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A-Gis Based Approach of an Evacuation Model for Tsunami Risk Reduction

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Abstract In a tsunami mitigation plan, evacuation plays a crucial measure for saving human lives, especially for communities who are living in low-lying coastal areas. In some locations, higher grounds may not exist or local tsunami make it not possible for community to evacuate to a distant location due to the short warning time. Thus, a possible solution is vertical evacuation into the upper level of buildings or structures designed to resist the effects of the tsunami.

This research developed a method to choose the most effective evacuation routes using Geographic Information System (GIS) tools in a tsunami-prone area, the case of the Cilacap coastal area. Network analysis and various GIS techniques were used to determine the location and capacity of potential suitable evacuation shelter buildings (ESBs) and the most effective evacuation route for tsunami. The evacuation process used simulates that the residents of the inundation area will be encouraged to walk to safe areas in a certain amount of time.

Results of the modeling include the proposed location of additional ESBs, the capacity and service area of each building, and the evacuation route for each center of population to reach the escape buildings. The number of additional shelters was different for the different-time scenario since daytime and nighttime scenarios will give a different distribution and different number of shelters needed. In addition, the effective evacuation routes were developed for each service area. In this case, travel time was an essential factor since it would limit the movement of evacuees in the evacuation process.

Key words Evacuation; Shelter; Tsunami; Cilacap; Network analyst.

1. INTRODUCTION

Tsunami is a wave or series of ocean waves created by sudden, large disturbances of the deep ocean-water mass (Abbott, 2004). There are many factors, which cause tsunami such as earthquakes, volcanic eruption, landslides, slumps, and meteor impacts. Tsunami is most commonly generated by subsea fault movements with prominent vertical dislocation of the sea floor that disturbs the deep ocean-water mass. This is often triggered by earthquakes along deep ocean trenches and convergent plate boundaries.

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The destruction due to tsunami impact varies depending on the source, the distance from the epicenter and the intensity of the trigger factors which cause the tsunami. Mostly, coastal areas, which are densely populated, may suffer severe damages because of high concentration of population, buildings, infrastructure and socio-economic facilities. In these areas, a tsunami can cause a huge number of fatalities, damages, and cause considerable economic and business losses.

In a tsunami mitigation plan, evacuation plays a crucial role for saving human lives. NTHMP (2001) stated that the primary strategy for saving lives immediately before tsunami waves arrive is to evacuate people from the hazard zone. There are two methods to evacuate people in case of a tsunami as follows; a) Horizontal evacuation; people move to safer areas in a distant location or higher ground such as a hill; b). Vertical evacuation; this method will evacuate people to the higher floors of a tsunami-resistant building nearby.

In case of buildings for evacuation, because tsunamis have long periods before occurrence, there are no buildings functioning only as evacuation shelter buildings (ESBs). Finding the suitable buildings that can be used as ESBs is necessary due to high building construction cost and efficiency in space occupation. These ESBs should have certain design and configuration including size, shape and orientation (NTHMP, 2001). Moreover, it is necessary to determine the capacity, spatial distribution and accessibility of ESBs within a region. Besides, it is important to identify to which evacuation building people in a certain area should go to and how to get there in a fast and efficient way. It is important to identify the existing buildings that have the potential to function as ESBs. The identification of those existing buildings should be integrated with the effort of finding new ESBs locations. Furthermore, the existence of ESBs should be included in the spatial plan with regards to disaster mitigation aspects.

This research developed a method to choose the most effective evacuation routes and determine the locations and capacities of potential suitable evacuation shelter buildings using GIS tools in a tsunami-prone area.

1.1 Study Area

Indonesia's southern coastlines are located along the convergent boundary of Eurasian and Indo – Australian plates making those areas prone to tsunami hazard triggered by major earthquakes.The tsunami which hit the South coast of Java, Indonesia on July 17th, 2006 brought on massive damages to the coastal area of many provinces i.e. West Java, Yogyakarta Special Province, and Central Java, including Cilacap (Lavigne *et. al.*, 2007).

Cilacap is one of the regencies in Central Java Province, Indonesia (Figure 1). Some areas in Cilacap have become industrial centers and sea ports and are highly populated. Many buildings are situated on the coastal plain just a few meters away from the present shoreline, since the region occupies a flat area. Some areas are fishing villages that form squatter areas.

Cilacap lies in a tsunami hazard zone and may be struck by tsunami again in the future, so it is important to improve measures to support evacuation of residences, tourists, and others. In the case of the Cilacap coastal area, since higher places are very limited and sometimes do not exist, this city needs vertical evacuation. This is due to the short period of time available beforea tsunami waves strike.

1.2 Previous Studies

Budiarjo (2006) developed a method for conducting vertical evacuation using Flowmap, an accessibility software developed by Utrecth University of the Netherlands. The flow map generated model uses three types of data: maps, flow data and a distance table. Flowmap is able to determine the ESBs' possible locations and the effective evacuation routes. However, the flowmap model does not consider the land cover of possible ESBs's location.

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Figure 1.Cilacap Coastal Area

Other studies were conducted by Laghi*et. al.* (2007) and Widyaningrum (2009). They developed a model which performs minor cost path calculation and Cost Weighted Distance (CWD) to calculate the shortest (not simply in terms of physical distance) and safer evacuation routes. A series of ArcGIS tools have been built, defining evacuation routes by means of geographic information system spatial analysis techniques. Tools used to identify the shortest way option include spatial analysis, hydrological models and tri-dimensional analysis. This model considers land cover in ascertaining the possible location for ESBs.

In this research, the author developed a new model by incorporating ArcGIS and several GIS tools. ArcGIS and ArcView are used widely in Indonesia, so that many stakeholders such as local government, and other related institutions can apply this model. In addition, land cover was incorporated in ascertaining the possible location for ESBs.

2. DATA AVAILABILITY

Data used for this research includes a QuickBird image of 2006, a topographic map at a scale of 1:25.000, road network of 1:10.000, a tsunami model from Mardiyatno (2008), and population data at the village level.

A QuickBird image was used for extracting the building map. The buildings will become the point of origin of evacuation. The same image was also used to improve the road network from topographic map which is less detailed than is needed.

The available tsunami hazard map was used as a basis to derive the tsunami evacuation map. It gave prediction regarding potential inundated and safe areas. The map was developed by Mardiatno (2008) derived by using a tsunami model developed by Fumihiko Imamura from the Disaster Control Research Centre - Tohoku University, Japan.

3. CONCEPT AND METHODOLOGY

3.1 Building Inventory

The research started from the identification of existing evacuation shelter buildings (ESBs) by using a QuickBird high-resolution image. The QuickBird image was used to a derive building use map of the areas as well. Furthermore, field observations were conducted to validate the building use maps and to assess selected buildings for ESBs, which were predicted as potential evacuation shelter buildings. Budiarjo (2006) and Widyaningrum (2009) listed several requirements of building resistance for tsunami as follows: 1) Located at a distance of more than 200 m from shoreline or 100 m from a river near the coast; 2) Located near the population concentration; 3) Having alternate function as public facilities, such as mosque, school, parliament building, government office, market, shopping centre, convention centre, sport hall, hotel, and parking building; 4) Building floor reserved for evacuation located above tsunami wave height in the area; 5) Well-planned and designed; 6) Good quality construction (tsunami and earthquake resistant building).

3.2 Building Capacity Estimation

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

$$\mathbf{TEBC = (CS \times BA \times NrF) / (SpP)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

TEBC = Tsunami Evacuation Building Capacity (number of person)

CS = Capacity Score (%)

BA = Building Area (m^2)

NrF = Number of Floors

SpP = Space needed for one person (m^2)

The formulas used can be seen in Table 1 as follows:

Table 1. The TEBC for each building types

Type of Building	Tsunami Evacuation Building Capacity
Mosque/worship	78% * BA / 1 m^2
School	30% * BA / 1 m^2
Office	23,6% * BA / 1 m^2
Market building/Mall	23% * BA / 1 m^2

Hotel	26,3% * BA / 1 m^2
Hall/Gallery	100% * BA / 1 m^2

Source : (Budiarjo, 2006; Widyaningrum, 2009)

The building area is the total floor area of the building for evacuation. This is particularly important when there is more than one floor used for evacuation purposes.

