Tsunami Vulnerability of Critical Infrastructures in the City of Padang, West Sumatera

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Abstract. The City of Padang, West Sumatera, Indonesia has experienced four large earthquakes in the last six years. However, the risk of another even larger earthquake followed by tsunami remains high because the energy contained in the seismic gap of Sumatera megathrust has not been fully released. Learning from the 2004 Aceh tsunami and the 2011 Japan tsunami, critical infrastructures have significantly contributed in the processes of aid distributions, emergency responses, and rehabilitation/reconstruction efforts. Padang has prepared several mitigation efforts to deal with the future earthquake and tsunami by setting-up tsunami early warning system, tsunami hazard maps, vertical/horizontal evacuation systems, as well as raising public awareness. However, the existence and the role of critical infrastructures which are mostly located within the reach of predicted tsunami inundation zones has never been investigated in details. Therefore, we have identified 13 (thirteen) groups of critical infrastructures and assessed the tsunami vulnerability of each infrastructure based on Papathoma Tsunami Vulnerability Assessment (PTVA) to produce Tsunami Vulnerability Index. With the assumption that they will survive from the earthquake (as they did from the previous earthquakes), we found more than 15% out of 272 critical infrastructures have high and very high tsunami vulnerability indexes.

Keywords: *earthquake, tsunami, critical infrastructures, Padang, vulnerability.*

Abstrak. Kota Padang, Sumatera Barat telah mengalami empat kali gempa bumi dalam enam tahun terakhir. Namun, resiko kejadian gempabui diikuti oleh tsunami tetap tinggi karena energi yang tertahan pada celah seismik sepanjang "Sumatera Megathurst" masih besar. Belajar dari kejadian gempabumi dan tsunami di Aceh (2004) dan di Jepang (2011), infrastruktur strategis berperan sangat penting dalam proses tanggap darurat, distribusi bantuan, dan upaya-upaya rekonstruksi dan rehabilitasi. Padang telah mempersiapkan upaya-upaya mitigasi bencana tsunami dengan memasang sistem peringatan dini, menysun peta resiko bencana tsunami, membangun sistem evakuasi vertikal/horizontal dan peningkatan kesadaran masyarakat. Namun, keberadaan dan peran dari infrastruktur strategis yang terletak pada daerah bahaya tsunami nampaknya masih belum diteliti secara mendalam. Oleh karena itu, penelitian ini berhasil mengidentifikasi 13 (tigabelas) kelompok infrasruktutr strategis dan menentukan indeks kerentanan terhadap bencana tsunami berdasarkan Papathoma Tsunami Vulnerability Assessment (PTVA). Dengan asumsi bahwa bangunan-bangunan tersebut akan bertahan dari bencana gempabumi seperti yang pernah terjadi pada tahun-tahun sebelumnya, kami menemukan lebih dari 15% dari total 272 infrastruktur strategis di Kota Padang memiliki kerentanan tsunami tinggi dan sangat tinggi.

Kata kunci: *gempabumi, tsunami, infrastruktur strategis, Padang, kerentanan.*

1 Introduction

Located in the world active tectonics plates, earthquakes and tsunami often occurred in Indonesian archipelago. Statistics shows that there were 110 fatal tsunami occurred in Indonesian islands since 1600 AD where 90% of them triggered by earthquakes in the ocean (Latief *et al.* (2000) and Dinar *et al.* (2012)). Sumatera island is one of the regions with high earthquake frequencies generated by the Sumatera Megathrust along Western Sunda Arc. Therefore, West Sumatera Province in Indonesia, particularly the City of Padang has been considered as one of the most vulnerable cities to experience large earthquake and tsunami in the near future because large earthquakes is predicted to occur at the seismic gaps, offshore the Mentawai Islands (Natawidjaja *et al*. (2006), Wisemann *et al*. (2011) and Huang *et al.* (2009)). Moreover, *paleotsunami* records also show evidence of a super-cycle large earthquake occurrences every ~200 years where the last ones occurred in 1789 and 1833 (Sieh *et al*., 2008).

Situated in a low-lying coastal area surrounded by hills in the Eastern and Southern parts, Padang (0°57′0″S, 100°21′11″E), the capital city of West Sumatera province has a population of nearly a million and serves as the nerve centre of West Sumatra economy. The city of Padang is the focus of tsunami vulnerability assessment in this study because most critical infrastructures which support the livelihood of the population in West Sumatera are located there. The vulnerability of the city against the impact of future tsunami has significantly increased due to high concentration of population in the ‘red zone’ or the zone with high risk of tsunami inundation according to the official tsunami hazard map produced by the local disaster mitigation agency (BPBD, 2010).

Learning from previous fatal tsunami events (e.g. the 2004 Aceh Tsunami), the existence of critical infrastructures is very important to secure the processes of emergency responses, rehabilitation and reconstruction efforts. Compared to other regions such as Sri Lanka and Thailand, the hardest hit tsunami region, Aceh Province was out of media coverage as well as national and international attentions for few days after the tsunami, due to most of critical infrastructures were paralyzed. Transportation system, communication networks and energy supplies were cut-off and government facilities were destroyed making the emergency efforts and aid supplies mostly from the central government agencies were stuck. Similarly, the 2011 Japan Tsunami caused multiple disasters, from earthquake and tsunami to energy and environmental disasters because one of critical infrastructures, the nuclear power plant in Fukushima suffered serious damages.

Critical infrastructures are defined as “systems and assets, whether physical or virtual, so vital to a region (a city or a country) that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters” (Parfomak, 2007). Meanwhile, for the case of tsunami, we define critical infrastructures as infrastructures that directly or indirectly have significant role/contributions to the processes of live saving activities, emergency responses, and rehabilitation and reconstruction efforts. These infrastructures include vertical evacuation buildings (shelters), banking and financial centres, commercial centres, religious facilities, energy sources, communication and IT networks, transportation systems, government buildings/facilities, educational facilities, public health centres, food (livestock) and drinking water facilities, military facilities, manufacture/chemical industries, and emergency facilities (i.e. tsunami early warning system networks).

