*IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*
*ISSN: 2319-2402, ISBN: 2319-2399. Volume 1, Issue 4 (Sep-Oct. 2012), PP 05-11*
*www.iosrjournals.org*

# Predicting Tsunami Inundated Area and Evacuation Road Based On Local Condition Using GIS

Agus Suharyanto[1], Alwafi Pujiraharjo[2], Fadly Usman[3], Keisuke Murakami[4], Chikashi Deguchi[5]

[1, 2](Civil Engineering Department, University of Brawijaya, Indonesia)
[3](Regional and City Planning Department, University of Brawijaya, Indonesia)
[4, 5](Civil and Environmental Engineering Department, University of Miyazaki, Japan)

***Abstract :*** *Tsunami is very important phenomena in the disaster management problems. Based on the tsunami was occurred in Aceh Indonesia on December 26, 2004 was killed more than 200.000 peoples, the tsunami disaster management become very important to study. One of the studies is disaster management due to the tsunami hazard along shoreline of southern beach of East Java Province Indonesia. According to the geological data, area of east Java Ocean has high potential of earthquake. The history shows that there are many time tsunami occurred in east Java. In 1994 the tsunami was occurred in Kabupaten Banyuwangi (Banyuwangi Regency) beach and was killed 240 peoples. From this initial study, one of the area predicted as dangerous area for the tsunami is Pacitan city. To minimize the effect of tsunami hazard, the tsunami disaster management study was done for Pacitan city. In this research predicting of inundation area caused by tsunami and evacuation road to mitigate from the tsunami was studied. GIS was used as tool to predict the inundation area and evacuation route. From this research it can be shown that GIS is useful to predict the inundation area and evacuation road.*

***Keywords -*** *Evacuation Road, GIS, Inundation Area, Tsunami*

## I. Introduction

On December 26, 2004, the biggest tsunami on world was occurred in *Banda Aceh*, Indonesia. More than 200.000 peoples were killed by this tsunami. To prevent this disaster in the others areas which are dangerous with the tsunami hazard, it is necessary to analyze how to mitigate the peoples if tsunami occurs (Atu, 2000). The purposes of this study are to minimize the tsunami victim and properties damage if the tsunami occur.

East Java Province is located in dynamic area, because there are three plates get together in Java Island. Those three plates are Eurasian, Indian Ocean, and Australian plates. Consequently, the earthquake often occurs in Java Island included East Java Province area (*Kabupaten Banyuwangi*, 2005). Tsunami will be occurred if there is earthquake in the sea area. Therefore, the potential of tsunami occurrences in southern beach of East Java Province is high. To prevent the tsunami disaster hazard, the research of tsunami disaster mitigation management for East Java Province based on the local characteristics of shoreline was done.

For understanding the local characteristics of shoreline physical and existing land use conditions, the research was done by supporting the satellite remote sensing (R/S) data and GIS. The R/S data is used to analyze the land use condition and GIS is used to simulate the inundation area due to the wave elevation or run-up elevation.

The purposes of this research are to analyze the location of evacuation area, evacuation road, and shelter location based on the local condition on the area inundated by tsunami. The inundation area is simulated based on the run-up elevation. In this research the 5 m and 10 m of run-up elevation was simulated to find the inundation areas. To realize the purpose of the research, the appropriate data is used.

Based on the 2007 research, Pacitan city located in south west of east Java Province, Indonesia is selected as research area (Agus and Fadly, 2007). To generate the tsunami mitigation map, data of evacuation area, evacuation road, evacuation route, location of shelter, location of sign board are needed. And there are many parameters to decide the evacuation area, evacuation road, and location of shelter. Because of the budget limitation, data of evacuation area, evacuation road and location of shelter will be analyzed. Only three parameters (road width, road pavement condition, predicted number of people will passed) will be used to predict the evacuation road. Location of shelter will be predicted using location from road, number of floors, volume capacity, and function of building parameters. Based on the theoretical frame, there are more parameters to predict the evacuation area, evacuation road, and location of shelter (Tang et.al, 2009). Because of research budget limitation, in this research only described parameters are used to predict evacuation area, evacuation road, and location of shelter.

This research will be continued in 2012. The research is funded by Directorate General Higher Education, Ministry of Education and Culture, Indonesia for three years (2012 – 2014).

