An overview of the down-scaling values of physical and social vulnerability parameters for tsunami disaster at the city level – a case study of Banda Aceh

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Abstract. The Indian Ocean earthquake and tsunami occurred on December 26, 2004, has been one of the deadliest disasters in modern history. Banda Aceh City is one of the severely affected cities by the disaster. Many of the casualties were due to lack of knowledge in the community about the disaster and preparedness in facing the disaster. Now, after more than 10 years since the deadly disaster, the Indonesian government has created disaster risk maps for the provincial level and utilizing some of the provincial level parameters to create a district- or city-level risk maps. The purpose of this study was to analyze the dynamics of physical and social vulnerabilities at the district level over the last 10 years and to evaluate the sensitivity of the disaster vulnerability values by down-scaling the parameter values to the district or city level. This study is using Geographic Information System (GIS), which spatial data are encompassing the infrastructure, housings and the growth of population at risk up to the year 2017. The results reveal the remarkable distribution of risk levels at each investigated village. The physical vulnerability is valued moderately in Banda Aceh city about 54% whereby Gampong Laksana at Kuta Alam sub-district are among the highest vulnerability areas (0.933). As for the social vulnerability is valued high in Banda Aceh city, the highest vulnerable areas are located in Punge Ujong at Meuraxa sub-district (0.833). Overall, the vulnerability parameter value for a tsunami disaster in Banda Aceh city remains high, particularly at those villages located very close to the sea. More mitigation effort should, therefore, be reinforced at those highly risky coastal areas.

Keywords: tsunami, Banda Aceh, GIS, risk mapping, vulnerability

1. Background.

Indonesia is a vulnerable country to disasters both from natural events and those caused by human activities. The process of natural disasters occurrence can take place suddenly or progress slowly closely related to geographical conditions, geology, climate and other factors. The earthquake and tsunami disaster on December 26, 2004 was a deadly disaster in modern history, especially in Aceh. The death caused from the disaster reached more than thousand people and destroyed infrastructures and coastal areas, especially on the west coast of Aceh. The large number of casualties due to lack of community knowledge about the disaster and preparedness in the face of disasters. The city of Banda Aceh, which is directly adjacent to the sea, makes this region vulnerable to the tsunami disasters. Vulnerability has a dynamic characteristic in spatial-temporal because it is influenced by the number of populations, property, and environmental conditions in areas with high threats. The dynamics of vulnerability in an area that has the potential for disaster threats within a certain period of times determines the level of disaster risk in the region. To minimize these conditions, the efforts are needed to socialize knowledge and potential disasters in their respective neighbour-hoods.
Knowledge about disasters is one part of disaster mitigation. One product that results from disaster knowledge is a disaster risk map. Disasters risk map can be used as a tool to increase a disaster knowledge and awareness. Indonesia already has a disasters management agency (BNPB), disasters management law Nr. 24/2007 and disasters guidelines for risk assessment that is Head of BNPB regulation Nr. 2/2012. In the guideline there are various type of disasters such as for earthquake, tsunami, floods, etc.

Each province and district in Indonesia should have a disaster risk map to find out the potential disasters in their respective regions. For making a risk map it requires valid data so that it can represent the actual conditions that occur in the field. Aceh itself already has a provincial-level disaster risk map called Aceh Disasters Risk Mapping (ADRM) created by TDMRC in 2011. The ADRM contains 11 potential disasters in Aceh including abrasions, storm surges, floods, epidemics, earthquakes, volcanoes, forest fires, droughts, landslides and tsunamis. The risk map is based on the Head of BNPB (Indonesia Agency for Disasters Management) regulation Nr. 2/2012 concerning general guidelines for disaster risk assessment. Banda Aceh city is one of the cities that are prioritized to have a risk map because Banda Aceh city is ranked fifth as tsunami disasters prone area based on the Indonesian Disaster Risk Index book [2].

Vulnerability is a condition that is determined by physical, social, economic and environmental factors or processes that can increase vulnerability in a community [3]. Based on these four factors, physical vulnerability and social vulnerability are the most influential in the disaster, especially the tsunami disaster. The previous research about tsunami disaster risk in the city of Banda Aceh has been conducted in 2014 with the result the city of Banda Aceh was in low level of vulnerability [4]. So, the purpose of this study was to study the dynamics of physical vulnerability and social vulnerability at the district/city level after more than 10 years of the tsunami by taking research locations in villages in Banda Aceh. Villages that are chosen as the object of the research are the only villages that affected by the tsunami threats.

2. Method
This is a semi-qualitative research that takes place in the city of Banda Aceh which is divided into nine sub-districts. The method in making the physical vulnerability and social vulnerability maps of the tsunami disaster depends on the use of geographic information systems (GIS) and the stages of data collection based on secondary data obtained from Statistic Center Agency (BPS) of Banda Aceh and Regional Development Planning Agency (BAPPEDA). The data for population, poverty, disability, the number place of worship, school and health facility was obtained from BPS. For administrative map was obtained from BAPPEDA.