The capacity score depends on the type of building since each building type will have different conditions of free space available. The capacity score was adopted from Budiarjo (2006) who estimated it by using an architectural approach. For example, a mosque has a 78% capacity score derived from the following estimation. Space requirement for a mosque design is 1.8m^2/person and 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 purposes 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 (Budiarjo, 2006).

The space requirement needed per refugee can vary depending on the length of occupancy and the type of hazard. The longer the duration of occupancy, the greater the minimum space requirement per occupant for comfort requirements, for building infrastructure, systems, and services needed when housing people on an extended basis. FEMA (2008b) stated that, the recommended minimum square footage per occupant for a tsunami refuge was 10 square feet per person. It is equal to 0.93 square meter per person. Furthermore, the National Development Agency of Indonesia (BAPPENAS, 2005) noted that the space needed for accommodating one person was 1 square meter. It is anticipated that this density will allow an evacuee to sit down without feeling overly crowded for a relatively short period. This space of 1 square meter would not be considered appropriate for longer stays that included sleeping arrangements. It should be adjusted up for longer stays.

3.3 Population Estimation

The evacuation model was started from the concentration of evacuees. By using Network Analyst, both shelter destinations and center of evacuees were expressed in term of points. From building maps, we can see that there were 3,937 building blocks which represented the source of evacuees. Due to the time constraint, the author made the simplification for the model input. The population distribution was systematically divided into equal-sized portion by using tessellation or grid. It was assumed that residents live concentrated at its center (the center of this tessellation were called centroid). Ideally, people evacuate from every building block and try to find the nearest network. For this purpose, one-hectare hexagonal tessellation was used; each side was 62.04 m in length. The area of 1 hectare is a manageable extent of detail level for spatial planning and building design.

Hexagonal tessellation was chosen since a hexagon has a shorter perimeter than a square of equal area, which potentially reduces bias due to edge effects (Krebs, 1989) after (Birch *et. al.*, 2007). Furthermore, the hexagon tessellation is attractive because it minimises spatial distortion and, if constructed on an equal-area map projection, provides an equal-area sample.

To generate the hexagonal tessellation over the study area, an extension of ArcGIS called Repeating Shape for ArcGIS was used (Jenness, 2009). The results were then overlaid with the building maps and population data.

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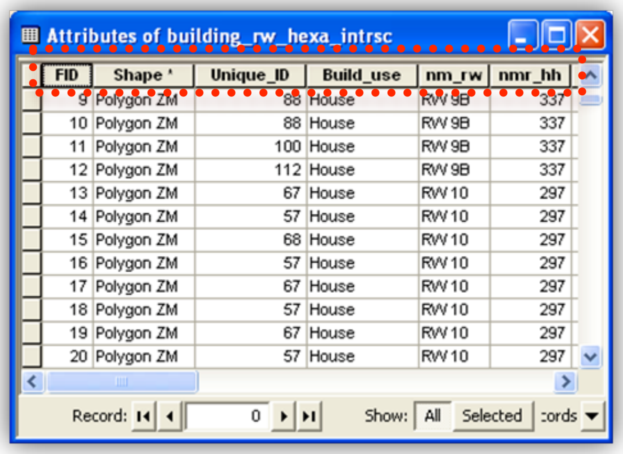

Attributes of building_rw_hexa_intrsc

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

Record: 0 Show: All Selected :ords

Figure 2.The attributes of intersection between building maps, population data and hexagonal tessellation

The result of this process was a building map, which was completed with all data regarding the number of households in each building, and hexagonal ID, as can be seen in Figure 2. Each building in the building map had the following information:

1. Numeric field **Unique_ID** refers to a certain hexagonal label in which the building is attached.
2. String field **Build_use** refers to the usage of the building.
3. Numeric field **nmr_hh** refers to number of households in a particular building.

The scenarios of day and nighttime were used to run the evacuation model. For each scenario, the population in the houses were calculated using the following formula (Budiarjo, 2006):

Daytime 50% (occupants) * (nr_houses) * (nr_occupants/house) …………… (2)

Nighttime 100% (occupants) * (nr_houses) * (nr_occupants/house) …………… (3)

It is assumed that 50% of the occupants were at home and the rest were outside the house conducting their activities. In the nighttime scenario, the assumption is that all family members are at home.

The formulas, which were used for estimating the population in facilities, can be seen in Table 2.

3.4 Network Datasets

In order to perform the analysis, network datasets must be developed on a detailed road network including setting the travel time for each segment of the road, defining direction, and one-way streets. All processes were conducted by using Network Analyst of ArcGIS.

Table 2. Population estimation for day and night-time scenarios

Scenario	**Formula**
Mosque	
Day	10% (capacity) * building area / 1.8 (space requirement)
Night	1 person
	Only one security guard is available during the night
School	
Day	110% (capacity) * building area / 4 (space requirement) or 110% (capacity) * number of occupants
	10% for other occupants i.e. teacher, officer, food & merchandise seller
Night	1 person
Boarding house	
Day	1 person
Night	100% (capacity) * building area / 4.6 (space requirement)
	It is assumed only 2 person stay at the building (cleaning service & security)
Office	
Day	100% (capacity) * building area / 8.5 (space requirement)
Night	1 person
Shop	
Day	4 person (employee and/or visitor)
Night	1 person
Ruko (shop & house)	
Day	(50% (family member) * pop./household)+ 4 (employee and/or visitor)
Night	100% (family member) * population/household
	The owner (mostly) also lives in the building
Hotel	

Day	50% (capacity) * building area / 16 (space requirement)
Night	80% (capacity) * building area / 16 (space requirement)
Factory	
Day	Total people in the whole facility area
	It is assumed that the area contain its regular occupant
	Based on field observation, estimation is conducted by knowing the number of people in factory (workers, security, cleaning service, etc)
Night	2 person (security guard)
Fish Market	
Day	Total people in the whole facility area
	It is assumed that the area contain its regular occupant
	Based on field observation, estimation is conducted by knowing the number of people in fish market (fisherman, officer, buyer, cleaning service, etc)
Night	2 person (security guard)

Source: modified from (Budiarjo, 2006)

3.5 Speed of Evacuee

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

Actually, for distant tsunami, there may be sufficient time to escape by vehicles, thus it is not necessary to prohibit it. Even during a local tsunami event, in case where roads and pedestrian evacuation routes do not intersect, prohibition of vehicle evacuation is not necessary.

In this research, evacuation was assumed to be performed by walking. The speed of evacuees in this case was the speed of walking of evacuees from the Japan Institute for Fire Safety and Disaster Preparedness (Table 3).

The National Land Agency of Japan/NLA(1998) suggested that the time required to evacuate was set at human walking speed. For safety reason, it is preferable that the speed be adjusted to the velocity of the elderly or disabled in areas where many such residents live. Based on that, the speed of walking of an evacuee, which was used for the model, was 0.751 m/s. It was assumed that if the evacuees with the slowest speed can reach the evacuation destination, other evacuees that move faster could reach the ESB consequently.

Table 3.Evacuee walking speed

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

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

3.6 Estimated Time Arrival

The estimated arrival time of tsunami (ETA) is the time required for the first tsunami wave to propagate from its source to a given point on the coastline (IOC, 2008a). It is defined as the time lasting from the end of the earthquake to the time of arrival at the shore of the first huge destructive wave, so that travel time is considered as arrival time. Tsunami travel time will depend on the types of tsunami. It can take minutes or even hours.

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

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

3.7 Evacuation Time

Evacuation time is the available time for evacuation. It is defined by knowing the remaining time after the issuance of a tsunami warning to the arrival of tsunami waves.