## II. Materials And Methods

Base on the initial result was done on 2007; the area selected for this research is Pacitan city. This city is located in South-West of East Java Province, Indonesia. Pacitan city have 65,138 people and in occupied 76.37 $km^2$. The topographic condition along 3 km from beach until centre of city is flat with slope less than 5%. The population density in the beach area is 2,000 peoples per $km^2$. From this condition it can be predicted that Pacitan city is very dangerous from the tsunami (Agus, 2008). Geographically, Pacitan city is located between 111°5' East Longitude and 8°13' South Latitude. The map of the Pacitan city is shown in Fig.1.

This research was done using several materials relating to the parameters need in the analysis process. In summarize the materials used in this research can be shown as follows.

1. Topographic map in scale 1:25,000 and 1:5,000
2. Quick Bird satellite imagery
3. Land use detail planning map in scale 1:5,000
4. Building condition map

The run-up elevation can be simulated using numerical method base on the initial wave generated by earthquake location and magnitude (Xiaoming, et.al., 2008). In this paper, numerical analysis to find the run-up elevation is not discussed. The run-up elevation were assumed base on the appropriate run-up elevation when the tsunami occurred. The other paper will be discussed how to analyze the run-up elevation using numerical simulation. Base on 5 m and 10 m run-up elevation, the inundated area of Pacitan city will be simulated. Base on the population number living, road network, road geometry, housing construction quality located along road in inundated area the evacuation road and location of shelter will be predicted. The location of evacuation area will be analyzed based on the topographic map and road network map.

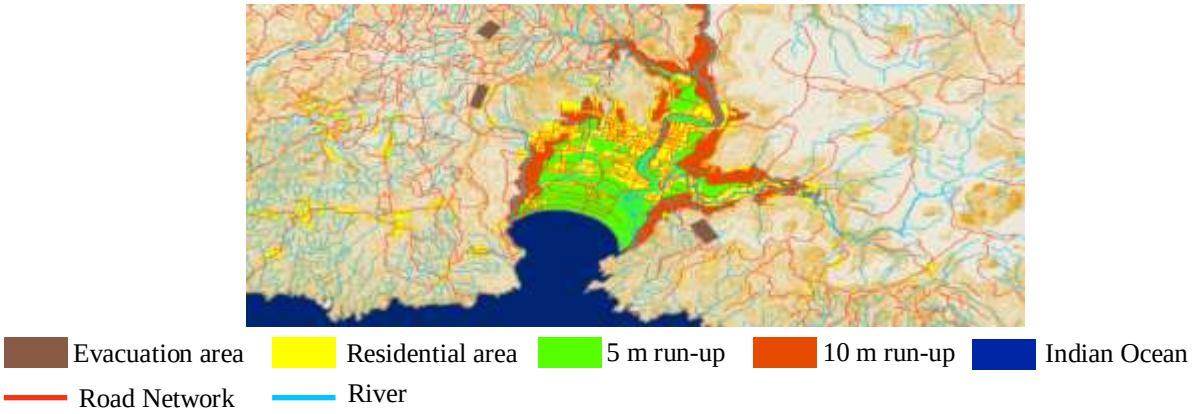


**Figure 1. Location of evacuation area**

GIS was applied to analyze the evacuation road and shelter location. Evacuation road is very important to evacuate when the tsunami occurred. People living in the area predicted inundating by tsunami should be knows well how to evacuate when tsunami occurred. Inundated area was predicted and plotted to the topographic map base on the assumed run-up elevation. Contour line is used to predict the inundation area. Using population density data (BPS, 2009), the number of people predicted inundating by tsunami can be analyzed. By using high resolution satellite remote sensing data, the housing distribution and road network can be drawn. From the drawn map, the housing quality was checked by ground survey. The housing quality was check base on the houses materials. Houses made from concrete are not easy broken by earthquake. If more than 50% of the houses quality in surrounding one road is bad quality, that road is not suggested as evacuation road. The houses along that road have high probability broken if attached by tsunami and earthquake. Therefore, it is very dangerous if that road used as evacuation road. After analyzing the road network and houses quality along the road network, the availability of road network as evacuation road can be predicted. The capacity of each road to accommodate the number of people for evacuating is calculated base on the road width. From the road capacity map and number of people should be evacuated, the direction and evacuating distribution of people can be analyzed. After this analyzing process, the evacuation road map can be drawn.