2.1. Physical vulnerability
Factors that affecting physical vulnerability generally refer to the weaknesses of the location and the environment that has a vulnerability to the disasters. The vulnerability is related to threats so that risks can change linearly as a function of threat and vulnerability parameters if they are interrelated [4]. Indicators of physical vulnerability include the density of houses, the density of worship buildings, the density of school buildings and the density of health buildings. After obtaining the building density from each indicator of physical vulnerability, it is necessary to define an index classification of each indicator. Index classifications used in the physical vulnerability are shown in Table 1 as follows

| Component/Indicator        | Low (0.333) | Moderate (0.666) | High (1.000) | Total Weight |
|----------------------------|-------------|-----------------|--------------|--------------|
| House Density              | < 150 per km² | 150 – 1000 per km² | > 1000 per km² | 40%           |
| Place of Worship Density   | < 5 per km²  | 5 – 15 per km²  | > 15 per km²  | 20%           |
| School Density             | < 2 per km²  | 2 – 6 per km²   | > 6 per km²   | 20%           |
| Health Facility Density    | < 3 per km²  | 3 – 9 per km²   | > 9 per km²   | 20%           |

Table 1. Physical vulnerability parameters [5]
2.2. Social Vulnerability

Social vulnerability is a function of the presence of victims of disaster events. The considerable parameters used in social vulnerability are the lives of individuals, communities and people behaviour. Indicators of social vulnerability include population density, sex ratio, ratio of poverty, ratio of disabled people and ratio of age groups. The next step is to define index classification with units on the four indicators of social vulnerability. Table 2 shows index classification used in social vulnerability.

Table 2. Parameters of social vulnerability [5]

| Indicator | Index Classification (Score) | Total Weight |
|-----------|-----------------------------|-------------|
|           | Low (0.333) | Moderate (0.666) | High (1.000) |
| Population Density | <500 people/km² | 500-4000 people/km² | >4000 people/km² | 60% |
| Vulnerability Group | Sex Ratio | >80% | 80-60% | <60% | 10% |
| | Poverty Ratio | <20% | 20-40% | >40% | 10% |
| | Disability Ratio | <20% | 20-40% | >40% | 10% |
| | Age Group Ratio | <20% | 20-40% | >40% | 10% |

3. Results and Discussion

3.1. Physical Vulnerability

Based on the results of research, the highest house density in the city of Banda Aceh is in Bitai (Jaya Baru sub-district) with 11935.05 houses per km² and the lowest is in Rukoh (Syiah Kuala sub-district) with 88.53 houses per km². The level of house density in the city of Banda Aceh is shown in figure 1.

Figure 1. House density in the City of Banda Aceh

The density of worship buildings included in the calculation such as mosques, mushalla, churches, temples, and monasteries which found in the villages of the city. The level of the place of worship density is shown in figure 2. The results showed that the highest density of worship buildings in the City of Banda Aceh was in Gampong Laksana (Kuta Alam sub-district) with 30.01 unit per km² and the lowest was in Pango Raya (Ulee Kareng sub-district) with 0.
School buildings are one indicator of physical vulnerability that must be considered. The City of Banda Aceh itself has 236 school buildings scattered into 9 sub-districts in each village in the sub-district. The highest density of school buildings in the City of Banda Aceh is at Ateuk Pahlawan (Baiturrahman sub-district) with 32.92 units per km$^2$ and the lowest is in Bitai (Jaya Baru sub-district) with 0 because the area does not have a school building. Figure 3 shown the level of school building density of Banda Aceh in the object area.

![Figure 2. Place of Worship Density in Banda Aceh](image)

![Figure 3. School building density in Banda Aceh city](image)

Similar to place of worship and school buildings, the location of a health facility also needed to be considered. Health facilities are important during a disaster and it categorizes as a critical facility because in the health facility usually there are many vulnerable groups, especially sick people who might become the victims during the disasters. In Banda Aceh city, there are 112 health facility such as hospitals, maternity hospital, health-center, and others. So the calculations were carried out in
the areas where the health facility are located in the vulnerable of tsunami disasters area. The vulnerability level of health facility density was shown in Figure 4.

In Banda Aceh city, the highest density of health facility was in Gampong Laksana (Kuta Alam sub-district) with 35.01 unit per km$^2$ and the lowest one was in Keudah (Kuta Raja sub-district) with 0 because there were no health buildings in the area.

![Figure 4. Health facility density in Banda Aceh city](image)

The physical vulnerability which is obtained from the four indicators in the Banda Aceh city was shown in Figure 5 as follows. Based on the figure, it can be seen that the physical vulnerability in the Banda Aceh city were in moderate level of vulnerability. The level of a high category is 44% of the area, 54% of the area is in the medium category and 2% of the area is in a low category. Alue Naga (Syiah Kuala sub-district) is a village in the City of Banda Aceh which is categorized as the lowest one and Gampong Laksana (Kuta Alam sub-district) is a village in the city that is the highest one of physical vulnerability. The score of total physical vulnerability at Alue Naga (Syiah Kuala sub-district) is 0.333 while the score at Gampong Laksana (Kuta Alam sub-district) is 0.933.

