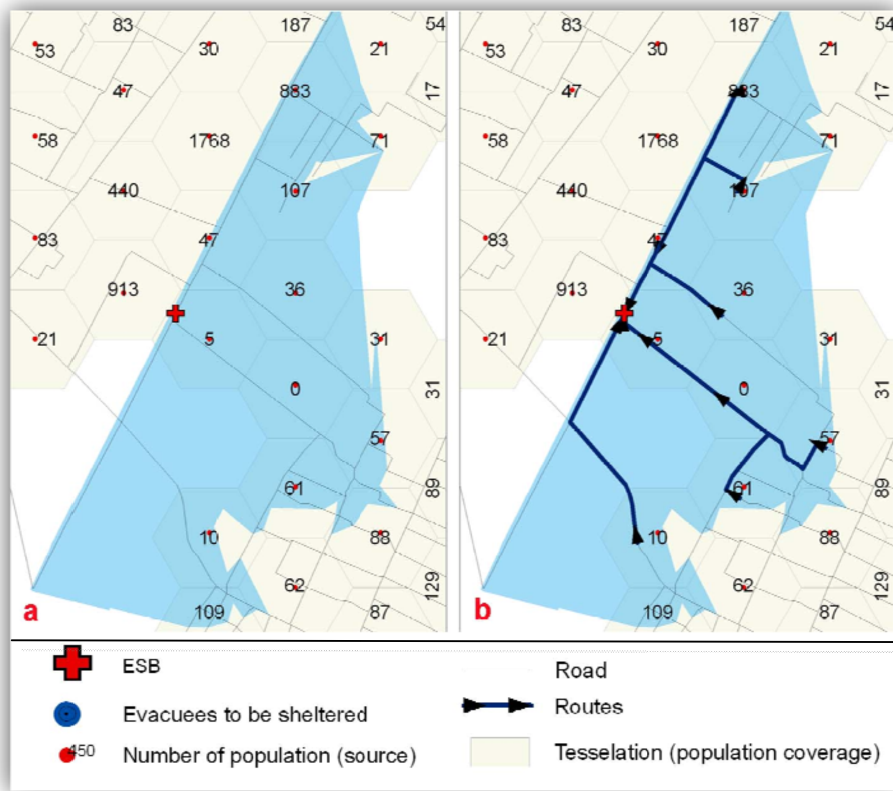


Figure 5. 18. The process of creating service area based on travel time

4. The next step is to check, compare and select which population (centroids) can be loaded to ESB by considering the shortest TT needed, number of populations, and ESB capacity.
5. The population in each centroids is then calculated and added so that the number of population to be sheltered will not exceed the capacity of the existing ESB (Table 5.4). It is possible that not all population in the service areas can be sheltered to certain ESB. It really depends upon the capacity of ESB and how fast people can go to particular ESB.
   a) There are 1,308 people in the service area based on TT. As we know, ESB can only cover 350 evacuees, so in this case we should select evacuees from particular tessellations which have the fastest TT and could be sheltered in ESB.
   b) Table 5.4 (in grey shading) shows the evacuees that can be sheltered in ESB (the tessellation ID : 38, 40, 39, 37, 41)

Table 5. 4. Attribute of service area

Tessellation ID	Name	Minutes (Minute)	Length (m)	Pop_day (person)
38	**Graphic Pick 5 - Graphic Pick 46**	**1.38**	**47.88**	**5**
40	**Graphic Pick 7 - Graphic Pick 46**	**2.16**	**88.98**	**47**
39	**Graphic Pick 6 - Graphic Pick 46**	**4.07**	**158.37**	**36**
37	**Graphic Pick 4 - Graphic Pick 46**	**4.45**	**151.59**	**0**
41	**Graphic Pick 8 - Graphic Pick 46**	**6.52**	**255.12**	**107**
42	Graphic Pick 9 - Graphic Pick 46	6.76	278.72	883
34	Graphic Pick 1 - Graphic Pick 46	7.00	284.20	10
35	Graphic Pick 2 - Graphic Pick 46	8.90	301.62	61
36	Graphic Pick 3 - Graphic Pick 46	8.98	304.61	57
	Total population			**1,308**

6. The following step is to create service area by using the selected evacuees/tessellation in point 5b. In Figure 5.19 (a), the blue polygons refer to service area of ESB based on capacity.
7. This coverage is used as a basis for the next step, establishing the most effective routes of tsunami evacuation by using Find Closest Facility command in Network Analyst. The final result can be seen in Figure 5.19 (b).

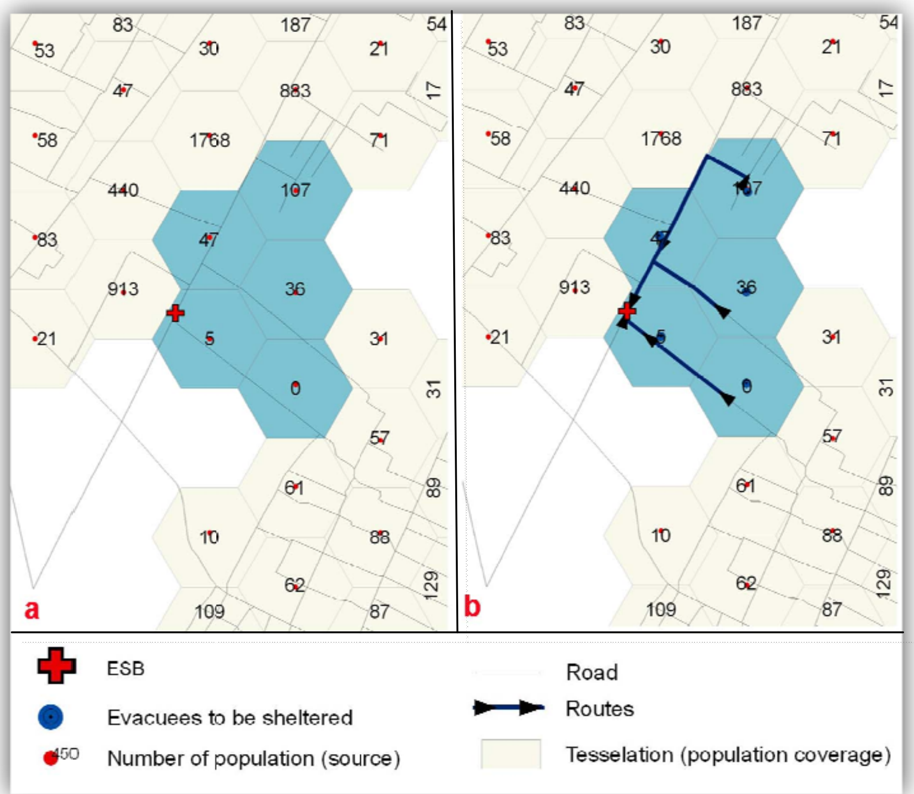


Figure 5. 19. Process of creating the service area based on capacity

5.6.3 Additional ESB

This process tries to define the number of evacuation buildings should be added and their spatial distribution. Service Area of Network Analyst is utilized in order to allocate additional ESB for high population density areas. It is a contrary process compare with the one which is developed from the existing ESB. The process starts from the centroid of tessellation as an origin of people to move. From these centroids, service areas are then developed by considering the 17-minute TT and one-way rule in network for avoiding the shoreline direction meaning that the evacuee will move away from centroid to go further inland. The service areas refer to the polygons or coverage which is created by joining the extent of road segment which can be reached in 17 minutes by evacuees. The concept of the different approach in developing the service areas between existing ESB and centroids of tessellation can be seen in figure below (Figure 5.20).

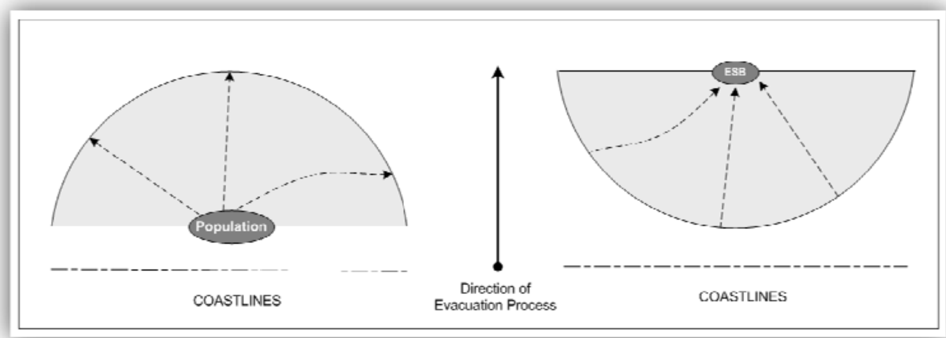


Figure 5. 20. Service area creation from different source, from evacuees (left) and to existing ESB (right)

The arrow in Figure 5.20 refers to the direction of people in evacuation process to run away from the shorelines. The dash lines in each half-circled polygon refer to the network used by evacuees to evacuate. The service area of population and ESB correspond to the accessible areas for each point. During disaster, population will move away from the shorelines to find the closest facility to evacuate. Meanwhile ESB serves a particular area or population who are in the most at-risk condition during disaster.

Figure 5.21 illustrates how the locations of additional ESBs were selected. The steps were as follows:

1. The red cross corresponds to the point of origin where evacuees start to move to find the closest ESB. From the point of origin, service areas were developed using Service Area command of Network Analyst. The 17-minute of TT was used as impedance for the process. The direction of travel can be set based on behavior of people during disaster. Usually, people will run away from the shorelines.
2. The blue polygon in figure 5.21 (a) shows the accessibility of population center (centroids) including all accessible streets which can be reached within the available TT.
3. The service areas were then built for many centroids by considering the capacity for additional ESBs required, because population from these centroid tessellations

later would be added to fulfill the capacity of ESB. The results can be seen in Figure 5.21 (b, c, d)

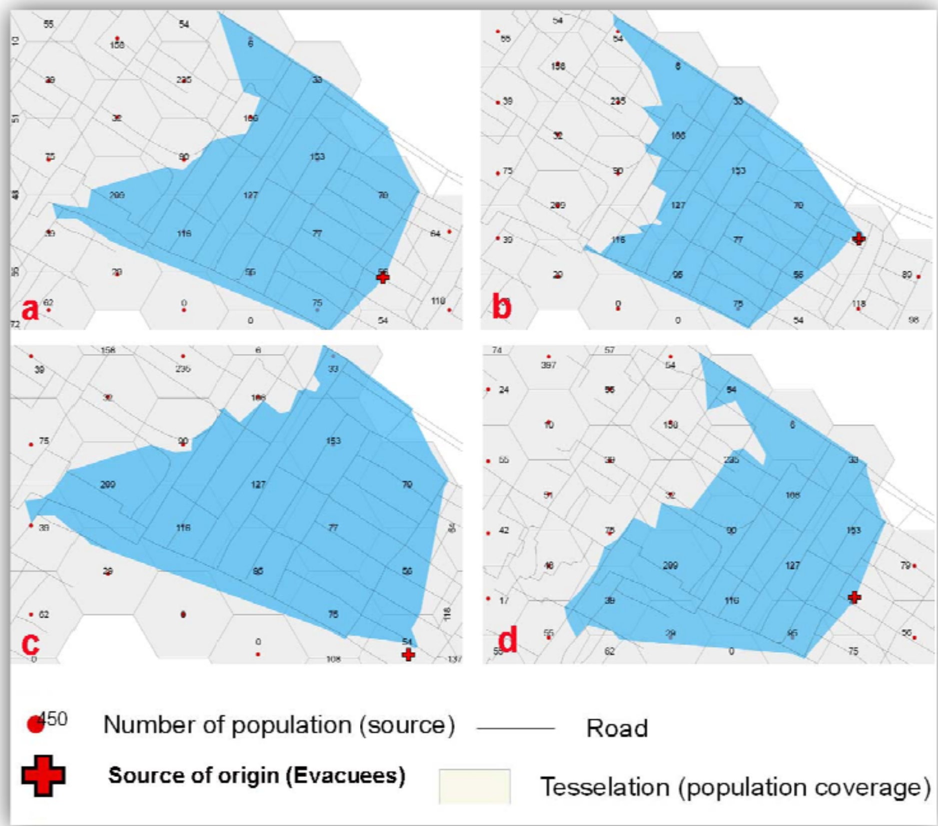


Figure 5. 21. The process of deriving service area (step 1-3)

The capacity of additional ESBs is adjusted to meet the required capacity. It will depend on the construction cost, the available of open space, and also the existing buildings which can be retrofitted. Even though, retrofitted will generally be more difficult rather than to build a new tsunami-resistant building, it still can be one alternative for evacuation purposes.

4. This process resulted in many polygons of service area which overlay one another. The following Figure 5.22 (a) shows the overlaid service areas from four centroids (source of population). Each polygon then was converted to shape file. An attribute was then added and given 1 value (see Figure 5.26 (b) in red dash box).

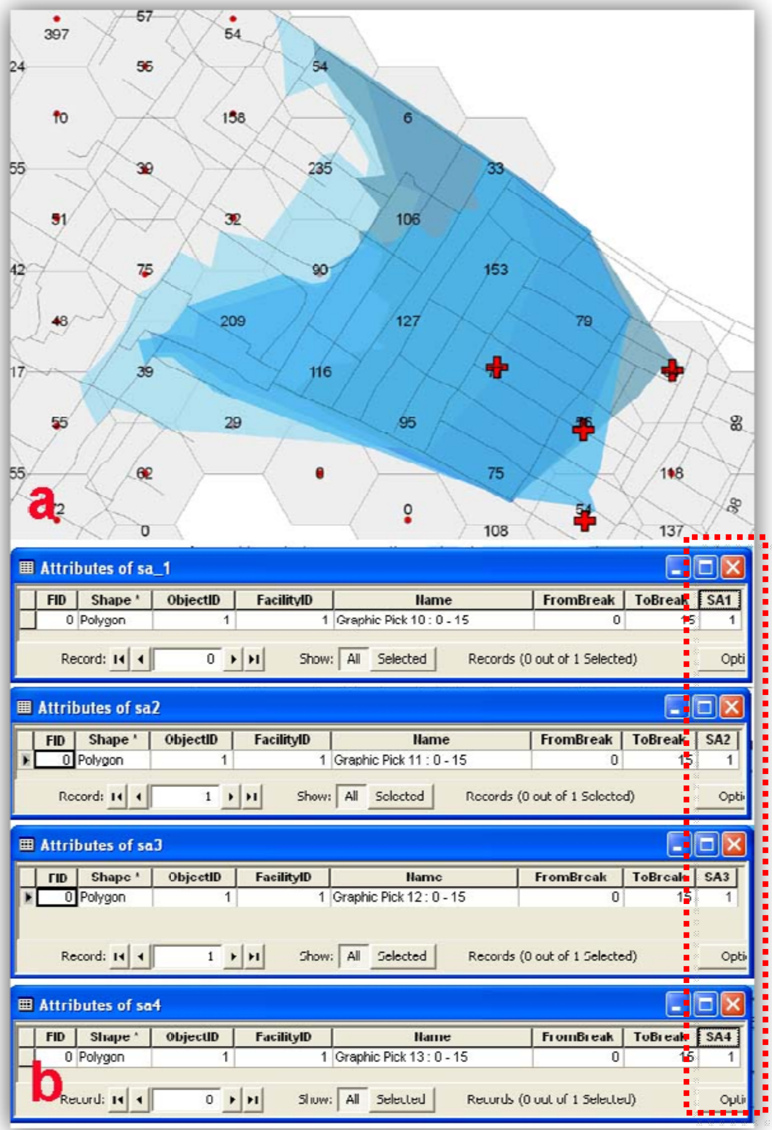


Figure 5. 22. The process of deriving service area (step 4)

5. All polygon of service areas were merged using union command of ArcGIS. The result is showed in Figure 5.23 (a)
6. In the result file, an attribute was added and the value was the total value from polygon attributes of service area 1, 2, 3 and 4 in Figure 5.23 (b) in red dash vertical box.
7. Polygon which has the highest value in its attribute refers to the most accessible polygon (red dash horizontal box in Figure 5.23 (b)). The proposed locations for additional ESBs were determined by looking at the most overlapping areas of the service areas which have been built.

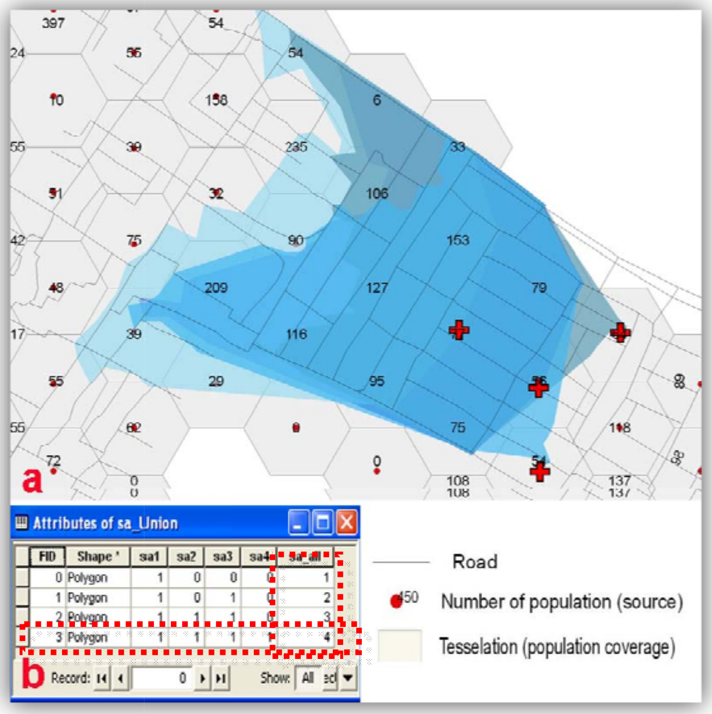


Figure 5. 23. The process of deriving service area (step 5-7)

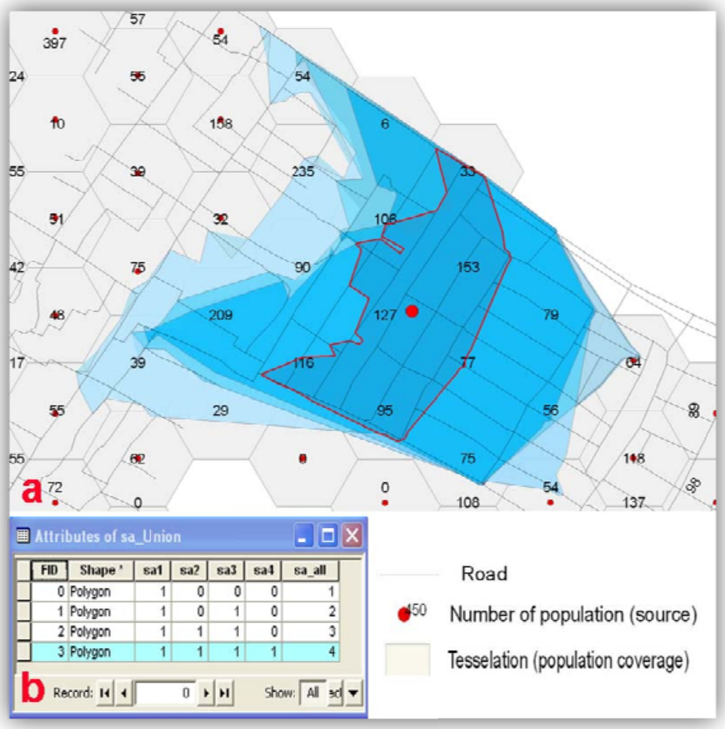


Figure 5. 24. The process of deriving service area (step 8-9)

8. The overlapping area (the red polygon) indicates the area which were the most accessible areas (Figure 5.24 (a)).
9. The centroid of the most overlapping area (the red dot inside the red polygon) would be proposed as additional ESB. Figure 5.24 (b) displays its attribute.
10. The next step is to check the suitability of location using land cover map (Figure 5.25. This figure shows land cover map with proposed location for additional ESB (red dot) and red polygon refers to the service area of the proposed ESB (union polygon from step 5).
11. From the land cover map, it was obvious that the areas inside the red polygon consisted of residential areas, open spaces, mix crops and paddy. The proposed location of additional ESB was located in the residential areas, which was not suitable for additional ESB. Hence, the location of additional ESB therefore, would be shifted to open areas as the first priority. The precise location of additional ESB can be at any location in red polygon because all locations in this polygon are accessible from selected centroids which includes in the process (step 1-10).

Figure 5. 25. The proposed location of additional ESB

Chapter 6.Model Input and Other Data

This chapter describes the results of the processed data which support the evacuation model. It begins with the description about the inundation map chosen for this research. Further, the building maps, existing evacuation shelter buildings and their capacity, and estimation of population are presented. This chapter ends with the description about the accessibility model.