Many studies have been carried out to assess the vulnerability of buildings or infrastructures against the impact of tsunami as mentioned by (Koshimura *et al.* (2009) and Omira *et al*. (2010)) However, one of the methodologies with more complete parameters that has been used in many tsunami vulnerability assessment for buildings is Papathoma Tsunami Vulnerability Assessment method version 3 (PTVA-3). This method was originally developed by (Papathoma *et al*. (2003)) and it has been used to assess building vulnerability in Greece, Italy, Maldives, and Perth, Australia (Papathoma *et al.* (2003), Dominey *et al*. (2007 and 2010), and Dall`Osso *et al*. (2009)). Therefore, the objective of current study is to assess the vulnerability of critical infrastructures in the city of Padang based on PTVA-3 approach. The details of this method are explained in the following sections.

2 Methodology

The flow chart of general methodology is shown in Fig. 1. It is started by the simulation of tsunami inundation using Shallow Water Equation Model with high resolution bathymetry/topography for the city of Padang based on source parameters and fault model in the Sumatera Megathrust (Natawidjaja *et al*., 2006), (more detailed discussion is in the following chapter). The second step is identification of 13 (thirteen) critical infrastructures which have important role in disaster mitigation and management processes in the city of Padang. A field survey in August 2012 was carried out to collect data of 13 (thirteen) critical infrastructures, consisting of government buildings, vertical evacuation buildings, security and military facilities, religious buildings, banking and financial centres, commercial buildings, transportation infrastructures, communication and IT facilities, hospitals and health centres, food and drinking water facilities, educational facilities, energy resources, and chemical/raw material industries (Table 1). For each building, 11 (eleven) influencing building parameters such as; building materials, number of floors, hydrodynamics of the first floor, foundation types, maintenance conditions, artificial coastal protections, natural coastal protection, outdoor building fences, building shapes and orientation to the expected incident tsunami waves, number of building between the sea and the analysed building, and moving objects were measured and estimated. Finally, assessment of building vulnerability in term of Relative Vulnerability Index (RVI) was calculated based on PTVA-3 considering physical aspects related to building structures and tsunami inundation:

$$RVI = (2/3)SV + (1/3)WV \qquad (1)$$

where:

SV : vulnerability of building structures with scores 1-5

WV : vulnerability of structure due to water intrusion with scores of 1-5

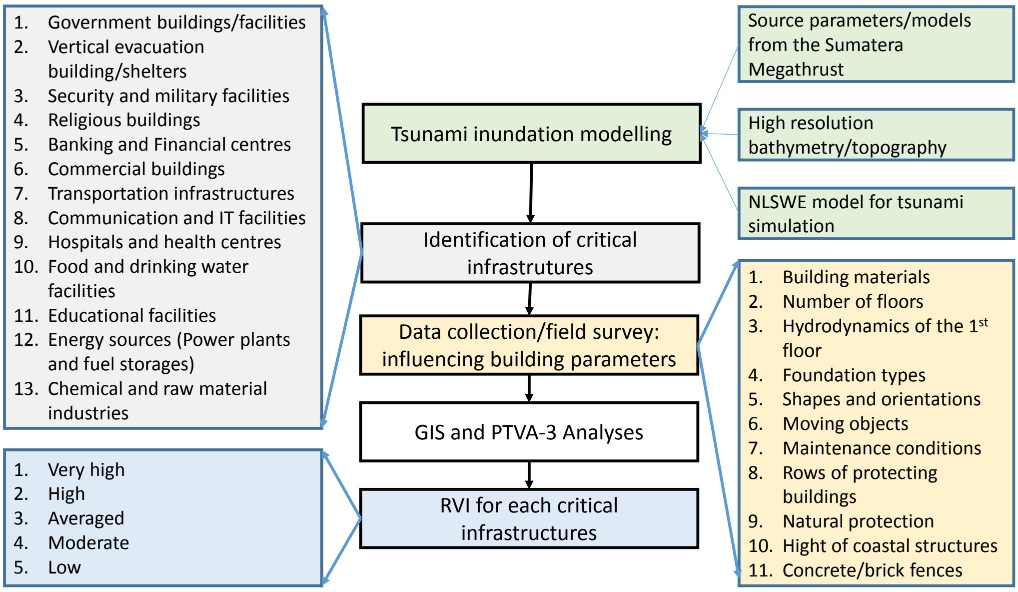

Figure 1 Flow chart of research methodology

Table 1 Determination of the Relative Vulnerability Index (RVI) (Dominey – Howes *et al*., 2010 and Dall`Osso *et al*., 2009)

Relative vulnerability index (RVI)	RVI score	Descriptions
Low	1.1>RVI ≥ 1.8	Negligible damage
Moderate	1.8>RVI ≥ 2.6	Minor damage observed in the exterior of the building
Averaged	2.6>RVI ≥ 3.4	Doors and windows destroyed, interior damaged, walls still intake, structural damage not observed
High	3.4>RVI ≥ 4.2	Structural damage observed, interior destroyed
Very high	4.2>RVI ≥ 5.0	The entire building completely destroyed

SV is calculated based on the 11-building parameters and calculated using certain weighing factors. Meanwhile, WV is calculated based on the ratio of inundated floor(s) to the total building floors. More detailed discussion on this topic can be found in (Dominey – Howes *et al*. (2010) and (Dall`Osso *et al*. (2009)). The RVI is then determined based on the following scoring system:

3 Tsunami hazard map of Padang

Historically the major tsunamis happened in 1797 and 1833 where Padang hit more than 6 m tsunami height (McCloskey *et al*. (2008)). In 2009 Padang again was shaked by earthquake leaving more than 1200 casualties and thousands of damage buildings. Even though it did not substantially change the megathrust strain-energy budget, it triggered us to strategically mitigate the future event especially those associated with tsunami. The up to date research, seismically Padang and surroundings is a “locked” area, likelihood of major earthquake and subsequent tsunami is extremely high in near future. The threat is clear and the need for urgent mitigating action is extremely high (McCloskey *et al*., 2010).