Charnokol and Tanaboriboon (2006) and Post *et.al.* (2009) explained that there are four components of evacuation time which consist of decision time (time between event detection and official/institutional decision to warrant an evacuation), notification time (evacuation warning), preparation time or the reaction time of the population (RT), and response time or actual response time (RsT) which is the time required for respondents to physically evacuate to safer areas. Additionally, Post *et.al.,* (2009) stated that technical or natural warning signs (ToNW) will be determined by institutional/official decision time (IDT) and notification time (INT). Generally, human response can be based on natural or technical warning signs. It requires knowledge of tsunami warning signs like earthquake or sudden drop of sea level and the knowledge of what to do such as evacuation by community.

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

RsT= ETA – ToNW - RT …………… (4)

ToNW= IDT + INT …………… (5)

RsT =ET = Time required for people to evacuate

ETA =Estimated Tsunami Arrival (40 minutes)

ToNW =Technical or Natural Warning (8 minutes)

RT = Reaction Time of Population (10 minutes)

IDT =Institutional Decision Time (Time issuance from INA-TEWS, 5 minutes)

INT =Institutional Notification Time (Time issuance by local government, 3 minutes)

For this research, 10 minutes was taken as the time needed for people to react and 22 minutes for people to go to shelter buildings. Regarding the evacuation process, this 22 minute-evacuation time was split into 17 minutes travelling on the network to shelter buildings and 5 minutes climbing up to the upper floor (Figure 3).

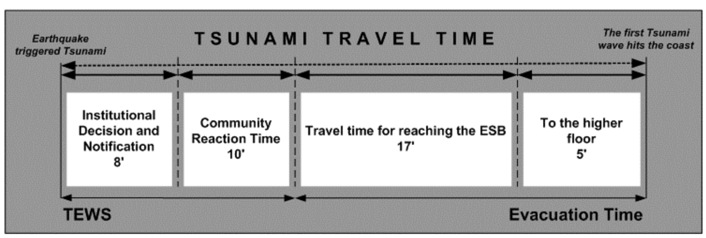

Figure 3.Time allocated for tsunami evacuation in Cilacap

Source : Modified from Charnkol and Tanaboriboon (2006), Post *et. al.*(2009), Widyaningrum (2009)

3.8 Evacuation Model

Evacuation is a main protecting action in disaster occurrence such as floods, landslides, tsunami, volcanic eruptions, etc. It is defined as the act of evacuating or leaving a place because of a real or anticipated threat or hazard (Sorensen and Vogt, 2006). In this research, the evacuation modeling took into account the capacity and accessibility of the evacuation shelters.

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

Accessibility modeling tried to calculate the capacities and service areas of the destination location using two scenarios -daytime and night-time-. Service areas are defined as a region that encompasses all accessible streets especially streets that are within a specified impedance. In this case, travel time was

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assigned as cost attribute of the impedance (Figure 5.16).

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

3.8.1 Service Areas of ESBs

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

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

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

(a) Service area based on evacuation time (time area)

It defines the total number of people in certain areas who are able to reach the evacuation building in a given time (represented by L1 in Figure 4). To develop service area based on evacuation time to ESB, the function of New Service Area tools of Network Analyst was incorporated. In this case, a 17-minute service area for a point includes all the streets that can be reached within 17 minutes from that point.

(b) Service area based on capacity

It defines the number of people in certain area who can be sheltered in a shelter building in a given time (represented by L2 in Figure 4). It is derived from the tsunami evacuation building capacity calculation (TEBC). Service area based on the number of people who can be sheltered in ESBs was developed by calculating number of people in the nearest tessellations. The coverage of this service area was created by joining the tessellation, which participated in the calculation. The shortest travel time and the number of people in each tessellation were the parameters to create the service area based on capacity.

Based on those point of views, there are two scenarios for defining the service area. First scenario related to the service area based on evacuation time (time area), represented by L1 and second scenario related to service area based on capacity, represented by L2. In fact, the service area based on evacuation time (L1) maybe broader than service area based on capacity (L2), see Figure 4 (left) or in vice versa, Figure 4 (right). However, the service area based on capacity will be assigned as the service area of the shelter building since the main focus of the service area is the capacity of the building.

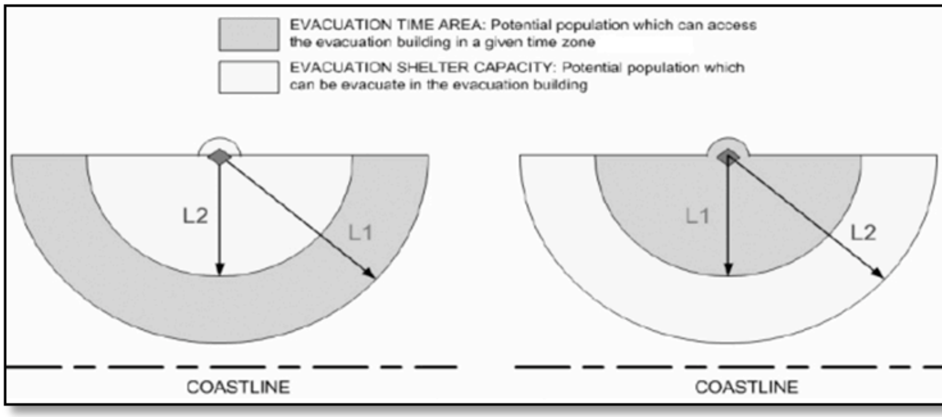

Figure 4.Service area coverage

Source : Tsunami Mitigation Guidelines for Evacuation Building – Japan (2005) *after* Widyaningrum (2009)

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

1. By using Service area command of Network Analyst, the service areas of ESBs were created based on 10 minute travel time. The result is like in Figure 5(a).
2. In Figure 5(a), the blue coverage refers to the service area of ESB based on travel time. The red cross refers to ESB.
3. Using this service area as a basis, Find Closest Facility command of Network Analyst was used to find the ESBs from centroids (source of evacuees) which were located inside the service area based on time. The result can be seen in Figure 5(b). The dark blue lines in Figure 5(b) show the routes from each tessellation (dark blue dot) to ESB (red cross).

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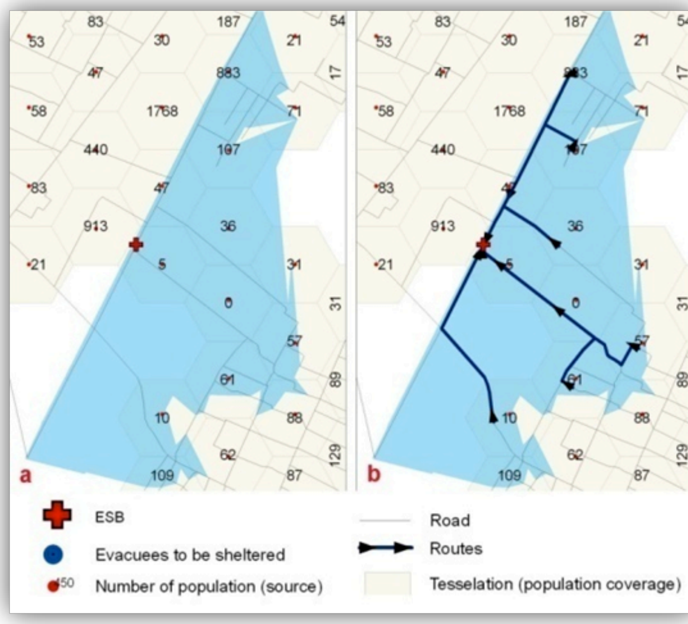

Figure 5.The process of creating service areas based on travel time

4. The next step was to check, compare and select which population (centroids) could be loaded to ESB by considering the shortest travel time needed, number of people, and ESB capacity.
5. The population in each centroids was then calculated and added so that the number of people to be sheltered would not exceed the capacity of the existing ESB (Table 4). It is possible that not all population in the service areas can be sheltered to certain ESB. It really depends upon the capacity of ESB and depends upon how fast people can go to particular ESB.
   a) There are 1,308 people in the service area based on travel time. As we know, ESB can only cover 350 evacuees, so in this case we should select evacuees from particular tessellations, which have the fastest travel time and could be sheltered in ESB.
   b) Table 4 (in grey shading) shows the evacuees that can be sheltered in ESB (the tessellation ID : 38, 40, 39, 37, 41)
6. The following step was to create service areas by using the selected centroids of tessellations (evacuees) in point 5b. In Figure 6(a), the blue polygons refer to service area of ESB based on capacity.
7. This coverage is used as a basis for the next step, establishing the most effective routes of tsunami evacuation by using Find Closest Facility command in Network Analyst. The result can be seen in Figure 6(b).