6.1 Model Input

6.1.1 Building Assessment

6.1.1.1 Building Inventory

The detailed building classification was needed since it contributes in the evacuation process as a source of evacuation where people are concentrated. Buildings also serve as target of evacuation (potential shelters). Different building uses would give different distribution of population over the day. Hence, by applying different scenario of population would therefore result in different strategy of evacuation. For these purposes, building classes were classified into worship, factory, fish market, hotel, residential house, mosque, office, 'ruko', school, shop, and sport center. Ruko stands for 'rumah toko' which is meant multi-storey house which has function as shop (usually the first floor) and the second floor is used by the owner to live.

During fieldwork the classified building use maps have been checked. There were 141 buildings taken for field observation in location #1 and 54 samples for location #2. The samples were taken from all building sites comprise of 29 buildings of sea-front site, 25 buildings of river-front site, and 87 of tsunami-reached inland site. Meanwhile for the second area, there were 21 buildings of sea-front site, 4 buildings of river-front site, and 29 of tsunami-reached inland site.

For each building visited, pictures were taken (Figure 6.1). This figures show the activity of building observation during fieldwork. Accompanying the building survey, open interview was also conducted to many key persons. Several questions related with their perception regarding tsunami and evacuation were asked. Additionally, the information such as the use of the buildings were taken, also other information, e.g. the number of workers, the number of student, the possibility of building as tsunami evacuation point, etc. Further, this information was used not only for validating the building map based on their uses but also for estimating the population in different scenarios (day and night-time).

Figure 6.1 shows building observations in the different location and in various building uses. For example, Figure 6.1 #(3) was located in a private school which has 4 floors. In this location, the author interviewed the head of administrative section asking about the number of students and teachers. There are 150 students and 40 teachers who studied there from 07.00 am until 02.00 pm. During the night, the school is empty and only two securities stay in the location.

Figure 6. 1. Building inventory during fieldwork in study area #1
Source: Fieldwork (2009)

Figure 6.1 #(7) shows the activities in Fishing Market (Tempat Pelelangan Ikan/TPI) in Tegal Kamulyan village. The author interviewed the head of TPI Tegal Katilayu. He explained that the activity in this market begins at noon until 03.00 am in the afternoon. There were approximately 75 fishermen, 7 TPI officers, 8 cleaning services and approximately 25 buyers. During the night, no one stays in TPI. Further, these data related to the occupant number per building will be stored in the attributes of population data.

The final results of building inventory can be seen in Figure 6.2 and Figure 6.3. The description on how to perform the classification process and field observation can be found in sub chapter 5.3.3 and sub chapter 5.4.2 respectively. From the building maps that had been checked, it can be concluded that most of the building uses in the study areas were dominated by settlements. It covers almost 90% of the whole buildings in study area #1 and 95% of buildings in the second area. Commercial areas, for instance shops, cover less than 3% of the building uses in the first location. Most of the commercial areas were located in the northwest part of the city. They were concentrated along the main road. The other types of building uses cover less than 1% of the whole buildings in the study areas, such as offices, factories, schools, etc.

Figure 6. 2. The building map of study area #1

Figure 6. 3. The building map of study area #2

6.1.1.2 Building Assessment for ESB

The existing evacuation target points in study areas were very limited. From 13 buildings which was expected potential as existing shelter buildings, only seven buildings were adequate for evacuation purposes (Table 6.1). Four of them share the same service areas due to the close position to each other.

Table 6. 1. The existing evacuation shelter building

No	Name, location, Coordinate	Function, floor, distance from shoreline	Pictures
1	SMA Al-Irsyad, Sidanegara, WGS84, UTM 49S 281476, 9146883	School, 3 floors Shore distance : 1.328 m	
2	STIKES, Sidanegara, WGS84, UTM 49S 281494.4, 9146957	School, 3 floors Shore distance : 1.366 m	
3	Masjid Al-Islah, Sidanegara, WGS84, UTM 49S 281518.1, 9147038	Mosque, 2 floors Shore distance : 1.400 m	
4	SMP Al-Irsyad, Sidanegara, WGS84, UTM 49S 281549.2, 9147056	School, 2 floors, Shore distance : 1.386 m	
5	SD Al-Azhar, Sidanegara, WGS84, UTM 49S 281444, 9146765	School, 2 floor Shore distance : 1.283 m	
6	SMP Al-Azhar, Sidanegara, WGS84, UTM 49S 281362, 9146830	School, 2 floor Shore distance : 1.425 m	
7	SMK Srimukti, Gunung Simping, WGS84, UTM 49S 281844.9, 9147439	School, 4 floor Shore distance : 1.398 m	

Source: Fieldwork (2009)

Buildings which can function as shelter buildings mainly are public facilities or public service oriented function, multi-storey building, reserve space for additional capacity, well planned and have a good construction quality. FEMA (2008b) further explained that those buildings can be single buildings or part of a larger facility. They can be single-purpose facilities, or multi-purpose facilities. They can also be single-hazard (for tsunami only) or multi-hazard facilities. Those buildings could be mosque, school, parliament building, government office, market, shopping centre, convention centre, sport hall, hotel, and parking building, etc.

Many shelter buildings are located close to each other. Hence, two buildings which are located in the same location were considered as one evacuation shelter destination. Mostly, the buildings which are potential for tsunami evacuation shelters are located in the study area #1. So far, no buildings which could be identified potential for tsunami evacuation shelters in the second location, since mostly the areas are dominated by settlement and agricultural areas.

The assessment of building as evacuation destination was done based on visual observation. The number of floors, design, construction, alternate function and the location of the building were several criteria used to assess the buildings. In fact, more comprehensive building assessment is necessary to be conducted. It comprises an assessment of construction quality such as earthquake resistance and tsunami resistance done by the expert. The aim is to provide tsunami resistant structures that are intended to be a safe place for evacuees during tsunami event.

As noted previously, the duration of occupancy in a tsunami vertical evacuation shelter building could be 24 hours or more. So in this case, FEMA (2008c) stated that food and water will be needed, and storage areas for them should be included in the design of the safe room. These issues should be addressed in the operations plan for the safe room. From field visit to several existing shelter buildings, the author found that STIKES and SMA Al Irsyad (Figure 6.4) were buildings which are supported with such facilities. Furthermore, there is mini hospital which can be used to cure injured people in emergency situation.

Further, observation to the buildings was conducted regarding sanitation facilities such as separated toilets for men and women and also clean water. Figure 6.5 shows the clean water facilities in SMA Al Irsyad buildings. ICC-500 *after* FEMA (2008c) stated that if the occupancy is less than 50 persons so one toilet is sufficient. FEMA (2008c) recommended a minimum of two toilets for both tornado and hurricane community safe rooms. In general, this standard could be use for short-duration occupancy for tsunami evacuation.

Figure 6. 4. Many facilities which can be used to support evacuees need in emergency situation (Source: Fieldwork, 2009)

Figure 6. 5. Clean Water is an important concern that should be provided in emergency condition (Source: Fieldwork, 2009)

6.1.1.3 ESB Capacity Estimation

Evacuation is rarely an individual process. Evacuations usually take place in a group context (Sorensen, J. and Vogt, 2006). In emergency evacuation situation, evacuees will just try to find the closest shelter without knowing much about the capacity of ESB. Thus, the capacity of ESB should be prepared to support the number of population in a particular location.

Estimation of building capacity was as necessary as building assessment have been described above. This information was needed by planners in estimating the number of additional ESBs and their distribution. The calculation of building capacity took into account the existing of furniture such as table, chairs, or desks in the building. For that reason, besides conducting building assessment for building design, construction, and emergency provision, it was necessary to check the availability of free space in the buildings. For example, the author fortunately was allowed to check many school rooms in SMA Al Irsyad and also STIKES during fieldwork. From the observation being conducted many rooms in those buildings could be used for evacuation purposes since the free spaces exist. Many rooms are fully empty and the others are partly filled with furniture (Figure 6.6). Figure 6.6 #(1) shows a laboratory which cannot be used for evacuation since it is full of furniture and also chemical stuff which can harm people, whilst Figure 6.6 (4) is an example of classroom which is fully empty. Figure 6.6 #(2) and Figure 6.6 #(3) are examples of classrooms which can be used for evacuation purposes since the existing furniture can be removed outside the classroom.

Figure 6. 6. Building observation regarding free space for evacuation purposes
(Source: Fieldwork, 2009)

For the existing potential shelter buildings, the estimation could be conducted based on the building areas. So the number of evacuee to be sheltered can be predicted. Whilst for additional shelter buildings, the capacity of such building can be design to fulfill the required capacity needed based on the population number in particular areas. The capacity of potential evacuation shelter buildings that have been assessed are presented in the following table (Table 6.2). Figure 6.7 presents the locations of each evacuation shelters spatially.

Table 6. 2. The capacity of potential existing esb based on building assessment

ESB Nr	Build.Nr	Name of Building	Floors	Build.Area (m2)	TEBC (person)
01	1114	SD Islam Al Azhar	2	2,368	710
	1123	SMP Islam Al Azhar	2	1,360	408
				3,728	**1,118**
02	1131	SMA Al Irsyad	3	6,460	1,938
	3158	STIKES	3	3,662	1,098
				10,123	**3,037**
03	1282	Masjid Al Islah	2	448	349
	1281	SMP Al Irsyad	2	2,312	694
				2,760	**1,043**
04	3864	SMK Srimukti	4	**2,721**	**816**

Source: Data Analysis (2009)

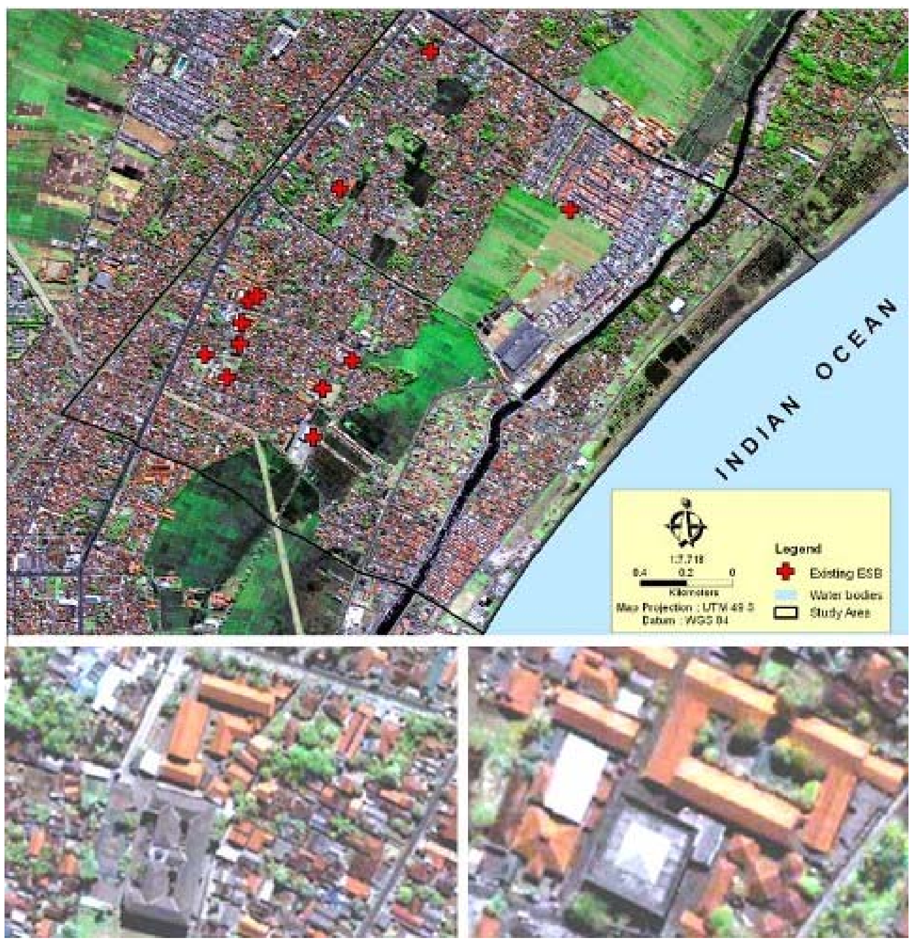


Figure 6. 7. The distribution of potential existing ESB #(1) and zoom in existing evacuation shelter buildings #(2, 3)

From Table 6.2, it can be seen that the shelters #2 has the highest capacity for evacuees (3.037 persons). These shelter buildings consist of STIKES building and SMA Al Irsyad (SMA here stands for Senior High School). Meanwhile, the smallest capacity refers to shelter #4 (816 persons). The overall capacity for existing evacuation buildings was 6,014 persons. If this value was then compared to the total population of study area #1 which is approximately 112,000 people, it is obvious that this area need more shelters. Furthermore, by looking at the situation of the area which is located in a flat coastal area, vertical evacuation shelter buildings and evacuation plan for tsunami evacuation are a must.

The main issue in determining the capacity of ESBs is in deciding the minimum square footage per person. The longer the duration the greater the square footage needed per person. As consequences, less people could be sheltered and more ESBs needed for evacuation purposes. Finally, it will also determine how many ESBs that should be added in particular location.

6.1.2 Road Network Assessment

The existing road network was obtained from the topographic map which had been improved using the Quick-Bird image. The existing road network data which was in shape file format was overlaid with the Quick Bird image. Then the missing roads were added using heads up digitizing in ArcGIS (see chapter 5.3.4 for more detailed explanation). This road network was also added during fieldwork by using mobile PDA and GPS (see sub chapter 5.4.4). The following figure shows part of the sample road locations (Figure 6.8). During fieldwork, many missing roads were identified. Usually they were categorized as path and were located in the middle of settlement and covered by trees, making difficult to identify them from the image (Figure 6.8 #(5)).

Figure 6. 8. Road checking and measurement during fieldwork

Based on the width and surface condition, the road network was classified into five classes (Table 6.3). The improved road networks are presented in Figure 6.9 and 6.11. Meanwhile, the road networks which were resulted from topographic map are presented in Figure 6.10 and 6.12.

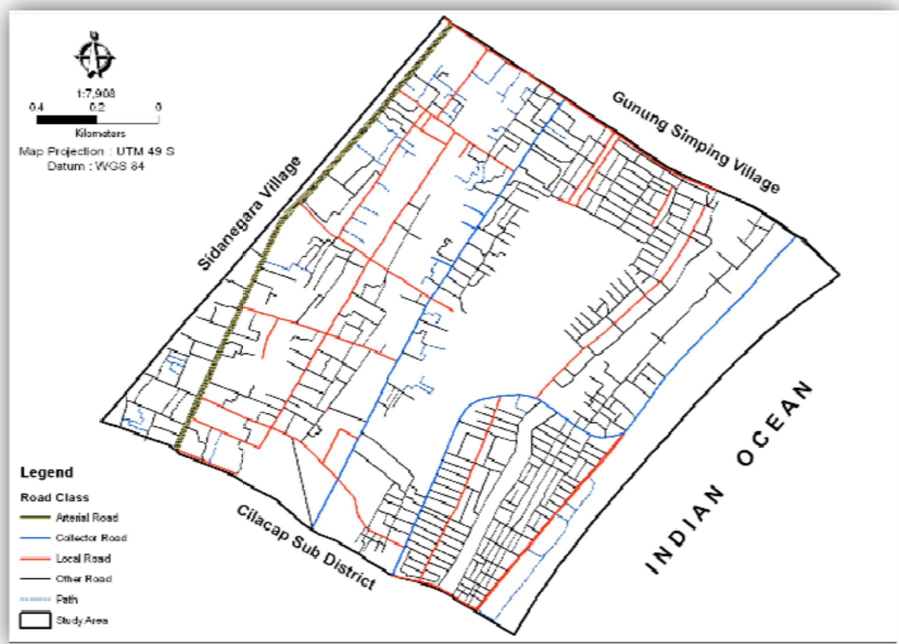


Figure 6. 9. Improved road network of study area #1

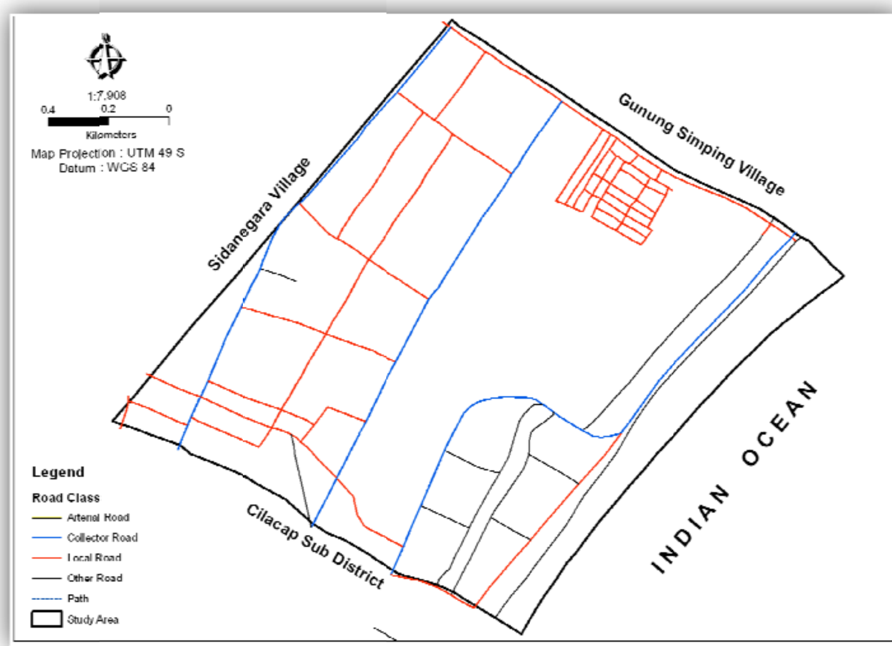


Figure 6. 10. Road network from topographic map of study area #1

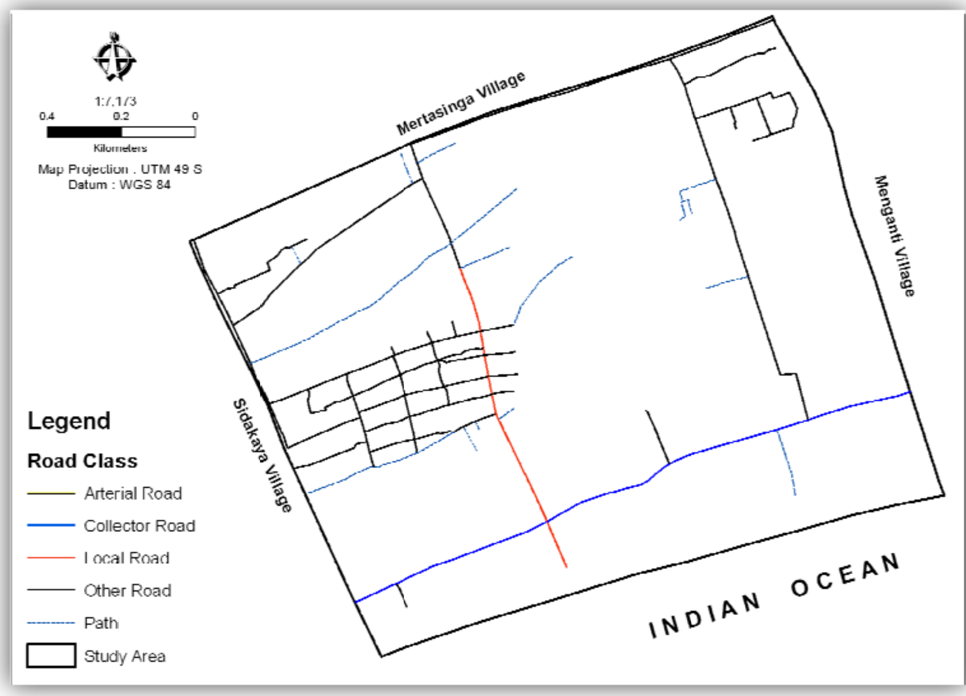


Figure 6. 11. Improved road network of study area #2

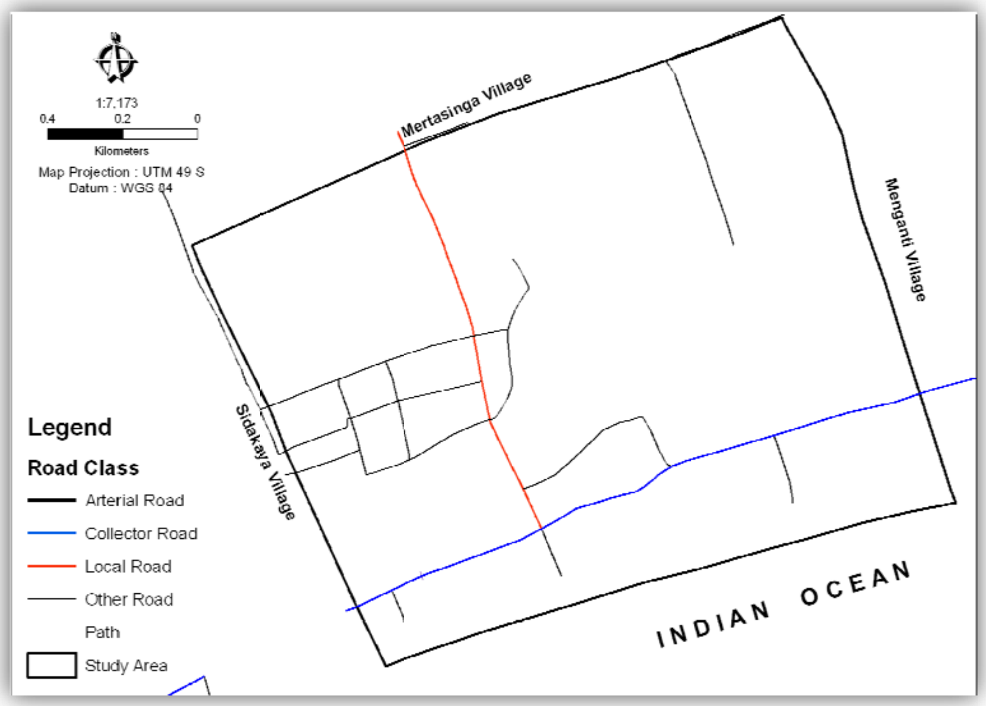


Figure 6. 12. Road network from topographic map of study area #2

Table 6. 3. Road Classification

No	Road Width (meter)	Road Classes
1.	≤ 1.5	Pathway
2.	$1.5 < x \leq 4$	Other Road
3.	$4 < x \leq 7$	Local Road
4.	$7 < x \leq 11$	Collector Road
5.	> 11	Arterial Road

Source: PP 43/1993 *after* Widyaningrum (2009)

The detailed road network is necessary to be implemented in network modeling. These road networks serve as connection to the shelters and provide the evacuation routes. As mentioned in sub chapter 2.8, the evacuation of tsunami in this research was assumed to be conducted by walking. This is because the evacuation using vehicle, i.e. motorcycle, or automobile can obstruct the roads and moreover, they pose a threat to life (NLA *et al.*, 1998; VC OES, 2006; IOC, 2008c). In addition, mass evacuation on-foot very often is the only means for community to quickly escape from sudden natural disaster. It is also to overcome the problem dealing with the shutting down of roads and transport system. In that case, the residents of the inundation area will be encouraged to walk to safe areas and they should be able to move to vertical evacuation shelters on foot in 17 minutes. In fact, evacuation using vehicles can be possible if only there are separate routes for evacuation by walking and evacuation using vehicles. The other possibility is if tsunami is categorized as long distance tsunami, so there will be enough time for evacuees to evacuate by motorcycle or automobile.