A year back in 2008, the International Workshop on Official Tsunami Hazard Map for Padang launched the Padang Consensus. It established dialogue and initiate decision-making process on official tsunami hazard map for Padang among government, NGOs, and scientists from Indonesia, Germany, Japan and USA. The Main agreements on this initiative were sharing geo-data basis and plausible source scenario among the different groups/institutions. Before the development of the map being finished, the conservative solution for disaster preparedness based on the tsunami inundation maps developed by (Borerro *et al*., 2006 and Protocol of Padang, 2008).

Continuing to advance the process above, during 2007-2010 in the Project of GITEWS (German-Indonesia Tsunami Early Warning System), the “Last-mile” approach’s project produced the reasonable tsunami inundation map according to

Padang Consensus above. This initiative was also taken due to the fact that the multi-version of maps are available for the public and brings the communities in confused. Besides that, the available tsunami inundation map was produced by using rough data. This is the main reasons why the hazard map of Padang based on the reliable tsunami scenario with a highly resolved geo-data was produced and formally launched in 2010.

3.1 The geo-data and tsunami source

Before this study, the geometric data input for the tsunami inundation model by far relies on the relative coarse data basis. In order to perform accurate modeling of tsunami run-up, a very detailed model of near-shore bathymetry and coastal topography was performed to satisfy planning requirements for housings scale. The grid geometric digital elevation model for data input, i.e. topography and nearshore bathymetry were acquired from flight campaign of highly resolved stereo camera (HRSC) and hydrographic of multi-beam survey providing the resolution of less than a metre (Schlurmann *et al.*, 2011 and Kongko *et al.*, 2010).

A tsunami source was modelled from a sophisticated data derived from continuous Global Positioning System (cGPS) data and Coral Atoll study. The GPS array stations had been installed in this region to collect both horizontal and vertical motion of seismic activity on the past. The ground vertical displacements were measured at the GPS stations and from the emergence or submergence of coral micro-atolls. By analysing this to estimate the cumulative seismic slip in this region, we proposed moderate tsunami scenario and worst tsunami scenario for inundation map model in Padang, by adding the factor of 0.5 to adopt the uncertainties in determining the seismic slip. To obtain vertical ground deformation, the analytical solution of the homogenous material of Mansinha & Smylie deformation model has been used (Mansinha & Smylie, 1971). The results are depicted in Figure 2.

