Evacuation Shelter Building Planning for Tsunami-prone Area; a Case Study of Meulaboh City, Indonesia

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Evacuation Shelter Building Planning for Tsunami-prone Area; a Case Study of Meulaboh City, Indonesia

by

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Abstract

This research aims at developing a method to determine possible allocation of evacuation shelter buildings (ESB) using geo-information technology as a part of urban reconstruction planning in a tsunami-prone urban area; case study is of Meulaboh City, Aceh, Indonesia.

Initiated by the great earthquake of Mw=9.3 in the northwest of Sumatra island, Indonesia, the devastating tsunami of December 26, 2004 has become the most important research topic in tsunami research and disaster mitigation efforts today. Disaster mitigation aspects, including minimising casualties, will be part of the reconstruction planning of the tsunami-affected areas. The main effort in minimising casualties in tsunami disaster is to evacuate people from the hazard area before tsunami strikes by means of either horizontal or vertical evacuation. In coastal areas, where reachable safe higher ground is not available, where building and population densities are high, and where roads, bridges, and other horizontal evacuation methods are limited, or where available evacuation time is insufficient, vertical evacuation is an alternative or supplement to the more common approach of horizontal evacuation. Robust multi-storey building assigned as the destination in vertical evacuation is defined as evacuation shelter building (ESB) or escape building. To function as an ESB, a building should meet specific requirements of structure, evacuation floor, function, design and capacity, accessibility, and security.

Accessibility analysis and location-allocation modelling are utilised to determine possible allocation of ESB since they can simulate the network-based evacuation process as well as define the optimised spatial distribution of escape building in the study area. The population in tsunami hazard area is simulated to proceed by foot following the road network and other passable paths to the closest ESB within a certain assumed time. Time parameters are derived from the December 26 tsunami's travel time and the development of tsunami early warning system for the study area. Population distribution through the study area is estimated by houses and facilities occupants' calculation incorporating population data, spatial reconstruction guidelines, architectural design space requirements, as well as field observation. High-resolution satellite images of Quickbird and Ikonos are used as the base for spatial identification and analyses. Location-allocation modelling is utilised in the Flowmap software package. Results of the modelling include proposed location of ESBs, capacity and coverage area of each building, statistics of the evacuees' travel time, and the load effect of road occupation.

The research shows an application of accessibility analysis and location-allocation model in tsunami evacuation plan and architectural space requirement approach in estimating population distribution in the disaster-affected area. The method developed here can be used as a tool to allocate public facility with ESB function, escape tower, and evacuation route in the spatial planning of tsunami-prone areas.

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1. Introduction

This chapter is discussing the background of research, research problem, research objectives, research questions, and research design. The research attempts to develop an approach to plan evacuation shelter building using geo-information technology (GIT) as a part of spatial planning process in the tsunami-prone urban area. The structure of the report ends this chapter.

1.1. Background

Tsunami(s) are a series of ocean waves generated by abrupt, large disturbances of the ocean bottom such as earthquakes, volcanic eruption, landslides, slumps, and meteor impacts. Tsunamis are a major hazard to coastal residents in earthquake-prone regions (Bernard, 1999). This disaster may cause catastrophic loss of life, destruction of property and coastal infrastructure, and lead to major economic and business interruption losses. By the end of March 2005, the Indian Ocean tsunami of December 26, 2004 had caused 126,732 people killed, 93,662 people missing, and US$ 4.45 billion damages and losses in the Province of Nanggroe Aceh Darussalam and North Sumatera, Indonesia (Bappenas, 2005).

Cities located in a hazard-prone area are vulnerable to disasters because of the high concentration of people, buildings, infrastructure and socio-economic activities. Once the tsunami strikes, there will be tremendous losses and damages in the city. Therefore, it is very important to prepare the city and its community with a disaster mitigation plan in order to reduce the damage and losses.

The city of Meulaboh, Province of Nanggroe Aceh Darussalam, Indonesia, has suffered serious damage due to the December 26 tsunami. The water inundation reached 4 km inland. Settlements and facilities along the coastal areas were destroyed (Bappenas, 2005). Responding to this disaster, the central and local government has decided to prepare the city to be able to cope with the tsunami disaster by implementing a rehabilitation and reconstruction program for the region that embed disaster mitigation aspects.

Figure1.1. Location of Meulaboh City (BBC, 2004)

The National Development Planning Agency *(Badan Perencanaan Pembangunan Nasional, Bappenas*) of the Republic of Indonesia has made a masterplan for the rehabilitation and reconstruction of the tsunami-affected community and area in the Province of Nanggroe Aceh Darussalam and North Sumatera. In this masterplan, a zoning concept plan for Meulaboh City has been proposed as a preliminary plan to be developed further by the local government and community of Meulaboh. The scenario of reconstruction of Meulaboh City is based on the minimisation of relocation of urban activities and heavily-impacted settlements, and to revive the functions that should exist in the affected area –particularly in the city centre– in accordance with disaster mitigation plan (Bappenas, 2005). Several functions of urban activity in the city centre such as harbour, ferry port, and commercial areas will be revitalized to support economic activities in the region. The city centre itself is located in the tsunami hazard area and suffered serious damage.

In the tsunami mitigation plan, disaster evacuation plays a very important role in before, during, and after disaster strikes. The main issue of this research is tsunami evacuation planning, with focus on vertical evacuation to shelter buildings as pre-tsunami evacuation destination. The success of evacuation relies much on the remaining time after the earthquake and before the tsunami hits the coast. Pre-tsunami evacuation is determined by the warning information disseminated by tsunami warning centre.

1.2. Research problem

Tsunami is generated by abrupt, large disturbances of the ocean bottom such as earthquakes, volcanic eruption, and landslides. In a tsunami-prone area, this disaster is initiated by the earthquake. After the earthquake there are several minutes to hours remaining before the waves reach the shore, depending on the distance of the area from the epicentre and tsunami source location. Within this time, it is still possible to alarm the coastal population and evacuate them from the hazard area to safe places. In combination with the existence and development of tsunami early warning system in the tsunami-prone regions, the evacuation time can be defined more precisely and therefore pre-disaster evacuation is expected to be more effective.

The main effort to save lives before tsunami waves arrive is to immediately evacuate people from the hazard area. Two methods are generally available: horizontal evacuation –moving people to more distant locations or higher ground– and vertical evacuation –moving people to higher floors in buildings– (Eisner and NTHMP, 2001a). In the common method of horizontal evacuation, evacuating large number of people in the hazard area to safer locations may not be possible due to inexistence of adequate reachable higher ground, and limitation of time, infrastructure, and mode of transport. In a coastal urban area where population and building densities are high, vertical evacuation to a reachable safe place can be considered as the most appropriate action. In these circumstances, evacuating people to the second or third floor of robust buildings which withstand the earthquake and tsunami waves is the most effective way to save lives. The robust building is further defined as evacuation shelter building (ESB).

Regarding the long return period of tsunami disasters and efficiency in urban space occupation and building construction cost, there is no building designated or allocated only for evacuation shelter. However, such a building can be a mosque, school, market, etc. Therefore, it is necessary to identify which building can be assigned or allocated as ESB and what characteristics and specifications it requires. Learning from Japan and United States, the ESB should have a certain design, building layout and accessibility, and structural specifications.

Furthermore, regarding the concentration of people in urban areas, it is strongly recommended to define the capacity, spatial distribution, and accessibility of evacuation shelter buildings within a city. As a part of the disaster evacuation plan, it is important to plan to which ESB should people in a certain area go and how to get them there in a fast and efficient way. In this allocation, despite finding new ESB location(s), existing tsunami-survived buildings that are potential to function as ESB should also be incorporated. And after all, the existence of ESB should be embedded in urban spatial plan with regard to disaster mitigation aspects.

The research problem is how to optimize evacuation of population in a tsunami-prone urban area to evacuation shelter buildings in a very limited time.

1.3. Research objectives

The main objectives of this thesis research is to develop a methodology to determine possible allocation or designation of evacuation shelter buildings using geo-information technology as a part of urban reconstruction planning in a tsunami-prone urban area, case of Meulaboh City.

The more specific objectives are:

1. To review existing methods of tsunami evacuation
2. To identify the location and design characteristics of tsunami-survived buildings after the December 26 tsunami
3. To identify the design characteristics of a building that can function as ESB based on literature study and field observations
4. To develop a methodology of ESB location planning using geo-information system (GIS) and accessibility modelling for tsunami evacuation

1.4. Research questions

In order to achieve the research objectives, the following research questions shown in *Table 1.1* will be addressed.

Table 1.1Research Objectives and Research Questions

No.	Research Objectives	Research Questions
1.	To review existing methods of tsunami evacuation	a. Based on literatures, how is evacuation of people before tsunami exposure? b. Based on literatures, which area would need vertical evacuation? c. What are the relevant characteristics of evacuation shelter building (ESB)? d. What is the response or evacuation time to be assumed?
2.	To identify the location and design characteristics of tsunami-survived buildings after the December 26 tsunami	a. Which type of buildings in the study area could resist the December 26 tsunami? b. What factors did influence the building resistance against the December 26 tsunami?
3.	To identify the design characteristics of a building such that can function as ESB based on literatures and field observation	a. What are the already-known design requirements for ESB? b. What are the alternative functions for ESB based on literatures and field observation? c. Which building that resisted the December 26 tsunami can be functioned as ESB?
4.	To develop a methodology of ESB location planning using geo-information system (GIS) and accessibility analysis for tsunami evacuation	a. How many people need to be evacuated and how is their spatial distribution in the study area? b. How do people travel to reach the ESB? c. How many and how big are the ESBs needed for the study area? d. How to locate the ESBs in the study area and how to optimize their spatial distribution?

1.5. Research design

The research design is presented in *Figure 1.2.* It comprises six groups of activities:

1. Literature study and experts' and authorities' interviews
2. Delineation of the study area
3. Estimation of the population distribution
4. Identification of travel components
5. Identification of existing potential ESB and restricted allocation area
6. Location-allocation modelling.

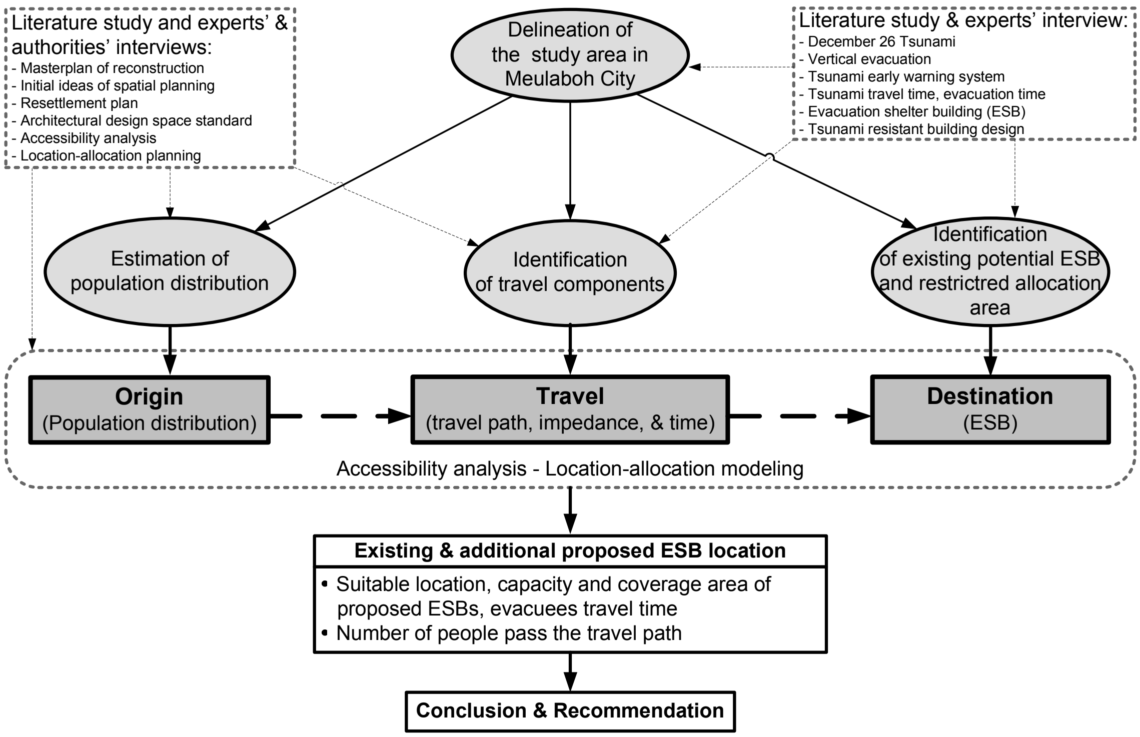

Figure1.2. Research Design

1.5.1. Literature study and experts' and authorities' interviews

Literature study aims at acquiring a comprehensive understanding of existing knowledge of the relevant topics. Sources of the study include: scientific publication (books, journal papers, proceedings) and internet sources of official or reliable institutions. The relationship between the literature study topics and their relevant groups of activities are presented in *Table 1.2.*

Table 1.2 Literature study topics in relation to groups of activities

No	Literature study topic	Relevant group of activities
1	Masterplan of rehabilitation and reconstruction of Aceh	Estimation of population distribution and identification of travel components
2	Architectural design space requirement	Population distribution estimation
3	The event of tsunami of December 26, 2004	Delineation of the study area and identification of existing potential ESB
4	Tsunami evacuation particularly in vertical evacuation	Delineation of the study area
5	Tsunami early warning system	Identification of travel components
6	Tsunami travel time in relation to evacuation time	Identification of travel components
7	Definition and requirements of evacuation shelter building (ESB)	Identification of existing potential ESB

No	Literature study topic	Relevant group of activities
8	Tsunami-resistant building design	Identification of existing potential ESB
9	Accessibility analysis	Location-allocation modelling
10	Location-allocation planning	Location-allocation modelling

Experts' and authorities' interviews aim at exploring the local knowledge of the relevant topics and identifying possible implementation of the relevant topics in the local context of Meulaboh City and Aceh. The relationship between the literature study topics and their relevant groups of activities are presented in *Table 1.3.*

Table 1.3 Literature study topics in relation to groups of activities

No	Interview topic	Relevant group of activities
1	Initial ideas of spatial planning	Estimation of population distribution and identification of travel components
2	Resettlement plan of the local government	Population distribution estimation
3	Vertical evacuation and evacuation time in Aceh context	Delineation of the study area and identification of travel components
4	Tsunami early warning system for Aceh region	Identification of travel components
5	Requirements of evacuation shelter building (ESB)	Identification of existing potential ESB
6	Tsunami-resistant building design	Identification of existing potential ESB

The literature study and interviews are used as a theoretical background and justification for the analyses in this thesis research. More detailed explanation of these activities is given in *Sub-chapter 4.3 and 4.4.*

1.5.2. Delineation of the study area

Due to time constraints and in order to meet an optimal performance, the research focuses only on a part of Meulaboh City which is seriously affected by tsunami and requires vertical evacuation. This part of Meulaboh City is observed in more detail, delineated and defined as the study area.

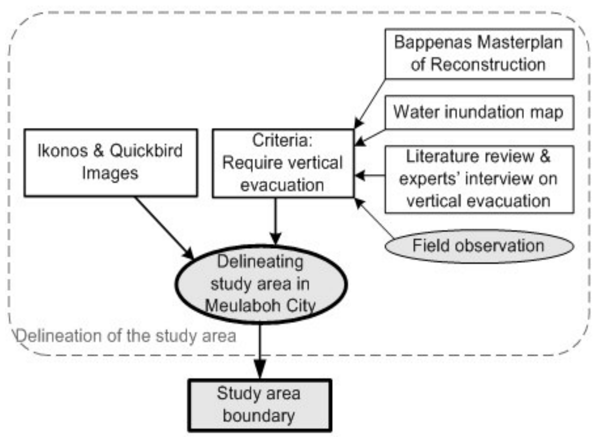

Figure1.3. Delineation of the study area

As shown in *Figure 1.3,* the delineation is based on criteria relevant to the requirements of the area for vertical evacuation. The concept of vertical evacuation in is excerpted from literature review and experts' interviews. Ikonos and Quickbird images are used for delineating and mapping the study area.

Criteria to define the study area include the following:

1. Masterplan of reconstruction

   Vertical evacuation is needed particularly in the area of revived city centre area of Meulaboh. The selected area in the masterplan of reconstruction can be used as a first identification of the study area.

2. Tsunami-affected villages

   The study area must incorporate tsunami-affected villages to ensure the existence of the data and area description before and after tsunami. A Village *(desa or kelurahan)* is the smallest governmental unit in Indonesia. Hence, the most detailed official data is organized and presented at this level. There are 16 out of 21 villages affected by the tsunami, include: Suak Indrapuri, Kampung Belakang, Ujung Kalak, Kuta Padang, Rundeng, Ujung Baroh, Kampung Pasir, Pasar Aceh, Panggong, Padang Seurahet, Gampong Darat, Seneubok, Suak Ribee, Suak Raya, Suak Nie, and Suak Sigadeng *(See Figure 1.4 and Appendix 4)*.

3. High-density population and city centre area

   Vertical evacuation is mostly needed in the high-density population and low-lying coastal urban area. In the Meulaboh context, vertical evacuation is needed in the revived city centre area as a part of the disaster mitigation plan. All tsunami-affected villages include in this classification except the villages of Gampong Darat, Suak Ribee, Suak Nie, and Suak Sigadeng. In a more detailed scale, the population density of the study area can be identified through visual building interpretation in the satellite image.

4. Water inundation

   The study area should be a part of area with an inundation of more than 1.5m depth –as shown in the map in *Appendix 1* – where vertical evacuation is needed.

5. Variety of land use

   More land use variety included in the study area represents and takes into account the existence of various land uses in the real situation. The study area should include facilities of residential, commercial, institutional, recreational and industrial use, and particularly facilities engaged with ESB function. In Meulaboh context, the delineated area should include settlements, a market, shopping centre, port, hotel, restaurant, mosque, school, and a meeting hall. According to the masterplan of rehabilitation and reconstruction (Bappenas, 2005) and the local government plan for the relocation of settlements[1], the former settlements in Suak Indrapuri, Padang Seurahet, and Kampung Pasir village will be allocated for an urban park and tsunami historical museum. While the port and fishing docks in Suak Indrapuri will be revived as they were before the tsunami.

6. Variety of geographic characteristics and distance from the shore

   Tsunami waves arrive first at the in shoreline, estuary, and river. After this, they enter the city through rivers, canals, or by destroying settlements in the shore area. These different geographic characteristics i.e. coastal, river front, and inland area, should be a part of the study area. Since the different areas have a different distance from the shore, different allocation of ESB may be obtained from the vertical evacuation simulation.

7. Existence of road network, river, and canal

   The existing roads, rivers, and canals will influence the vertical evacuation simulation. In the simulation, people evacuate themselves through the road network. The network will be occupied

[1] It refers to the settlement relocation document provided by the Local Task Force of Disaster Management of Aceh Barat District *(Satlak PB Aceh Barat),* Meulaboh.

by the evacuees located in both side of it. Rivers and canals can be used to define the boundaries of the study area since they can restrict movements of evacuees.

Based on the aforementioned criteria, the study area is defined as presented in *Figure 1.4.* This 350 hectare area is administratively located within the villages of Suak Indrapuri, Kampung Belakang, Kampung Pasir, Ujung Kalak, Kuta Padang, Pasar Aceh, Panggung, and Ujung Baroh. Part of the study area are the buffer zone, tsunami historical park, ports, warehouses and fishing dock in the South; the bus station, market and commercial area in the central part; the mosques, schools, offices, and settlements are spread out in the whole area. The area is bounded by the Indian Ocean in the South and East; Suak Ribee River in the West; settlements in the North; and drainage canal and Padang Seurahet river in the East.

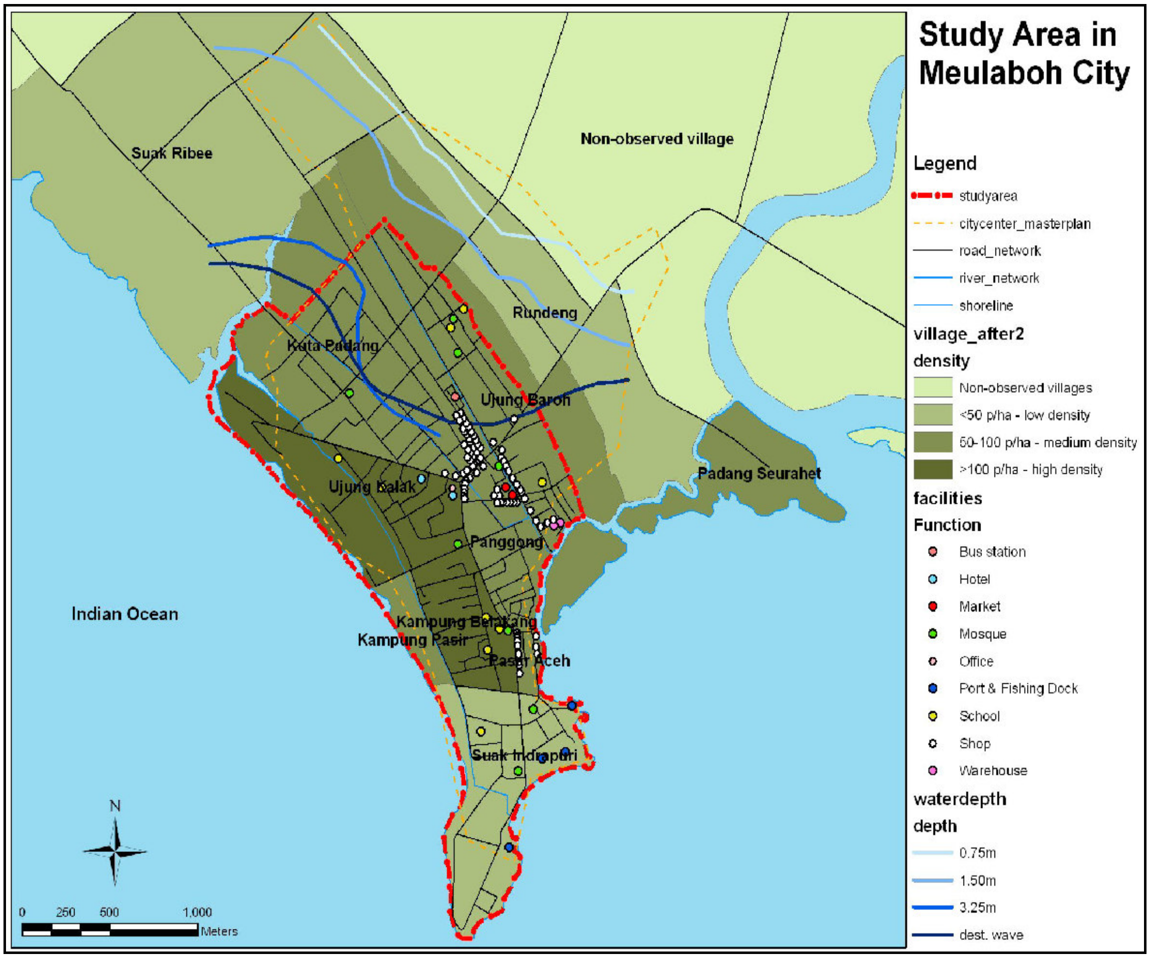

Figure1.4. Delineated study area

1.5.3. Estimation of population distribution

An attempt is made to estimate the number of people which needs to be evacuated. The steps of this estimation are shown in *Figure 1.5.* In this research, the available population data is on village *(desa)* level. At this level, the distribution of the population is not so accurate because the village area varies from 4 to 120 hectares and it covers the areas with different population densities. Hence, population distribution is estimated in equal size tessellations throughout the study area. The tessellation is in the shape of one hectare hexagon. The population distribution is estimated from the building occupants' number and calculated in residential land use (houses) and other land uses (facilities). The configuration of houses and facilities is assumed as the "physical condition to be" that will be achieved after the city reconstruction stage. The condition is observed and defined from:

- Visual interpretation of Quickbird and Ikonos images that cover the study area before (May 18, 2004) and after (January 4, 2005) the tsunami
- Assumption on similarity of reconstructed areas (houses and facilities) as it was before the tsunami (May 2004)
- Local government plan on minimising relocation in the city centre area, the settlements relocation in totally destroyed villages and the buffer zone
- Masterplan of reconstruction and initial ideas of spatial planning team on the buffer zone and tsunami historical park
- Field survey in identification of the facilities locations, subsiding land, and applicable range of the buffer zone which is 100m from the shore.

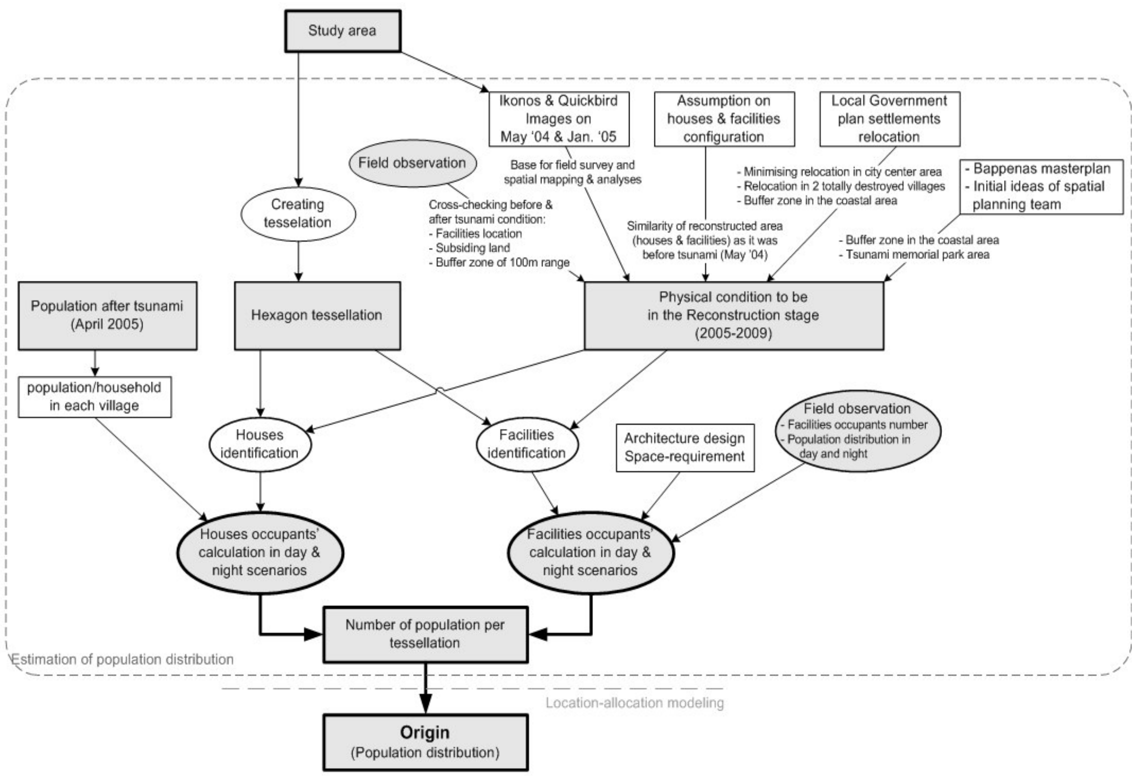

Figure1.5. Estimation of population distribution

The population number is calculated as follows.

- Houses counting incorporating the number of people per household for residential use. The houses are counted manually from visual interpretation on the Quickbird and Ikonos satellite images of. This process incorporates the masterplan of reconstruction, local government decision on resettlement, as well as population data of after the tsunami.
- For other land uses, the population is calculated in architectural design space requirement approach incorporating spatial plan policy of designated buffer zone, the resettlement plan, and field observation on facilities occupants' number. The facilities of the land uses are identified from visual interpretation on the Quickbird and Ikonos satellite images and field observation.

Regarding different concentration of people over the day, the population distribution is calculated in two scenarios: day and night. The resulted population number is stored in a field of a table with reference to the tessellation where the population is located. This table of population calculation is presented in *Appendix 8.*

The population distribution number per tessellation is represented in the tessellation centroid, and the centroid is assigned as the origin of people in the next location-allocation modelling. Detailed explanation of these activities is given in *Sub-chapter 5.1.*

1.5.4. Identification of travel components

The identified travel components include: travel path, travel impedance, and travel time. During evacuation, people evacuate themselves through the travel path of a road network and other passable paths. Particularly in the buffer zone (public park and green belt), where people can go off-the road to any direction, the passable path is represented in a virtual foot path network. The virtual network actually does not exist, it is created to model or represent the possible (off-road) evacuees' movement in that particular area. Similar to the population distribution estimation, delineation of the buffer zone incorporates the masterplan of reconstruction, the relocation plan, and is supported with field observations.

The travel path includes the road network and virtual network. The identification of river and canal network is required since this network may restrict or limit the movement during evacuation. The travel path is identified and digitized from Ikonos and Quickbird images and cross-checked by field observations. This applies particularly for the recovered or rebuilt roads after the tsunami.

Travel impedance is the assignment of evacuees' speed –which is derived from existing tsunami research– to the travel path.

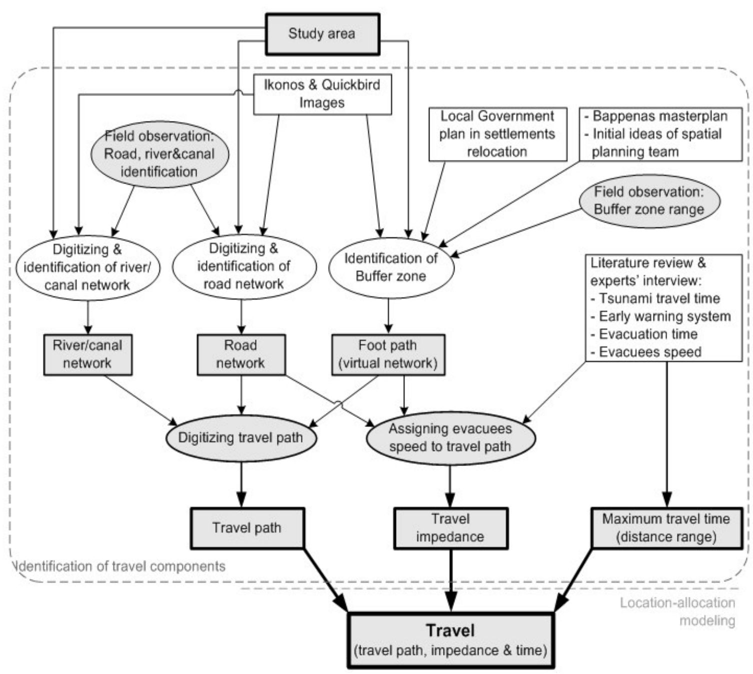

Figure1.6. Identification of travel components

Travel time is the available time to carry out vertical evacuation (evacuation time) after the earthquake and before the tsunami strike. It relates with the travel time of the December 26 tsunami and the development of the tsunami early warning system in the Indian Ocean region. These parameters are defined from literature study and experts' interview. Detailed explanation of these activities is given in *Sub-chapter 5.2.*

1.5.5. Identification of existing potential ESB and restricted allocation area

The justification of the necessity of vertical evacuation to emergency shelter buildings (ESB) is given by the experiences of tsunami-affected countries, i.e. United States and Japan. Based on these literatures, experts' interview, the definition and requirements of ESB are identified.

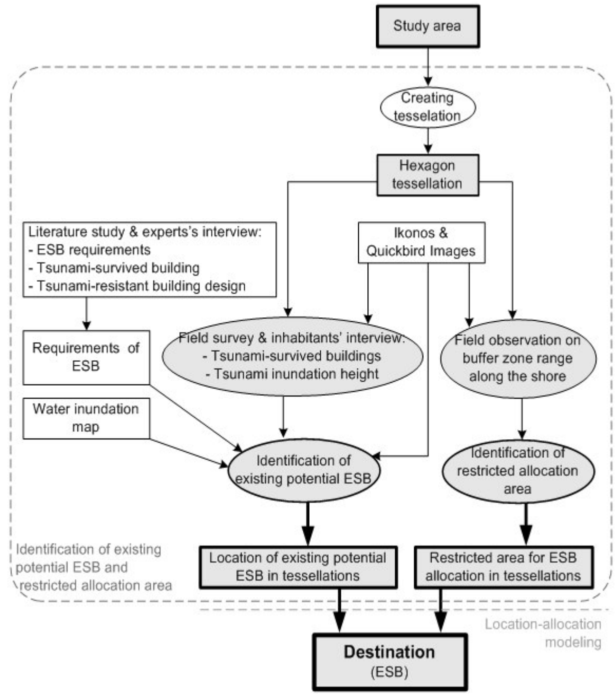

Figure1.7. Identification of existing potential ESB

The survey on tsunami-survived buildings and alternative suitable function for ESB is carried out to assess the possible implementation of vertical evacuation to ESB, as well as to develop ESB characteristics in a local context. Based on ESB requirements, existing tsunami-survived buildings that can function as an ESB are then selected and defined as the existing potential ESB. After this, the available capacity of these buildings in accommodating the evacuees is estimated. The locations of existing potential ESBs are represented in the tessellation centroid and assigned as existing destination of vertical evacuation in the location-allocation modelling.

Related to ESB allocation, the areas that cannot be allocated for ESB are identified. Here, the area along the shore is considered as a restricted area, reflecting evacuee response or behaviour to run away from the shore during tsunami evacuation. Inline with the buffer zone plan, the allocation restriction is applied to an area of 100m range from the shore.

Preparing the location-allocation modelling, locations of existing potential ESBs and restricted allocation areas are represented in the tessellation centroid. In these analyses, Ikonos and Quickbird images are used as the base for identification of the buildings and restricted locations. Detailed explanation of these activities is given in *Sub-chapter 5.3.*

1.5.6. Location-allocation modelling

All the aforementioned activities are actually the preparation for location-allocation modelling as a simulation of the vertical evacuation process. The steps of location-allocation modelling are presented in *Figure 1.8.* The model attempts to define the optimised proposed location of ESB using accessibility analysis. Here, evacuees are simulated to travel from the centroid of each tessellation (origin) to the closest ESB (destination) through the travel path within a maximum travel time (evacuation time). There are three ESB allocations to be carried out: ESB allocation for day population distribution scenarios, ESB allocation for night population distribution scenarios, and Final ESB allocation

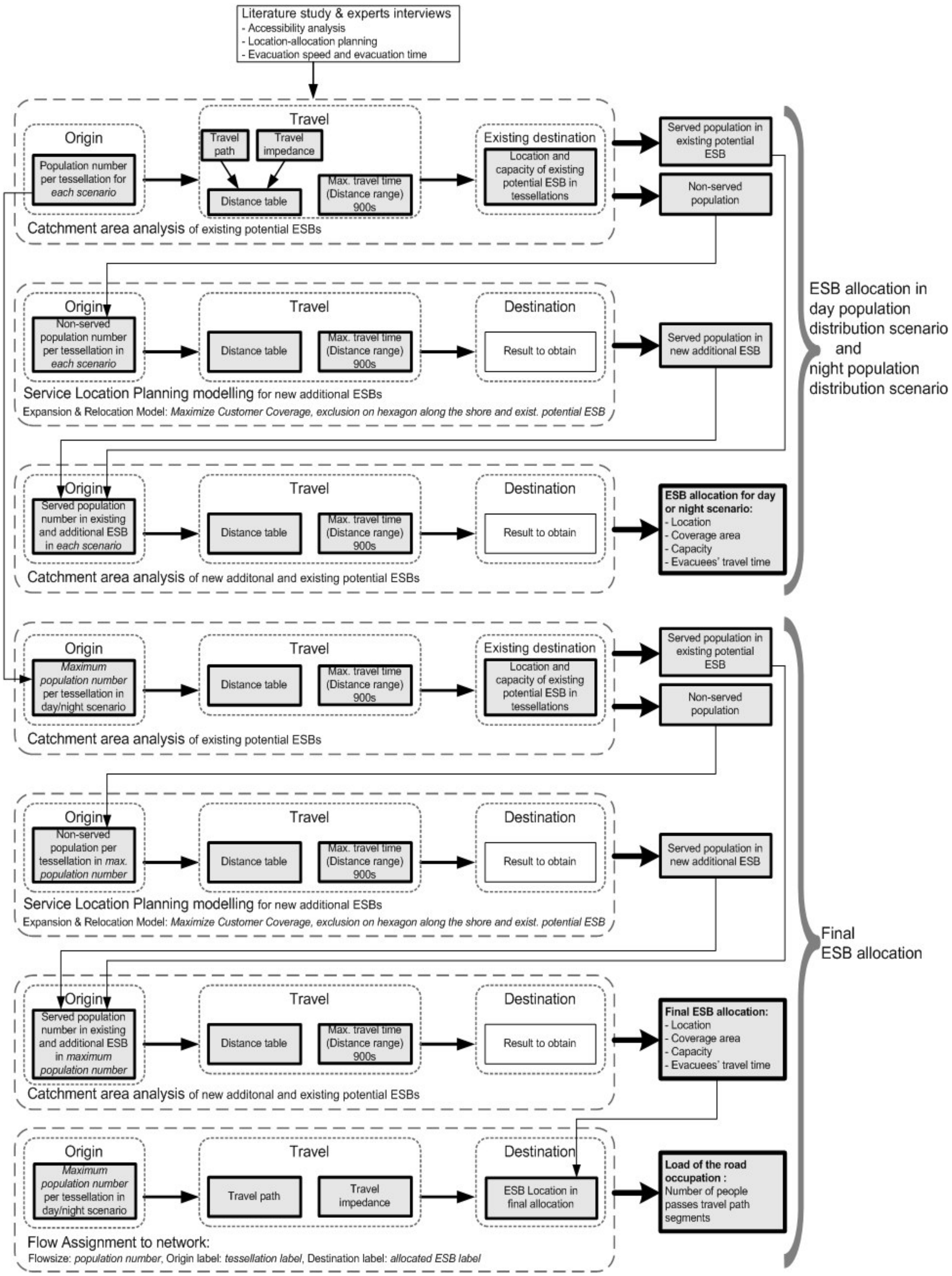

Figure1.8. Location-allocation modelling

The steps in ESB allocation for the day and night population scenarios are actually the same. The distinction of the day scenario and the night scenario is the population number per tessellation that is calculated based on day and night situation respectively. In ESB allocation, the service coverage of existing potential ESBs (with their capacity) in serving the total population is first analysed. From this analysis, new allocation modelling is carried out to allocate the remaining non-served population in the new additional ESBs. Combining the existing and additional ESBs, a catchment (coverage) area analysis is conducted to get the results of proposed ESB locations and coverage area and capacity of each ESB and also the travel time of the evacuees.

The steps of final ESB allocation is similar to ESB allocation in the day or night scenario. In final ESB allocation, the population number taken into account is the maximum population number either in the day or night scenario. First, the maximum population is simulated to travel to the existing potential ESBs. Then, the service coverage of existing potential ESBs and non-served population can be found. The location-allocation modelling is carried out to find the new additional ESB locations to accommodate the non-served population. A catchment (coverage) area analysis is carried out to incorporate the existing potential ESBs with the new additional ESBs and obtain the final results of proposed ESB locations, coverage area and capacity of each ESB, and the evacuees' travel time. In addition to the results, population number is assigned to the network flow in order to get the number of people passes certain travel path segment in the evacuation process. The last information can be used to identify the traffic density and designate the evacuation route.

The ESB allocation modelling runs in *Maximize Customer Coverage* option which aims to allocate the ESB in the area with high population number. In the modelling, the distance range or maximum allowed travel time is 15 minutes (900s) in accordance with the evacuation time. As mentioned in previous *Sub-Chapter 1.4,* the locations of the buffer zone along the shore are assigned as restricted allocation area. In the modelling, the travel is modelled in the shortest travel path algorithm from the origin (population distribution) to the destination (ESB). The modelling is carried out in the Flowmap software package. Detailed explanation of these activities is given in *Sub-chapter 5.4.*

1.6. Structure of report

To address the aforementioned issues systematically, this thesis writing is organized as follows:

- **Chapter 1** is about general introduction and justification of the research includes the background, research problem, research objectives, research questions, and research design.
- **Chapter 2** discusses the literature study that explains the December 26 tsunami, spatial planning and design for tsunami mitigation, vertical evacuation, definition and requirements of the ESB, and accessibility analysis and location-allocation model as tool to allocate the ESB locations.
- **Chapter 3** describes the study area of Meulaboh City in relation to the impacts of the December 26 tsunami to the city and the reconstruction plan.
- **Chapter 4** describes the data collection process includes required data, data availability, data acquisition method, and findings from the field survey. It also shows the data preparation process for further analysis.
- **Chapter 5** explains the analysis process of population distribution estimation, travel components identification, existing ESBs and restricted allocation areas identification, and the location-allocation modeling.
- **Chapter 6** discusses the limitation and possible improvement of the thesis research
- **Chapter 7** concludes achievement of the research and gives some recommendations for further research, Meulaboh's city reconstruction, and the development of Flowmap software.

2. Tsunami vertical evacuation to evacuation shelter building (ESB)

Initiated with short description of tsunami phenomena and the event of December 26 tsunami, this chapter mainly explains the existing spatial planning and design techniques for tsunami mitigation. It discusses further tsunami vertical evacuation and evacuation shelter building (ESB). A brief introduction of the concept of accessibility and its application in vertical evacuation ends this chapter.

2.1. Tsunami of December 26, 2004

On Sunday, December 26, 2004, an earthquake of Mw=9.3 occurred in the northwest coast of Sumatra island, Indonesia. The earthquake generated a catastrophic tsunami that caused destruction in 11 countries bordering the Indian Ocean, and enormous death toll in Indonesia, Thailand, Sri Lanka, and India. The December 26 tsunami has became the most important item in tsunami research and disaster mitigation efforts in the future.

2.1.1. Tsunami generation and propagation

Tsunami is defined as a series of ocean waves generated by abrupt, large disturbances of the ocean bottom such as earthquakes, volcanic eruption, landslides, slumps, and meteor impacts (Bernard, 1999). Literally, the term *tsunami* comes from the Japanese language meaning *harbor* ("tsu", 津) and *wave* ("nami", 波 or 浪).

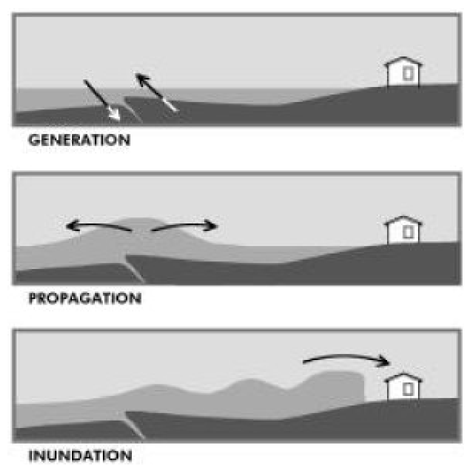

Figure2.1. Tsunami generation, propagation, and inundation (Eisner and NTHMP, 2001b)

Tsunami is a natural phenomena consisting of a series of waves generated when water in a lake or sea is rapidly displaced on a massive scale. It can be generated when the sea floor abruptly deform and vertically displaces the overlying water. Sea floor deformation is actually the earth's crust deformation that is associated with tectonic earthquake. When the earthquake occurs beneath the sea, the water above the deformed area is displaced from its equilibrium position and attempts to regain the equilibrium by gravity influence such that waves are formed. Tsunami can be generated when large areas of the sea floor –continent plates- elevate or subside. Tsunami begins to lose energy as it rushes onshore, the shoreward wave energy is dissipated through bottom friction and turbulence. Despite this energy loss, tsunami still reaches the coast with tremendous amounts of energy. It has great potential erosion, stripping beaches of sand and undermining trees and other coastal vegetation (Department, 2005). The destructive waves can crush coastal structures, displace the roads and bridges, and inundate four kilometers inland. Tsunami wave may reach a maximum vertical height –called run-up– of up to 30 meters above sea level.

On December 26, 2004 tsunami, the tsunami-genic earthquake occurred at 00:58:50 UTC or 07:58:50 local time. The earthquake epicentre was located at the southeast of Banda Aceh City, Indonesia, at 3.307°N, 95.047°E and 30 km depth (USGS, 2005a). The magnitude was reported at Mw=9.0 and later revised at Mw=9.3 (Stein and Okal, 2005b). The earthquake occurred on the interface of the India and Burma plates and was caused by the release of stresses that develop as the India plate sub-ducts beneath the overriding Burma plate. The India plate begins its descent into the mantle at the Sunda trench which lies to the west of the earthquake's epicentre. The trench is the surface expression of the plate interface between the Australia and India plates, situated to the southwest of the trench, and the Burma and Sunda plates, situated to the northeast (USGS, 2005a).

