INTEGRATED APPROACH IN DETERMINING BUILDING RISK TO TSUNAMI HAZARD : A CASE STUDY OF PENANG, MALAYSIA

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Building risk category within coastal zones is crucial to be identified in order to mitigate the impact of each building due to tsunami disasters. The northern part coastlines of Penang, Malaysia (Teluk Bahang and Batu Feringgi) are mostly exposed by the disastrous Indian Ocean tsunami waves of December 26, 2004. The objective of this study is to identify building risk to tsunami hazard within coastal area by using integrated approach for the district of Penang, Malaysia. This study used Pleiades and Radarsat-2 to generate parameters into Tsunami Inundation Hazard Map model and Papathoma Tsunami Vulnerability Assessement-3 (PTVA-3) models. Tsunami inundation hazard map was generated using five parameters namely, elevation, slope, relation to tsunami direction, coastal proximity and coastal shape by applying multi-criteria decision analysis using tsunami worst case scenario creating maximum run-up. The result was then categorized into two classes namely medium, and high risk. In this study, the result is significant with the actual observation data, where the wave height is around 3.14m (MetMalaysia) and the inundation is around 555.00m from the beach. A shapefile of polygons representing all the building footprints extracted by using object-oriented image analysis method with rule-based classification (multiresolution segmentation algorithm and contrast-split segmentation) is generated. Ground measurement for building parameters such as number of stories, material, years of construction, ground floor hydrodynamics and preservation condition as an input to identify the building RVI by using Papathoma Tsunami Vulnerability Assessment-3 (PTVA-3) model. The building RVI map was then integrated with the WV (Water intrusion) result derived from Tsunami Potential Vulnerability Map. A total number of 504 buildings in the Batu Feringgi, Penang coastal areas are estimated to be exposed to the tsunami flood zone during the worst-case tsunami event and 60% of the buildings will suffer severe damages. The output of this study will contribute to the development of immediate emergency risk management strategies along with designing the evacuation plan for the coastal community of Penang.

1. INTRODUCTION

Although the impact of the Indonesian earthquake has often been felt, West Coast of Peninsular Malaysia has not experienced any tsunami in living memory (Keizrul, Tan, & Ghazali, 2005) . On 26 December 2004, three hours after a magnitude 9.3 earthquake shook Banda Acheh with an epicenter of 3.32° North and 95.85° East at 00:58:53 GMT equivalent to 07:08:53: Malaysian time in Northen Sumatera (Ismail, et al., 2012), Malaysian has been struck by a disastrous tsunami that propagates throughout the Indian Ocean and penetrated the Straits of Malacca via Andaman Sea. Tsunami forces can cause serious damage and failure of structures because tsunami waves in deep oceans can reach shorelines within several minutes and subside until several kilometers from the coast and sweep away more infrastructures including the building of community (Eckert, Jelinek, Zeug, & Krausmann, 2011). In Penang alone, these gigantic waves caused the death of 54 people, destroying 615 homes,79 aquaculture projects and sea farm amounting to RM50 million (A Rahim, Mat Said, A Bakar, Sulaiman, & Ahmadun, 2014). Therefore, in this paper we chose Batu Feringgi, Penang as our study area. The area is located in the northern part coastlines of Pulau Pinang, Malaysia, covering the coastal area between Teluk Nangka to Teluk Pinang. A major portion of northern coastline comprises the reclaimed area and there is neither natural nor man-made structure for coastal protection purposes located along this coastline. Penang is remarkably urbanized island with the highest population density in Malaysia that is rapidly developing along the shoreline. These densely populated areas comprise of township, housing estates, fishing villages business and tourist centres (Hadibah Ismail, 2006). Therefore, in order to safeguard the coastal communities and minimize the losses that will be associated with future tsunami, assessment of building vulnerability are necessary. Hence, Tsunami Inundation Hazard Map Model and Papathoma Tsunami Vulnerability Assessment-3 Model are presented.

2. TSUNAMI INUNDATION HAZARD MAP

2.1 Recently, tsunami inundation hazard study is using Geographical Information System (GIS) multi-criteria as to analyze the effect of tsunami in the regional environment analysis. Multiple geospatial parameters have been used such as topographic elevation and slope, topographic relation to tsunami direction, coastal proximity, and coastal shape (Tumpal P. & A., 2010). Each parameter were then assigned based on analytical hierarchy process (AHP) as reasonable weighting method. We could distinguish the tsunami inundation hazard area by overlaying all the parameters and classified them into 3 categories which are low, medium and high.

