Determining Evacuation Service Areas and Evacuation Route Risk Level as Disaster Mitigation Plan using GIS – based Software in Hyuga, Japan

Indradi WIJATMIKO*, Keisuke MURAKAMI**

Abstract

In recent years, studies on tsunami mitigation and the tsunami emergency management have been frequently conducted. Further, many of tsunami mitigation methods have been introduced to minimize assets damages, injuries or fatalities. In case of Tsunami, the main point is to evacuate victims from inundated areas to the evacuation places or secure areas as soon as possible. However during tsunami attack, refuges are often rushing to their shelters without considering safety of evacuation routes, thus inappropriate decision of evacuation route may lead to the injuries or fatalities. Therefore the aim of this study is to provide spatial information on evacuation route with its risk level by using geographic information system (GIS).

Through GIS, evacuation service areas, recommended evacuation routes, and road risk level can be determined. In this study, evacuation service area refer to zones surrounding selected evacuation places that achievable by walking people with average speed in short amount of time. While the road risk level gives information on the safety condition in each routes, which is scaled 1-10 (1 refers to the safest route). Hyuga city in Miyazaki province in Japan is taken into study area. Moreover, this area will be divided into 5 subzones in order to carry out more accurate investigation.

Network analysis in Arc GIS 9.2 was used to generate service areas based on tsunami's travel time and human's walking speed. Subsequently, inside the evacuation service areas, risk level were calculated by analyzing soil conditions, road width, slope elevation and inundated areas. The output indicated that risk level in Hyuga city are between 2-8, and blocking some roads due to the dangerous areas effected on evacuation service area deduction.

Keywords: *Evacuation Service Areas, Road Risk Level, Geographic Information System, Evacuation Routes.*

INTRODUCTION

Tsunami attacks are categorized as one of the natural disaster which cannot be precisely predicted on where and when it will happen. And as consequences of its sudden and quick appearances, many refugees died on their neighborhood or on their ways to shelter or evacuation building. Moreover, Lacks of evacuation simulation, inappropriate choice of evacuation route and the unawareness of tsunami appearance are the most responsible factors to these losses. However, many tsunami mitigation and tsunami awareness method have been researched lately to overcome those problems.

As described by Tomotsuka Takayama (2005), there were two countermeasures against tsunami disaster; the first one is the hard countermeasures which are represents by tsunami breakwater, water gates, sea walls and also dikes along coastal line area. While the second ones is the soft countermeasure, which is hazard map with information on depth of inundation area, arrival time of tsunami and locations of the shelters or evacuation building. Recent researches on soft counter measures are conducted by using geographic information system (GIS), either to simulate or to analyze the impact of tsunami attack. GIS gives advantages on presenting information that will be easily understood by reader. In 2007, E. Alparslan and friends conducted a study about GIS model for settlement suitability regarding disaster mitigation, with the case study in Bolu, Turkey. Further, it was investigated that GIS model could performed as useful tools to conduct spatial analysis, such as evaluate the existing settlement, creating the settlement suitability map (SSM), analyze the SSM against road network, etc. The objective was to investigate the suitability of settlement with the relation to the disaster mitigation by implementing GIS model. And it was concluded that developing GIS in this study has been proved to be very useful both in mitigating disaster and in planning the future urban expansion.

Previous studies on spatial method in tsunami evacuation management rarely discussed on the safety of evacuation routes. However, this topic is essential during the tsunami attack. Inappropriate choice of evacuation route may result in fatalities. Therefore, study in spatial analysis to illustrate the risk of evacuation routes during tsunami attack should be carried out. Thus, areas that can be serviced by evacuation places or shelters should be determined first.

*) Lecturer and Researcher, Civil Engineering Department, University of Brawijaya, Indonesia.
**) Associate Professor, Interdisciplinary Graduate School of Agriculture and Engineering, University of Miyazaki, Japan.

STUDY AREAS

Hyuga city is one of the harbor cities in Miyazaki Prefecture, Kyushu Island, Japan. It is located at southern west of Japan and as a consequence it has many potential of tsunami attack. In addition, there are three existing areas of seismic activity around the Kyushu Island that may execute large tsunamis, namely: 1) Tonankai-Nankai, 2) Hyuganada North and 3) Hyuganada South.