During evacuation process, not all of people can be evacuated continuously until evacuation area. The weakness peoples such as old people, pregnant woman, children, and handicap people will be used to take consideration in the analyzed. Consequently, the rest area during evacuation process is needed. The rest area during evacuation process usually called as shelter. The shelter is necessary too when the arrival time of tsunami

is faster with the evacuation process (Richard, 2003). Hopefully, when the tsunami arrived and evacuation process still running people can be safe by stop in the shelter area. Shelter area is area have good houses quality, located along evacuation road, can be accommodated many people, and predicted safe from earthquake and tsunami attack. The example of area can be used as shelters are houses more than two floors, school, hotel, office, and mosque. The number of shelter is predicted by the number of people will be evacuated, especially the weakness peoples. The availability of buildings can be used as shelter are depend on the buildings quality and the nearby from the evacuation road.

Base on the GIS analyses requirements, the layer will be generated can be summarized as follows.

a. Contour line layer
   This layer is generated from topographic map published by BAKOSURTANAL in scale 1 : 25,000. The original contour interval is 12,5 m. The ground survey is needed to increase contour interval become 1 m. The attribute of the layer is contour elevation
b. Inundation area layer
   Inundation area decided base on the contour elevation. Base on the assumed tsunami run-up elevation, the location of inundation area is the area occupied by contour 5 m, 10 m, and 15 m. The attribute of this layer is area of inundated location.
c. Evacuation area
   This layer was developed by interpreting the topographic map. The evacuation area was selected base on the location have elevation more than 25 m, easy to access, and with distance nearest inundation area. The selected area is shown in Fig. 1.
d. Land use layer
   Land use layer was generated from high resolution satellite imagery. The IKONOS satellite imagery is used in this research. After geometric correcting, the building located 100 m of both side road center lines is digitized. This work was done for all road network layers. The attribute of this layer are building quality and distance from road centre line.
e. Road network layer
   This layer was generated from topographic map form BAKOSURTANAL (National Survey and Mapping Coordination Bureau) combined with data from IKONOS. All roads located in inundation area and connected to the evacuation area are digitized. The attribute of this layer are road width, pavement type and condition, road alignment, and number of bridges cross the road.
f. Houses along predicted evacuation road
   This layer is similar with the land use layer. But here only building located along predicted evacuation are digitized. The attribute of this layer are building construction quality, number of floor, and floor area.

The Universal Transverse Mercator (UTM) with zone number 40 is used for mapping the research area. After the all layers is ready as input data the inundation area, evacuation road, and shelter location can be predicted using overlapping analyses method in GIS. The polygon of inundation area is predicted base on the 5 m and 10 m elevation of contour. From this process, the inundation area with 5 m and 10 m run-up can be predicted. To predict the evacuation road, the inundation area is overlapped with road network layers. Base on the road geometry and buildings construction quality along road network, the evacuation road is predicted. The weights and scores of road geometry parameters and level of buildings construction quality will be used as basic assumption to predict the appropriate road as evacuation road. From this analysis the network of evacuation road can be predicted. To predict the shelter location, the floor area and the quality of buildings construction, and the nearby from the evacuation road will be used as basic parameters. The weight and score for those parameters will be used to decide that building is available or not as shelter. This analysis method in general can be said as geostatistical method.

## III. Basic Equations

As mentioned above, to predict the inundation area, evacuation road, and shelter location, the GIS is applied. Geostatistical method is used to decide the evacuation road and shelter location. The parameters can be used to predict the evacuation roads are road width, road pavement condition, horizontal and vertical road alignment, and building construction quality along road network (Murakami et.al., 2009) This paper is result of initial research of authors to study the tsunami mitigation. On this paper, the parameters used to predict the evacuation are road width, road pavement condition, and predicted number of peoples will passed to the evacuation road. The score for each parameter of road condition can be seen in Table 1. The total score used to decide a road can be used as evacuation road are between 3 – 5, 6 – 9, and 10 – 12. If the total score is 3 -5 means that road is not suitable used as evacuation road, if total score is 6 – 9 means that road in the middle condition to use as evacuation road. The final criterion is if the total score is 10 – 12. If the road have total score like this means that road is suitable used as evacuation road. The total score is calculated after overlapping road network, inundation area, and location of evacuation area layers.