Table 4.The attributes of service areas

Tessellation ID	Name	Minutes (Minute)	Length(m)	Pop_day(person)
38	**Graphic Pick 5 - Graphic Pick 46**	**1.38**	**47.88**	**5**

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40	**Graphic Pick 7 - Graphic Pick 46**	**2.16**	**88.98**	**47**
39	**Graphic Pick 6 - Graphic Pick 46**	**4.07**	**158.37**	**36**
37	**Graphic Pick 4 - Graphic Pick 46**	**4.45**	**151.59**	**0**
41	**Graphic Pick 8 - Graphic Pick 46**	**6.52**	**255.12**	**107**
42	Graphic Pick 9 - Graphic Pick 46	6.76	278.72	883
34	Graphic Pick 1 - Graphic Pick 46	7.00	284.20	10
35	Graphic Pick 2 - Graphic Pick 46	8.90	301.62	61
36	Graphic Pick 3 - Graphic Pick 46	8.98	304.61	57
	Total population			**1,308**

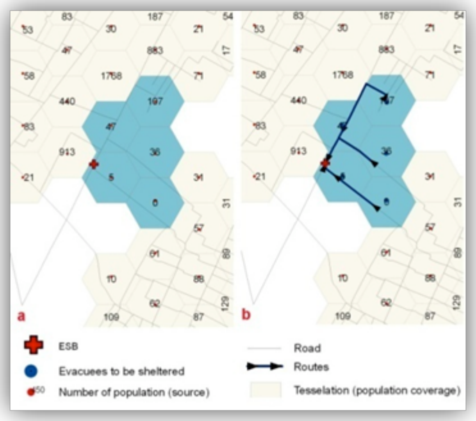

Figure 6.The process of creating the service area based on capacity

3.8.2 Additional ESBs

This process will attempt to define the number and spatial distribution of evacuation buildings that should be added. Service Area of Network Analyst was utilized in order to allocate additional ESBs for high population density areas. The process was started from the centroid of tessellation as an origin of people to move. From these centroids, service areas are then developed by considering the 17-minute travel time and one-way rule in network for avoiding the shoreline direction, meaning that the evacuee will move away from centroid to go further inland, Figure 7 (left). The service areas refer to the polygons or coverage, which were created by joining the extent of road segment which can be reached in 17 minutes by evacuees, Figure 7 (right).

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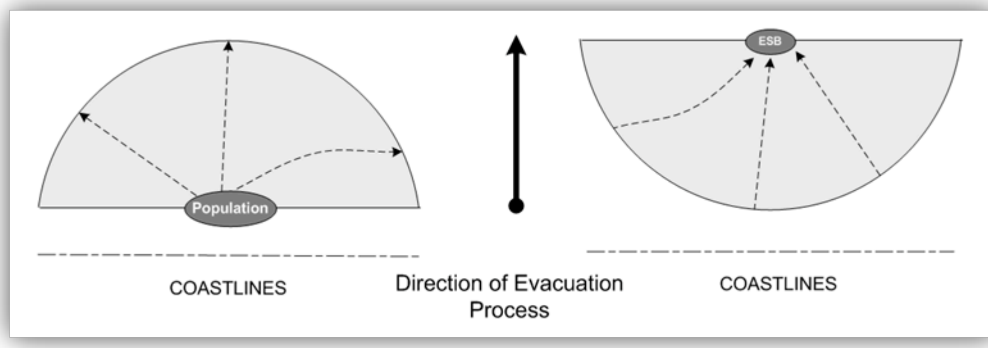

Figure 7.The service area creation from different sources, from evacuees (left) and to existing ESB (right)

The arrow in Figure 7 refers to the direction of people in evacuation process to run away from the shorelines. The dash lines in each half-circled polygon refer to the network used by evacuees to evacuate. The service area of population and ESB correspond to the accessible areas for each point. During a disaster, the population will move away from the shorelines to find the closest facility to evacuate. Meanwhile ESB serves a particular area or population who are in the most at-risk condition during a disaster.

Figure 8 illustrates how the locations of additional ESBs were selected. The steps were as follows:

1. The red cross corresponds to the point of origin where evacuees start to move to find the closest ESB. From the points of origins, service areas were developed using Service Area command of Network Analyst. The 17-minute travel time was used as impedance for the process. The direction of travel can be set based on behavior of people during disaster. Usually, people will run away from the shorelines.
2. The blue polygon in figure 8(a) shows the accessibility of population center (centroids) including all accessible streets which can be reached within the available travel time.

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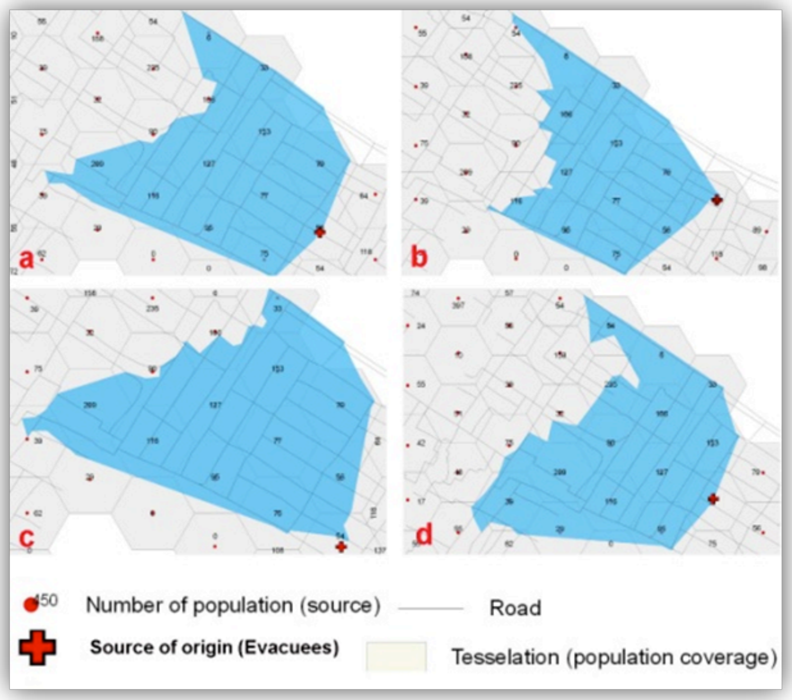

Figure 8. The process of deriving service areas (step 1-3)

3. The service areas were then built for many centroids by considering the capacity of additional ESBs required, because people from these tessellation centroids later would be added to fulfill the capacity of ESB. The results can be seen in Figure 8(b, c, d). The capacity of additional ESBs was adjusted to meet the required capacity. It would depend on the construction cost, the available of open spaces, and also the existing buildings which can be retrofitted. Even though, retrofitted will generally be more difficult rather than to build a new tsunami-resistant building, it still can be one alternative for evacuation purposes.
4. The previous process resulted in many polygons of service areas. The following Figure 9(a) shows the service areas from four centroids. Each polygon was converted to shape fileand an attribute was added in the shapefile, given 1 value (see Figure 9(b) in red dash box).