Figure2.2. Tectonic setting of December 26 2004 earthquake (USGS, 2005b)

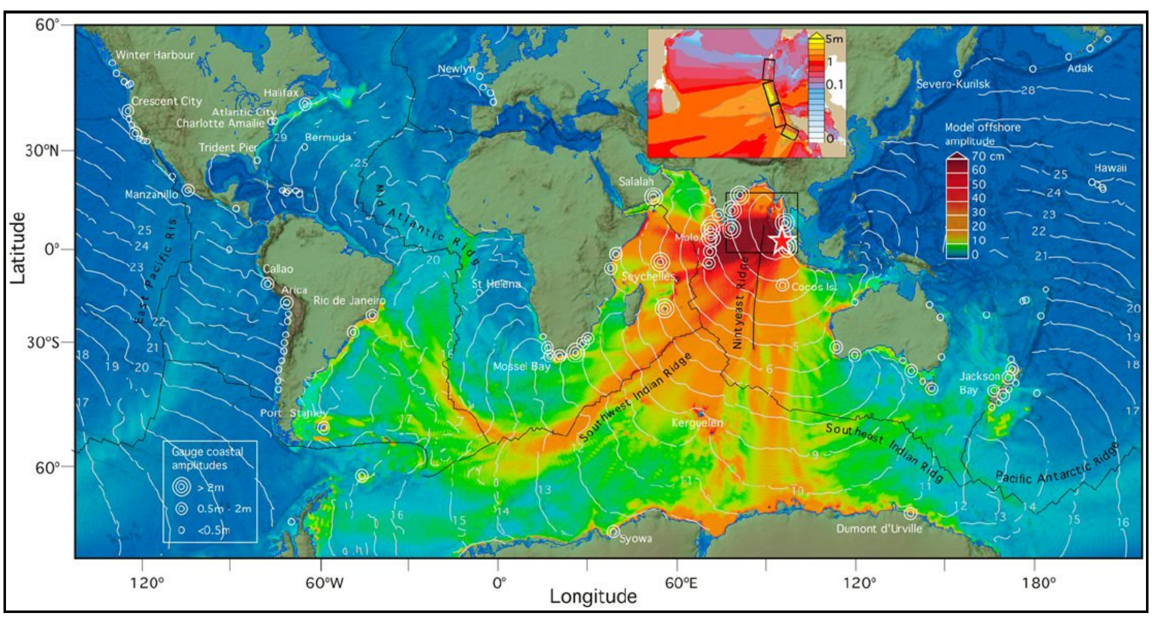

Figure2.3. Global reach of the waves generated on December 26 as a result of numerical model simulations combined with tide gage and satellite altimetry data. The result shows that wave amplitudes, directionality, and global propagation patterns of the December 26 tsunami were primarily determined by the orientation and intensity of the offshore seismic line-source and by the trapping effect of mid-ocean ridge topographic wave guides (Titov et al., 2005).

Measured by gauge coastal amplitude, the tsunami waves traveled the globe. The overview of this disperse can be seen in *Figure 2.3.* Based on the field survey, the wave exceeded 28m high in

Lampuuk coast of Banda Aceh (ITST, 2005), and 15m high in the port of Meulaboh, Indonesia (Yalciner et al., 2005). In this disaster, there were 18 affected countries include Indonesia, Thailand, India, Sri-Lanka, Malaysia, Myanmar, Bangladesh, Maldives, Reunion Island (French), Seychelles, Madagascar, Mauritius, Somalia, Tanzania, Kenya, Oman, South Africa and Australia (Department, 2004). The wave also travelled the globe, and was measured in New Zealand (Goring, 2005), South Africa (Farre, 2005), and Southern Brazil (Melo and Rocha, 2005).

2.1.2. Tsunami travel time, evacuation time, and early warning system

Tsunami travel time is defined as the time that it took tsunami waves to travel from the source (epicentre) to a particular location in the coastal area (Eisner and NTHMP, 2001a). It is identified by the time lasting from the end of earthquake to the moment of first big destructive wave arrived at the shore, such that travel time is considered as waves arrival time. The overview of December 26 tsunami travel time and arrival time is illustrated in the following *Figure 2.4.*

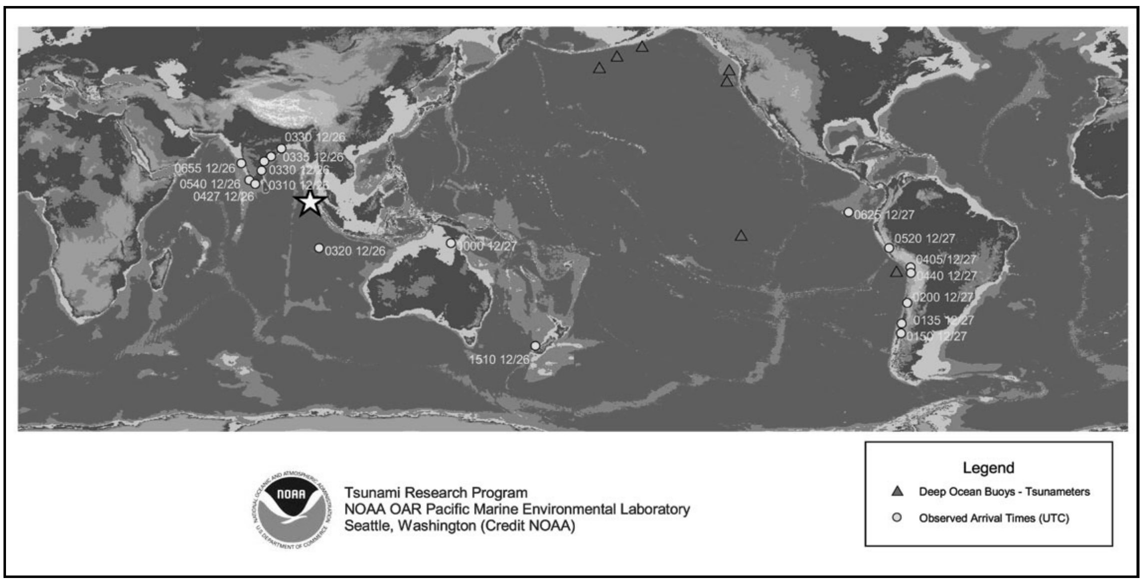

Figure2.4. Observation of the December 26 tsunami travel time and arrival time worldwide (NOAA, 2005)

Based on the field survey conducted by the International Tsunami Survey Team in January 21-31 2005, the wave arrived in Medan (north coast of Sumatra) within 4 hours, and Simeulue and Meulaboh (west coast of Sumatra) within 30-40 minutes (Yalciner et al., 2005). A Compilation of this survey result and inundation map (by the United Nations Humanitarian Information Centre Meulaboh) is presented in the following *Table 2.* The complete result of this survey can be seen in *Appendix 1.*

Table 2.1Result of tsunami survey by the Turkish-Indonesian-USA team
during field survey on Sumatra (HICSumatra, 2005a; Yalciner et al., 2005)

No	Survey Point	Coordinate	Date of Survey	Max. Flow Depth	Innundation Distance	Arrival time	Max. wave height
1	Simeulue Labuhan Bakti	02°24.404N 96°29.000E	24-01-05	3 m	1.5 km	~ 30 min.	4 m
2	Meulaboh Port	04°07.740N 96°07.738E	28-01-05	3.5 m	5 km	~ 40 min.	>15 m
3	Medan East Belawan Port	03°47.059N 98°42.921E	21-01-05	-	-	~ 4 hours	-

In tsunami mitigation particularly in planning for pre-tsunami evacuation, the tsunami travel time is used to define the available time for evacuation of population in coastal area. After an earthquake, the tsunami early warning system needs several minutes to analyse and decide whether it generates a tsunami or not. If it does, the system needs more minutes to alarm coastal population for evacuation. The remaining time after decision-making and alarming process is then considered as evacuation time. Evacuation time is then defined as the available remaining time to evacuate people from tsunami-hazard-prone areas to safe places before the tsunami waves arrive on the shore of an area. Along with the development of tsunami early warning system in tsunami-prone regions, the tsunami travel time and evacuation time can be defined more precisely.

Principally, a tsunami warning system works on the record of pressure sensors embedded in the ocean bed. The sensors record every giant wave and every shudder of a seaquake together with the buoys at sea level. Supported by satellites, the record is sent to the tsunami warning centres on the coast. In the centre, the data is processed and the population will be alarmed if there is a grave risk. If the location and magnitude of an earthquake meet the known criteria for generation of a tsunami, a tsunami warning is issued to warn of an imminent tsunami hazard. The warning includes predicted tsunami arrival times at selected coastal communities within the geographic area defined by the maximum distance the tsunami could travel in a few hours (Eisner and NTHMP, 2001b).

There has been an international cooperation for tsunami early warning system for the Pacific Ocean coastal regions called Pacific Tsunami Warning System (PTWS). Located in Hawaii, PTWS comprises 26 member states organized as international coordination group. Its functions include monitoring seismological and tidal stations throughout the Pacific Basin to evaluate potential tsunami triggering earthquakes and disseminating tsunami warning information. Responding to the December 26 tsunami, a new early warning system will be developed for the Indian Ocean coastal regions (Bappenas, 2005). Instead of international warning centre, regional (or local) tsunami warning centre is responsible for the detection of tsunamis originating within the regional area of responsibility. Furthermore, the centre will be responsible for the prediction of tsunami arrival time within the region and, if possible, coastal impact, and the provision of the earliest possible information and warnings to those national interests responsible for the life and safety of the population of those coastal areas nearest to the tsunami source (Bappenas, 2005).

Related to the study area, Indonesia has decided to install a tsunami early warning system developed by *GeoForschungszentrum* –GFZ (Geo Research Centre) Potsdam, Germany. Besides of GFZ Postdam, the other main institutions involved in the development are *Helmolz-Gemeinschaft Deutscher Forschungszentren* –HGF (Helmholtz Association of National Research Centres) and *Deutschen Zentrum für Luft- und Raumfahrt* –DLR (German Aerospace Centre) Germany. Initially, the system will be set up in Indonesia and Sri Lanka, and later on will be expanded to the whole Indian Ocean region. The technology applied in this system is claimed to be better than the existing PTWS since it can differentiate between fatal tsunami waves and other high waves. Based on the proposed seismologic research network GEOFON of the GFZ Postdam, it will be possible to issue a warning within 13 minutes to seismologic institutions and medias automatically (BMBF, 2005). This will require the extension of gauging stations in order to achieve the necessary quality of such a system.

2.1.3. Destruction caused by the tsunami

The effects of a tsunami can range from unnoticeable to devastating. For the coastal residents in earthquake-prone regions, tsunamis are a major hazard to coastal areas. This disaster may cause catastrophic loss of life, destruction of property, coastal infrastructure and lead to major economic and business interruption losses. According to the Masterplan of rehabilitation and reconstruction (Bappenas, 2005), the December 26 tsunami has caused US$ 4.45 billion damages and losses in the Province of Nanggroe Aceh Darussalam and North Sumatera. By the end of March 2005, 126,732 people were killed and 93,662 people were missing. Worldwide, the reports on fatalities are varied, but as of March 1, 2005 the death toll was approaching 300,000 people. Over five million people were affected by the tsunami and well over a million were left homeless. Of the fatalities, almost half were in Indonesia, with very high casualties in Sri Lanka, India and Thailand as well. People were also killed in Somalia, Myanmar, the Maldives, Malaysia, Tanzania, the Seychelles, Bangladesh, South Africa, and Kenya. Included in the death toll were tourists from countries all around the world (Department, 2004). The death toll shows that the December 26 tsunami is the most destructive tsunamis in human life history. The disaster has not only caused damages and loss of lives but also shaken the psychology, social life, scientific considerations, understanding of hazards, and priorities of disaster mitigation measures.

2.2. Spatial planning and design for tsunami mitigation

In tsunami disasters, the biggest damages and losses occur in the urban areas. Cities located in tsunami-prone areas are vulnerable to disasters because of the concentration of people, buildings, infrastructure and socio-economic activities in the area. Once the tsunami strikes, there will be tremendous losses and damages in the city. Therefore, it is very important to prepare the city and its community with a disaster mitigation plan in order to reduce or minimise potential loss or damage. Tsunami mitigation strongly relates to the communities of the tsunami-prone areas, those are the subject (main actors) as well as the object (target) of mitigation efforts. Since 1994, United States has conducted a state-federal partnership by the National Tsunami Hazard Mitigation Program (NTHMP), which aims at developing the ‘‘tsunami resilient’’ communities (Bernard, 2005; Jonientz-Trisler et al., 2004). The community is characterized as follow:

1. Understand the nature and risk of the tsunami hazard particularly to coastal areas.
2. Have the tools it needs to mitigate the tsunami risk.
3. Disseminate information about the tsunami hazard such as vulnerable populations, risk areas, evacuation routes, and appropriate response.
4. Exchange information with other at-risk areas to mitigate other natural hazards may occur.
5. Institutionalize planning for a tsunami disaster.

In tsunami mitigation, it is important to understand the risk, which is a probability of loss and damage due to a certain disaster exposure. The risk is a loss function of three factors: the nature and extent of the tsunami hazard; the vulnerability of facilities and people to damage; and the amount of development or property or number of people exposed to the hazard (Eisner and NTHMP, 2001a). In urban areas, the risk is very high because of concentration of people, property, and infrastructure.

2.2.1. Land use and site planning for tsunami mitigation

Through land use planning, tsunami risk can be mitigated most effectively by avoiding or minimizing the exposure of people and property. Development should be prevented in high-hazard areas wherever possible (Eisner and NTHMP, 2001a). Relocation of settlements and facilities from tsunami hazard area may become the extreme alternative but are mostly unrealistic. Where development cannot be prevented, land use intensity, building value, and occupancy should be kept to a minimum. If these strategies are not possible and development will occur in possible tsunami inundation areas, mitigation efforts must be embedded in site planning, building and infrastructure design and construction.

To reduce tsunami hazard risk, recommendations on land use planning strategies include the following:

1. Designation or acquisition of tsunami hazard areas for open-space uses
   The open space can function as agriculture, parks and recreation area. It aims at controlling or keeping development at a minimum in hazard areas. The strategy is particularly effective in areas that have not yet experienced development pressure, and is obviously more difficult in areas that are already partially developed or that have strong development pressures. In the last situation, open-space acquisition may be carried out to ensure that the land will be controlled by a public agency or nonprofit entity, and it removes any question about a regulatory taking (Eisner and NTHMP, 2001a). The primary disadvantage of acquisition is the cost.

2. Land use designation in hazard area.
   Where development cannot be avoided in tsunami hazard areas, the strategy aims at controlling the type of development and uses allowed in tsunami hazard area and avoiding high-value and high occupancy uses as much as possible. Large-lot zoning designation can ensure that only very low density residential uses are allowed in hazard areas *(see Figure 2.5 left)*. Another strategy is designation for clustering of development on site where risks are the lowest *(see Figure 2.5 left)* (Eisner and NTHMP, 2001a).

Figure2.5. Large-lot zoning (left) and clustered development (right) (Eisner and NTHMP, 2001a)

3. Zoning arrangement from the public to private zone
   The arrangement aims at allocating residential use far from the shore. Settlements are protected by the buildings in the buffer and civic zone *(See Figure 2.6).* Function located in the civic zone are the functions with public service orientation such as parliament building, government offices,

and mosque. These function may be used for evacuation shelter in emergency situation[2]. In this arrangement, the extent of each zone should be reconfigured considering different topographical and geographical characteristics of a coastal area.

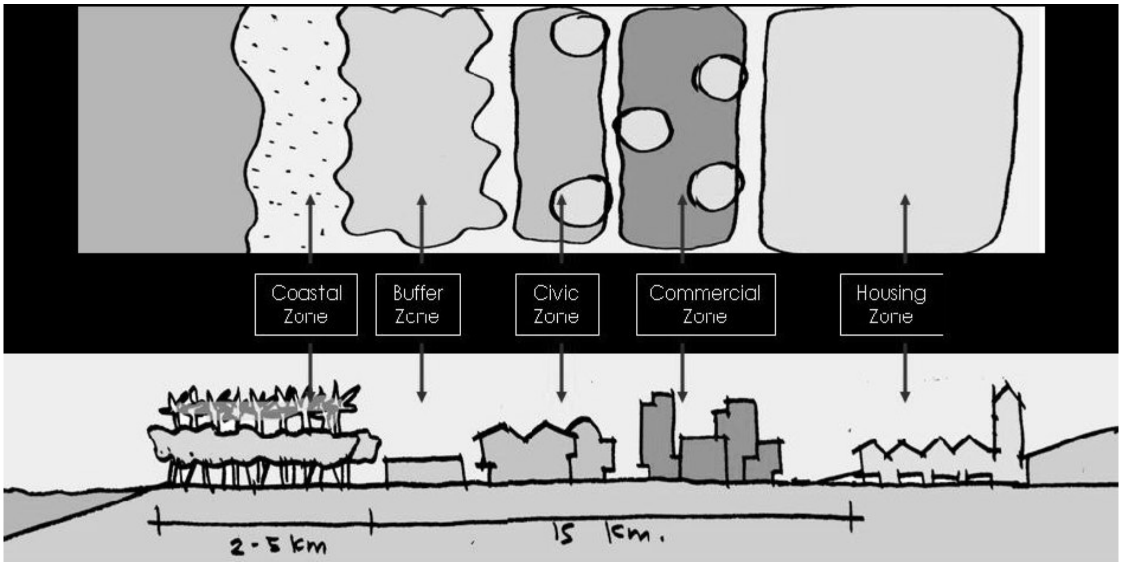

Figure2.6. Zoning arrangement to protect settlement [2]

4. Capital improvement planning and budgeting
   This strategy can be used to reinforce land use planning policies. A major factor in determining future development patterns is planning and development of infrastructure and public facilities. Decisions made can either discourage or encourage development in tsunami and other hazard areas. Hazard mitigation should be integrated into infrastructure policy. Infrastructure policies by themselves will not preclude development in certain areas, but they can reinforce land use plans, and shape market forces to encourage development in less hazardous areas by not supporting infrastructure that serves a higher-risk hazardous area (Eisner and NTHMP, 2001a).

In the situation where development is to be sited within a tsunami hazard area, the physical configuration of structures and uses on a site can reduce potential loss of life and property damage. This includes the strategic location of structures and open space areas, interaction of uses and landforms, design of landscaping, and the erection of barriers. According to the US National Tsunami Mitigation Hazard Program –US NTHMP– (Eisner and NTHMP, 2001a), there are four basic site planning techniques to reduce tsunami risk that can be developed or combined with other broader built environment design. These site-planning techniques include the following:

1. Avoid inundation areas
   This technique can be considered as the most effective mitigation method. At the site planning level, this can include siting buildings and infrastructure on the high side of a lot or raising structures above tsunami inundation levels on piers or hardened podiums *(See Figure 2.7 left).*

[2] The ideas and documents (images) were addressed by Dr. Budi Faisal of the Architecture Department of Institute of Technology Bandung (ITB) in the interviews during the fieldwork period.

2. Slow water currents

   Slowing technique attempts to create friction that reduces the destructive power of tsunami waves. Specially designed forests, ditches, slopes, and berms can slow and strain debris from waves. To work effectively, these techniques are dependent on correctly estimating the inundation that could occur *(See Figure 2.7 right)*.

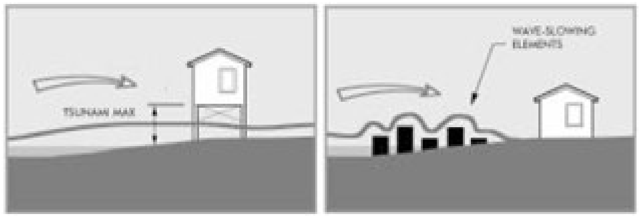

Figure2.7. Avoiding inundation area (left) and slowing water currents (right) (Eisner and NTHMP, 2001a)

3. Steer water forces

   Steering technique guide the force of tsunamis away from vulnerable structures and people by strategically spacing structures, using angled walls and ditches, and using paved surfaces that create a low-friction path for water to follow *(See Figure 2.8 left)*.

4. Block water forces

   Hardened structures such as walls, compacted terraces and berms, parking structures, and other rigid construction can block the force of waves. Blocking, however, may result in amplifying wave height in reflection or in redirecting wave energy to other areas *(See Figure 2.8 right)*.

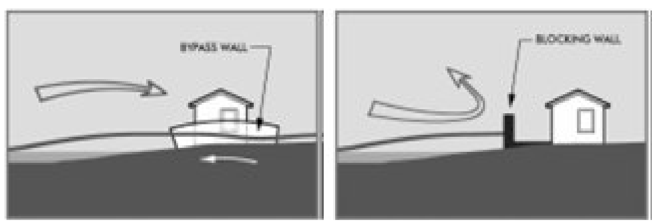

Figure2.8. Steering water forces (left) and blocking water forces (right) (Eisner and NTHMP, 2001a)

The examples of implementation of aforementioned techniques in urban planning and design can be seen in the following *Figure 2.9-2.11*.

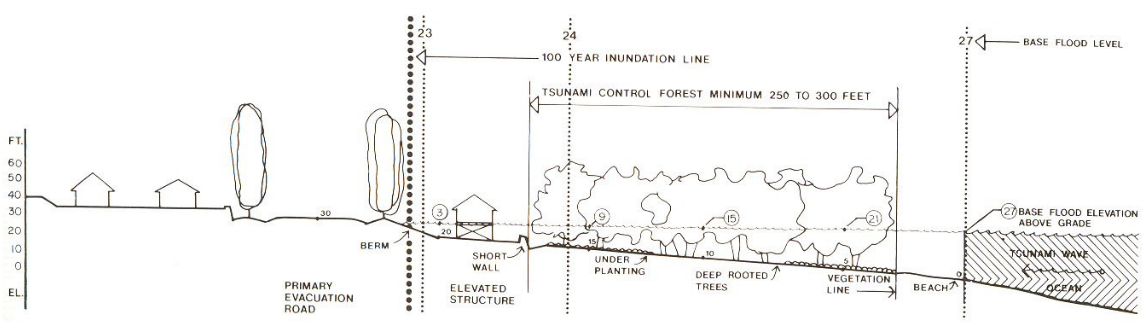

Figure2.9. Siteplan concept section of Kodiak Island, Alaska. It shows combination of siteplan techniques in avoiding, slowing, steering, and blocking tsunami waves by incorporating the tsunami control forest, elevated construction, drainage canal, and evacuation road (Preuss, 1983)

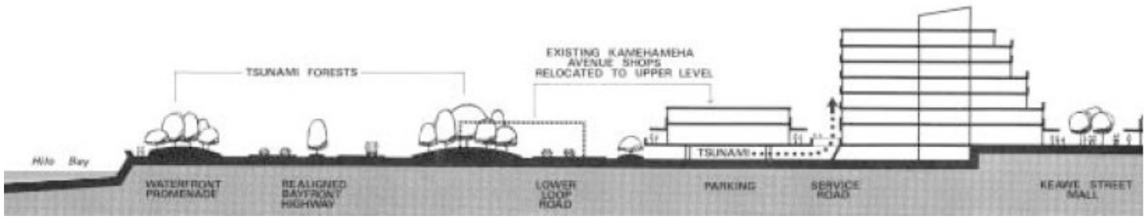

Figure2.10. Hilo Downtown Redevelopment Plan, Hawaii. Development of tsunami forest is to slow down the water currents and relocation of parking lot and avenue shop to upper level is to provide evacuation area and steering tsunami waves (Eisner and NTHMP, 2001a).

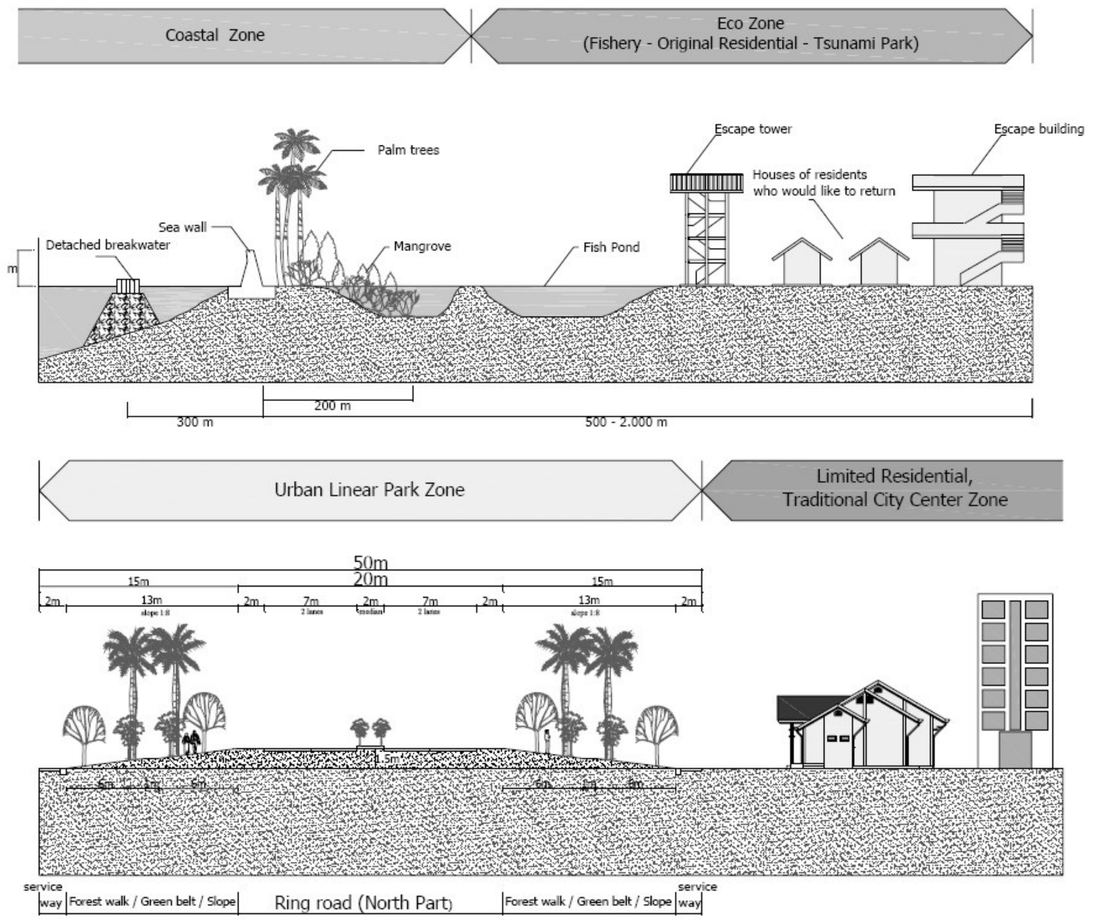

Figure2.11. Schematic diagram from coastal area to relief road in Banda Aceh City. Top: near-shore part, bottom: around ring-road (relief road) part (JICA, 2005).

2.2.2. Emergency road network planning for tsunami mitigation

To support the mobility of evacuation and aid efforts, the planning for emergency road network is strongly required. Emergency road network is organized into escape road and relief road (JICA, 2005). Escape roads accommodate people in the hazard zone to escape from disaster in a short time. Relief roads mainly function for immediate treatment (first-aid), evacuating citizens, and supplying relief materials. The road network ensures connection with safer area in surrounding region of tsunami hazard zone.

Taking an example of the Urgent Rehabilitation and Reconstruction Plan (URRP) of Banda Aceh City, Indonesia (JICA, 2005), the escape roads are connecting coastal zone to national road. The road provides safely escape for the citizens. Escape buildings are provided along the escape roads for the people failed to get out in time. While emergency road network is planned not only for escape, rescue and relief activities during disastrous event but also for supplying goods and materials for dislocated families after the disastrous event. Incorporating the road network into land use planning, the schematic diagram from coastal area to relief road of Banda Aceh City is shown in *Figure 2.11.*

2.2.3. Facility planning and design for tsunami mitigation

2.2.3.1. Coastal structures

The following structures are required to build in coastal area in order to reduce destructive energy of tsunami waves. Materialisation of these structures should consider local condition of tsunami-prone area in terms of geography, topography, and financial resources.

a. Detached breakwater

Detached breakwaters are structures situated offshore and generally parallel to the shore. Detached breakwaters protect the adjacent shoreline by reducing incoming wave energy due to storm surge, mid-scale and small-scale tsunami. Sand transported along the beach is then carried into the sheltered area behind the breakwater where it is deposited in the lower wave energy portion. If the breakwater attenuates much wave energy, sediment may eventually fill in the sheltered part of the breakwater and form a tombolo (JICA, 2005).

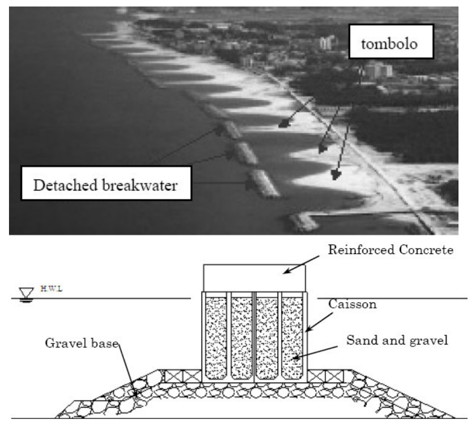

Figure2.12. Top: Detached breakwater, bottom: Typical cross-section of detached breakwater (JICA, 2005).

b. Sea wall

A sea wall is a structure built along the shoreline parallel to the beach. Its purpose is to impose a landward limit to coastal erosion and to provide protection to development behind the wall. Seawalls are commonly constructed from dumped rock, concrete and gabions. The face of a seawall may be vertical, curved, stepped or sloping *(See Figure2.13-2.14)* (JICA, 2005).

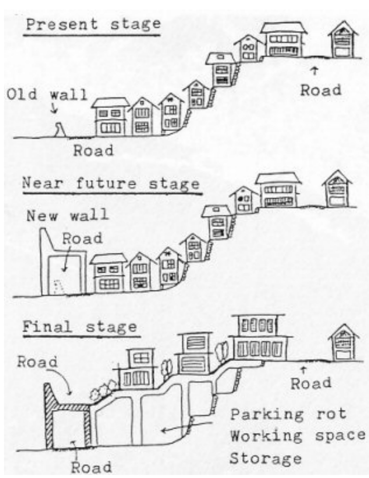

Figure2.13. Sketch of village improvement plan of fishing villages along the Sanriku Coast, Japan. Tsunami protection relies much on sea wall (Fukuchi and Mitsuhashi, 1983).

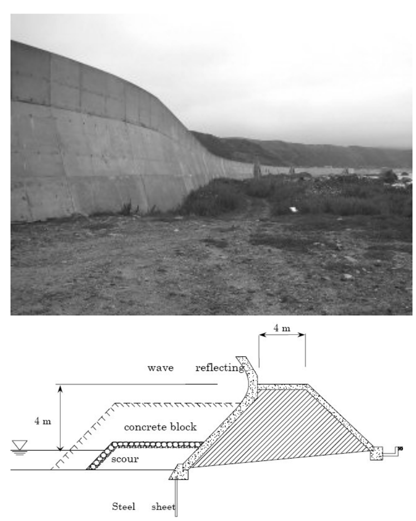

Figure2.14. Top: Sea wall, bottom: Typical cross-section of sea wall (Nishimura, 2004)

c. Coastal forest

Implementation of detached breakwater and sea wall -considered as artificial measures– involves high construction and maintenance cost as well as environmental changes along the shoreline. Coastal forest, with mangrove, sago palm, casuarinas tree and coconut tree, is known as natural functions to reduce the tsunami force and it is an alternative solution to avoid disadvantages of artificial measures (JICA, 2005). Mangroves tolerated the December 26 tsunami waves without showing any apparent damage such that being considered as the most suitable species to mitigate the effects of mighty tidal waves (Kathiresan and Rajendran, 2005). Example of coastal forest implementation in urban planning is shown in the top picture of previous *Figure 2.11.*

d. Tidal gate

Tidal gate located in the river mouth to prevent tsunami run-up and inundation through the river channel. It also prevents the collapse of bridges due to hydraulic bore of tsunami waves that travel to upstream. Lower priority is given to the construction of tidal gate because of high construction cost. The tidal gate would be required when development of facilities and infrastructures along river channel is carried out (JICA, 2005).

Figure2.15 Tidal gates (JICA, 2005; Nishimura, 2004)

2.2.3.3. Public Emergency Facilities

Referring to the Urgent Rehabilitation and Reconstruction Plan (URRP) of Banda Aceh City (JICA, 2005), public emergency facilities for tsunami disaster preparedness include escape building, escape bridge, emergency base and city park.

a. Escape building

An escape building or evacuation shelter building (ESB) is a public facility that functions as temporary shelter during evacuation before a tsunami strike. This building is located within reachable distance from population concentrations and along escape roads. In case that people cannot reach higher ground because of the far distance and limited time, escape building can be an alternative place to go. Evacuation floor in this building must be higher than (estimated) tsunami inundation in its area. Escape building can also be in the form of tower building *(See Figure 2.16).* The coming *Sub-chapter 2.5* explains escape building or ESB more detail. The location of ESB should be easily accessed by the evacuees.

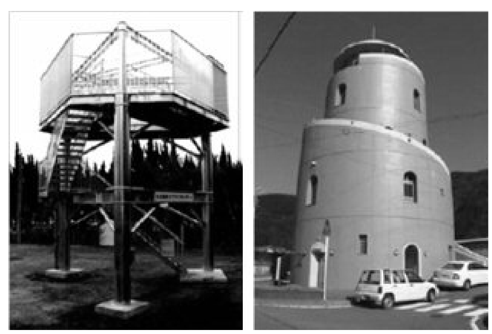

Figure 2.16 Escape building (JICA, 2005)

b. Escape bridge

Similar to the escape building, an escape bridge is located along the relief road. The bridge is raised above tsunami inundation level of the river such

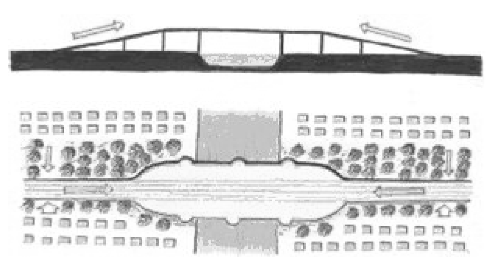

Figure2.17 Schematic illustration of escape bridge (JICA, 2005)

that people rushes into the crest of the bridge. The enlargement of the bridge crest enables the people to stand temporarily.

c. Emergency base and city park

Emergency base is the building and open space utilized for the purpose destination of escape destination and base for rescue, relief and temporary housing. A city park can be functioned as emergency base function in emergency situation as well as public education and recreation function in normal situation.

Figure2.18. Left: Inland cast of PLN ship in Banca Aceh (fieldwork doc.), right: artistic view of city park designation plan of the surrounding area (JICA, 2005)

2.2.3.4. Housing strategies

Particularly in housing and settlements, the following strategies need to consider in tsunami mitigation.

1. High-density housing

   Spatial arrangement in housing development is encouraged to form high-density housing rather than dispersed one. The inhabitants are motivated to live close to one another in high-rise town house or apartment. This condition will make communication and coordination between disaster management and inhabitants much easier during disaster [3]. High-density living is also suitable to be applied in urban area where the land is scarce.

2. Clustered buildings and tower building

   Several buildings are clustered and connected to a tower or high-rise building that can be used as evacuation area during tsunami exposure. In normal situation, the tower itself can be used as *mushalla* or mosque, social meeting room, or function room [3].

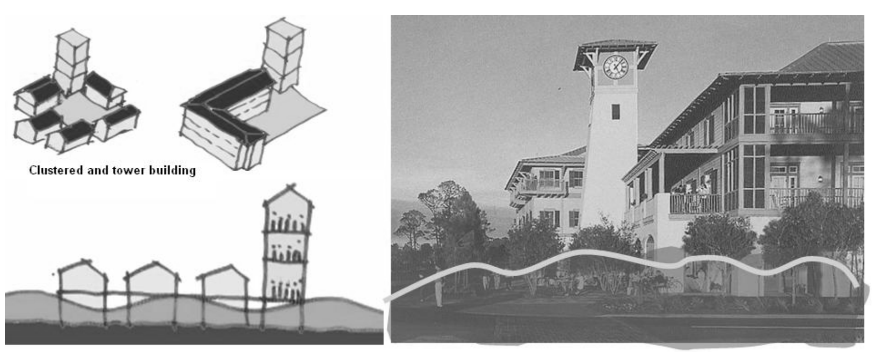

Figure2.19. Clustered and tower building to prepare for evacuation [3]

[3] The ideas and documents (images) were addressed by Dr. Budi Faisal of the Architecture Department of Institute of Technology Bandung (ITB) in the interviews during the fieldwork period

3. Building reorientation
   When tsunami waves can reach the buildings, building mass reorientation is meant to avoid the building from blocking tsunami waves and to allow the waves to pass through in between spaces [4].

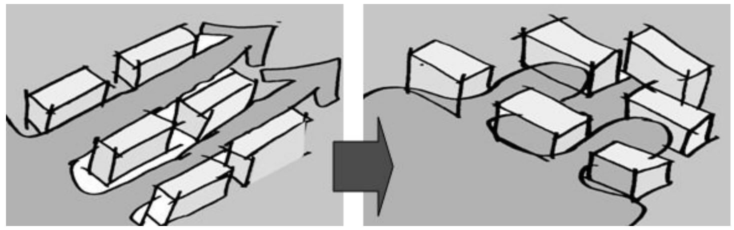

Figure2.20. Building mass reorientation [4]

4. Vegetation plantation
   Inhabitants are motivated to plant high tress around their houses such that can be used as an alternative of escape or evacuation from tsunami disaster [4]. Experience shows that many people survive December 26 tsunami by climbing up the trees.

5. Designation of main function in upper floor of the building
   In multi level building, the main activities are located in the upper floor where tsunami waves cannot reach. In residential building, living and other activities involving high number of population are conducted in upper floor. The ground floor can be used as parking lot and limited or small-scale commercial use [4]. This designation is very useful during tsunami exposure that water can go through the building and minimize the loss of people.

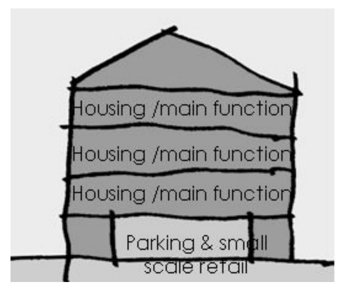

Figure2.21. Upper floor designation [4]

2.2.3.5. Critical facilities

In tsunami mitigation, vital infrastructures and critical facilities in a community deserve special precautions in the planning and design process to minimize damage to them. Vital infrastructures are required to operate continuously or rapidly recovered after disaster. They include: transportation systems for people and goods and utility systems such as communications, natural gas, water supply, power generation and transmission systems (Eisner and NTHMP, 2001a). The failure in these facilities may cause much more damages and losses. Other facilities are considered critical because of their occupants or the functions they contain. These facilities include:

- Essential service facilities: fire stations
- Hazardous facilities: chemical plants, fuel storage tanks, nuclear reactor
- Special facilities: government or authority buildings, high occupancy buildings, convalescent homes with non-ready occupants for evacuation

Figure2.22. Destroyed bridge in Meulaboh after Dec. 26 tsunami practically isolated some villages from aid (fieldwork doc.)

[4] The ideas and documents (images) were addressed by Dr. Budi Faisal of the Architecture Department of Institute of Technology Bandung (ITB) in the interviews during the fieldwork period

According to the US NTHMP (Eisner and NTHMP, 2001b), specific strategy for vital infrastructures and critical facilities include the following:

1. Strengthen or phase out existing facilities.
2. Relocate portions of at-risk facilities.
3. Raise existing facilities above the inundation elevation and protect against impact forces and scour.
4. Construct barriers.
5. Provide redundant facilities.
6. Relocation on obsolescence of existing infrastructure and critical facilities in tsunami hazard area
7. Do not allow expansion or renovation of existing facilities in tsunami hazard areas without requiring measures to reduce the risk.
8. Prepare emergency plans to cope with the emergency situation and expedite recovery.

Figure2.23. Fire on petroleum tank due to damage from 1946 tsunami in California (Eisner and NTHMP, 2001b).

Tsunami mitigation should also consider or incorporate other hazard that may occur due to or following a tsunami such as flooding in coastal area, fire, or explosion of chemical plant.

2.2.4. Building design and construction

In a situation that buildings must be constructed in a tsunami hazard area, the design and construction of the buildings can reduce loss of life and property damage. Even though tsunami specific design, good engineering techniques and materials will help a building resist tsunami forces and inundation, in cases of intense tsunamis such as December 26 tsunami, they will only reduce losses but not prevent severe damage. And still, the best approach to minimizing or avoiding tsunami losses is to locate buildings beyond the reach of tsunami run-up.

To be able to deal with tsunami hazard, the building is designed to meet a particular performance level, which is the amount of damage the owner can tolerate and the ability of the building to support its intended uses after tsunamis strikes. Performance level should be considered in the process of planning, construction, occupation and maintenance of the building. The US NTHMP (Eisner and NTHMP, 2001a) defines the following factors to be considered in formulating performance objective of a building:

1. Location of the building and its configuration (size, shape, elevations, and orientation)
2. Intensity and frequency of the tsunami hazard selected for design
3. Structural and non-structural design standards
4. Choice of structural and finish materials
5. Reliability of utilities
6. Professional abilities of designers
7. Quality of construction
8. Level of confidence in these factors

According to Camfield (1994), there are five types of forces may result when the tsunami run-up strikes the building as a high velocity surge:

1. Buoyant forces caused by partial or total submergence
2. Surge forces caused by the leading edge of the surge impinging on a structure

3. Drag forces caused by the high velocity of the surging water where the water is relatively constant
4. Impact of forces caused by buildings, boats, vehicles, fuel tanks, logs, broken trees, or other material (debris) carried by the surging water
5. Hydrostatic forces caused by partial or sub-mergence of structures by the tsunami.

In relation to the building design, *Table 2.2* shows the typical drag coefficients on the shape of building components (wall, column, plate).

Table 2.2 Typical drag coefficients *(Camfield, 1994)*

Object	L/d	Reynolds number	C_D
Circular cylinder	1	10^5	0.63
	5	10^5	0.74
	∞	10^5	1.20
	∞	$>5 \times 10^5$	0.33
Square cylinder	∞	3.5×10^4	2.0
	∞	10^4 to 10^5	1.6
Rectangular flat plate (totally submerged)	1	$>10^3$	1.1
	5	$>10^3$	1.2
	20	$>10^3$	1.5
	∞	$>10^3$	2.0

NOTE.--L = The height of a submerged cylinder, or the length of the flat plate.
d = The projected dimension shown, or the width of the flat plate.

In order to prepare the building for tsunami, the listed below are technical measures and consideration in building design and construction. The more detailed building design solution for tsunami effects can be seen in *Appendix 3.*

1. Preparing for tsunami forces

   Design and construction of new buildings and the retrofitting of existing buildings should address forces associated with water pressure, buoyancy, currents and waves, debris impact, scour, and fire *(See Figure 2.24-2.25)*(Eisner and NTHMP, 2001b).

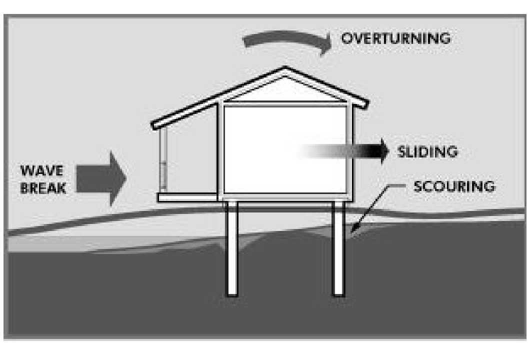

Figure2.24. Forces on structures created by tsunami (Eisner and NTHMP, 2001b)

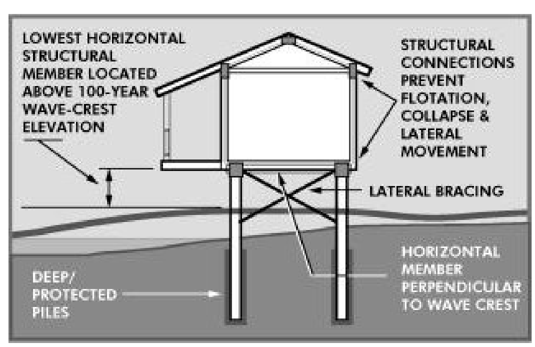

Figure2.25 Design solution to tsunami effects (Eisner and NTHMP, 2001b)

2. Allowing the wave flows

   It is very difficult–almost impossible– for the building to be able to cope with intense and destructive tsunami waves.

   In this circumstance, the building is prepared to allow the waves to pass through by breaking the façade or (non-structural) walls at tsunami-reached level –mostly at ground floor–, while the building structure (column, beam, lateral bracing, foundation, and structural connection) is designed and constructed to withstand the waves. For this purpose, the large percentage of openings such as door, window, arch, ventilation hollow, and corridor are allocated in the ground floor or wave-reached elevation floor[5]. The example of openings role in supporting building resistance against the December 26 tsunami is given in *Figure 4.6-4.7*.