2.2 As for data processing and classification, for each parameter, we extracted the data from the satellite imageries. Radarsat-2 satellite image is used to extract the topographic elevation and slope, while SPOT6/7 image is used to delineate topographic relation to tsunami direction and coastal shape.

2.2.1 Topographic Elevation

We used Radarsat-2 with a 10-m grid to obtain Digital Elevation Model (DEM) for this area and classified them into five groups considering the tsunami run-up height at coast (Iida, 1963). Table 1 shows the vulnerability and weightage for the topographic elevation.

Table 1: Vulnerability and weightage for Topographic Elevation

Elevation (m)	Vulnerability	Weightage
5 or lower	High	5
5-10	Rather High	4
10-15	Medium	3
15-20	Rather Low	2
20 or higher	Low	1

Source: (Diposaptono. S. and Budiman, 2005)

2.2.2 Topographic Slope

DEM from Radarsat-2 was obtained to get the slope parameter and was classified into five classes by using Van Zuidam's (1983) classification. Table 2 shows the vulnerability and weightage in terms of topographic slope

Table 2: Vulnerability and weightage in Terms of Topographic Slope

Topographic slope (%)	Vulnerability	Weightage
0-2	High	5
2-6	Rather High	4
6-13	Medium	3
13-20	Rather low	2
20+	Low	1

Source: (Lida, 1963)

2.2.3 Topographic Relation to Tsunami Direction

The speed of water and wave height at the coast area will influence the direction of tsunami. The area affected by the energy concentration of the wave facing perpendicular to the direction of the tsunami will give high impact in the classification (Diposaptono & Budiman, 2005). While the area covered by the other land from the direction of a tsunami wave gives low vulnerability in the classification in the modeling. The effect will be categorized as medium when the area is oblique to the direction of the tsunami. The classification of this parameter was divided into 3 classes as per Table 3.

Table 3: Vulnerability and weightage in Terms of the Topographic Relation to Tsunami Direction

Topographic relation to tsunami direction	**Vulnerability**	**Weightage**
Perpendicular	High	5
Oblique	Medium	3
Covered	Low	1

Source: (Van & R., 1983)

2.2.3 Coastal Proximity

Coastal proximity is generated based on 1m grid IFSAR data. Distance from coastline is associated with the possible reach of a tsunami. The vulnerability becomes higher as coastal proximity increases. The (Bretschneider & Wybro, 1976): logXmax = log400+4/3log (Y_0/10), where Xmax is the maximum reach of the tsunami over land, and Y_0 is the tsunami height at the coast.
With this formula, tsunami with 5m run up can reach up to 556m from the shoreline, while a 5-10 m run-up can reach 556-1400m from the shoreline, whereas runs-up of 10-15 and 15-20 correspond to distances of 1400-2404m and 2404-3528m accordingly. In this study, the approximate run-up data for the vulnerability area is given by Malaysian Meteorological Department. The classification of this parameter is shown in Table 4.

Table 4: Vulnerability in Terms of Coastal Proximity

Distance (m) from shoreline	**Vulnerability**	**Weightage**
0-556	High	5
556-1400	Rather high	4
1400-2404	Medium	3
2404-3258	Rather Low	2
>3528	Low	1

Source: (Bretschneider, 1976)

2.2.4 Coastal Shape

The shape of the coastline profile can also influence tsunami height and speed. The coasts with indentation may have higher run-ups than coasts without indention because wave energy tends to concentrate within gulfs (Ikawati, 2004). In this study, we used three categories of coastal shape such as gulf, straight coast, and cape and the weightage shown in Table 5.

Table 5: Vulnerability and weightage in Terms of Coastal Shape

Coastal Shape	**Vulnerability**	**Weightage**
Gulf	High	5
Straight coast	Medium	3
Cape	Low	1

Source: (Ikawati, 2004)

3. Multi-criteria Analysis and Vulnerability Mapping

3.1 Weighing Scheme

The Weighted Overlay tool applies one of the most used approaches for overlay analysis to solve multicriteria problems such as topographic elevation, topographic slope, topographic relation to tsunami direction, coastal proximity and coastal shape. In this approach, each pixel in each parameter is given a score and weightage value. These variables were combined in the form of a weighted mean, and the weight for each variable was calculated using the AHP approach. The AHP is an effective method for eliciting expert knowledge and can be a useful tool for risk assessment of natural disasters, even if expert knowledge is often incomplete (Herath & Prato, 2006). The value for each pixel of each parameter was then combined in order to get the ultimate value. The ultimate value were then reclassed according to the certain range in generating in the vulnerability mapping.

