The correlation of tsunami heights and coastal conditions in Palu Bay using the Contingency Coefficient Analysis

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Abstract. The accelerated development of Palu City and its vicinity areas surrounding Palu Bay has changed the land use especially in the coastal area. These changes may reduce the function of the beach as a natural bathing wave. The 2018 Palu Bay tsunami have varying heights. This height variation is probably because of the difference in both geographical and geological conditions in coastal areas which are located surrounding the bay. The research used the contingency coefficient as a method for determining the magnitude of the correlation between tsunami heights and several parameters, such as: land cover, slope, and lithology. The results show the land cover parameter has the most effect the height of the tsunami wave recorded. Based on the significance test using the Chi-Square, the slope of the coastal area is the most representative parameter with a 66% confidence level.

1. Introduction
Population growth in the city of Palu since it was established as a municipality in 1994 increased by 42.55% from 1990 to 2000 and by 18.37% from 2000 - 2010 [1]. This growth requires that development in Palu City and areas along the coast of Palu Bay be accelerated to serve the needs of the community and provide adequate facilities. Based on the earthquake and tsunami catalog, Palu Bay was recorded to have experienced an earthquake and tsunami from 1921 to 2018 with a span of 20 years [2]. Palu Bay itself is bypassed by an active fault called the Palu Koro fault that stretches from the mainland of southern Sulawesi to the northwest to the waters of North Sulawesi [3]. This fracture activity can make earthquake, tsunami, and liquefaction possible later. The earthquake on 28 September 2018 which was centered in Donggala Regency, caused land movements which caused a tsunami due to underwater landslides and liquefaction phenomena in Palu City [4].

The implementation of the post-disaster survey showed the difference in height of the tsunami waves that reached the coast. This difference can be due to changes in land use of coastal areas for development at some point so that it changes the function of the beach as a natural wave absorber [5]. In addition, other geographical and geological parameters at these locations may have a role in changing tsunami wave heights. This study aims to find out how big the correlation of these parameters (land cover, slope, and lithology) to the height of the tsunami wave that has been classified using contingency coefficients as a determinant of the correlation value. The results of this study are expected to be input in evaluating disaster management in terms of natural factors so as to minimize the impact of tsunamis that occur in the future.
2. Data dan methods

2.1. Data

The data used in this study consisted of:

a. Digital Map of Indonesian Coastal Environment (LPI) Number 2015-05
   This 1: 50,000 scale map was obtained from the Geospatial Information Agency (BIG). Data taken from the map is bathymetry data for slope processing and land cover data. The bathymetry data itself is the result of compilation of 2014 hydrographic survey data, generalization of a 1:25,000 scale RBI Map in 2013, and a 1:200,000 Scale Marine Map in 2013 [5]. Based on technical rules, the vertical datum used in digital LPI maps is the lowest low water level (LLWL) [6].

b. Tsunami Observation Point Survey Data
   The 2018 Tsunami Observation Point Survey Data provides authentic field measurements at 24 sample points along the coast of Palu Bay. Administratively, the location is spread in Palu City and Donggala Regency. Wave height data collection is done by using a laser point, GPS Handheld to measure the coordinates of the location of the sample point, and several other supporting equipment [7]. Tsunami wave height measurement methods are measured based on trace water lines that remain on building walls, the presence of dry trees caused by seawater, rubbish or material involved, or coral rocks that have been shed to the mainland.