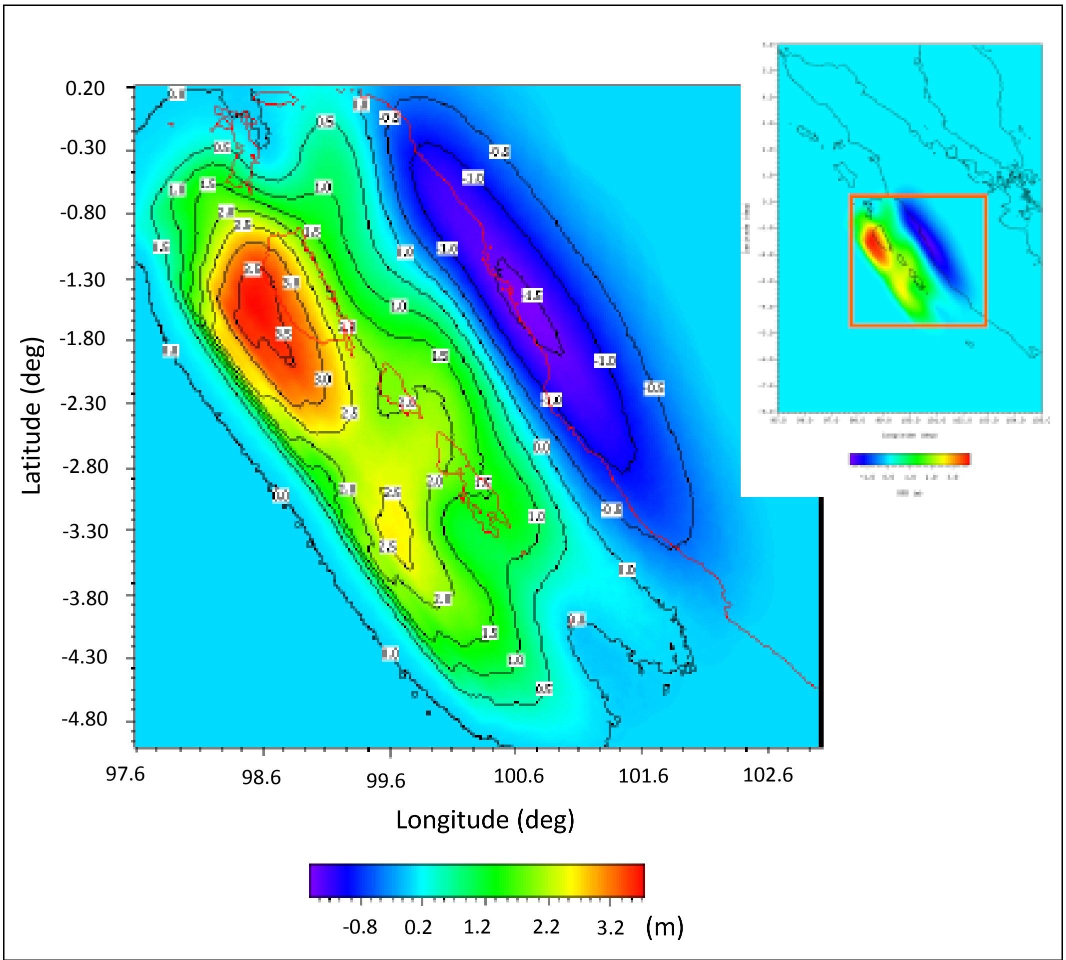

Figure 2 Fault Model of Padang

3.2 Setup model

The vertical ground displacement resulted in previous chapter will be assumed as an area of sea surface height and to be used for input tsunami model. TUNAMI model with Non-linear Shallow Water Equation (NLSWE) has been used. The detail explanation of governing equations and numerical schemes of TUNAMI refers to the source code's manual (Imamura *et al*. (2006)). To save computational time, nested grid system was used. To achieve 5m resolution (high resolution) and 15m (medium resolution), we use 6 Levels of nested grids. The detail properties for each domain (1 to 6), i.e. node size, grid size and spacing, time step, and their bounding coordinates are shown in the Table 2 below.

The model was run for total 2 hours time of tsunami, and under several conditions, i.e. with and without tide where it is to be assumed 80cm. Based on the resume Padang Consensus 2^{nd} (2010), the Digital Elevation Model (DEM) by combining land cover such as housings and vegetations was chosen as topography data input. The DEM data with uniformly *Manning* roughness of n = 0.025 and distributed roughness approach have been considered for the uncertainties of the model.

Table 2 Constitutive parameters of the six TUNAMI simulation sub grids (domains)

Domain	No. of cells		Longitude [^{o}]		Latitude [^{o}]		Edge length [m]	Time step [s]
	x	y	Minimum	Maximum	Minimum	Maximum	dx/dy	
01	914	1279	95.000000	105.000000	6.000000	-8.000000	1216.14	1.0
02	277	331	99.656263	100.665777	-0.371658	-1.575767	405.38	1.0
03	572	653	99.878669	100.573600	-0.610923	-1.404737	135.26	0.5
04	934	871	100.075846	100.454116	-0.776288	-1.129124	45.06	0.3
05	1649	1507	100.197668	100.420491	-0.861872	-1.065506	15.04	0.2
06	2784	2281	100.268177	100.393553	-0.875714	-0.978461	5.01	0.1

3.3 Model result

We produce two kinds of tsunami inundation map. The first is the map that represents the flow depth of tsunami onto land. This map refers to the flow depth of tsunami that its height to be measured from ground. It is useful for designing the evacuation routes as well as determining buildings' level in the designing stage. The second one is the specific energy map that reflects the superposition of the tsunami flow depth and energy height. This concept accounts the amount of energy in an existing flow condition and describes the hazardous inundation dynamics much better than pure flow-depth, especially for designing infrastructures' purposes.

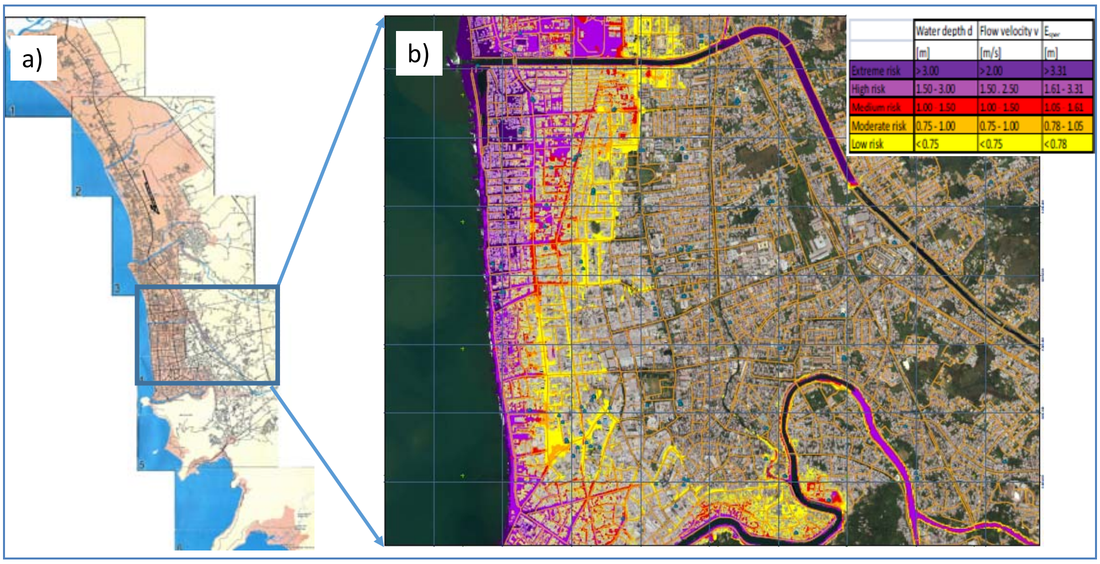

Figure 3 Simulation results**:** a)The offical tsunami hazard map released by BPBD Padang in 2010 and b) The map of Inundation and Specific Energy of Padang

The formula for the specific energy map is adopted from the hydraulic steady flow as denoted below:

$$E_{spec} = h + \frac{v^2}{g} \quad (2)$$

Where:

E_{spec} : specific energy (m)

h : tsunami flow-depth (m)

v : velocity (m/s)

g : gravity acceleration (m/s2)

The released of official tsunami hazard map of Padang by BPBD in 2010 was based on these maps as shown in Fig. 3a. The example of inundation and specific energy map that is used for the analyses of RVI is shown in Figure 3b.