In case of Cilacap, the routes for evacuation are only available for some locations and in the study areas, the routes for tsunami evacuation do not exist yet. So in that case, it is recommended for local authority to provide those routes for tsunami evacuation for the whole Cilacap areas especially which are located in the coastal areas. It is possible to consider having separate routes for evacuation by walking and using such vehicles. As a matter of fact, choosing means for evacuation whether by walking or using vehicles, is an issue that must be decided by local authority and local community as well.

There are many factors which determine the walking speed of people such as road density, number of pedestrian in a group, the signal cycle length, crosswalk markings, stop lines, on-street parking, etc. Not all those factors could be incorporated in determining the walking speed for this research due to the limited data available and also due to time constraint.

In this case, walking speed of evacuees was determined by walking speed of evacuees which was determined by the walking condition and the width of the road. The walking condition of a group of elderly people (0.751 m/sec) was selected. It is the slowest evacuee speed. It was assumed that if the evacuees with the slowest speed can reach the evacuation destination, other evacuees that move faster can reach the ESB consequently (see sub chapter 2.8 for more detailed description related walking speed of evacuee).

During disaster, when people get panic to survive, it was assumed that the crowded condition will slow down the walking speed of evacuees since everybody will try to move faster than the others. In this case the width of the road was used as one factor in determining the speed of evacuees to walk on the network. To estimate the speed of walking at different road width, the space requirement approach is used. It is assumed that if evacuees walk side by side on the street, they need 0.625 sq meters space to walk (see section 5.5.4 for more detailed explanation).

The example calculation of the speed of walking for each class of road is presented in Table 6.4. The equations used were equation 9 – 11 (section 5.5.4). The Vs value then would be used for network datasets creation (Figure 6.13).

Table 6. 4. The calculation of walking speed

No	Road width	Base Capacity (C0)	Actual Capacity (C1)	Actual Speed (Vs)
1	1 m	= 1/0.625 = 1.6 = 1 (round-up)	= 1/0.625 = 1.6 = 2 (round-down)	= 1/2 * 0.751 = 0.38 m/sec
2	4 m	= 4/0.625 = 6.4 = 6	= 4/0.625 = 6.4 = 7	= 6/7 * 0.751 = 0.64 m/sec
3	8 m	= 8/0.625 = 12.8 = 12	= 8/0.625 = 12.8 = 13	= 12/13 * 0.751 = 0.69 m/sec
4	12 m	= 12/0.625 = 19.2 = 19	= 12/0.625 = 19.2 = 20	= 19/20 * 0.751 = 0.71 m/sec

In fact, more detailed data regarding walking speed on the network were needed to have a more realistic network model. For example, the density of the road, the traffic condition and time (in the morning and afternoon there will be more people who commute to school or their workplaces), road surface condition (asphalt, dirt, paving, etc), evacuee condition (walking alone or in a group, carrying heavy bags, impaired person, etc), age of evacuee (elderly people or young children will have different speed of walking) and even weather condition can give effect to the walking speed.

Before performing the analysis, the network dataset should be developed in the detailed road network and set many parameters and rules, such as setting the travel impedance for each segment, defining directions and one-way streets, and also managing restricted turns.

In this research, setting applied to the network datasets comprises time impedance, one-way, and direction (see sub chapter 2.5). These settings allow the model to manage the movement of people in the network. It represents the behavior of evacuees to avoid the shorelines. The model can be improved by giving other rule such as turns. Turns can be created at any junction. It gives rule to the network whether turn at certain junction is allow or not, and applied speed of movement at every junctions. But of course, detailed setting and rules for the network datasets need a comprehensive data and timely field survey.

The following figure (Figure 6.13) shows the attributes of network datasets which have been created (see sub chapter 2.5 and section 5.5.3). It can be described as follows:

1. Numeric field called FID and string filed called SHAPE were automatically given by the software.
2. String field named NAMA_JALAN was optional and it refers to the name of the road.
3. String field named ROAD_CLASS and numeric field named WIDTH2_M refer to the class of the road considering their width which was expressed in meter.
4. Numeric field named LENGTH refers to the length of the road.
5. Numeric field called TF_MINUTES and FT_MINUTES refer to the time impedance to travel on the roads which were expressed in minutes. The calculation of these values can be seen in Table 6.4. The minus (-) values for FT_MINUTES or TF_MINUTES were meaning that people cannot move to shoreline directions.
6. String field named ONEWAY was used to set directions. It restricted the movement of evacuees to the shoreline directions. Then create evaluators that interpret its value as follow:
   a. “FT” or “F” indicates a one-way street only permitting travel in the digitized direction of the edge.
   b. “TF” or “T” indicates one-way street only permitting travel against the digitized direction of edge.
   c. “N” indicates a street that does not permit travel in either direction.
   d. Any other value (in this case “B” was used) indicates a street that permits travel in either direction.

Attributes of road_11_area1

FID	Shape *	NAMA_JALAN	ROAD_CLASS	WIDTH2_M	length	TF_MINUTES	FT_MINUTES	ONEWAY
1179	Polyline	Jalan Sri	Local Road	4.5	16.42823	0.416768	0.416768	B
642	Polyline	Jalan Kompeni	Other Road	3	16.484062	0.438871	0.438871	B
91	Polyline	Jalan Manokwari	Local Road	4.5	16.567532	0.420294	0.420294	B
142	Polyline	Jalan Malang	Local Road	4.5	16.675521	0.423034	0.423034	B
24	Polyline	Jalan Kopi	Other Road	2.5	16.677116	0.46325	0.46325	TF
32	Polyline	Jalan Tanjung	Other Road	2	16.809098	0.497602	0.497602	TF
13	Polyline	Jalan Sentosa 5	Other Road	3	16.96244	0.451597	-0.451597	TF
493	Polyline	Jalan Kranji 3	Path	2	17.379097	0.514476	-0.514476	TF
3	Polyline	Jalan Jembatan Ungu	Local Road	5	17.466681	-0.435803	0.435803	FT
191	Polyline	Jalan Ember	Collector Road	7.5	17.530539	0.421621	0.421621	B
119	Polyline	Jalan Damai	Collector Road	7.5	17.546934	0.422006	0.422006	B
239	Polyline	Jalan Jari	Other Road	3	17.608539	0.468823	0.468823	B
157	Polyline	Jalan Bawor	Local Road	4.5	17.715217	0.449391	0.449391	B

Record: 0 Show: All Selected Records (0 out of 1196 Selected) Options

Figure 6. 13. Network datasets attribute

6.1.3 Population Estimation

6.1.3.1 Pre-processing Population Data

During fieldwork, population data from Central Bureau of Statistics of Cilacap Regency was collected. The data which is in village level can be seen in Table 6.5. The study area #1 consists of five villages namely: Sidakaya, Cilacap, Tegal Kamulyan, Sidanegara and Gunung Simping. Meanwhile the second area consists of two villages, Menganti and Mertasinga. The first five villages are located in an urban area which is densely populated. Sidanegara has the densest population among those villages.

Table 6. 5. Population data of study area in village level year 2007

Sub District	Village	Area (km)	Household	Population	Avg number of people per household	Density per km2
South Cilacap	Sidakaya	1,310	2,556	12,049	4.71	9,198
	Cilacap	1,710	4,300	16,050	3.73	9,386
	Tegal kamulyan	2,940	3,160	13,927	4.30	4,737
Central Cilacap	Sidanegara	3,380	7,743	30,638	3.96	9,064
	Gunung Simping	2,170	3,397	14,541	4.28	6,701
North Cilacap	Mertasinga	4,930	3,788	15,493	4.09	3,077
Kesugihan	Menganti	6,550	2,598	10,002	3.85	1,527
Total		22,990	27,542	112,700		43,690

Source: BPS (2007)

Population data in village unit was improved by using population data (number of households) in RW unit. The main objective was actually for knowing the number of occupants per house (per building), so that the number of people to be evacuated could be estimated properly. By knowing the number of households per RW and the number of buildings per RW, we estimated the number of households per building and further this value will be used to calculate the number of occupants per building.

The table below (Table 6.6) shows the number of household per RW collected during fieldwork and Figure 6.14 and 6.15 shows the boundary of each RW resulted from PGIS mapping.

Table 6. 6. The number of household in RW level of study area

No	Sub-district	Village	Name of RW	Number of Households
1	Cilacap Selatan	Tegal Kamulyan	RW 5A	182
2			RW 6	192
3			RW 7	252
4			RW 8	324
5			RW 15B	77
6		Sidakaya	RW 3A	264
7			RW 4A	221
8			RW 15A	142
9	Cilacap Tengah	Gunung Simping	RW 1	264
10			RW 2	183
11			RW 9A	459
12			RW 3B	340
13			RW 4B	276
14			RW 5B	216
15			RW 13A	203
16			RW 14	240
17		Sidanegara	RW 9B	337
18			RW 10	297
19			RW 11	318
20			RW 12	479
21			RW 13B	384
Total				**5,650**

Source: Fieldwork (2009)

Table 6. 7. The number of household in RW level of study area 2

No	Sub-district	Village	Name of RW	Number of Households
1	Cilacap Utara	Mertasinga	RW 10	182
2	Kesugihan	Menganti	RW 12	279
3			RW 13	192
4			RW 14	220
			RW 15	322
Total				**1,195**

Source: Fieldwork (2009)

To improve the number of population in village level, the following steps were conducted.

1. The number of residential houses per RW was calculated. In this case, buildings that function as offices, commercial areas, facilities, etc. were not included.
2. The number of households in each RW was divided by the number of residential houses (see equation 12 in sub section 5.5.4.1). The results showed the number of households in each building/house.
3. Then the number of occupants per each buildings/houses was resulted by multiplying the number of households per house and the number of occupants per house (see equation 13 in sub section 5.5.4.1).
4. For example, if RW 13A consists of 203 households and the number of residential houses in that area were 117 houses, so the averaged number of households per house were 1.2 (there is one household per house in RW 13A). The results of this calculation can be seen in Table 6.8.

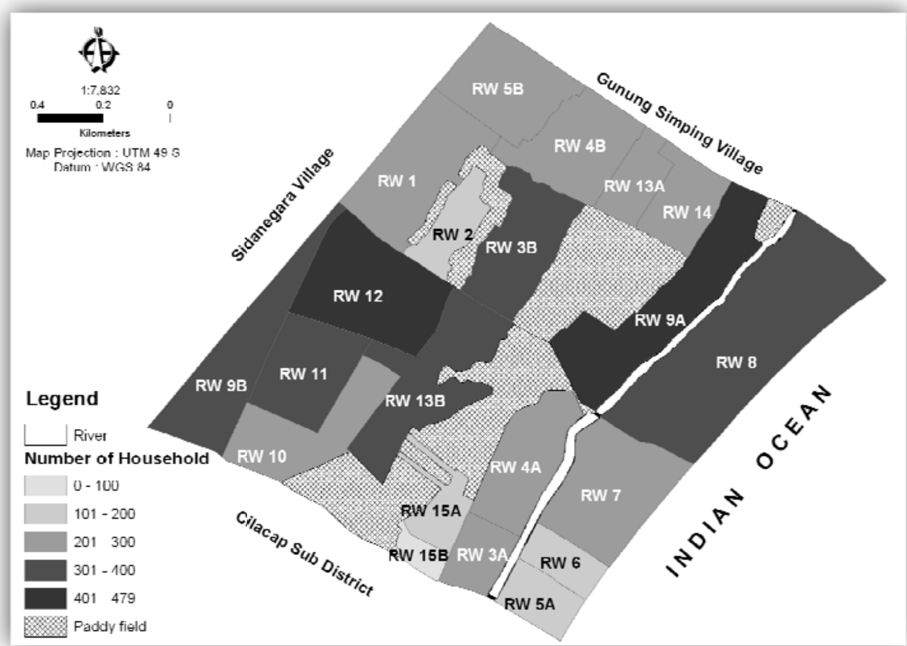


Figure 6. 14. Boundary maps of RW in study area #1

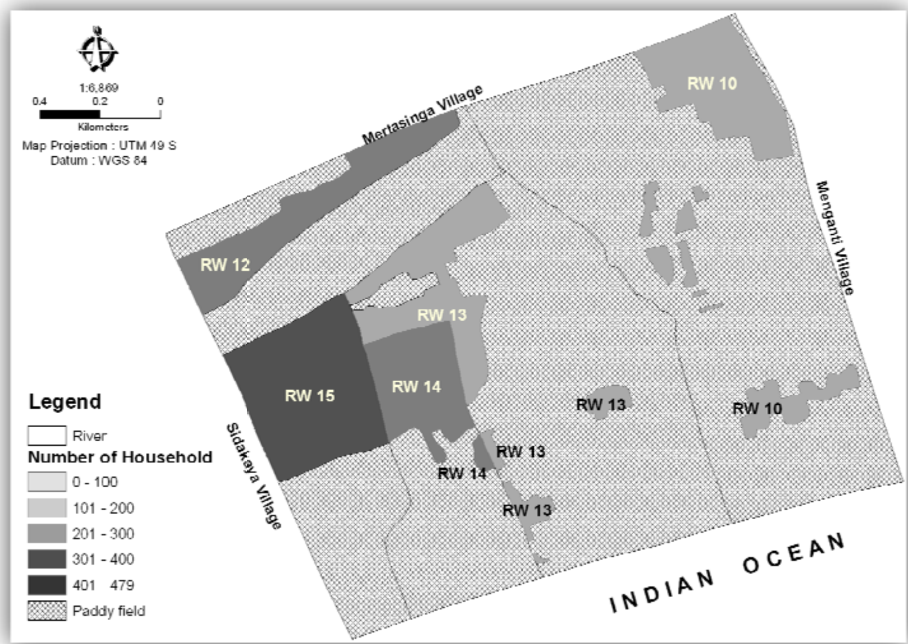


Figure 6. 15. Boundary maps of RW in study area #2

Table 6.8 displays the result of the estimation of number of household in a house. The last column (HsPH) gives the number of household in a house. It varies for each RW. These kinds of data are not available in Central Bureau of Statistics (BPS). From this data (HsPH), we can calculate the number of people in a house by multiplying HsPH with data regarding average number of person per household (this data is available from BPS). The following sub section will describe it in more detail.

6.1.3.2 Estimation of Population in the Houses

Calculation of population number in houses was conducted by calculating the number of residential houses per hexagon and multiplying the result with the number of occupants per house (see equation 14 and 15 in sub section 5.5.4.3).

In this case, number of occupants per house was calculated by multiplying number of household in a house and average number of person in a house (see equation 13 in sub section 5.5.4.1). The number of houses was calculated using ArcGIS software by selecting the houses attributes. The calculation can be seen in Table 6.9.

Table 6. 8. Estimation of number of people per household for each RW

RW	Avg person/hh	Nr of hh (HPR)	Nr of house (BPR)	Nr of hh/ house (HsPH)
RW 5A	4.3	182	101	**1.8**
RW 6	4.3	192	181	1.1
RW 7	4.3	252	218	1.2
RW 8	4.3	324	205	**1.6**
RW 15B	4.3	77	33	**2.3**
RW 3A	4.7	264	169	1.6
RW 4A	4.7	221	180	1.2
RW 15A	4.7	142	66	**2.2**
RW 1	4.3	264	154	1.7
RW 2	4.3	183	96	**1.9**
RW 9A	4.3	459	210	**2.2**
RW 3B	4.3	340	210	**1.6**
RW 4B	4.3	276	189	1.5
RW 5B	4.3	216	111	**1.9**
RW 13A	4.3	203	171	1.2
RW 14	4.3	240	231	1.0
RW 9B	4.0	337	322	1.0
RW 10	4.0	297	213	1.4
RW 11	4.0	318	116	**2.7**
RW 12	4.0	479	241	**2.0**
RW 13B	4.0	384	186	**2.1**
Note: nr=number, hh=household, occ=occupants HPR, BPR, HsPH (see equation 12 and 13 in subsection 5.5.5.1)				

Source: Data Analysis (2009)

Table 6. 9. Calculation of population in the house

Hex Label	Household per House	Avg Person per Household	Number of House	Number of Occupants	
				Day	**Night**
01001	1.8	4.3	16	= (50% * 1.8 * 4.3 * 16) = 62	= (100% * 1.8 * 4.3 * 16) = 124
01004	1.6	4.7	10	= (50% * 1.6 * 4.7 * 10) = 38	= (100% * 1.6 * 4.7 * 10) = 75
01005	1.8	4.3	27	= (50% * 1.8 * 4.3 * 27) = 104	= (100% * 1.8 * 4.3 * 27) = 209
01006	1.6	4.7	31	= (50% * 1.6 * 4.7 * 31) = 117	= (100% * 1.6 * 4.7 * 31) = 233
01008	1.7	4.3	5	= (50% * 1.7 * 4.3 * 5) = 18	= (100% * 1.7 * 4.3 * 5) = 37

Source: Data Analysis (2009)

The calculation in Table 6.9 shows the process of calculating population number in houses in one hexagon. The number of 'households per house' data for each tessellation was obtained after overlaying the hexagonal tessellation with RW maps. Hence, the calculation of day and night population could be conducted by multiplying all data (households per house, number of person in household and number of houses).

6.1.3.3 Estimation of Population in the Facilities

Calculation of population number in facilities (non-residential use) is conducted by incorporating architectural space requirement and field observation. Table 6.10 shows the calculation of population in facilities by using both approaches. Budiarjo (2006) stated that space requirement approach is actually estimating the number of occupants from the area of building spaces using the norms or standards of architectural design. Further it was stated that in reality, the space requirement may vary related to the facility type or class such as different grade of school and hotel.

The facilities that exist in study areas include: mosques, schools, boarding houses, offices, shops, hotels, factories and fish markets. To estimate the number of occupants in each facilities, general norms and standard of design were incorporated and also by considering the real number of occupants in the facilities.