![Figure 5. Physical vulnerability map to tsunami disaster in Banda Aceh](image)
3.2. Social Vulnerability

There are five indicators should be considered in defining social vulnerability maps for the District / City level. The indicators are population density, sex ratio, poverty ratio, the ratio of disability, and the ratio of age groups.

Based on the calculation that is shown in Figure 6 the highest population density of Banda Aceh is at Gampong Laksana (Kuta Alam sub-district) with 25095 people / km$^2$ and the lowest one is in Gampong Pande (Kuta Raja sub-district) with 359 people / km$^2$.

The population density in Banda Aceh city is categories as the medium category with almost all villages close to the beach were in the medium category except for Gampong Pande (Kuta Raja sub-district) which falls into the low category.

Almost all the sex ratio of the City of Banda Aceh has a low level of social vulnerability by the tsunami disaster. Only one village that has considered as moderate level. The lowest sex ratio (percentage male: female) in the City of Banda Aceh was in Gampong Pande (Kuta Raja sub-district) which is categorized as moderate level and the highest sex ratio was in Lamseupeung (Lueng Bata sub-district) in a low-level category as it shown in Figure 7.
The poverty ratio data describes the level of poverty that exists in an area. In the City of Banda Aceh, the lowest poverty ratio was in Gampong Pande (Kuta Raja sub-district) and the highest one was in Punge Ujong (Meuraxa sub-district). Figure 8 shows the poverty ratio of social vulnerability in the city.

In Banda Aceh city, all of the villages were in the lowest disability ratio. The calculation based on the total number of disability divided by the hazard area in km$^2$. The disability ratio map is shown in Figure 9.
The ratio of age group data in defining social vulnerability maps is classified based on the age of (0-4) years and the elderly over 65 years. The calculation is based on the ratio of the total number of the (0-4) and the elderly over 65 years divided by the hazard area in km$^2$. The highest age group ratio in Banda Aceh city is at Kopelma Darussalam (Syiah Kuala sub-district) and the lowest one at Lamjabat (Meuraxa sub-district) as shown in Figure 10.

Overall with five indicators, Banda Aceh city were in high social vulnerability with 43% of its area was in the medium category and 57% of its area were in the high category. The village with the lowest social vulnerability in Banda Aceh is in Gampong Pande (Kuta Raja sub-district) and the highest one is in Punge Ujong (Meuraxa sub-district). The map of social vulnerability to tsunami disaster is shown in Figure 11.
3.3. Vulnerability level in the City of Banda Aceh

In the physical vulnerability of the District / City level, the most influential indicators are the house density and the school density. The density of building like house density and school density have an important role. Because the higher building density in the area, the more vulnerable that area will be. Whereas in the social vulnerability the most influential ones are the population density and the age group ratio. These two indicators are relatively dominant for the effect of the disaster. And also the indicators might have the most effective in causing on the number of victims of the disaster. Women, children and the elderly are as vulnerable groups as components which are included in these two influential indicators. These groups should be take into account in the management process of evacuation.

4. Conclusion

Based on the results, it is indicated that 54% of the area in the City of Banda Aceh was included in the category of moderate physical vulnerability. The lowest physical vulnerability is found at Alue Naga village (0.333) and in the contrast of that, the highest one is at Gampong Laksana (0.933). The most influential indicators in determining the highest level of physical vulnerability are the density of houses and the density of school buildings.

In social vulnerability, it is found that 57% of the area were categorized as a high social vulnerability. It means that the number of the total score is still quite high. Punge Ujong (0.833) is the village with the highest level of social vulnerability in Banda Aceh city. The most influential indicator of social vulnerability in the Banda Aceh city are population density and age group ratio.

5. References

[1] BNPB 2013 Indeks Risiko Bencana Indonesia (IRBI) Tahun 2013 Direktorat Pengurangan Risiko Bencana Deputi Bidang Pencegahan dan Kesiapsiagaan : Sentul
[2] Republik Indonesia Pedoman Umum Pengkajian Risiko Bencana Perka BNPB No.2 Tahun 2012
[3] Løvholt F, Setiadi N J, Birkman J, Harbitz C, Bach C, Fernando N, Kaiser G and Nadim F 2014 Tsunami risk reduction – are we better prepare today than in 2004? International Journal of Disasters Risk Reduction vol 10 pp 127-142
[4] Fauziah, E. Fatimah, Syamsidik 2014 Penilaian Tingkat Risiko Bencana Tsunami Untuk Kawasan Kota Banda Aceh Berdasarkan Skenario Tsunami Desember 2004 Jurnal Teknik Sipil Universitas Syiah Kuala Vol 3 pp 145-56
[5] BNPB and JICA 2015 Petunjuk Teknis Penyusunan Peta Ancaman dan Risiko Bencana untuk Tingkat Kabupaten/Kota

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