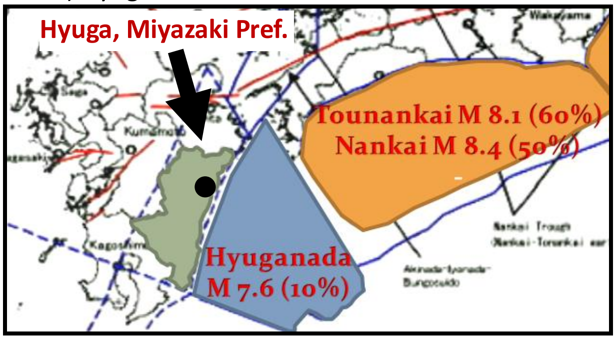

Fig.1. Seismic activities around Hyuga City

As can be seen in figure 1 above, even though Tonankai-Nankai is not the nearest seismic activity around Hyuga city area, however historically 60% of Tonankai earthquake was around 8.1 Richter scale, and 50% of Nankai earthquake was around 8.4 Richter scale. In addition, the closest seismic activity, which are Hyuganada north and Hyuganada south, have lower historical seismic strength compare to Tonankai-Nankai. Therefore in order to simulate the worst case scenario on tsunami attack in Hyuga city, this study applied Tonankai-Nankai seismic activity as the generated tsunami source.

Hyuga city is an intermediate city with a total area of 336.29 km^2 and the density of more than 200 persons per km^2. Consequently, due to effectiveness and precisions of analyzes, 5 districts in Hyuga city are taken as study areas, which are Sone, Haripou, Hososhima, Hataura and Kajiki. Each of study area, which can be seen in figure 2 below, is subjected to have same similar behavior on procedure and parameter in establishing service area and determining risk rank of evacuation routes.

Fig.2. 5 Study areas in Hyuga City

TSUNAMI HAZARD MAP

Tsunami hazard map can be done by reassembling the following data in GIS, namely: 1) digital elevation modeling (DEM), 2) road network, tunnel and railways, 3) river and ocean, 4) land use region (include resident area), 5) tsunami inundation area, and 6) evacuation and shelter places.

DEM 2500m data were collected from the government of Miyazaki prefecture in *.thm format, while infrastructure and shelter places data were given by local government in Hyuga City. There are two types of shelter places which are suggested from local government, first is the shelters which were made in case of earthquake or flood disaster, while the second one is public buildings which can be used as a evacuation building during tsunami attack, such as schools or community hall. However, public buildings in the inundate areas were not defined as evacuation buildings. In addition, ASTER satellite data were used on determining land use classification and the tsunami inundation data were calculated using Tonankai–Nankai seismic activity scenarios without any hard counter measures.

During this study, Arc GIS 9.2 was used to perform spatial analysis. Therefore, each data need to be converted into shape file format with the referenced coordinate at UTM 52E zone. Reassembles tsunami hazard map are carried out by building triangular irregular network (TIN) from DEM and buffer it with other data layers such as road network, tsunami inundation area, evacuation places, etc. these steps can be seen in figure 3 below.

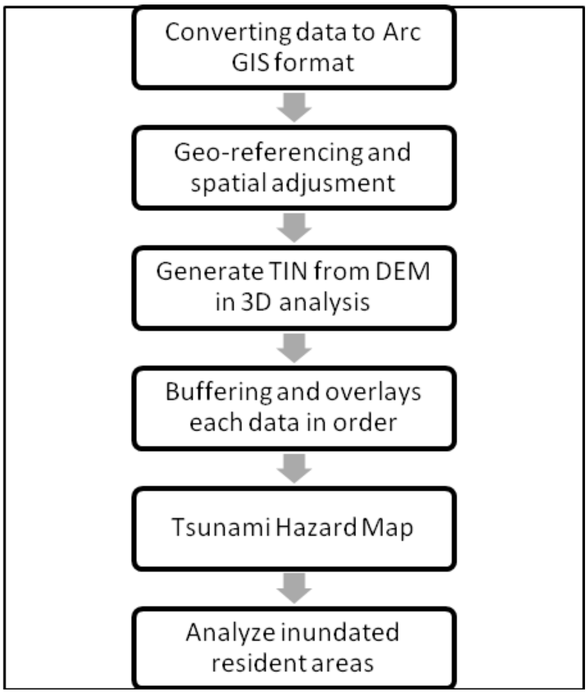

Fig.3. Tsunami hazard map flowchart

After reassemble tsunami hazard map, it was found that Sone District has the highest risk against tsunami attack. Tsunami hazard map in Hyuga City can be seen in figure 4 below: of tsunami wave from the Tonankai-Nankai seismic activity areas to the shoreline of Hyuga city will approximately takes 25 minutes. Thus, by deducting 10 minutes for early warning system, the adequate