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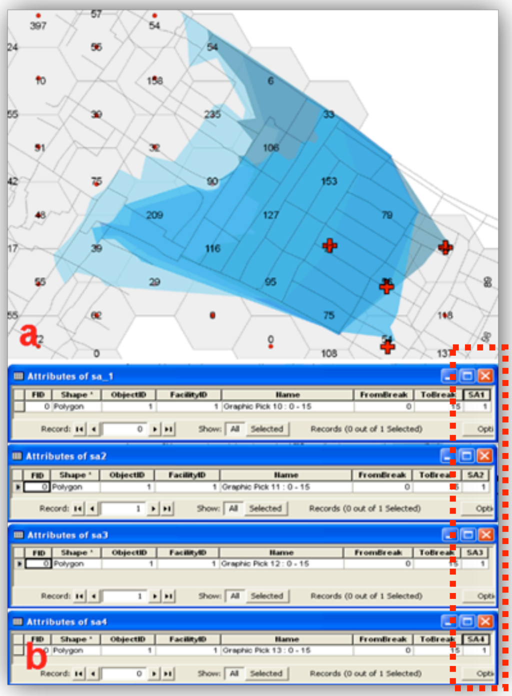

Figure 9.The process of deriving service areas (step 4)

5. All polygons of service areas were merged using Union command of ArcGIS. The result is shown in Figure 10(a)
6. The new attribute was added in the last shapefile and the value came from the total value of polygon attributes of service area 1, 2, 3 and 4 in Figure 10 (b) in red dash vertical box.
7. The polygon which has the highest value in its attribute refers to the most accessible polygon (red dash horizontal box in Figure 10(b)). The proposed locations for additional ESBs were determined by looking at the most overlapping areas of the service areas.

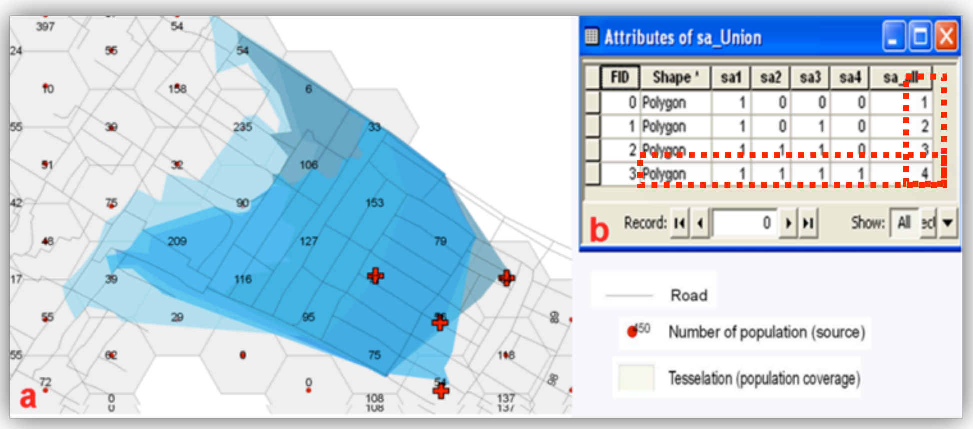

Figure 10.The process of deriving service areas (step 5-7)

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8. The overlapping area (the red polygon) indicates the most accessible area for developing additional ESB (Figure 11(a)).
9. The centroid of the most overlapping area (the red dot inside the red polygon) would be proposed as additional ESB. The attribute table of those red dot is displayed in Figure 11(b).
10. The next step was to check the suitability of location using land cover map (Figure 12). This figure shows land cover map with proposed location for additional ESB (red dot) and red polygon refers to the service area of the proposed ESB (union polygon from step 5).
11. By examining Figure 12, it was obvious that the areas inside the red polygon consisted of residential areas, open spaces, mix crops and paddy. The proposed location of additional ESB was located in the residential areas, which was not suitable for additional ESB. Therefore, the location of additional ESB would be shifted to open/vacant areas. The precise location of the additional ESB can be at any location in red polygon because all locations in this polygon are accessible from centroids (step 1-10).

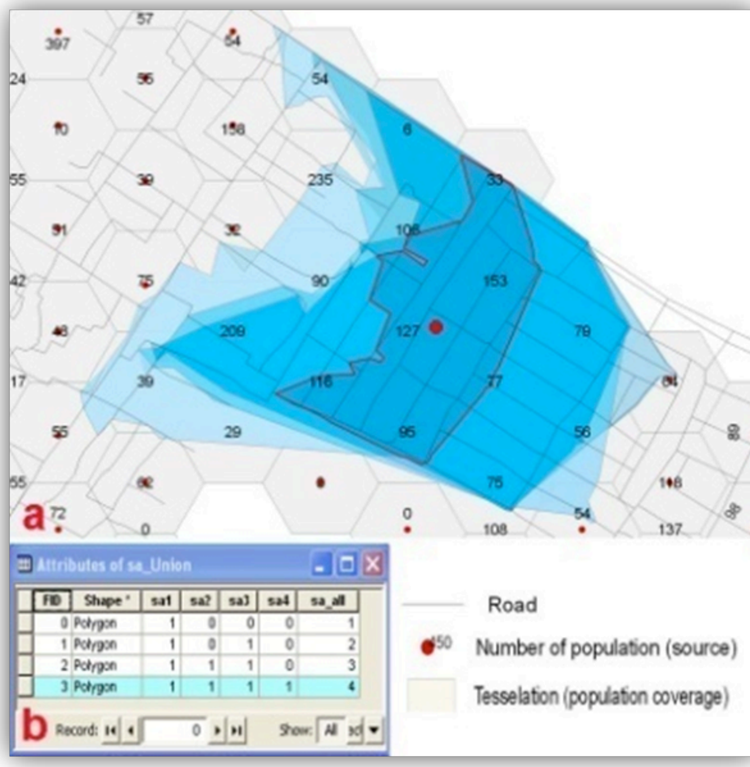

Figure 11.The process of deriving service area (step 8-9)

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

(a) The first priority was open/vacant area since it has not occupaid yet, so it would be the most suitable location for an additional shelter building.

Figure 12.The proposed location of additional ESB

(b) The second priority would be the existing facilities in the surroundings. Those facilities could be schools, government offices, community centers, recreational facilities, sports complexes, libraries, museums, police or fire stations, mosque, etc. Retrofitting of those public facilities was the other alternatives for additional shelters.

(c) The next alternative was mix crops. Mix crops are usually located near settlements and consist of various plants such as mango trees, banana trees, coconut trees, etc. These areas were less economical compare to the paddy field.

(d) Paddy, ponds, and river were not suitable for additional shelters regarding the unsafe condition when these areas strucked by tsunami waves. Paddy and pond were less suitable for an additional shelter because commonly they are located in low-lying areas and their bearing capacity of the soil are less appropriate for tsunami's resistant building. Bearing capacity is the capacity of soil to support the loads applied to the ground. Meanwhile, tsunami would be able to enter the river with more destructive waves caused more destruction to the surrounding area.Thus, river was not recommended for shelter building locations.

4. RESULTS AND DISCUSSION

4.1 Existing ESBs

The number of people who sheltered was different during daytime and nighttime scenarios. It is related to the different concentration of people regarding their activities over the day. During the day, there will be more people outside the houses such as at schools, offices, workplaces and other facilities, meanwhile during the nighttime more people stay in the houses.These scenarios made different existing ESB capacity during daytime and nighttime.

From the fieldwork's result, there are four buildings which can be functionally used as evacuation shelter buildings, namely Al Azhar (an elementary school), STIKES (an academy), Al Islah (a mosque), and Sri Mukti (a senior high school). These buildings are called existing ESBs. Table 5 describes the ratio of the existing ESBs's population during daytime and nighttime by considering service areas based on travel time. Figure 13 shows the service areas of each ESBs based on travel time only (represented by the blue, green and grey areas), red cross symbols refer to the existing building which can function as ESBs. Meanwhile, Table 6 shows the number of population who can be sheltered in the existing ESBs based on capacity.