4 Results and Analysis

4.1 Identification of critical infrastructures in Padang

Within the tsunami inundation zone (or “red zone”), there are 272 (two hundred and seventy two) critical infrastructures categorised in 13 groups namely: Vertical evacuation buildings/shelters (19 buildings), government facilities (40 buildings), educational facilities (38 buildings), commercial facilities (58), religious facilities (49 buildings), banking and financial centres (21 buildings), public health facilities (13 hospitals), information technology (IT) and communication networks (5 buildings), agricultural/food and drinking water facilities (2 storages), chemical and raw material industries (5 factories/storages), transportation facilities (12 buildings/bridges/facilities), military facilities (9 buildings), and power plants/petrol station (18 buildings/facilities). More than 90% of the infrastructures are located in the northern part of the city where the population is also very high compared to the population in the southern part of the city (Fig. 4 and 5). Most of these buildings have survived (or experienced minor damage) from the 2007 and 2009 earthquakes, except for the newly built infrastructures. Some of the collapsed buildings have been re-erected and reinforced to deal with future large earthquakes (e.g. Hotel Bumi Minang).

Vertical evacuation buildings (or shelters) are mostly located in the city centre where the population density is very high and there are no high grounds. All shelter buildings have double functions, not only for vertical evacuation but also used as schools, hotels, government buildings, mosques and apartments. These shelters have at least 4 floors with reinforced concrete and some of them were constructed by the help of the Japanese Government. Governmental buildings and facilities are mostly located along the main roads (e.g. Jl. Khatib Sulaiman) which are parallel with the coastline. Governmental buildings include governor/major offices, local government agencies, and central government branch offices. Some of them are poorly maintained or in damage condition due to previous earthquakes. Some of these buildings are being relocated to a safe zone in Bypass Area (east of the city). Schools, laboratories and universities are categorised as educational facilities. The largest university, Andalas Universsity's main building complex is already located far from the coastline while the largest private university (Bung Hatta University) building complex is being relocated to a safe zone in Bypass Area. Commercial buildings such as hotels, shopping malls, public markets and shopping arcades are mostly located in the “red zone”. Many of commercial buildings are multi-storey buildings with reinforced concrete, such as Basko Mall and Plasa Andalas. Large banking and financial services are also located in the “red zone” alongside with governmental and commercial facilities. Meanwhile, health centres and hospitals in Padang are better distributed. Though the largest hospitals (RS M. Djamil) are located in the “red zone”, some of the hospitals are already in the safe zone (Bypass area) such as RS Siti Rahma and RS Semen Padang. Religious facilities, such as mosques, Buddhist Temples and Churches follow the distribution of populations and social conditions. Buddhist Temples are mostly located in the old town area while Churches are mainly located in the city centre. Large mosques are also located along the main roads. These religious facilities located in the red zone with multi-storey structure (e.g. Mesjid Raya Padang) also serve as shelters.

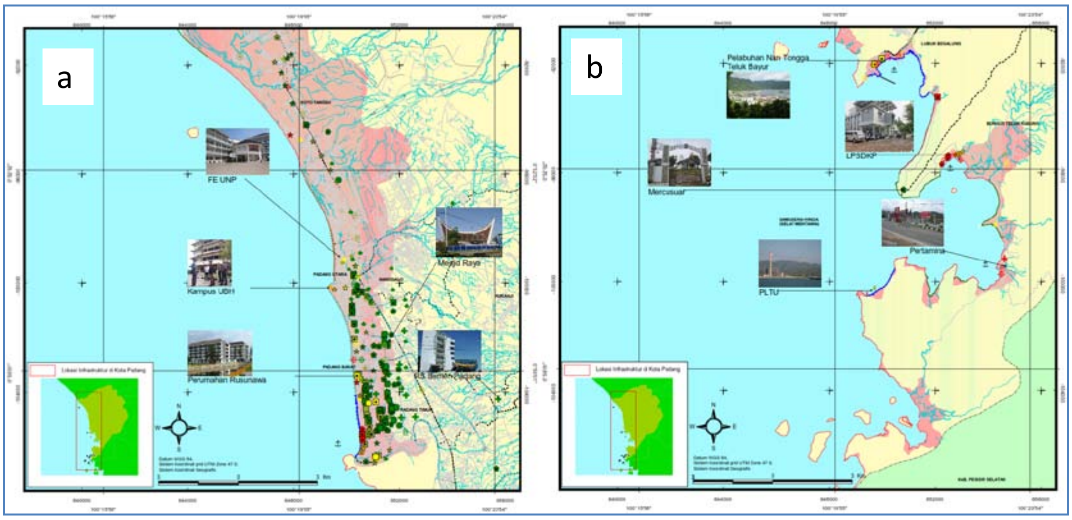

Figure 4 Distribution of critical infrastructures in the city of Padang within the estimated tsunami inundation zone, a) North of Padang and b) South of Padang.

Padang is well served by the neighbouring regions for foods and drinking waters. Though, tap water facility and temporary food storages are located in the red zone, mountainous terrains in the East and in the South of Padang secure the needs of fresh water for the city. Manufacture and raw material industries are mainly located near the Ports of Teluk Bayur and Teluk Bungus (red zone) for the ease of trade access. Power plants and main electricity facilities as well as fuel storages are also located in the coastal area (e.g. PLTU Teluk Sirih and Pertamina Bungus Storage Station). Pertamina fuel stations (SPBU) are also considered as critical infrastructures due to its important role in securing the needs of fuel. SPBU stations are better distributed but the Pertamina Bungus Storage Station as the source of fuel distribution is located in the red zone. Lastly, transportation infrastructures consists of bridges, rail networks and port facilities as well as communication/IT networks are also considered in the analyses because these infrastructures are very important for the access to any corners of the city. Communication/IT networks, transportation infrastructures, and power plant facilities/fuel storage are independently further analysed due to their special infrastructures/functions in inundated conditions.