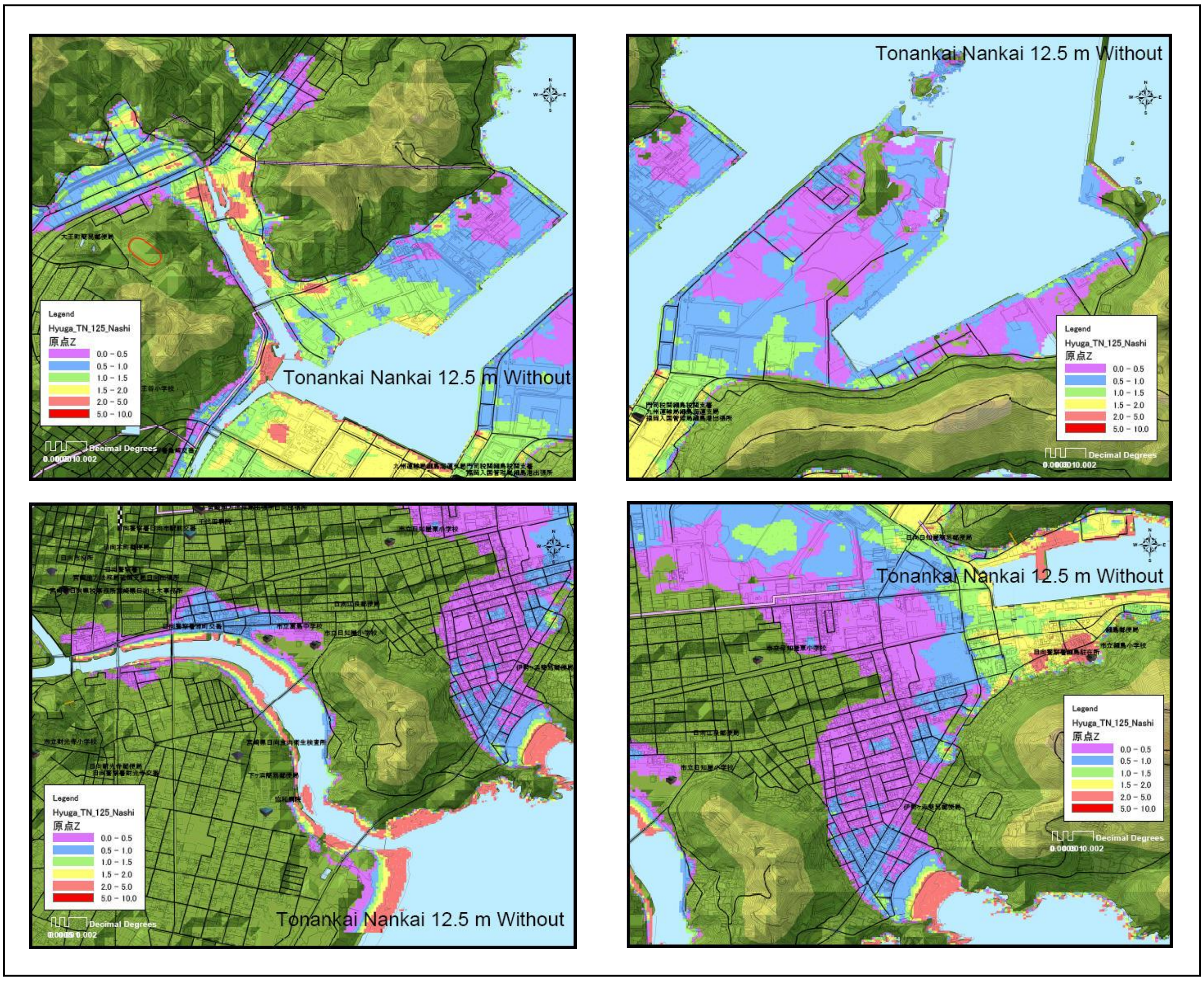

Fig.4. Tsunami hazard map in Hyuga City

In advance, even though the simulated inundation heights in Sone district were not exceeding than 1.5 meter, Sone population are known as the densest among other districts. Figure 4 show tsunami hazard map with the inundation level. The lowest inundation level was shown in purple color with the inundation level between 0 – 0.5 meter, blue color indicated the inundation level 0.5 – 1 meter, while 1 – 1.5 meter of inundation level was represent by green color. Yellow, pink and red color showed the inundation level of 1.5 – 2 meter, 2 – 5 meter and above 5 meter respectively.