In this study, the topographic elevation carried the greatest weight because ground height is directly associated with tsunami inundation according to the run-up of tsunamis. The topographic relation to tsunami direction was considered to be more important than coastal proximity because land lying perpendicular to the tsunami. Coastal shape and topographic slope had relatively low weights.

3.2 Tsunami Vulnerability Mapping

Integration for each parameter to derive the vulnerability map used a weighted mean of the variables in the form of $\sum_{i}^{5} =_{1} w_i s_i$, where w_i is the weight of the *i*th variable, and s_i is the score for the *i*th variable. Score 3,2 and 1 were assigned to the categories of **average and high** vulnerability. Table 7 shows the classification of tsunami vulnerability. We classified the value into 2 groups using Jenks' natural break method to make internally homogenous groups. As for the purpose of this study, we classified the class of vulnerability as average and high vulnerability as per Figure 1.

Table 7: Classification of the Tsunami Vulnerability

Vulnerability Index	Class
1.24-2.75	Average
2.75-4.34	High

Source: (Tumpal P.T. Sinaga, 2010)

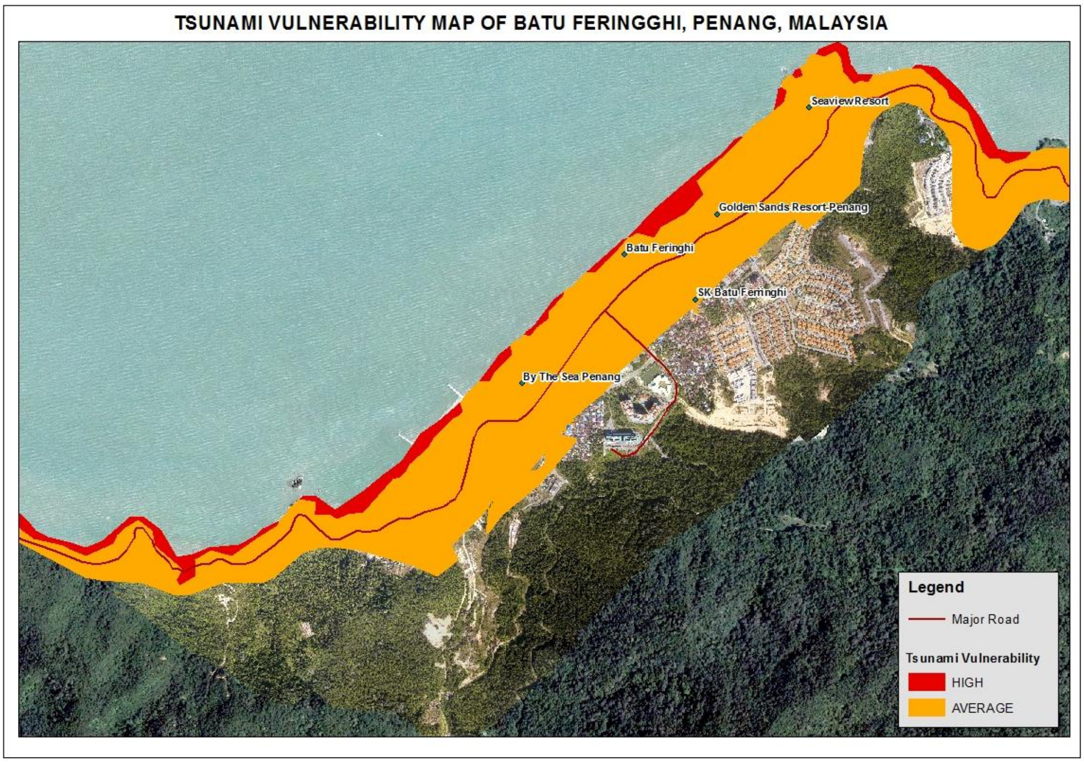


Figure 1: Expected Tsunami Vulnerability Map for Bt. Feringgi, Penang, Malaysia (worst-case scenario)

3.3 Comparisons with the Andaman 2004 Tsunami.

Based on the documented eyewitness accounts, the observed tsunami inundation at Batu Feringgi, Penang is around 300 to 400m with the run-up is around 2.00 to 3.00m (Yalciner, et al., 2005). In this study, the result is significant with the actual observation data, where the wave height is around 3.14m (MetMalaysia) and the inundation is around 555.00m from the beach. The study will then be expanded to anticipate the tsunami vulnerability map that will contribute to preliminary mitigation planning efforts in Penang, especially in Batu Feringgi area.