   Openings may also be located adjacently to the column or other structural elements. In wave-reached floor, structural loads are assigned to the columns that can be designed in a circular cylinder shape also to allow the passing waves. As shown in *Table 2.2,* the circular cylinder shape has the lowest drag coefficient such that increases the building resistance against the waves.

   Since the façade and walls are designed to be broken or destroyed by the waves, their joint to the main structural system (column, beam, etc.) should not be made too rigid. They can also have their own structure separated from the main structural system [5]. Lay-out of this floor can be an open lay out type or using easily breakable construction such as partition walls.

   As mentioned in previous *Sub-chapter 2.2.2.*, the main function or activity of the building is located at the upper floor of the wave-reached floor, such that the building should be multi-storey one. The example of building design to withstand tsunami is presented in the *Figure 2.26-2.28.*

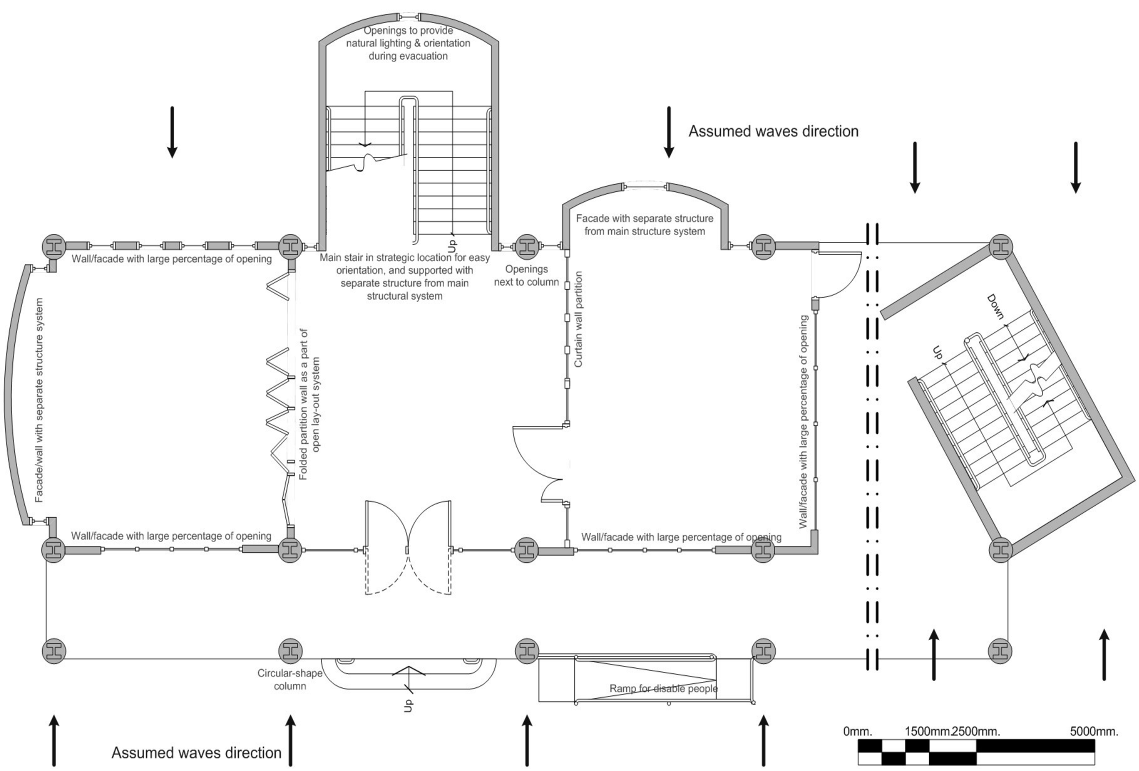

Figure2.26. Example of building design that responds to tsunami waves

[5] The design ideas were addressed by Ir. Andry Widyowidjatnoko of the Architecture Department of Insitute of Technology Bandung (ITB) in the interview during the fieldwork.

Figure2.27. Elevated restaurant building in Hilo Hawaii to allow waves to pass through (Eisner and NTHMP, 2001a).

Figure2.28. Building design that allows water flow has proven surviving tsunami. (fieldwork doc.; (Navy, 2005)

3. Material and construction.
   Substantially built buildings of concrete, masonry, and heavy steel frames are likely to perform fairly well in a tsunami unless compromised by earthquake shaking. Wood frame buildings, manufactured housing, and light steel frame structures at lower elevations close to the shoreline are likely to fare poorly (Eisner and NTHMP, 2001b).

4. Earthquake-resistant.
   Instead of withstanding tsunami disaster, the building must survive from the earthquake that occurs before the tsunami, such that the design and construction should meet the requirement of earthquake-resistant codes or standards.

Not every area affected by tsunami run-up will experience damaging forces. Buildings in less hazardous areas affected by shallow run-up water depths should survive with repairable damage if well designed and constructed. The force of currents and breaking waves, fast-moving waterborne debris, and scouring currents will exceed the resisting capabilities of most buildings unless the building is built with specific design elements and materials.

Implementation of tsunami mitigation in building design and construction is strongly related with the enforcement of building codes. Building codes are applied to new construction as well as to existing buildings undergoing reconstruction, repair, rehabilitation, or alteration, or when the nature of the use is changed to a new occupancy that increases the risk or exceeds the structural capability of the building. However, codes are not a substitute for competent engineering and design or construction and quality assurance. Since the circumstances applicable to each building differ, and thorough and independent consideration should be given to each building. Knowledge regarding tsunamis and building performance is constantly changing and therefore improvements should be anticipated (Eisner and NTHMP, 2001b).

2.3. Pre-tsunami evacuation

2.3.1. The methods and suitability

Before tsunami exposure, the primary strategy to save lives is to evacuate people immediately from the hazard area to the safe places. The US NTHMP (Eisner and NTHMP, 2001a) classified available methods of tsunami evacuation into horizontal and vertical evacuation.

1. Horizontal evacuation
   This method evacuates people from the hazard area to the safe places in a distant locations or higher ground. This method is commonly applied in many tsunami disaster cases (Eisner and NTHMP, 2001b).

2. Vertical evacuation
   In this method, people are evacuated to the upper floors of the robust multi-storey buildings located around them.

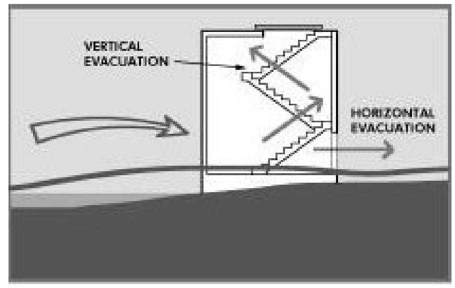

Figure2.29. Vertical and horizontal evacuation (Eisner and NTHMP, 2001b)

These two methods may be applied solely or complementary one another. The example of tsunami evacuation scheme is shown in the *Figure 2.30*

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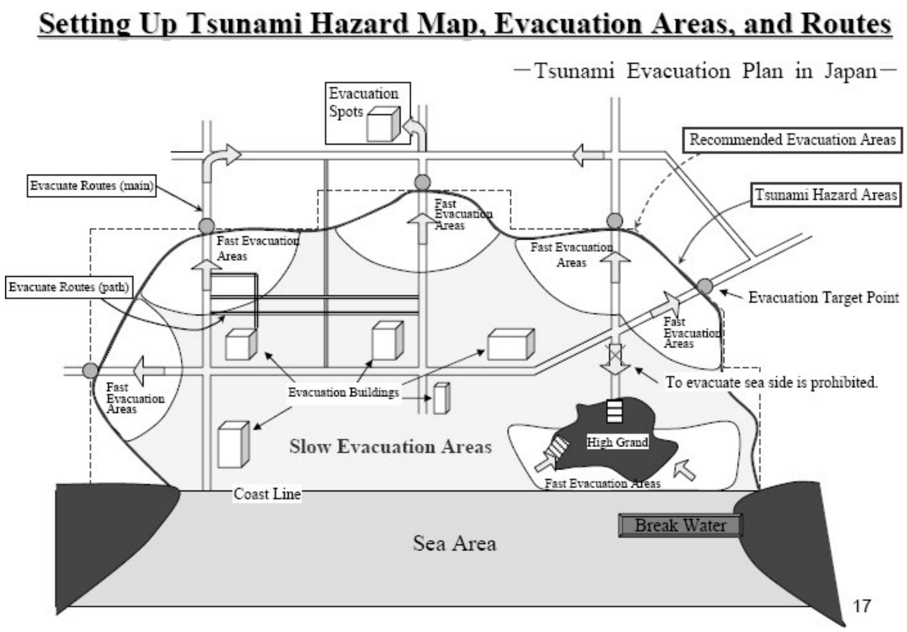

Figure2.30. Scheme of tsunami evacuation plan in Japan, showing both horizontal and vertical evacuation (Nagao, 2005).

Implementation of those methods in a certain tsunami-prone area depends on the characteristics of the tsunami, hazard area, and existing facilities and infrastructures. Listed below are factors to be considered in deciding appropriate method in tsunami evacuation. The suitability of implementation of these methods in a certain tsunami-prone area is presented in the following *Table 2.3.*

1. Available evacuation time
   The available time for evacuation depends on remaining time from tsunami warning alarm to the wave arrival time on shore. It ranges from just several minutes to hours. Before alarm, the early warning system needs several minutes to analyze and decide whether the detected earthquake will generate a tsunami, and disseminate the tsunami information to the disaster management authority in coastal area. Vertical evacuation can be carried out in a relatively short time because people just move to the designated building around them. Therefore, it is suitable for an area exposed to locally generated tsunami, where the waves arrive on shore in a relatively short time. While

horizontal evacuation can be applied in areas exposed to distant tsunami –longer tsunami arrival time– since it takes more time to travel to the safe area in a distant place or higher ground.

2. Land topography
   Topography characteristics in the coastal area determine which evacuation method to be carried out. Horizontal evacuation requires higher elevation of the land above the elevation of tsunami-reached area. The land can be a hill or high inland. For the coastal area which is topographically flat or in which there is no hill or high elevation land, vertical evacuation becomes the choice.

3. Supporting infrastructure and facilities
   Horizontal evacuation requires good condition of roads and bridges and designated evacuation route to support the movement of huge number of population within the same time period. An assembly hall in the evacuation place and mode of transportation is also important factors to be considered. Vertical evacuation requires the destination buildings to be adequate in terms of strength, capacity, utility, and accessibility.

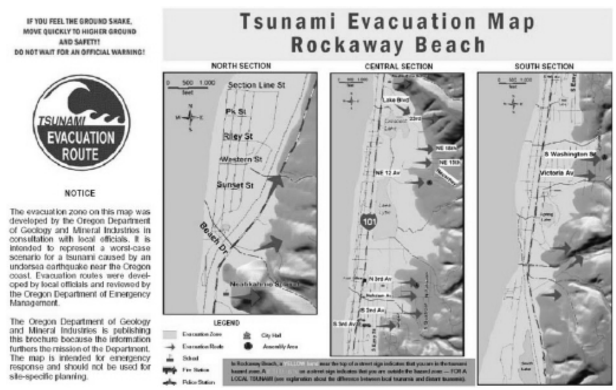

Figure2.31. Map for horizontal evacuation showing the evacuation zone, evacuation route, assembly hall, and critical facilities (Bernard, 2005).

4. Wave run-up speed and inundation level
   Wave run-up speed is influenced by tsunami-genic earthquake magnitude, bathymetry, and condition of coastal feature (existence of buffer zone). Bigger earthquake magnitude will cause bigger force and higher water level tsunami. Deep sea or steep bathymetry around the coastal will reduce the power and slow down the movement of tsunami. The existence of mangrove, coastal forest, breakwater, protection wall will also reduce the tsunami force and slow the wave reaching the land. Following the destructive waves, the seawater will inundate the land for a couple of hours. Water inundation above tolerated level –depends on geographic condition and community perception- will cause fatalities. The faster wave run-up and the higher inundation level imply that inhabitants in the hazard zone require vertical evacuation (Eisner and NTHMP, 2006). For the area has not experienced tsunami, run-up and inundation can be assumed from tsunami modeling.

Table 2.3 Suitability of tsunami evacuation method

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

Both in horizontal or vertical evacuation, effective warning systems and public information, notification, and training programs are critical to the success of all evacuation measures.

2.3.2. Evacuees' speed

In allocating the evacuation facility such as an ESB, the speed of evacuees' movements in evacuation is the key factor since they must have reached the ESB before the tsunami strike. It is difficult to grasp the speed quantitatively when the disaster occurs. The Japan Institute for Fire Safety and Disaster Preparedness (1987, in Sugimoto et al. 2003) gives an overview of the walking condition and average walking speed in disaster evacuation as shown in *Table 2.4.*

Table 2.4 Evacuee walking condition and average walking condition
(Sugimoto et al., 2003)

Walking condition	Average walking speed
A person pushing a perambulator	1.07 m/s
A person with a child	1.02 m/s
A independent walking elderly person	0.948 m/s
A group of walking elderly people	0.751 m/s

(Institute for Fire Safety & Disaster Preparedness, 1987)

2.4. Vertical evacuation

In coastal areas, where building and population densities are high, where roads, bridges, and other horizontal evacuation methods and facilities are limited, or where available evacuation time may be insufficient, vertical evacuation is needed as an alternative or supplement to horizontal evacuation (Eisner and NTHMP, 2001b). Furthermore, land use planning, site planning, and building design play an important role in a community's ability to rely, at least partially, on vertical evacuation to protect people. Other planning issues relate to managing the number of occupants, providing in-building security, compensating building owners, and addressing liability issues of different groups of age, gender, etc. associated with vertical evacuation.

The concept of vertical evacuation originated as a hurricane emergency preparedness and response measure. Vertical evacuation can be more complicated to use in tsunami-hazard areas because of the differing hazard characteristics, such as strong ground shaking and potential ground failures, and their implications for siting, design, and construction of built environment. The use of a building for vertical evacuation implies that the building should not be damaged or just slightly damaged by to the advance earthquake and tsunami, and that it can continue to serve as a temporary safe shelter.

In tsunami vertical evacuation, people are planned or directed to reach the nearest ESB around them by walking or running through the road network, foot path, or other passable path within a very limited evacuation time. Evacuation route, signage system, and building sign should be planned and incorporated in development planning and building regulation. These efforts will be helpful to guide people to go to shortest shelter although in panic evacuation situation people may just go through any passable paths avoiding shore area. Public awareness and education in hazard preparedness play a very important factor for building the population capacity to cope with disaster.

According to the US NTHMP (Eisner and NTHMP, 2001a) strategies to implement in vertical evacuation include the following.

1. Identification of specific buildings to be functioned as vertical shelters
   Existing buildings can serve as vertical shelters as well as newer ones can be located, designed, and constructed for that consideration. Factors to consider in determining building suitability include size, number of stories, access, contents, and available services. Only those buildings that are judged able to withstand the potential tsunami and earthquake forces and that meet other occupancy criteria should be designated as shelters.

2. Working out agreements and procedures with building owners
   Instead of government or public facility buildings, vertical evacuation shelters can also be designated in privately owned buildings. Hence, appropriate agreements should be negotiated with the owners, and the owners should be involved in the creation and maintenance of tsunami mitigation program.

3. Procedures in receiving and disseminating warnings
   It is very important that tsunami-vulnerable communities ensure that procedures and systems exist for notification by official warnings so appropriate actions can be taken before tsunami strike.

4. Implementation of effective information and education programs
   Media of disseminating information and education can be brochures, single-page instructions, periodic warning system tests, electronic and print media information, signs, and emergency response exercises to maintain awareness and instill effective response behavior. Some of this information will be directed towards special institutions, such as schools, hospitals, and convalescent-care facilities.

Figure2.32. Signage system of tsunami evacuation route (left) and evacuation brochure in a hotel bathroom (right) (Bernard, 2005; Joninentz-Trisler, 2001; Nagao, 2005)

5. Program sustainability
   Since tsunami events are rare, it is a challenge to maintain emergency preparedness programs and procedures when the threat is perceived as remote. Therefore, it is important that vertical evacuation measures not only be integrated into community response plans, but also be reviewed and revised regularly incorporating building owners and others stakeholders. Periodic simulations of evacuation are necessarily required among tsunami hazard inhabitants.

2.5. Evacuation shelter building (ESB)

2.5.1. Definition of ESB

Evacuation shelter building –abbreviated to ESB– can be defined as a building that is assigned as a destination for tsunami vertical evacuation. In some literatures, ESB is also called escape building (Bappenas, 2005; JICA, 2005) and vertical shelter (Eisner and NTHMP, 2001b). The main concern in determining ESB is that the building should withstand the disaster and have the upper floor above tsunami-inundated level.

2.5.2. Requirements of evacuation shelter building

Instead of general characteristics of the building design as mentioned in the previous *Sub-chapter 2.2.3* specific requirements are required for a building to be assigned as evacuation shelter. These requirements mostly relate to building performance during vertical evacuation process and are mentioned as follows. To be able to serve as evacuation shelter, a building should posses the following requirements:

1. Structure
   The use of a building for vertical evacuation implies that the destination building is expected to be not damaged or damaged only to a certain extent of not endangering lives due to disaster, and that it can continue to serve as a temporary safe shelter. Therefore the building should be earthquake and tsunami-resistant (Bappenas, 2005; Eisner and NTHMP, 2001b). Detailed characteristics of this building have been discussed in the previous *sub chapter 2.2.3 on Building design*.

Figure2.33. Examples of ESB in Japan (JICA, 2005; Nishimura, 2004)

2. Evacuation floor
   In an ESB, the evacuation area or evacuation floor should not be reached or inundated by tsunami waves such that the floor elevation must be higher than the wave height. In most cases the building is multi-storey in which people can evacuate to the first or second floor or to other designated upper floor. ESB could also be a single floor elevated construction above tsunami wave elevation. Incorporating the building design, the flat concrete roof can also be used as an evacuation area *(See Figure 2.34)*. The main consideration in the evacuation area design is to provide the space that can accommodate as many evacuees as possible in a temporary period of evacuation.

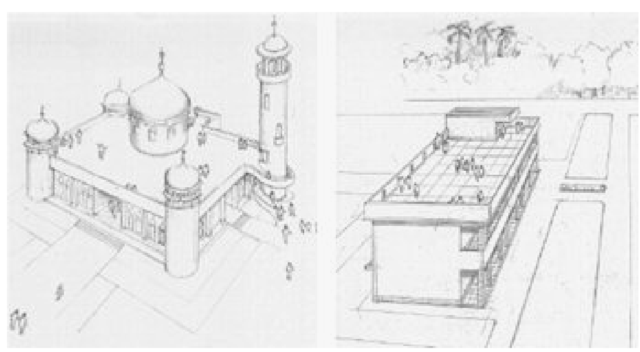

Figure2.34. Sketches of ESB designation on mosque (left) and school (right) buildings, as a part of tsunami preparedness in spatial planning of Banda Aceh, Indonesia (JICA, 2005).

3. Function

   Regarding the long return period of tsunami disaster and efficiency in urban space and cost, there is no such a building designated or allocated only for vertical evacuation shelter. ESB is defined by an additional function assigned to the planned or existing buildings which already has a specific function hence every ESB is a multi-function building. The existing function should be public function or public service oriented function. The examples include: mosques, school [6] (Bappenas, 2005), hotel, restaurant (Eisner and NTHMP, 2001b), government offices, parliament building [6] (Eisner and NTHMP, 2001b), convention centre, shopping centre (Bappenas, 2005), sport hall, parking and market building.

4. Design and capacity

   ESB should have sufficient reserve space to accommodate more people during evacuation. For evacuation purpose, the design of ESB must designate space of 1m^2/person (Bappenas, 2005). The accommodation of evacuee can use available empty spaces in ESB that is occasionally or non-permanently occupied such as meeting room or gathering room in the offices for instance. It can also be by occupying the main room such as in the mosque, sport hall and meeting hall, as well as by re-arrangement or re-lay-outing existing property or furniture in the class room, open market building, dining room of restaurant, or hotel rooms.

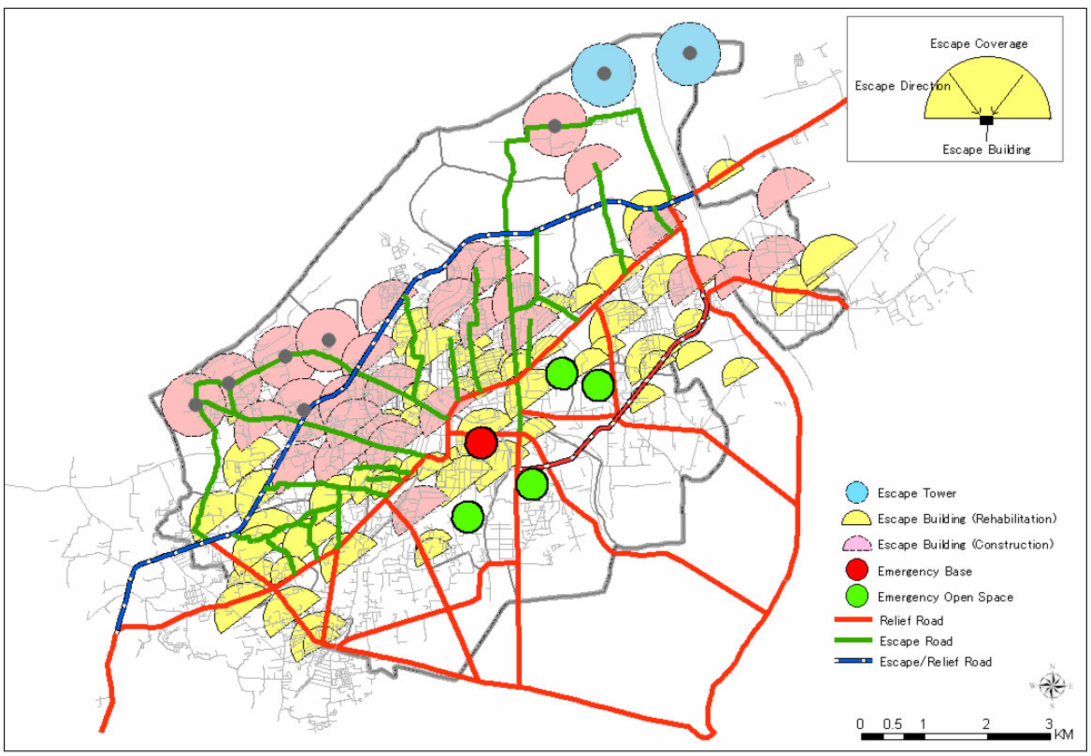

Figure2.35. ESB allocation map for Banda Aceh City, Indonesia (JICA, 2005)

5. Location or horizontal accessibility

   ESB should be located within reachable walking or running distance from population location in tsunami hazard zone. The Bappenas' masterplan of rehabilitation and reconstruction (Bappenas,

[6] The opinion was addressed by Dr. Krishna S. Pribadi of Disaster Mitigation Center and Dr. Budi Faisal of Architecture Department of Institute of Technology Bandung (ITB) in the interviews during the fieldwork period.

2005) define reachable distance of 500m, 1000m, 1500m, and 2000m corresponding to the shortest travel time of 5, 10, 15, and 20 minutes respectively by elderly people, women and children. While the Urgent Rehabilitation and Reconstruction Plan (URRP) of Banda Aceh (JICA, 2005) requires possible distance for evacuation on foot is estimated at the radius of 900 m corresponding to 15 minutes travel time at a walking speed of 1m/s on the average among the aged, handicapped and children. Example of ESB allocation map is shown in *Figure 2.35.*

The closer the distance is to shore areas, the faster residents must be able to reach ESB. In addition, the further away from shore areas, the smaller the need for ESB. To allocate or designate the ESB, the assumed maximum travel time relates to the available remaining evacuation time from tsunami early warning system.

6. Vertical accessibility

   Vertical accessibility in ESB is critical point since evacuee must be able to reach the upper floor as soon as possible. ESB must have adequate stair and ramp which are designed to meet the building safety requirement and regulation. A ramp is not always available in every building because there is less concern toward disabled persons; it needs more space and is costly. Stair is almost available in every multi-storey building. For vertical evacuation, the stair width must be able to accommodate at least two people movement. Stair steepness -dimension of horizontal and vertical step/path, railing handle- should meet the architectural standard [7]. The design of stairs can be enclosed with stronger construction such as concrete to perform building core structure, as well as oriented to direct allowing the wave flows in the ground floor [8]. The location of these vertical paths should also be easily identified and accessed and the construction itself must not be damaged due to previous earthquake to ensure to function as ESB.

7. Security

   Since ESB becomes a public-accessed building during vertical evacuation, each ESB should have a mechanism of security handling to protect its property from stealing. Security has became crucial problem and debates in determining ESB particularly to private-owned buildings such as hotel and restaurant (Eisner and NTHMP, 2001b).

2.5.3. Implementation of evacuation shelter building

Consideration of ESB function in detail level spatial planning (masterplan, siteplan) is strongly required. In Meulaboh and other tsunami-affected areas context, allocation or designation of ESB function to the mosque, school, office, and shopping centre buildings can be implemented in the facility planning in reconstruction process. It is carried out in order to repair or replace the destroyed facilities.

In vertical evacuation, people actually can also evacuate themselves to the upper floor in their own houses (if the houses fulfill basic ESB requirements). In this case, the construction strength is questionable because it may not be able to withstand tsunami waves. In developing countries such as

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[7] The opinion was addressed by Dr. Krishna S. Pribadi of Disaster Mitigation Center of Institute of Technology Bandung (ITB) in the interviews during the fieldwork period.

[8] The idea was addressed by Dr. Krishna S. Pribadi of Disaster Mitigation Center of Institute of Technology Bandung (ITB) in the interviews during the fieldwork period.

Indonesia, there is inadequate enforcement of building regulation and construction quality control. In Indonesia for instance, the middle and low class population usually do not build their houses wholly in multi-storey construction. They build the house partially like a "growing house" as the financial capability improved or the number of family members increase. In this case, the strength of construction joint between the "old construction" with the "new additional one" needs more attention [9].

The concept of vertical evacuation and ESB should be enforced and supported with the implementation of building codes and regulation for building planning, redevelopment, and retrofitting. The implementation will rely much on local government role rather than national-wide authority [9]. In countries where the building codes exist and be applied, the codes usually address only new buildings or substantial modifications to existing buildings. Very few, or only special codes, laws, or ordinances, address the complexities associated with rehabilitating or retrofitting of existing buildings to meet life safety threats posed by expected hazards (Eisner and NTHMP, 2001b).

2.6. Accessibility modelling for tsunami evacuation

2.6.1. Concept of accessibility

The concept of accessibility has varied meanings such as the amount of effort for a person to reach a destination; or the number of activities which can be reached from a certain location. In a study of accessibility measures, Geurs and Eck (2001) define accessibility as the extent to which the land-use transport system enables (groups of) individuals or goods to reach activities or destinations by means of a (combination of) transport mode(s). Moseley (1979, in Jong and Eck, 1996) conceptualises the basic components of accessibility into: the people; the activities or services which people require; and the transport that links between those two. The actual accessibility depends on each of the components of the following scheme.

People → **Transport** → **Activities**

Figure2.36. Components of accessibility (Moseley, 1979 in Jong and Eck, 1996)

In this scheme, people in the figure represent the population. The size and the composition of the population affect the accessibility, because they determine the scale of the demand for services or activities. The transport links reflect the travel time, costs and effort to travel between origin and destination location. The activities reflect the spatial distribution of activities at destinations and the demand for those activities.

At Moseley's scheme, accessibility analysis can be applied to both ends. For comparative potential accessibility measures, Jong and Eck (1996) rewrite the scheme in geographic information system (GIS) terms as follows. Here, which origin(s) located within destination's reach can be calculated, and vice versa.

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[9] The opinion was addressed by Dr. Krishna S. Pribadi of Disaster Mitigation Center of Institute of Technology Bandung (ITB) in the interviews during the fieldwork period.

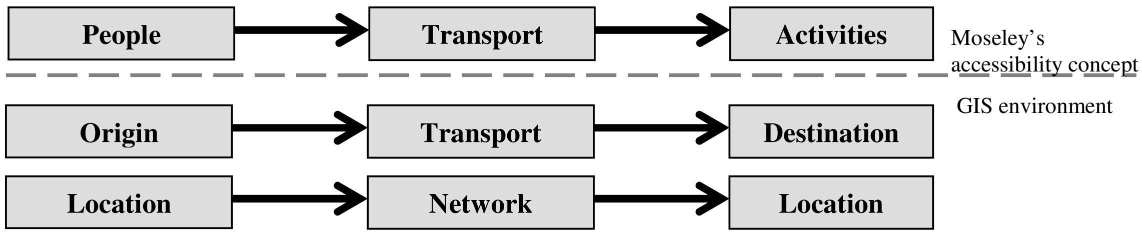


Figure2.37. Moseley's concept of accessibility in GIS environment (Jong and Eck, 1996)

According to Geurs and Eck (2001), there are four interdependent components in determining accessibility:

1. Transport component, reflecting the travel time, cost and effort to travel between origin and destination location.
2. Land use component, reflecting the spatial distribution of activities at destinations (e.g. jobs, schools, shops) and the demand for those activities (e.g. workers, pupils, inhabitants).
3. Temporal component, reflecting the time restrictions of individual and availability of activities at different times of the day.
4. Individual component, reflecting the needs, abilities and opportunities of individuals.

Relationship among these components can be seen in *Figure 2.38.*

Geurs and Eck (2001) also identify three basic perspectives on measuring accessibility:

1. Infrastructure-based accessibility measures
   It is mostly used in transport and infrastructure planning. The common measures are level of congestion and travel speed.
2. Activity-based accessibility measures
   Divided into geographical measures and space-time measures, this type of measures analyse the range of available opportunities with respect to their distribution in space and travel impedance between origins and destinations.
3. Utility-based accessibility measures
   Having its origin in economics studies, this type of measures analyses the benefits people derive from access to the spatially distributed activities.

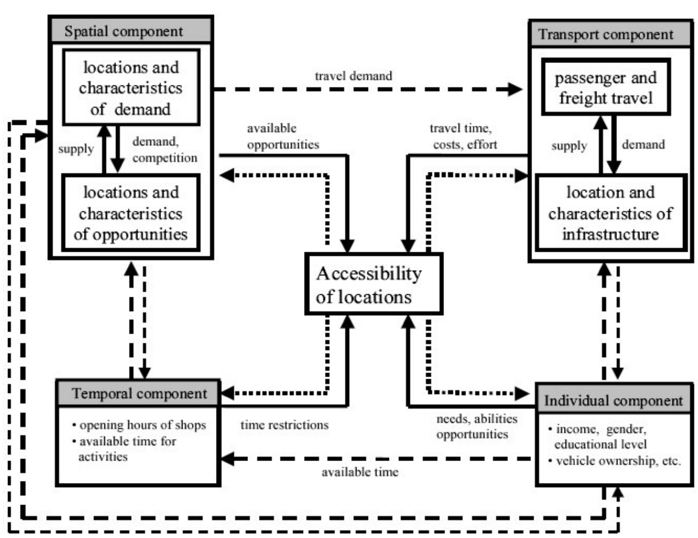


Figure2.38. Relationship among components of accessibility (Geurs and Eck, 2001)

Relationship between accessibility measures and accessibility components is presented in *Table 2.3.*

Table 2.5 Type of accessibility measures and components
(Geurs and Eck, 2001)

measure \ component		transport component	land-use component	temporal component	individual component
infrastructure-based measures		average travel time; travelling speed; vehicle hours lost in congestion		peak hour period 24-hr period	trip-based stratification (e.g. home-work, business trips)
activity-based measures	geographical measures	travel time and/or travel costs between locations of activities, typically using a distance decay function	distribution of opportunities in space (e.g. number of jobs per zone or grid)	travel time and costs may differ between hours of the day, between days of the week, or seasons	stratification of the population (e.g. by income, educational level)
	time-space measures	travel time	distribution of opportunities in space	temporal constraints for activities and time available for activity participation are accounted for	accessibility is analysed at individual or household level
utility-based measures		travel costs between locations of activities, using a distance decay function	distribution of opportunities in space	travel time and costs may differ between hours of the day, between days of the week, or seasons	utility is estimated for population groups or at individual level

2.6.2. Location-allocation model

Since last decade, there has been a sophisticated development in GIS-based accessibility analysis for business and commercial facility location planning (Clarke, 1997), where there is a need for simple, yet effective , indicators of market accessibility that can be easily visualized (Eck and Jong, 1999). According to Jong, et al. (1991, in Eck and Jong, 1999) accessibility analysis can be applied to various stages of the facility siting in terms of:

- Existing facilities can be evaluated in order to estimate their respective market size which may indicate that some facilities should be relocated or closed
- All locations in the area can be evaluated for a single new facility to be added to the set of existing facilities; in this way, an accessibility surface can be constructed that can help the decision maker in choosing a suitable site
- The decision maker can make one or more proposals for a new location pattern, either based on the existing locations with propose some relocations and a number of new facilities, or completely new locations.

Location planning or facility location problems investigate where to physically locate a set of facilities (resources) so as to minimize the cost of satisfying some set of demands (customers or population) subject to some set of constraints (Hale and Moberg, 2003). It can be done easily by locating the facility in the centre of neighbourhood area, or in a more comprehensive way such as locating several facilities to meet the optimum location configuration in serving the population. The last method involves simultaneously selecting a set of locations for facilities and assigning spatially distributed sets of demand to these facilities, to optimise some specified measurable criterion. This is done in location-allocation model.

A location-allocation model is a method for finding optimal sites for facility locations, where optimality is defined in terms of highest possible access within the given constraints in under-served and/or non-served areas (Rahman and Smith, 2000). The model provides a framework for investigating service accessibility problems, comparing the quality (in terms of efficiency) of previous locational decisions, and generating alternatives, either to suggest more efficient service systems or to improve the existing systems. Examples for applying location-allocation model are location planning of car dealer (Clarke, 1997), drugstore (Eck and Jong, 1999), health facilities (Rahman and Smith, 2000), ware house, hazardous material site, rail station, ATM machine, and SAR station (Hale and Moberg, 2003). Location-allocation model involves three basic elements: a set of consumers (demand) distributed over an area, a set of facilities (service centres) to serve consumer, and a network connecting demand points to service centres

Referring to (Church and ReVelle, 1976), there are three methods in location-allocation model for finding optimal location:

1. P-Median Problem, the method tries to locate a given number of facilities in such a way that the resulting average travel distance is minimized.
2. Location Set Covering, the method tries to locate the minimum (fixed) amount of facility but maximizing the population falls within the maximum-service-distance.
3. Maximal Covering Location Problem (MCLP), it is aimed at locating the number of facilities so that the largest number of population falls within the desired service distance.

2.6.3. Accessibility analysis for vertical evacuation

Vertical evacuation is about evacuees' movement to reach ESB from their location within certain evacuation time through the road network and other passable path. Evacuation process fits in the frame of accessibility concept, where people's location that needs to be evacuated is represented as "origin" or "people"; ESB location as "destination" or "service/activities"; and evacuation path as "network" or "transport". These components are easily represented in GIS environment.

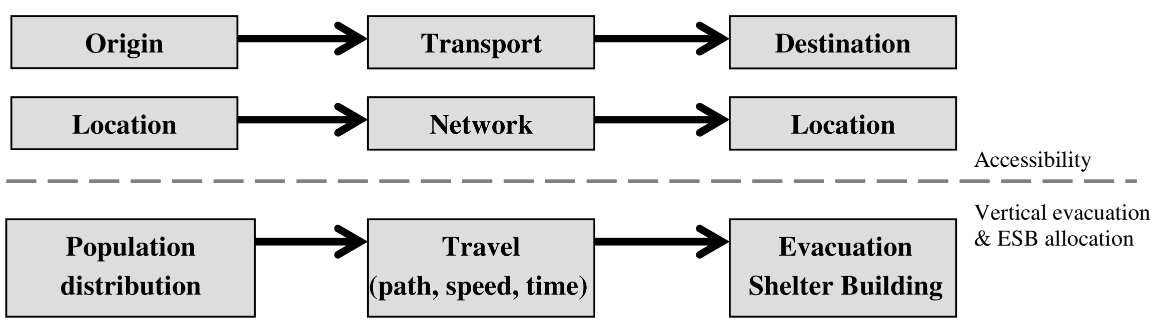


Figure2.39. Vertical evacuation in accessibility frame

In ESB location planning, location-allocation model is required to find optimal spatial distribution of ESB location through the study area in maximising ESB coverage to population within an evacuation travel time. The model can be applied to assess the service coverage of existing potential ESB as well as to determine or allocate new additional ESB if the existing one can not cover total population.

Utilisation of accessibility analysis and location-allocation model in ESB allocation is considered to be able to represent more realistic or lifelike the tsunami evacuation and spatial planning as the following.

- It attempts to find optimal number and spatial distribution of ESB, inline with the ESB concepts of location accessibility and multi-function buildings

- It incorporates the network (road, foot path) or travel path in the analyses, rather than just buffer and overlay analysis in GIS.
- It takes into account different population density may exist through the study area

2.6.4. Location-allocation model in Flowmap

Flowmap[10] is a software package dedicated to analyzing and displaying interaction of flow data. This type of data is special in the sense that there are two different geographic locations connected to each data item: an origin location where the flow starts and a destination location where the flow ends. The flow data itself can be people (e.g. commuters, shoppers, hospital visitors), goods, usage of agricultural services or telecommunication and so on (Geosciences, 2003).

Flowmap provides useful measures for accessibility analyses such as locational profile, catchment profile, proximity counts, proximity coefficient, threshold distance and service location model that have not been provided by popular commercial GIS-packages. Such capabilities make it a powerful tool to be incorporated in facility location planning.

For assessing the service performance of a given existing facility or service provider, Flowmap provides *Catchment Area Analysis* feature that allocates the origins (demand, population) to the nearest destination (facility, service provider). In a *Catchment Area Analysis*, an origin can be allocated only to one single destination. Flowmap allows two bounds to be set: a destination can have a maximum capacity or destination can have a maximum reach (distance, travel time) (Zwan et al., 2005). In the former, if the maximum capacity is reached, the destination is not taken into account any longer in the remainder of the allocation procedure. While in the latter, origins that fall outside this reach cannot be allocated to this destination. The maximum reach must be set and is equal for all destinations. The result from catchment area analysis include: the number of allocated demand (population) to a destination, the coverage area of each destination (facility), the distance or travel time from each origin to its destination, and the remaining non-allocated demand can be obtained. In relation with evacuation process, catchment area analysis can be used to assess the service performance of both existing potential ESB and additional ESB.

Particularly for location-allocation model, Flowmap provides an interesting model, namely the *Service Location Planning* Model, which is a combination of various accessibility statistics, accessibility measurements, and other GIS techniques. Currently there are four different service location models: *Set Coverage Model, Expansion Model, Relocation Model,* and *Reduction Model.*

1. Set Coverage Model
   It aims to determine minimal number of service location to fully serve an area based on Spatial Pareto optimality. Spatial Pareto uses the concept of efficient location to significantly reduce the number of permutations in a full brute force solution (Zwan et al., 2005). Pareto optimality exists if allocation of resources to improve the well-being of one area cannot be accomplished without making at least one other area worse off.

[10] Flowmap has been developed at the Faculty of Geosciences of Utrecht University in the Netherlands. It has been applied in the facility location planning of the drugstore, ambulance station, police station, car dealer, public/health facilities, etc. in the Netherlands, South Africa, and Tanzania. The educational edition of this software is freely available online.

2. Expansion Model

   It aims to find best new or additional service location(s) by adding step by step the service location such that:

   - results in largest increase in customer (population) coverage, or
   - results in largest decrease in average overall travel time (distance), or
   - results in largest decrease in worst case or longest travel time (distance), or
   - the added service location is located where highest market share would be realised, when spatial rationality is assumed

   In this model, the first option is called *Maximize Customer Coverage;* the second one is *Minimize Overall Average Distance;* the third one is *Minimize Overall Worst Case Distance;* and the fourth one is *Maximize Individual Market Share.* The model runs based on the Greedy Algorithm. It can accommodate both expansion upon existing location or start from the scratch. The Greedy model often leads to an optimal or close to optimal solution. There is no guarantee that a solution involving more then one new location is anyway optimal. But it is one way of approaching the problem and sometimes gives very good (or even the best possible) results.

3. Relocation Model

   Running based on Alternate Algorithm, relocation model aims to optimise spatial distribution of a given set of service locations by relocating step by step the service location such that:

   - has the highest impact on the increase in the amount of customers (population) covered, or
   - minimising the average of customer travel time or distance, or
   - minimising the worst case (longest) customer travel time or distance, or
   - the relocated service location has the highest impact on the increase in the amount of customers covered, when spatial rationality is assumed

   In this model, the first option is called *Maximize Customer Coverage;* the second one is *Minimize Average Distance;* the third one is *Minimize Worst Case Distance;* and the fourth one is *Maximize Spatial Competition*.

4. Reduction Model

   In reverse to expansion model, reduction model aims to reduce or remove existing service location(s) by removing step by step the service location such that:

   - results in the smallest decrease of customers (population) covered, or
   - results in the smallest increase in average travel time (distance), or
   - results in the smallest increase in worst case (longest) travel time (distance), or
   - the removed service location has the lowest market share, when spatial rationality is assumed

   The first option is called *Least Effect on Customer Coverage;* the second one is *Least Effect on Average Distance;* the third one is *Least Effect on Worst Case Distance;* and the fourth one is *Remove Worst Market Position.* In this model, one or more existing location can be retained from being removed.

Further information on Flowmap's functionalities can be found in the Flowmap72 Manual *(See reference Zwan et al., 2005).*

Related to this research, the population needs evacuation can be considered as customers (origin), ESB as service location (destination), and travel time as evacuation time. The *Catchment Area*

Analysis is used to assess the coverage area and capacity of existing potential ESBs and additional ones. The *Expansion Model* is utilised to allocate the new additional ESB. Detailed explanation of the application of location-allocation modelling is given in *Sub-Chapter 5.4*.

2.7. Conclusion

- The 40 minutes December 26 tsunami travel time for Meulaboh City and the 13 minutes seismic data processing and tsunami occurrence determination time will be used as the time parameters to define the evacuation travel time in the next evacuation simulation.
- Vertical evacuation suitability is used as criteria to delineate part of Meulaboh City as the study area.
- In evacuation situation, the slowest speed of movement is assigned as the evacuees speed in evacuation simulation.
- The location and design characteristics of the ESB will be used as the criteria to define or identify the potential ESB from the tsunami-survived buildings.
- Tsunami evacuation process is put in an accessibility frame of origin-travel-destination. The ESB allocation is carried out based on the accessibility analysis and location-allocation model.

3. Meulaboh City and the December 26 tsunami

This chapter describes the City of Meulaboh in relation to the events of the December 26 tsunami. The description is focused on the impact of the tsunami, the reconstruction plans, and the latest situation during the fieldwork period.

3.1. General introduction to Meulaboh City

The City of Meulaboh is located at the north-western coast of Sumatra. It is the capital of Aceh Barat (West Aceh) District, Province of Nanggroe Aceh Darussalam (NAD), Republic of Indonesia. Administratively, the territory of Meulaboh City is under the authority of the Johan Pahlawan Sub-district *(kecamatan).* Johan Pahlawan Sub-district comprises 21 villages *(desa or kelurahan).* Village is the smallest governmental unit in Indonesia. The description of villages of Meulaboh City is given in *Figure 3.2,* while *Figure 3.9* shows the Johan Pahlawan Sub-district and its surrounding area.

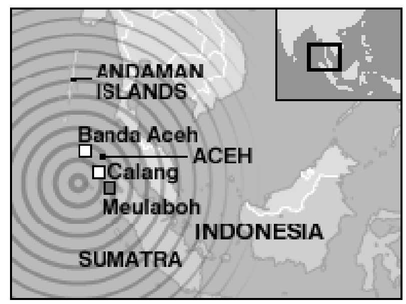


Figure 3.1. Location of Meulaboh City (BBC, 2004)

Trade has become the main activity of the city since it was established in the 15th century in Pasir Karam, Meulaboh Bay. In the early days, development of settlement and facilities concentrated in the port and commercial areas of Suak Indrapuri, Pasar Aceh, Kampung Belakang, Panggong, and Padang Seurahet *(Figure 3.2)*. Critical facilities (harbor, ferry port, oil bunker) as well as commercial and supporting facilities (shops, traditional market, warehouse, and fishing dock) are located at the shore area *(Figure 3.6)*. Before the tsunami, high density settlements could be identified within 1 km from the shore. Institutional land use buildings such as the grand mosque, public hospital, and government offices are located in the northern part of the city at some distance from the shore. Medium density settlements are located in this area. In the south, is the parliament building (*Dewan Perwakilan Rakyat Daerah –DPRD* of Aceh Barat District) located close the commercial area *(Figure 3.4)*; the local military headquarter is located on the peninsula (Ujung Karang) in Suak Indrapuri Village *(Figure 3.5)*. The urban expansion expands northward toward the low-density area along the provincial road connecting Meulaboh and Tutut Geumpa *(Figure 3.9)*.