Table 6. 10. Calculation of Population in the Facilities

Hex Label	Facilities	Area (sq meter)	Day Population	Night Population
01019	Mosque	101.3	= 10%*101.3/1.8 = 6 person	1 security
01020	Shop	-	= 2 shopkeepers+2 customers = 4 person	1 security
01067	Fish Market	-	= 75 fishermen + 25 buyer + 7 cleaning services + 8 officer = 115 persons	1 security
01073	School	1523.8	= 110%* 1523.8/4 =419 persons	1 security
01180	Hotel	4317	=50%*4317/16 =135 persons	= 100%*4317/16 = 270 persons
01054	Sport Center	1658	= 60%*1658/1.2 = 829 persons	2 securities

Source: Data Analysis, 2009

All information related to the number of people in house and facilities in day and night population scenarios was saved in the attributes of the centroid of hexagonal tessellation, as described in Figure 6.16 up to Figure 6.19. In those figures, the population number is displayed using hexagonal tessellation as a basis. From the calculation, the population number of people during daytime and night-time for both study areas are displayed in Table 6.11.

Table 6. 11. Population number for daytime and night-time scenario

No	Study Area	Population (person)	
		Daytime	**Night-time**
1.	Area #1	24,566	24,357
2.	Area #2	2,831	5,010

Source: Data analysis (2009)

From the Table 6.11, it can be seen that the number of people in daytime and night-time are almost the same for area #1, because the population number in daytime are coming from at home population and facility population such as at work, at school and special facility population (hospital, large institution, large retail center, etc). Further, Southworth (1991) explained that there are two reasons to include facility population in the database. First, there may be large number of people to be present during a typical day (workday or weekend). For example, shopping malls, concentration of hotels, and centers of higher education. A second reason for inclusion may be unique problems associated with a rapid evacuation. For example, hospital and nursing homes for sick and elderly may have problem with patient movement and vehicle availability; prison are another example where special attention. Meanwhile for the second study area, the different number between daytime and night-time is almost twice. It is because in second location, the residential houses are dominant.

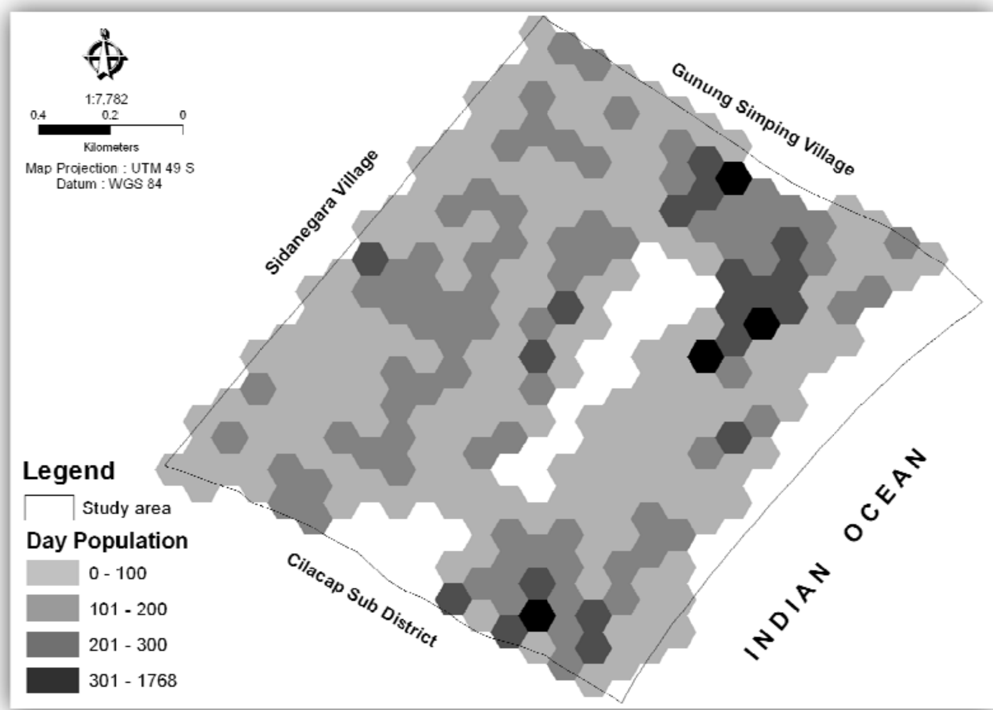


Figure 6. 16. Day population distribution in study area #1

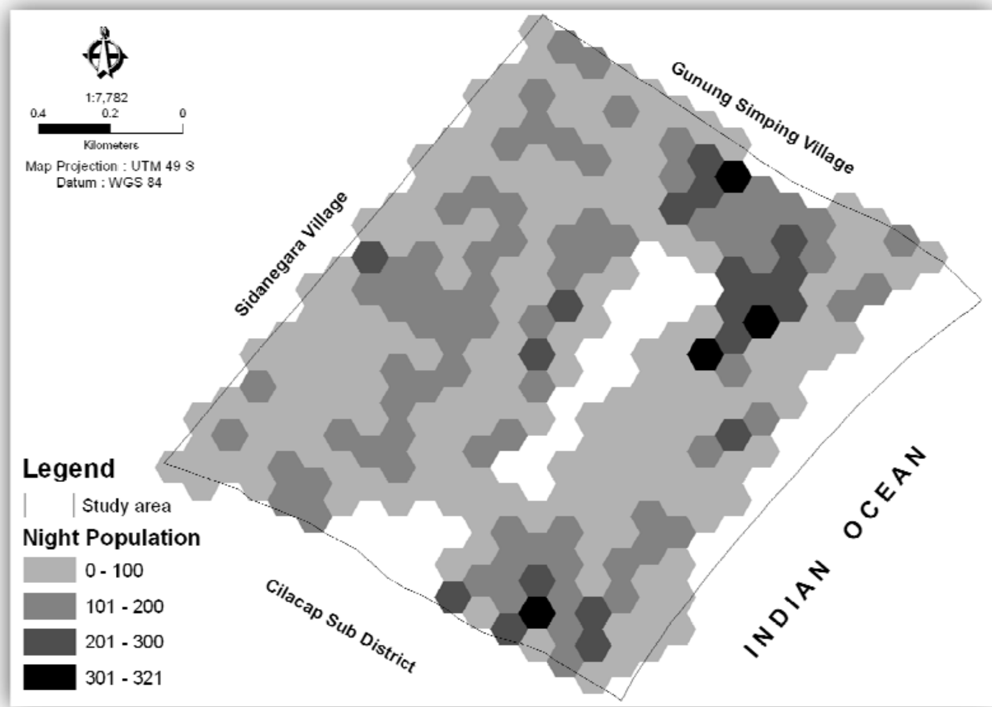


Figure 6. 17. Night population distribution in study area #1

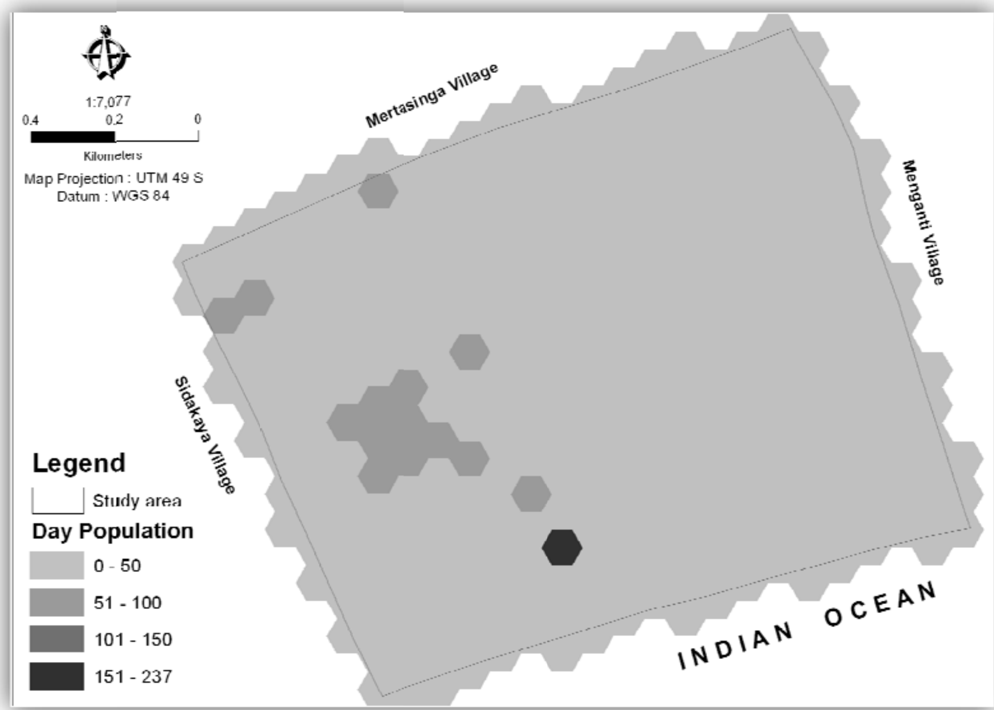


Figure 6. 18. Day population distribution in study area #2

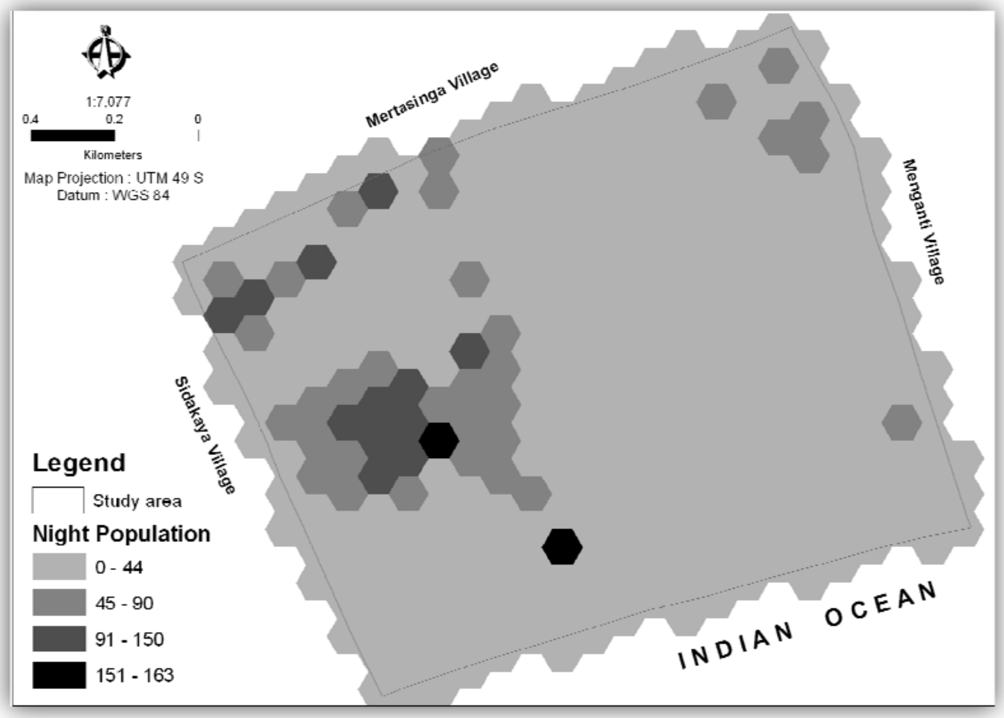


Figure 6. 19. Day population distribution in study area #2

Population data are the main input for evacuation model. The evacuation shelter buildings can be allocated properly if the population data such as the number of population and their distribution has already known.

To estimate the number of population in facilities, there were two approaches were conducted, by interviewing key persons such as principal of school, officer, seller, etc and by using space requirement approach. Having population data from interviewing key persons will result in more accurate and precise data compare to the population data using space requirement approach. For example, private school which has 1,650 squares meter building area (4 floors), it may have 650 persons if the calculation was conducted by using space requirement approach. In reality, there are only 190 persons comprises 150 students and 40 staffs (including teachers). These data based on field observation and interview to the key person. So, the chosen of the method will depend upon in which scale the research will be conducted since interviewing key persons will be time consuming and expensive for small-scale or regional scale.

6.2 Other Data

6.2.1 Tsunami inundation map

Tsunami hazard maps was developed by Mardiatno (2008). The model was developed using TUNAMI which consist of 3 parts: the tsunami source (initial condition), tsunami propagation and inundation.

The tsunami numerical model using worst case scenario (Earthquake Mw 8.5) results in tsunami hazards in terms of the extent of inundation and local flow depth distribution within Cilacap coastal areas. These tsunami hazard maps show the estimated tsunami inundation zone which were classified into 5 classes, as can be seen in Table 6.12.

Table 6. 12. The Tsunami Inundation Class

No	Class	Flow Depth (m)
1	Very low	>0 – 0.25
2	Low	>0.25 – 0.5
3	Medium	>0.5 – 1.0
4	High	>1.0 – 2.0
5	Very High	>2.0

As shown in Figure 6.20 the first study area was highly impacted by tsunami waves. The tsunami waves can reach further inland up to 1.5 km away from the shorelines where the densely populated areas are located. The flow-depth of 1 – 2 meters high mainly occurs along the river sites which are less than 1 km from the shorelines. Meanwhile, tsunami waves can reach further inland approximately 0.5 km in the study area #2 (Figure 6.21). These areas are dominated by paddy, but there are also a group of settlements and factories. The areas which are not impacted by tsunami inundation (presented dark green in color) or located outside the inundation zones can be assumed as potential safe areas. The safe areas in this case are quite far for the occupants who live near the coastlines because the potential ESBs were located in 1.5 km from the shorelines in study area #1. Whilst, for the second area there are no ESBs exist.

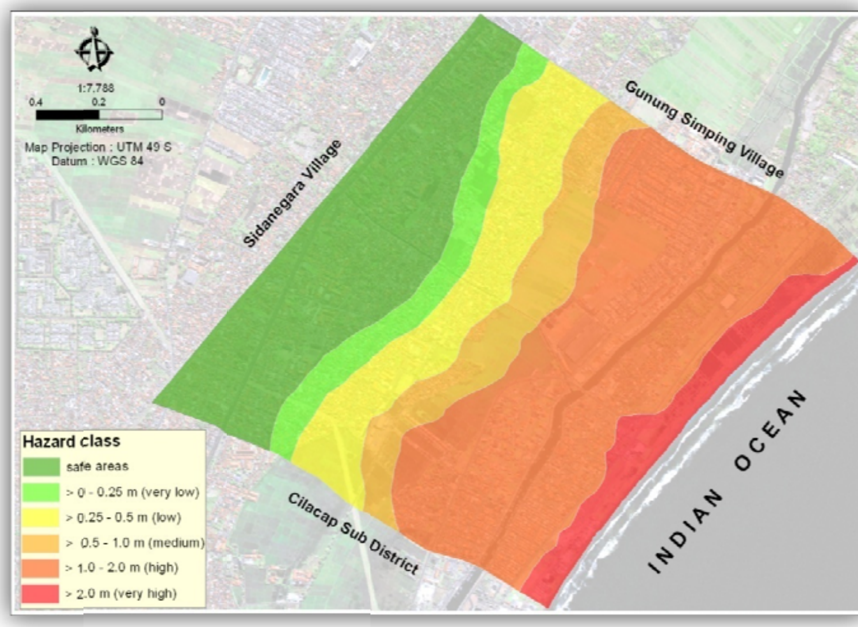


Figure 6. 20. Tsunami hazard map of study area #1

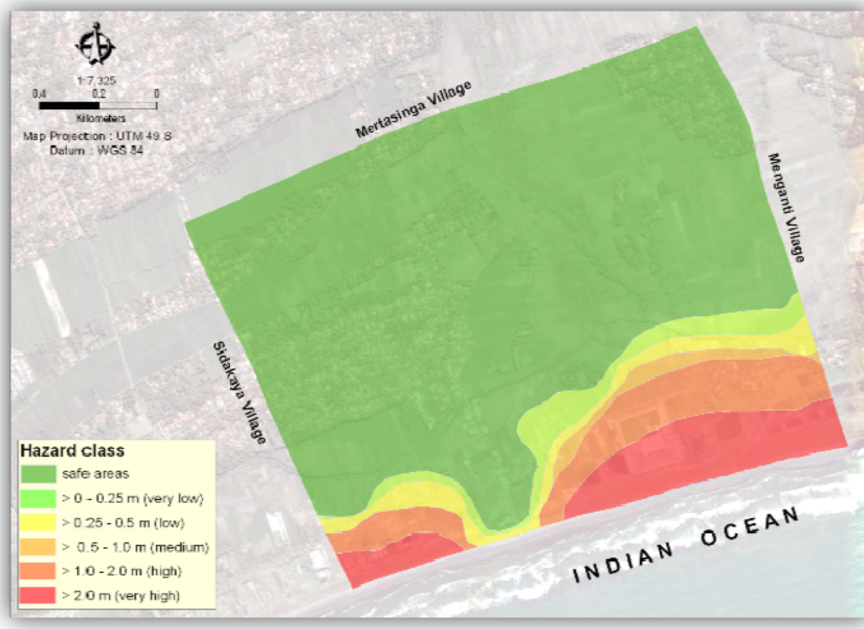


Figure 6. 21. Tsunami hazard map of study area #2

Further, after knowing the inundated areas from tsunami inundation maps, one can determine the safe areas which are not affected by a tsunami wave and hence outside the inundation zone. They are regarded as potential safe areas, where locations of evacuation destination are located.

The different approach in deriving tsunami hazard map or tsunami impact map will result in different danger areas and affected community. Moreover different location of tsunami source will give different tsunami travel time and also evacuation time.

Therefore, more reliable model in determining the inundated areas including tsunami wave height in certain location is necessary. The more reliable model of tsunami inundation will result in the more reliable model of tsunami evacuation. In fact, different scenario of the identification of tsunami inundation zones and safe areas will lead to the differentiation in evacuation planning strategies.

6.2.2 Land cover classification

Land cover map was interpreted visually from QuickBird image and the results were validated during fieldwork. There were more than 200 samples taken for each study area. For each site visited, pictures were taken and coordinates were recorded (Figure 6.22 and 6.23). This figures show the activities of land cover observation during fieldwork.

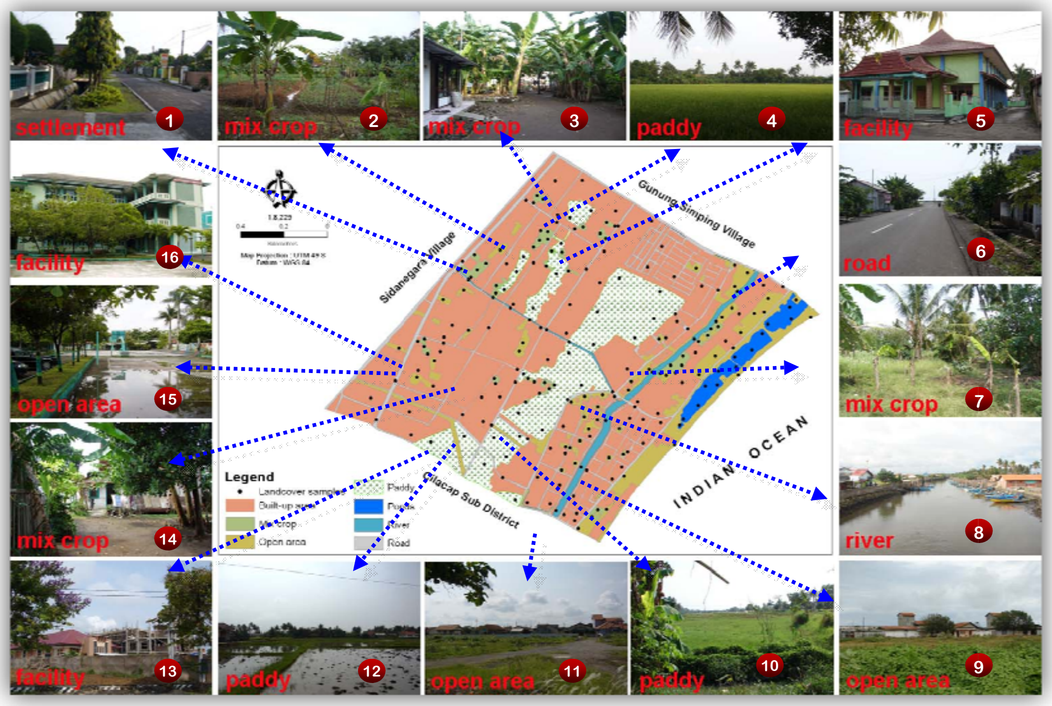


Figure 6. 22. Land cover checked during fieldwork in location #1

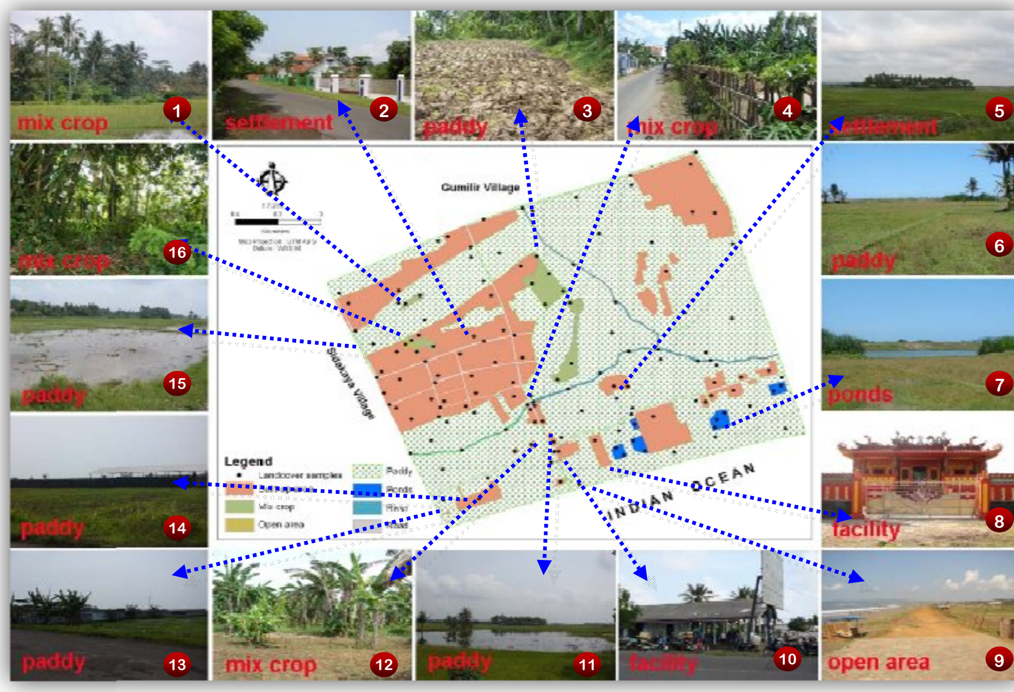


Figure 6. 23. Land cover checked during fieldwork in location 2

Figure 6.22 and 6.23 show land cover observation in the different locations and in various land cover classes. Field observation was necessary since there was different time between land cover map creation and image acquisition. The time different was three years (from 2006 to 2009).