Figure 5 Examples of critical infrastructures in Padang a) a school as a shelter, b) BIM airport, c) Power plant (PLTU) Teluk Sirih and d) Apartment towers (Rusunawa Purus)

The city of Padang is protected by both natural and artificial coastal structures. Pantai Padang in Central Padang, the most important tourism attraction of the city is heavily protected by seawalls and groins to prevent coastal erosion, while in the northern and the southern part of the city is mostly protected by the existence of natural barriers such as coastal forests or protecting cliffs/islands (Fig. 6). These artificial and natural protection systems contribute to the analyses in reducing the score of RVI.

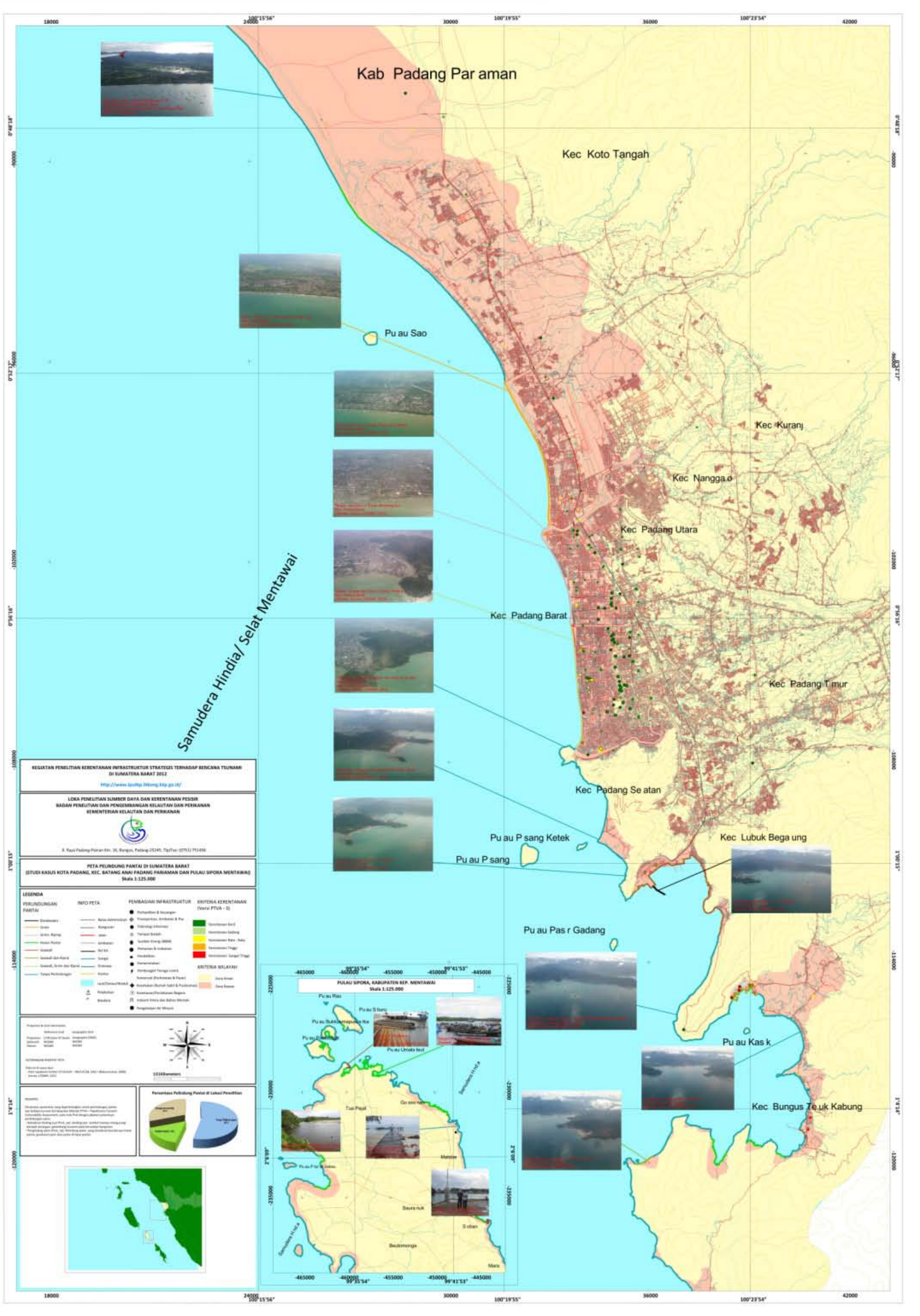

Figure 6 Coastal protection systems in the city of Padang

4.2 Relative Vulnerability Index (RVI)

Considering 13 building parameters and tsunami inundation map as required by equation (1), the calculation of RVI for individual building of critical infrastructures are shown in Table 3. Table 3 shows that 7% of all critical infrastructures considered in current study are very highly vulnerable against tsunami, 4% high, 9% averaged, 20% moderate and 60% low. From each group of infrastructures, chemical and raw material industries have the highest percentage of critical infrastructures with very high RVI (83%). This conditions occur because most of these facilities are located in Teluk Bayur and Teluk Bungus Ports which are located near the coastline, high concentration of moving objects (floating debris potentials) and predicted tsunami inundation heights between 5 - 6 m.

Food/agriculture/drinking water facilities and communication/IT networks have the smallest RVI because most of them are located outside the red zone or in the area where inundation levels are low. Banking and financial centres are also have small RVI scores because many of the buildings have better structural quality and many of them have already been relocated to the area where low inundation is expected. Located in Teluk Bungus, there is one military facility with very high RVI because it is exposed to the open sea, high concentration of moving objects, poor structural strength (low rise), and high tsunami inundation. Transportation facilities have the highest score of RVI because most sea ports and airports are located in the area where tsunami inundation at the highest. Government and commercial facilities have also significant numbers of building with high RVI mainly due to their location in the red zone with high tsunami inundation. For vertical evacuation buildings, there are two buildings with high RVI because they are really located in the area where tsunami inundation is high and very near to the beach or river mouths (Fig. 7). Since these buildings will play very important role during tsunami events, the local authority should re-evaluate their function as vertical evacuation buildings in order to minimize human casualties.