The urban structure is formed by the coastline, one arterial road in the north, and three arterial roads meet in Simpang Pelor cross-road *(See "P" in Figure 3.2).* These roads run toward northwest, south, and northeast. The local road network pattern follows in parallel and perpendicular direction off the shore. Settlements are scattered along the road. Before the December 26 tsunami, the national road which is the main distribution line of the Sumatran west coast, was located next to the shore within a 500m range. After the tsunami destruction, the road has been moved 2km inland on higher grounds.

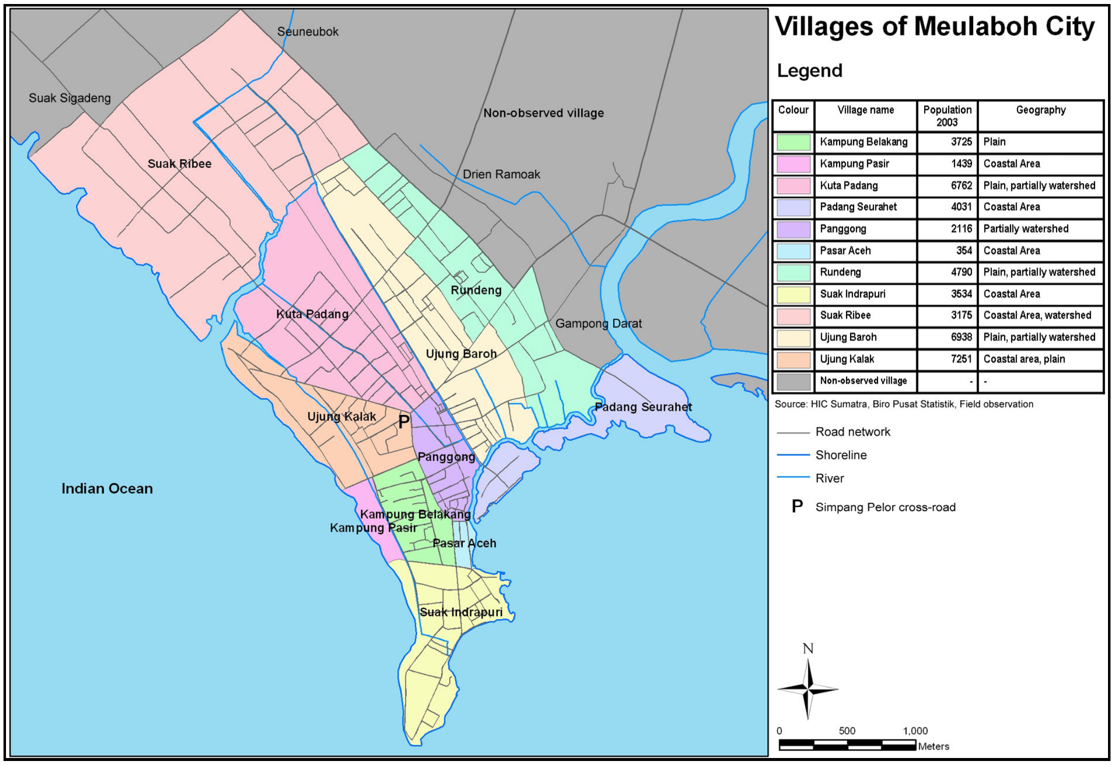


Figure3.2. Description of villages in Meulaboh City. *Data source:* (BPS, 2005a; HICSumatra, 2005b)

3.2. Destruction after the December 26 tsunami

Meulaboh City is located 150 km from the epicentre of the December 26 9.3 magnitude earthquake. The city facilities and infrastructures suffered severe damage as well as death toll to the coastal population due to both the earthquake and the tsunami. The destruction of due to the earthquake was difficult to identify since the debris, ruins, and bodies were swept away by tsunami waves several minutes later *(See Figure 3.4 and 3.5)*. Some survivors reported that they were washed away by the waves and landed up to 30 km distance from their initial location. Based on the field survey of the international tsunami team (Yalciner et al., 2005) in Meulaboh port, the first 1.5 m high wave arrived 10 minutes after the earthquake, followed by a second destructive tsunami wave 30 minutes later. The wave exceeded 15 m in the port area and inundated up to 4 km inland.

*Figure 3.3.*QuickBird satellite images of south part of Meulaboh City, acquired on May 18, 2004 (left) and January 7, 2005 (right) (DigitalGlobe, 2005)

Figure3.4. Debris after the tsunami in Pasar Baru (left, "A" in *Figure 3.5*) and the Parliament Building (right, "B" in *Figure 3.5*) (BBC, 2005).

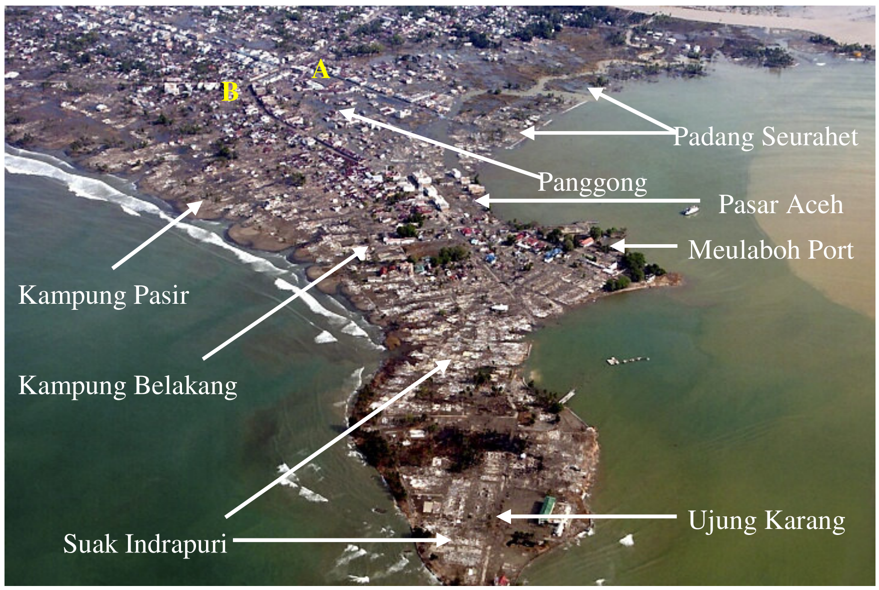


Figure3.5. Destruction in villages in the southern part of Meulaboh City after the December 26 tsunami (Pararas-Carayanis, 2005)

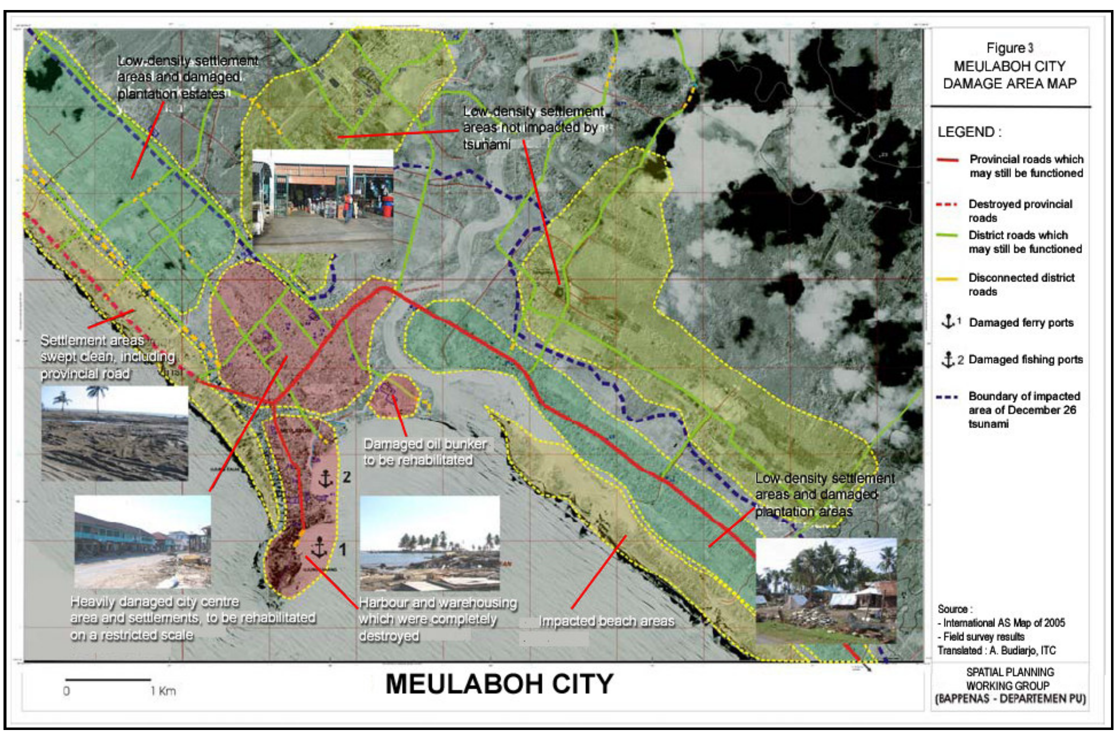


Figure3.6. Overview of destruction of Meulaboh City after the December 26 tsunami. *Translated from* (Bappenas, 2005)

3.2.1. Physical damage

The Masterplan of rehabilitation and reconstruction (Bappenas, 2005) identified some totally destroyed areas located facing the tideline at an approximate distance of 500m from the coast; structural building damage areas within a range of 500-1000m from the coast; and light damage areas within excess of 1000m from the coastline.

Fifteen out of 21 villages in Johan Pahlawan Sub-district were affected by the December 26 tsunami, with physical damage ranging from 20% to 100%. Areas located next to the shore and water body (river and canal) suffered serious damage too. Villages of Suak Indrapuri, Padang Seurahet, Kampung Pasir, and the coastal part of Suak Ribee, Suak Nie, and Suak Sigadeng were totally destroyed. Some land of Padang Seurahet village has been subsiding below sea level *(See Figure 3.6)*. The overview of the physical damage can be seen in *Figure 3.6 and 3.7.*

During the fieldwork period, there was no official report available of physical damage estimation or calculation for Meulaboh City, but the local government has identified 10,287 houses damaged and totally destroyed[11]. The Local Task Force of Disaster Management *(Satlak PB Kabupaten Aceh Barat)* estimated the percentage of physical damage in each village as shown in *Figure 3.7.*

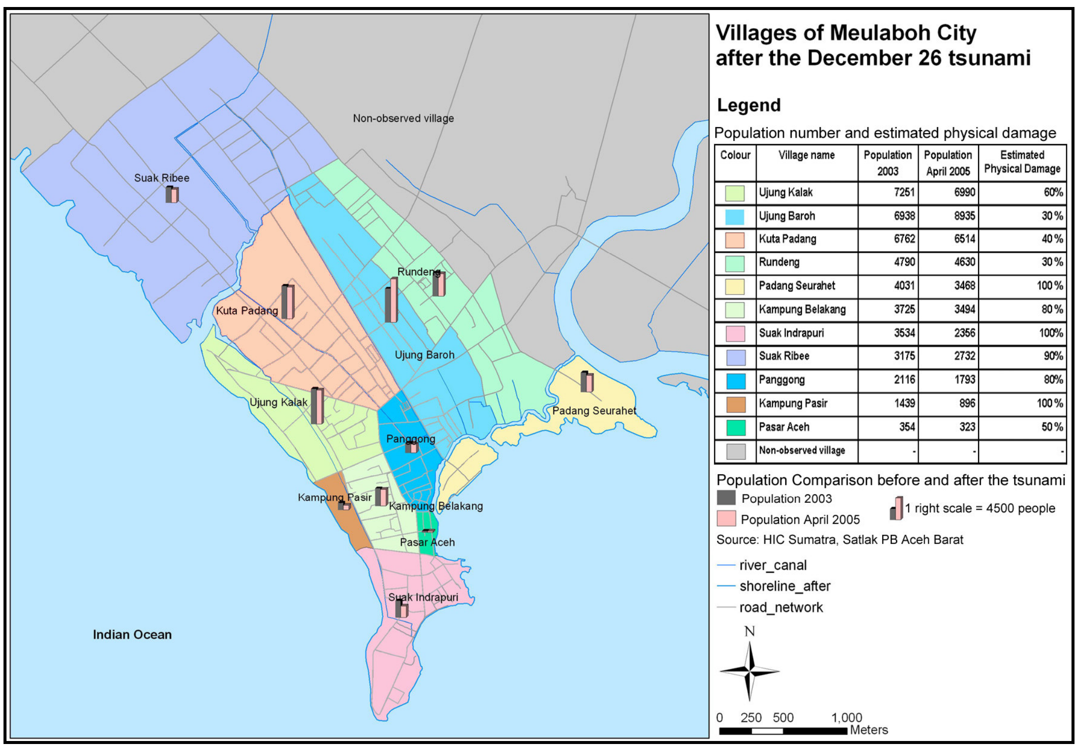


Figure3.7. Population number and estimated physical damage of Meulaboh's villages after the December 26 tsunami

As mentioned in the Masterplan of reconstruction and rehabilitation (Bappenas, 2005), damage to road networks caused the isolation of a number of areas, which inhibited evacuation and logistical distribution and impacted the social economic system in Meulaboh and along Aceh's west coast. The entire road system situated on the level land at an approximate distance of 4 km from the coastline

[11] It refers to the settlement relocation document provided by the Local Task Force of Disaster Management of Aceh Barat District *(Satlak PB Aceh Barat)* Meulaboh.

was destroyed for over 127 km. The Banda Aceh – Meulaboh road, with 64 bridges with a total span of 1950m were heavily damaged. Only a number of small bridges have been spared, with only some bridge ramps being damaged and rubbed down. For a couple of months, the land connection between Banda Aceh-Lamno-Calang-Teunom-Meulaboh had been completely cut off. Also damaged were electricity networks, fishing ports, and buildings and settlements. In the wake of the quake and tsunami disaster, most of the agriculture, plantation, fisheries and livestock farming areas were damaged and destroyed. Damaged fisheries facilities and infrastructure reduced fish catch.

3.2.2. Population loss

The earthquake and tsunami disaster of December 26 caused a huge number of casualties. According to the report of the Head of Johan Pahlawan Sub-district (HICSumatra, 2005b), by April 2005 there were 6,858 people reported dead or missing; 27,540 refugees and 15,883 survivors who had return to their houses. The report said that the existing population of Meulaboh was 62,157 people in 14,505 households. Based on this data, the number of people per household in each village can be identified; the average for the whole city is 4.29 people/household. Tracing on the total population in 2003 and April 2005 (HICSumatra, 2005b), it can be concluded that there are at least 980 inhabitants of Meulaboh City dead or missing due to the disaster *(See Appendix 4)*.

By August 2005, the government of Aceh Barat District[12] reported that there were 39,902 refugees in 9727 households living in camps, barracks, and survived houses of the inhabitants in Johan Pahlawan Sub-district. An overview of population number after tsunami is presented in *Figure 3.7,* while the complete data on population is given in *Appendix 3.*

3.3. Meulaboh City and tsunami evacuation

To prepare the city inhabitants to be able to cope with the similar tsunami of the December 26, Meulaboh City, particularly the study area, requires vertical evacuation method. It can be explained as follows based on the implementation suitability of tsunami evacuation method *(See Table 2.3 in Sub-chapter 2.3.1)*.

- The tsunami travel time for Meulaboh City is 40 minutes (short)
- The City is a low-lying land and topographically flat. There is no hill or close high elevation ground; the contour line of 15meter elevation (in topographic map) located at a distance of around 4km from the shore
- Based on survivors information, the tsunami run-up is fast, while the inundation level is more then 1meter *(See inundation map in Appendix 2)*
- There are some existing multi-storey buildings that survived the December 26, as an example of the possibility of ESB assignment in the existing and to be planned buildings

[12] It refers to the statistics data of the tsunami victims and refugees provided by the Local Task Force of Disaster Management of Aceh Barat District *(Satlak PB Aceh Barat)* Meulaboh.

3.4. Spatial planning and resettlement

3.4.1. Masterplan of rehabilitation and reconstruction of tsunami affected area

Responding to the December 26 earthquake and tsunami disaster, the government of the Republic of Indonesia through the National Development Planning Agency *(Badan Perencanaan Pembangunan Nasional, Bappenas)* made a masterplan of rehabilitation and reconstruction for the tsunami affected population and area. The masterplan was legalized as a Regulation of the President of the Republic of Indonesia Number 30 Year 2005. The vision on the reconstruction of Future Aceh is to realise an Acehnese community that is advanced, fair, safe, peaceful, and prosperous based on Islamic values and to take into account Aceh's dignity in the context of the Unitary State of the Republic of Indonesia and in the universal perspective.

According to the masterplan (Bappenas, 2005), there are three stages in disaster response and mitigation:

1. Emergency Response Stage (January 2005 – March 2005)
   The stage is aimed at rescuing the surviving community members and to immediately fulfil their minimum basic needs. The main goal of this response stage is humanitarian rescue and aid.

2. Rehabilitation Stage (April 2005 – December 2006)
   This is aimed at urgently recovering and restoring the functions of structures and infrastructures to follow up the stage of emergency response, such as the rehabilitation of mosques, hospitals, basic social infrastructures, as well as economic infrastructure and facilities that are badly needed.
3. Reconstruction Stage (July 2006 – December 2009)
   The stage is aimed at reconstructing the areas of the city, village and agglomeration of areas by involving all communities of the disaster victims, experts, representatives of non-government organizations, and the business community. Once the adjustment to the spatial structure plan has been completed at provincial level and particularly at *kabupaten* (district) and *kota* (city) levels in coastal areas, infrastructure and facility construction have to start.

The framework of the rehabilitation and reconstruction plan is presented in *Figure 3.8*.

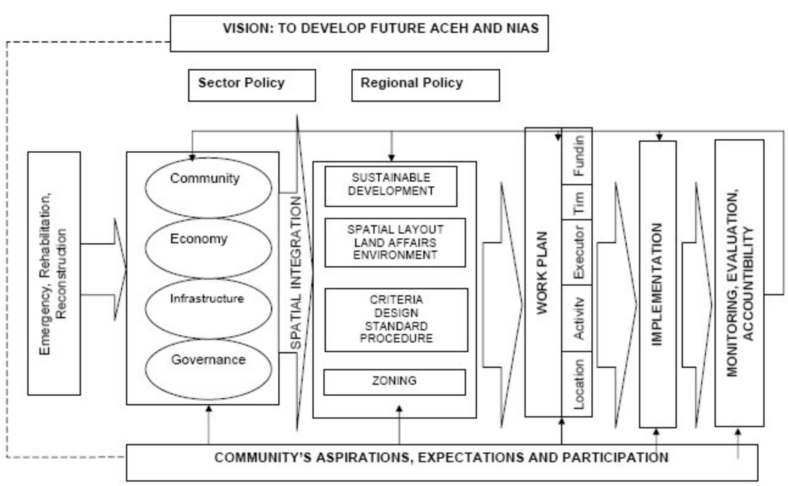


Figure3.8. Framework of rehabilitation and reconstruction of Aceh and Nias (Bappenas, 2005)

3.4.2. Spatial planning guidance for reconstruction

According to the maspterplan of rehabilitation and reconstruction (Bappenas, 2005), elements of spatial planning for quake and tsunami vulnerable areas include: escape buildings or ESB; escape routes; greenbelts; early warning systems; and public awareness of rescue.

The masterplan has stated Meulaboh's spatial structure after the tsunami –and inline with national development directives and in anticipation of tsunami disasters– will remain to see the city as a Centre of Regional Activities *(pusat kegiatan wilayah, PKW).* In this context, Meulaboh will remain to function as a trade centre serving regions along Aceh's west coast, i.e. inclusive of the district of Simeuleu, which in turn are serviced by ferry ports and Meulaboh's seaport. Meulaboh also is a gateway for distribution of goods into the Aceh Tengah (Central Aceh) District, from which goods are carried to Aceh Utara (North Aceh) and Aceh Timur (East Aceh) Districts along the national road of Ladiagalaska. The directives on Aceh's Provincial Spatial Structure can be seen in *Appendix 5*. The above mentioned demands have created the need for Meulaboh's medium and long term urban development to feature development of a city central area, a city sub-central area, and urban settlements. The settlements, in the long term, will be shifted eastwards out of harm's way of tsunamis, i.e. the village of Leuhan or Meurebo Sub-district located 5-6 km from Meulaboh's original central area *(See Figure 3.9).*

The decision making process for the masterplan involved central and local government and local community. The scenario of Meulaboh's reconstruction is to minimise relocation of urban activities and heavily-impacted settlements, and to preserve site-bound activity functions, which are equipped with disaster mitigation plans (Bappenas, 2005). The scenario can be outlined as follows:

- The area directly facing the sea and tidal water which was swept clean by the tsunami was 200-500m wide;
- Areas vulnerable to tsunamis in excess of 2m above normal sea level may be used for tree cropping and low-density settlement areas;
- Harbour and fishing dock areas, and fishing settlements directly facing tidal water will be kept in place on a restricted scale and be equipped with protection and escape facilities;
- Ujung Karang (Suak Indrapuri village) is to be turned into an urban park and a Tsunami Heritage Museum;
- Functions of business areas in the original city centre situated in highly vulnerable areas are revitalized and equipped with protection and escape facilities;
- Development of urban settlement areas affected by tsunami waves of less than 2m will in the long term be shifted to safe locations, e.g. Suak Nie village and Ujung Tanjong village (Meurebo Sub-district);
- Areas lying on the borderline of tsunami-affected and safe areas are to be kept in place and to be developed into low- to medium-density settlements;
- Areas lying on the borderline of tsunami-affected areas but of which the spatial use has yet to be developed/ farmland will be turned into urban parks and sport fields which will act as buffer zones;
- Medium- and long-term development of the new city centre and sub-city centre will focus on safe locations in Leuhan and Ujung Tanjung village;

Spatial orientation of the discussed locations refers to the map in *Figure 3.7 and 3.9.*

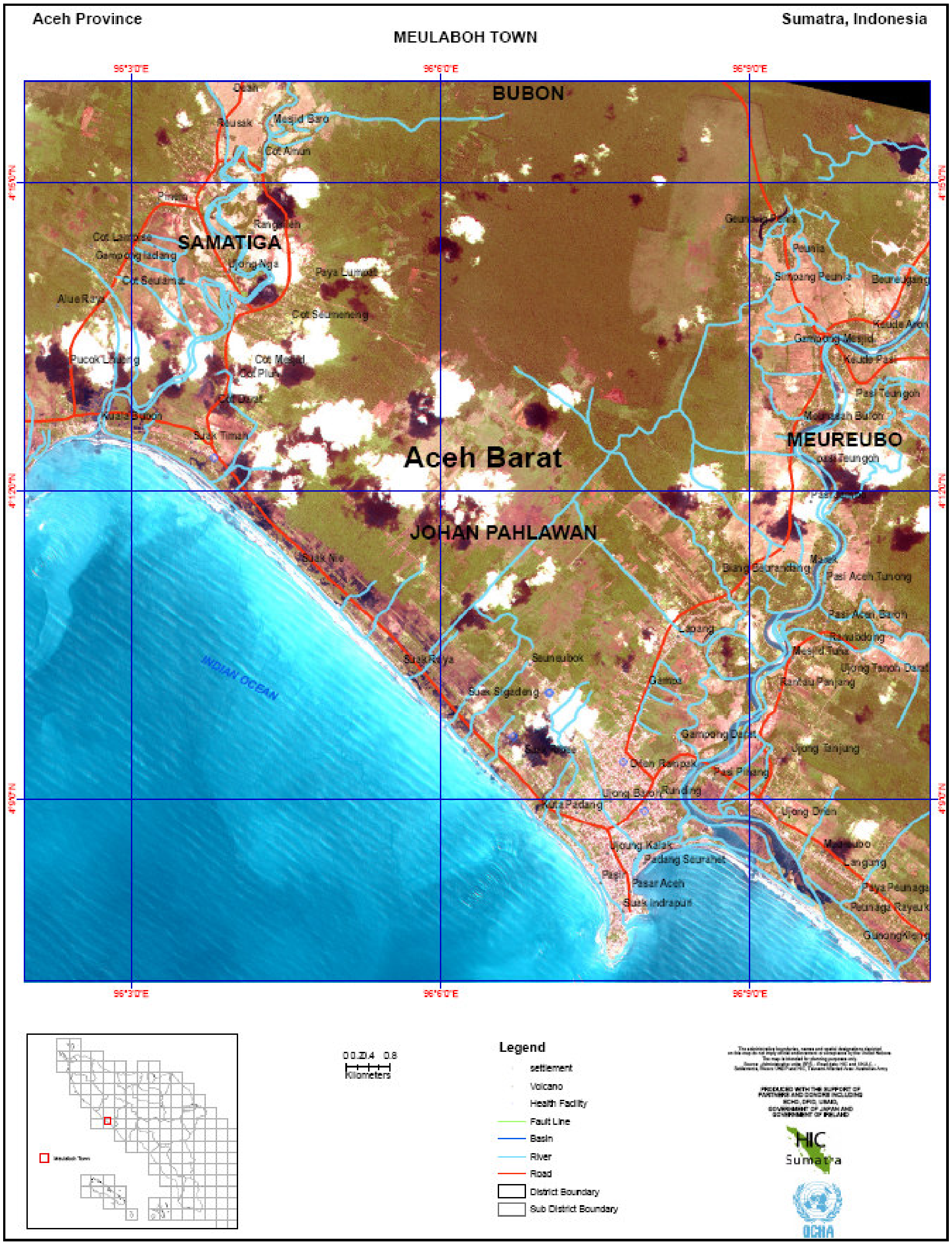


Figure3.9. The map of Johan Pahlawan Sub-district surrounded by Samatiga and Meureubo Sub-districts (HICSumatra, 2005c)

The map of Zoning Concept of Meulaboh City is presented in *Figure 3.10.* The spatial use pattern of the area along the coastline of Aceh Barat District and particularly Meulaboh City is adjusted to the disaster-prone characteristics. It includes the following zones:

1. Zone N1

   Tidewater front zone minimum 100 meters away from high tide. This zone will be used as a protective facility (buffer zone) with mangrove forest, sea hibiscus, and other hedgerow vegetation suitable for shore areas.

2. Zone N2

   Zone reached by tsunami waves of more than 1 meter above sea level. This zone will be used as plantation estates or urban parks featuring hedgerow vegetation in order to have them function as buffer zones. It will also feature buildings, though on a restricted scale, and low-density settlements (fish auction houses, fishing settlements, etc) in compliance with disaster mitigation planning. Areas lying 200-300m from the tideline are most vulnerable to heavy damage, which has therefore created the need for several protection and escape facilities. It is advised not to construct new buildings in these areas.
3. Zone B1

   Transitional zone (intermediate zone) reached by tsunami waves of less than 1 meter above sea level, located before the safe zone. This zone will feature services and trade activities and low to medium-density settlements.
4. Zone B2

   Tsunami-safe zone featuring central business district (CBD), social services, and high density urban settlements adjusted to the capacity of local land and existing spatial use.

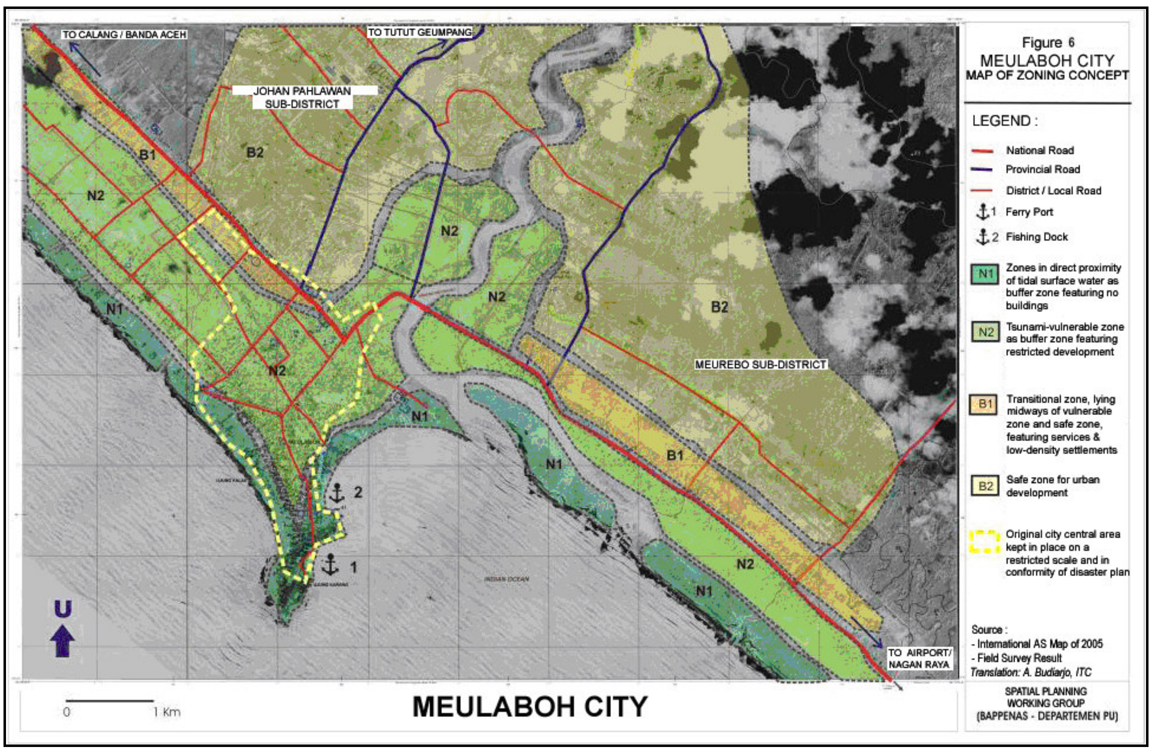


Figure3.10. Map of Zoning Concept of Meulaboh City. *Translated from* (Bappenas, 2005)

This zoning is an initial or preliminary conceptual planning that will be used, refined, or revised in further detailed spatial planning.

3.4.3. Resettlement and field situation

Referring to the masterplan of rehabilitation and reconstruction, the scenario to carry out in Meulaboh is to minimize relocation of urban activities and destroyed settlements and revive the site-bound activity functions in conformity with disaster mitigation plan (Bappenas, 2005). The zoning concept potentially triggers the conflicts of settlements relocation and land ownership.

Cross-checking the zoning concept with settlements identification in Quickbird image and field observation, implementation of zone N2 for low-density settlements in the city centre seems to be not so realistic since it will effect the relocation of inhabitants that were living in this area. According to the population data of the Head of Johan Pahlawan Sub-district (HICSumatra, 2005b), there are some high density settlements (56-142 people/ha, administrative-based registered at April 2005) exist in this area. During the fieldwork period, most of their inhabitants were still living in refugee. If these inhabitants are about to be relocated, the government will face financial difficulties to buy new land and prepare new housing. In detailed spatial planning, the requirement of low-density settlements in the N2 zone may change or be compromised to the latest field situation.

Population in the city centre is subject to tsunami vertical evacuation. In this area, there are also some tsunami-survived buildings including the parliament building, schools, and market buildings. They are located within a range of 700 m from the coast and may potentially function as ESB. Some schools and houses have been reconstructed in a better way.

The realisation of the masterplan of reconstruction stages has been delayed due to lack of coordination among stakeholders (government, inhabitants, NGOs). At the moment of the fieldwork period in September 2005, there was no spatial or strategic plan for reconstruction and redevelopment of Meulaboh City at a more detailed level. Then, the planning was about to start in a co-operation between the District Development Planning Agency *(Bappeda)* of Aceh Barat District and the Gadjah Mada University under the United States Agency for International Development (USAid) facilitation.

Figure3.11. Reconstruction of coastal canal along south coast of Meulaboh bordering destroyed Kampung Pasir village on the right side (fieldwork doc.)

Designation of the national road (Banda Aceh – Meulaboh – Medan route) in the conceptual zoning plan has been implemented and used for logistics and distribution of aid. Construction of the harbour has been started. Harbour and ferry transport activities now take place in a temporary port. The coastal canal along the south coast of Meulaboh (villages of Ujung Kalak, Kampung Pasir, and Suak Indrapuri) has been reconstructed wider *(See Figure 3.11)*. The canal can be used for slowing down tsunami waves as well as a boundary of the buffer zone –NI and N2 zone– in the spatial plan.

Figure3.12. The destroyed Padang Seurahet village with some subsiding land (fieldwork doc.)

The Government of Aceh Barat District has decided to relocate high-density settlements in three totally destroyed areas of Suak Indrapuri, Padang Seurahet, and Kampung Pasir Villages *(See Figure 3.7)*. There will be 2,318 houses relocated to Blang Berandang village and Meureubo Sub-district in the northern sub-urban area[13]. Some of the land of

[13] It refers to the settlement relocation document provided by the Local Task Force of Disaster Management of Aceh Barat District *(Satlak PB Aceh Barat)* Meulaboh and the interview with the Chairman and Administrator of Satlak PB Aceh Barat.

these villages has been subsiding below the sea level. The area of these villages will be allocated as a buffer zone or tide water front zone –N1. By carrying out the relocation plan, local government faces financial problems to buy and prepare new land and settlements in the designated area.

Not all the survivors want to be relocated, some of them prefer to return to their old land. For marking the land, they put wooden signboards, marks and tents on their land. Some even live in tents. A few settlements have been reconstructed by NGOs both in the old location (Ujong Baroh village) or new locations (Kuta Padang and Suak Ribee village). Lack of information of the land status in relation to relocation and resettlement to the inhabitants has put them in a confusing and uncertain situation.

Figure3.13. Survivors return to their old land and live in the tents (fieldwork doc.)

3.5. Conclusion

- Latest population data contains population number and household number in each village will be used to estimate the population distribution (inhabitants to be evacuated) in residential use.
- Meulaboh City, particularly the study area, require tsunami vertical evacuation to prepare the inhabitants to be able to cope with the similar tsunami of December 26.
- The spatial guideline and zoning concept of Meulaboh City in the Masterplan of reconstruction and rehabilitation can be used as a spatial planning consideration in population distribution estimation, road network or travel path identification, and restricted area for ESB allocation.
- Population in the settlements of Suak Indrapuri and Kampung Pasir Villages will not be taken into account as evacuees in evacuation simulation since the settlements will be relocated and designated as a buffer zone.

4. Data collection

This chapter describes the data collection process, starting from defining the required data, data acquisition methods, to the result and findings after the fieldwork. The data was acquired through literature review and internet browsing, secondary data, office data, expert and authority interview, and field observation in the study area in Indonesia.

4.1. Data requirement and data acquisition methods

Data collection process is conducted before and during the fieldwork period. Before the fieldwork, the data are obtained from literatures and internet sources. While during the fieldwork period, data acquisition method includes interview and field observation as well as data acquisition for secondary sources. The following *Table 4.1* provides the list of data requirement and data acquisition methods in relation to the research questions.

Table 4.1 Data collection in relation with research questions

No.	Research Question (RQ)	Data requirement	Source	Acquisition method
1.	RQ: 1a, 1b, 1c, 3a Justification of the necessity of disaster mitigation, vertical evacuation, and ESB characteristics in the study area	- Reference on tsunami vertical evacuation - Reference on existing countries experience in dealing with tsunami - Standard on tsunami-resistant building - Design of tsunami-resistant building	- Scientific Journal - FEMA/NOAA – US, Japan experiences - IOC, UN-ISDR, etc. - Masterplan of Aceh's reconstruction – Bappenas - Puskim – Public Works Department - Dr. Krishna S. Pribadi, Ir. Andry W. MT., Dr. Budi Faisal – ITB - Prof. Soetikno, Dr. Sudibyakto, PSBA UGM	- Literature study - Internet browsing - Experts interview
2.	RQ: 2a, 2b, 3b, 3c Identification of existing tsunami-survived buildings, potential ESB, and ESB's alternate suitable function	- Location and capacity of potential ESB - Alternate suitable function of ESB - High-res. satellite image (Quickbird & Ikonos)	- Field observation - Pacific Disaster Center	- Building survey in the study area - Field observation in other tsunami-affected area in Aceh
3.	RQ: 1d Assumptions on early warning system and water inundation	- Travel time, data processing, & response time for evacuation - Water height (inundation) map	- GFZ Postdam, HGF, DLR, NOAA Coastal Service, PTWS, etc. - UNHIC Sumatra - Dr. Hamzah Latief – ITB - Dr. Sudibyakto, PSBA UGM	- Internet browsing - Expert interview
4.	RQ: 4a Estimation of population distribution	- Population number per village - Population growth rate - Local government plan/decision in resettlement/relocation - Village boundary delineation - Buffer zone delineation	- Satlak PB and Bappeda of Aceh Barat District - Masterplan of Aceh's reconstruction – Bappenas - UNHIC Sumatra - ARRIS – JICA - Field observation - Pacific Disaster Center	- Secondary data acquisition - Authority interview - Internet browsing - Village boundary identification - Buffer zone identification - Facility identification

No.	Research Question (RQ)	Data requirement	Source	Acquisition method
		- Facilities location and their occupants number - High-res. satellite image (Quickbird & Ikonos)		
5.	RQ: 4b, 4d Identification of road, river, and canal network	- Road network - River and canal network - High-res. satellite image (Quickbird & Ikonos)	- Satlak PB and Bappeda of Aceh Barat District - UNHIC Sumatra - Field observation - Pacific Disaster Center	- Secondary data acquisition - Internet browsing - Road, river, and canal identification
6.	RQ: 4c, 4d Accessibility in tsunami evacuation	- Concept of accessibility - Location-allocation model - Standards/norms in tsunami evacuation	- Scientific journal - Dr. Tom de Jong – UU - Dr. K.S. Pribadi – ITB	- Literature study - Experts interview

4.2. Pre-fieldwork data acquisition and fieldwork preparation

Before the fieldwork, data collection mainly focused on the secondary data, collecting information about existing knowledge of vertical evacuation and ESB, maps and satellite images of Meulaboh area, and documentation and demographic data of Meulaboh City. Based on these acquired data, an initial analysis is conducted to prepare for the data acquisition in the field. The preparation includes:

1. Developing interview guidelines
   Preparing for the interview, the information and knowledge to obtain were formulated in the interview guidelines and translated into interview questions. Questions were then fine-tuned to the perceptions of the interviewees. The question lists is given in *Appendix 6.*

2. Determining buildings to survey and designing building survey form
   This activity is carried out based on Quickbird and Ikonos satellite images that covered the study area before and after the December 26 tsunami. The Quickbird (of Digital Globe) images were acquired on May 18, 2004 and January 7, 2005. While the Ikonos image was acquired on January 7, 2005. To determine which buildings to survey, the following sampling design was applied:
   a. Building site classification
      Based on the tsunami run-up and inundated area, the building site was classified into: sea-front site, river/canal-front site, and tsunami-reached inland site. Further observation was carried out in each classified site.
   b. Survived-building identification
      Within each of the classified sites, observation focused on survived buildings surrounded by serious damaged or totally destroyed (swept away by tsunami) buildings. A building is considered suffering serious damaged if more than half of the building mass is collapsed –

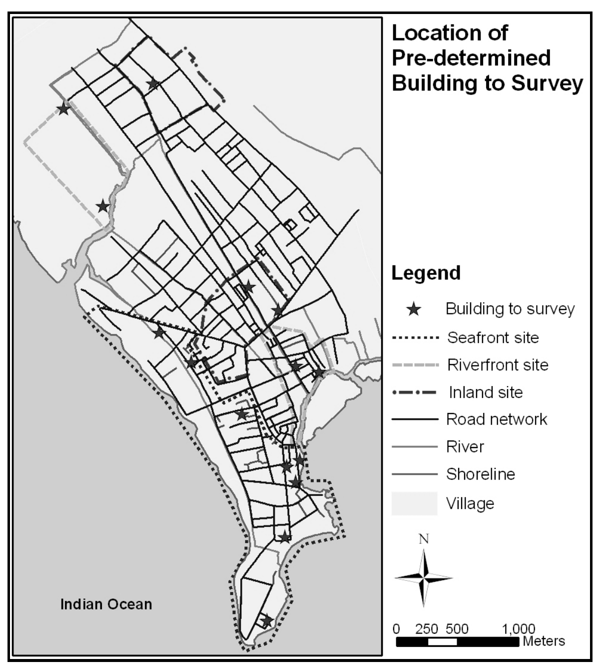


Figure4.1. Pre-determined surveyed buildings

identified the remaining building roof and wall in the images of before and after tsunami. While totally destroyed buildings were identified by inexistence of the structure or remaining building components.

c. Building selection

The identified buildings are then selected to limit the sampling number into 8 buildings of sea-front site; 4 buildings of river/canal-front site; and 3 buildings of tsunami-reached inland site to compromise limited time and resources during the fieldwork. Since the sea-front site suffered the most destruction due to tsunami, bigger sampling number is assigned to it, namely 8 buildings.

The location of these pre-determined buildings to survey is shown in *Figure 4.1.* Accompanying the building survey, the survey form is designed to record the characteristics of architectural and structural design of tsunami-survived buildings. Information of building location, coordinates and photo documentation are included in the survey form.

3. Digitizing road network, river and canal network

This activity was carried out based on Quickbird and Ikonos satellite images. The results are used as an orientation in the field, particularly to identify the destroyed and non-passable road as a component of evacuation simulation. In the evacuation simulation, the road network will be used as travel path, while river and canal will restrict the evacuees' movement where no bridge is available.

4.3. Secondary data acquisition

During the fieldwork period, secondary data acquisition was conducted at the Regional Centre for Research on Human Settlements *(Pusat Penelitian dan Pengembangan Permukiman –Puskim)* of Public Works Department in Bandung and at Disaster Management Task Force *(Satuan Pelaksana Penanggulangan Bencana –Satlak PB)* of Aceh Barat District in Meulaboh. In fact, there is no research and data related with tsunami-resistant building in *Puskim*, due to lack of concern on tsunami hazard in Indonesia before the December 26 tsunami. Complimentarily, the standard and design of earthquake-resistant building are acquired. Satlak PB of Aceh Barat District provided information on refugee number, government decision in resettlement and relocation, and estimation of physical damage percentage in each village.

Population data was acquired from the website of National Statistical Bureau *(Biro Pusat Statistik, BPS),* and United Nation Humanitarian Information Centre (UNHIC) Sumatra of Meulaboh office. UNHIC or HIC Sumatra provided the data of population and household number per village that was signed by the *Camat* or Head Johan Pahlawan Sub-district at April 2005. There is no information on how the data is collected at that moment. Regarding the destruction of buildings and infrastructure, it can be assumed that the population data shows the number of people that administratively registered at a certain village, but they may not live in that village at the moment of data acquisition. The complete population data is presented in *Appendix 4.* HIC Sumatra also provided the maps of Meulaboh, water inundation and offices location, road network, and school reconstruction.

Despite Bappenas' Masterplan of reconstruction and rehabilitation, there is no data on detailed spatial planning for Meulaboh City –that before was expected to have reached a certain progress–. Initial ideas of spatial planning are obtained in the expert interview of Research Centre of Natural Disasters Gadjah Mada University *(PSBA UGM)*[14]. The following *Table 4.2* shows all the acquired secondary data.

Table 4.2 Acquired secondary data

No	Acquired Data	Source
1.	- Population number per village - Geographic and topography condition per village	National Statistical Bureau, BPS *(BPS website)*
2.	- Number of refugee - Decision of settlements relocation	Satlak PB Aceh Barat District, Meulaboh
3.	Design of tsunami and earthquake-resistant building	Regional Centre for Research on Human Settlements –Puskim
4.	- Population number per village before and after tsunami, report of Sub-district Head *(Camat)* of Johan Pahlawan - Water depth inundation map recorded in the NGO and government offices in the north part of Meulaboh (contain road network) - Map of school reconstruction of Johan Pahlawan Sub-district (contain road network)	United Nation Humanitarian Information Centre (UNHIC) Sumatra, Meulaboh office *(email delivery)*

4.4. Experts and authorities interviews

Interview is aimed at understanding certain knowledge particularly in its application at the local level of Aceh or Indonesia, based on the expertise and experience of the interviewees. As mentioned before, the questions are asked within certain guides to which required knowledge and information is obtained. This kind of interview is very useful in situations where either in-depth information is needed or little is known about the area. The flexibility allowed the interviewer to elicit extremely rich information in the topics of interest (Kumar, 1996). During the interview, some interviewees made sketches or drawing illustrating the explanation as well as provided secondary data of relevant information. The experts might gave different opinions of a certain topic, and therefore field observation was required to check, justify, and take the best applicable consideration[15]. *Table 4.3* shows the list of interviewees and the discussed topics. The interview guide and list of questions are provided in *Appendix 6.*

Table 4.3 Acquired interview data

No	Topic	Interviewee
1.	- Situation during and after the December 26 tsunami in Aceh - Concept, experience, and possible implementation of vertical evacuation in Aceh - ESB characteristics	Dr. Krishna S. Pribadi, Disaster Mitigation Centre, Institute of Technology Bandung (ITB).
2.	- National policy in disaster management in Indonesia - Ideas on reconstruction of tsunami-affected area	Dr. Sudibyakto, Faculty of Geography Gadjah Mada University; Expert of Ministry of Social Affair
3.	Initial ideas of Meulaboh's spatial plan	Prof. Soetikno, Research Centre for Natural Disaster (PSBA UGM)
4.	- Ideas of tsunami-resistant building design & local construction - Design of earthquake-resistant building	Ir. Andry Widyowidjatnoko, MT., Department of Achitecture ITB
5.	- Early warning system for Aceh region	Dr. Hamzah Latief, Department of Geophysics and Meteorology ITB
6.	Ideas on urban design and reconstruction for tsunami-prone area	Dr. Budi Faisal, MLA., MAUD., Department of Architecture ITB, Expert of Ministry of Housing

[14] PSBA UGM was appointed by the Bappeda of Aceh Barat District to carry out several projects of spatial plan in Meulaboh City.