Figure 6.22 #(13) shows the development of a university on the built-up area which previously was paddy. In the developing city, the land cover changes very fast due to the city development, that's why field observation usually is needed to get the recent condition of the areas. Whilst, in the second location, the land cover condition was relatively the same (Figure 6.23). The region is dominated by agriculture area, for instance paddy and mix crops.

The final results of land cover maps which have been verified during fieldwork are displayed in Figure 6.24. It was utilized in the process to ascertain whether certain location suggested by the model was suitable as additional shelters, since the model only consider fast route as the main factor to determine the most suitable location for additional shelters. The fast route was measured in term of travel time on the network. Consequently, land cover map was needed to check the suitability of particular location as additional shelters.

Figure 6. 24. Land use map of the study area #1

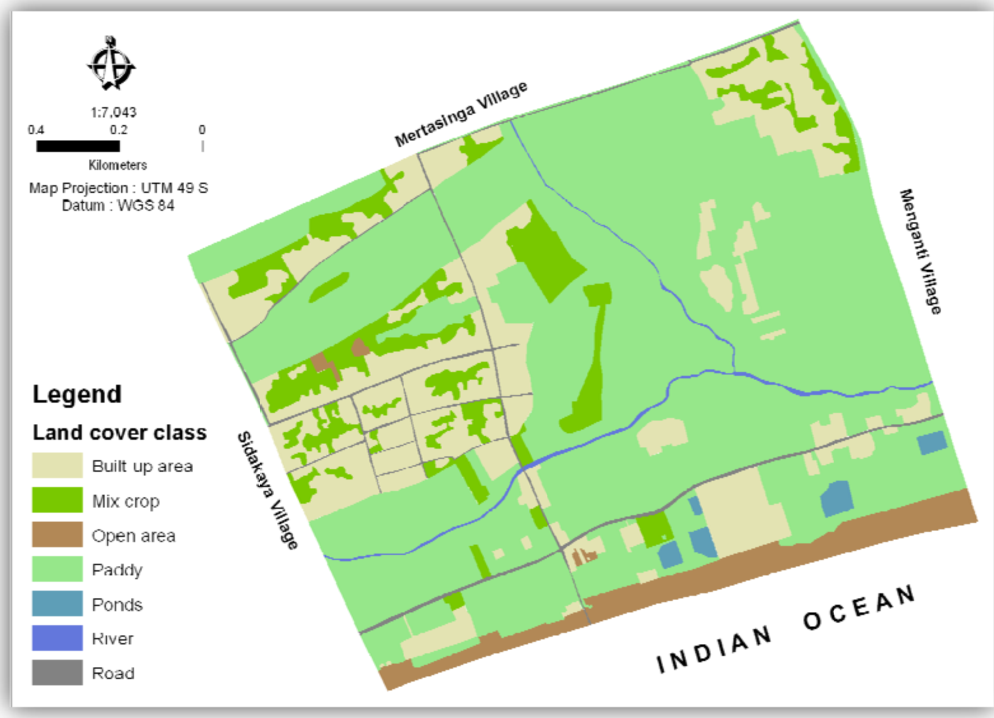


Figure 6. 25. Land use map of the study area #2

The classification error matrix or confusion matrix (or contingency table) has been performed to derive the classification accuracy. The results of classification accuracies are as follows:

Table 6. 13. Error matrix of land cover classification versus field measurement of study area #1

		Field Measurement							
	Class	**BA**	**MC**	**OA**	**PD**	**PN**	**RV**	**RD**	**Total**
Classified	**BA**	45	2	3	0	0	0	0	50
	MC	0	46	3	1	0	0	0	50
	OA	1	6	43	0	0	0	0	50
	PD	1	0	1	32	0	0	0	34
	PN	0	0	1	0	13	0	0	14
	RV	0	0	0	0	0	19	0	19
	RD	0	0	0	0	0	0	31	31
	Total	47	54	51	33	13	19	31	**248**

Producer's accuracy

BA = 45/47 (96%) (4% omission error)
MC = 46/54 (85%) (15% omission error)
OA = 43/51 (84%) (16% omission error)
PD = 32/33 (97%) (3% omission error)
PN = 13/13 (100%) (0% omission error)
RV = 19/19 (100%) (0% omission error)
RD = 31/31 (100%) (0% omission error)

User's accuracy

BA = 45/50 (90%) (10% commission error)
MC = 46/50 (92%) (8% commission error)
OA = 43/50 (86%) (14% commission error)
PD = 32/34 (94%) (6% commission error)
PN = 13/14 (93%) (7% commission error)
RV = 19/19 (100%) (0% commission error)
RD = 31/31 (100%) (0% commission error)

Overall accuracy = (45+46+43+32+13+19+31)/248 = 229/248 = 92.3%

The overall accuracy for land cover classification of location #1 was 92.3%, which meant 92.3% of sampled points in this classification have agreed with field measurements.

The following is the accuracy calculation of location #2. The overall accuracy for land cover classification was 94.2%, which meant 94.2% of sampled points in this classification have agreed with field measurements.

Generally speaking, from the land cover maps in study area #1, it can be concluded that this area was dominated by built-up area (residential areas) for almost 55%. This area was part of city center which has a high population density. Open areas covers almost 21% of the whole areas and mostly were located near the shorelines. Meanwhile, mix crop, paddy and ponds only covers less than 9%, 5% and 2% respectively. On the other hand, location 2 was dominated by paddy field for almost 63%. Built-up areas only cover less than 20%. Mix crop, open areas and ponds covers 9% and paddy only 1% respectively.

Table 6. 14. Error matrix of land cover classification versus field measurement in study area #2

		Field Measurement							
	Class	BA	MC	OA	PD	PN	RV	RD	Total
Classified	**BA**	50	0	0	0	0	0	0	50
	MC	5	45	0	0	0	0	0	50
	OA	0	0	14	3	0	0	0	17
	PD	0	2	0	37	0	0	2	41
	PN	0	0	0	0	10	0	0	10
	RV	0	0	0	0	0	26	0	26
	RD	0	0	0	0	0	0	14	14
	Total	55	47	14	40	10	26	16	**208**

Producer's accuracy		**User's accuracy**	
BA = 50/55 (91%)	(9% omission error)	BA = 50/50 (100%)	(10% commission error)
MC = 45/47 (96%)	(4% omission error)	MC = 45/50 (90%)	(8% commission error)
OA = 14/14 (100%)	(0% omission error)	OA = 14/50 (82%)	(14% commission error)
PD = 37/40 (93%)	(7% omission error)	PD = 37/50 (90%)	(6% commission error)
PN = 10/10 (100%)	(0% omission error)	PN = 10/10 (100%)	(7% commission error)
RV = 26/26 (100%)	(0% omission error)	RV = 26/26 (100%)	(0% commission error)
RD = 14/16 (88%)	(12% omission error)	RD = 14/14 (100%)	(0% commission error)

Overall accuracy = (50+45+14+37+10+26+14)/208 = 196/208 = 94.2%

6.3 Concluding Remarks

From building inventory, it can be concluded that most of the buildings in the study areas were dominated by settlement. It covers almost 90% of the whole building uses in study area #1 and 95% of buildings in the second area. Commercial areas, for example shops, cover less than 3% of the building uses in the first location. The other types of building use cover less than 1% of the whole buildings in the study areas.

There were seven buildings which were potential as evacuation shelter buildings. All of them were located in study area #1. Six of the existing shelters building function as schools and one of them is a mosque. The overall capacity for existing evacuation buildings is 5,308 persons.

Walking speed of evacuees was determined by walking speed of evacuees which was determined by the walking condition and the width of the road. The walking condition of a group of elderly people (0.751 m/sec) was selected. It is the slowest evacuee speed. It was assumed that if the evacuees with the slowest speed can reach the evacuation destination, other evacuees that move faster can reach the ESB consequently. The width of the road was used as one factor in determining the speed of evacuees to walk on the network. To estimate the speed of walking at different road width, the space requirement approach was used. It was assumed that if evacuees walk side by side on the street, they need 0.625 sq meters space to walk.

Population data in village unit was improved by using population data (the number of households) in RW unit. The main objective was actually for knowing the number of occupants per house (per building), so that the number of people to be evacuated could be estimated properly.

Strictly speaking, it can be concluded that the number of people in daytime and night-time were almost the same for area #1 (24,566 persons in daytime and 24,357 in night-time). Since the population number in daytime was coming from at home population and facility population such as at work, at school and special facility population (hospital, large institution, large retail center, etc). Meanwhile for the second study area, the different number between daytime and night-time was almost twice (2,831 persons in daytime and 5,010 persons in night-time).

From supplied model of tsunami inundation, it can be concluded that the first study area was highly impacted by tsunami waves. The tsunami waves could reach further inland up to 1.5 km away from the shorelines where the densely populated areas were located. The flow-depth of 1 – 2 meters high mainly occurred along the river sites which are less than 1 km from the shorelines. Meanwhile, tsunami waves could reach further inland approximately 0.5 km in the study area #2. These areas are dominated by paddy field, but there were also a group of settlements and factories. The areas which were not impacted by tsunami inundation or located outside the inundation zones can be assumed as potential safe areas.

Chapter 7. Evacuation Modeling

This chapter illustrates the evacuation modeling part. The description begins with results descriptions regarding service areas, both based on travel time and capacity and the selecting of proposed additional ESB. This chapter ends by figuring out the evacuation route from source of origin to existing ESB and additional ESB as well.

7.1 Service Area of ESB

Accessibility expresses the ease with which a location is reached from other location through the network. In this research, the accessibility model tried to calculate the capacity and service area of destination location using daytime and night-time scenario.

It is necessary to define the coverage of each evacuation shelter building before applying them in evacuation modeling. The coverage of each ESB refers to the area which can be served by that building as a target of evacuation. The process was conducted by considering the TT and the number of population in the surrounding areas. A service area shows the number and distribution of population to be evacuated. It also shows from which direction the population should be sheltered.

In this research, service areas were developed by giving 17-minute TT as limitation to the model. The one-way rule and direction were given to manage the movement of evacuees. This setting represents a natural tendency of evacuees to move away from the shore. Hence, these resulted in vertical evacuation structures located on the inland side of evacuation zones or service areas. FEMA (2008b) gives a good illustration that can be seen in Figure 7.1.

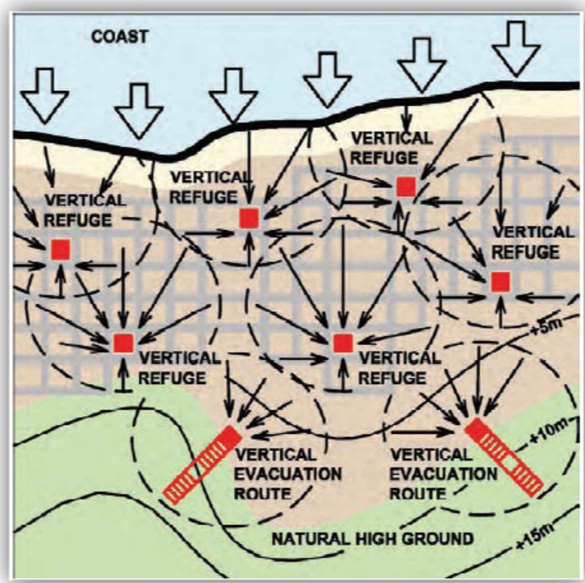


Figure 7. 1. Vertical evacuation refugee considering travel distance and evacuation behavior

7.1.1 Service area based on travel time

The first coverage to be determined was time area. The areas were determined by considering the actual TT which was meant how much time available to move on the network. The model runs using Service Area of Network Analyst. The time impedance of 17 minutes was used since it is the available time for people to evacuate. The location of shelter buildings became the location of facilities. The setting of movement direction was toward facility (see section 5.6.2). Figure 7.2 shows the service areas of each existing ESB.

Since the locations of several existing ESBs are closed to each other, they have an overlapping service area. They have the same coverage and can be reached within 17 minutes from the point of origin (evacuees). For example, STIKES building which is located across Al Islah Mosque, they share almost the same service area. In that case, the service area was then split into two by considering the closest road network. The final service areas based on TT from each shelter can be seen in Figure 7.3.

Consideration must be given to TT, since this was a fix parameter in this model. All the evacuation process should not exceed the available TT. This TT also determines the selecting of location suitable for proposed ESB. The longer the available TT, the more space for vertical evacuation structures would be. Moreover, the more ESB available, meaning that the less capacity needed for each ESB, and on the contrary the less ESB available, the more capacity needed for each ESB in order they can serve exposed population.

7.1.2 Service area based on capacity

Evacuation shelter buildings capacity was necessary to be estimated, since it limits the number of evacuees to be sheltered. The service areas based on TT was used as basis for selecting and calculating the population who can be served by ESB. There were two factors to determine which tessellation can be served by ESB, i.e. the shortest time needed to ESB and the number of population exist in the tessellation.

Service areas considering capacity was determined by using many GIS commands, for instance query, statistics, union and dissolve (see section 5.6.2) since this process cannot be supported by Network Analyst. In this case, the process to determine service area based on capacity became more complex due to further steps required. If functions to support these are available, however, the complexity of such process could be reduced. Extended script for this process actually can be created to be attached to Network Analyst. The concept of developing the service area regarding population capacity was applied by adding the population in closest tessellations by considering the maximum capacity of particular ESB. It needs iteration processes in selecting which tessellations can fulfill the required ESB capacity. Figure 7.4 shows the process of creating both service areas of existing ESB.

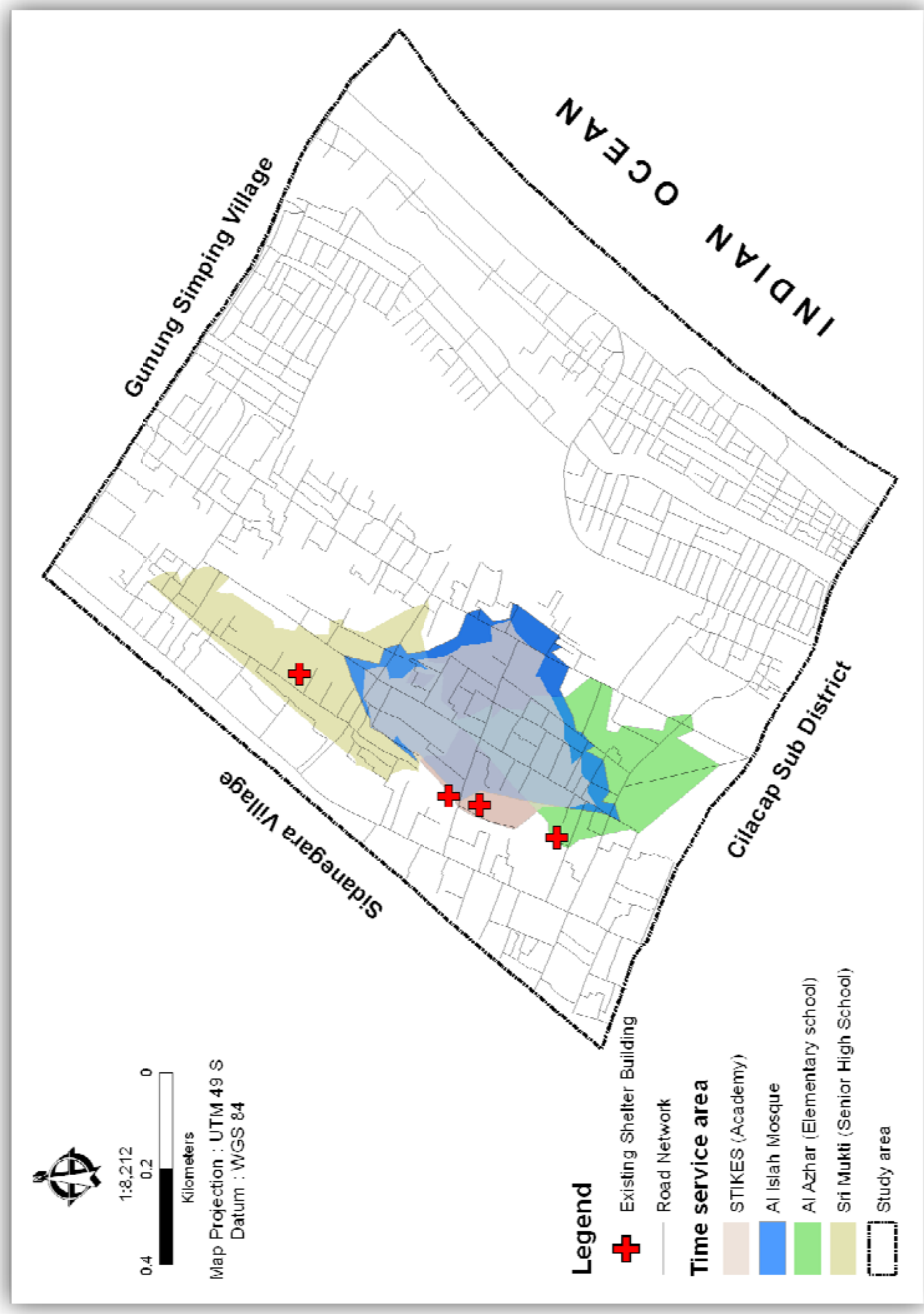


Figure 7. 2. The overlapping service area of existing ESB based on 17 minutes travel time

Figure 7. 3. Allocation of service area for each existing ESB considering 17 minutes travel time

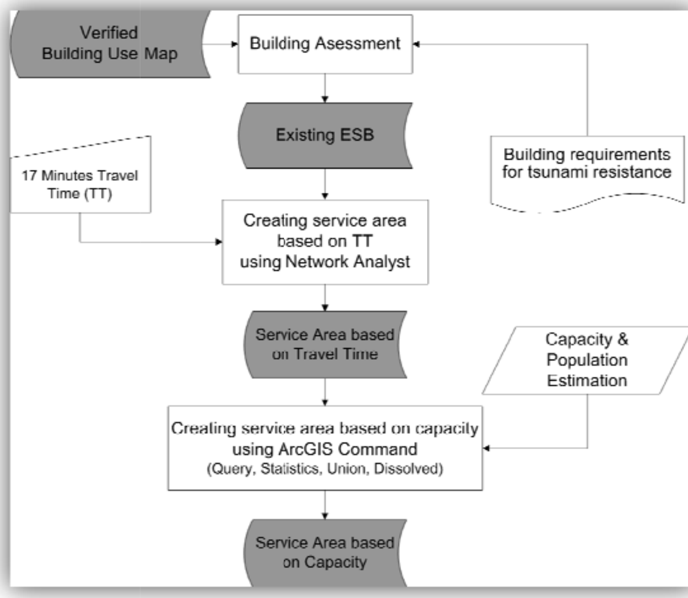


Figure 7. 4. The workflow of creating service area of ESB

Figure 7.5 shows the result of service area creation based on capacity estimation of ESBs using daytime population scenario and Figure 7.6 shows the capacity of ESBs using night-time population scenario. The service areas would limit the source of evacuees who can be sheltered, and the capacity of each ESB would limit the number of evacuees. Hence, evacuees from other tessellation (outside these service areas) should find other shelters.