4. TSUNAMI BUILDING VULNERABILITY ASSESSMENT

We used the Papathoma Tsunami Vulnerability Assessment-3 (PTVA-3) model to determine the Relative Vulnerability Index (RVI) score for every building (Dall'Osso, Gonella, Gabbianelli, Withycombe, & Dominey-Howes, 2009) in Batu Feringghi, Penang which located in the vulnerable zone during worst case tsunami scenario described in Figure 1. The RVI is calculated using PTVA-3 Model and takes into account thepotential damage to the building structure and to those parts of the building that were exposed to contact with water. RVI calculation depends on the Structural Vulnerability (SV) (fig.2) and the Vulnerability to Water Intrusion (WV) (fig.2). WV is calculated by the relationship between the number of inundated levels and the total number of levels, while for SV, the capacity it has to sustain the hydrodynamic forces of a tsunami flow calculation considers the attributes of the building structure (Building Vulnerability, BV), the building flood depth (Exposure, Ex) and its protection level (Prot)(fig.2).The Bv calculation considers 6 different parameters (fig.2).The Prot calculation includes 4 parameters (fig.2) while the exposure parameter (Ex) is classified from flood depth map values. In order to build the GIS database and run the PTVA-3 Model, the following data sets were acquired:

- High-resolution image of Batu Feringghi, Penang that is used as the geographical base of the study. The image was used in determining the building vector and for determining specific building features needed by the model (eg: shape and orientation, building row, the presence of the moveable objects and protection provided by natural barrier)
- A Digital Elevation Model (DEM) with a 1m resolution was used to calculate the water depth above the ground surface by subtracting the ground elevation from the horizontal flood surface.
- A shapefile of polygons representing all the building footprints that extracted by using the object-oriented image analysis method with rule-based classification. The basic processing units of object-oriented classification are image objects or segments, rather than single pixels. (Liu, Wang, & Liu, 2005). (multiresolution segmentation algorithm and contrast-split segmentation) utilizing e-cognition software. The algorithm creates clusters of homogeneous pixels through segmentation. Several land cover classes were classified from the orthophoto such as urban, vegetation, road and water. Only the urban class is extracted and the miss-classed building roof edges are then manually extracted.

The data were entered into a GIS database and categorized according to their specific formats. The flood-water depth value for this area using worst-case scenario provided by MetMalaysia is 3-meter height. Finally, the RVI score for each building was calculated using the format described by Dall Osso et al (2009) and appropriate maps generated.

5. RESULTS AND DISCUSSION

5.1 Structural Building Vulnerability (SV)

We divided the result into 3 sectors stretching from Teluk Nangka (P1), Batu Feringgi (P2) and area between Kg. Keling and Teluk Pinang (P3) and the result is classified as high, average and low as shown in figure 3. Figure 4 shows the SV distribution within inundated area. The result shows 40% of the building classified in average vulnerable followed by 32% in minor vulnerable and 28% of the building within that area not in the good condition to withstand the tsunami hazard. SV results for sector P1 and P3 do not show extreme results for structural vulnerability because of the building type itself. This area dominated by double-storey and condominium houses that have a good preservation condition and protection mechanism thus reducing the structural vulnerability risk (Jabatan Pengairan dan Saliran Malaysia, 2005).

The main focus area for this study is at P2 sector. This sector is a highly developed area along the shorelines and mainly dominated by residential building, shop lots and motel and hotel with mostly 3 storey and above (tourism area). Residential and shop lots contribute most of the total number of highly vulnerable classes in this area. Majority of residential and shop lots within this sector can be classified as single storey, timber and single brick material with poor preservation condition and lack of protection mechanism. This factor contributes most to the poor structural vulnerability condition.

5.2 Relatives Vulnerable Index (RVI)

RVI was calculated by combining the SV (Structural Vulnerability) result with the WV (Water intrusion) result derived from Tsunami Potential Vulnerability Map (Figure 1). Figure 5 shows the RVI classes map for each of the building located within the inundated zone during worst-case tsunami event for Batu Feringgi area. A total number of 504 buildings in the Feringgi coastal areas are estimated will be exposed to the tsunami flood zone during the worst-case tsunami event. 62% of these buildings are residential type, 20% shop lot, 10% are tourism buildings, 6% government facilities, and the rest (commercial buildings) make up about 2%. It is also shown that there is no structure or buildings located within the high-risk area. Figures 6 and 7 show the overall distribution of inundated buildings according to RVI classes and the type of the building at Bt. Feringgi respectively.The result shows there are 303 buildings within inundated zone will suffer severe damages as a result of worst-case tsunami event, comprised of 57.1% residential, 31.2% shop lot, 7.5% tourism buildings, 2.4% government buildings and 0.67% commercial centre. Most of these buildings are situated in sector P2. 189 buildings categorized in average vulnerable that shows residential buildings contribute the highest numbers which are 75%, followed by hotel and resort 11.2%, government facilities 7.4% and commercial centre 4.7% and there are only 12 buildings classified as safe building consist of 83% of government facilities and 16.7% hotel and resort. Through this study, designation of the shortest evacuation routes possible (safe building) can be identified. Thus can minimise the tsunami risk. Urban planning matters in relation to zoning restriction, renovation and reconstruction of building structures by government bodies also need to be strengthen. Both of these strategies could be adopted to reduce impacts in order to protect life and property in tsunami hazard zones.