[15] As an example, the experts expressed different ideas in determining the buffer zone range (100-400m) along the shore, regarding the Zoning Concept Map of the Masterplan of reconstruction.

No	Topic	Interviewee
7.	- Physical damage of Meulaboh City after tsunami - Village boundaries of Meulaboh City - Buffer zone and relocation plan - Water inundation after tsunami	The Chairman and Administrator (Mr. Jaharuddin) of the Disaster Management Task Force (Satlak PB) Aceh Barat District

Initially, data acquisition on spatial planning process were planned to be obtained during the interviews or discussions with experts and authorities involved in the project of Meulaboh's spatial plan[16]. The interview was about the concept of spatial plan and implementation of disaster mitigation aspect. In fact, the project was delayed due to lack of coordination and financial resource. No detailed spatial plan was available during the fieldwork period. At that moment, the spatial planning project was about to achieve a memorandum of understanding (MoU) between the Government of Aceh Barat District and Gadjah Mada University under USAid support. In this circumstance, initial ideas of spatial planning are obtained from the interviews with the experts of the Research Center for Natural Disasters *(PSBA)* Gadjah Mada University, Secretary of the Bappeda of Aceh Barat District, and the Head and Data Administrator of Satlak PB of Aceh Barat District.

4.5. Field survey

The field survey was conducted in September 13-19, 2005 in the study area of Meulaboh City as well as in Lampu'uk and Ulheelheu next to Banda Aceh City. The survey observed the tsunami survived buildings and alternative suitable ESB function and identified the road, river, and canal network.

4.5.1. Tsunami-survived building survey

The survey of tsunami-survived building was carried out based on the map of pre-determined buildings. The steps of survey include:

1. General observation of destruction on the surveyed site
   The idea of this observation was to give an overview of destruction –particularly of buildings and non-passable roads– guided with the satellite images of before and after tsunami situation. The survey was conducted nine months after tsunami, and at that time, changes occurred at the survived buildings. The components –roof, wood frame, openings frame– of several non-occupied survived buildings have been taken away by other survivors to be used for temporary shelter. Based on the existing condition, the resistance of survived buildings were classified into 3 classes:
   - High, >90% of building components are not destroyed and can still be functioned. Building example of this class is given in *Figure 4.5.*
   - Moderate, 75-90% of building components are not destroyed and can still be functioned. Building example of this class is given in *Figure 4.2.*
   - Low, 50-75% of building components are not destroyed and can still be functioned. Building example of this class is given in *Figure 4.3.*

   In this classification, the judgement is based on visual observation. The observed building components include architectural component (wall, openings, doors, roof, floor) and structural

[16] They were coming from Gadjah Mada University Yogyakarta, District Development Planning Agency *(Bappeda)* of Aceh Barat District, and other local government agency.

one (column, beam, foundation, lateral bracing, roof frame). If the remaining functioned building components are less than half of the whole building, the building is not considered as resistant or tsunami-survived building.

Figure4.2 Moderate-resistance surveyed building

Figure4.3 Low-resistance surveyed building

2. Identification of pre-determined surveyed buildings and other survived buildings
   After general observation of the site, pre-determined surveyed buildings were identified and judged whether they meet the requirement of resistant building. Some of the pre-determined surveyed buildings in fact did not meet the requirement of building resistance. Therefore, other existing survived buildings in the site were identified for survey.

3. Building observation
   An observation was then carried out on the identified resistant buildings. The observed components include: location and site, architectural and structural design, and accessibility to upper floor of the building.

The location of surveyed buildings is shown in *Figure 4.4*, while the complete results of this survey are presented in *Appendix 7*. Some pre-determined surveyed buildings are not observed because the building condition did not meet the criteria of tsunami-survived building. In the satellite images, these buildings are assessed by the roof condition, shadow (height), and surrounding landscape. From ground observation, it was found that the structure beneath the roof was seriously damaged. In the course of time, in some cases, the building components such as roof, roof frame, window frame were taken away by survivor victims for temporary shelter.

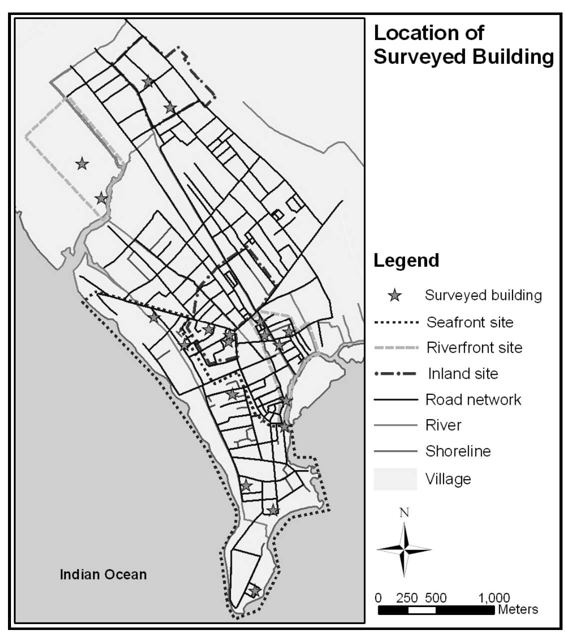


Figure4.4. Location of surveyed buildings

Based on the building survey, it can be concluded that the factors influence the building resistance against a tsunami include the following:

1. Location and orientation

   Most of the buildings located within the range of 200m from the coast are totally destroyed. Within 200m range from the shore, very few building survived from tsunami in the range of 100m. Building mass orientation influences the building resistance against tsunami. Building mass or part of the building mass that situated in the same direction with the waves is found to be more resistant than the one blocked by the wave flows. The wave direction can be simply predicted from how does the wave approach the building, whether directly (perpendicularly) from the shore, through the river and canal, or through the road and spaces between other buildings.

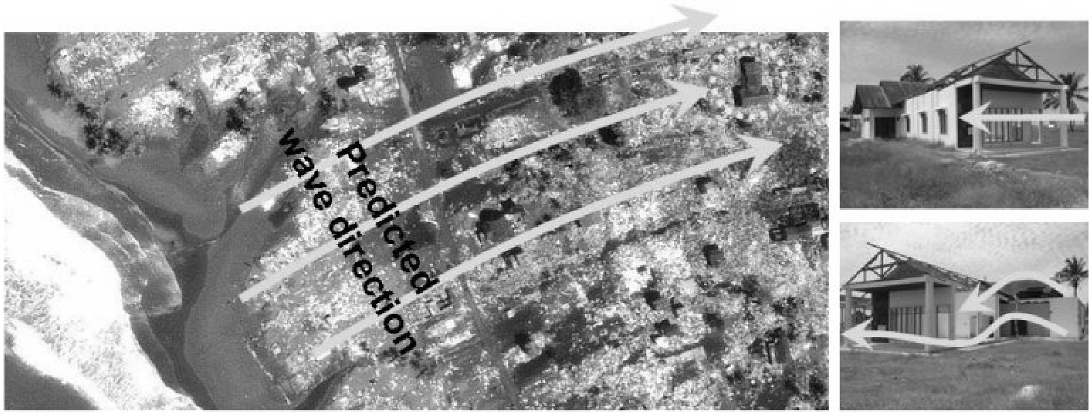


Figure4.5. Building mass orientation towards tsunami waves direction (DigitalGlobe, 2005; fieldwork doc.)

2. Façade and openings

   Large percentage of openings such as door, window, and air ventilation exist in the façade of tsunami-survived buildings prevented the destruction of the buildings. During the survey, the doors did no longer exist since they had been broken and swept by the wave. The same thing occurred to window glasses, where only the wooden window frames remained *(See Figure 4.6.)*. Façade comprises corridor, opening arch, and terrace or porch had proven to support the building resistance since they can allow the wave flows *(See Figure 4.7.)*.

Figure4.6. Broken glass at the windows of the building in *Figure 4.5.* (fieldwork doc.)

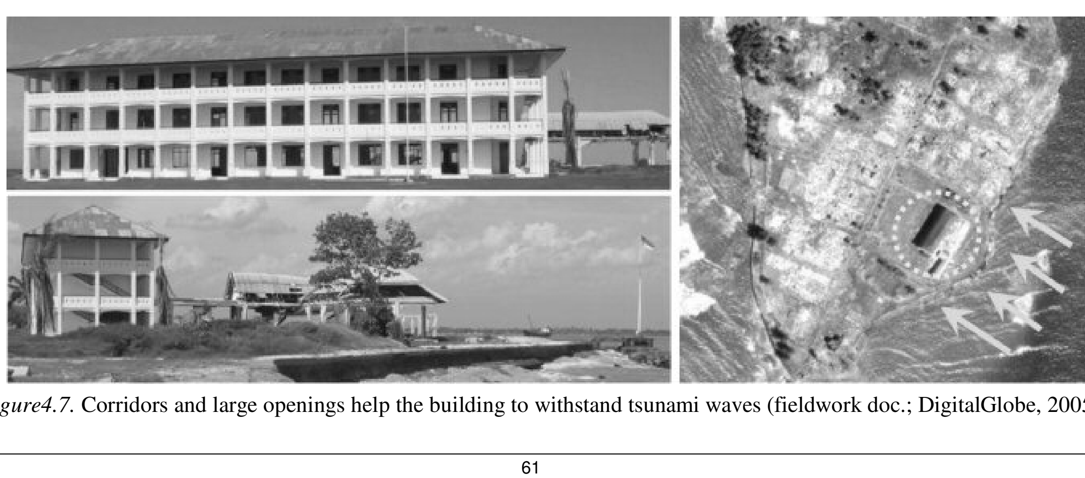


Figure4.7. Corridors and large openings help the building to withstand tsunami waves (fieldwork doc.; DigitalGlobe, 2005)

3. Structural components

   Structural design of the surveyed buildings fulfil basic requirement of horizontal and vertical load distribution based on dimension of column, beam, slab, lateral bracing *(ring balk, sloof –Bahasa Indonesia)* and foundation showed to improve the resistance of buildings. Even some of the survived-buildings are found over structure. All of the structures are reinforced concrete structure. Joint between column and beam are found to be critical due to serious damage at the destroyed building in this part.

4. Construction quality

   Building construction is the most critical and important factors for a building to withstand tsunami. Despite good plan and design, the building quality still relies much on the construction phase where the building is constructed to meet a certain specification and requirement. Some of the identified buildings constructed by upper-class (national level) contractor are found to be more resistant than other building built by the owner itself or local contractor.

The conclusions above were made from visual observation in the field and analysis in combination with information from literature review and expert interview (Ir. Andry Widyowijatnoko, MT. of Architecture Department of Institute of Technology Bandung). Further detailed research and structural calculation –particularly about a structure behaviour in dealing with the dynamic fluidal load of tsunami waves– are strongly required to review the conclusions.

4.5.2. Alternative suitable ESB function

This observation is aimed at identifying which building functions exist in Meulaboh City and Aceh region can be assigned as ESB for vertical evacuation. Referring to the characteristics of ESB, the criteria of observation are: public facilities or public service oriented function, multi-storey building, reserve space for additional capacity, and well planned and good construction quality. Overview of the observation is presented in *Table 4.4* as follows.

Table 4.4 Overview of suitable alternate function of ESB

No	Building function	Suitability for ESB	Public-oriented function	Building design and construction	Critical issue
1.	Mosque	Suitable	Accommodate prayer, education, socio cultural activities for Moslems and surrounding communities. Accessible for almost the whole day and night	- Open lay-out suitable for accommodating huge number of evacuee - Well planned, good material, advanced construction technique, good construction	
2.	School	Suitable	Accommodate education activity for students living in surrounding area.	- Hall and classes can be occupied for evacuation. - Well planned & good construction	
3.	Bus station	Suitable only for people within the building	Public facilities, accessible to everybody the whole day and night.	- Commercial oriented, lack of empty space - Rest area, and hall at the upper floor can be used for evacuation - Well planned & good construction	During evacuation situation the building can only accommodate the people in it.
4.	Parliament building	Suitable	Civic building, oriented to serve the people. Designated for public	- Hall, foyer, and function room can be occupied for evacuation	

No	Building function	Suitability for ESB	Public-oriented function	Building design and construction	Critical issue
			hearing and demonstration.	- Well planned, good material, & good construction	
5.	Government office	Suitable	Civic building, oriented to serve the people	- Hall, foyer, and function room can be occupied for evacuation - Well planned & good construction	
6.	Market building	Suitable only for people within the building	Public facilities, accessible to everybody in a certain operating hours	- Commercial oriented, lack of empty space, full of merchandise & storage - Planned & good construction	During evacuation situation, the building can only accommodate the people in it.
7.	Shopping centre	Suitable only for people within the building	Public facilities, accessible to everybody in a certain operating hours	- Commercial oriented, lack of empty space, full of merchandise & storage - Planned & good construction	Vulnerable to robbery & stealing in emergency situation. During evacuation situation, the building can only accommodate the people in it
8.	Convention centre	Suitable	Accommodate various activities of the users/customers as well as public.	- Open lay-out suitable for accommodating huge number of evacuee - Well planned, good construction	
9.	Sport Hall	Suitable	Accommodate sport activities of the users/customers as well as public	- Open lay-out suitable for accommodating huge number of evacuee - Well planned, advanced construction technique	
10.	Hotel	Suitable	Serve the customers, limited access to public.	- Hall, foyer, and function room can be occupied for evacuation - Well planned & good construction	Security and privacy issues should be arranged together by owner and disaster authority.
11.	Parking building	Suitable	Serve the users/customer, accessible to public. Exist in the big city only.	- Remaining empty space can be used during evacuation - Well planned, advanced construction technique	

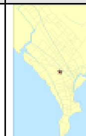
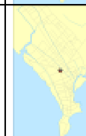
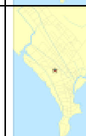
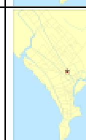
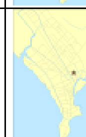
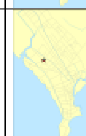
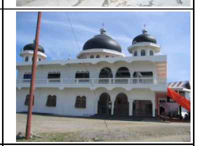
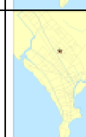
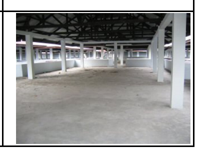
4.5.3. Potential ESB identification

Focusing to the study area, some existing tsunami-survived buildings have the potential to function as ESB. In simulation, these buildings will be assigned as destination for vertical evacuation. Referring to ESB characteristics and tsunami-survived building survey, the criteria used to determine which building is potential ESB include the following:

1. Located at a distance of more than 200m from the shore
2. Include within alternate suitable building functions as mentioned in the previous *Sub-chapter 4.5.2* which are: mosque, school, parliament building, government office, market, shopping centre, convention centre, sport hall, hotel, and parking building.
3. Building floor reserved for evacuation located above tsunami wave height in the area.
4. Well-planed and designed
5. Good quality construction

In relation to ESB function, the capacity or number of evacuees that can be accommodated in each building is estimated using architectural design space requirement approach. The estimation is further explained in *Sub-chapter 5.3.2.* In the study area, buildings that meet these criteria are described in the following *Table 4.5.*

Table 4.5 Potential ESB in the study area of Meulaboh City

No	Coordinate, Rec. time, shore dist, water height[17]	Name, Location, Function, Capacity[17]	Upperfloor, Accessibility	Map	Image	Image
1	GPS 4 - UTM 47N 181057.72,458355.55 09/16/05 07:06 Shore distance 604m Water height ~4m	Hotel Tiara, Sp. Pelor - Ujung Kalak, Commercial Housing, 0.263*((662*2)+ (0.85*135)) = 378p	2&3 floors, 2 used. Poor			
2	GPS 5 – UTM 47N 181036.17,458423.42 09/16/05 07:02 Shore distance 631m Water height ~4m	Local Parliament (DPRD Aceh Barat), Sp. Pelor – Uj. Kalak, Office&Social -Institutional, 0.236*0.85*1832 = 367p	2 floors, 1 used. Good			
3	GPS 6 - UTM 47N 180849.80,458481.92 09/16/05 07:00 Shore distance 557m Water height ~4m	Hotel Meuligou Sp. Pelor - Ujung Kalak, Commercial Housing - Residential, 0.263*0.85*2*1249=558p	3 floors, 2 used. Good			
4	GPS 51 - UTM 47N 181291.49,458499.15 09/18/05 07:20 Shore distance 843m Water height ~4m	New Market Mosque, Panggong , Pray&Social -Institutional, 0.78*0.85*143 = 95p	2 floors, 1 used. Good			
5	GPS 58 - UTM 47N 181532.80,458437.75 09/18/05 07:47 Shore distance 591m Water height ~4m	Madrasah, Ujung Baroh, School - Institutional, 0.3*0.85*1*202 = 52p	2 floors, 1 used. Medium			
6	GPS 20 - UTM 47N 180400.53,458910.04 09/17/05 09:48 Shore distance 542m Water height =3.5m	Mosque, Kuta Padang, Pray&Social –Institutional, 0.78*0.85*582 = 386p	2 floors, 1 used. Medium			
7	GPS 33 - UTM 47N 181046.23,459292.69 09/17/05 11:22 Shore distance 1573m Water height =2.25m	Ahlusunah wal Jamaah Mosque, Rundeng, Pray&Social –Institutional, 0.78*0.85*676 = 448p	3 floors, 2 used. Medium			
8	GPS 52 - UTM 47N 181304.41,458445.29 09/18/05 07:24 Shore distance 702m Water height ~4m	New Market (Pasar Baru), Panggong, Market - Commercial, 0.23*0.85*4616 = 902p Only for people within	2 floors, 1 used. Medium			

4.5.4. Identification of road, river, and canal network

The idea of this activity was to make field checks the real condition of road network – that has been digitized before–. Focuses of these field checks were the road destruction and accessibility, and analysing the possibility to have the roads rebuilt or recovered. For the river and canal network, this activity aimed at identifying their

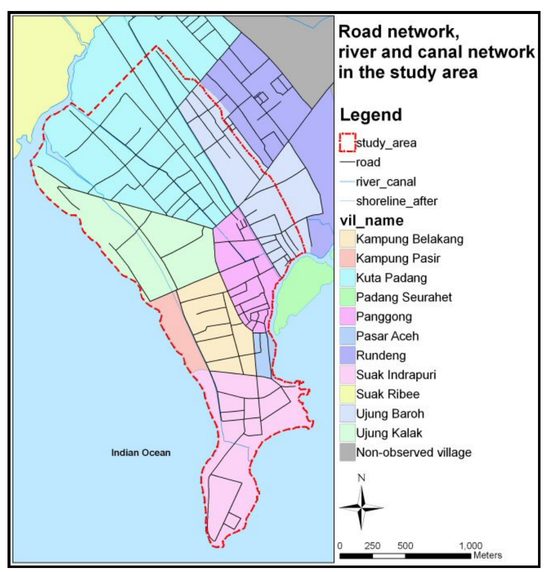


Figure4.8. Road network, river and canal network in the study area

[17] Capacity unit is in person (p); water (inundation) height is obtained from inundation map *(Appendix2)* and inhabitants interviews.

existence since the network may not be clearly identifiable from satellite images because of being covered by land, debris, and ruins, as well as covered by building structure before tsunami. The result of this observation is presented in *Figure 4.8*, showing the river and canal network, and passable road network that can be used as evacuation path.

4.5.5. Identification of the buffer zone area

Responding to the December 26 tsunami, there will be a buffer zone designated in the shore area. In Meulaboh City's zoning concept of the Masterplan of reconstruction (Bappenas, 2005), it is included in the tidewater front zone (N1) and tsunami vulnerable zone (N2), designated at minimum 100-300m away from high tide *(See Figure 3.10*). The zone will be used as an urban park or plantation estates with mangrove, sea hibiscus, and other hedgerow vegetation suitable for shore areas. The local experts addressed different opinions on the buffer zone range –from 200 to 400m– regarding the high-density (particularly fishermen) settlements and that existed in the area.

Field observation was carried out to assess the applicable buffer zone range. It was found that most of the area within a distance of 300m from the shoreline was totally destroyed, and there were high-density settlements in some area. Considering the already-started house and coastal canal reconstruction and the financial constrain for the settlement relocation *(See Sub-chapter 3.3.3)*, the critical and applicable buffer zone range is determined to be within 100m distance from the shoreline. At this zone the settlements will have to be relocated and therefore it is assumed that there is no population taken into account in ESB allocation. The range may increase for a certain shore area where no settlements existed before the tsunami.

4.5.6. Identification facilities location

This field observation aimed to identify the facilities location through the study area and estimate the facilities occupants' number. The result will be used in population distribution estimation as explained in *Sub-chapter 5.1.3.* The facilities include: mosque, school, office, market, shop, hotel, bus station, port, and warehouse. The facility location is presented in *Figure 1.4.*

4.6. Conclusion

- A building survey was carried out to the identify the building resistance characteristics of the tsunami-survived buildings
- Based on the ESB characteristics and its alternative suitable function, the existing tsunami-survived buildings were identified, selected and proposed to be the ESBs (and therefore called existing potential ESBs). These buildings will be assigned as the (existing) destination in ESB allocation modelling.
- Identification of the road network, and river and canal network in the field cross-checked the digitized network that will be used as a travel path in ESB allocation modelling.
- The buffer zone area is assumed to be designated within 100m distance from the shoreline, and therefore there will be no population taken into account in this area.
- Field identification on facilities location and their occupants' number is used to estimate the population number in the area of non-residential uses.

5. Accessibility modelling for vertical evacuation simulation

This chapter explains the steps of accessibility modelling used in this research. It includes preparation and execution of location-allocation modelling as vertical evacuation simulation. The individual steps include: estimation of population distribution; identification of travel components; identification of existing potential ESB and restricted allocation areas; and location-allocation modelling.

Tsunami vertical evacuation is simulated using location-allocation modelling since the modelling demonstrates the effort of people to move or evacuate themselves from their initial location to the nearest evacuation shelter buildings (ESBs) around them. The origin is defined as the population distribution that needs to be evacuated. The destination is the result of this modelling that proposes ultimately ESB location through out the study area. The modelling considers the existing potential ESB and finds out the location of new additional ESB since the available capacity of existing ESB can not fulfil the population number to be evacuated (demand). As mentioned in previous *Sub-chapter 2.4*, during vertical evacuation people evacuate themselves within a limited evacuation time through the road network and passable paths.

5.1. Estimation of population distribution in day and night scenarios

5.1.1. Population distribution and spatial planning considerations

The steps carried out in this population distribution estimation is provided in *Figure 5.2*. The population number in the study area was obtained from the population data in village *(desa)* level. Village *(desa)* is the smallest governmental unit with an area of 4 to 120 hectares covering the areas of different density. The village area is too large to represent the population distribution through the study area for ESB allocation planning. The planning requires detail information of population existence that varies through the area and through the time, such that the idea to safe all the people in tsunami hazard area can be achieved. To have a more detail information on population distribution, the population number is estimated in smaller and equal size of tessellations covering the whole study area. The tessellation has the shape of 1 hectare hexagon (63m length of hexagon vertices). The area of 1 hectare is manageable extent of detail level spatial planning and building design.

In each hexagon, the population number is calculated from building occupants' number in the houses (for residential use) and facilities (non-residential land uses). As mentioned earlier, configuration of houses and facilities is assumed as the "physical condition to be" that will be achieved after

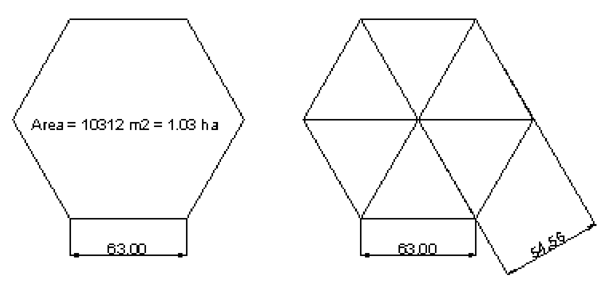


Figure5.1. Tessellation of 1 hectare hexagon

the city reconstruction stage. The condition is observed and defined from:

- Visual interpretation of Quickbird and Ikonos images that cover the study area before (May 18, 2004) and after (January 4, 2005) the tsunami
- Assumption on similarity of reconstructed areas (houses and facilities) as it was before the tsunami
- Local government plan on minimising relocation in the city centre area and the settlements relocation in totally destroyed villages and the buffer zone
- Masterplan of reconstruction and initial ideas of spatial planning team on the buffer zone and tsunami historical park
- Field survey in identification of the facilities locations, subsiding land, and applicable range of the buffer zone which is 100m from the shore.

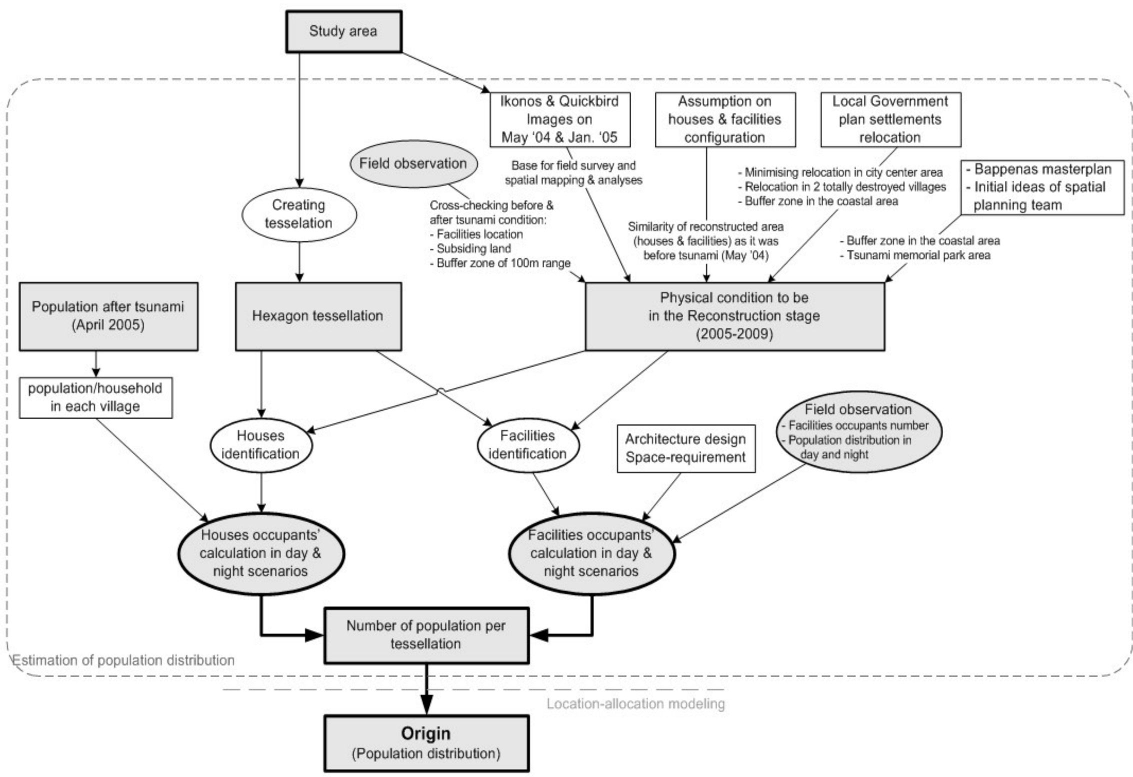


Figure5.2. Population distribution estimation

Regarding different concentration of people over the day, the population distribution is calculated in two scenarios: day and night.

- Day scenario, estimation of population in each hexagon around 12.15 in the afternoon, where most people are at their daily activity places outside the house.
- Night scenario, estimation of population in each hexagon at around 24.00 in the midnight, where most people rest or stay at their houses.

The calculation is based on satellite images of Quickbird and Ikonos that cover the study area at May 18, 2004 and January 7, 2005 and also incorporating the following spatial planning consideration:

1. Population of Kampung Pasir Village and south part of Suak Indrapuri Village is included in the calculation since the settlement in the area will be relocated to the northern part of the city [18]. Referring to the masterplan (Bappenas, 2005) and initial ideas of spatial planning team[19], the south part of Suak Indrapuri Village (Ujung Karang area) will be allocated as an urban park and tsunami historical museum.
2. Considering the spatial guidelines of the masterplan (Bappenas, 2005), initial ideas of spatial planning team [13], and field observation, the area within 100m range from the shore is assumed to be designated as buffer zone –i.e. public park, coastal forest, green zone– such that no settlement is assumed to exist in the future.

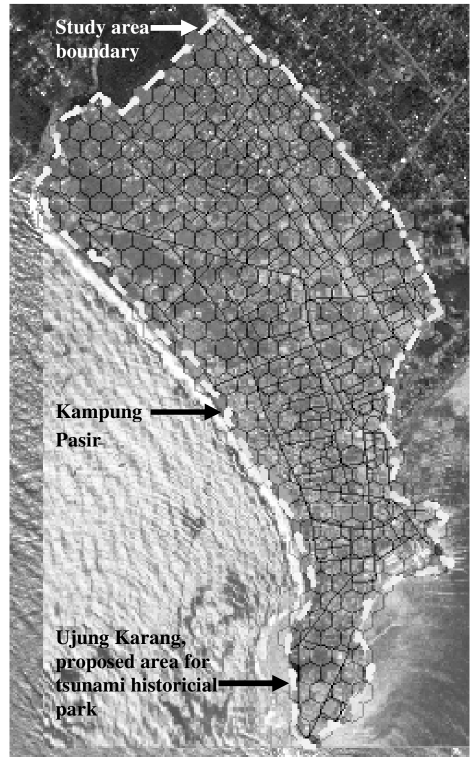


Figure5.3. Hexagon tessellation covers the study area overlaid on Quickbird and Ikonos images. *Images:* (DigitalGlobe, 2005; SpaceImaging, 2005)

The population data is derived from population and household number per village at April 2005 signed by the Head of Sub-district *(Camat)* Johan Pahlawan and provided by United Nation Humanitarian Information Centre (UNHIC) or HICSumatra. There is no information on how the data acquisition was performed. In an after tsunami situation, where most survivors were refugees (living in refugee camps and barracks) it can be assumed that the data shows the number of inhabitants that were administratively registered for a certain village and will return to their places during or after city reconstruction phase. This population data will be used in the population calculation in residential houses *(next Sub-chapter)*. As mention before, population of two relocated settlements (in Suak Indrapuri and Kampung Pasir) and population along 100m range from the shore are not taken into account.

The study area includes the Villages of Ujung Kalak, Suak Indrapuri, Kampung Belakang, Kampung Pasir, Pasar Aceh, Panggong, and some part of Kuta Padang and Ujung Baroh Villages. Population data of those villages is presented in the following *Table 5.1*. While for the location of each village can refer to *Figure 1.4* and *3.2.*

Table 5.1 Population and household number of Meulaboh City on April 2005
Modified based on (HICSumatra, 2005b)

Village name	Population April 2005	Household April 2005	Pop/hh April 2005	Note
Suak Indrapuri	2356	762	3.09	Settlements in the south part will be relocated, the area will be assigned as buffer zone & public park.
Pasar Aceh	323	75	4.31	
Panggong	1793	434	4.13	

[18] It refers to the settlement relocation plan that was addressed by the Secretary of District Development Planning Agency *(Bappeda)* of Aceh Barat District as well as the Chairman and Administrator of Local Task Force of Disaster Management of Aceh Barat District *(Satlak PB Aceh Barat)* in the interview during the fieldwork period.

[19] They are coming from the Recearch Center for Natural Disasters *(Pusat Studi Bencana Alam, PSBA)* Gadjah Mada University Yogyakarta. The spatial planning ideas were acquired in the fieldwork period.

Village name	Population April 2005	Household April 2005	Pop/hh April 2005	Note
Ujung Baroh	8935	1851	4.83	
Kampung Belakang	3494	785	4.45	
Kampung Pasir	896	312	2.87	Settlements will be relocated, no population counted in the area of this village
Ujung Kalak	6990	1571	4.45	
Kuta Padang	6514	1235	5.27	

5.1.2. Estimation of population in the houses

Estimation of population number in houses (residential use) is carried out by calculating the number of the houses per hexagon and multiplying the result with the number of population per household shown in *Table 5.1.* The houses are calculated manually from visual interpretation of Quickbird and Ikonos images before and after the tsunami. In day scenario, it is assumed that 50% of the family members are at home and the rest 50% conduct their activities outside the house. As an example of one family consist of father mother and 2 children, the mother and 1 child stay at home while the father and 1 child are at work or school. In night scenario, it is assumed that all family members are at home. An example of calculation, if there are 50 houses in a hexagon located in Ujung Kalak Village, then there are:

- 50% (occupants) * 50 (houses) * 4.45 (pop/hh) = 111 person in day scenario, and
- 100% (occupants) * 50 (houses) * 4.45 (pop/hh) = 222 person in night scenario

5.1.3. Estimation of population in the facilities

For the facilities occupants (non-residential use), the population estimation is calculated with architectural space requirement (approach) as well as field observation. The approach of architectural space requirement is actually estimating the number of building occupants from the area of building space using the norms or standards of architectural design. For example, the norms or standard of space requirement in designing a mosque is $1.8m^2$/person. It implies that a $180m^2$ mosque can accommodate 100 person at its full capacity (180/1.8=100). It is difficult to apply this approach for public facilities that include outdoor space such as bus station and port. Here, the population number is estimated from the field observation considering the capacity of transport mode –number of passenger and crew of bus, ferry, ship, truck, etc.– exist in the facilities. The estimation is based on the normal activity of related facility in Sumatra.

From the field observation, the facilities that exist in the study area include: mosque, school, boarding house, office, traditional market area, market building, shop, hotel, ferry port, fishing port, warehouse, bus station, and multi-function hall. In this occupants' number estimation, general norms and standard of design are incorporated. In reality, the space requirement may vary related to the facility type or class such as different grade of school and hotel.

For the totally destroyed areas, identification of facilities in the satellite image is supported with identification of building mass typology, land use of surrounding area, as well as information from local inhabitants and authority. Identification of the facilities can be described as follows:

- The existence of specific facilities such as market building, traditional market site, port, bus station can be easily identified from the field observation.

- Mosques are identified from the building orientation to *Qiblat* (Mecca) that differs from surrounding buildings. From the field observation, the boarding house *(asrama, pesantren)* is found to be a part of Islamic school complex located close to the mosque.
- The existence of hotel is identified from field observation since not so many hotels exist in the study area (only 2 hotels at fieldwork period).
- Shops are identified by the shop-front in commercial area. While *Ruko* (*rumah-toko,* shop in ground floor and residential use at the upper floor) is identified from the rectangular multi-storey building mass with short flank heading the main road. The roof of *ruko* is mostly concrete flat deck with small part covered with tile or corrugated metal sheet.
- Warehouse is identified through large roof plane and large open space surrounded by commercial facilities
- School and office are identified through their building mass typology as shown in the following *Figure 5.3.*

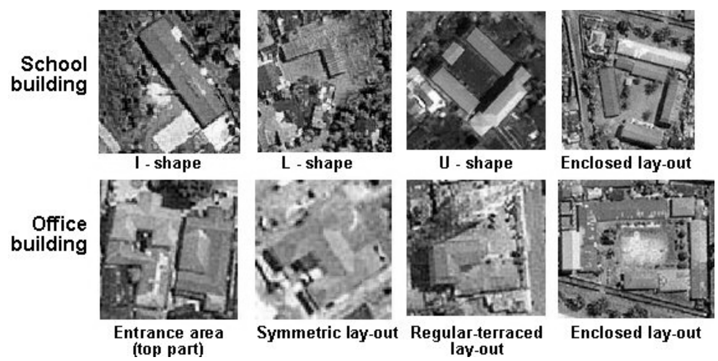


Figure5.4. Building mass typology of school and office identified from Quickird image. *Image:* (DigitalGlobe, 2005)

The general estimation of occupants' number per facilities in day and night scenarios includes the following.

1. Mosque

   Day scenario: ***10%*** *(capacity)* **** building area / 1.8*** *(space requirement)*
   - The day scenario time is around the preparation of *Zhuhur* prayer (between 12.30-13.00), such that the facility is filled at its 10% capacity
   - Space requirement for a mosque is 1.8m^2/person comprises: 1.2m^2/person for praying room; 0.2m^2/person for circulation; 0.4m^2/person for utilities and other supporting facilities such as ablution room, toilet, storage room, etc.

   Night scenario: ***1 person***
   - It is assumed that no one stays at the facility except 1 person of security and cleaning service.

2. School

   Day scenario: ***110%*** *(capacity)* **** building area / 4*** *(space requirement)*
   - It is assumed that the facility contain its regular occupants (100% capacity)
   - Space requirement for a school is 4m^2/student for building area (Neufert, 1997)
   - Despite students, the number of other occupants i.e. teacher, officer, food and merchandise seller is assumed to be 10% of the student number, such that total occupants is 110% of students number.

Night scenario: ***1 person***

- It is assumed that no one stays at the facility except 1 person of security and cleaning service.

3. Boarding house *(Asrama* and *pesantren)*

   Day scenario: ***2 persons***

   - It is assumed that no one stays at the facility except 2 persons of security service.

   Night scenario: ***100%** (capacity)* **** building area / 4.6*** *(space requirement)*

   - It is assumed that all members of the facility stay (100% capacity)
   - Space requirement for a boarding house is 4.6m^2/member comprises: 3.6m^2/member for sleeping room; 0.4m^2/member for circulation; and 0.6m^2/member for utilities and supporting facilities such as bathroom, washing room, living room, kitchen, etc.

4. Office

   Day scenario: ***100%** (capacity)* **** building area / 8.5*** *(space requirement)*

   - It is assumed that the building contains its regular occupants (100% capacity)
   - Space requirement for an office is 8.5m^2/person comprises: 4m^2/person for working station (Neufert, 1997); 1m^2/person for meeting room; 1m^2/person for circulation, lobby and foyer; 0.5m^2/person for rest area and utilities; 1m^2/person for hall; and 1m^2/person for archive and equipment room.

   Night scenario: ***1 person***

   - It is assumed that no one stays at the facility except 1 person of security and cleaning service.

5. Traditional market area

   Day scenario: ***100%** (capacity)* **** site area / 7.6*** *(space requirement)*

   - It is assumed that area is at its full capacity (100% capacity)
   - Space requirement for a traditional market is 7.6m^2/person comprises: 0.6m^2/person for buyer; 2m^2/person for circulating transporters; 3m^2/person for seller, merchant display and storage; and 2m^2/person for utilities and supporting facilities such as public toilet, parking area, etc.

   Night scenario: ***2 persons*** *(in the whole site)*

   - It is assumed that the area contains only 1 petty trader and 1 person of security guard.

6. Market building

   Day scenario: ***100%** (capacity)* **** building area / 5.2*** *(space requirement)*

   - It is assumed that the building contains its regular occupants (100% capacity)
   - Space requirement for a market building is 5.2m^2/person comprises: 1m^2/person for buyer; 0.2m^2/person for circulation; 2m^2/person for seller and merchant display; 1m^2/person for storage room, and 1m^2/person for utilities and supporting facilities such as toilet.

   Night scenario: ***2 persons*** *(in the whole area)*

   - It is assumed that the building contains only 2 persons of security service.

7. Shop *(Ruko* – shop and house)

   Day scenario: *[* ***50%*** *(family member)* **** population/household*** *]* ***+ 4*** *(employee and/or visitor)*

   - Family of the owner (mostly) also lives in the building comprises. In day scenario, it is assumed that half of the family members conduct their activities outside the shop.

- It is assumed that each shop contains its average regular occupants of 4 person include the employee(s) and visitors.

Night scenario: ***100%*** *(family member)* **** population/household***

- It is assumed that all family members of the shop owner stay

8. Hotel

Day scenario**:** ***50%*** *(capacity)* **** building area / 16*** *(space requirement)*

- It is assumed that the hotel contains 50% of its full capacity as an average of building occupation, where some of the hotel guests are outside.
- Space requirement for a hotel is $16m^2$/person comprises: $12m^2$/person for staying room and 1.5 m^2/person for circulation; $0.5m^2$/person for utilities; 1.5 m^2/person for hall, lobby, and restaurant (public function); $0.3m^2$/person for employees room; and $0.2m^2$/person for office function.

Night scenario: ***80%*** *(capacity)* **** building area / 16*** *(space requirement)*

- It is assumed that the hotel contains 80% of its full capacity as an average of building occupation, where most of the hotel guests are inside the building.

9. Ferry port

Day scenario: ***295 persons*** *(in the whole facility area)*

- It is assumed that the area contains its regular occupants.
- Based on field observation on ferry port of Meulaboh, the port is estimated to contain 295 persons comprises: 100 passengers to leave; 100 passengers to arrive; 30 passengers' companies (15% passenger number); 5 in-office officers; 10 field officers; 10 petty traders or commercial service providers; 20 crews of 2 ferry ships; 20 crews of 10 trucks or minibuses.

Night scenario: ***4 persons*** *(in the whole facility area)*

- It is assumed that the area contains only 2 petty traders and 2 security guards.

10. Fishing dock and harbor

Day scenario: ***108 persons*** *(in the whole facility area)*

- It is assumed that the area contains its regular occupants.
- Based on field observation, the port is estimated to contain 108 persons comprises: 56 crews of 8 ships or boats; 5 in-office officers; 5 field officers; 10 petty traders or commercial service providers; 20 porters; and 12 crews of 6 trucks or pick-up vehicles.

Night scenario: ***4 persons*** *(in the facility whole area)*

- It is assumed that the area contains only 2 petty traders and 2 security guards.

11. Warehouse

Day scenario: ***40 persons*** *(in 1 hectare site)*

- It is assumed that the area contains its regular occupants.
- It is estimated that there are 40 people in 1 hectare of warehouse site comprises: 35 employees (officer, porter, driver); and 5 petty traders or commercial service providers.

Night scenario: ***2 persons*** *(in 1 hectare site)*

- It is assumed that the site contains only 2 security guards.

12. Bus station

Day scenario: ***228 persons*** *(in the whole facility area)*

- It is assumed that the area contains its regular occupants.
- Based on field observation, the bus station is estimated to contain 228 persons comprises: 60 waiting passengers; 64 passengers in vehicles/minibuses (40%capacity*8passangers*20minibuses); and 60 crews of 30 vehicles; 9 passengers' companies (15% passenger number); 10 officers; and 25 petty traders or commercial service providers.

Night scenario: ***4 persons*** *(in the whole facility area)*

- It is assumed that the area contains only 2 petty traders and 2 security guards.

13. Multi-function hall

Day scenario: ***60%*** *(capacity)* **** building area / 1.2*** *(space requirement)*

- It is assumed that the site contain 60% of its full capacity as an average of building space occupation
- Space requirement for the building is 1.2m^2/person comprises 1 m^2/person for staying and 0.2m^2/person for circulation and utilities.

Night scenario: ***0 person***

- It is assumed that no one stays at the building

14. Public park (Buffer zone)

Day scenario: ***20%*** *(capacity)* ****site area / 500*** *(space requirement)*

- It is assumed that the site contains 20% of its full capacity
- Space requirement is 500m^2/person for the site

Night scenario: ***0 person***

- It is assumed that no one stays at the site.

The building area obtained from the satellite images is actually planar-roof area. In the study area (and in Indonesia in generally) the building has overhang roof structure of approximately 1m length surrounding the building. The percentage of the below-overhang area (of total planar-roof area) varies and decreases as the building area increases. Roughly calculated for medium size building –which exists mostly in the study area–, the percentage area below overhang structure is around 15% of the whole planar-roof area. Hence, the actual building area or (more or less) floor area is 85% of planar-roof area. The floor area is used as the building area in aforementioned occupants' number calculation.