**Table 1. Score for Evacuation Road**

| Road Condition | Criteria | Score |
|---|---|---|
| Road Width | < 3 m | 1 |
| | 3 - 4 m | 2 |
| | 4 - 5 m | 3 |
| | > 5 m | 4 |
| Pavement | Poor | 1 |
| Condition | Fair | 2 |
| | Good | 3 |
| Predicted Number | > 1,000 | 1 |
| of People passed | 500 - 1,000 | 2 |
| to the road | 250 - 500 | 3 |
| | 50 - 250 | 4 |
| | < 50 | 5 |

**Table 2. Score for Shelter Location**

| Building Condition | Criteria | Score |
|---|---|---|
| Location from | Road side | 1 |
| the road | Intersection of local road | 2 |
| | Main road side | 3 |
| | Intersection of main road | 4 |
| Number of floors | One floor | 1 |
| | Two floors | 2 |
| | Three floors | 3 |
| | > Three floors | 4 |
| Volume capacity | < 100 peoples | 1 |
| | 100 - 500 | 2 |
| | 500 - 1,000 | 3 |
| | > 1,000 peoples | 4 |
| Fuction of buildings | Residential | 1 |
| | Health facilities | 2 |
| | Government or private office | 3 |
| | School, Religious | 4 |

The same way, location of shelter was analyzed using geostatistical method. The layers of predicted evacuation road and building standees along predicted evacuation road are overlapped to analyze the shelter location. The location of building form predicted evacuation road and building condition are used as parameters. The building condition parameters are number of floor, floor area, function of building, and construction quality. Because of limitation research budget, in this research the data of the last parameter i.e. construction quality is collected yet. Therefore, in this research this parameter is not taken account to predict the location of shelter. This research will be continued from 2012 funded by Directorate General Higher Education, Ministry of Education and Culture, Indonesia. The score of each parameter to predict the location of shelter is shown in Table 2. If the total score is between 4 – 7, means those building is not suitable used as shelter location. Total score is 8 – 12, means that building in the middle condition to use as shelter location. If the building has total score is 13 – 16 means that building is suitable used as shelter location. The total score is calculated after overlapping predicted evacuation road, inundation area, and houses along predicted evacuation road layers.

From the above analyses, the tsunami mitigation map can be drawn. In principle, the tsunami mitigation map of Pacitan city can be shown Fig. 1.

When the tsunami attached in one area, the people living in this area will be panic. Consequently, which road and which direction people should be evacuated will be confused. There is high possibility the evacuation doesn't distributed well due to the capability of evacuation road capacity. To minimize this occurrence, the direction of evacuation from housing area should be decided. In this paper, the analysis method is not discussed. But the principle of direction of evacuation route can be seen in Fig. 2.

## IV. Results and Discussions

After all research material ready to analyze, the contour line, inundation area, land use, road network, and houses along predicted evacuation road layers can be developed. The first step analysis is predicting the evacuation area surrounding the inundation area. Base on the contour line map and others parameters as mentioned above, the evacuation area for Pacitan city can be decided on three evacuation locations. The three locations of evacuation area can be seen at Fig. 1. The second analysis is predicting evacuation road. By overlapping the inundation, evacuation area, road network, land use, and location of evacuation area layers the evacuation road to mitigate the tsunami of Pacitan city was predicted. There are 70 road segment can be founded as evacuation road. Among them one road can be categorized as suitable road for evacuating road, 64 categorized in middle condition, and five road categorized in not suitable condition. From this result it can be concluded that almost road network in Pacitan city categorized in middle condition for evacuating road. To increase from middle condition to suitable category, it is necessary to increase the road width and road pavement condition. Part of this analysis can be shown in Table 3. Base on the total score, the road can be used for evacuating when tsunami attached to Pacitan city was predicted. The evacuation road analysis result is

became predicted evacuation road layer. The part of predicted evacuation road shows in Fig. 2. The next analysis step is predicting the shelter location. This analysis was done by overlapping predicted evacuation road and houses along predicted evacuation road layer. From the field survey, there are 20 buildings can be predicted as shelters. The attribute of these building such as location of building form predicted evacuation road, number of floor, floor area, and function of building are described in this layer. From the overlapped result, two buildings can be categorized as not suitable as shelter, 11 buildings categorized in middle condition as shelter, and seven buildings categorized in suitable as shelter. Almost building with minimum two floors and function as public services (school and government office) categorized as suitable building as shelter. Part of this analysis can be shown in Table 4.