SERVICE AREAS AND EVACUATION ROUTES

Service areas are defined as areas where refugees have a sufficient amount of time to travel from their house to the evacuation buildings shelters before tsunami attack. It was calculated that the travel time time to reach evacuation places is only 15 minutes. In case of tsunami attack, the best way to evacuate is by foot, due to vehicles may cause chaos and traffic jams. And by assuming the average velocity of normal walking speed on the plain surface is 4 km per hour, therefore the maximum evacuation route distance can be calculated by following equation:

$$Max\ ERD = (T1 - Wt)\ x\ Vw \qquad (1)$$

With:

- ERD = Evacuation route distance (meter)
- T1 = Travel time of tsunami wave (minutes)
- Wt = Warning system time (minutes)
- Vw = Velocity of human walk (meter / minutes)

  Vw = 4 km/hours = 66,667 m/min

Using the previous equation, it has been calculated that within 15 minutes, the maximum distance for evacuation route is 1 km. Thus, the service areas were generated based on 1 km distance.

Generating evacuation service area on Arc GIS can be done by creating network dataset in Arc Catalog. However, to perform network dataset, it requires a shape file of network routes. Thus during this study, road network digital data from local government in Hyuga City were used to generated evacuation service areas. The generated evacuation service areas can be seen in figure 5.

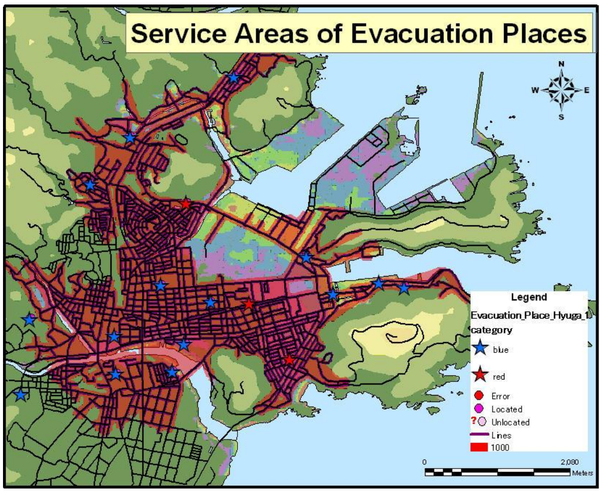

Fig.5. Service areas of evacuation places

Finding the most appropriate evacuation route is a complex process. It is because there are many factors need to be considered. However, in this study these factors are narrowed down into 5 criteria, which are:

a. Distance length

The evacuation clearing time must be less than the tsunami travel time. Therefore the amount of time to evacuate becomes the main consideration to find the most appropriate route. However, by generating evacuation service areas, it will simply differs the areas that refugees have sufficient time to reach evacuation building before the tsunami attack, and areas that does not have sufficient time. As a consequence, areas which do not covered on service areas became the highest risk areas against tsunami.

b. Route Safety Situation

The evacuation route need to be secured from any additional disaster which may occur as a consequence of tsunami disaster, such us the blast of exploded materials, the broken down of bridges, the collapse of high rise building, the land slide disaster and etc. Therefore data regarding the soil condition, the industrial area, the high building area and also data about bridges are analyzed to locate the most appropriate route.

c. Route Capacity

In order to avoid traffic congestion and chaos situation at the evacuation stage, the route capacity should have the sufficient wide for refugees to pass. Smaller capacity than the required ones becomes a high risk of evacuation route, because it will delay the evacuation clearing time, and it may produce greater chaotic conditions.

d. Slope Condition

The condition of the slope route also give influence to the evacuation time, areas with stiff slope generally needs more time to be traveled compare to the plain slope. Therefore on choosing the most appropriate evacuation route, the stiff slopes need to be avoided as it may delay the refugee to reach the evacuation place.

e. Inundation Depth

In case that the required clearing time for the evacuation cannot be fulfilled, the evacuation route may be inundating. For this case, the priority of the evacuation route is shifted to the level of inundation depth. The evacuation route with low level of inundation depth becomes the most appropriate evacuation route compare to the high level ones.

