Spatial model of vulnerability to tsunami in Buleleng Sub-district

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Abstract. Buleleng Sub district is the activity center in Buleleng Regency. It is adjacent to the Bali Sea in the northern part, which is crossed by the Flores back arc thrust fault. Considering the fact that the fault activities in Flores had caused an earthquake and tsunami in 1992 in Flores which killing up to 2100 people and in 1976 in Buleleng Regency, hence a spatial modelling for tsunami vulnerability in Buleleng Sub district was developed. The aim of this study was to analyze the tsunami elevation model, and to analyze the integration of tsunami-exposed areas with the distribution of populations and buildings in Buleleng Sub district. The methods used for making a spatial modelling for tsunami vulnerability in Buleleng Sub district were quantitative analysis and spatial analysis. Analytical Hierarchy Process (AHP) used to determine the value, weight, and score. Built land variables distinguished the residential buildings, and trade and service areas. Distribution variables used an estimation of per 10 hectares in the grid. Based on the results, there are three wave height scenarios to identify how big the tsunami exposure area is in Buleleng Sub district. The scenario of 6-meters shows the number of victims will reach up to 2,493 people and around 482 buildings will affect. While, the 9-meters scenario estimates that there will be 147,276 victims and 8,052 buildings will affect. The last scenario is the 20-meters that estimates around 161,199 people and 18,293 buildings will affect.

1. Introduction
Bali is one of Indonesian regions that included in earthquake prone areas. Bali is flanked by two earthquake sources, namely the subduction zone in the south of Bali which is a meeting of two plates namely the Indo Australia plate which moves from south to north and the Eurasian plate which moves from north to south. The northern part of Bali has a Back-arc trust zone that stretches from north Bali to Flores [1]. Flores faults stretch out in the northern sea of Bali Island through Buleleng and Karangasem Regencies. The tip of the Flores fault is right above the northern sea in Buleleng Regency.

The selection of research locations in Buleleng Sub district was inseparable because of the history of seismicity that once struck Buleleng Regency. Then looking at the population, it is noted that in 2018 the population in Buleleng Regency is 814,536 people [2] while in Karangasem Regency the population is 97,584 people [3]. The location of the center of activity in Buleleng Regency in Buleleng Sub district is directly adjacent to the Bali Sea which has a history of seismicity and potential tsunamis, while in Karangasem Regency the center of activity mostly occurs in Karangasem Sub district which borders the Bali Strait and does not directly border the Bali Sea. Among other risky elements, building is one of the important aspects to be protected, because in addition to having economic value the building also functions as a place of residence for those who survived the disaster[4, 5] The different characteristics of the building form a function of building durability or can be referred to as building vulnerability. Thus an effort is needed to find out the distribution of building risks so that proper steps are taken in the face of disasters.
Spatial modeling for tsunami vulnerability can be done with the help of geographic information systems. A spatial information system within the scope of a geographic information system (GIS) can provide a support for decision making by answering questions such as which buildings are more resistant to waves based on wave height and distance. When a disaster occurs, GIS can be an important tool for emergency evacuation. Planners can quickly estimate the number of people who need to be evacuated by overlaying and analyzing a number of spatial information.

2. Material and Method

2.1 Variables and Data

This research uses five main variables, namely: slope, maximum tsunami wave potential, land cover, built up land and population distribution. The five variables are the basic aspects used in determining the area of vulnerability to tsunami hazards on the northern coast of Buleleng Sub district. Table 1 is an explanation of the limits of each of these variables.