Table 5. The ratio between number of population during daytime and nighttime by considering service areas based on travel time

Name of ESB	Total Number of People in tessellations (persons)	
	Daytime	Nighttime
Al Azhar	1,410	624
STIKES	1,265	468
Al Islah	1,909	1,477
Sri Mukti	1,302	1,377
Total	**5,886**	**3,946**

Source: Data Analysis (2009)

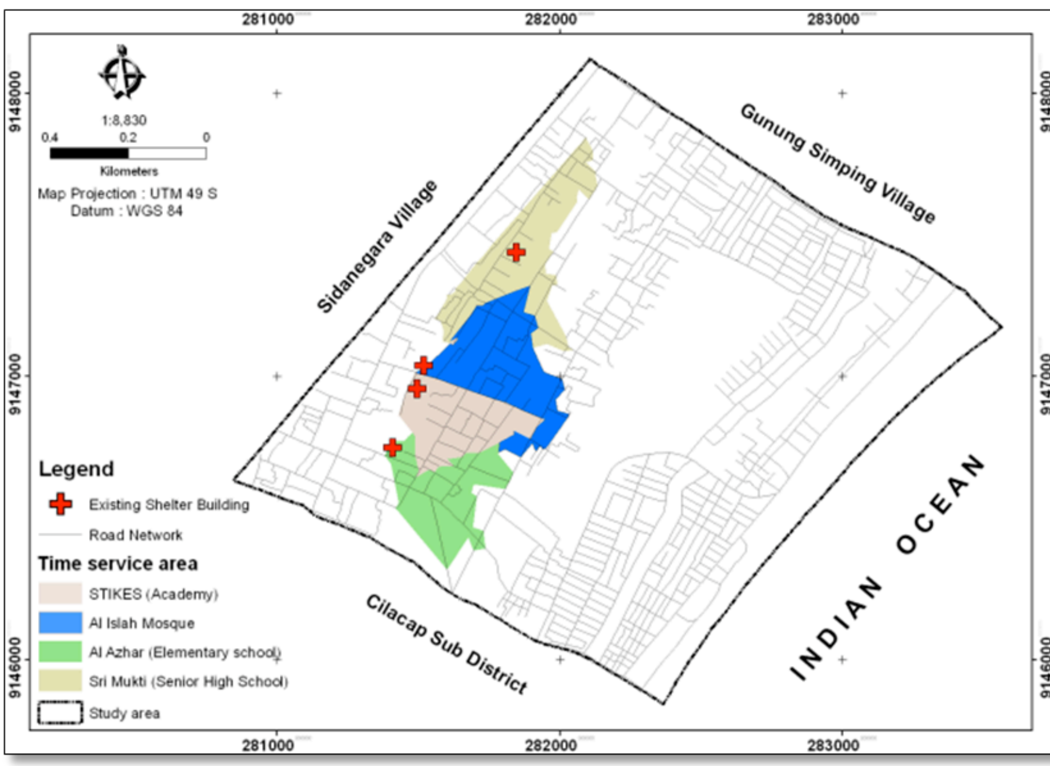

Figure 13.Service areas for each existing ESB considering a 17-minute travel time

Figure 14.Service areas based on travel time and capacity during daytime

Table 6.The number of evacuees who can be sheltered in existing ESB during daytime and night-time by considering capacity of ESB

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

Source: Data Analysis (2009)

Note: TEBC= Tsunami Evacuation Building Capacity. ESB= Evacuation Shelter Building.

Figure 15.Service area based on time and capacity during nighttime

Figure 14 and 15 show the service areas of ESBs based on capacity of the buildings. It means not all the evacuee in the service areas based on time (Figure 13) can be sheltered in the existing shelter buildings.Table 5 and 6 shows only 91% (5,357 evacuees from total 5,886) can be evacuated in the existing ESBs during daytime scenario and only 66% (2,623 evacuees from 3,946) could be sheltered in nighttime scenarios. Therefore, 529 evacuees in daytime and 1,013 evacuees in nighttime scenarios should find other shelters. The number of people sheltered in three existing ESBs (Al Azhar, STIKES and Sri Mukti) were far below the maximum capacity due to the time constraint (17 minutes). Time constraint inhibits people from outside the tessellations for reaching those ESBs. Thus, additional shelters should be added to rescue the rest of evacuees.

4.2 Additional ESBs

The process for determining the suitable locations for additional ESBs was begun from the centroid of each polygon. The direction of movement was away from centroids by applying the one-way rule: people should avoid shorelines direction and go further inland. The deriving of service areas was conducted by considering 17-minute travel time and the maximum capacity of additional ESB. The proposed locations for additional ESBs were the overlapping areas of those service areas. The overlapping areas indicate the areas whichare the most accessible areas. These areas will be the proposed locations for additional ESBs. Furthermore, those purposed locations for additional ESBs should be suitability checked by using the landcover maps.

The result of the process in deriving additional ESBs can be seen in Figure 16, where 14 additional ESBs were proposed to be built for day population scenario. While, 18 additional ESBs were proposed for nighttime scenario, see Figure 17. The capacity of these additional ESBs varies depending on the number of people in the surrounding areas, the available travel time and the number of vertical evacuation structures located in the areas (Table 7 and 8).

FEMA (2008b) stated that the size considerations of ESBs could necessitate an adjustment of the number and vertical space of evacuation structures. In fact, determining large of an additional ESB, choosing the design and constructing a vertical evacuation structure for short-term refugee, or for longer periods of time (involving supply and managementof evacuees), are emergency management issue that must be decided by the state, municipality, local community, or private owner. In this case, since the TEBC was calculated from the number of people in each tessellation, so the number of TEBC was equal to the number of people in the areas.

Table 7.The capacity of the proposed additional ESB for daytime population scenario

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

Source: Data Analysis (2009), Note: Nr=Number.

Table 8.The capacity of the proposed additional ESB for nighttime population scenario

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

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09	861	**18**	778

Source: Data Analysis (2009), Note: AESB=Additional Evacuation Shelter Building

Figure 16 and 17 show proposed locations of additional ESBs during daytime and nighttime population scenarios. The green cross symbols in those figures represent the existing ESBs, and the grey and orange areas represent the service areas of those existing ESBs. Meanwhile, the red cross symbols represent the additional ESBs recommended for this location, the blue and brown areas show the coverage of each additional ESBs.

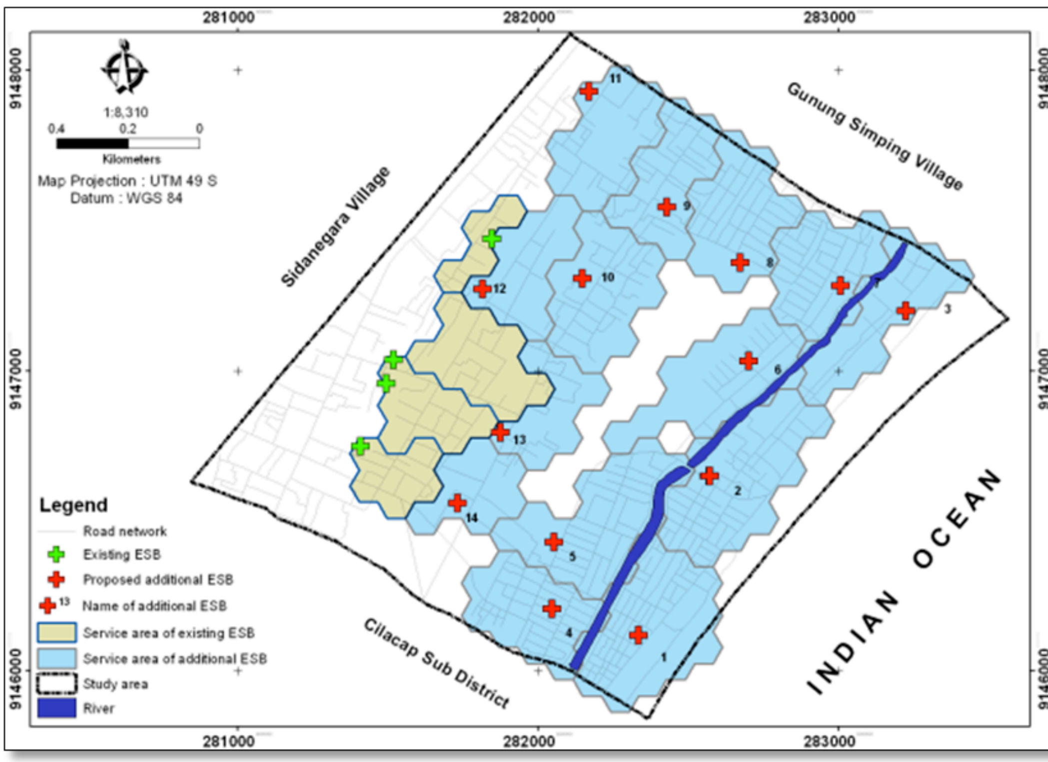

Figure 16.Distribution of existing ESBs and additional ESBs using day population scenario