| No | Location       | Longitude (°) | Latitude (°) |
|----|----------------|---------------|--------------|
| 1  | Panggang       | 119.775       | -0.719       |
| 2  | Lolilondo      | 119.781       | -0.747       |
| 3  | Lolipesua      | 119.789       | -0.770       |
| 4  | Lolisaluran    | 119.811       | -0.818       |
| 5  | Primkopal      | 119.819       | -0.844       |
| 6  | Tipo           | 119.829       | -0.861       |
| 7  | Silae          | 119.835       | -0.875       |
| 8  | Ruko Lere      | 119.840       | -0.881       |
| 9  | Grandmall Palu | 119.843       | -0.882       |
| 10 | Mercure Palu   | 119.850       | -0.884       |
| 11 | TVRI Palu      | 119.863       | -0.886       |
| 12 | Kp Nelayan     | 119.878       | -0.864       |
| 13 | Citraland      | 119.881       | -0.837       |
| 14 | Tondo          | 119.880       | -0.832       |
| 15 | Pergudangan    | 119.882       | -0.823       |
| 16 | Kp Mambaro     | 119.877       | -0.802       |
| 17 | Poltekes       | 119.865       | -0.790       |
| 18 | Resort Taipa   | 119.859       | -0.782       |
| 19 | PLTU Tawaeli   | 119.855       | -0.732       |
| 20 | Pantoloan      | 119.852       | -0.708       |
| 21 | Ngada Wani     | 119.840       | -0.695       |
| 22 | Labuan         | 119.817       | -0.662       |
| 23 | TPI Lero       | 119.812       | -0.629       |
| 24 | Pasir Marana   | 119.789       | -0.595       |

c. Geological Map
   Geological Map Review Palu Sheet, Sulawesi scale of 1: 250,000 second print of 1996 from the Center for Geological Research and Development. This map contains some information about lithology or types of rocks making up the coast of Palu Bay and its surroundings, contours, important objects, and other geological information.
2.2. Equipment
The equipment that used in this research are:

- ArcGIS
  This software is used to display and perform spatial data processing.
- Microsoft Office
  This word and number processing tool is used to do correlation tests and make reports.

2.3. Methods

2.3.1. Identification of Land Cover
The parameters of land cover are obtained from the LPI Map Number 2015-05. There are several types of land cover that are available. Then identify the observation points for each overlayed land cover type.

2.3.2. Identification of Slope
Slope shows the magnitude of the slope angle in percent or degree [8]. In this study, slope is determined from the waters to the point of observation so that the processing uses bathymetry data and height data of several points on the coast of Palu Bay. The entire data is then interpolated into raster using the Topo to Raster method with a cell size of 9×9 m and then reclassify if its result.

| Class | Slope % |
|-------|---------|
| I     | 0 - 8   |
| II    | 8 - 25  |
| III   | 25 - 40 |
| IV    | 40 - 100|

After being classified, it is then identified each observation point to the existing slope.

2.3.3. Identification of Lithology
Lithology is a description of rocks in outcrops based on characteristics such as color, mineral composition and grain size [10]. Lithology parameters were obtained from the identification of each sample point against the Geological Map Review of the Palu Sheet, Sulawesi. The process of identifying points of observation of lithology parameters is carried out on ArcGIS by displaying both layers simultaneously.

2.3.4. Classification of Tsunami’s Height
Because the overall parameter data is nominal, then tsunami height data is also needed for classification to match the type of measurement scale in the parameter data. The recorded tsunami wave heights are then classified according to the following table [11]:

| Class | Magnitude | Energy $E_t$ (ergs) x $10^{22}$ | Max Height $H_t$ (m) |
|-------|-----------|--------------------------------|---------------------|
| I     | 1.0       | 1                              | 2 - 3               |
| II    | 1.5       | 2                              | 3 - 4               |
| III   | 2.0       | 4                              | 4 - 6               |
| IV    | 2.5       | 8                              | 6 - 8               |
| V     | 3.0       | 16                             | 8 - 12              |

2.3.5. Correlation Value Determination
Determination of the magnitude of the correlation of all parameters with the classification of tsunami wave heights uses the contingency coefficient method. The contingency coefficient itself is a statistical test to determine non-parametric correlations using two variables from nominal-scale data [12].
\[ C = \frac{\sqrt{X^2}}{\sqrt{N + X^2}} \]  

(1)

Where \[ X^2 = \sum_{i=1}^{b} \sum_{j=1}^{k} \frac{D_{ij}^2}{E_{ij}}, \quad df = (b - 1) \times (k - 1) \]  

(2)

\[ D_{ij} = O_{ij} - E_{ij} \]  

(3)

Information:
- N: total number of observations
- C: contingency coefficient
- b: number of rows in the contingency table
- k: number of columns in the contingency table
- i: 1, 2, ..., b
- j: 1, 2, ..., k
- O_{ij}: observation data the ‘i’ row and the ‘j’ column in the contingency table
- E_{ij}: expectation frequency values of ‘ij’ for O_{ij}
- X^2: Chi-square calculation results

2.3.6. Significance Test
To find out how good the correlation results are, a significance testing method is needed. Testing the results of contingency efficiency can use the chi-square test. Comparison of the chi-square value calculated from the correlation will then be compared with the ideal chi-square value in the coefficient table. Then the conclusion will be obtained how well each calculated correlation result has been calculated.