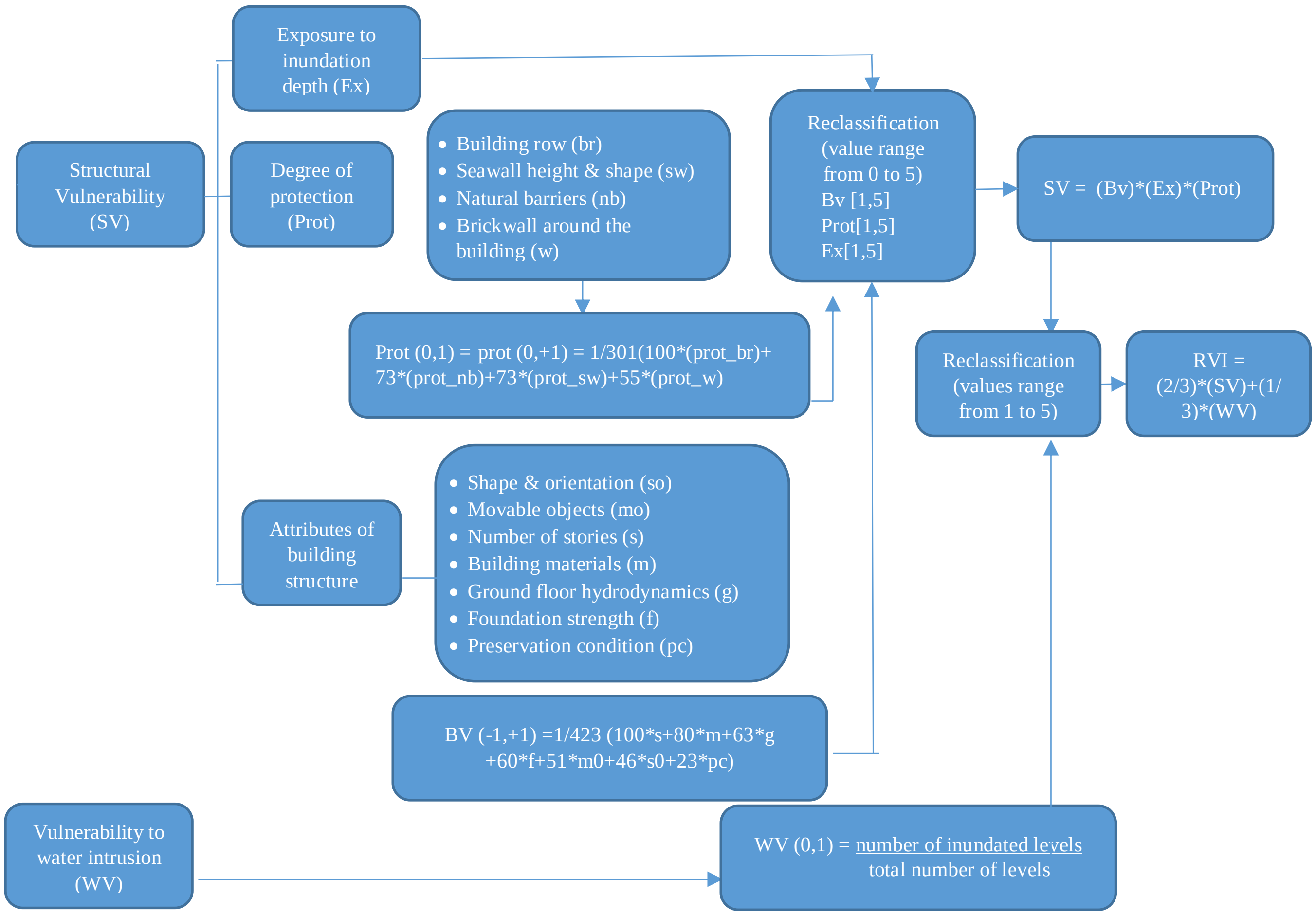


Figure 2: PTVA-3 model

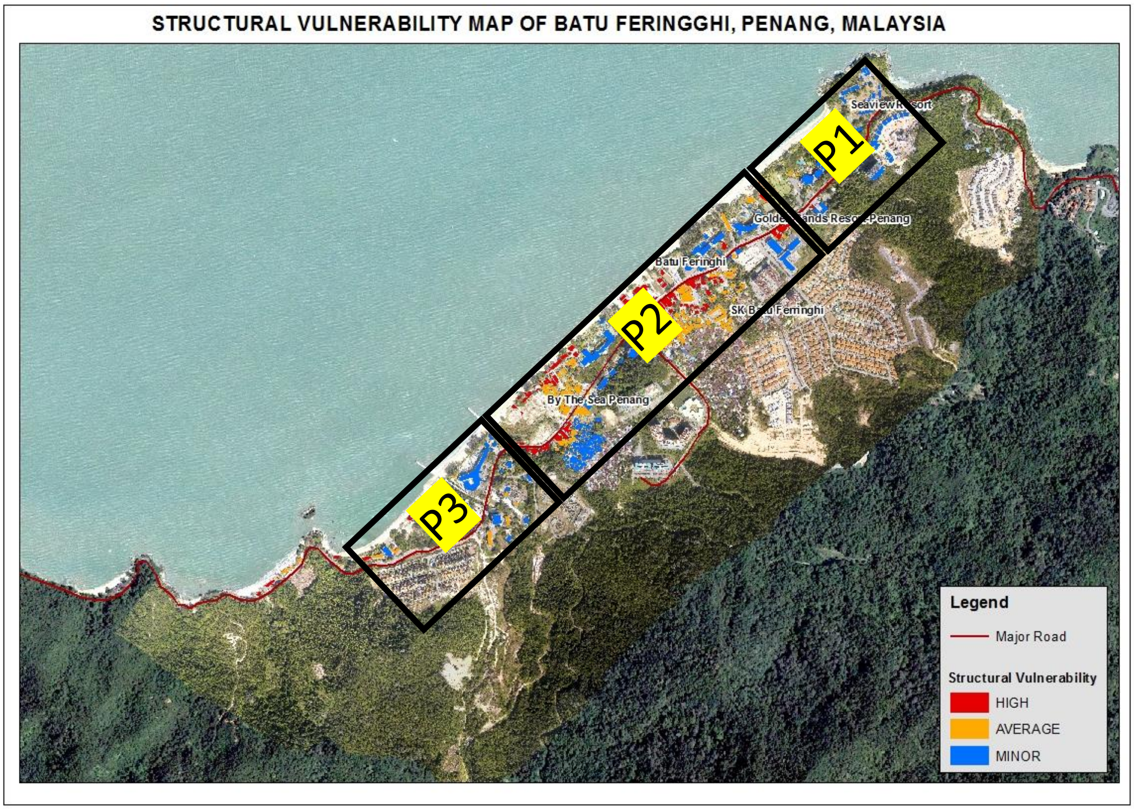


Figure 3: Structural Building Vulnerability (SV) Map for along Feringgi Coastlines Divided into 3 Sector