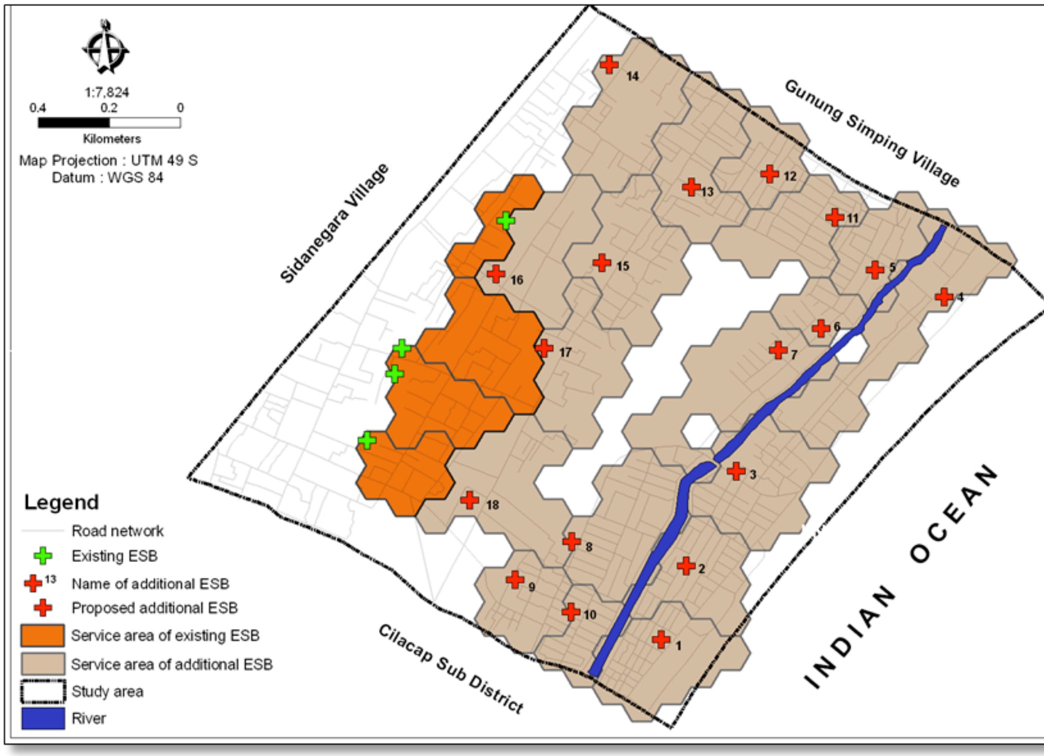

Figure 17.Distribution of existing ESB and additional ESB using night population scenario

The number of occupant will define the size of ESBs. Furthermore, type of occupancy and the duration of occupancy will also determine the sizing of vertical shelters (FEMA, 2008b). The decision on choosing the design and construction such vertical structures is an issue that should be involved the state, municipality, local community, or even private owner as part of public policy decision making since it is not always feasible to construct new building for vertical evacuation purposes due to land ownership and economic constraint. In that case, retrofitting existing building and corporation with private sector can be alternative solutions. Although retrofitting of existing building can be more expensive but in some extend, it is the most possible option. The buildings, which are used as vertical evacuation, should have certain structural attributes that are associated with tsunami-resistant structures and also seismic effect.

By considering the number of population, GIS approach and landcover map, the author selected the proposed location for additional ESBas illustrated in Figure 18. Figure 18 shows the example of proposed location for ESBs thatlocated in the settlement area, represented by black dot. This meanswe have to relocate people if we want to build an evacuation building in that location. On the other hands, relocation of people would be the last option since it may not always feasible to relocate community to other locations due to social and economic issues

To overcome such kind of problem, the author used expert judgement approach to ascertain location of ESBs by using land cover map. From this point of view, there were two options available (represent by the red cross symbols in Figure 18), first option was to build an additional ESB on the open area, and the second option was to retrofit existing school for an additional ESB. The choices between those various options (open area or school building) will be depending on emergency response planning and needs of the community, the financial project situation of the local municipality, and the owner consideration such as building’s structure.

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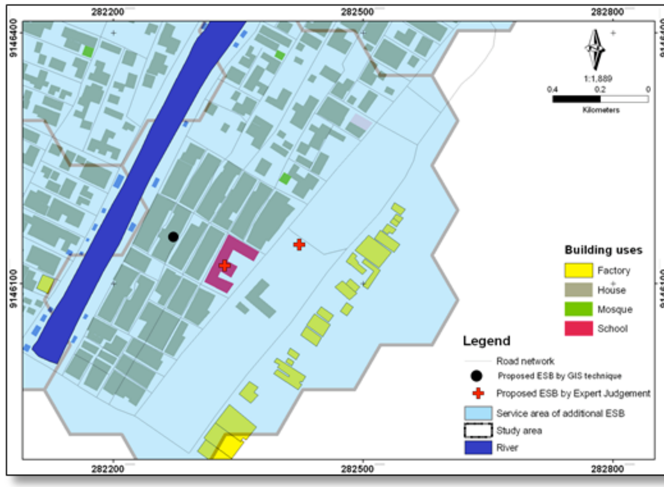

Figure 18. Expert judgement in determining proposed location of additional ESB

4.3 Evacuation Route

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

Finding Closest Facility of Network Analyst was used to develop the most effective routes. This effective route was developed by considering the shortest travel time. The information, which was given by this command, includes the routes to go to the nearest shelter destination, the time needed to travel and the distance between points of origin up to the evacuation destination. Figure 19 and Figure 20 illustrate the evacuation routes. The green cross symbols in those figures represent the existing ESBs, and the grey and orange areas represent the service areas of those existing ESBs. While, the red cross symbols represent the additional ESBs recommended for this location, the blue and brown areas show the coverage of each additional ESBs, the symbology is related to Figure 16 and 17. Further, red dots represent the center of population and the black arrows show the direction to escape to the nearest shelter building.

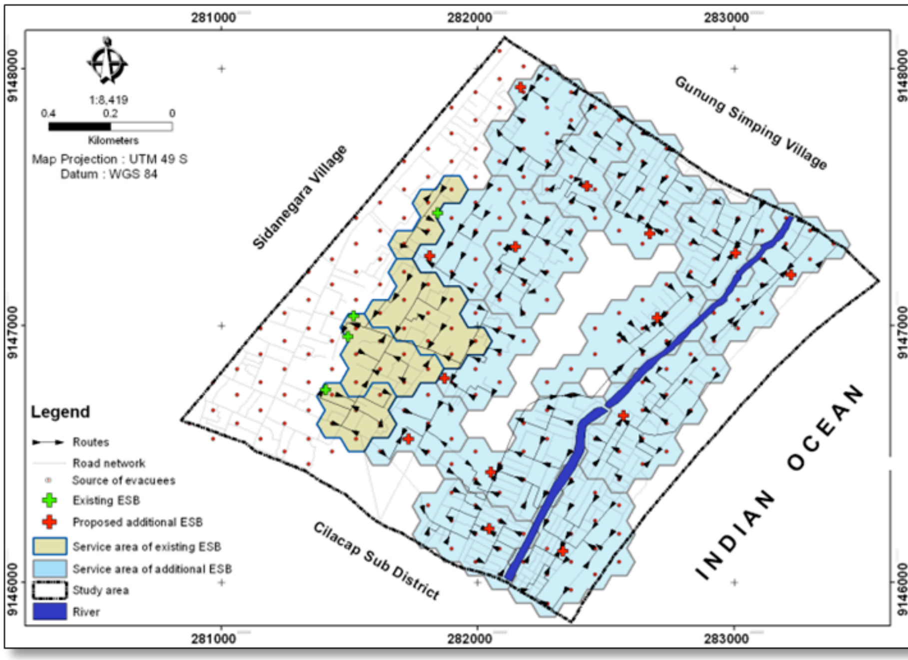

Figure 19.Evacuation routes for each allocated ESBs using day population scenario