3. Results and Discussion

3.1. Land Cover
Based on the identification of the location of sample points against land cover data through the LPI Map Number 2015-05, the results obtained are as shown in Table 4.

| Land Cover   | Sample Point |
|--------------|--------------|
| Residential Area | 11           |
| Bush         | 7            |
| Farm         | 1            |
| Field        | 3            |
| Vacant Land  | 2            |

3.2. Slope
The results of the bathymetry data obtained from the LPI Map Number 2015-05 will then be processed into a slope or slope with classification and results as shown in Figure 1.
Figure 1. Slope Classification.

Table 5. The Area of Each Class.

| Class | Slope % | Area (m²) |
|-------|---------|-----------|
| I     | 0 - 8   | 58952478.894 |
| II    | 8 - 25  | 10143358.648 |
| III   | 25 - 40 | 13181428.148 |
| IV    | 40 - 100| 2966008.567 |

In addition, slope identification results at all sample points are presented in Table 6.

Table 6. Slope Results.

| Slope % | Sample Point |
|---------|--------------|
| 0 - 8   | 1            |
| 8 - 25  | 1            |
| 25 - 40 | 14           |
| 40 - 100| 8            |

3.3. Lithology

The results of identification of all sample points for lithology through the Geological Map are shown in the following Table 7.

Table 7. Lithology.

| Lithology Type        | Sample Point |
|-----------------------|--------------|
| Alluvium               | 19           |
| Formation of Tinombo   | 4            |
| Formation of Pakuli    | 1            |
3.4. Tsunami’s Height Classification

Tsunami wave heights with vertical datum in the form of mean sea level (MSL) then are classified so that they reach a conclusion as shown in Table 8.

| Class | Run-up | Sample Point |
|-------|--------|--------------|
| II    | 3 - 4  | 3            |
| III   | 4 - 6  | 5            |
| IV    | 6 - 8  | 10           |
| V     | 8 - 12 | 6            |

3.5. Correlation

Correlation test obtained from the calculation of contingency coefficients obtained results as in the following Table 9.

| Parameter   | Contingency Coefficient |
|-------------|--------------------------|
| Land Cover  | 0.561                    |
| Slope       | 0.548                    |
| Lithology   | 0.430                    |

3.6. Significance Test

To determine the suitability of the results of the sample point correlation with the overall population data, a significance test was performed using the Chi-Square analysis method. The results of the analysis of each parameter are shown in the following Table 10.

| Parameter   | Calculated Chi-Square | Chi-Square on the Table | Degree of Freedom % |
|-------------|------------------------|-------------------------|---------------------|
| Land Cover  | 11.034                 | 10.960                  | 47                  |
| Slope       | 10.286                 | 10.228                  | 66                  |
| Lithology   | 5.432                  | 5.350                   | 50                  |

4. Conclusions

In this study, from the results of the correlation show that the parameters of land cover to be the most influential parameter to the difference in height of the tsunami wave that is equal to 56.12%. While in the significance test, the slope parameter becomes the parameter that has the highest degree of freedom that is equal to 66%. These results indicate that the results of the slope sample correlation data have the closest match to the results of population data processing.

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This research was made possible thanks to the contribution of the Geospatial Information Agency as the provider of data for the LPI Map Number 2015-05. In the future, this research can be developed in determining the effect of each variable's parameters on tsunami wave heights. Weaknesses in this study can be corrected in subsequent studies in the form of adding measurement parameters, adding sample points, and conducting significance tests at a more varied level of confidence.

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