The total populations who can be sheltered were different during daytime and night-time. It is related to the different concentration of people regarding their activities over the day. During the day, there will be more people outside the houses such as at schools, offices, workplaces and other facilities, meanwhile during the night more people stay in the houses. The following table (Table 7.1) describes the ratio of population during daytime and night-time for ESBs by considering service areas based on TT in Figure 7.3. Meanwhile, Table 7.2 shows the number of population who can be sheltered in ESBs based on capacity (service areas in Figure 7.5 and 7.6).

Table 7. 1. The ratio between number of population during daytime and night-time by considering service areas based on travel time

Name of ESB	Total Number of People in tessellation (person)	
	Day	Night
Al Azhar	1,410	624
STIKES	1,265	468
Al Islah	1,909	1,477
Sri Mukti	1,302	1,377
Total	**5,886**	**3,946**

Source: Data Analysis (2009)

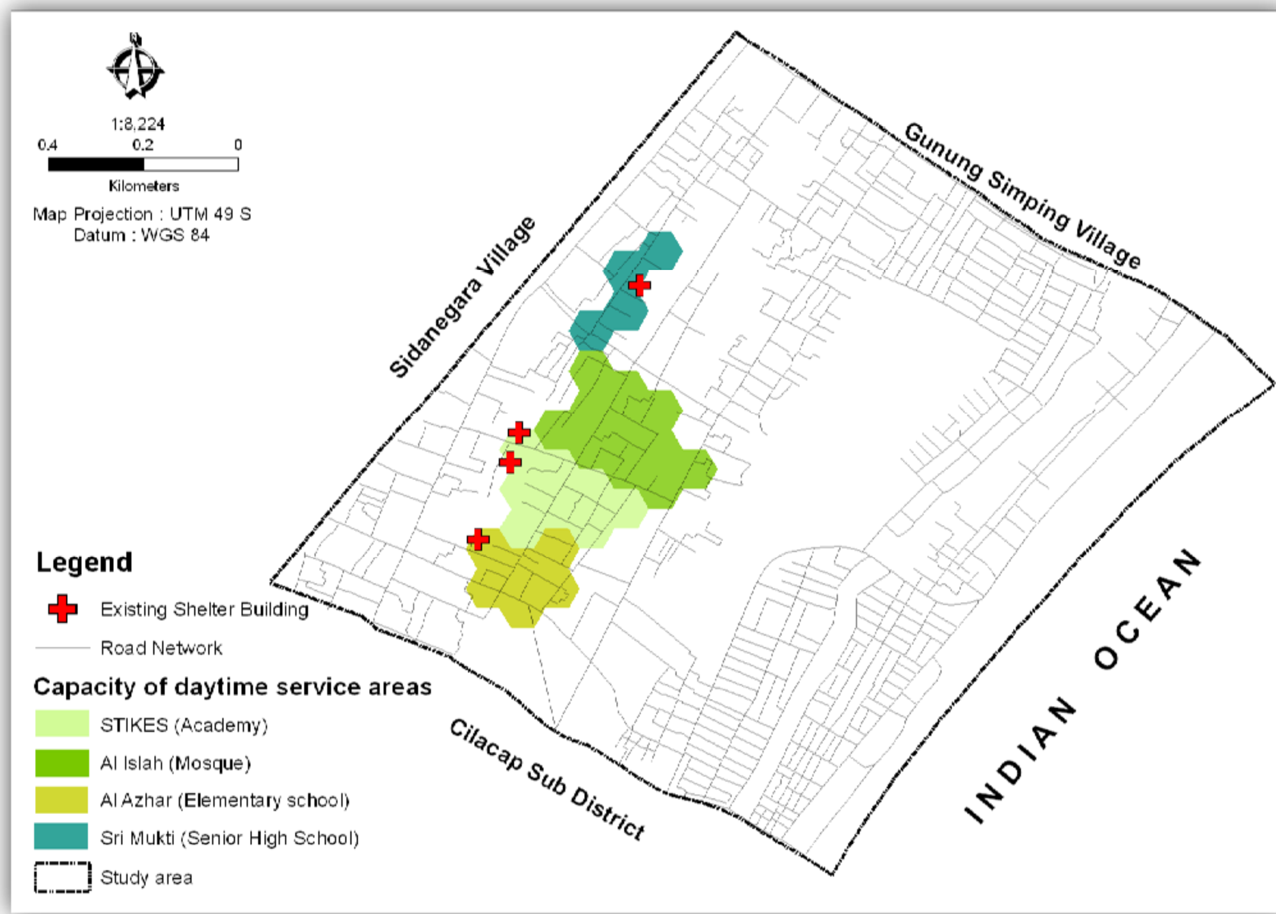


Figure 7. 5. Service area based on travel time and capacity during daytime

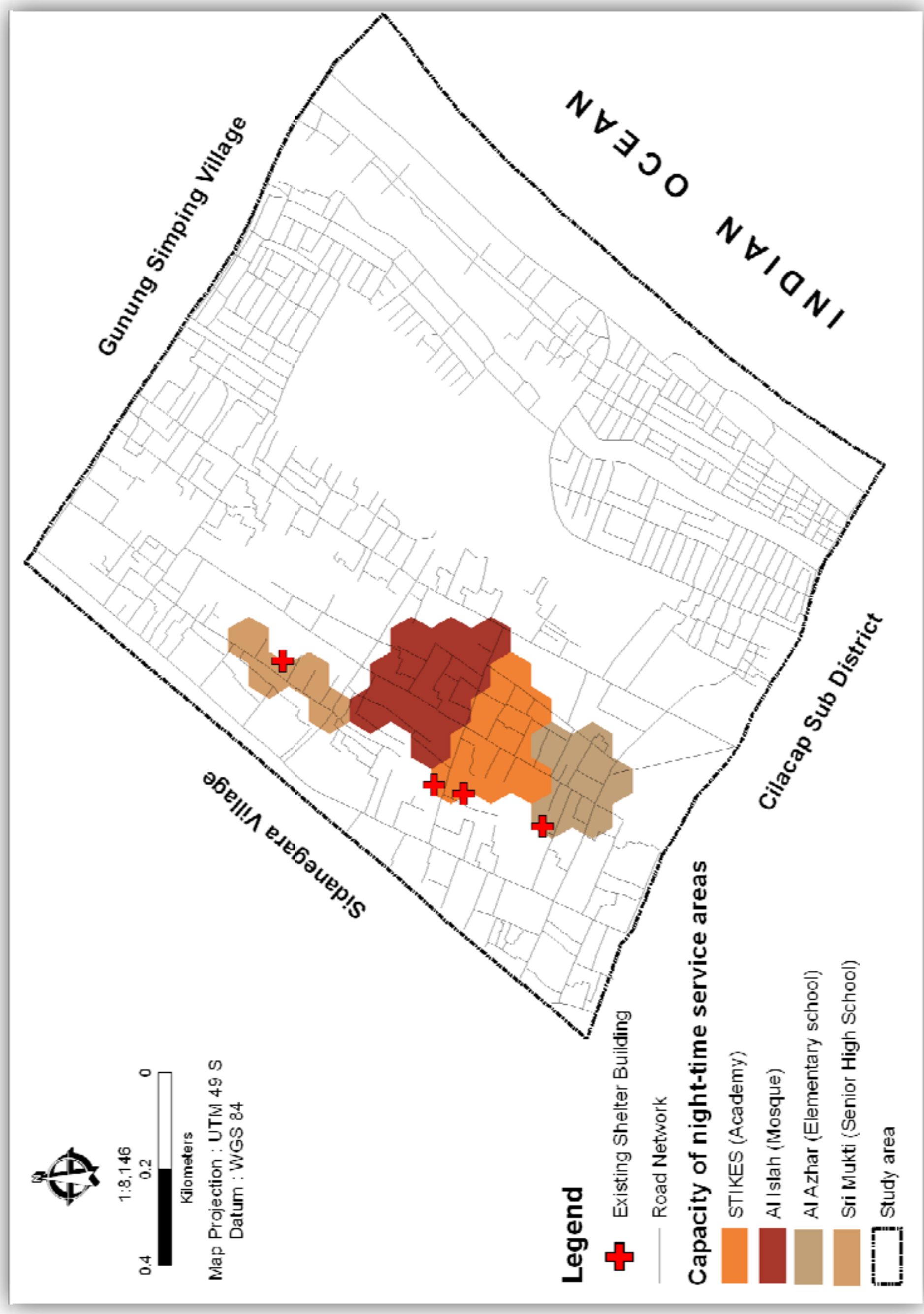


Figure 7. 6. Service area based on time and capacity during night time

Table 7. 2. The number of evacuees who can be sheltered in existing ESB during daytime and night-time by considering capacity of ESB

Name of ESB	TEBC (person)	Number of People in tessellation (person)	
		Day	**Night**
Al Azhar	1,118	1,021	741
STIKES	3,037	2,734	730
Al Islah	1,043	802	1,040
Sri Mukti	816	800	422
Total	**6,014**	**5,357**	**2,933**

Source: Data Analysis (2009)

From Table 7.1 and Table 7.2, it can be concluded that there were 5,886 evacuees that should be evacuated in daytime scenario, but only 91% (5,357 evacuees) could be sheltered in the existing ESB. Meanwhile, from 3,946 evacuees in night-time scenarios, only 66% (2,623 persons) could be loaded. So there were 529 evacuees who should find other shelters for daytime scenarios and 1,013 evacuees left for night-time scenarios. The number of people who can be sheltered in night-time scenario for three ESBs are far below the maximum capacity of those ESB's, but in fact people from other location (other tessellations) cannot be loaded to those shelters due the TT constraint. It means people from other tessellations cannot reach the shelters in the given time (17 minutes) since they are located outside the service areas of those ESBs. Thus, additional shelter should be added to rescue the rest of evacuees and these additional shelters were also needed in study area 2 since there were no existing buildings which can function as ESBs.

7.1.2 Additional ESB

Since the existing ESBs could only cover 5,357 people at daytime and 2,933 people at night-time (see Table 7.2), there were more than 19.000 people who could not be served by the existing shelters. These people were very vulnerable to tsunami. Consequently, more additional ESBs were needed.

The process of determining the suitable location for additional ESB was began from the point of origin or centroid of each polygon. The service areas of 17-minute TT were developed using Network Analyst. The direction of movement was away from incident (centroid) by applying the one-way rule meaning that people should avoid shorelines direction and go further inland (see section 5.6.3 for more detail method).

The deriving of service areas were conducted by considering 17-minute TT and maximum capacity of additional ESB. The proposed locations for additional ESBs were the overlapping areas of those service areas. The overlapping areas indicate the areas which were the most accessible areas. These areas will be the most optimum location for additional ESB. Further, the land cover map was used to check the suitability of the area for additional ESB location. The following flowchart (Figure 7.7) figures out the concept in determining the additional ESB.

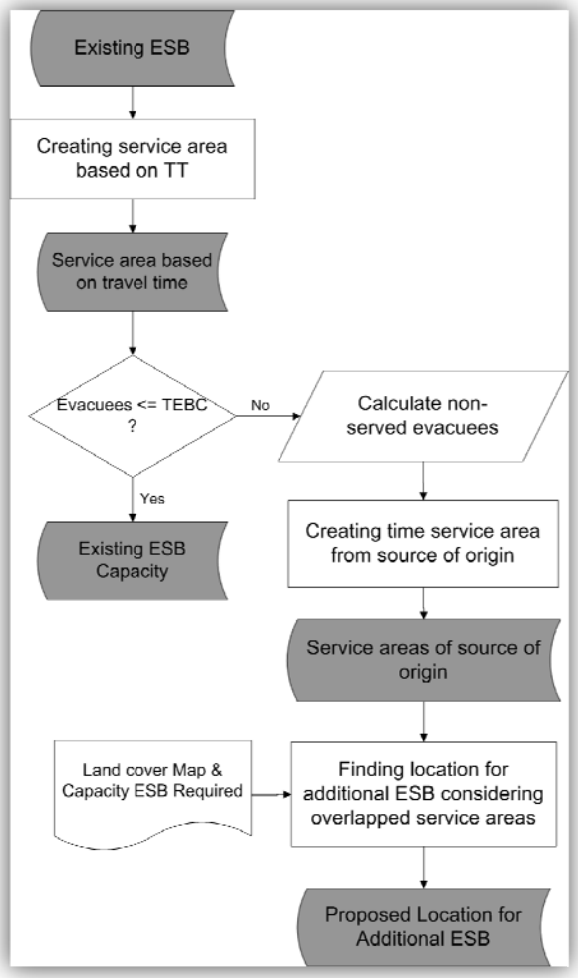


Figure 7. 7. The concept in determining additional ESBs

The result of the process in deriving additional ESBs can be seen in Figure 7.8, there were 14 proposed additional ESBs that should be built in this area for day population scenario. Meanwhile for night-time scenario, there were 18 additional ESBs that proposed to be build, as mentioned in Figure 7.9. For this research, the capacity of additional ESBs varies depend on the number of people in surrounding area, the available TT and, the number of vertical evacuation structures located in the area (Table 7.3).

FEMA (2008b) stated that sizing considerations could necessitate an adjustment in the number and spacing of vertical evacuation structures if it is not feasible to size the resulting structures large enough to accommodate the surrounding population at the maximum spacing. In fact, determining how large an ESB should be built, choosing to design and construct a vertical evacuation structure for short-term refugee, or to supply and manage it to serve evacuees for longer periods of time, is an emergency management issue that must be decided by the state, municipality, local community, or private owner. In this case, since the TEBC was calculated from the number of population in each tessellation, so the number of TEBC was equal to the number of population in the areas.

Table 7. 3. The capacity of proposed additional ESB for day population scenario

ESB Nr.	Proposed TEBC (person)	ESB Nr.	Proposed TEBC (person)
01	1,014	**08**	957
02	877	**09**	972
03	338	**10**	873
04	1,029	**11**	944
05	662	**12**	551
06	849	**13**	1,206
07	971	**14**	3,337

Source : Data Analysis (2009)

Table 7. 4. The capacity of proposed additional ESB for night population scenario

AESB Nr.	Proposed TEBC (person)	AESB Nr.	Proposed TEBC (person)
01	1,012	**10**	1,068
02	933	**11**	955
03	919	**12**	1,030
04	902	**13**	963
05	1,009	**14**	927
06	989	**15**	1,066
07	935	**16**	931
08	1,030	**17**	808
09	861	**18**	778

Source : Data Analysis (2009)

Figure 7.8 and Figure 7.9 show proposed location of additional ESBs in study area #1, and Figure 7.10 shows the distribution of proposed location of ESBs in study area #2 during day and night-time population scenarios. In this case, the second area had the same additional ESB for day and night-time population scenario due to limited number of occupants. The locations of villages are outside the tsunami inundation zones. So in this case, it would be recommended that the villagers evacuate themselves horizontally and move away from shorelines. The occupants who live in tsunami inundation zones were people who work for several factories. From field observation during field work, there were several factories operated there and few of these factories had been abandoned. There were fisheries productions, sand mining, traditional harbor and fish market. Mostly the areas consist of agriculture areas, for instance paddy fields, and mix crops. So, in this case, retrofitting of factories and fish market can be solution for evacuation purposes.

As mentioned before in section 7.1.1 and section 7.1.2 (service area based on TT and capacity), consideration should be given to the time needed for designated occupants to reach a safe place. Two factors required to determine the spacing of additional ESBs were evacuation TT and mobile condition of community in responding the tsunami warning. In this research, the time travel became limitation in developing the service areas of each population concentration. Consequently, 14 additional ESBs for day population scenarios and 18 ESBs for night population scenarios were realistic. It is because vertical evacuation structures should be located such that all persons who evacuate can reach the structure within the time available between tsunami warning and tsunami inundation.

How large the ESBs will be built depend on the intended number of occupants. Further, FEMA (2008b) stated that the type of occupancy and the duration of occupancy will also determine the sizing of vertical shelters. The decision on choosing to design and construct such vertical structures is an issue that should involved the state, municipality, local community, or even private owner. It may not always feasible to construct new building for vertical evacuation purposes due to land ownership and economic constraint. In that case, retrofitting existing building and corporation with private sector can be alternative solutions. Although retrofitting of existing building can be expensive but it is the most practical option available. The buildings which are used as vertical evacuation should have certain structural attributes that are associated with tsunami-resistant structures and also seismic effect.

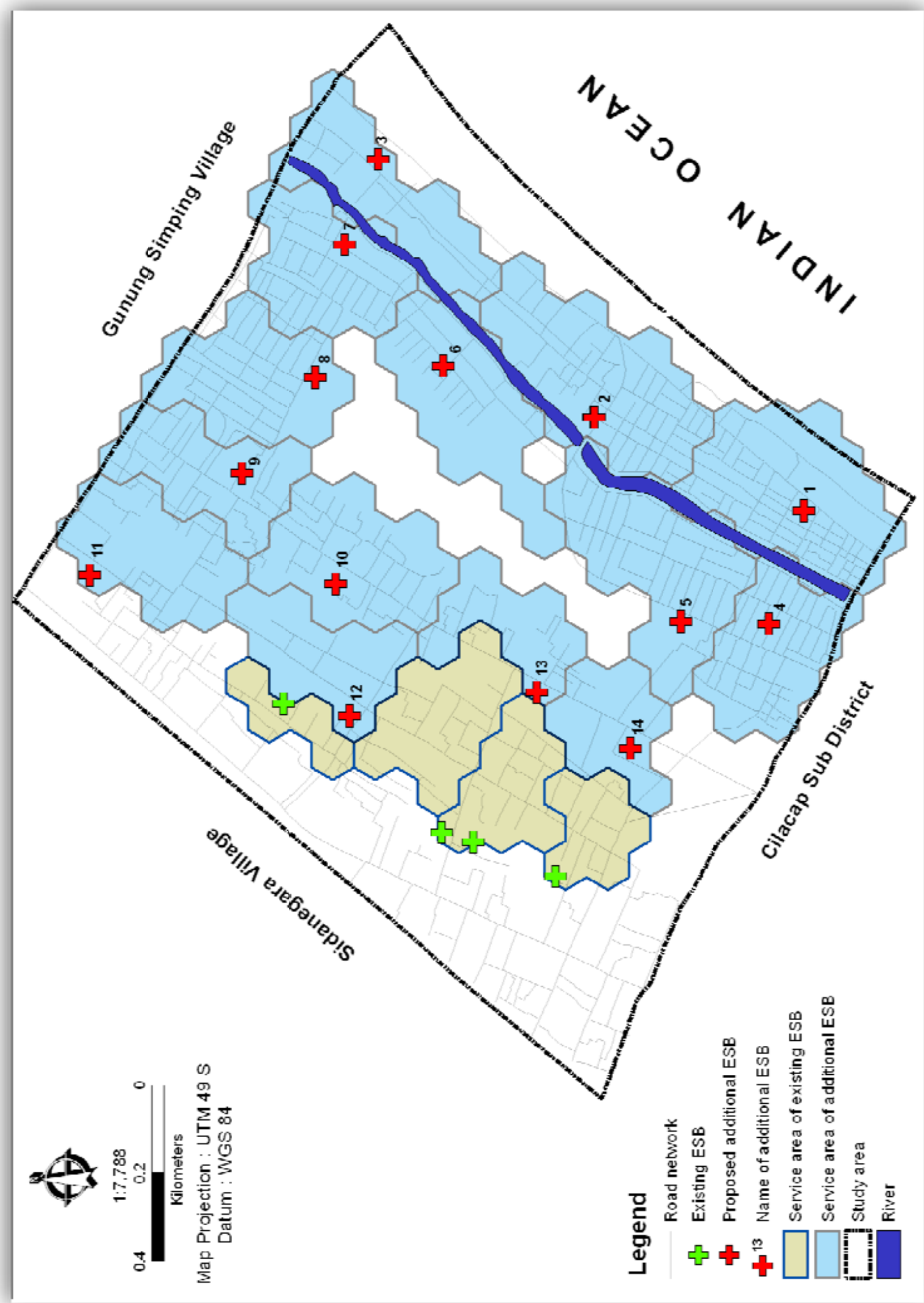


Figure 7. 8. Distribution of existing ESB and proposed additional ESB using day population scenario in study area #1