The example of houses and facilities identification and calculation within the hexagon (explained before) is presented in *Figure5.6.*

In some hexagons, the coverage is extended to cover the neighbouring area where the adjacent hexagon is partially not occupied due to relocation plan or designation as buffer zone. As shown in *Figure 5.5.,* parts of some hexagons on the left side of coastal canal lie in the relocated area and buffer zone such that there will be no settlement development. While the remaining of those

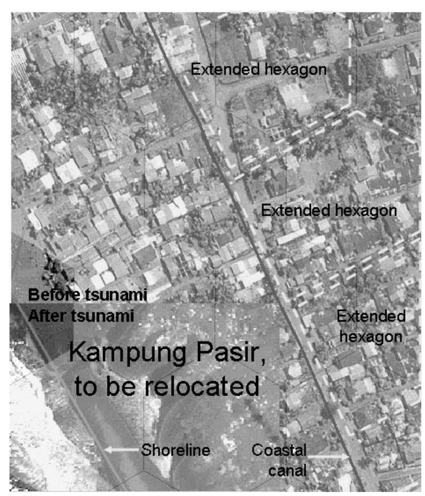


Figure5.5. Extended hexagons overlaid on Quickbird images. *Image:* (DigitalGlobe, 2005)

hexagons lie on the right side of coastal canal. These areas contain settlements that need to be calculated. Hence, these parts are included in the extended coverage area of their (right) adjacent hexagons

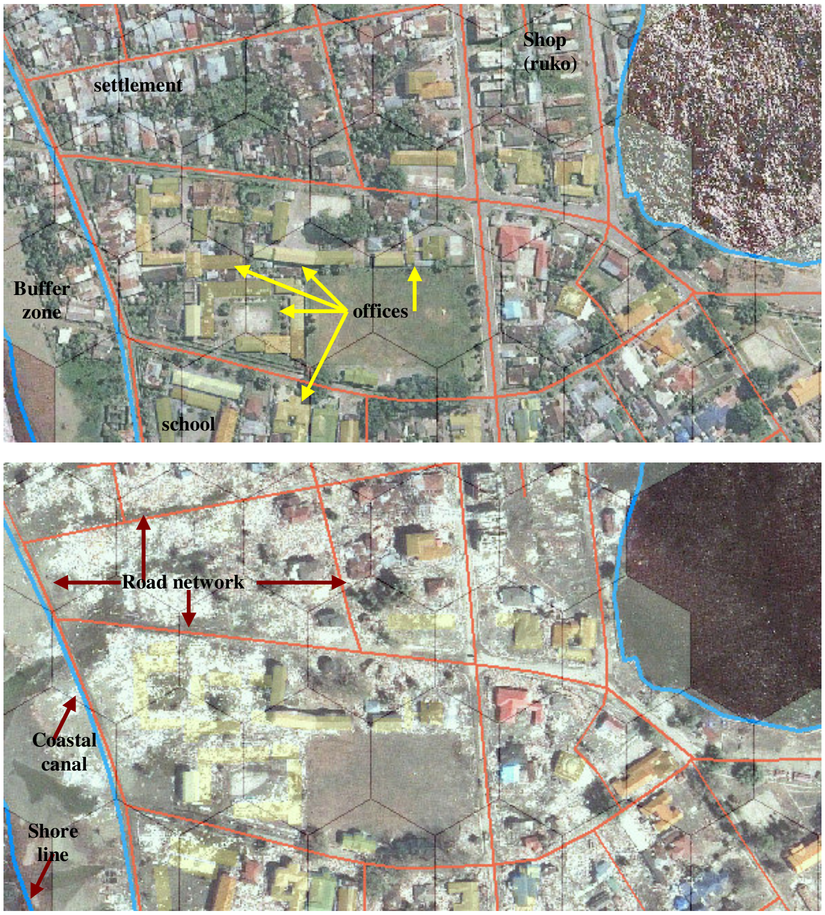


Figure5.6. Estimation of population number per hexagon from Quickbird satellite images before (top) and after (bottom) the tsunami. *Image:*(DigitalGlobe, 2005)

The calculated population number is stored in a field of a table with a reference to the hexagon tessellation where the population is located. This example of population calculation in the table is presented in *Appendix 8.* As results (of the population calculation), the total population for the day scenario is 24,891 people and for the night scenario is 19,988 people. To respond to the possibility of disaster occurrence through the day, the maximum population number in each tessellation in the two scenarios are combined and defined as the maximum population number. The maximum population number, which is 31,606 people, is used as the number of population to be evacuated in the final ESB allocation.

5.2. Travel components

The travel components include the travel path, travel impedance, and evacuation time. Travel path relates with road network and off-road passable path. The speed of movement refers to existing evacuation research and relevant assumptions of the movement in the study area. Evacuation time is defined by the estimated (available) travel time of the December 26 tsunami for Meulaboh City.

5.2.1. Travel path

In this research, the travel path comprises the road network and off-road passable path. As explained in previous *Sub-chapter 4.5.4*, the road network is identified and digitized from Quickbird and Ikonos satellite images and cross-checked in the field survey for its possibility to be rebuilt or recovered in city reconstruction process.

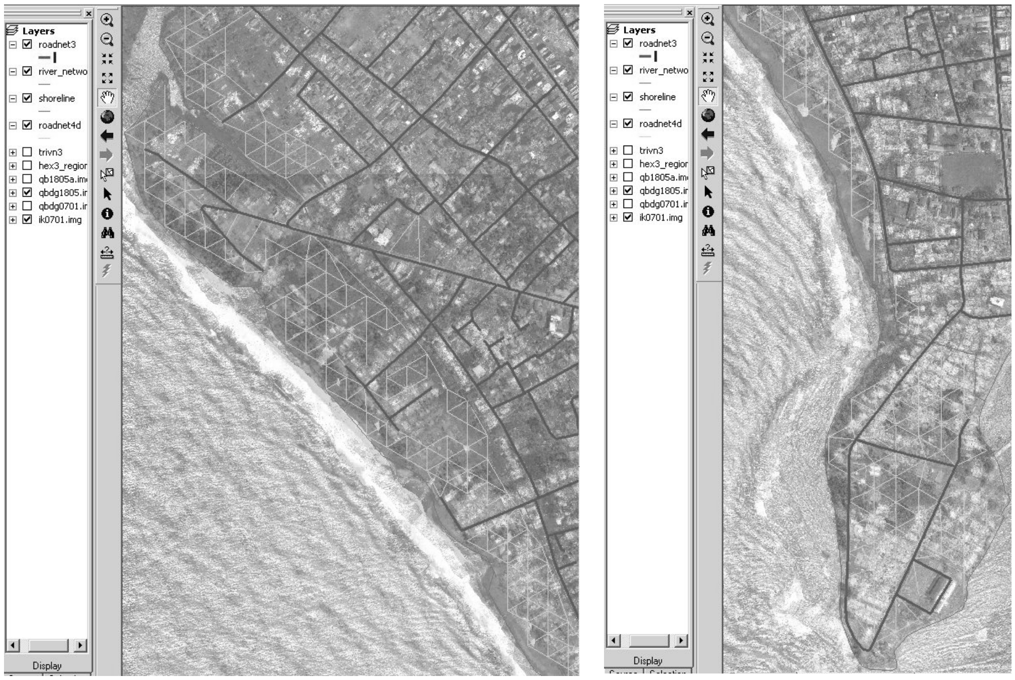


Figure5.7. Virtual network (triangles shape) in the buffer zone, vacant or vegetated land (left), and proposed area of tsunami historical park (right). The creation of virtual network also considers the existence of sinking in the shore area.

The road network includes district and local roads. Smaller foot paths that exist particularly in high-density settlements are not incorporated because these paths are no longer exist after tsunami and may change due to land consolidation, relocation, and resettlement in city reconstruction process.

Off-road passable paths are assigned to the buffer zone (100m range from the shore), vacant or vegetated land along the shore and estuary, and proposed area of tsunami historical park (Ujung Karang area), under assumption that these areas will be functioned as public park or coastal forest. Here, people can run (off-the road) to any direction; such movement is represented in virtual foot path network or virtual network. The virtual network actually does not exist, it is created to model or represent the possible (off-road) evacuees' movement in those particular areas. The virtual network is in the shape of smaller size (than the hexagon) triangle network that meets the road network in some nodes. All the paths are divided into segments in relation to the crossing path and direction distinction. In each segment, the travel impedance is assigned. The example of road network and virtual network is shown in *Figure5.7.*

5.2.2. Travel impedance

In order to model the movement, the speed is assigned to each network path segment as travel impedance. Travel impedance can be of distance, time, or cost. In vertical evacuation simulation, the impedance is expressed in time (second unit) since the evacuation is strongly related with the limited evacuation time.

In this research, the slowest speed of evacuees' movement during evacuation is assigned for the evacuation simulation. According to the Institute of Fire Safety and Disaster Preparedness Japan (Sugimoto et al., 2003), the slowest evacuees' speed is 0.751m/s that occurs on a group of elderly walking people. Since ESB allocation is based on the travel of the slowest evacuees, other evacuees that can move faster are able to reach the ESB before the tsunami strike accordingly. This is in line with the goal of tsunami evacuation to move as many people as possible from away the hazard area before tsunami strike.

During evacuation, people will move away from the shore. Consequently within the study area people will move to the northern part of the city. This behaviour is represented in assigning different travel impedance to the network segments for sea-ward and inland ward direction. For the inland-ward direction the speed of 0.751m/s is applied such that the travel impedance is *"segment length/0.751"* (in second unit). While for the sea-ward direction, where people are likely not to go to, a very slow speed is assigned. This implies long travel time or high number of travel impedance. For this sea-ward direction, the travel impedance is formulated as *"1000s + inland-ward impedance"*.

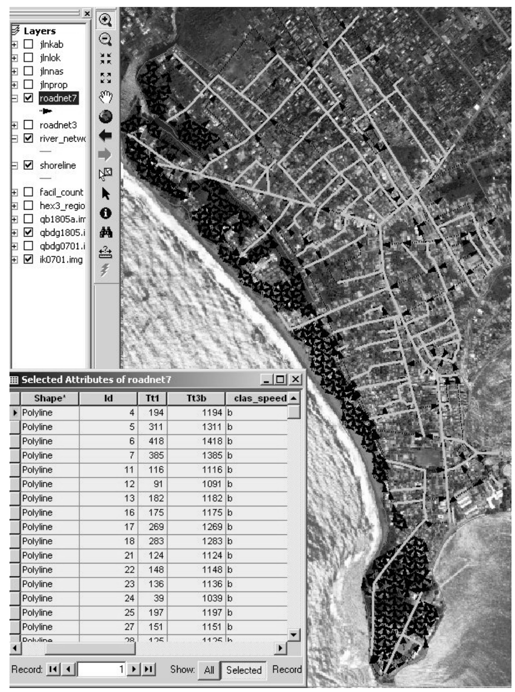


Figure5.8. Selected road segments with different travel impedance for sea-ward and inland-ward directions

Distinction of travel impedance is applied on the road segments that make an angle of 45°-135° from the shoreline and the road segments that connect the Meulaboh peninsula (Ujung Karang area) to the northern part of the city. For the road segments that are more or less parallel to the shore line or where people tends to go to both end segment directions, the assigned travel impedance is the same (inland-ward impedance) for both directions.

5.2.3. Evacuation time

As explained in previous *Sub-chapter 2.1.2,* tsunami travel time can be defined as the time between tsunami-trigger event (mostly is the earthquake in the ocean bottom) to the moment of the first tsunami wave reaches the shore of a certain area. Within this time, the process of analyses and tsunami occurrence determination, communication and coordination among disaster management authorities, and tsunami alarm to the community will take place before the evacuation can start. Evacuation time is considered as the remaining available time after aforementioned processes and before tsunami wave reaches the shore *(See Figure 5.9).*

In this research, tsunami travel time for Meulaboh City is referred to the event of December 26 tsunami which was 40 minutes (Yalciner et al., 2005). At the moment, the proposed tsunami early warning system for Indian Ocean region claims to be able to detect and determine the occurrence of tsunami at 13 minutes after the earthquake in the ocean (BMBF, 2005). Related to dissemination of information of the disaster management authorities in Indonesia[20], it can be assumed that the coordination among authorities and tsunami alarm will take 8 minutes. Therefore, evacuation time for Meulaboh City is 19 minutes. Related to the vertical evacuation process, the 19 minutes evacuation time is split into 15 minutes travelling to the ESB and 4 minutes climbing up the upper floor of the ESB. This 15 minutes travel time is considered as the distance range or maximum travel time in vertical evacuation simulation in order to safe people before a tsunami strike.

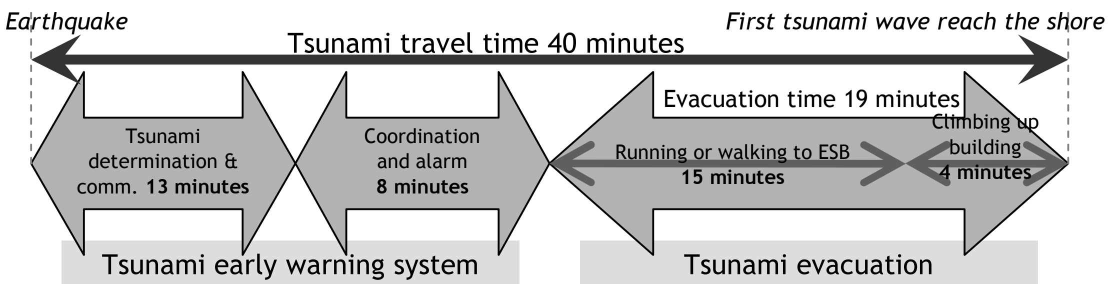


Figure5.9. Allocation of time within tsunami travel time for Meulaboh City

5.3. Existing potential ESB and restricted allocation area

5.3.1. Calculating the capacity of existing potential ESB

From the building survey in the study area, some tsunami-survived multi-storey buildings meet the ESB requirements. They have the potential to be assigned as ESB and therefore is further called existing potential ESB. Description of location, function, and images of these potential ESB is shown in the previous *Table 4.5.*

It is important to know the capacity of the existing potential ESB for the allocation of total population number to be evacuated. Related to the accessibility modelling, once the allocated evacuees meet the maximum capacity of an existing potential ESB, no more evacuees can be allocated to it. These evacuees should then be allocated to other existing potential ESB or to a new additional ESB. Referring to *Table 4.5,* the existing potential ESBs include: mosque, school, office, market building, and hotel.

The estimation of available reserve space *(available evacuation space)* of these facilities is calculated based on architectural design space requirement similar to the estimation of occupants number carried out in the previous *Sub-chapter 5.1.2.* While the space required for accommodating evacuees is $1m^2$/person (Bappenas, 2005). It can be described as $0.8m^2$/person for stay and $0.2m^2$/person for circulation. Hence, the capacity (in person unit) can be calculated as:

Available evacuation space * building area /1,

where: Available space	= available reserve space for evacuation in existing potential ESB *(m^2)*
Building area	= evacuation floor(s) area of existing potential ESB *(m^2)*
1	= space requirement for accommodating evacuees *(m^2/person)*

[20] It refers to the expert interview with Dr. Sudibyakto of the Research Center for Natural Disasters of Gadjah Mada University *(PSBA UGM)*

The building area mentioned here is the total evacuation floor area of the building. It should calculate the total area of the other floor(s) in case there is more than one evacuation floor.

The capacity calculation of existing potential ESBs is presented in *Table 5.2.* The assumptions and formula to calculate the capacity for evacuation of each building function is explained as follows.

1. Mosque

   Capacity for evacuation: ***78% * building area / 1***

   Space requirement for a mosque design is 1.8m^2/person comprises: 1.2m^2/person for praying; 0.2m^2/person for circulation; and 0.4m^2/person for utilities and other supporting facilities.

   From this space requirement, the spaces that can be occupied for evacuation purpose are the praying area (1.2/1.8 = 67% area) and circulation area (0.2/1.8 = 11% area).

   Hence, the total available space for evacuation is 67%+11%= 78% of the total building area.

2. School

   Capacity for evacuation: ***30% * building area / 1***

   The school building space (interior) is assumed to be occupied for furniture and equipment at approximately 70% of the total area, such that the rest 30% (circulation and empty space) can be used for evacuation space.

3. Office

   Capacity for evacuation: ***23.6% * building area / 1***

   Space requirement for office design is 8.5m^2/person comprises: 4m^2/person for working station (Neufert, 1997); 1m^2/person for meeting room; 1m^2/person for circulation, lobby and foyer; 0.5m^2/person for rest area and utilities; 1m^2/person for hall; and 1m^2/person for archive and equipment room.

   From this space requirement, the spaces that can be occupied for evacuation purpose are the circulation, lobby, and foyer area (1/8.5 = 11.8% area) and hall area (1/8.5 = 11.8% area).

   Hence, the total available space for evacuation is 11.8%+11.8%= 23.6% of the total building area.

4. Market building

   Capacity for evacuation: ***23% * building area / 1***

   Space requirement for market building design is 5.2m^2/person comprises: 1m^2/person for buyer; 0.2m^2/person for circulation; 2m^2/person for seller and merchant display; and 2m^2/person for storage.

   From this space requirement, the spaces that can be occupied for evacuation purpose are the buyer area (1/5.2 = 19.2% area) and circulation area (0.2/5.2 = 3.8% area).

   Hence, the total available space for evacuation is 19.2%+3.8% = 23% of the total building area. Regarding the crowd in this building, in evacuation situation the building can only accommodate the people located in it.

5. Hotel

   Capacity for evacuation: ***26.3% * building area / 1***

   Space requirement for hotel design is 16m^2/person comprises 12m^2/person for staying and 1.5 m^2/person for circulation; 0.5m^2/person for utilities; 1.5 m^2/person for hall, lobby, and restaurant (public function); 0.3m^2/person for employees' room; and 0.2m^2/person for office function.

From this space requirement, the spaces that can be occupied for evacuation are the area (1.5/16= 9.4% area); public function area (1.5/16 = 9.4% area); and assumed 10% non-occupied rooms (0.1*12/16 = 7.5% area).

Hence, the total available space for evacuation is 9.4%+9.4%+7.5% = 26.3% of the total building area.

Table 5.2 Capacity of evacuation floor existing potential ESB

No.	Building name and location	Evacuation floor – total floor	Calculation	Capacity (person)
1	Hotel Tiara, Simpang Pelor – Uj. Kalak	2nd and 3rd – 3	0.263*((662*2)+(0.85*135))/1 = 378	378
2	Local parliament (DPRD), Sp. Pelor	2nd – 2	0.236*0.85*1832/1 = 367	368
3	Hotel Meuligou, Ujung Kalak	2nd and 3rd – 3	0.263*0.85*2*1249/1 = 558	558
4	New Market Mosque, Ujung Baroh	2nd – 2	0.78*0.85*143/1 = 95	95
5	Madrasah, Ujung Baroh	2nd – 2	0.3*0.85*1*202/1 = 52	52
6	Mosque, Kuta Padang	2nd – 2	0.78*0.85*582 /1 = 386	386
7	Ahlussunah wal Jamaah Mosque, Rundeng	2nd – 2	0.78*0.85*676/1 = 448	448
8	New Market (Pasar Baru), Ujung Baroh	2nd – 2	0.23*0.85*4616/1 = 902	902
			Total capacity	**3187**

In Hotel Tiara and Hotel Meuligou *(See number 1 and 3 in Table 5.2),* where there are 2 floors assigned as the evacuation floor, the calculation is multiplying by 2 at the building mass of the 2 evacuation floors. From *Table 5.2,* it can be concluded that total capacity of the existing potential ESB (3187 person) can not cover the total population in the study area which are 24,891 people, 19,988 people, and 31,606 people in day scenario, night scenario, and maximum population number respectively. Therefore, new additional ESB is required in the study area.

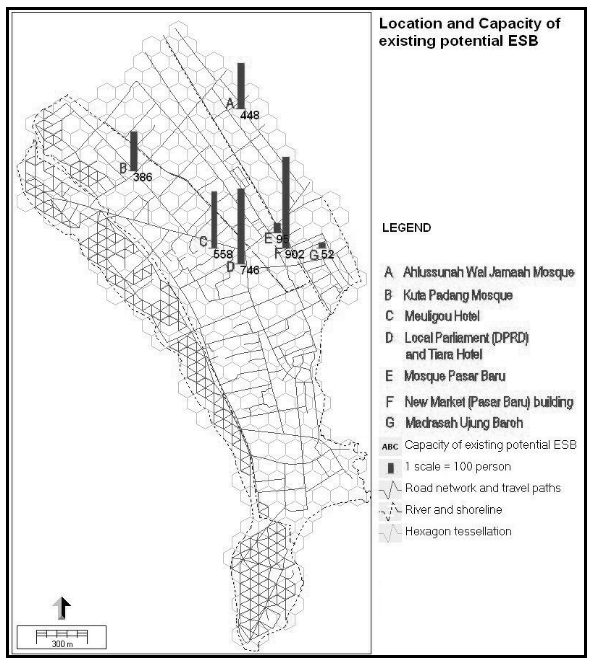


Figure5.10. Location and capacity of potential exsting ESBs

The percentage of population (evacuees) covered by the existing potential ESBs is given in *Figure 5.14, 5.15, and 5.22.* While *Figure 5.10* shows the location and evacuation capacity of each existing potential ESB. Hotel Tiara and parliament building in fact are located next to each other and put in 1 hexagon tessellation (location D) as can be seen in *Figure 5.10.*

5.3.2. Capacity of ESB

A critical issue in vertical evacuation is the accessibility of evacuees to shelter building before tsunami strike. During an emergency evacuation situation, evacuees will just run to the closest ESB and not care about the ESB capacity. Hence, the capacity of proposed ESB should be prepared to accommodate the maximum number of population that may exist in a particular location. For the population number, it can be managed by calculating the population number based on activity or building function in every location (tessellation) in the study area. For the ESB, the capacity is considered as tailor-made, meaning that the building(s) design can be adjusted to meet the required capacity. This tailor-made capacity can be applied on new additional ESB, where the ESB capacity is incorporated in the building planning and design process. While for existing potential ESB, it will be difficult –and may become unrealistic considering the construction cost– to prepare more space for evacuation e.g. by constructing additional floors.

Thus, the capacity of potential existing ESB is considered to be fixed or no expansion is applicable, while the capacity of new additional ESB is assumed to be tailor-made or adjustable. This capacity issue will be considered in the next step of location-allocation modelling for ESB allocation.

5.3.3. Restricted allocation area

It is possible that some areas cannot be allocated for ESB function because of safety or security concern. The area could be hazardous material site, high-risk industrial area, power plant, or other critical facilities.

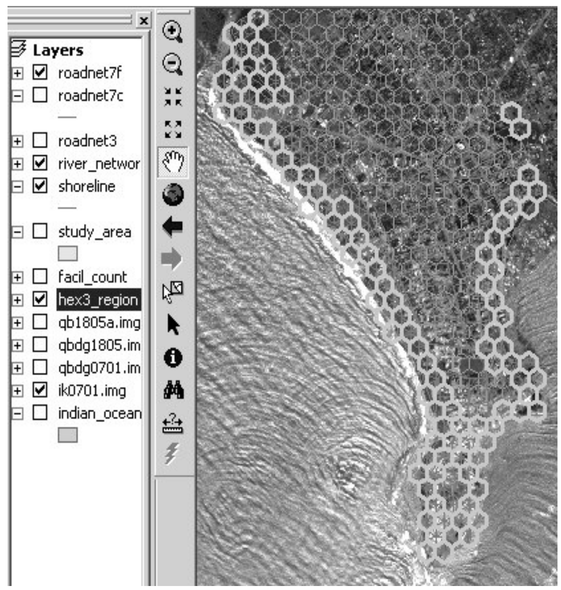


Figure5.11. Restricted areas for ESB allocation

There is no such information on such critical facility in the study area. Allocation restriction is applied on: water bodies of river or sea (which is wholly or partially located in the tessellation) and area along the shore particularly on the planned buffer zone area, where no settlement should be located. During evacuation, inhabitants or evacuee will avoid the shore and run away to inland-ward. Hence, ESB allocation in this area will not be effective in tsunami evacuation situation. The restricted allocation areas is represented in the hexagon tessellations along the shore, and can be seen in *Figure 5.11.*

5.4. ESB allocation using location-allocation modelling

Flowmap software package is utilised for location-allocation modelling to determine suitable optimized location of ESB in the study area. As shown in *Figure 5.12,* the three modelling carried out are the following:

1. ESB allocation for day population distribution scenario
2. ESB allocation for night population distribution scenario
3. Final ESB allocation.

Each modelling can be carried out solely. The third modelling, which combine the population number in both day and night scenarios, is actually the main ultimate modelling to arrive at the spatial distribution of ESB in the study area. The first and second modelling attempt to get an overview of ESB allocation for both the day or night population distribution.

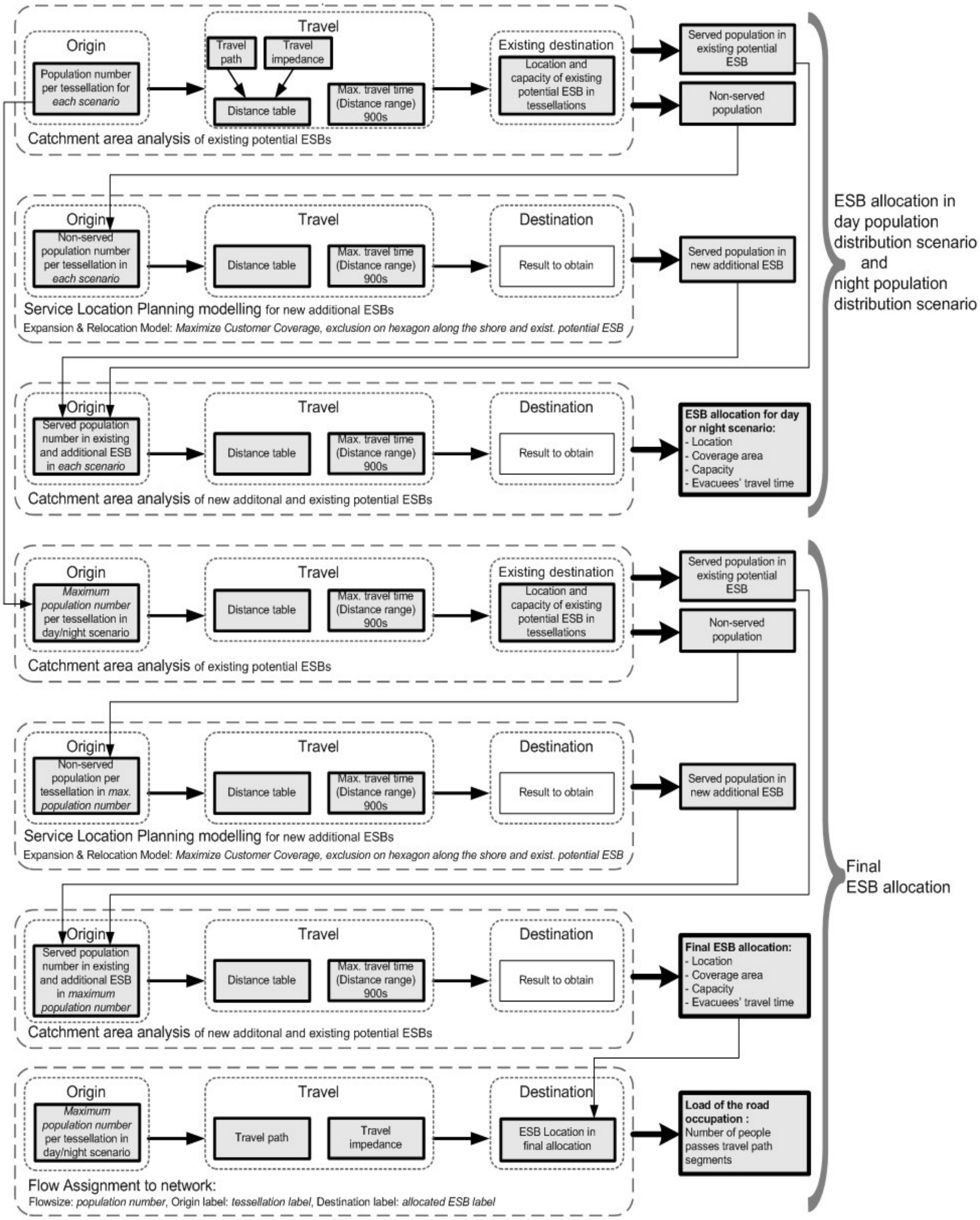


Figure5.12. Location-allocation modelling for ESB allocation

The steps in finding ESB location in each modelling are actually the same. They include:

1. *Catchment area analysis* of existing potential ESBs, which is an assessment of their service coverage in serving the population considering their capacity
2. *Service Location Planning Modelling (SLP) in Expansion and Relocation Model* to find the location of new additional ESBs required to population that is not covered by the existing potential ESBs
3. *Catchment Area Analysis* of additional and existing potential ESBs to find the coverage area of each ESB and evacuees' travel time.

To run the analysis in Flowmap, all the relevant files (study area boundary, digitized road nework or travel path, location of the existing potential ESBs and resticted allocation areas) should be converted to the Flowmap's file. Brief description of relevant Flowmap's functionality used in this research was given in previous *Subchapter 2.6.4.*

In the analyses, the travel path is defined as the shortest distance or shortest travel time algorithm. It starts from the centroid of each hexagon and proceeds along travel path network located nearest to that centroid. Population number per hexagon (population distribution) is taken as weight in allocating the destination (ESB) and coverage area.

5.4.1. ESB allocation for day population scenario and night population scenario

Location-allocation modelling in these two scenarios is actually the same. The distinction between day and night scenarios is based on different population distribution (population number in a particular area) in day or night situation. The difference in population distribution through out the study area will result in different ESB allocation. As mentioned before, there are three steps in this modelling: *Catchment Area Analysis* of existing potential ESBs, *Expansion and Relocation Model* for new additional ESBs, and *Catchment Area Analysis* of additional and existing potential ESBs.

1. *Cathcment Area Analysis* of existing potential ESBs
   Before allocating new ESB in the study area, it is necessary to have an overview of the performance or service coverage of the existing potential ESB in accommodating population in day population scenario and in night population scenario. These analyses are conducted using *Catchment Area Analysis.*
   Related to the travel components, the travel impedance is assigned to the (digitized) travel path to create a distance table or distance matrix. A distance table (in this research using network travel, not airline/buffer analysis travel) stores the travel distance information in order to get the shortest possible distance in modelling the travel from origin to destination. The created distance table can be used in other allocation modelling (in final ESB allocation), as long as the modelling uses the same origin and destination (hexagon tessellation) and travel path network.

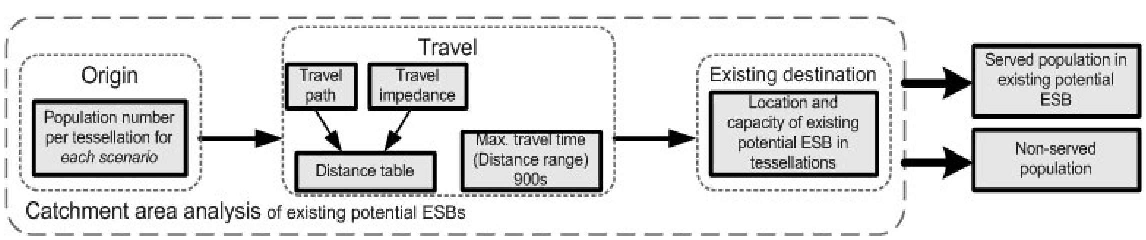


Figure5.13. Catchment Area Analysis of existing potential ESBs

   As shown in *Figure 5.14-5.15,* the analysis results in the served population number in existing potential ESBs, coverage area of each ESB and evacuees' travel time for both day and night scenarios. For the day population distribution *(See Figure 5.11)*, the existing potential ESBs can only cover 13% of the total population. If the capacity of these buildings is not taken into account, within 15 minutes (900 seconds) evacuation travel time, the buildings could cover 47% of the total population. While for the night population distribution *(See Figure 5.12)*, the existing potential ESBs buildings can only cover 16% population and 48% population if the capacity is out of count.

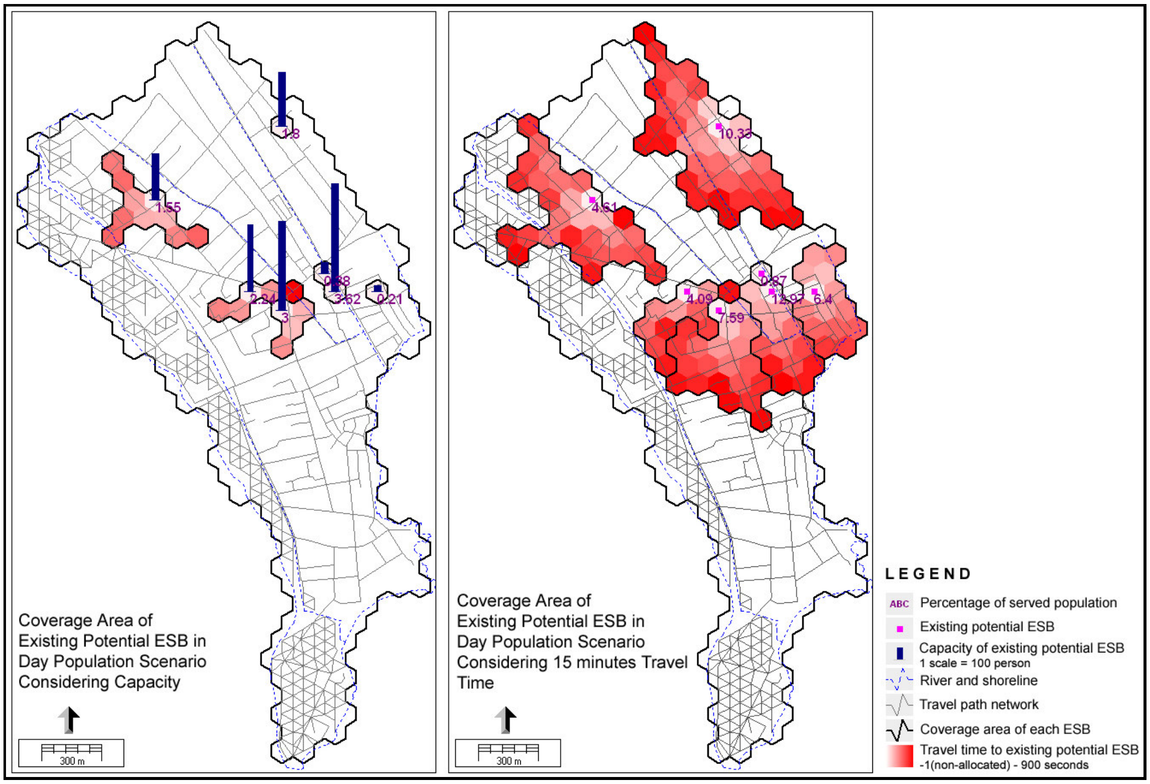


Figure5.14. Coverage area of existing potential ESBs in the day population scenario

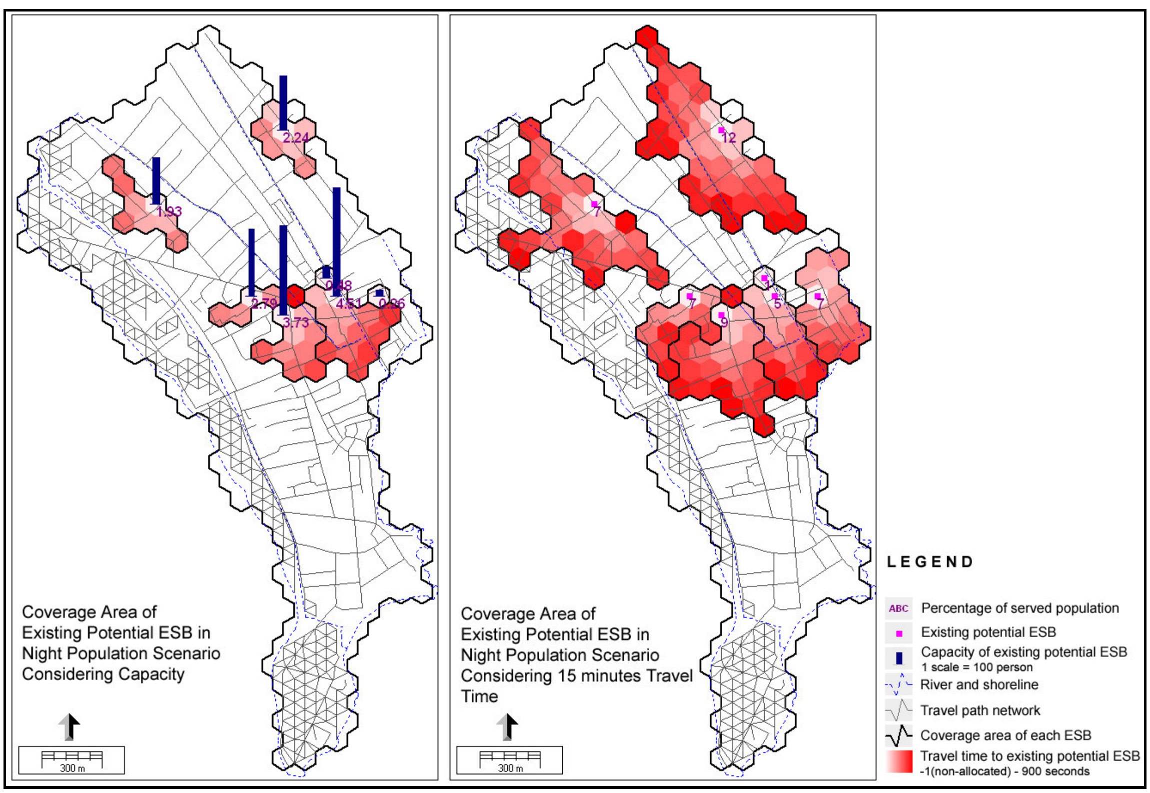


Figure5.15. Coverage area of existing potential ESBs in the night population scenario

The non-considered capacity imply that the building have to be substantially modified or enlarged. Since the evacuation capacity of existing ESBs is considered to be fixed, the non-considered capacity option will not be used in the next step. From these catchment area analyses, the remaining non-served population can be obtained and assigned into the *Expansion* and *Relocation Model* to define the location of new additional ESBs in the two scenarios.

2. *Expansion and Relocation Model* for new additional ESBs

   The *Expansion Model* in *Maximize Customer Coverage* attempts to allocate additional ESB particularly at the location which contains high population number (high density area). The option is chosen because the ESBs should be located at high-density areas where the demand or population (disaster risk) is high rather than at the low-density areas. The model runs in *full coverage* parameter such that it takes all population within the study area into account. In this modelling, the areas (hexagon tessellations) along the shore (restricted allocation areas) are excluded. Thus, there will be no ESB allocation in those locations. This reflects that in the evacuation situation people will tend to run away from the shore. Exclusion is also applied to locations of existing potential ESBs to avoid overlapping ESB allocation. In this model, the *distance range* or maximum allowed travel time is set to 15 minutes (900s), which is the assumed time to reach an ESB during evacuation in Meulaboh City *(see Figure 5.9).*

   The *Relocation Model* optimises or reconfigure a given set of location of ESBs as the result of expansion model, in order to reduce the longest evacuees travel time (here is in *Minimize Worst Case Distance* option). For the day and night scenarios, the expansion models result in best optimum ESB configuration (spatial distribution). When the relocation model is run, the resulting longest travel time exceeds the maximum allowed travel time of 15 minutes. Hence, the *Minimize Worst Case Distance* option cannot be applied. The relocation model is then run in *Maximizing Customer Coverage* option –which results in the same allocation as in previous expansion model– to get the location and capacity information (that is unlimited capacity or tailor-made) of each ESB. This information will be used in the next step of *Catchment Area Analysis*.

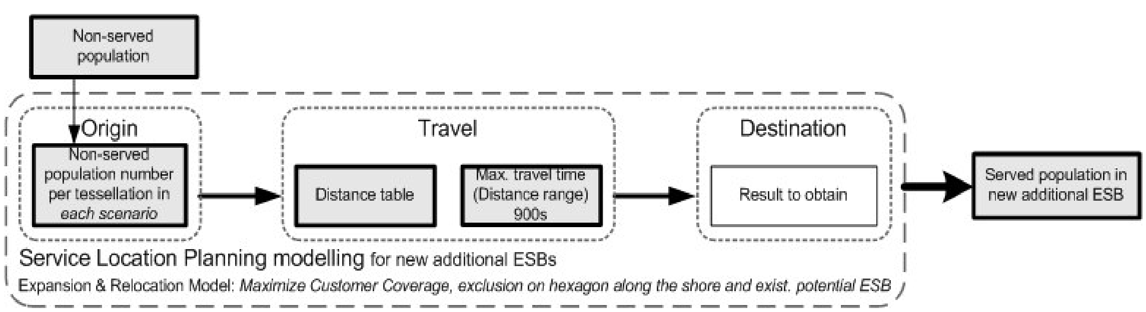


Figure5.16. Expansion and Relocation Model for new additional ESBs

The result of additional ESB allocation in both scenarios is given in the *Figure 5.17.* The study area requires 30 additional ESBs for day scenario and 21 additional ESBs for night scenario, with the longest evacuees travel time of 14 minutes and 55 seconds. The day scenario requires more ESBs than the night scenario because the population number in the day scenario is higher than in the night. It can be explained that during the day, people from out side the study area, such as the city outskirts or other region of Aceh's west coast, come and conduct their activities in the study area (Meulaboh's city centre).