To predict which road is suitable as evacuation road, only three parameters are used in the analysis. Those parameters are road width, pavement condition, and people will be passed at the road or volume. The weight of each parameter is same. Basically there is more parameters influence to predict a road can be used as evacuation road or not. For examples road alignment, quality of building along road side, there any bridge or nor along road. People is easier evacuate pass to the flat road comparing to the road with slope. If the building along road side is easy broken by earthquake or tsunami, that road is not suitable as evacuation road. There are many obstacles will be appears along that road. Bridges is easier broken affected to earthquake and tsunami. The

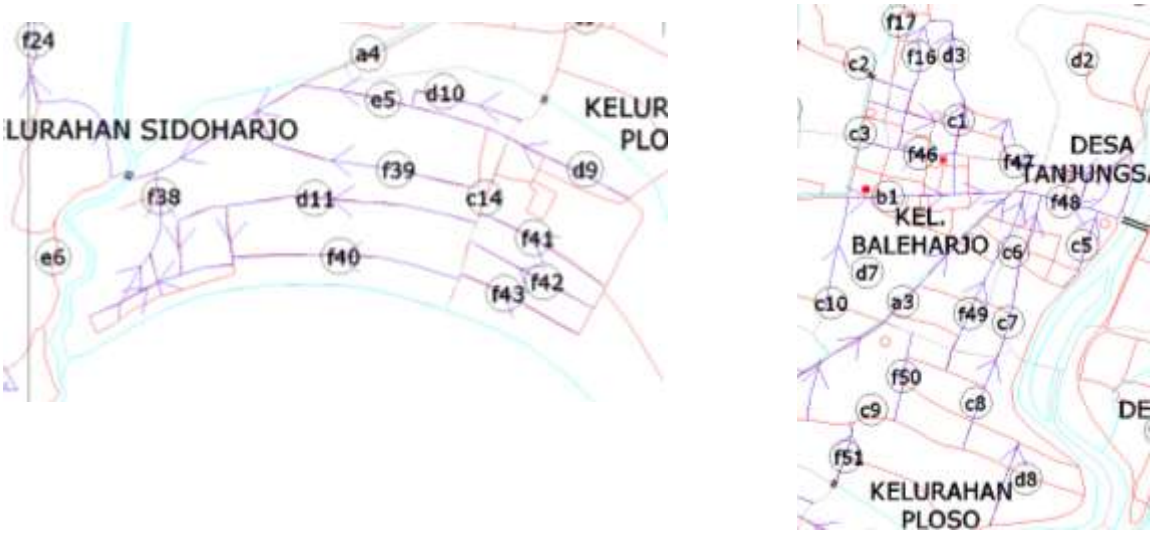


**Figure 2. Part of evacuation road of Pacitan city**

**Table 3. Criteria for Evacuation Road**

| No. | Road Code | Width (m) | Pavement Condition | Volume | Total Score | Criteria |
|---|---|---|---|---|---|---|
| 1. | a2 | 4 | 2 | 1 | 7 | Middle |
| 2. | a3 | 4 | 3 | 1 | 8 | Middle |
| 3. | b1 | 4 | 3 | 1 | 8 | Middle |
| 4. | b2 | 4 | 3 | 1 | 8 | Middle |
| 5. | c1 | 3 | 3 | 1 | 7 | Middle |
| 6. | c2 | 3 | 2 | 2 | 7 | Middle |
| 7. | c3 | 3 | 3 | 1 | 7 | Middle |
| 8. | f30 | 1 | 2 | 2 | 5 | Not Suitable |
| 9. | f31 | 1 | 2 | 1 | 4 | Not Suitable |
| 10. | f36 | 4 | 3 | 4 | 11 | Suitable |
| 11. | f49 | 3 | 3 | 1 | 7 | Middle |
| 12. | f50 | 2 | 3 | 1 | 6 | Middle |
| 13. | f62 | 2 | 2 | 1 | 5 | Not Suitable |
| 14. | f63 | 1 | 2 | 4 | 7 | Middle |
| 15. | f64 | 1 | 3 | 4 | 8 | Middle |

evacuation process will be fully stopped if the bridge is broken. Base on the correlating each parameter to the easier of people pass to the road, weight should be considered in the analysis. By the same logic, there is more parameters should be considered to analyze the shelter location such as building quality and distance from the road. The weight should be put on to the each parameter. Building have good quality, especially in structure quality is expected not easy broken when earthquake or tsunami attached. Buildings like this condition have

high possibility as shelter. Consequently, data of each building along road predicted as evacuation road and distance from road centerline is necessary. These considerations will be used on the analysis for the next research.