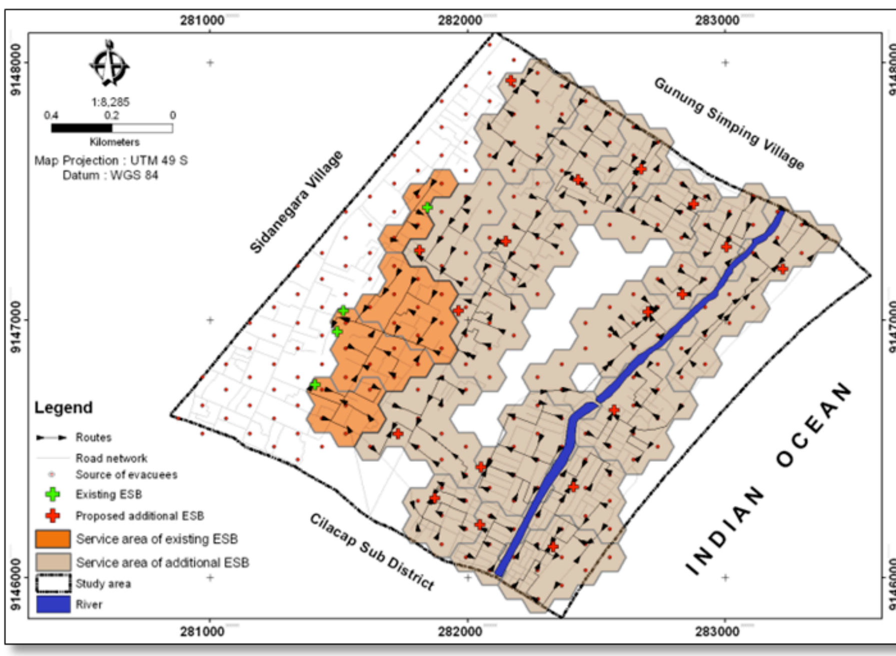

Figure 20.Evacuation routes for each allocated ESBs using night population scenario

In the evacuation route, detailed road networks were necessary. The accessibility to an ESB will require sufficient evacuation routes so that evacuees can reach the ESBs in time. In determining the evacuation routes, hazardous areas should be avoided as many as possible. For example, river which is located near the coastal areas (Figure 21) was assumed as a barrier meaning that evacuees should avoid these areas or the existence of river obstructs people to migrate further inland. In these cases, the one-way

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rule and direction to avoid shoreline direction could not be applied. Hence, evacuees can run to any directions as long as the destinations could be reached in less than 17 minutes.

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

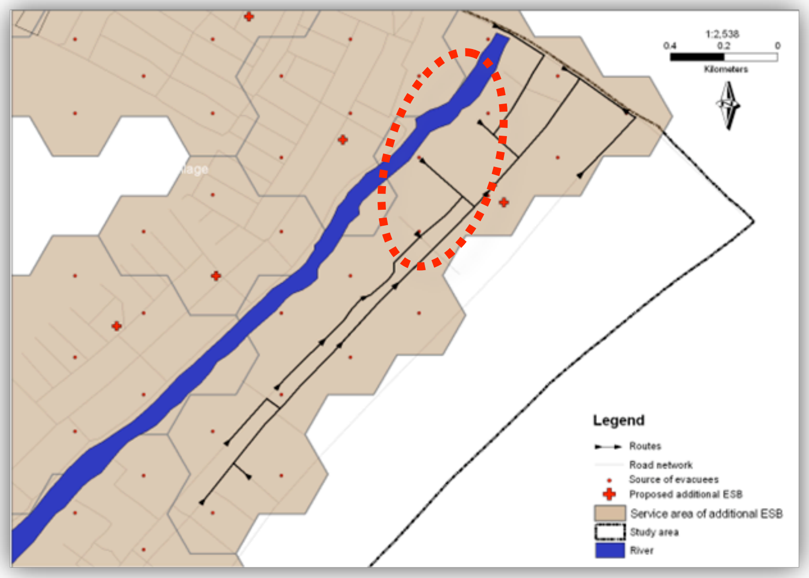

Figure 21.River as barrier that should be avoided by evacuees

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In defining the ESBs and additional ESBs, the difference in population distribution over the day must be considered. Distribution of population is more dynamic over daytime, due to the concentration of people on the business establishment, offices, and settlements while the distribution of population mostly consentrate on the settlement area during nighttime. For instance, in the commercially areas or office buildings, there will be a higher number population during daytime and it will be decreased significantly during the nighttime.

The proposed locations for additional ESBs were determined by looking at the overlapping areas of the coverage, which have been built for each centroid of tessellations. The overlapping areas indicate the most accessible areas. These areas will be the most approprite location for additional ESBs. Before applying the most overlapping areas as the most approprite location for ESBs, the suitability of location for ESBs were checked using landcover map. The capacities of additional ESBs were adjusted to meet the required capacity. It will depend on the construction cost, the available of open spaces, and the availability of existing buildings, which can be retrofitted.

In determining the ESBs and additional ESBs, there are some characteristics of building required to function it as tsunami evacuation shelter, such as:

a) Building construction should be earthquake and tsunami-resistant**.**

b) Space for living in building structures must be elevated above the wave height and the buildings support areas are parallel to the expected direction of flow. Spaces below the design flood elevation must be free from obstruction.

c) Buildings for evacuation shelters can be single-purpose, multi-purpose facilities, single-hazard, and multi-hazard considerations. The surrounding communities can set vertical evacuation structures for general use.

d) Sufficient spaces were needed for evacuation shelter buildings so that they must be able to load a large number of people in a short time frame.

e) People should easily access the buildings and the routes to the buildings should be well marked.

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

In addition to the structural design of ESBs and addtional ESBs, the most important thing to consider is the evacuation route to reach those ESBs. In designing the significant evacuation routes, the hazardous area must be avoided, such as river and bridge over the river that located in theshorelines (estuary) areas.

5.2 RECOMMENDATION

The realistic model from network analyst is determined by the detailed input data of road network, network attributes and population data. The detailed road network will enhance the model since the travel will be carried on from the centroids of tessellations to the closest network. In line with developing more detailed road networks, more detailed network attributes will result in a better evacuation model. Detailed network attributes used in this research include cost (travel time) and restriction (one-way rule and barrier). Another factor that important to improve the model,is to include barrier information such as bridges locations, danger areas, obstructions, etc. They refer to the areas, which should be avoided by evacuees or for sitting the vertical evacuation structures.

It is also important to investigate the effectiveness of the different road network structures under emergency, since evacuation performance is largely dependent on the network structure and the number of vehicles produced in an emergency planning zone. The road network structure in emergency circumstance will need thoroughly field observation and extensive data regarding road network and traffic condition such as traffic volumes, traffic speed, vehicle concentrations and occupancies.

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

This evacuation model can be improved further if congestion areas can be identified by calculating the number of evacuees that passes a certain road or travel path segment. Moreover, if we can formulate the problem in optimization form, we can answer such *what-if* question, as the followings: what is the effect of increasing (or decreasing) the capacity of ESBs?, what changes when an ESB is removed or added from the network?, what happened if the new roads are constructed?, and what will be the result of an increase (or decrease) of population?

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