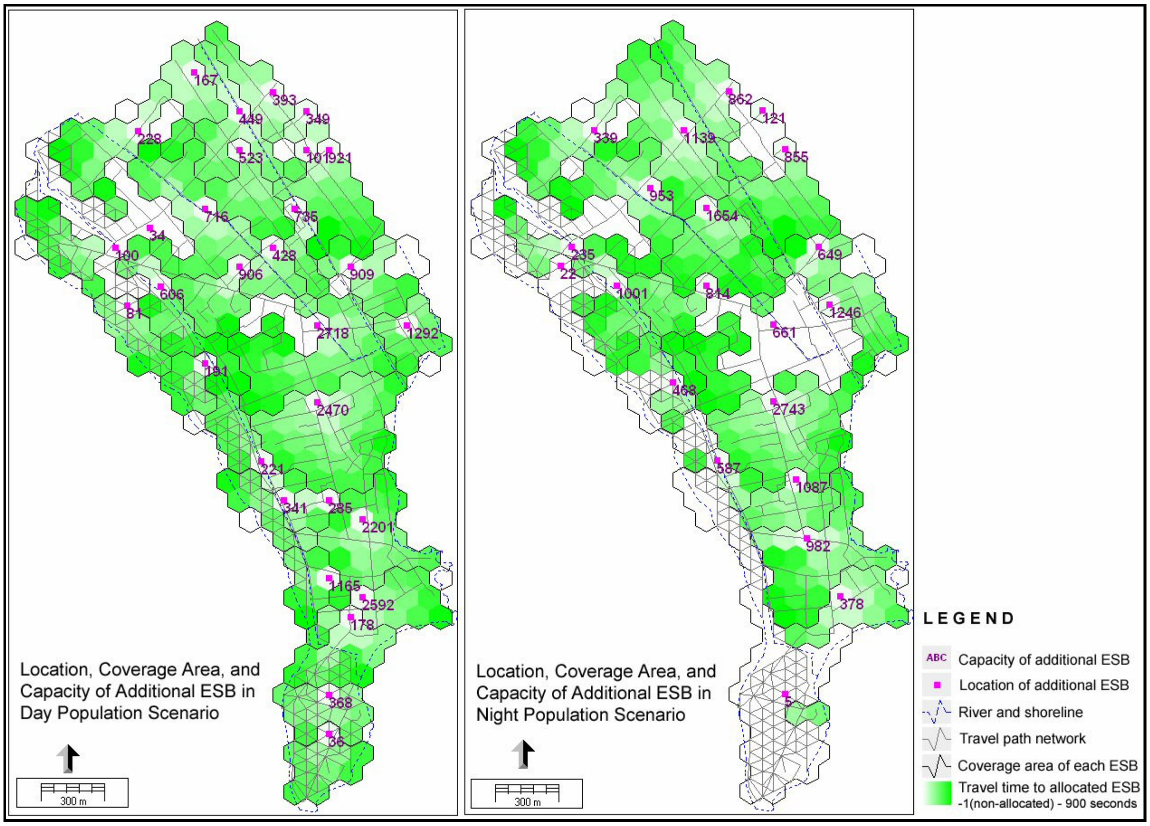


Figure5.17. Allocated additional ESB for day population scenario (left) and night population scenario (right)

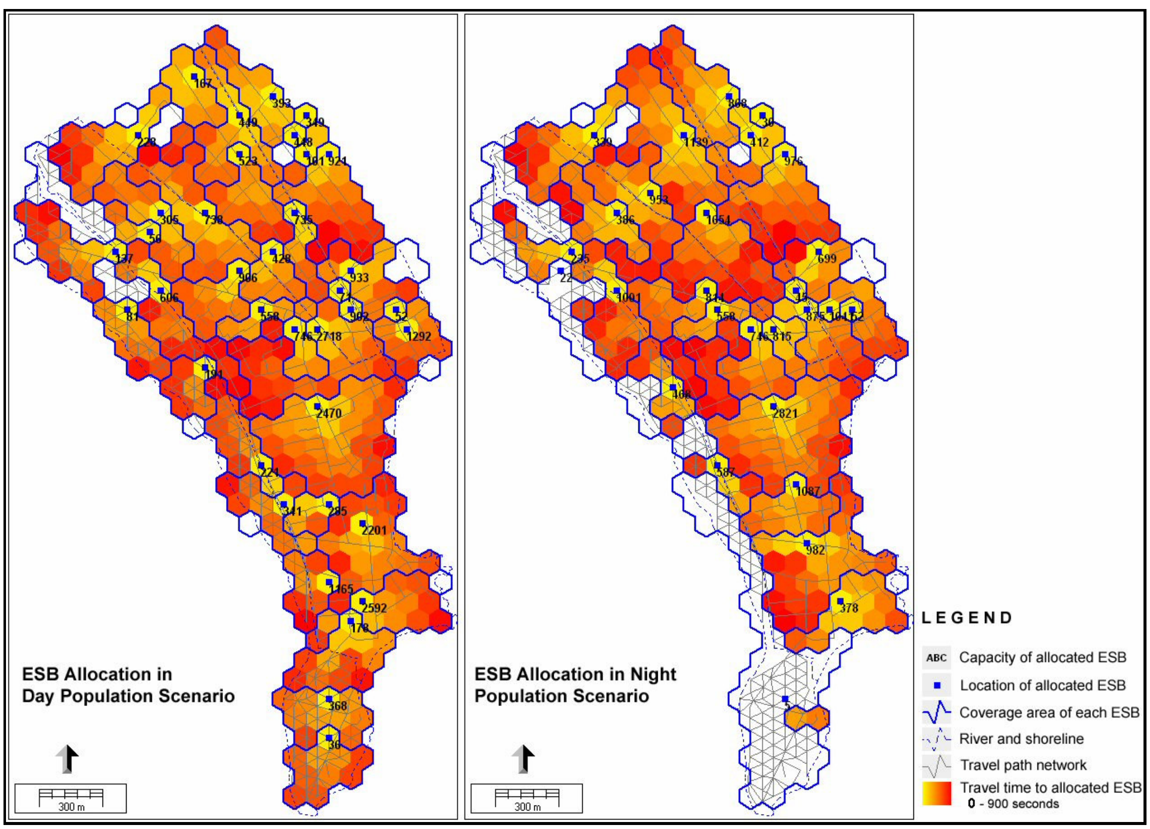


Figure5.18. ESB allocation in day population scenario (left) and night population distribution scenarios (right)

3. *Catchment area analysis* of additional and existing potential ESBs
   To combine or incorporate the existing potential ESBs with the proposed additional ones, *Catchment Area Analysis* is conducted to get the location, coverage area, and capacity of each allocated ESB as well as evacuees' travel time from each hexagon tessellation to its allocated ESB. The result of ESB allocation in day scenario and in night scenario is given in *Figure 5.18.* Evacuees' travel time from each hexagon tessellation to the allocated ESB is presented in a gradual colour spectrum of yellow (minimum) to red (maximum). For both scenarios, the shortest travel time is 56 seconds which is the maximum possible travel time within a hexagon, and the longest one is 14 minutes and 55 seconds. The uncoloured (white) hexagons are non-allocated locations because these hexagons are actually water body of river or sea and/or no population exists in it. Some hexagons are allocated to ESB outside its coverage area like the one in the south part of the study area in the night scenario *(See the right map in Figure 5.18).*

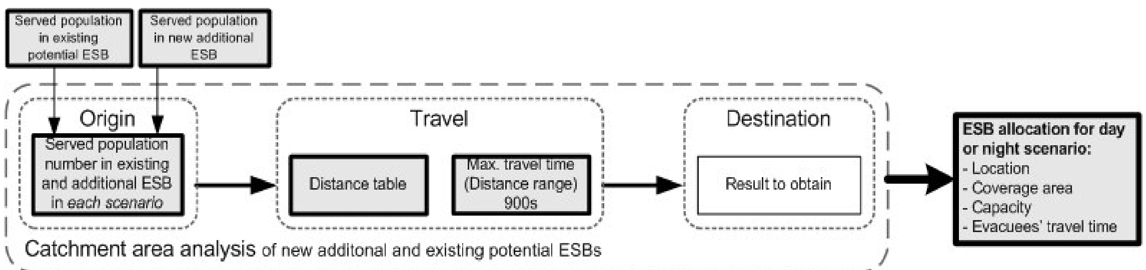


Figure5.19. Catchment Area Analysis for additional and existing potential ESBs

5.4.2. Final ESB allocation

The steps for the final ESB allocation are the same as for the previous day and night scenarios. Explanation of every step carried out has been given in the previous *Subchapter 5.4.1.* The only difference is, that in the final allocation the population number (evacuees) taken into account is the maximum population may exist in a particular location (hexagon tessellation) in either day scenario or night scenario. The day and night scenarios actually reflect the extreme situation where most people are conducting their activities outside the house or staying inside the house. Thus, incorporation of the two scenarios has taken into account the possibility of tsunami occurrence at any time. In addition to the final allocation, the statistics overview of the evacuees' travel time is addressed and the load effect of the travel path (road) network is analysed.

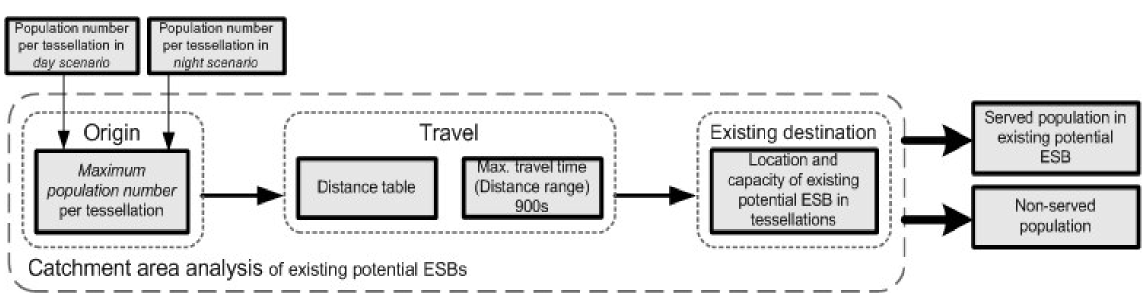


Figure 5.20 Catchment Area Analysis of existing potential ESBs in final allocation

1. *Cathcment Area Analysis* of existing potential ESBs
   The *Catchment Area Analysis* is conducted on performance or coverage area of exiting potential ESBs using the maximum population number *(See Figure 5.20).* The analysis result is presented in the left map *in Figure 5.22.* To accommodate the maximum population number, the existing

potential ESBs can only cover 10% population. The non-served population will be allocated in the new additional ESBs in the next step.

2. *Expansion and Relocation Model* for new additional ESBs

   The modelling aims to find the new additional ESBs to accommodate the non-served population *(See Figure 5.21)*. The location, coverage area, and capacity of additional ESBs and the evacuees' travel time to reach ESB are presented in *Figure 5.22.* The study area requires 26 additional ESBs, with the longest evacuees' travel time of 14 minutes and 54 seconds.

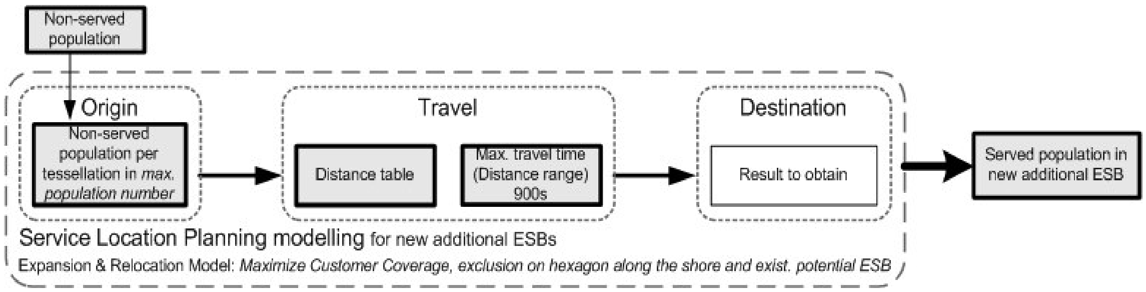


Figure5.21. Expansion and Relocation Model for new additional ESBs in final allocation

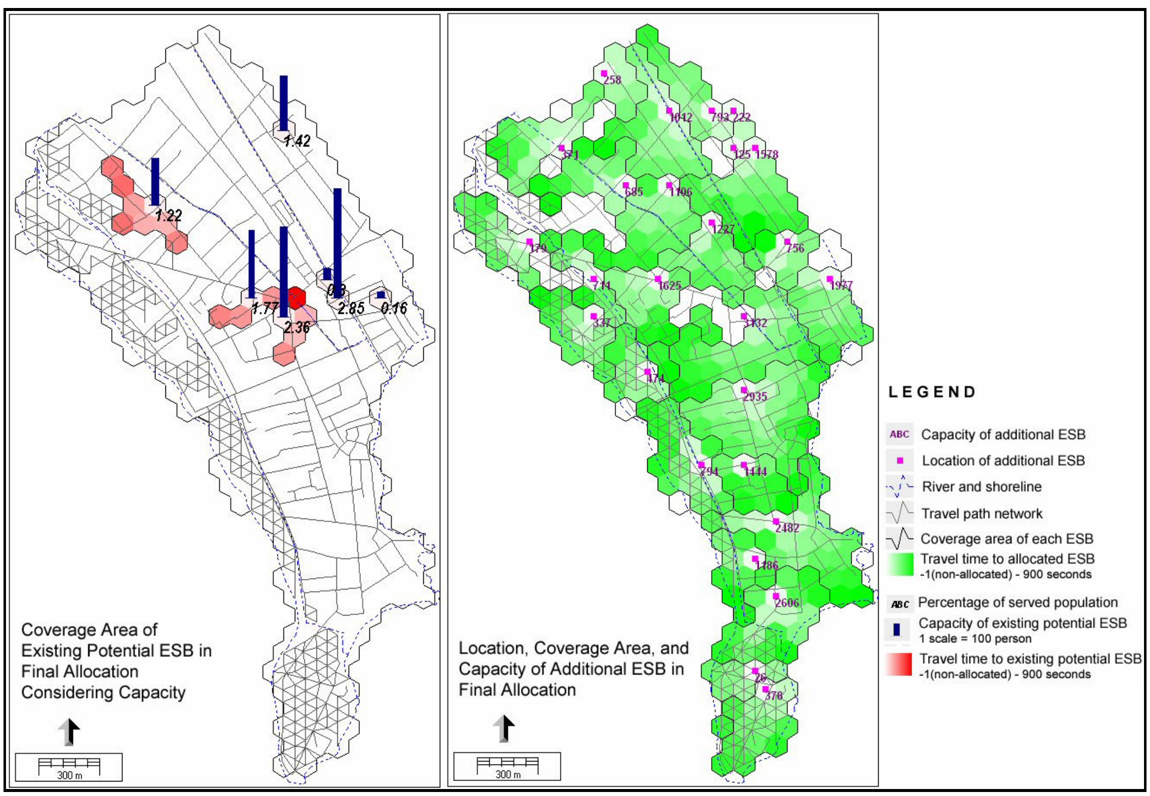


Figure5.22. Coverage area of existing potential ESB (left) and allocated additional ESB (right) in final allocation

3. *Catchment area analysis* of additional and existing potential ESB

   Same with previous allocation, the existing potential ESBs are combined with the proposed additional ones in a *Catchment Area Analysis* is conducted to get the location, coverage area, and capacity of each allocated ESB as well as evacuees' travel time from each hexagon tessellation to its allocated ESB *(See Figure 5.23)*. The Final ESB allocation is presented in the *Figure 5.24.* The figure shows that the study area requires 26 additional ESBs in addition to the 8 existing ones (the 8 existing potential ESBs are represented in 7 hexagon tessellations).

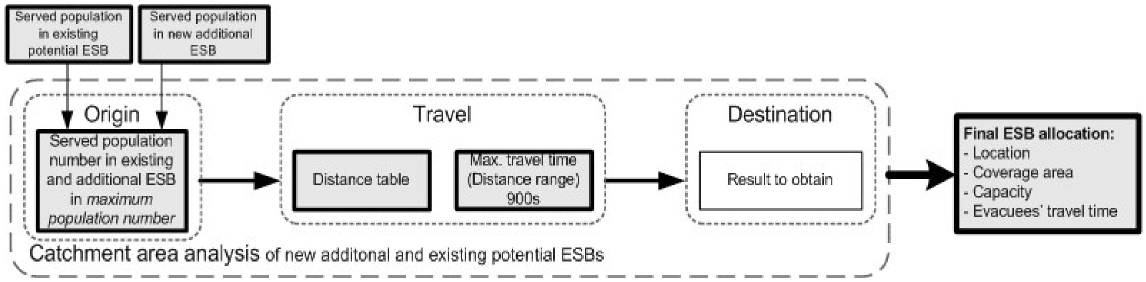


Figure5.23. Cacthment Area Analysis for additional and existing potential ESBs in final allocation

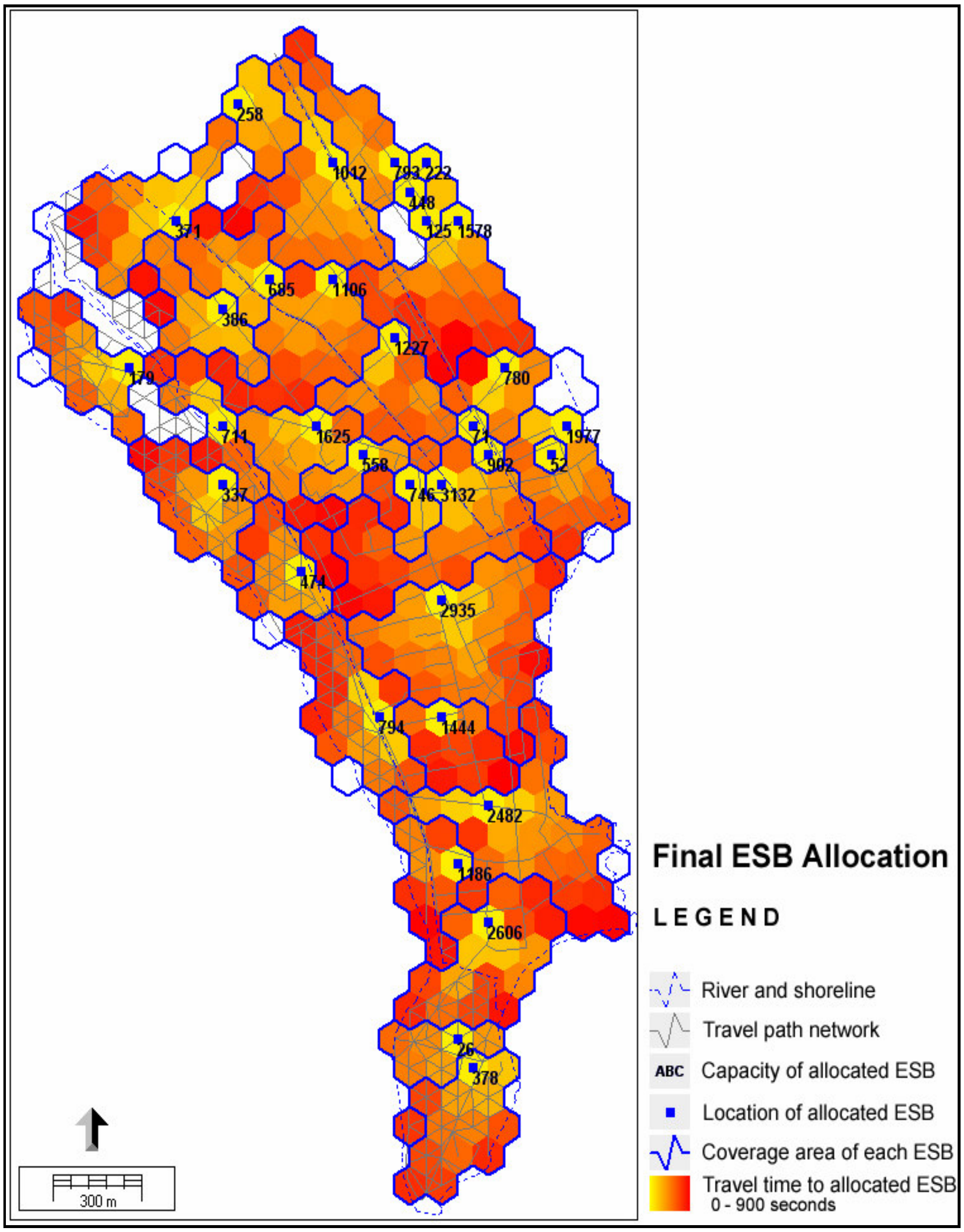


Figure5.24. Final ESB allocation

Evacuees' travel time from each hexagon tessellation to the allocated ESB is presented in a gradual colour spectrum of yellow (minimum) to red (maximum). The shortest travel time is 56 seconds which is the maximum possible travel time within a hexagon, and the longest one is 14 minutes and 54 seconds. As mentioned before, the uncoloured (white) hexagons are the non-allocated locations because these hexagons are actually water body of river or sea and/or no population exists in it.

In the result, there is a concentration of ESBs in the north part of the study area. Despite reflecting the high population number in this area (*Maximizing Customer Coverage* option), it also reflects the accumulation of evacuees from the surrounding area that move northward (to the higher or safe location) and the movements are ended or bounded by the study area boundary. In reality, the evacuees still can move northward to the northern part of the city, such that they may be allocated to other ESB or higher ground in the other part of the city. Incorporating larger study area will result in more comprehensive ESB allocation and take longer time for the analysis and modelling accordingly.

The location-allocation model in Flowmap provides statistics overview related to the evacuees' travel time. *Figure 5.25* shows the distance catchment profile or overview of overall evacuees' travel time in the final ESB allocation.

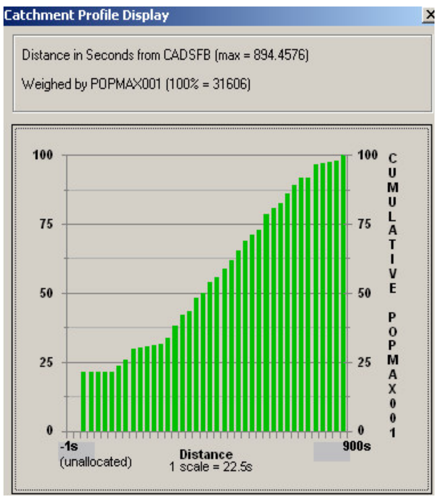


Figure5.25. Overview of evacuees travel time in final ESB allocation

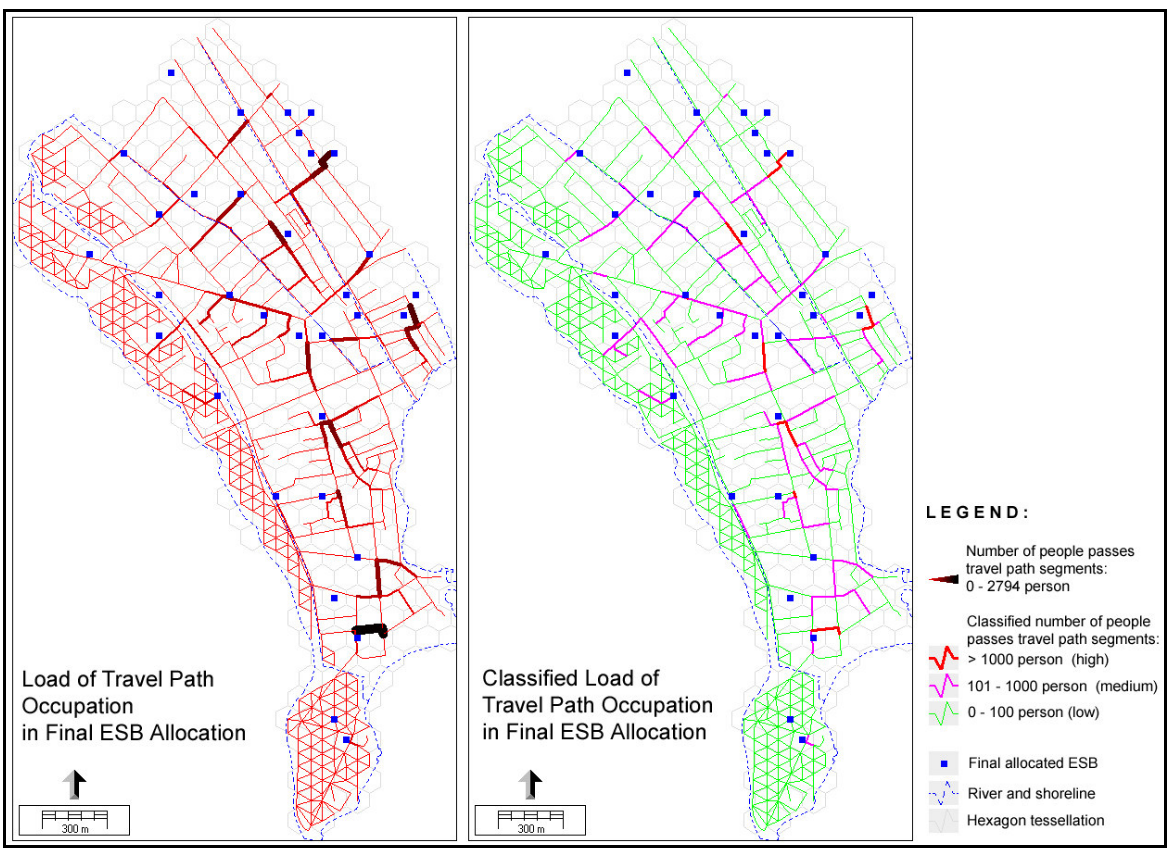


Figure5.26. Travel path load in final ESB allocation

The vertical scale shows the cumulative population number, while the horizontal one shows the travel time in seconds. The unallocated (no-population) tessellations are assigned with the -1 second travel time. The shortest travel time is 56 seconds and the longest one is 894 seconds. This figure can be used to assess the population accessibility to a given set of ESB location. As an example from the statistics overview, it can be concluded that in the final ESB allocation more than 75% evacuees will have to travel for more than 10 minutes to reach the allocated ESBs.

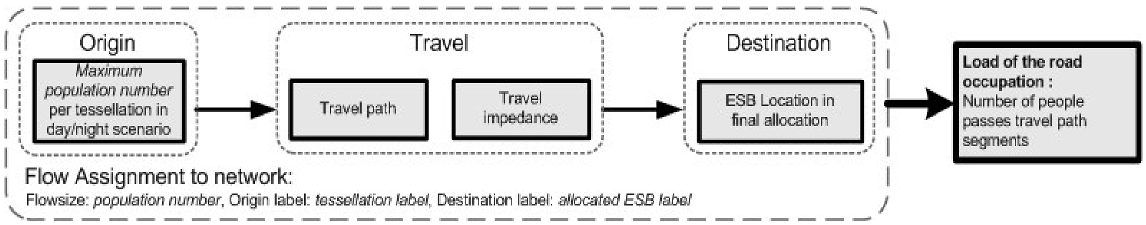


Figure5.27. Flow Assignment to Network in final ESB allocation

Accessibility to an ESB will require sufficient suitable evacuation route (road network or travel path) for the evacuees in order to reach the ESB in time. The travel paths passed by many evacuees in a very short evacuation time would need to be designated as evacuation route. Therefore it is necessary to identify the travel paths with high occupation by identifying the number of evacuees that passes a certain road or travel path segment. This number of evacuees can be called as the load effect of the travel path. It can be obtained from *Flow Assignment to Network* analysis that incorporates the population number per tessellation as *Flow Size*, location or label of all tessellation as *Origin*, location or label of allocated ESB as *Destination*.

Figure 5.26 shows the travel path load in final ESB allocation. The left map shows the number of people passing a certain travel path segment (single component of the whole travel path network) in a gradual thin red (minimum) to thick black (maximum) lines. While on the right map, this number of people is classified into: low (0-100 person), medium (101-1000 person), and high (>1000 person) to give a short impression for a further application of this result. Incorporating this numbers with segment length and width (road class), the traffic density in each segment can de defined. The road or travel path with high traffic density can be considered for the evacuation route designation. In a spatial planning context, evacuation routes should be incorporated within the infrastructure plan for defining the road class and road width. While in an urban management context, an evacuation route relates with the construction quality and maintenance of the road network.

5.5. Conclusion

- Based on population distribution estimation, the total population number in the study area is 24,891 people in the day scenario, 19,988 people in the night scenario, and 31,606 people in maximum population number.
- The considered evacuees' speed during evacuation process is 0.751m/s.
- Based on time allocation within the tsunami travel time for Meulaboh City, the maximum evacuee's travel time to reach ESB is 15 minutes or 900 seconds.
- Based on space estimation using the architectural design space requirement approach, the total evacuation capacity of 8 existing potential ESBs is 3187 people.

- The evacuation capacity of existing potential ESBs can only cover 13%, 16%, and 10% of the total population in day scenario, night scenario, and maximum population respectively.
- In addition to the 8 existing potential ESBs, the study area requires 30 new additional ESBs for the day scenario and 21 new additional ones for the night scenario. In these allocations, the longest travel time is 14 minutes 55 seconds.
- For the final allocation, the study area requires 26 new additional ESBs in addition to the 8 existing potential ones. In this allocation, the longest travel time is 14 minutes 54 seconds.

6. Discussion

This chapter discusses the ESB implementation in tsunami-affected areas and existing limitations and possible improvements of the research.

6.1. Impelementation of ESB function

6.1.1. Inter-related result components

The result of ESB allocation planning comprises three inter-related main components: the number of allocated ESB, the capacity of allocated ESB, and different evacuees travel times. In the same optimum spatial distribution, the more ESB allocated will effect in less capacity of each ESB, and so in reverse. The more ESB allocated will also reduce the evacuees' travel time.

In tsunami evacuation case, the travel time can be considered as a fix parameter. It means that the travel should not exceed maximum allowed evacuation time, which is available time to reach ESB before tsunami wave arrive at the area. Hence, the ESB allocation will be either in many buildings with small capacity or fewer buildings with larger capacity.

6.1.2. ESB construction in the tsunami-affected area

ESB designation or allocation is an iterative process along with the decision making process of spatial planning in the levels of masterplan, strategic plan, siteplan, or building design. An ESB can be built in the form of an evacuation-designated tower building, or multi-function building such as a mosque, school, and office as being discussed before in *Sub-chapter 4.5.2.* In the frame of the reconstruction process of tsunami-affected areas, the designation or assignment of ESB function is inline with the idea of replacing or rebuilding the destroyed public facilities, if the facilities should exist in (not relocated from) the area.

The final ESB allocation *(Figure 5.16)* shows the proposed location of each ESB. The allocated location is a one hectare hexagon, and the ESB can be built in a suitable location within this area. In partially or totally destroyed areas, ESB function can be constructed if land consolidation or land readjustment is applicable. It certainly will deal with serious and crucial land administration issues. For a location which has been densely occupied by buildings and infrastructures, constructing a new ESB as a fill-in development will be very difficult –hardly impossible– to apply unless there is a land readjustment process. In this circumstance, designation of ESB function to existing suitable ESB function, such as mosque or school vertical extension can be an alternative.

The final ESB allocation *(Figure 5.16)* also shows the capacity or number of people each ESB will serve. Some locations accommodate more than 1000 people. Accommodating this huge number of people in a location will be very difficult and may cause a new problem. The capacity can be split into several buildings within or in the surrounding area. Speaking of a tolerable maximum capacity, roughly estimated, the average capacity of existing potential ESB is 400person/building. To accommodate this number of people, it requires 512m^2 upper-floor area of a mosque, or 1333m^2 of a school, or 1739 m^2 of a market building. Again, ESB planning (including its capacity) is an iterative and dynamic process at all level of spatial planning and built environment design. Implementation of ESB may cause vertical growth of the built environment due to the construction of many multi-storey buildings.

The above mentioned capacity problem can be incorporated in the modelling. A certain capacity threshold (maximum number of allocated demand/population) can be assigned in the location-allocation modelling, such that the model outcome will result in more ESB with a smaller capacity. Unfortunately this parameter is not yet developed in the current Flowmap software package.

If ESB function cannot be implemented in an allocated area (hexagon tessellation), the area can be designated as a restricted allocation area in the modelling *(see Sub-chapter 5.3.3).* The location-allocation can be re-run until it meets the possible optimised ESB location(s). The method of ESB location planning developed in this research can be repeated as an iterative process. It can incorporate changes, adjustment, or revision of the result. This will support the process of decision making involving many stakeholders.

6.1.3. Public awareness and education of the hazard

Implementing ESB function will cost significantly in building construction and maintenance. Careless calculations in ESB multi-function facility planning may result in inefficient occupancy of land and buildings. In disaster mitigation efforts, public awareness and education on the hazard is not less important. A sustainable programme of public awareness raising and education on tsunami, earthquake, and other hazard are strongly required to prepare the community to deal with the hazard. Under limited evacuation facilities and infrastructures, a well-educated community may still be able to identify and respond properly to the hazard signs and strike.

6.2. Tsunami hazard and ground elevation

The ESB location planning as developed in research can also be used for the mitigation of similar disasters as the December 26 Aceh tsunami. Different tsunami source locations will imply a different tsunami travel time and different evacuation time subsequently *(See Figure 5.9)*. The longer the evacuation time, the less allocated ESB will be needed and vice versa.

Reliable tsunami run-up data –either from modelling or aftermath observations– and detailed ground elevation data will refine the identification of existing potential ESB, particularly in defining the safe evacuation floor level which should be higher than the (expected) wave height. There is no such data available for this research. The available ground elevation data was the topographic map in 1:50,000 scale and contour interval of 15m, while all the study area is located within below 15meters elevation above sea level. Digital Elevation Model (DEM) creation from the Aster image had been conducted. It resulted in an unreliable ground elevation due to existence of clouds in the image (in the resulted DEM, the area turned to be mountainous area). Hence, the identification of wave height and inundation level is based on the inundation map of HIC Sumatra and local inhabitants' interviews.

In this research, it is assumed that the evacuation process starts at the same time in the whole area. In reality, the tsunami wave may arrive later at locations at some distance from the shore, and therefore more (longer) evacuation time is available for that location. Tsunami run-up modelling can estimate the wave arrival time in a particular area and will refine the time parameter for different areas.

6.3. Modelling improvement

The accuracy of the results from the location-allocation modelling relies on the details of the input data of tessellation size, population number, travel path network, and restricted allocation area. These data can be obtained from the detailed spatial plan. Related to this research, there are no data available for Meulaboh City.

A smaller tessellation size supported by more detailed population data (e.g. population number of building block or neighbourhood, occupants' number of facility) will result in a better population distribution to take into account in the modelling. Population estimation through the estimation of facilities occupants' number can be improved by surveying and/or interviewing the facilities owner or occupants. It can be better done in the normal situation where activities in the facilities run normally (not in after disaster situation).

In line with a decrease in tessellation size, a more detailed/complete travel path network (in foot path and passable path of open field or yard) will refine the modelling, since the travel will proceed from tessellation centroid to the closest network. Yet, this information is difficult to acquire in disaster-affected or destroyed areas where relocation, land readjustment, or land consolidation may occur.

Along with allocation restrictions in a particular area such as the presence of a water body, hazardous material site, a high risk industrial area, where ESB cannot be allocated, information on this area can be incorporated in the modelling to find the best possible allocated location(s).

7. Conclusion and Recommendation

This chapter concludes the thesis research by reflecting on the achievements referring back to the research objectives and research questions. Recommendations are also presented for relevant further research, for Meulaboh's city reconstruction, and the development of Flowmap software.

7.1. Conclusion

Generally, the thesis research can satisfy the research objectives and answer the research questions addressed in *Chapter 1.* The research aims to develop a methodology to plan the ESBs in a tsunami-prone area. Since an ESB is a destination for the vertical evacuation, the justification of vertical evacuation necessity applied in a certain are is firstly observed by reviewing the existing tsunami evacuation methods. Related to the study area of Meulaboh City, the characteristics of the December 26 tsunami-survived buildings is observed and analysed. The results are incorporated in defining the ESB requirements as an addition to the existing relevant knowledge in literatures. Finally, the accessibility analysis and location-allocation model are introduced and applied to find the optimised spatial distribution of ESB allocation. The planning process requires an estimation of population distribution, identification of the road network, identification of existing potential ESB, and identification of restricted allocation areas as a preparation work before the allocation modelling.

In relation to each research objective, the research can be concluded as follows:

1. *Tsunami evacuation methods*
   There are two tsunami evacuation methods available: horizontal and vertical evacuation. The first method evacuates people from the hazard area to the safe places in a distant locations or higher ground, while the second evacuates people to the upper floors of the robust multi-storey buildings located around them. Each method relates to certain tsunami hazard characteristics and required facilities and infrastructures. In coastal areas, where reachable safe higher ground is not available, where building and population densities are high, where roads, bridges, and transportation modes are limited, or where available evacuation time is insufficient, vertical evacuation is an alternative or supplement to the more common approach of horizontal evacuation. Based on these, the study area requires vertical evacuation.

2. *Characteristics of the tsunami-survived buildings after the December 26 tsunami*
   Based on the building survey, the characteristics of tsunami-survived buildings include the following:
   - Located (mostly) at a distance of more than 200m from the shoreline
   - Building mass orientation is inline with tsunami waves direction
   - Possess large percentage of openings (window, door, opening arch, etc.), corridor, and terraces at the building façade

- Fulfil structural basic requirements of horizontal and vertical load distribution
- Good construction quality

3. *ESB requirements*

   To function as an ESB, a building should possess the following characteristics:
   - Earthquake and tsunami-resistant structure
   - Evacuation floor should not be reached by the tsunami waves
   - Multi-function building with public service oriented function
   - Provide adequate reserve space to accommodate additional occupants (evacuees)
   - Easily accessed by the population in the hazard area
   - Provide adequate stairs and/or ramps to evacuate people to the upper floor
   - Possess a security mechanism embedded in the building management

   The elevation of evacuation floor can be defined from the marks of previous tsunami's wave height and inundation level or from local inhabitants' interview. Multi-function building strategy is applied to optimise the land and building occupation. The space requirement to accommodate evacuees is $1m^2$/person.

4. *ESB planning methodology*

   To plan the ESB location(s) in a tsunami-prone area, the following activities should be carried out:
   a. Identification of the area that require vertical evacuation
   b. Estimation of population distribution that needs evacuation
   c. Identification of evacuation travel path (road network, foot path)
   d. Identification of existing potential ESB and restricted allocation areas
   e. Running a location-allocation modelling that simulates the people's accessibility in evacuation process

   The first step (a) is required to justify firstly whether a vertical evacuation strategy is needed in the study area. The second, third, and forth one (b, c, d) can be carried out simultaneously after the first step is finished. The last step is the final one that requires the three previous steps (b, c, d) as the input data.

Additional findings in the research are:
- In disaster-affected areas, the approach of architectural design space requirement can be used to estimate in detail the population distribution based on high-resolution satellite images, supported by field observations. This method can be easily conducted in the normal situation (not after disaster in the destroyed area) as a disaster preparedness effort in a tsunami-prone area.
- A location-allocation model also can be used for tsunami evacuation facilities and infrastructures planning despite the more common use for commercial and public facility planning.
- At this moment, facility (ESB) planning analysis that incorporates accessibility analysis cannot be conducted at the common GIS package (e.g. ArcView/GIS) because there is no specific flow data application available (yet). In this research, it is carried out in combination with the *Flowmap* software package that is dedicated to analysing and displaying interaction of flow data.

The reference of achievements obtained in answering the research questions is presented in *Table 7.1*.

Table 7.1Cross-checking the achievement of research objectives and research questions

No	Research Questions	Reference
1.	**Research Objective:** To review existing methods of tsunami evacuation	
	Based on literatures, how is evacuation of people before tsunami exposure?	Sub-chapter 2.3 and 2.4
	Based on literatures, which area would need vertical evacuation?	Sub-chapter 1.5, 2.3, and 2.4
	What are the characteristics of evacuation shelter building (ESB)?	Sub-chapter 2.5
	What is the response or evacuation time to be assumed?	Sub-chapter 2.1 and 5.2
2.	**Research Objective:** To identify the location and design characteristics of tsunami-survived buildings after the December 26 tsunami	
	Which type of buildings in the study area could resist the December 26 tsunami?	Sub-chapter 4.5
	What factors did influence the building resistance against the December 26 tsunami?	Sub-chapter 4.5
3.	**Research Objective:** To identify the design characteristics of a building such that can function as ESB based on literatures and field observation	
	What are the already-known design requirements for ESB?	Sub-chapter 2.5
	What are the alternative functions for ESB based on literatures and field observation?	Sub-chapter 2.5 and 4.5
	Which building that resisted the December 26 tsunami can be functioned as ESB?	Sub-chapter 4.5 and 4.5
4.	**Research Objective:** To develop a methodology of ESB location planning using geo-information system (GIS) and accessibility analysis for tsunami evacuation	
	How many people need to be evacuated and how is their spatial distribution in the study area?	Sub-chapter 5.1
	How do people travel to reach the ESB?	Sub-chapter 2.3.2, 4.5.4 and 5.2
	How many and how big are the ESBs needed for the study area?	Sub-chapter 5.3, 5.4, and 5.5 *See Figure 5.24* and *Subchapter 5.5 Conclusion*
	How to locate the ESBs in the study area and how to optimize their spatial distribution?	Sub-chapter 5.4

7.2. Recommendation

7.2.1. Possible further research

The designation of an existing or planned building as an ESB is strongly related with financial aspects since the building should provide sufficient adjustable space for evacuation functions, more stairs and ramps, and apply higher (stronger) building structure requirement. It will result in a larger building construction and higher maintenance cost. Therefore multi-function building assignments, tax compensation, and specific building regulation will be needed. Identification and exploration of financial feasibility and supporting policy on ESB implementation can be a challenge for further research.

In risk assessment and management, the presence of ESB function will become a coping mechanism that reduces people's vulnerability. The dynamic and complex relationship among these components of risk, such as how far can an ESB construction reduce the vulnerability, is also an interesting topic to research.

7.2.2. Recommendation for Meulaboh City

For Meulaboh City, as well as for other tsunami-prone areas, the developed methodology can be used as a tool to plan or allocate ESBs or escape buildings and evacuation routes. For the implementation in the whole city area, different evacuation facilities, different disaster magnitudes, and various development restrictions in the area should be taken into consideration.

For the reconstruction process of Meulaboh City, the results of the research show optimal proposed locations for ESBs or escape buildings, including existing tsunami-survived buildings to cope with the similar tsunami of December 26. At these locations, public facilities such as mosques, schools, government offices, can be rebuilt. Newly-planned facilities such as a museum or public hall at tsunami historical park and an escape tower in the public park of the buffer zone can also be built as long as the function is suitable for and can accommodate ESB function.

ESB location planning can be incorporated in the levels of city masterplan *(Rencana Detil Tata Ruang Kota –RDTRK)*, built environment plan and urban design *(Rencana Tata Bangunan dan Lingkungan – RTBL)*, and the siteplan of smaller estate area such as ferry port siteplan and village planning.

In the city masterplan level, ESB location planning can be carried out before (as a consideration/factor) and after (as a review and refinement) the land use and function designation. Road class planning should consider the access to the ESBs. An evacuation route to the ESB can be allocated to a certain road with a restriction for the vehicles. Additional road access may be required to serve the surrounding area. A signage system planning should follow the ESB and road planning. As mentioned before, land consolidation or land readjustment may be necessary.

In the lower level planning, ESB planning concerns on the access or entrance to an ESB site that should be located in a strategic position and easily oriented with a certain landmark such as gate, small tower, or flag pole. Certain colours or symbols can be applied to mark the ESB and access to ESB in the forms of flag, gate and fence colour or specific colour for the building wall and roof.

In relation to building design, ESB requirements should be incorporated in building regulation (such as building code and *Terms of Reference* of the building design) for public service facilities planning and design. The regulation should also include the supervision (by relevant government agencies or professional associations) of requirements implementation in the construction process.

The existence of a buffer zone (coastal forest or vegetated area) has proven to protect the inland area from a tsunami. On the long run, the designation of a buffer zone along the coast should be kept and supported with strict regulation enforcement, although this may cause settlement relocation. Designation of the buffer zone’s range (from the shore) and type should consider existing coastal functions, geographic features, ecological characteristics, and settlements.

7.2.3. Recommendation on the Flowmap software

After having used the Flowmap software, the following recommendations are given for further development and refinement.

- In the *Service Location Planning (SLP)* feature, the capacity of allocated service provider is set unlimited and considered to be tailor-made. For some planned objects (school, hospital, ESB) capacity constraint is an important issue and needs to be incorporated in the planning process. Hence, it is necessary to incorporate the capacity constraint of the allocated facility as a parameter in the SLP modelling.
- Despite existing file conversion, the conversion of the analysis result, particularly the boundary of the coverage or catchment area, needs to be provided for further analysis in the mainstream GIS package such as ArcView/GIS.
- More complete and advanced display menu such as hatch type, line typology and colour, and exchangeable overlaid layer order will make the software more powerful not just for analysis of the flow data but also in the presentation.

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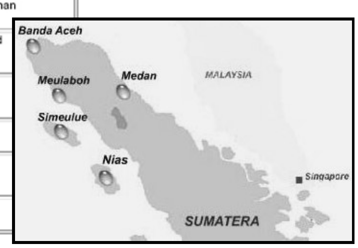
Appendices

Appendix 1

The list of measured parameters by the Turkish-Indonesian-USA Team during the field survey on Sumatra on January 21-29, 2005 (Yalciner et al., 2005).