| No | Variables                              | How Data Acquired                                                                 | Sources      |
|----|----------------------------------------|----------------------------------------------------------------------------------|--------------|
| 1  | Slope                                  | Processing data of DTM Image Terrasar-X uses a slope class classification, processing using ArcGis software | LAPAN        |
| 2  | maximum tsunami wave potential         | Data processing is done using ArcGIS software by utilizing the Raster Calculator tools for the process of entering formulas, with three different altitude scenarios. | - 6 meters [7] - 9 meters [8] -20 meters [1] |
| 3  | Land cover                             | Interpretation of High-Resolution Satellite Images manually in ArcGIS software in accordance with the classification of surface magnification index. | SPOT-6       |
| 4  | Built up land                          | Interpretation of High-Resolution Satellite Images manually in ArcGIS software distinguishes the building of trade and services and settlements. | SPOT-6       |
| 5  | Population distribution                | Data processing is performed on ArcGIS Software by calculating the building area in each grid, with estimated built area calculated in 100x100m2 filled by 5 people (father, mother and 3 children) or one grid with 500 people. | Interpretation of land for buildings |

Source: Data Modification

Mapping of built up land will distinguish two types of built land, namely trade and services and settlements. Determination of built up land is done by interpreting high-resolution imagery and field surveys to see the type of material and ensure the function of the building. After obtaining the area in each of the constructed land, a grid of 100x100m2 will be calculated to assess the density of the building trade and services and see the intensity of the losses. The building density determined by following equation.
Density = \frac{\text{building area in 1 grid}}{\text{grid area}} \times 100\% \quad (1)

**Table 2.** Density building area of trade and services

| No | Density building area of trade and services | Classification |
|----|--------------------------------------------|----------------|
| 1  | < 25 %                                     | Very low       |
| 2  | 25 - 50 %                                  | Low            |
| 3  | 50 – 75 %                                  | High           |
| 4  | 75 – 100 %                                 | Very high      |

Calculation of building area density to determine the intensity of losses to trade buildings and services is only carried out in the economic area and tourism area in Buleleng Sub district. The distribution of the calculation of the exposed population is carried out by evaluating the total area of land built on each grid of 100x100m² with an estimated 500 people in 10 ha. The tsunami vulnerability model in the northern coastal region of Buleleng Sub district uses the AHP formula and weighting. How to Test AHP results with the following steps [9]:

**Table 3. Recapitulation of respondents**

|                  | Vulnerability | Population | Building |
|------------------|---------------|------------|----------|
| Vulnerability    | 1.000         | 2.000      | 3.000    |
| Population       | 0.500         | 1.000      | 3.000    |
| Building         | 0.333         | 0.333      | 1.000    |
| **Total**        | **1.83**      | **3.33**   | **7.00** |

Source: Data processing 2019

Make a normalization matrix by summing each cell column in the comparison criteria matrix column, divided by the total sum of cells in the comparison matrix column. The rating indicator is searched by the number of rows divided by the number of variables/indicators.

**Table 4. Indicator Rating**

|                  | Vulnerability | Population | Building | Number of Rows | Indicator Rating |
|------------------|---------------|------------|----------|----------------|------------------|
| Vulnerability    | 0.546         | 0.600      | 0.429    | 1.574          | 0.525            |
| Population       | 0.273         | 0.300      | 0.429    | 1.001          | 0.334            |
| Building         | 0.182         | 0.100      | 0.143    | 0.424          | 0.141            |

Source: Data processing 2019

formula for Finding lambda:

\[ \lambda_{maksimum} = \frac{\sum \lambda}{n} = \pmaksimum = \frac{9.16}{3} = 3.05 \]  
\[ C_i = \frac{\lambda_{maksimum}}{n-1} = Ci = \frac{3.05}{2} = 0.03 \]  
\[ R_i = \frac{1.98x1}{n} = Ri = \frac{1.98x1}{3} = 0.66 \]
\[ CR = \frac{C_i}{R_i} = CR = 0.03/0.66 = 0.04 \]

Because CR <0.1, the consistency ratio of the calculation is acceptable [9].
2.2 Analysis
The analysis used in this study is a GIS-based spatial modeling analysis. The process includes three main analysis components, namely exposure area modeling, assessment of built-up land and population distribution, and tsunami disaster vulnerability modeling. Exposure area modeling is simulated based on data on the scenario of tsunami maximum wave potential with slope and surface roughness index of each land cover classification and calculated based on Regulation of the head (PERKA) of the national disaster management agency (BNPB) [8].