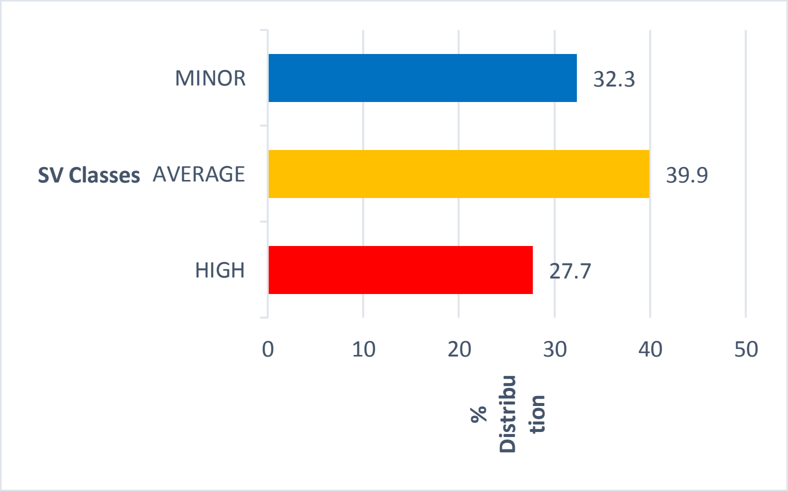


Figure 4: SV Distribution within Inundated Zone

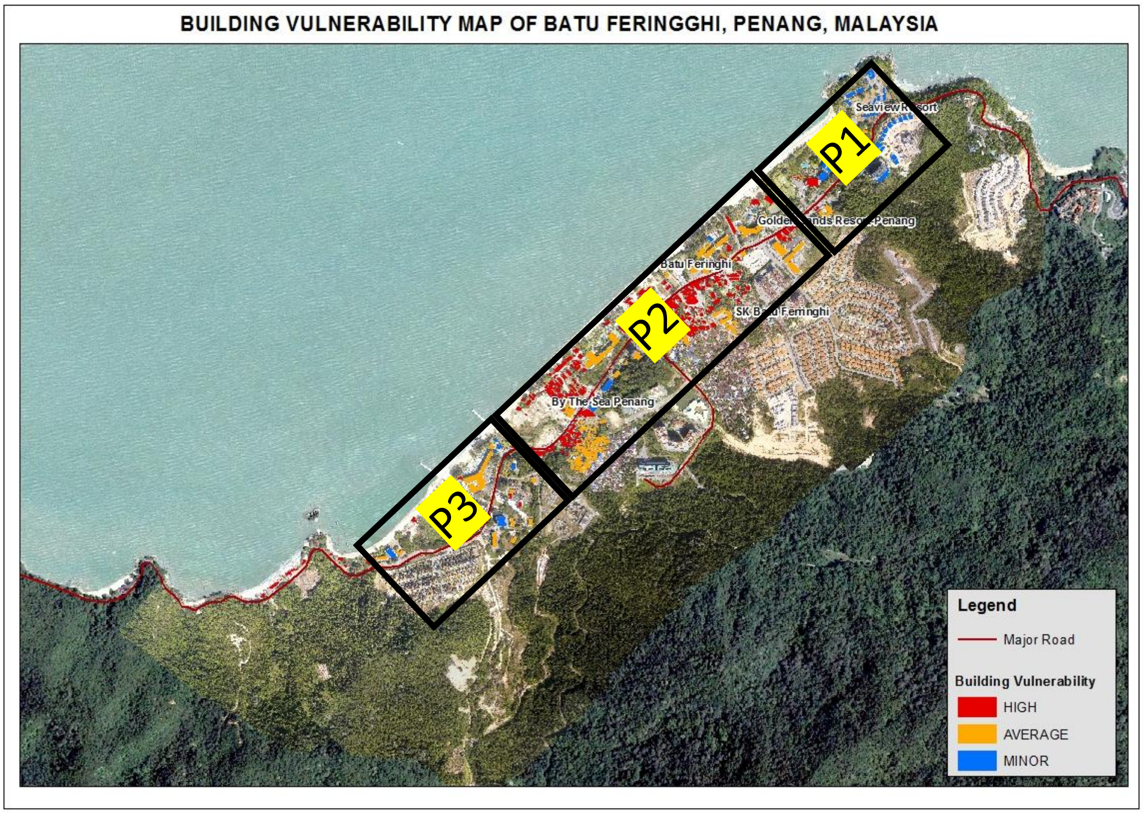
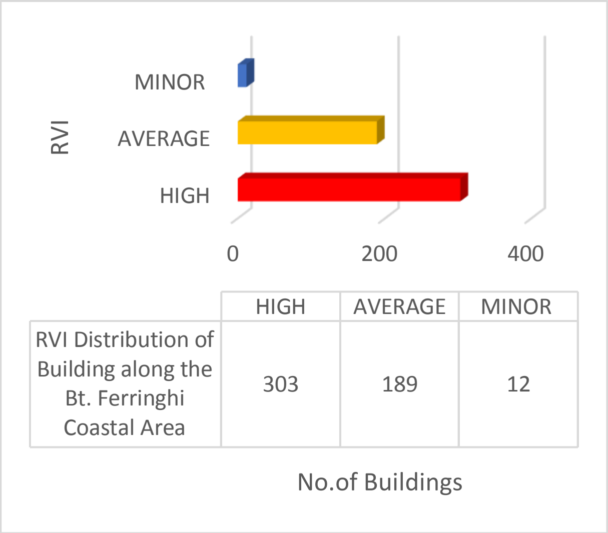


Figure 5: Relative Vulnerability Index (RVI) Class Map for Building Located Within Inundated Zone during Worst Case Scenario-Feringgi