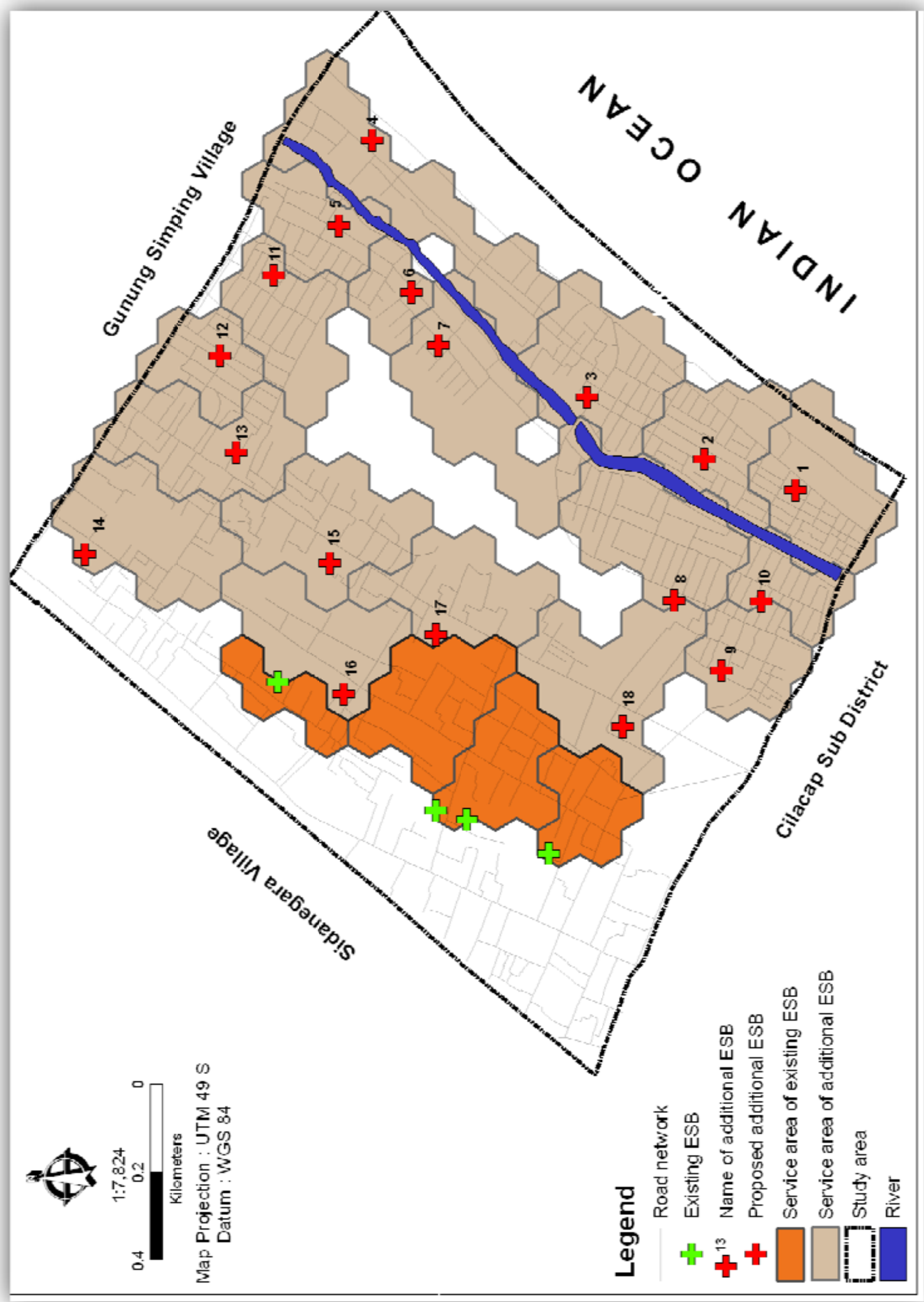


Figure 7. 9. Distribution of existing ESB and proposed additional ESB using night population scenario in study area #1

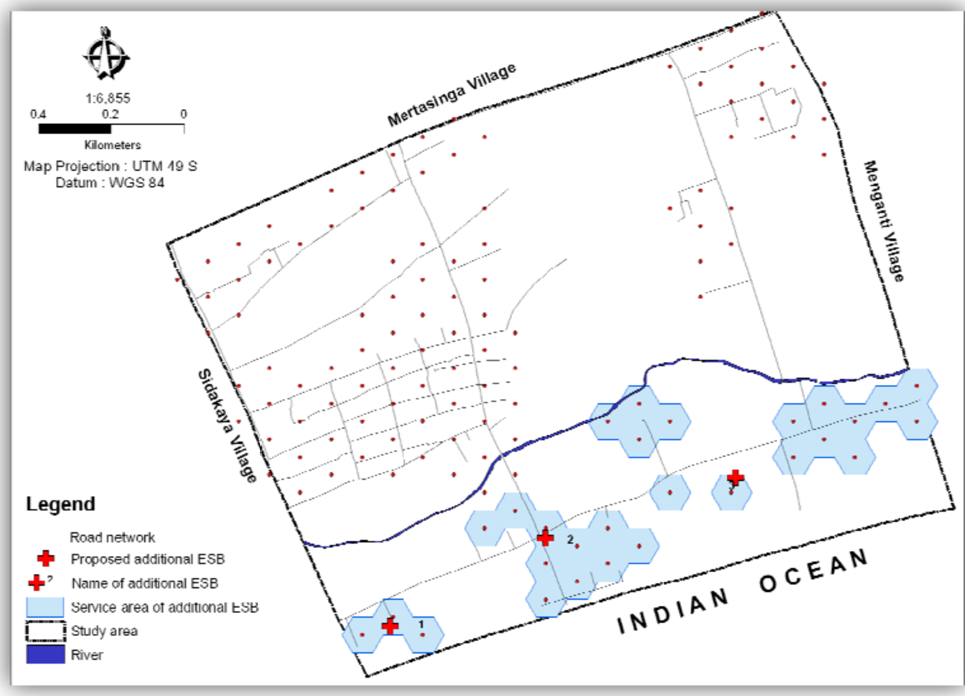


Figure 7. 10. Distribution of proposed additional ESB using day and night population scenario in study area #2

Even though FEMA (2008b) stated that vertical evacuation structures should be located on the inland side, but in the results of this research, not all proposed locations of additional ESBs were located on the inland side. The determining process not only focuses on the travel distance and evacuee behaviour but also the expert judgement by considering land cover condition of certain location (see section 5.5.1).

Figure 7.11 illustrates the selection of proposed additional ESB. From that figure, the proposed location ESB by using GIS technique was represented by the black dot which was located in the settlement area. We expected that relocation of people would be the last option since it may not always feasible to relocate community to other locations. To overcome such kind of problem, the author tried to use other approach to ascertain location of ESB. Expert judgement in this case was used by using land cover map of the area. In fact, there were two options available, first option to build additional ESB on the open area, and second option to retrofit existing school for additional ESB. But of course, the choice between those various options will depend on emergency response planning and needs of the community, the financial project situation of the local municipality, and also the owner considering such structure.

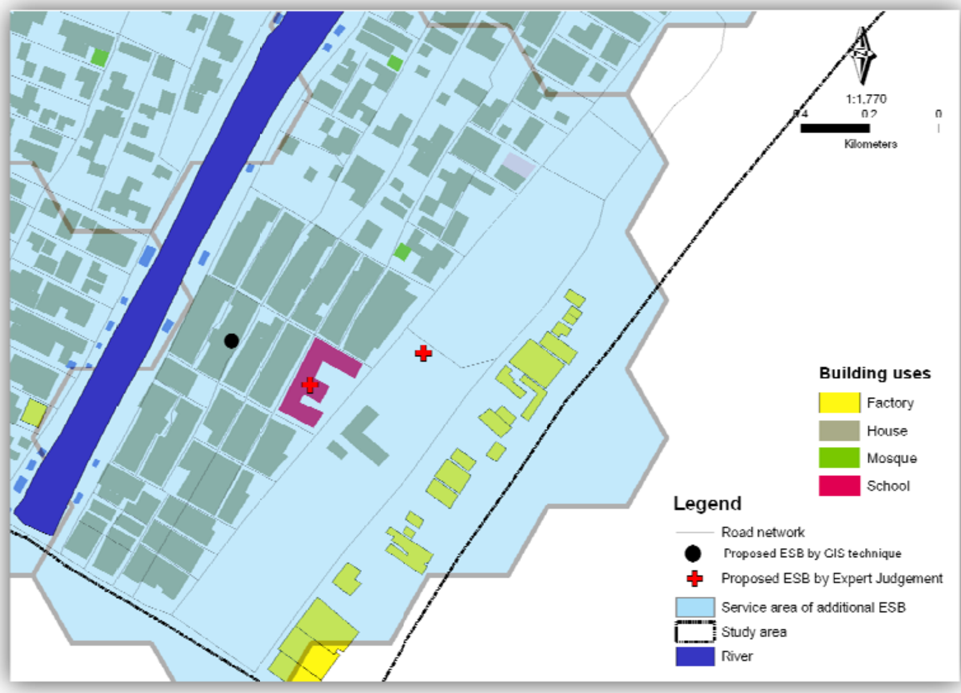


Figure 7. 11. Expert judgement in determining proposed location of additional ESB

7.1.3 Evacuation Route

The final result of this research is to determine the evacuation routes from population to the nearest shelters. After knowing the service area considering time and capacity, the next step was to develop the most effective routes from point of origin (population) to particular existing shelters or additional shelters.

Finding Closest Facility of Network Analyst was used to develop the most effective route. This effective route is developed by considering the shortest TT. The information which was given by this command includes the routes to go to the nearest shelter destination, the time needed to travel and also the distance between points of origin up to the evacuation destination. Figure 7.12 and Figure 7.13 illustrate the evacuation routes in study area #1, whilst, Figure 7.14 shows the evacuation route in study area #2. Figure 7.15 shows additional information which was given regarding routes, distance, and time required to move from source of origins to evacuation shelters as destination. So, in this case, the Network Analyst of ArcGIS could give very detailed information regarding time and distance of traveling condition. In addition, information regarding directions was also available.

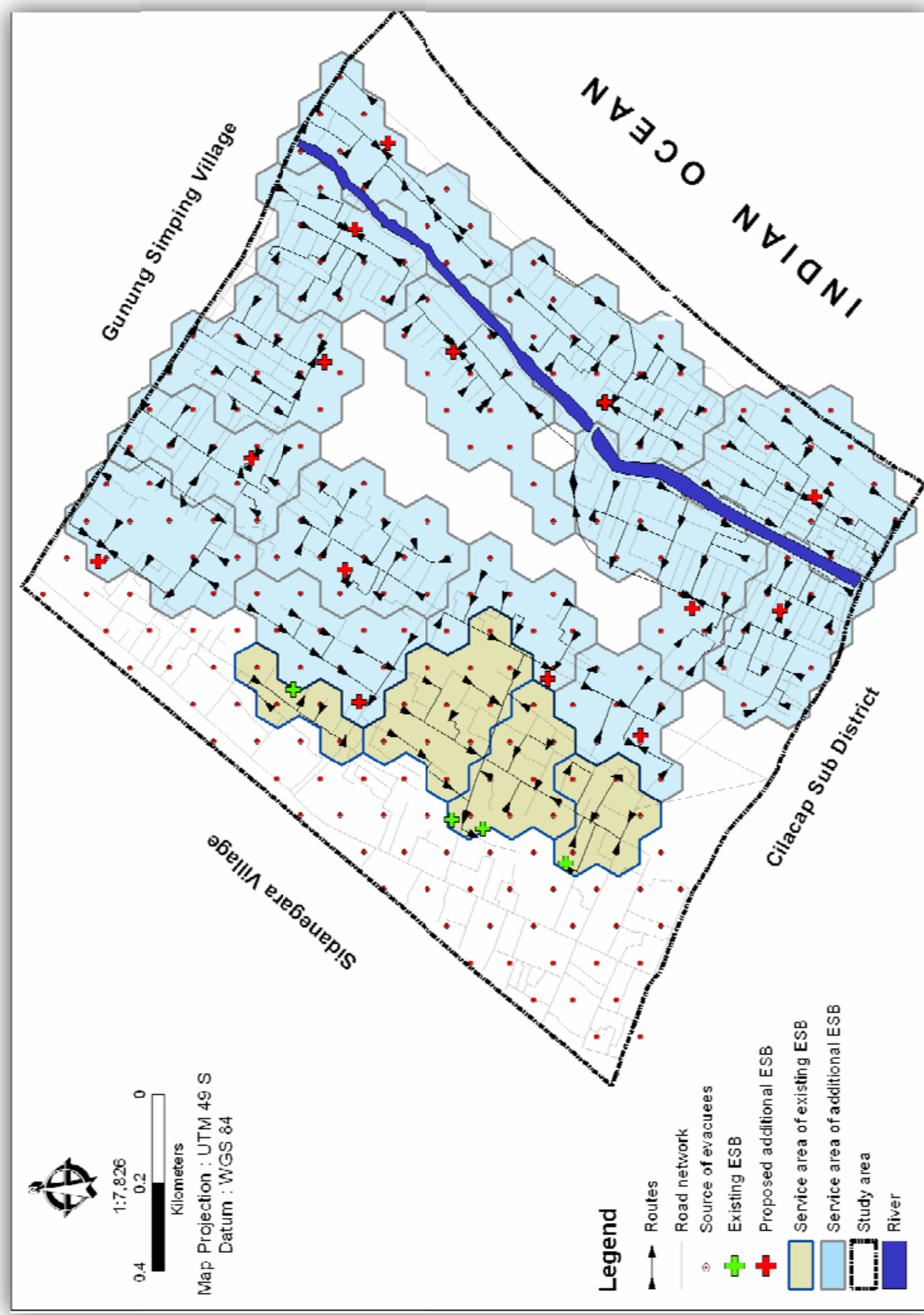


Figure 7. 12. Evacuation routes for each allocated ESBs using day population scenario in study area #1

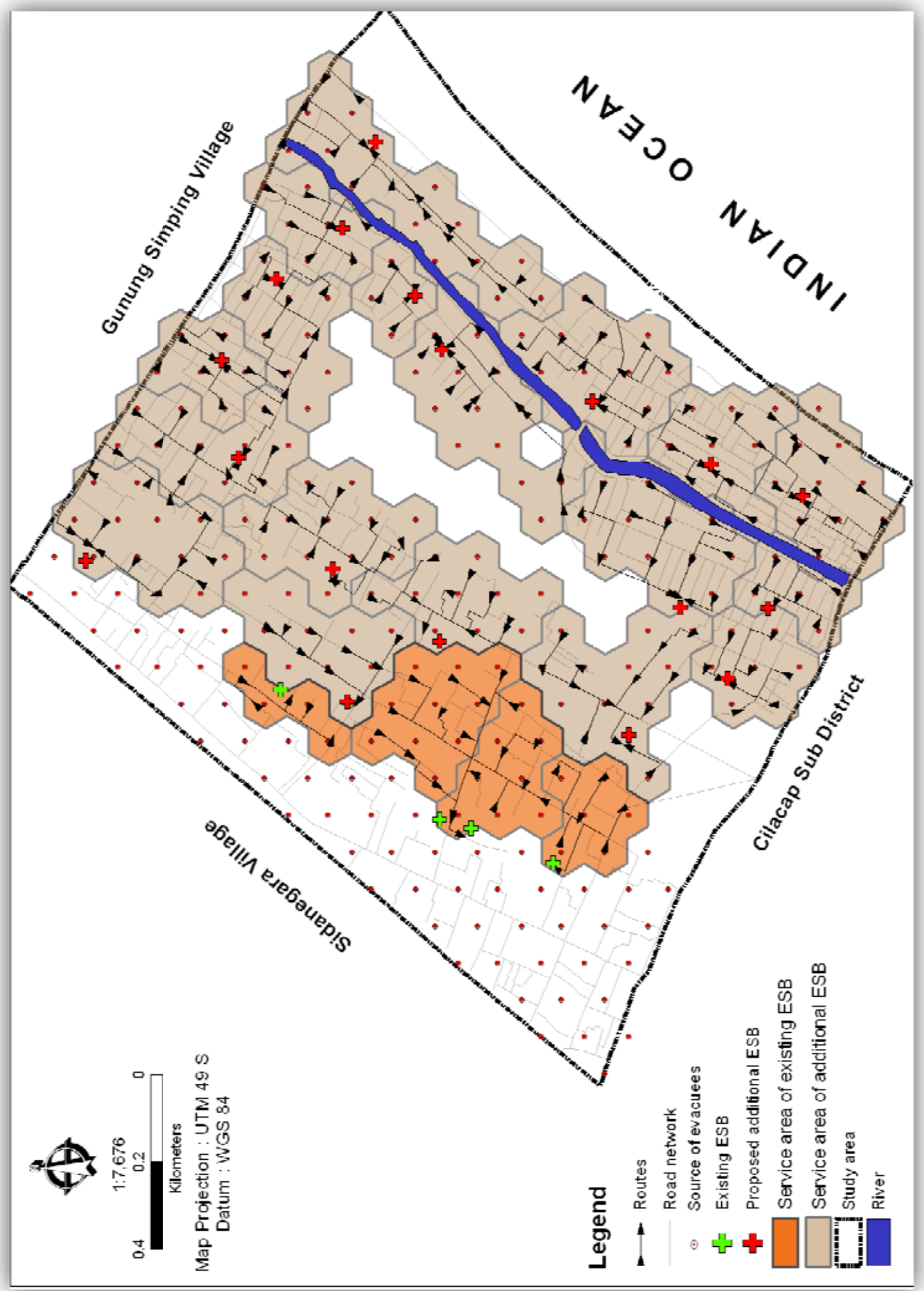


Figure 7. 13. Evacuation routes for each allocated ESBs using night population scenario in study area #1

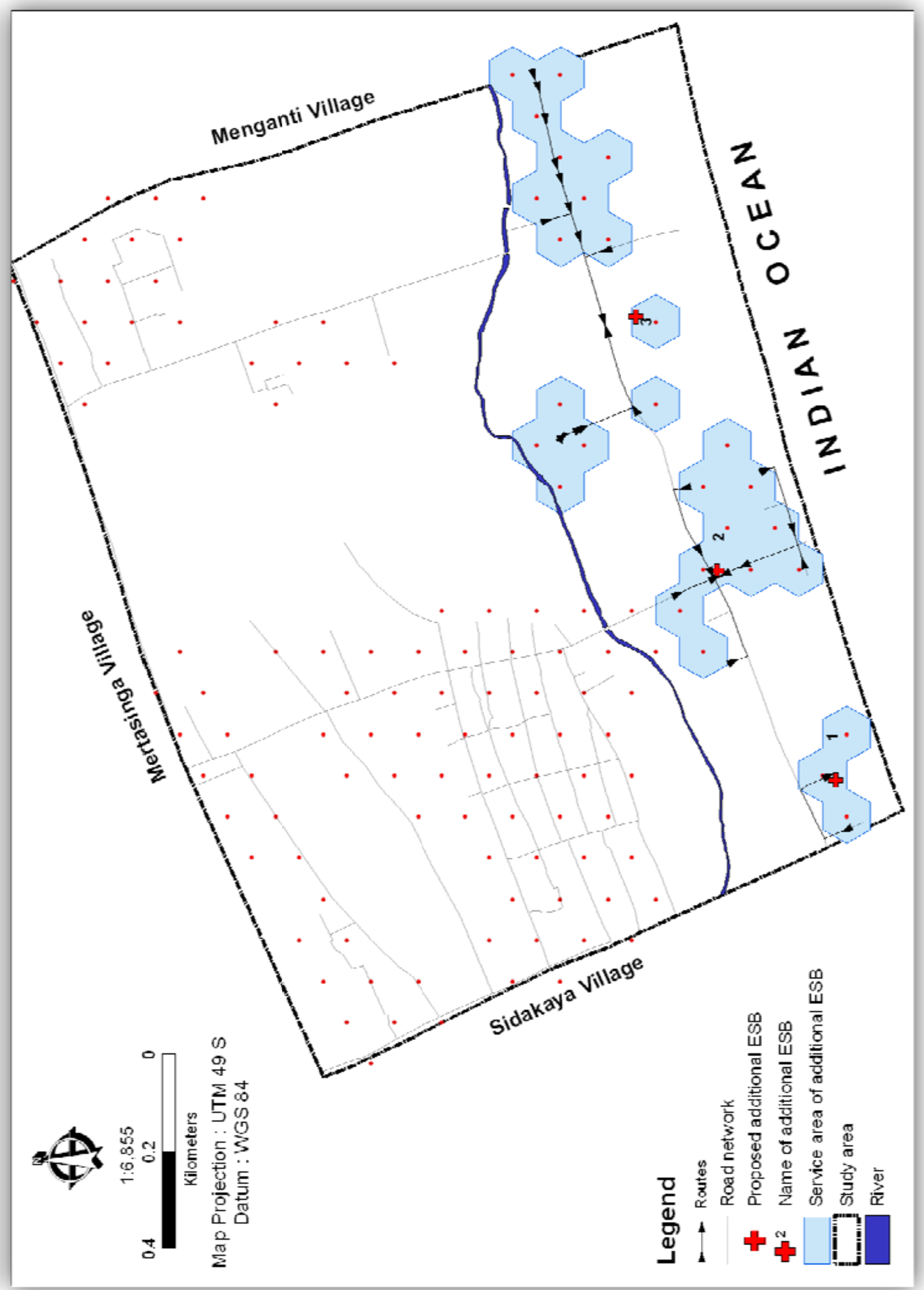


Figure 7. 14. Evacuation routes for each allocated ESBs using day and night population scenario in study area #2