Table 3: RVI for each group of critical infrastructures in Padang (see also Fig 7 and Fig. 8)

No.	Infrastructures	total	Relative Vulnerability Index (RVI)				
			Low	moderate	Averaged	High	Very high
1	Educational building/facilities	*38*	*30*	*3*	*3*	*2*	*-*
2	Government buildings	*40*	*26*	*4*	*1*	*5*	*4*
3	Commercial buildings	*58*	*41*	*11*	*3*	*-*	*3*
4	Religious facilities	*49*	*21*	*18*	*6*	*2*	*2*
5	Bank/financial infrasrtructures	*21*	*14*	*4*	*3*	*-*	*-*
6	Health/emergency centres	*13*	*10*	*2*	*-*	*-*	*1*
7	Agriculture/food, Drinking water	*4*	*4*	*-*	*-*	*-*	*-*
8	IT/Communication infrastructures	*5*	*5*	*-*	*-*	*-*	*-*
9	Military facilities	*9*	*4*	*3*	*1*	*-*	*1*
10	Chemical/raw materials industries	5	-	-	1	1	3
11	Transportation infrastructures	12	2	2	2	1	5
12	Power plant, Petrol station	18	5	7	5	-	1
13	Vertical evacuation buildings/Shelter	19	6	9	2	2	0
Total		272	162	54	25	11	20
Percentage		100%	60%	20%	9%	4%	7%

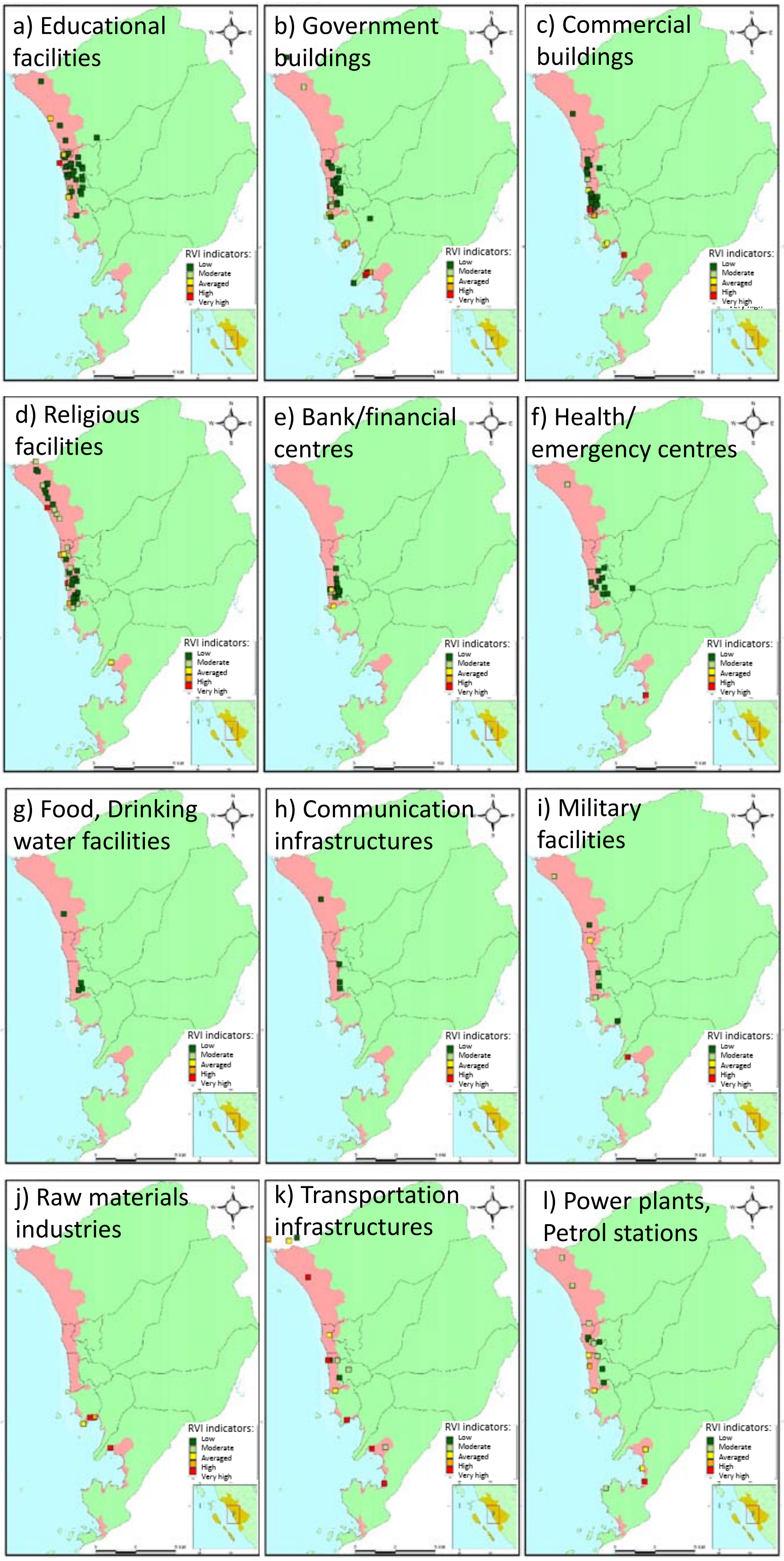

Figure 7 RVI for critical infrastructures in Padang inside the tsunami inundation zone. For vertical evacuation buildings, see Fig. 8