| No | Indicator          | Scale       | Value | Weight | Score |
|----|-------------------|-------------|-------|--------|-------|
| 1  | Vulnerability     | < 1.5 meters| 1     |        | 0.45  |
|    |                   | 1.5-3 meters| 2     | 0.45   | 0.9   |
|    |                   | > 3 meters  | 3     |        | 1.35  |
| 2  | Population        | < 100 persons| 1    |        | 0.41  |
|    | Distribution      | 100 – 150 persons| 2 |        | 0.82  |
|    |                   | 150- 500 persons| 3 |        | 1.23  |
| 3  | Built Land        | non settlement| 1   |        | 0.14  |
|    |                   | Settlement  | 2     | 0.14   | 0.28  |
|    |                   | Trade and services| 3 |        | 0.42  |

Source: Data processing 2019

Tsunami vulnerability model

\[
Vulnerability = E + S + P \tag{6}
\]

\[
Vulnerability: E: \text{exposure}, S: \text{sensitivity}, P: \text{population}
\]

3. Result and Discussion
3.1 Vulnerability of the area on the northern coast of Buleleng Sub district to the tsunami
The land cover map above shows the distribution of land cover in Buleleng Sub district. The map shows that in the western part, from Kalibubuk Village to Baktiseraga Village, land cover varies from plantations, rice fields and settlements. In the central part where it starts entering urban areas, land cover starts to be dominated by building objects. Buleleng Sub district which is included in the administrative area of Singaraja City, which is the Capital of Buleleng Regency, the center of activity is in the central part. Administrative areas that are included in urban areas are the kelurahan of the Banjar Jawa, the Bugis Banjar, Banjar Kajanan, Kampung Anyar and Kampung Baru, which are strategic trade and service areas. The development of Buleleng Sub district leads east and south. Seeing this land cover map still allows the development of this area for settlements and other activities.
Buleleng Sub district has a land cover of water bodies, namely rivers with an area of 5.53 ha or 0.11%. The river conditions in Buleleng Sub district often experience flooding during the rainy season considering the small cross-sectional area and the number of buildings built on the banks of the river. Table 5.1 shows the extent of each land cover with a total area of 4668.81 Ha. Rice fields are the widest land cover which reached 1963.72 Ha. Many plantations are planted in the southern part which coincides with the cover of paddy fields. The Balinese generally place plantation land and rice fields in adjacent locations so that it can facilitate the management of these two types of land simultaneously.
Figure 2 shows a comparison of tsunami wave height scenarios. There are three different height of the first tsunami which is at an altitude of 6 meters, 9 meters and 20 meters. The 6 meter scenario is determined based on the A National Tsunami Hazard Assessment for Indonesia where the probability of a tsunami with a height at the coast > 3 meters in 2500 years ago. Scenario 9 meters refers to the reference table for potential events and tsunami inundation for the Bali region, attached to Perka BNPB No. 2 of 2014. The height of 20 meters is based on the tsunami event that struck Flores in 1992, where the fault also affected an earthquake in the northern sea of Buleleng.

The 6 meters wave height scenario has 12 villages exposed. The village with the most exposed area is Pemaron Village, then Tukadmungga Village, where the villages are adjacent to each other. The 9 meters tsunami wave height scenario, there were 13 villages exposed to the tsunami. The number of villages is not much different from the 6 meters scenario, but has a wider exposure to the tsunami intensity. The scenario of a 20 meters tsunami wave height gets the results of 15 villages exposed to the tsunami. The intensity of the area exposed is also higher. Kampung Baru Village, Kampung Bugis Village and Kampung Kelurahan Selulur area was exposed to the tsunami.

The three villages are the economic center area of the residents of Buleleng Sub district. Where in this areas there are many shop houses and the Buleleng market which become the economic center for Buleleng Sub district residents in particular and Buleleng Regency residents in general. The village with the most area was exposed to the tsunami, namely the village of Baktiseraga. If you look at the condition of this village, the distribution of the construction of many settlements leads to near the coast. There are elite settlements and restaurants on the beach and the Temple which is the center of Hindu worship in the Sub district of Buleleng.