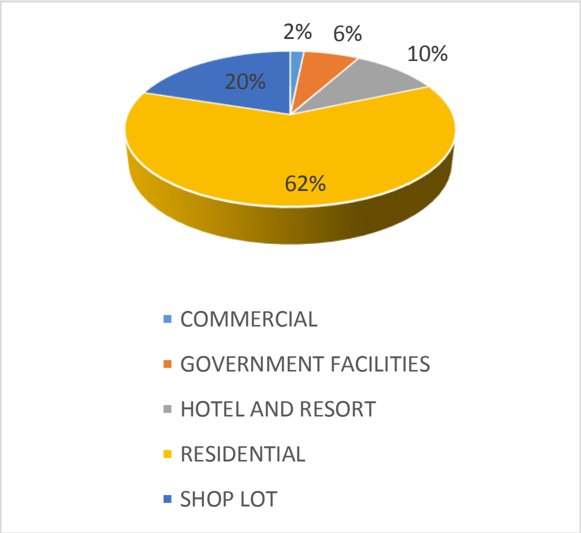


Figure 6: Overall Distribution of Inundated Building According to Its Relative Vulnerability Index at Bt. Feringgi

Figure 7: Overall Distribution of Inundated According to Its Type at Bt. Feringgi

6. REFERENCES

A Rahim, S., Mat Said, A., A Bakar, E., Sulaiman, N., & Ahmadun, F.-R. (2014). TSUNAMI 2004 PREPAREDNESS FROM THE PERSPECTIVE OF THE PENANG COMMUNITY. *Jurnal Pengguna Malaysia*, 71-86.

Bretschneider, C. L., & Wybro, P. G. (1976). Tsunami inundation prediction. *Proceeding of the 15th ASCE Conference on Coastal Engineering* , (pp. 1006-1024).

Dall'Osso, F., Gonella, M., Gabbianelli, G., Withycombe, G., & Dominey-Howes, D. (2009). A revised (PTVA) model for assessing the vulnerability of building to tsunami damage. *Natural Hazard and Earth System Science*.

Diposaptono, S., & Budiman, D. (2005). *Tsunami:Scientific Popular Book.* . Bogor.

Eckert, S., Jelinek, R., Zeug, G., & Krausmann, E. (2011). Remote Sensing Based Assessment of Tsunami Vulnerability and Risk in Alexandria,Egypt. *Elsevier*, 714-723.

H.Ismail, A. W. (2012). A 3-tier tsunami vulnerability assessment technique for the north-west coast of Peninsular Malaysia. *Springer*.

Herath, G., & Prato, T. (2006). Using multi-criteriadesicion analysis in natural resources managment. *Ashgate Publishing, Surrey, UK*, 239.

Ikawati, Y. (2004). Tsunami Wave Is Predictablke, In Canahar. . *P Earthquake Disaster And Tsunami, Kompas, Jakarta, Indonesia*, 550.

Ismail, H., Abd Wahab, A. K., Mohd Amin, M. F., Mohd Yunus, M. Z., Jaffar Sidek, F., & B., E. J. (2012). A 3-tier tsunami vulnerability assessment technique for the north-west coast of Peninsular Malaysia.

Jabatan Pengairan dan Saliran Malaysia. (2005). *Laporan Penyiasatan Pasca-Tsunami 26 Disember 2004.*

Keizrul, A., Tan, K. S., & Ghazali, N. M. (2005). NO MORE IN THE COMFORT ZONE-Malaysia's Response to the December 2004 Tsunami. *International Hydrography and Oceanography Conference and Exhibition.* Kuala Lumpur.

Lida, K. (1963). Magnitude, Energy and Generation Mechanism Of Tsunamis And Ctalogue Of Earthquakes . *Proceedings Tsunami Meeting at the 10th Pacific Science Congress*, (pp. 7-18). Jakarta, Indonesia.

Liu, Z. J., Wang, J., & Liu, W. P. (2005). Building Extraction from High Resolution Imagery Based on Multi-scale Object Oriented Classification and Probabilistic Hough Transform. *IEEE*, 2250-2253.

Tumpal P., S. T., & A., N. W. (2010). GIS Mapping of Tsunami Vulnerability: Case Study of the Jembrana Regency. *KSCE Journal of Civil Engineering*.

Van, Z., & R., A. (1983). Guide To Geomorphologic-Ariel Photographic Interpretation And Mapping. *The Netherlands: International Institute for Geo-Information Science and Earth Observation.* Enshede.

Yalciner, A. C., Perincex, D., Ersoy, S., Presateya, S., Hidayat, R., & McAdoo, B. (2005). *Report on 26 December 2004 Indian Ocean tsunami, Field survey on July 09-10, 2005 North West of Malaysia, Penang and Langkawi Island.*