Based on those 5 criteria, the risk level on each road can be calculated by assigning value by 0 to 10. Furthermore, the lowest number (0) indicates as the safest route, and a higher number acting as a higher risk. Each of criteria will have several categories, and it will be assigned specific value which associated with its risk condition.

These categories and its value are presented in fig.6. In order to be easily understood by its viewer, the average will be calculated from the sum of each route. Therefore the final result shows value on range of 0-10.

As can be seen in fig.6, as example, if the route has profiles as described below:

- More than 100 meter from dangerous area,
- Alluvium, Rank A and liqufaction of soil condition,
- No bridges or high buildings surrounding route,
- Width of route is 6.00 m,
- In the plain surface (no slope),
- Will be inundated to 0.05 m when the tsunamis attack.

Therefore, the risk level can be calculated as follow:

$$[(0+4+10+0+0+0)/6 + 8 + 0 + 1] / 4 = 2.78$$

No	Criteria	unit	Value										
			0	1	2	3	4	5	6	7	8	9	10
1	Safety												
	a. (distance from) Dangerous Areas	m	> 100	-	100-75.1	-	-	75-50.1		-	50.25.1	-	0-25
	b. Soil Condition 1		Natural Dune, Mountain	-	-	-	Alluvium	-	River Side	-	Shoar	-	Landfill
	c. Soil Condition 2		None	-	-	-	-	-	-	-	-	-	All Symbol
	d. Soil Condition 3		Not Liqufaction	-	-	-	-	-	-	-	-	-	Liqufaction
	e. Soil Condition 4	Rank	A	-	-	B	-	-	C	-	-	-	D
	f. Bridge (ratio of length and wide)	m/m	none	0.01-0.5	1.1-1.5	1.6-2	2.1-2.5	2.6-3	3.1-3.5	3.6-4	4.1-4.5	4.6-5	> 5
	g. High Building (more than 2 floor)	unit	none	1	2	3	4	5	6	7	8	9	> 10
2	Capasity (road width)	m	> 22	20 - 22	18 - 20	16 - 18	14 - 16	12 - 14	10 - 12	8 - 10	6 - 8	4 - 6	< 4
3	Slope (degree)	degree	0	0.01 - 2.5	2.51 - 5	5.01 - 7.5	7.51 - 10	10.1 - 12.5	12.51 - 15	15.01 - 17.5	17.51 - 20	20.01 - 25	> 25
4	Inundation Areas (inundation depth)	m	0	0.01 - 0.5	0.51 - 1	1.01-1.5	1.51 - 2	2.01 - 2.5	2.51 - 3	3.01 - 3.5	3.51 - 4	4.01- 5	> 5

Fig.6. Risk rank criteria, categories and values

Results of risk rank analyzes in 5 study areas are presented in figures below:

1. Sone District

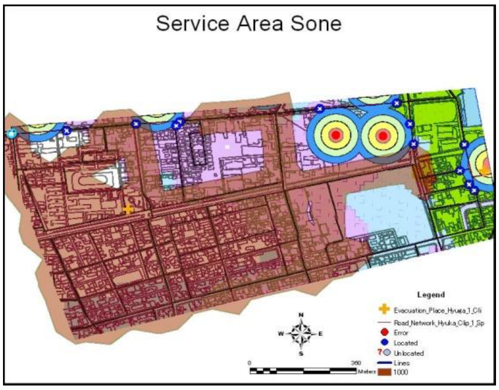

Fig.7. Evacuation Service Area in Sone District

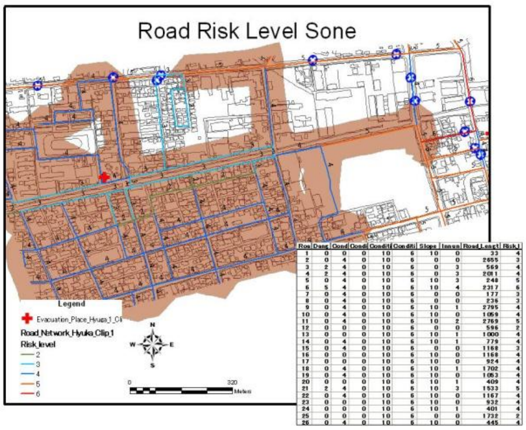

Fig.8. Road Risk Level in Sone District

Fig.7. and fig.8 show evacuation service areas and road risk level in Sone district respectively. Further, dangerous places which were buffered in 25, 50, 75 and 100 meters can be seen in figure 7 with certain colors. Therefore as a consequence, roads which overlaid by dangerous places are prohibited to pass. In addition, service areas are showed by pink color. While in figure 8, different colors were assigned to roads, as an indication of different risk level.