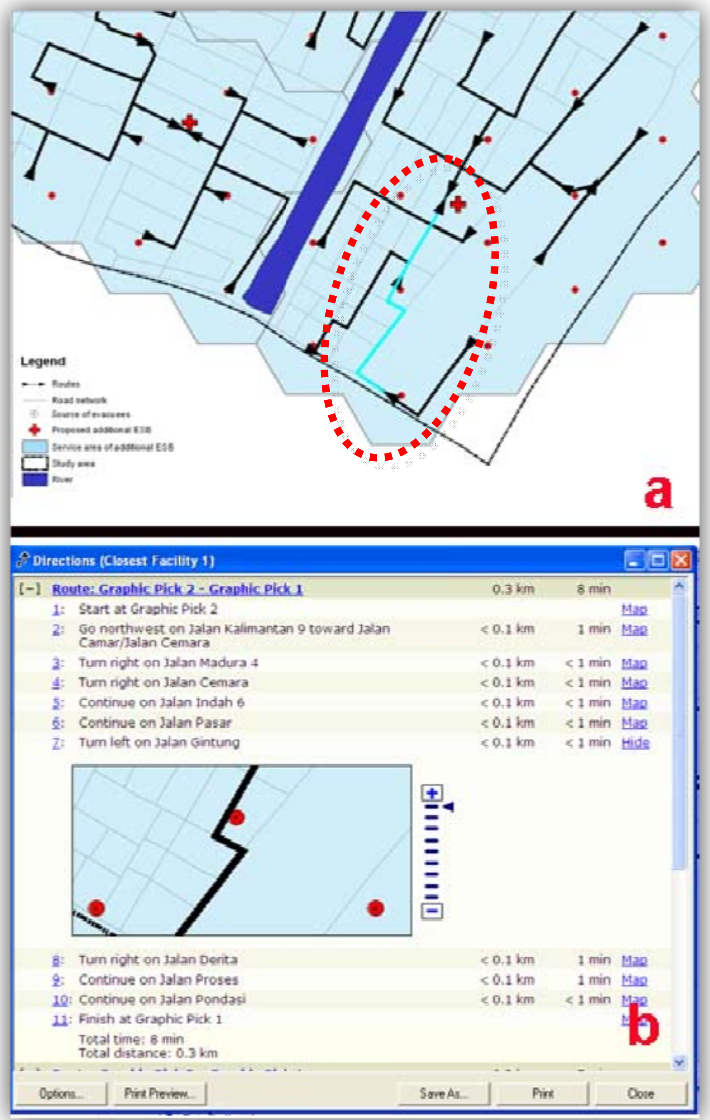


Figure 7. 15. Evacuation routes from source of origin to evacuation shelter (above) and its additional information (below)

The detailed road network was necessary. The accessibility to an ESB will require sufficient evacuation route so that evacuees can reach the ESBs in time. In determining the evacuation route, as much as possible, hazardous areas should avoided. For example, in study area #1, river which is located near coastal areas (Figure 7.16) was assumed as a barrier meaning that evacuees should avoid these areas. The existence of river obstructs people to migrate further inland. In this case, the one-way rule and direction to avoid shoreline direction could not be applied. Hence, for this research, evacuees can run to any directions as long as the destinations could be reached in less than 17 minutes.

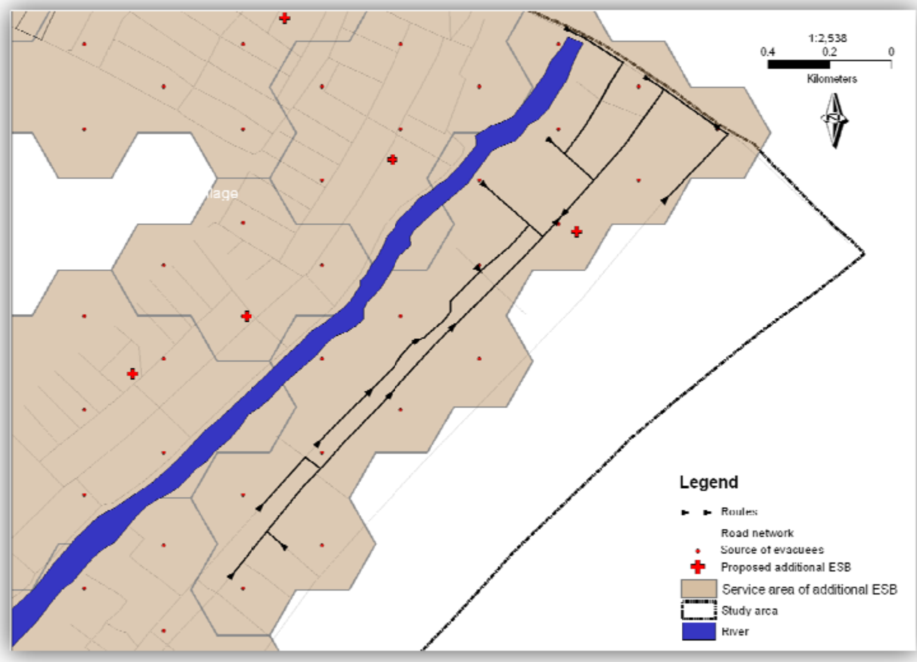


Figure 7. 16. River as barrier that should be avoided by evacuees

Developing bridges in certain location along the river can be useful, so that evacuees could evacuate themselves easily to go further inland. But, care must be taken if the river is located close to the shoreline (estuary). Since estuary can be main entry point for the destructive tunami and can cause a great damages and fatalities.

Generally, conclusion can be made that for daytime scenario, the shortest TT is 0.198 minutes for 76 meters and the longest TT for 579.7 meters is 14.98 minutes. For night-time scenario, the shortest TT is 0.08 minutes for 3.32 meters and the longest TT is 14.94 minutes for 577.57 meters. Meanwhile, in the second area, the shortest TT is 0.07 minutes for 2.7 meters and the longest TT is 14.5 minutes for 270.7 meters.

7.3 Concluding Remarks

It is necessary to define the coverage of each evacuation shelter building before applying them in evacuation modeling. Consideration must be given to TT since this was a fix parameter in this model. All the evacuation process should not exceed the available TT. This TT also determines the selecting of location suitable for proposed ESB. The proposed locations should be accessible from the closest center of populations.

There are 5,886 evacuees that should be evacuated in daytime scenario, but only 91% (5,357 evacuees) could be sheltered in the existing ESB. Meanwhile, from 3,946 evacuees in night-time scenarios, only 66% (2,623 persons) could be loaded. The total populations who can be sheltered were different during daytime and night-time. It is related to the different concentration of people regarding their activities over the day.

There were 14 proposed additional ESBs that should be built in study area 1 for day population scenario. Meanwhile for night-time scenario, there were 18 additional ESBs that proposed to be build. In the second area, for daytime and time, three additional ESB is proposed due to limited occupancy in that areas.

For daytime scenario, the shortest TT is 0.198 minutes for 76 meters and the longest TT for 579.7 meters is 14.98 minutes. For night-time scenario, the shortest TT is 0.08 minutes for 3.32 meters and the longest TT is 14.94 minutes for 577.57 meters. Meanwhile, in the second area, the shortest TT is 0.07 minutes for 2.7 meters and the longest TT is 14.5 minutes for 270.7 meters.

Chapter 8.Conclusion & Recommendation

This chapter presents the conclusions of the thesis research considering the research objective, specific objectives and research questions. Recommendations are also given an ends this chapter.

8.1 Conclusion

The research aims to determine the location and capacity of ESB and to develop a methodology to choose the most effective evacuation routes. The following description describes the conclusions of what have been conducted. From the specific research objectives perspective, the research can be concluded as follows:

1. **ESB characteristics**
   (*Specific research objective: To identify the most suitable building types that can function as evacuation shelter buildings for tsunami, based on literature studies and field observations*),

   Based on literature study, there are many characteristic of building design required for a building to function as tsunami evacuation shelter building, as follows:

   c. Building construction should be earthquake and tsunami-resistant**.** The structure attributes proofed having good behaviour in past tsunami are (a) strong systems with reserve capacity to resist extreme forces; (b) open systems that allow water to flow through with minimal resistance; (c) ductile systems that resist extreme forces without failure; and (4) redundant systems that can experience partial failure without progressive collapse.

   d. Space for living in building structures must be elevated above the wave height and the building supports area parallel to the expected direction of flow. Spaces below the design flood elevation must be free from obstruction.

   e. Buildings for evacuation shelters can be single-purpose, multi-purpose facilities, single-hazard, and multi-hazard consideration. Vertical evacuation structures can be set for general use by the surrounding communities.

   f. Sufficient space is needed for evacuation shelter buildings so that they must be able to load a large number of people in a short time frame. The buildings can transport people to the safer areas that located above the level of inundation.

   g. The buildings should be easily accessed by people and routes to the buildings should be well marked. The ESBs structures should be located such that all persons designated to take refuge can reach the structure within the time available between tsunami warning and tsunami inundation.

h. ESB must have an adequate stairs, or ramp which is designed to meet the building safety requirement. During evacuation process, people should have adequate time to not only reach the structure, but also to enter and move within the structure to safer areas that are located above the tsunami wave height.

2. Existing ESB Identification

(*Specific research objective: To identify existing buildings in the study area that can function as evacuation shelter buildings based on high resolution satellite image and field observation*)

High resolution satellite images are proved to be powerful in many applications including object identification. Quick-bird image of 0.6 meter resolution was interpreted visually to identify buildings which were predicted can function as evacuation buildings. The large buildings can be identified from their rectangle shape, their size from medium to large, their tone from orange to brown (depend on roof style) and their location in relatively easy-accessed area. For example, a U shape building or L shape building with open field can be school because of its location near settlement. This visual interpretation was validated by field observation.

During fieldwork, building assessment was conducted for buildings which are potential for tsunami evacuation. Building assessment was conducted for buildings which are potential for tsunami evacuation based on requirements as follows:

(a) Located at a distance of more than 200 m from shoreline or 100 m from a river near the coast;
(b) Located near the population concentration;
(c) Having alternate function as mosque, school, parliament building, government office, market, shopping centre, convention centre, sport hall, hotel, and parking building;
(d) Building floor reserved for evacuation located above tsunami wave height in the area;
(e) Well-planned and designed;
(f) Good quality construction (tsunami and earthquake resistant building).

There are four groups consist of seven buildings which can function as tsunami evacuation building (see table 6.1 in sub section 6.1.1.2).

3. Daytime and Night-time Population Distribution Map

(*Specific Research Objective: to generate day-time and night-time population density/distribution map of the area prone to tsunami inundation*)

Concentration and distribution of population are dynamic over the day due to the concentration of business establishment, offices, and settlements. In a commercially used market areas or buildings, there will be a high population during daytime and the number of people will be decrease significantly during the night-time. So the scenarios of day and night-time are used to run the evacuation model because the difference in population distribution over the day will result in different ESB allocation.

For houses, the night population scenario will have more people stay at home compare to the day population scenario, because it is assumed that during daytime only 50% of family members stay at home. As can be seen in the population number of study area #2, the population number during the day is 2,831 people and during the night is 5,010 occupants. This location is dominated by settlement and agricultural area. Meanwhile in the city (study area #1), the number of population during daytime and night-time are almost the same. There are 24,566 people during the day and 24,357 during the night-time. It is because in the city there are many facilities such as schools, offices and factories which have more people during the daytime. Moreover, this area is densely populated, so the number of population during the night is also high.

4. Additional ESB

(*Specific Research Objective: to identify suitable locations of additional evacuation shelter buildings based on the most effective evacuation route for tsunami and day-time and night-time population densities*)

The proposed locations for additional ESBs are determined by looking at the overlapping areas of the coverage which have been built for each centroids of tessellations. The overlapping areas indicate the areas which are the most accessible. These areas will be the most optimum location for additional ESB. The capacity of additional ESBs is adjusted to meet the required capacity. It will depend on the construction cost, the available of open space, and also the existing buildings which can be retrofitted. Even though, retrofitted will generally be more difficult rather than to build a new tsunami-resistant building, it still can be one alternative for evacuation purposes. Before applying the most overlapping area as the location of ESB, the suitability of location for ESB was checked using land cover map.

There were 14 additional ESBs should be built in this area for day population scenario. Meanwhile for night-time scenario, there were 18 additional ESBs that proposed to be build. For this research, the capacity of additional ESBs varies depending on the number of people in surrounding area, the available TT and, the number of vertical evacuation structures located in the area.

5. Utility

(*Specific Research Objective: to assess the utility of geo-information technique to identify the most effective evacuation route and suitable location for additional ESB*)

GIS software (ArcGIS including Network Analyst) is proved to be powerful in conducting evacuation modeling. All the processes carried out in this research are performed by using geo-information technique.

The following table addresses the research questions of this research.

Table 8. 1. Reference of research question achievement

No	Research Questions	Reference
1.	**To identify the most suitable building types that can function as evacuation shelter buildings for tsunami, based on literature studies and field observations**	
	a. What are the most appropriate characteristics of existing evacuation shelter buildings?	Sub chapter 2.6
	b. What are the already-known design requirements for existing ESBs?	Sub chapter 2.6
2.	**To identify existing buildings in the study area that can function as evacuation shelter buildings based on high resolution satellite image and field observations**	
	a. Which buildings can be functioned as evacuation shelter buildings?	Section 6.1.1.2
	b. How to identify evacuation shelter buildings using high resolution image?	Section 5.3.3 and 5.5.2
	c. What are the alternative functions of additional evacuation shelter buildings for tsunami based on literatures and field observations?	Sub chapter 2.6
3.	**To generate day-time and night-time population density map of the area prone to tsunami inundation**	
	a. How many people need to be evacuated?	Section 6.1.3, sub section 6.1.3.3
	b. How is their spatial distribution during daytime and night-time in the study area?	Sub section 6.1.3.3
4.	**To identify suitable locations of additional evacuation shelter buildings based on the most effective evacuation route for tsunami and day-time and night-time population densities**	
	a. How many additional evacuation shelter buildings needed for the study area and what are the capacities needed?	Section 7.1.2, Table 7.3 and 7.4
	b. How to locate the evacuation shelter buildings in the study area?	Sub section 5.5.2.1, section 5.6.3, sub section 6.1.1.2, sub chapter 7.1
	c. How to optimize their spatial distribution?	Sub section 5.5.2.1, section 5.6.3, sub section 6.1.1.2, sub chapter 7.1
	d. What is the evacuation time to be assumed?	Sub chapter 3.4
	e. How is evacuation of people after tsunami warning?	Sub chapter 2.3
	f. How do people reach the temporary evacuation shelter buildings?	Sub chapter 2.8 and section 5.5.3
	g. What is the walking speed of people to be applied?	Sub chapter 2.8
5.	**To assess the utility of geo-information technique to identify the most effective evacuation route and suitable location for additional ESB**	
	Is GI technique helpful to identify the most effective evacuation route and suitable location for additional ESB	Sub chapter 2.4 and 2.5

8.2 Recommendation

8.2.1 Research Contribution

The results have made contributions of this research, as follows:

1. The method which was developed in this study can be adopted by local government for developing evacuation planning as part of emergency planning.
2. The evacuation model can be used to help elevate awareness and educate both residents and local government regarding tsunami mitigation.
3. Existing ESBs, proposed additional ESBs locations and evacuation routes resulted in this study can be used as valuable information for local government and and community to anticipate problems and possible solutions for tsunami disaster reduction and to design policies as well.

8.2.2 Improvement of the Method for Further Research

The realistic model from network analyst 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. So, it is necessary to add more detailed network such as path, or virtual path where people can move during disaster event.

In line with developing more detailed road network, more detailed network attributes will result in a better evacuation model. Attributes used in this research include cost (TT) and restriction (one-way rule and barrier). Other attributes and properties can be added to make the model more reliable, such as hierarchy, descriptor and turn policy. But of course, it will need more data and further research. Other things which are important to improve the model are to include barrier information such as bridges location, danger areas, obstructions, etc. They refer to the area which should be avoided by evacuees or for sitting the vertical evacuation structures.

It is important to investigate the effectiveness of different road network structure under emergency situation, since evacuation performance is largely dependent on the network structure and the number of vehicles produced in an emergency planning zone. This of course need thoroughly field observation and extensive data regarding road network and traffic condition such as traffic volumes, traffic speed, concentration and vehicle occupancy.

The detailed population data will improve the population distribution as main component of the model. Tessellation in this research can represent the population distribution well, but it will be more realistic if the point of origin comes from building blocks. It represents the real condition where people start moving from their houses or their workplaces.

This evacuation model can be improved further if congestion areas can be identified by identifying the number of evacuees that passes a certain road or travel path segment.

Moreover, if we can formulate the problem in optimization form, we can answer such *what-if* question, as the followings:

1. What is the effect of increasing (or decreasing) the capacity of ESB?
2. What changes when an ESB is removed or added from the network?
3. What happened if the new roads are constructed?
4. What will be the result of an increase (or decrease) of population?

8.2.3 Recommendation for Cilacap City

The developed methodology in this research can be adopted by local government as a tool to plan evacuation planning especially for allocating evacuation shelters and evacuation routes. It is because this research developed a feasible method using GI technology and all modeling process in this research used common GIS software. Even though, more detailed data regarding road network, and building use was needed, this research is a low cost method, and it can be done in a short time. But of course, incorporating larger study area will result in more comprehensive ESB allocation and therefore, take longer time for the analysis and modeling.

Awareness is a prerequisite for any preparedness strategy and public education is a key component of the plan and plays a vital role in disaster preparation, mitigation, response and recovery. Communities can use brochures, single-page instructions, periodic warning system tests, electronic and print media information, signs, drills, workshop and other education programs to maintain and elevate awareness and establish response behavior. Even though in some parts of Cilacap city, there exist the guidance to safer places in case of tsunami but in the other places such kind of guidance is not available. Moreover, since tsunami are rare events, it is challenge to maintain emergency preparedness programs and procedures. Periodic simulations are a valuable learning exercise and regular information and instruction materials should be provided.

Regarding the building construction, ESB requirements should be include in building regulations for public service facilities planning and design. It is necessary to formulate building codes for buildings which are located in vulnerable areas.

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Appendices

Appendix 1. Field recording sheet for land cover

FIELD RECORDING SHEET FOR LAND COVER

Date : ____________________

No	Description		Land cover Classification	Existing Land cover	Photos number	Additional information
1	Sample number					
	District/Village					
	Coordinate					
2	Sample number					
	District/Village					
	Coordinate					
3	Sample number					
	District/Village					
	Coordinate					
4	Sample number					
	District/Village					
	Coordinate					
5	Sample number					
	District/Village					
	Coordinate					
6	Sample number					
	District/Village					
	Coordinate					
7	Sample number					
	District/Village					
	Coordinate					

Appendix 2. Field recording sheet for building use

FIELD RECORDING SHEET FOR BUILDING USE

Date/time : ___________________________________

Sample Number		
District/village		
Coordinate		
Photo number		
Name of building		
Building function	1. House	
	2. School	
	3. Office	
	4. Mosque/other	
	5. Shop/commercial	
	6. Market (Hotel	
	7. Other facility	
Number of floor		
Wall material	1. Wood 2. Bricks 3. Other	1. Good 2. Moderate 3. Bad
Distance from shoreline	.... meter	
Distance from river	.... meter	
Distance from road	.... meter	
Possibility as ESB		
Additional information	Number of workers	Daytime : Night-time :
	Number of student/teacher	Daytime : Night-time :
	Number of person in the building	Daytime : Night-time :
Activities Duration		

Appendix 3. Field recording sheet for building assessment

Field recording sheet for building assessment

Date/time : ______________________________

Sample Number		
District/village		
Coordinate		
Photo number		
Name of building		
Building function	1. House	
	2. School	
	3. Office	
	4. Mosque/other	
	5. Shop/commercial	
	6. Market (Hotel	
	7. Other facility	
Number of floor		
Ground elevation	.... cm	
Distance from shoreline	.... meter	
Distance from river	.... meter	
Distance from road	.... meter	
Description of ground floor	1. Allow water flow 2. Block water flow	1. Movable object (table, chairs) 2. Big glass window
Wall material	4. Wood 5. Bricks 6. Other	4. Good 5. Moderate 6. Bad
Floor material	1. Floor-tile 2. Floor-plaster 3. Other	1. Good 2. Moderate 3. Bad
Façade	1. Walkthrough	
	2. Entrance	
	3. Door sliding/rolling door	
	4. Outskirt corridor	
Number & size of door per floor	Number of door :	Size :
Road orientation	1. Facing 2. Paralel	The road width .... meter
Water body orientation	1. Facing 2. Paralel	
Upper floor height	1. 2nd floor : .... meter 2. 3rd floor : .... meter 3. 4th floor : .... meter	
Stairs condition/ accessibility	1. Good 2. Bad	