As already mentioned, power plant facilities/fuel storages should be further analysed considering their functionality. These infrastructures are very vulnerable even for small inundation conditions. For example, when the facilities are inundated by a metre of water, the power plant/electricity facilities or fuel storages/petrol stations will be automatically shut down. This means the facilities will not provide any helps during emergency response activities. Similarly, when electricity is down, most communication/IT networks which heavily rely on power supply will not work properly. This conditions will lead to much higher RVI for other critical infrastructures. This situation is called “the cascading effects” where the inability of a system to work properly paralyse other systems at the same time. For the vulnerability of bridges, determining structural parameters such as length of bridge span, length/width/height of deck, type of bearings and the height of the deck from the MSL should also be considered. According to the collected data from damaged bridges in Sri lanka and Aceh, bridges exposed by tsunami larger than 3 m may experience wash-out or deck collapse (high vulnerability) (Shoji *et al*. (2007)). Based on these findings, we reanalysed the RVI for bridges and we found that 7 out of 8 bridges in Padang are very highly vulnerable. Considering the discussion above, we concluded that the RVI for critical infrstructures in Padang with high and very high vulnerability rearch at least 15%.

Besides providing RVI for each infrastructure, current study also produce maps showing the locations of critical infrastructures and their RVI as shown exemplarily in Fig. 8 for vertical evacuation buildings. The RVI in this study is a preliminary work for the bases of disaster mitigation and management since similar studies have not existed yet.

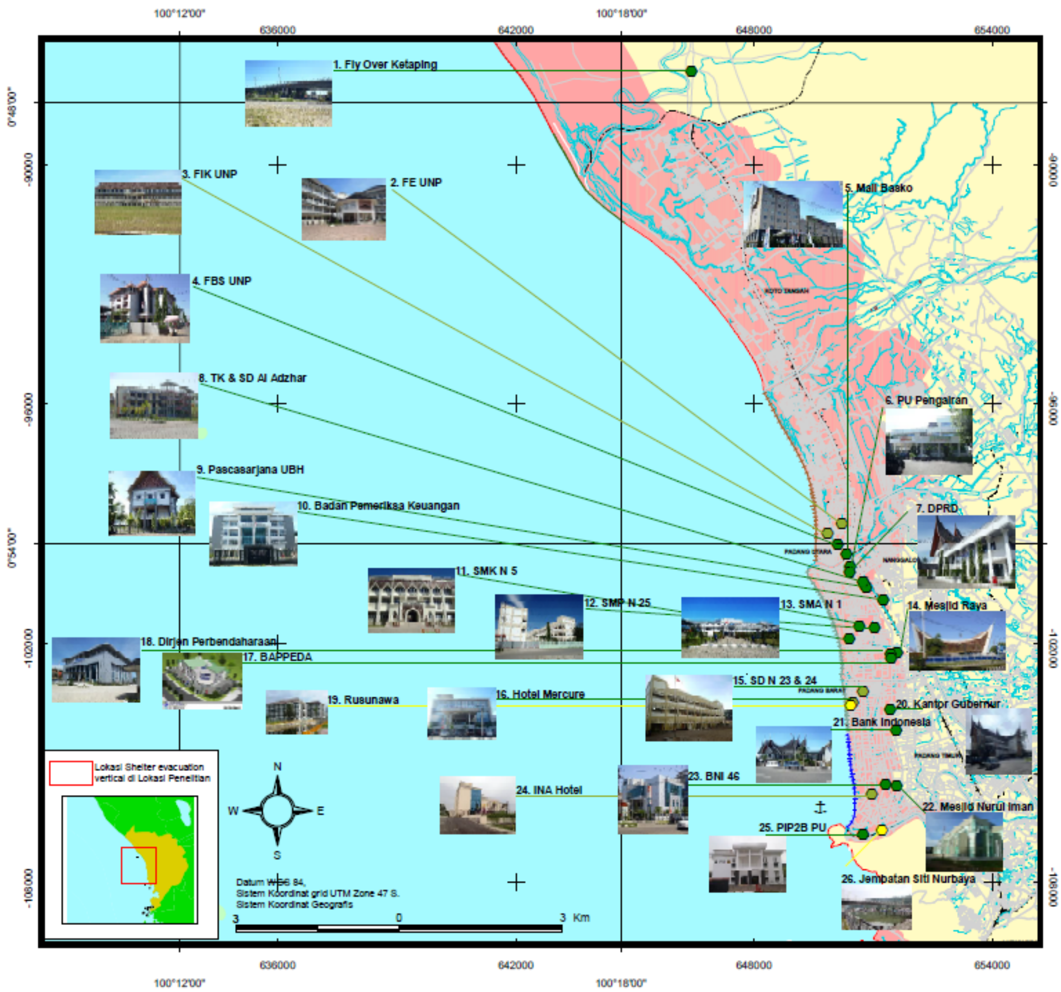

Figure 8 Map of RVI for vertical evacuation buildings indicated by dots in colours (see table 3)

5 Conclusion and Remarks

The analysis of tsunami vulnerability for critical infrastructures in the city of Padang has successfully assessed 272 infrastructures in which more than 15% of them have high and very high Relative Vulnerability Index (RVI). Though, some limitations should be taken into consideration such as building survival against the earthquakes and many unknown aspects from the immense power of huge tsunami, the results hopefully will contribute to disaster risk reduction programmes for the city of Padang such as the relocation of the city centre. The city of Padang has developed a master plan for the relocation of governmental facilities and other critical infrastructures to the “new city centre” far from the coastline (Bypass Area). Therefore, we hope the results from this study will be useful for the execution of this plan and other mitigation measures in order to minimize the impacts of tsunami in the future.

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