**Table 4. Criteria for Shelter Location**

| Picture | Location | No. of Floors | Volume | Function | Total Score | Criteria |
|---|---|---|---|---|---|---|
|  Hotel | 2 | 2 | 3 | 3 | 10 | Middle Condition |
|  Mosque | 2 | 2 | 1 | 4 | 9 | Middle Condition |
|  Senior high school | 3 | 2 | 4 | 4 | 13 | Suitable |
|  Elementary School | 4 | 2 | 4 | 4 | 14 | Suitable |
|  Business area | 3 | 2 | 3 | 3 | 11 | Not Suitable |

## V. Conclusion

From the result and discussion of this paper it can be concluded several items as described as follows. Geographic Information System is powerful to analyze tsunami mitigation. By overlapping each layer relating to tsunami mitigation analysis, evacuation area, evacuation road, and shelter location can be decided smoothly. Each parameter relating to tsunami mitigation analysis represented layer by layer in GIS. Each layer consisting spatial and attribute data. The local condition data such road condition, building condition along road, and land use are very important data in the tsunami mitigation analysis. Those data registered as attribute data to the relating spatial data.

Almost predicted evacuation road occupied more than 1,000 people will be passed. Therefore, it is necessary to increase the road quality especially road width to increase the road capacity for evacuating people. Shelter is location will be used as rest area during evacuation from resident's area to evacuation area. There is possibility tsunami will be attached during evacuation process. Therefore, the shelter area should be having high quality structure to protect the tsunami energy and having elevation more than two floors. The building along predicted evacuation road in Pacitan city, Indonesia almost categorized in middle condition. Only few building can be categorized as suitable building for shelter, because the buildings condition are maximum only two floors and far from the road centerline. Base on the local condition of Pacitan city, it is necessary to increase the road width, road pavement quality, building structure quality and number of floor of building predicted as shelter.

**Acknowledgements**

This research was supported by the Directorate General of Higher Education, Ministry of National Education, and Indonesia through the competitive research grants for International Publication. The authors would like to acknowledge the LPPM University of Brawijaya for their help in this research administration.

## References

[1] Atu Kaloumaria, Tsunami Mitigation For The City Of Suva, Fiji. Disaster Reduction Management Program, Suva, Fiji, *Science of Tsunami Hazards 18 (1),* 2000.

[2] Kabupaten Banyuwangi (Banyuwangi Regency, Indonesia), *Regional Plan 2005 – 2015 of Banyuwangi Regency*, 2005.

[3] L. Tang, V.V. Titov, and C.D. Chamberlin, Development, testing, and applications of site-specific tsunami inundation models for real-time forecasting, *Journal of Geophysical Research, 114(C12025),* 2009, 112-116.

[4] Agus Suharyanto, and Fadly Usman, *Research Study and Regional Structuring of Shoreline as Buffer Zone Due to Tsunami Intensity in East Java Province, Indonesia* (Research and Public Services Agency, Faculty of Engineering, University of Brawijaya, 2007).

[5] Agus Suharyanto, The Tsunami Disaster Management along Shore Line of Southern Beach of East Java Province, Indonesia, *International Symposium of Tsunami Disaster Mitigation*, in Miyazaki, Japan, 2008.

[6] Xiaoming Wang, Philip L., and F. Liu, Indian Ocean Tsunami on 26 December 2004: Numerical Modeling of Inundation in Three Cities on The South Coast of Sri Langka, *Journal of Earthquake and Tsunami, 2 (2),* 2008, 133-155.

[7] BPS (Centre Bureau Statistics), *Pacitan Regency in Figures*, (BPS-Statistics of Pacitan Regency, Indonesia, 2009)

[8] Richard K. Eisner, Planning for Tsunami: Reducing Future Looses Through Mitigation, *Natural Hazard, 35*, Springer, 2005, 155-162.

[9] Murakami K., Stikuno S., Wijatmiko I., Study on a Tsunami Evacuation Measure Considering Some Risk on Evacuation Network, *Journal of Beach Development (Kaigan Kaihatsu Ronbunshu), 25*, 2009, 807-812.