No.	Survey point	Latitude	Longtitude	Survey Date	Max. Flow depth	Inund. Dist.	Arrival Time of Tsunami (min after the earthq.	Max. positive tsunami amplitude near the shore	Notes
1	Simeulue Ganting	02°32.935N	96°20.083E	Jan 22, 05	1.5 m	1.5km along creek	~ 30min	1.75m	bridge damaged
2	Simeulue Ganting	02°33.022N	96°19.797E	Jan 22, 05	2 m	2km along creek	~ 30min	3m	Boat dragged 250m away from shore
3		02⁰ 33.484N	96⁰18.452 E	Jan 22, 05	2.5 m	2km	~ 30min	>4m	sea receeded upto 2km horizontally 10min. after earthq. and advanced 15min later
4	Simeulue Tsunami end point	02°34.517N	96°16.122E	Jan 23, 05	0.3 m	10m	~ 30min	<0.30m	IMPORTANT north of this point no significant wave action, sea water is very clear
5	Simeulue Tanjun Raya	02°33.892N	96°17.262E	Jan 23, 05			~ 30min	1.9m	
6	Simeulue Senebu village	02°33.430N	96°18.057E	Jan 23, 05	2 m	1.5 km	~ 30min	2m	2hr. after eq. sea receeded and advanced
7	Simeulue Near Senebu	02°20.630N	96°28.098E	Jan 23, 05	2 m	1ç5 km	~ 30min	2.5m	Sea receded first after 4hr from eq @ 12:00 o.clock
8	Simeulue Near Senebu village	02°23.156N	96°29.322E	Jan 23, 05	3 m	1.5 km	~ 30min		damaged walls, undamaged piers of mosque
9	Simeulue Labuhan Bakti	02°24.404N	96°29.000E	Jan 24, 05	3 m	1.5km	~ 30min	4m	hardest hit, southeast point of Simeulue
10	Simeulue Labuhan Bakti	02°24.459N	96°28.892E	Jan 24, 05	2 m	1.5km	~ 30min		
11	Simeulue Labuhan Bakti	02°24.265N	96°28.890E	Jan 24, 05	2 m	1.5km	~ 30min	2.5m	photo, inside government building , notes
12	Simeulue Labuhan Bakti	02°24.192N	96°28.854E	Jan 24, 05	2 m	1.5km	~ 30min		damaged cottage of old woman, photo
13	Simeulue near Labuhan Bakti	02°24.107N		Jan 24, 05	2 m	1.5km	~ 30min	2.5m	destroyed jetty, photo, subsidence proof
14	Simeulue Near Labuhan Bakti			Jan 24, 05		1.5km	~ 30min	2.5m	800m west of point 9
15	Simeulue Laubang	02°25.942N	96°15.626E	Jan 23, 05		500m	~ 30min	1.5m	
16	Simeulue Lantik or Tembah Barat	02°25.947N	96°15.624E	Jan 23, 05		500m	~ 30min	1.5m	
17	Simeulue Salur	02°26.528N	96°14.561E	Jan 23, 05		500m	~ 30min	1.5m	
18	Simeulue Busung	02°23.589N	96°20.204E	Jan 23, 05		500m	~ 30min	1.5m	
16	Meulaboh Suaktimah village	04°12.638N	96°03.884E	Jan 27, 05			~ 40min	>15m	village completely destroyed
17	Meulaboh Skoneda	04°12.552N	96°02.379E	Jan 2, 05			~ 40min	>15m	
18	Meulaboh Skoneda	04°12.501N	96°02.389E	Jan 27, 05		~5 km	~ 40min	>15m	shoreline
19	Meulaboh Kuala Buban Bay	04°12.455N	96°02.346E	Jan 27, 05		~5 km	~ 40min	>10m	
20	Meulaboh Kuala Tadu	03°57.930N	96°18.576E	Jan 28, 05		~5 km	~ 40min	>15m	
21	Meulaboh Port	04°07.740N	96°07.738E	Jan 28, 05		~5 km	~ 40min	>15m	harbour washed out and compltely destroyed
22	St 176, WPT17	04°12.525N	96°02.214E	Jan 27, 05			~ 40min	>15m	collapsed bridge at the north of Meulaboh near Palm oil Tank (near shoreline)
23	Meulaboh near Aronghan	04°18.504N	95°58.326E	Jan 27-28, 05		~5 km			inundation limit at land
24	Meulaboh Aronghan	04°17.797N	95°56.879E	Jan 27-28, 05		~5 km	~ 40min	15m	Shoreline near Aronghan
25	Meulaboh Aronghan	04°17.796N	95°56.831E	Jan 27-28, 05		~5 km	~ 40min	15m	Shoreline near Aronghan
26	Meulaboh near Aronghan	04°18.010N	95°59.235E	Jan 27-28, 05		~5 km		9m	inundation limit at land
27	Medan East Pentai Cermin			Jan. 21, 05		500m	~ 4 hr	1.7m	
28	Medan East Kuala Ruteri			Jan. 21, 05			~ 4 hr		
29	Medan East Belawan Port	03°47.059N	98°42.921E	Jan. 21, 05			~ 4 hr		
30	Medan East Ferry Port	03°47.235N	98°42.297E				~ 4 hr		

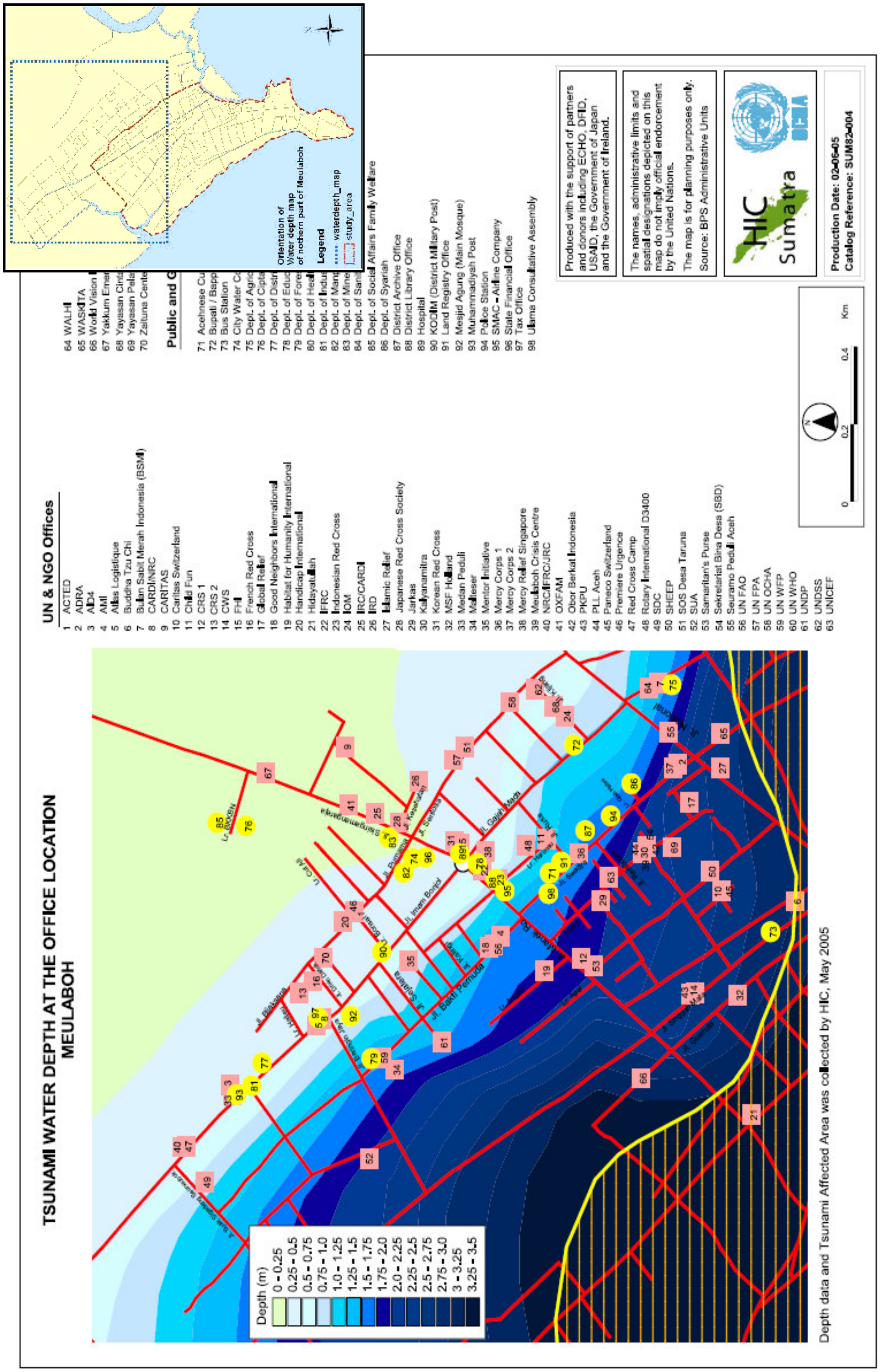
Note: The water level data are before tidal correction



Survey locations

Appendix 2

Tsunami water depth inundation in the north part of Meulaboh City (HICSumatra, 2005a)



Appendix 3

Tsunami effects and its design solution (Eisner and NTHMP, 2001b)

Phenomenon	Effect	Design Solution
Inundation	• Flooded basements • Flooding of lower floors • Fouling of mechanical, electrical, and communication systems and equipment • Damage to building materials, furnishings, and contents (supplies, inventories, personal property) • Contamination of affected area with waterborne pollutants	• Choose sites at higher elevations • Raise the building above the flood elevation • Do not store or install vital material and equipment on floors or basements lying below tsunami inundation levels • Protect hazardous material storage facilities that must remain in tsunami hazard areas • Locate mechanical systems and equipment at higher locations in the building • Use concrete and steel for portions of the building subject to inundation • Evaluate bearing capacity of soil in a saturated condition
	• Hydrostatic forces (pressure on walls caused by variations in water depth on opposite sides)	• Elevate buildings above flood level • Anchor buildings to foundations • Provide adequate openings to allow water to reach equal heights inside and outside of buildings • Design for static water pressure on walls
	• Buoyancy (flotation or uplift forces caused by buoyancy)	• Elevate buildings • Anchor buildings to foundations
	• Saturation of soil causing slope instability and/or loss of bearing capacity	• Evaluate bearing capacity and shear strength of soils that support building foundations and embankment slopes under conditions of saturation • Avoid slopes or provide setback from slopes that may be destabilized when inundated
Currents	• Hydrodynamic forces (pushing forces caused by the leading edge of the wave on the building and the drag caused by flow around the building and overturning forces that result)	• Elevate buildings • Design for dynamic water forces on walls and building elements • Anchor building to foundations
	• Debris impact	• Elevate buildings • Design for impact loads
	• Scour	• Use deep piles or piers • Protect against scour around foundations
Wave break and bore	• Hydrodynamic forces	• Design for breaking wave forces
	• Debris impact	• Elevate buildings • Design for impact loads
	• Scour	• Design for scour and erosion of the soil around foundations and piles
Drawdown	• Embankment instability	• Design waterfront walls and bulkheads to resist saturated soils without water in front • Provide adequate drainage
	• Scour	• Design for scour and erosion of the soil around foundations and piles
Fire	• Waterborne flammable materials and ignition sources in buildings	• Use fire-resistant materials • Locate flammable material storage outside of high-hazard areas

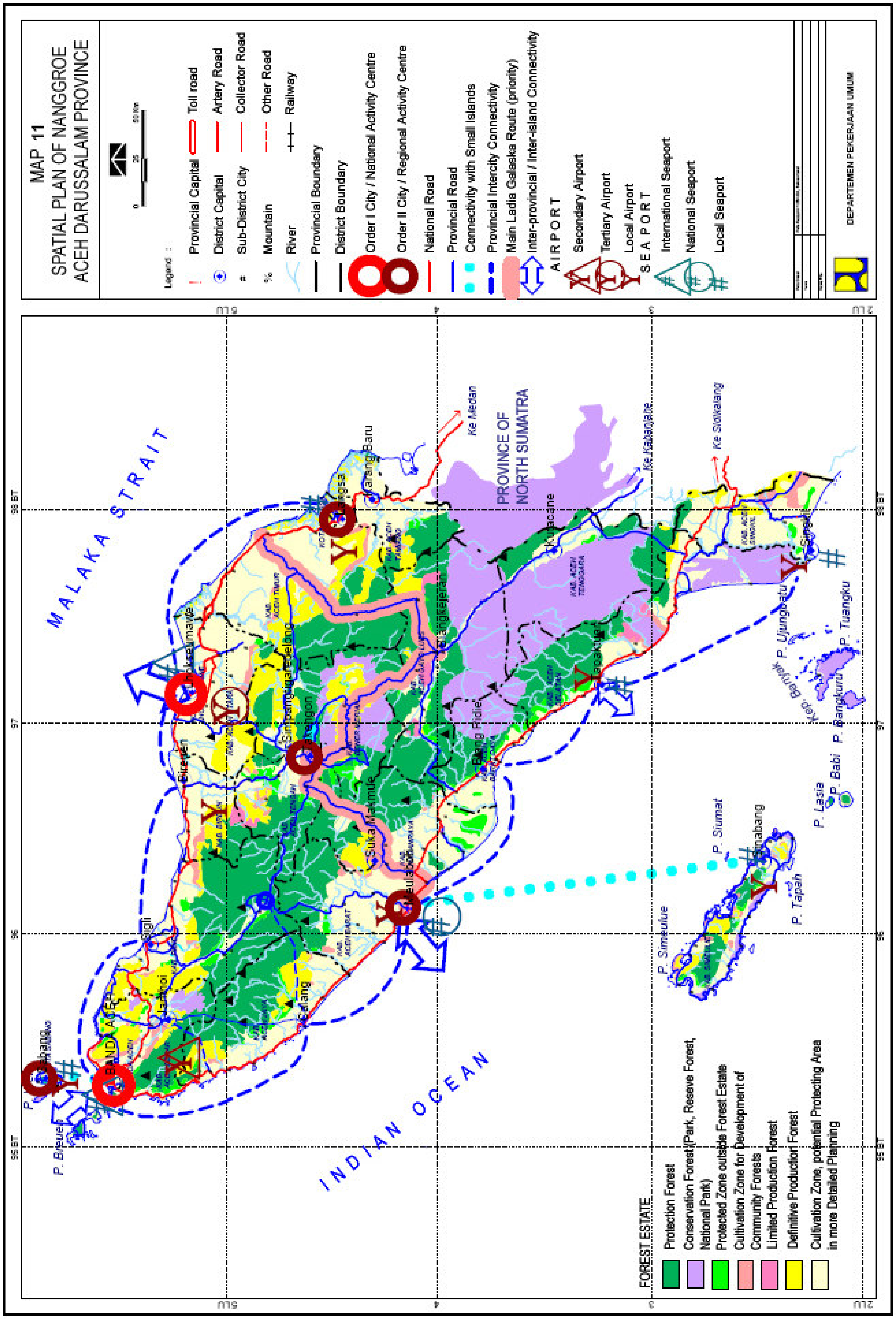
Appendix 4

Description of population and geographic situation in Johan Pahlawan Sub-district – Meulaboh, compiled from (field observation; (BPS, 2005a; BPS, 2005b; HICSumatra, 2005b)

No	Village	Geography	Topo-graphy	Area (ha)	Estimated Physical Damage (%)	Population 2000	Population 2003	Population April 2005	Household April 2005	Density (pop'03/ha)	Pop/hh April 2005
1	Suak Indrapuri	Coastal Area	Flat	61.30	100	3,506	3,534	2,356	762	38.44	3.09
2	Kampung Belakang	Plain	Flat	28.90	80	2,135	3,725	3,494	785	120.91	4.45
3	Ujung Kalak	Coastal and Plain	Flat	61.05	60	6,428	7,251	6,990	1,571	114.50	4.45
4	Kuta Padang	Plain, partially watershed	Flat	181.05	40	4,637	6,762	6,514	1,235	35.98	5.27
5	Rundeng	Plain, partially watershed	Flat	91.82	30	4,043	4,790	4,630	1,035	50.42	4.47
6	Drien Rampak	Plain	Flat	-	0	6,060	6,737	6,685	1,417	-	4.72
7	Ujung Baroh	Plain, partially watershed	Flat	62.96	30	7,104	6,938	8,935	1,851	141.94	4.83
8	Kampung Pasir	Coastal Area	Flat	10.98	100	1,365	1,439	896	312	81.57	2.87
9	Pasar Aceh	Coastal Area	Flat	4.93	50	179	354	323	75	65.55	4.31
10	Panggong	Plain, partially watershed	Flat	29.29	80	2,014	2,116	1,793	434	61.21	4.13
11	Padang Seurahet	Coastal Area	Flat	62.30	100	3,877	4,031	3,468	833	55.66	4.16
12	Gampong Darat	Plain and Watershed	Flat	-	20	490	621	615	148	-	4.16
13	Seneubok	Plain	Flat	-	20	3,730	3,291	3,245	552	-	5.88
14	Gampa	Plain	Flat	-	0	1,416	1,409	2,443	559	-	4.37
15	Lapang	Plain	Flat	-	0	2,982	2,912	3,255	1,225	-	2.66
16	Leuhan	Plain	Flat	-	0	892	1,057	1,452	347	-	4.18
17	Blang Beurandang	Plain, partially watershed	Flat	-	0	858	1,164	1,162	285	-	4.08
18	Suak Ribee	Coastal Area, Watershed	Flat	293.05	90	2,862	3,175	2,732	611	9.32	4.13
19	Suak Raya	Coastal Area, Watershed	Flat	-	100	784	1,053	686	259	-	2.65
20	Suak Nie	Coastal Area	Flat	-	100	237	262	123	46	-	2.67
21	Suak Sigadeng	Plain	Flat	-	100	-	516	360	113	-	3.19
						Total	**63,137**	**62,157**	**14,505**		

Appendix 5

Directives on Aceh's Provincial Spatial Structure. *Translated from* (Bappenas, 2005).



Appendix 6
Interview guide and questions

D2b-1.1, D2b-4.2, & D3-1.1 – Experts Interview

Objective:
- To get overview of tsunami vertical evacuation policy/strategy in Indonesia
- To explore the understanding and concept of vertical evacuation and escape building
- To explore the implementation of vertical evacuation in Aceh's context

Interviewee:
- Dr. Krishna S. Pribadi, Disaster Mitigation Research Group ITB Bandung
- Dr. Sudibyakto, Prof. Soetikno, PSBA UGM Yogyakarta

Topic: Disaster mitigation in vertical evacuation

Questions:

Policy for vertical evacuation
- Are there any national policy/guidelines for tsunami vertical evacuation?
- (If not), what existing policy/guidelines are relevant to tsunami vertical evacuation?

Vertical evacuation in Aceh
- Masterplan of Aceh's rehabilitation and reconstruction (Bappenas) has mentioned some general principles of vertical evacuation in tsunami mitigation. Which aspects do you emphasize in the workshop (ADPC, UNDRP) you have been doing? And why are they so important?
- Are there any norms/standard for vertical evacuation (scenario/plan, mode of transport, average speed, etc.)?
- Regarding the local knowledge and development of public awareness in Aceh (and particularly in tsunami-prone urban area), how can vertical evacuation be implemented successfully?

ESB
- What are the characteristics & requirements of ESB/escape buildings?
- What should be done to apply ESB concepts/standards (building regulation, building (&site) planning&design, construction phase)?

D3-2.2, D3-3.2, D3-3.3 – Experts Interview and/or group discussion

Objective:
- To get the ideas and concepts of spatial planning of Meulaboh
- To understand the methodology used in analysis and assumption of the population number and growth in the study area
- To understand the methodology used in defining the hazard zone and road network
- To identify the location of potential area/building for ESB in spatial plan

Interviewee/participants:

Working group for spatial planning of Meulaboh project (multi-discipline experts), Research Center for Disasters, Gadjah Mada University (PSBA UGM) Yogyakarta

Topic:
- Concepts and analysis of spatial planning for Meulaboh's reconstruction
- Identification of potential area/building for ESB in spatial plan

Technique:
- First introduction of myself and explanation of the purpose of discussion
- Brief explanation of thesis research, emphasized on ESB planning in spatial planning of Meulaboh
- Open discussion under certain guidance

Questions/discussion guideline:

Concepts
- What are the (basic) concepts of Meulaboh's spatial planning (RTRW&RTRK)? And how are they being implemented?
- Are there any specific considerations of disaster magnitudes and disaster mitigation in Meulaboh's spatial planning?

Analysis (land use, population, hazard zone, road network)
- What method/analysis do you do to allocate the land use related to the high-risk areas and dynamic situation of resettlement?
- Do you incorporate hazard zone& wave direction in the spatial analysis for allocating land use?
- How do you assume the population number of returned survivor to be accommodated in spatial planning?
- Do you have such data (number, map) for *desa/gampong* level?
- There is a statistic number of population growth of *Kabupaten Aceh Barat* (Meulaboh's regency) in 1990-2000. Did you take it as a consideration in estimating the population growth or do you have another method to do it?
- Regarding damaged road and mitigation aspects, what analysis and consideration did you take in planning of the road network and road class?

ESB
- Do you also consider vertical evacuation & ESB in the spatial planning particularly in the old-revived Meulaboh's city center area?
- (If yes), what type of facilities can be functioned as ESB?
- (If yes), how and where do you allocate the ESB?
- Related to ESB, what do you plan to respond the existence of specific facilities such as port/habor and revived city center (located in high-risk area) in the spatial planning?

D2a-1.2, D2b-1.2 - Experts Interview

Objective:
- To get the design concepts and standard of tsunami and earthquake-resistant building
- To know/update the development of tsunami and earthquake-resistant building in Indonesia
- To identify possible implementation of ESB

Interviewees:
- Ir. Andry W., MT., Department of Architecture ITB Bandung
- Expert (no information) in Puskim (Research Center for Housing and Settlements, Public Work Department) Bandung

Topic: Tsunami & Earthquake –resistant building

Questions:

Building/construction performance against tsunami
- How is actually a building destroyed in a tsunami disaster? How is the impact of the earthquake and tsunami waves?
- How should a local (Aceh) building/construction perform to withstand earthquake & tsunami hazard?

Development on Tsunami & Earthquake –resistant building
- What is the latest development/research in design of tsunami&earthquake –resistant building?
- Are there any standard of building design for that?
- Do you have such a standard or know other researcher/institution working on relevant research?

Continued on next page…

Implementation

- What should be done to apply ESB concepts/standards (building regulation, building (&site) planning&design, construction phase)?

D2b-1.5, D2b-3.1, D2b-4.1 – Expert Interview

Objective:

- To assure the definition/assumption on tsunami response time
- To ask the data on water height for Meulaboh

Interviewee: Dr. Hamzah Latief, Department of Geophysics and Meteorology, ITB Bandung and Dr. Subibyakto, PSBA UGM, Yogyakarta

Topic: Assumptions on early warning system & water inundation

Questions:

Tsunami warning system

- Referring to GFZ Postdam, what do you think of the early tsunami warning system to be implemented in Indonesia and Indian Ocean region (accuracy, regional cooperation, maintenance, resources)?
- How long does it take roughly for the Indonesian disaster management (central and local level) to communicate and alarm the coastal community after receiving the tsunami occurrence information?

Tsunami time

- How accurate are the tsunami travel time, data processing time, and response/evacuation time being used to define available time for evacuation before tsunami strike?
- Regarding various result of survey, estimation, and modeling of tsunami on those times (mentioned before), which approach should I take to assume the response time for evacuation in Meulaboh City?

Inundation & run up

- Based on tsunami modeling you made, do you have any data on water inundation area for Meulaboh?
- In some literatures (FEMA, Nagao, etc.) the ESB's upper floor is raised to allow the wave to go through the ground floor. What do you think the waves behavior (max 15-30m) toward those raised construction?
- In case there will be same tsunami as Dec 26 tsunami, what do you think of the existence of the buffer area (in coastal zone, Masterplan of Bappenas) to reduce the waves power in reaching the urban area?

D4a-2.1, D4b-2.1, D4a-2.2, D4b-2.2, – Local authorities & NGOs Interview

Objective:

- To get the ideas, concepts, and decision/execution of survivor's resettlement action
- To understand the methodology used in analysis/assumption of the population number and growth in the study area
- To get resettlement plan/scenario
- To get the map of desa/village/spatial unit representing population distribution

Interviewees:

- Provincial and Regency Office of Development Planning Agency, City Planning Agency, Statistics Bureau, and Cadastre, Banda Aceh and Meulaboh
- Rehabilitation and Reconstruction Agency, Banda Aceh
- ARRIS – JICA Office, Banda Aceh
- UN Agencies and NGOs, Banda Aceh and Meulaboh

Topic: Estimation/Assumptions on population distribution & population growth

Questions:

Resettlement

- What are the ideas, concepts, plan/scenario of survivor resettlement?
- How are they being incorporated in city reconstruction planning and implemented in the real action?
- Do you have the document of resettlement plan/scenario? May I make a copy of it?

Population data

- Do you have the data of population number and spatial distribution of returned survivor to be accommodated in resettlement/reconstruction process?
- (If no data), what approach and assumption will you take to do so?
- Regarding the population growth in the future, what assumption/consideration will you take in estimating the population growth?

Desa/gampong data

- Regarding the damaged areas and population distribution, will there be any changes in arrangements and boundaries of desa/gampong?
- Do you have such a data (number and map) for desa/gampong/other spatial unit level?

4a-3.1, D4b-3.1, D4a-3.1, D4b-3.2, – Local authorities & NGOs Interview

Objective:

- To get the overview of vertical evacuation strategy in local level
- To explore the understanding of ESB concept in local level
- To understand the methodology used in defining the hazard zone
- To understand the methodology used in defining/allocating rebuilt/recovered road regarding the tsunami mitigation
- To get the data (map) of hazard zone
- To get the data (map) of rebuilt/recovered road network and road classification

Interviewees:

- Provincial and District Office of Development Planning Agency, City Planning Agency, Public Works Agency, Statistics Bureau, and Cadastre, Banda Aceh and Meulaboh
- BRR Banda Aceh
- ARRIS – JICA Office, Banda Aceh
- UN Agencies and NGOs, Banda Aceh and Meulaboh

Topic: Identification of hazard zone, road network

Questions:

Vertical evacuation and ESB

- Regarding the Masterplan of reconstruction (Bappenas), what are the vertical evacuation strategies planned/applied in your area?
- What should be done to strengthen local building/construction to be able to withstand earthquake & tsunami hazard?
- What should be done to apply ESB concepts/standards in your area (building regulation, building (&site) planning&design, construction phase)?

Hazard Zone

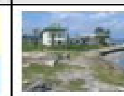
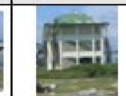
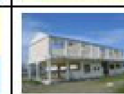
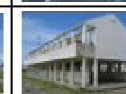
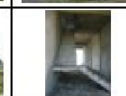
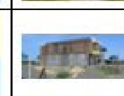
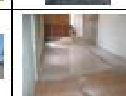
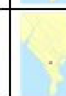
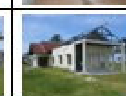
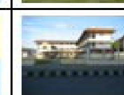
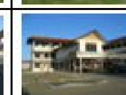
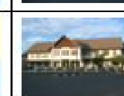
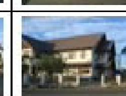
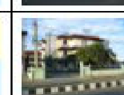
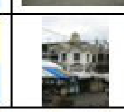
- Do you have a map/data about the tsunami hazard zone of your area? (If not), what will you do to identify the hazard zone?
- What will you (your institution) do to prevent the people from occupying the area in the hazard zone?

Road Network

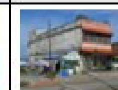
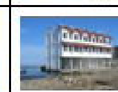
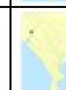
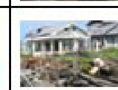
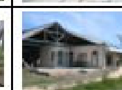
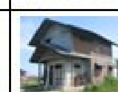
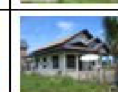
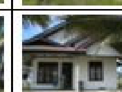
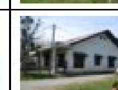
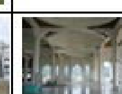
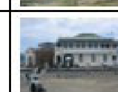
- What are the ideas or concepts of infrastructure (road network) recovery plan/action?
- Do you have a plan/map/data of existing road network and road recovery plan?
- (If not), what will you (your institution) do to determine which road to be rebuilt or recovered road?
- How do you incorporate tsunami evacuation aspect in it?

Appendix 7

The results of tsunami-survived building survey in Meulaboh and Banda Aceh City

No	Coordinate, Elevation, Time Rec.	Name, Resistancy, Function, Pot. ESB, Cap.	Site, Location	Ground Plan, Gr.Fl. elev, wall&floor material	Facade, Opening (per floor), Waterbody/Road orientation	Upper floor height, stair accessibility	Column, Beam, Sloof, Foundation, Sloof	Additional information	Map of location	Image	Image
1	GPS 12 UTM 47N 181190.13,4562098.3 09/16/05 15:05	Military Boarding House, High, Housing-RES, Y, 0.5x1080=540 p	Sea-front facing 60m, Road facing 70m, Suak Indrapuri	Allow water flow, Elev 50 cm, Wall brick-good, Floor tile-good	Outskirt corridor 2&3m, Door 2x10x0.9m – facing sea, Window 2x18x0.6x1.5m – facing sea	2nd fl 4m, 3rd fl 8m, Floor conc. good, Stair conc. good, Good loc., enough cap., easy access	C 40x40cm – 4x4m B 30x40cm – 4x4m, F local sloof - 2m	Rectangular shape, opening on long side on both sides			
2	GPS 13 UTM 47N 181416.45,4568742.8 09/16/05 14:56	Babul Jannah Mosque, Low, Pray&Social-INS, NO	Sea-front paralel 80m, Road paralel 30m, Suak Indrapuri	Allow water flow, Open layout, Elev 120 cm, Wall brick-poor, Floor tile-good	Arc-walkthrough 4.5m – facing & paralel sea (qiblat orientation)	-	C 20x20cm & dia 50cm – 4.5x4.5m B 20x40 & 30x50cm – 4.5x4.5 m, F cont. sloof h 1.2m	All walls were destroyed, 2 columns were broken,			
3	GPS 11 UTM 47N 181157.90,4571048.2 09/16/05 14:24	Ex Junior High School (SMP) 1, Low, School-INS, Y, 0.8x701=560 p	Sea-front paralel 80m, Road paralel 30m, Kampung Belakang	Allow water flow, Open layout, Elev 60 cm, Wall brick-good, Floor tile-modert	Outskirt corridor 18m, Door 8x1m – facing& paralel sea, Window 92x0.6x1.2m – facing& paralel sea	2nd fl 3m, Floor conc. good, Stair conc. moderate, Good loc., less cap., uneasy access	C 35x35cm – 3.45x7.8m B 30x60cm – 7.8m, F continuous sloof h 1m	2 buildings L-shape, Roof was stolen			
4	GPS 7 UTM 47N 180607.41,4582963.0 09/16/05 10:14	Ruko, Low, Commercial-COM, NO	Sea-front facing 33.5m, Road facing 14m, Ujung Kalak	Allow water flow, Open layout, Elev 50cm, Wall brick-good, Floor ground	Walkthrough 4x4m – facing sea	2nd fl 4m, Floor conc. good, Stair conc. poor, Good loc., enough cap., uneasy access	C 30x40cm – 3x4m B 30x50cm – 4m, F local 80x80cm-2m &continuous sloof – 0.5m	Building construction not finished yet			
5	GPS 8 UTM 47N 180384.41,4585634.7 09/16/05 10:41	Limco Computer Course, Moderate, School-INS, NO	Sea-front facing 307m, canal facing 4m, Road facing 13m, Ujung Kalak	Allow water flow, Open layout half, Elev 60cm, Wall brick-good, Floor tile-good	Door sliding 1x4m Metal - facing road,	2nd fl 4m, Floor conc. good, Stair conc. modeate, Bad loc., less cap., uneasy access	C 30x40cm – 3x4m B 25x40cm – 3m, F local 1x1m sloof depth 2m	Water from backward of building			
6	GPS 9 UTM 47N 181027.55,4578998.6 09/16/05 11:14	House of H. Teuku Daood, Low, Housing-RES, NO	Sea-front facing 430m, Road paralel 12m, Kp. Belakang	Block water flow, Elev 40 cm, Wall brick-good, Floor tile-good	Entrance 3x7m, Door 1x1m - facing road paralel sea, Window 6x40x2.2m prl road & 12x0.4x1.5m - face sea	-	C 30x40cm – 4x7m B 25x40cm – 3m, F continuous sloof 30x40cm	Sea-facing wall was destroyed, survived roof was stolen			
7	GPS 4 UTM 47N 181057.72,4583555.5 09/16/05 07:06	Hotel Tiara, High, Com.Housing-RES, Y, 0.5x 1434=717 p	Sea-front facing 652m, Road facing 26m, Ujung Kalak	Block water flow, Elev 10 cm, Wall brick-good, Floor tile-good	Outskirt corridor 2.5m, Door 15x1m face&parallel road, Window 15x2.5x1.5m Wd.face&parallel road	2nd fl 3m, 3rd fl 6m, Floor conc. good, Stair conc. modert, Good loc., less cap., uneasy access	C 20x30cm – 4x1.5m & 4x4m, B 25x30cm – 4x1.5m & 4x4m, F local-sloof – 1m	1 O-shape building remains, 2 others totally destroyed			
8	GPS 5 UTM 47N 181036.17,4584234.2 09/16/05 07:02	Local Parliament (DPRD Meulaboh), High, Office&Social-INS, Y, 0.4x1516=1212p	Sea-front facing 675m, Road facing 8m parallel 13m, Ujung Kalak	Block water flow, Elev 60 cm, Wall brick-good, Floor tile-good	Entrance 4x12m& 2x4x8m, Door 2x2m - facing road, Window 60x0.6x0.8m - facing road	2nd fl 5m, Floor conc. good, Stair conc. good, Good loc., sufficient cap., easy access	C circular dia. 50cm – 2.5x2.5m, B 30x50cm – 2.5x2.5cm, F local-sloof – 1m	Located frontally in 3-cross road, over structure			
9	GPS 6 UTM 47N 180849.80,4584819.2 09/16/05 07:00	Hotel Meuligo High, Com.Housing-RES, Y, 0.5x1168=594 p	Sea-front paralel 563m, Road facing 31m, Ujung Kalak	Block water flow, Elev 60 cm, Wall brick-good, Floor tile-good	Outskirt corridor 2m, Door 15x1m face&paralel road, Window 15x1x1.5m face&parallel road	2nd fl 3.5m, 3rd fl 7m, Floor conc. good, Stair conc. good, Good loc., enough cap., easy access	C 20x30cm – 4x2m & 4x4m, B 25x30cm – 4x2m & 4x4m, F local-sloof – 1m				
10	GPS 52 UTM 47N 181304.41,4584452.9 09/18/05 07:24	New Market (Pasar Baru), High, Market-COM, Y, 0.3x2784=835 p	River/canal-front parallel 4m, Road facing 27m, Pasar Aceh	Block water flow, Elev 30 cm, Wall brick-good, Floor tile-good	Outskirt corridor 4.5m, Door sliding 2.5m metal – face&paralel road& canal	2nd fl 3.75m, Floor conc. good, Stair conc. good, Good loc., less cap., uneasy access	C 30x30cm – 2.5x4m B 20x30cm – 2.5x4m F local-sloof	A group of 9 connected buildings			
11	GPS 51 UTM 47N 181291.49,4584991.5 09/18/05 07:20	New Market Mosque, High, Pray&Social-INS, Y, 0.8x72=57 p	River/canal-front 2m, Pasar Aceh	Block water flow, Elev 30 cm, Wall brick-good, Floor tile-good	Entrance 1.2x4m, Door 4x0.7m face road&canal, Window 10x0.6m face&paralel road&canal	2nd fl 4.3m, Floor conc. good, Stair conc. good, Good loc., less cap., uneasy access	C circ dia 30cm – 4m B 20x30cm – 4m F local-sloof	Octagon shape builing, vertex 4m			

Continued on next page…

No	Coordinate, Elevation, Time Rec.	Name, Resistancy, Function, Pot. ESB, Cap.	Site, Location	Ground Plan, Gr.Fl. elev, wall&floor material	Facade, Opening (per floor), Waterbody/Road orientation	Upper floor height, stair accessibility	Column, Beam, Sloof, Foundation, Sloof	Additional information	Map of location	Image	Image
12	GPS 17 UTM 47N 181442.03,4582967.6 09/16/05 16:31	Ruko, High, Commercial-COM, NO	River/canal-front facing 19m, Road facing 10m, Pasar Aceh	Allow waterflow, Elev 50 cm, Wallbrick-good, Floortile-good	Door sliding 1x3m metal - facing road&canal, Window 6x40cm - facing road&canal	2nd fl 4m, no info on upper floor	C 30x30cm – 4&2m B 30x40cm – 4&2m, F continuous sloof	-			
13	GPS 15 UTM 47N 181497.25,4578139.9 09/16/05 16:18	House, High, Housing-RES, NO	River-front facing 6m, Road facing 1m, Pasar Aceh	Block water flow, Elev 30 cm, Wallbrick-good, Floortile-good	Entrance 2x3m & 1x2m, Door 3x0.9m - face& paralel river&road, Window 9x0.7x1.6m - face&paralel river&road	2nd fl 4m, no info on upper floor	C 30x30cm – 3m B 20x30cm – 3m, F continuous sloof	Loc. adjacent to river(back), no info from riverside			
14	GPS 14 UTM 47N 181483.24,4575996.2 09/16/05 16:15	Ruko Pemkab, Moderate, Commercial-COM, NO	River-front facing 0-1m, Road facing 1m, Pasar Aceh	Allow waterflow, Open layout, Elev 30 cm, Wallbrick-good, Floortile-good	Door sliding 6x4m, & 6x0.9m – facing river&road	2nd fl 4m, Floor conc. good, Stair conc. good, Good loc., less cap., uneasy access	C 30x30cm – 4x4m B 30x40cm – 4x4m, F local pile - sloof 30x100 cm	Loc. adjacent to river(back), floor&wall were destroyed in 3 units			
15	GPS 58 UTM 47N 181532.80,4584377.5 09/18/05 07:47	Madrasah, Low, School-INS, Y, 0.8x120=96 p	River-front facing 264m, Road facing 40m, Pasar Aceh	Block waterflow, Open layout, Elev 30 cm, Wallbrick-good, Floor ground	Walkthrough 4m paralel road&canal	2nd fl 4m, Floor conc. good, Stair conc. good, moderate loc., less cap., uneasy access	C 25x25cm – 4x3m B 25x35cm – 4x3m, F local pile – sloof h 60cm	Building construction not finished yet			
16	GPS 21 UTM 47N 179928.58,4595937.9 09/17/05 09:53	House, Low, Housing-RES, NO	River-front facing 4.1m, Road facing 7m, Suak Ribee	Block water flow, Elev 10 cm, Wallbrick-moderate, Floortile-good	Outsk. corridor 2&3m, Door 1x0.9m - face road&river, Window 8x1x2m facing road&river	-	C 30x30cm – 2&3m, B 20x30cm – 2&3m, F no info, cont.-sloof – 0.8m	Back part – no corridor (35%) of the house destroyed,			
17	GPS 22 UTM 47N 179735.33,4598680.9 09/17/05 10:09	House of school teacher, High, Housing-RES, NO	River-front parallel 230m, Road facing 10m, Suak Ribee	Block water flow, Elev 60 cm, Wallbrick-good, Floorplaster-good	Entrance 1.5x4m, Door 1x0.9m - facing road, Window 7x0.6x1.5m face road & paralel river	2nd fl 3.3m, Floor conc. good, Stair conc. good, No info on stair	C 30x30cm– 4.5&3m B 20x30cm – 4.5&3m F no info, local-sloof – 1m	Became ESB during Dec 26 tsunami, side part (20%) destroyed			
18	GPS 23 UTM 47N 180326.50,4606009.7 09/17/05 10:29	House of T. Sapwan High, Housing-RES, NO	Tsunami-reached Road parallel 28m, Seuneubok	Block water flow, Elev 60 cm, Wallbrick-good, Floorplaster-good	Outskirt corridor 2m, Door 1x0.9m - face road, Window 12x0.6x2m - facing & paralel road	-	C 25x25cm – 3.6&4.2m B 25x25cm– 3.6&4.2m F local-sloof – 1.2m	Water from back side, height 1.5m.			
19	GPS 28 UTM 47N 180517.33,4603564.9 09/17/05 10:57	House, High, Housing-RES, NO	Tsunami-reached Road parallel 11m, Simpang Metro-Seuneubok	Block water flow, Elev 60 cm, Wallbrick-good, Floorplaster-good	Entrance 2.1x4m, Door 1x0.9m - facing road, Window 9x0.6x2m - facing&paralel road	-	C 15x30cm– 4m B 15x20cm– 4m F no info, continuous-sloof – 1m	Half of a coupled-house, Water from back side,			
20	GPS EKA1 N05°29.647' E095°14.120' Elev 1 m 09/14/05 12:00	Lampuuk Mosque, Low, Pray&Social-INS, YES	Sea-front facing, Lampuuk - Banda Aceh	Allow waterflow, Elev 100 cm, Wallbrick-poor, Floortile-good	Arc-walkthough 2.5&4m – face&paralel sea	2nd fl 6m, 3rd fl 9.5m Floor conc. good, Stair conc. good, bad loc., less cap., uneasy access	C 25x25&45x45cm, dia 25&50cm – 8.4m B 40x60&15x40cm – 8.4 m F local-sloof	-			
21	GPS EKA2 N05°33.353' E095°17.049' Elev 1 m 09/14/05 12:00	Ulheelheu Mosque, Low, Pray&Social-INS, YES	Sea-front facing, Ulheelheu - Banda Aceh	Block water flow, Elev 60 cm, Wallbrick-good, Floortile-good	Walkthrough 4&2m, Window 6x2x0.8m & 4x0.8x.4m - facing& paralel sea&road	2nd fl 4m, Floor conc. good, Stair conc. good, bad loc., less cap., uneasy access	C 30x30cm – 4m B 25x40cm – 4m F local-sloof – 1.2m	-			

Appendix 8

Population calculation in tessellations

Example of occupants' calculation in houses and facilities per tessellation in day and night scenario

Hex label	Housing_		Mosque_m			School_s			Boardhs_		Marketbld_t			Market_p		Shoprk_r		Hotel_h			Office_o			FerryP_p		FishHb_f		Warehs_w		Busst_b		Fhall_g		park_z		Totalpop_tot			Notes
	r_d	r_n	m_d	m_n	m_c	s_d	s_n	s_c	a_d	a_n	t_d	t_n	t_c	p_d	p_n	r_d	r_n	h_d	h_n	h_c	o_d	o_n	o_c	f_d	f_n	i_d	i_n	w_d	w_n	b_d	b_n	g_d	g_n	z_d	z_n	tot_d	tot_n	tot_c	
10279	36	71																																		36	71	0	
10280	51	102				132	1																													183	103	0	
10281	16	31																																		16	31	0	
10282	29	58																																		29	58	0	
10283	16	32																																		16	32	0	
10284	40	79	55	1	386																															94	80	386	
10285	18	37																																		18	37	0	
10286	34	69																																		34	69	0	
10287	16	32																																		16	32	0	
10288	0	0																																		0	0	0	
10289	11	21																																		11	21	0	
10290	5	11																																		5	11	0	
10316	0	0																																2	0	2	0	0	Buffer zone
10317	0	0																																3	0	3	0	0	Buffer zone
10318	118	236																																		118	236	0	
10319	51	102																																		51	102	0	
10320	13	27																																		13	27	0	
10321	33	67																																		33	67	0	
10322	13	27																																		13	27	0	
10323	9	18																																		9	18	0	
10324	34	69																																		34	69	0	
10325	24	47																																		24	47	0	
10326	26	53																																		26	53	0	
10327	34	69																																		34	69	0	
10328	21	42																																		21	42	0	
10329	26	53																																		26	53	0	
10330	18	37														13	11																			32	47	0	
10331	0	0																																		0	0	0	
10332	24	47																																		24	47	0	
10333	21	42																																		21	42	0	
10334	8	16																																		8	16	0	
10357	0	0																																		0	0	0	
10358	22	45																																4	0	26	45	0	Partial. sunk land & buf. zone
10359	0	0																																4	0	4	0	0	Buffer zone
10360	38	76																																		38	76	0	
10361	11	22																																		11	22	0	
10362	42	85				373	1																													416	86	0	
10363	33	67																																		33	67	0	
10364	18	36				113	1																													131	37	0	
10365	32	63																																		32	63	0	
10366	13	26				212	1																													225	27	0	
10367	42	84																																		42	84	0	
10368	11	21																																		11	21	0	
10369	37	74														7	5																			44	79	0	

1	HEXLABEL	POPDAY	POPNIGHT	POPMAX
2				
3	10030	0	0	0
4	10032	4	0	4
5	10072	4	0	4
6	10073	4	0	4
7	10074	11	21	21
8	10075	0	0	0
9	10076	0	0	0
10	10077	0	0	0
11	10113	3	0	3
12	10114	24	47	47
13	10115	5	11	11
14	10116	0	0	0
15	10117	0	0	0
16	10118	16	32	32
17	10119	8	16	16
18	10120	3	5	5
19	10154	3	0	3
20	10155	10	19	19
21	10156	32	63	63
22	10157	0	0	0
23	10158	0	0	0
24	10159	16	32	32
25	10160	11	21	21
26	10161	5	11	11
27	10162	8	16	16
28	10194	3	0	3
29	10195	4	0	4
30	10196	0	0	0
31	10197	0	0	0
32	10198	37	74	74
33	10199	0	0	0
34	10200	16	32	32
35	10201	18	37	37
36	10202	21	42	42
37	10203	21	42	42
38	10204	11	21	21
39	10234	1	0	1
40	10235	1	0	1
41	10236	22	45	45
42	10237	11	22	22
43	10238	0	0	0
44	10239	16	31	31
45	10240	37	74	74
46	10241	24	47	47
47	10242	21	42	42
48	10243	37	74	74
49	10244	29	58	58
50	10245	34	69	69

1	HEXLABEL	POPDAY	POPNIGHT	POPMAX
309	10682	1	0	1
310	10683	871	48	871
311	10684	180	27	180
312	10685	132	16	132
313	10686	39	32	39
314	10687	87	10	87
315	10688	75	79	79
316	10689	148	103	148
317	10690	74	60	74
318	10691	70	140	140
319	10692	41	83	83
320	10693	78	157	157
321	10694	37	74	74
322	10695	75	78	78
323	10696	25	50	50
324	10697	43	87	87
325	10698	128	159	159
326	10699	120	135	135
327	10700	70	140	140
328	10701	24	48	48
329	10702	51	101	101
330	10703	151	73	151
331	10725	1153	2	1153
332	10726	172	29	172
333	10727	22	43	43
334	10728	57	186	186
335	10729	140	5	140
336	10731	86	62	86
337	10737	44	55	55
338	10738	215	219	219
339	10739	518	94	518
340	10740	72	97	97
341	10741	192	152	192
342	10742	39	77	77
343	10743	0	0	0
344	10744	0	0	0
345	10767	8	15	15
346	10768	53	33	53
347	10769	66	10	66
348	10770	108	4	108
349	10780	0	0	0
350	10781	191	222	222
351	10782	56	111	111
352	10783	85	106	106
353	10785	0	0	0
354	10809	2	3	3
355	10811	0	0	0
356	10823	27	53	53
357	**TOTAL**	**24891**	**19988**	**31606**

Total population in day, night, and maximum population