2. Haripou District

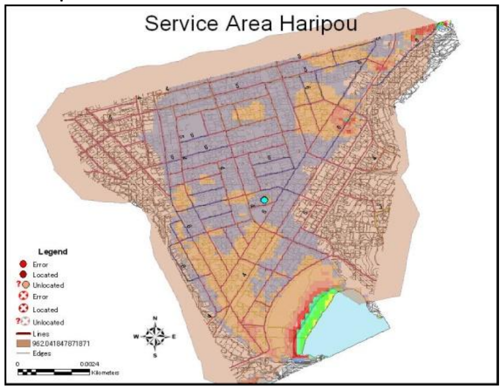

Fig.9. Evacuation Service Area in Haripou District

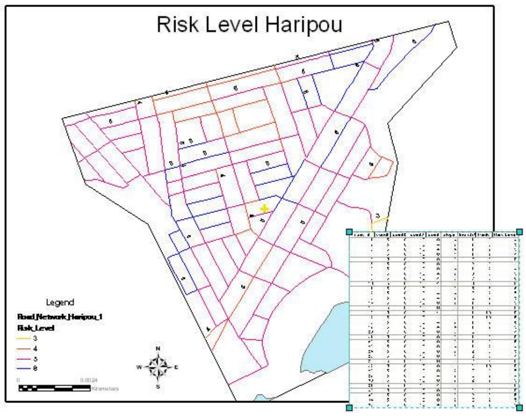

Fig.10. Road Risk Level in Haripou District

3. Kajiki District

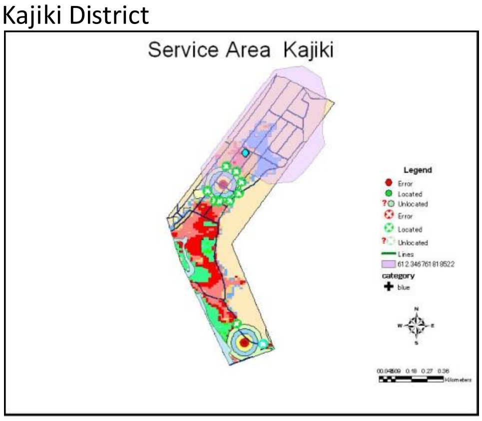

Fig.11. Evacuation Service Area in Kajiki District

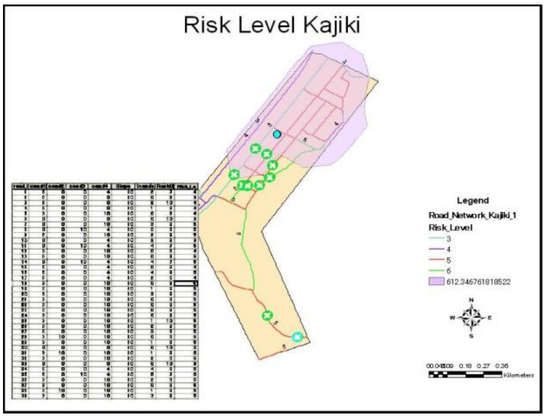

Fig.12. Road Risk Level in Kajiki District

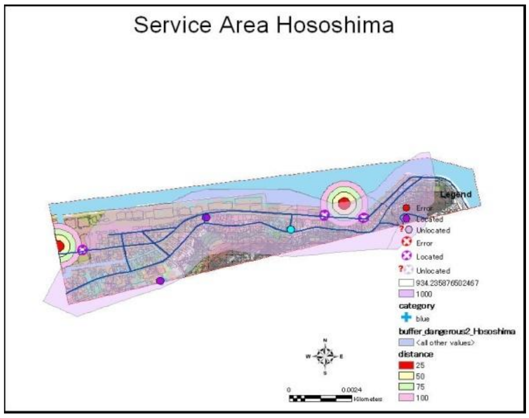

Fig.12. Road Risk Level in Kajiki District

4. Hataura District

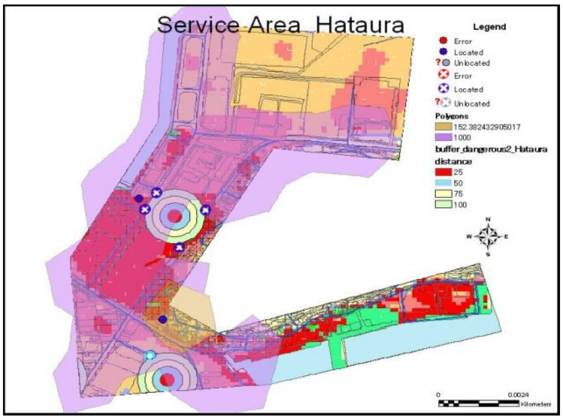

Fig.11. Evacuation Service Area in Hataura District

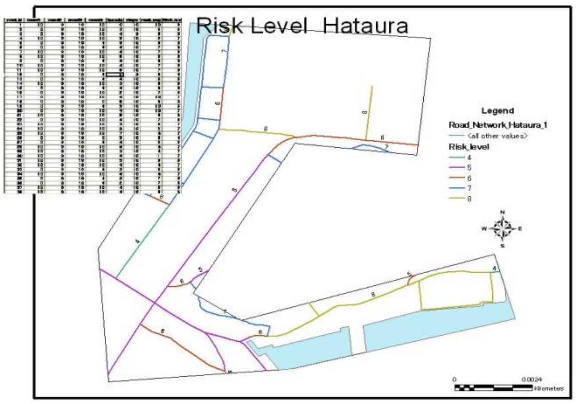

Fig.14. Road Risk Level in Hataura District

5. Hososhima District

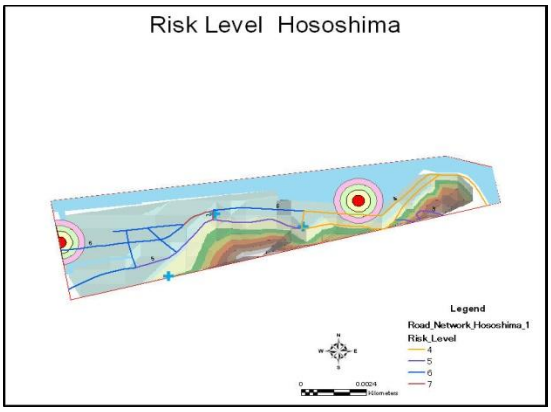

Fig.14. Road Risk Level in Hataura District

DISCUSSION AND CONCLUSION

Result indicated that some resident areas in Hyuga city have not been covered by evacuation places yet. While in another case, several evacuation buildings which usually used for either flood or earthquake disaster cannot be operated in term of tsunami disaster, due to its location in the inundated areas. As a solution, high buildings which has flat roof, such as park building or mini market, were selected as temporary evacuation place.

Blocking main roads due to buffering of dangerous places in Sone district was resulting in the deducting of covered evacuation service areas. However another scenarios on the blocking roads because of high level of inundation needs to be further research.

On the establishing network database phase, all roads were subjected to be passed by both directions. Further, no specific turn left nor turn right regulations were assigned to each road. In contrast, assigning one way pass or specific turn regulation may effecting the capacity of roads and resulting to the change of evacuation service areas.

While on the calculation of road risk rank, each of criteria were considered to affected in the same portion, therefore all of the criteria share same weight. And the result showed that the calculated risk rank level was between levels 2 to 8. The statistic showed that 64% roads in Hyuga city are in the risk level of 2-4, 22% of roads are in the risk level of 5-6, while the risk level 7 roads and level 8 roads are 7% and 5% respectively. However, there are 4 essential roads of level 8 in Hataura district which need to be further discussed. In addition, all of these roads are located in the bay area. And base on the calculation, the high of inundation level is the major factors for the high risk level.

GIS is a useful tool either to generate evacuation service area or evacuation routes risk rank. However, accurate result is determined by accurate and valid data. In the network analysis, the road network data, which included its capacity, junctions, length and wide of roads, become essential data for further process. Slight different of input data will result in the different covered service areas.

Further investigation on the blocking road scenarios need to be conducted in order to perform much clearer knowledge on the effect of blocking road due to dangerous areas or inundated areas to the change of evacuation of service areas.

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