3.2 Tsunami vulnerability to build land and population distribution in Buleleng Sub district

![Figure 3. Distribution of buildings in the tsunami exposed area of Buleleng Sub district](image-url)

Built land is obtained from the results of high-resolution image interpretation that is able to distinguish the shape of the roof of the building. The mapping of the built land is done to find out how much the building area is affected if a tsunami occurs with all three altitude scenarios. Mapping of built-up land also has a function as a reference to find out the distribution of residents exposed to the tsunami in
Buleleng Sub district. By using a 100x100 m² grid, the population distribution will be obtained assuming one house contains one family of five, namely father, mother and three children. Mapping population distribution can inform population distribution patterns. The distribution map of the building with a 20 meters scenario can be used as a reference to see population distribution and can explain that the pattern of population transport in Buleleng Sub district is spread evenly in each of the exposed villages, except for Penarukan and Banyuning Villages, considering that only a small portion of the administrative area is exposed tsunami.

![Figure 4. Map of the distribution of buildings in the tsunami exposed area of Buleleng Sub district](image)

The results of data processing show that in the scenario of a 20 meter wave height the number of people exposed is 161,599. Then at the wave height of 9 meters the number of people exposed reached 147,276 inhabitants and the last in the scenario of a height of 6 meters the number of people exposed reached 2,493. Buleleng Sub district in 2018 shows that the population in the tsunami-exposed area at a height of 20 meters reached 97,203 people. There is a difference of up to 64,396 people by including all the population in the administrative area. The difference in the number of estimation results with BPS data occurs because the estimated results are obtained regardless of the type of building, only looking at the building area per 10 Ha.

3.3 Vulnerability model in the northern coast of Buleleng Sub district

The tsunami vulnerability model on the northern coast of Buleleng Sub district was obtained by taking into account the extent of inundation, distribution of built-up land and population distribution. Modeling is done by analyzing the Analytical Hierarchy Process (AHP), where weighting is given a greater value on the parameters that are considered the most influential.
Modelling assessments are carried out using a 100x100 m² grid where each vulnerability parameter value is given a weight. The greatest weighting is given in the area of inundation. Inundation is considered to be the main determining factor in seeing the extent to which the area is exposed to the tsunami. There are three classes in the inundation distribution where the widest inundation is found in the third round, the height of the inundation is more than three meters. Population distribution is obtained from the grid results by calculating the estimated area of land built if 100x100 m², it will count as many as 500 people. The highest score is given in the range of the population of 150-500 people with a score of 50. Built land is classed based on trade and services, settlements and non-built land. Non-built land is intended because not all exposed areas are included in the built area. So that the non-built land was given a score of 15. This spatial model of analysis is correspond with urban map planning of Buleleng District in 2030, because the tsunami-exposed areas fall into the vital zones of the Buleleng regency, which this model can be use.

4. Conclusion
The vulnerability model in Buleleng Sub district distinguishes into 4 classification of vulnerable areas. Looking at the results of the model, it can be seen that the central economic region is a region that is very vulnerable to the tsunami disaster, where in the area there are many trade and service buildings, and for population distribution it is also high considering the calculation uses an estimated building area. Tsunami vulnerability to built-up land and population distribution of the 6 meters scenario have 482 built-up land exposed to 15.56% or 75 trade and service buildings and 407 or 84.43% residential
buildings with assumptions of 2,493 people affected. The 9 meters scenario shows that there are 8,052 buildings that are vulnerable to tsunamis. A total of 1,059 trade and service buildings or 13.15% and 6,993 settlements or 86.84% were vulnerable with the assumption that the exposed population of victims reached 147,276 inhabitants. The 20 meters scenario shows 18,293 buildings exposed to 38.59% or 7,061 trade and service buildings as well as 11,232 or 61.40% residential buildings with assumptions about 161,199 people affected.

5. References
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