Analysis of tsunami hazard in the Southern Coast of West Java Province - Indonesia

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Abstract. The Southern Coast of West Java Province in the Java Islands is one of prone and exposed area to tsunami hazard. It has about 428 kilometers coastline length, covering 5 administrational regencies (i.e. Sukabumi, Cianjur, Garut, Tasikmalaya, and Pangandaran). It is a strategic area that support many economic activities including tourism, fisheries, electricity power plants, agriculture, markets as well as social factors such as coastal villages, schools and other public facilities. The existence of this strategic area is threatened by the potential for a tsunami disaster mainly from megathrust along the Southern Coast of Java Island. On 2006, a tsunami earthquake of M7.7 occurred off Pangandaran Regency with tsunami height of 5-8 meters and inundated about 500 meters along southern coast of West and Central Java Province. The tsunami caused more than 600 casualties and damage to buildings, public facilities and infrastructure. Yet, the Indonesia National Earthquake Source and Hazard Map suggest a bigger threat of a plausible M8.7 – M9.2 megathrust earthquake off Java island. This research aims to analyze and map potential areas affected by the tsunami in the South Coast of West Java Province based on numerical modelling carried out with Cornell Multi-grid Coupled Tsunami Model (COMCOT) v1.7 based on the several megathrust earthquake scenarios in southern off West Java. The results of tsunami modelling show that the highest impact is generated in the Sunda Straits & West Java - Central Java Megathrust Scenarios with highest tsunami inundation and the fastest travel time occurred in Cianjur Regency with 26.7 meters height and estimated arrival time of tsunami wave approximately 10 minutes after the mainshock, while the farthest inundation distance is estimated in Sukabumi Regency about 5.8 kilometers from the coast due to existence of river.

1. Introduction
Tsunamis are sudden ocean waves which can be triggered by several factors. However most of tsunami are generated by seismic activities that create large earthquakes that occur under or near the ocean. The other generating factors are submarine and subaerial gravitative mass wasting, volcanism, atmospheric disturbances and meteorite impacts [1]. Like many other natural phenomena, tsunamis can range in size
from micro-tsunamis with no effect to coastline, to mega-tsunamis that can affect large area on the coastlines, as with the Indian Ocean tsunami of 2004 or Japan 2011.

Tsunami disaster risk means the potential of human loss, damages and economic losses that can be caused due to tsunami. Tsunami has shown in the past able to extraordinary, catastrophic impact due to large number of victims, large material losses and high economic loss. Tsunami disaster mitigation measures are those that eliminate or reduce the impacts and risks of tsunami hazards through proactive measures taken before an emergency or disaster occurs. Assessment of tsunami hazard and risk is required to support preparedness measures and effective disaster reduction.

Accessibility to tsunami safe zone or tsunami shelters is one on important key measure of adaptive capacity in response to tsunami risks. Important information for tsunami disaster risk reduction strategic planning include understanding of tsunami hazard and risk to support preparedness measures and effective disaster reduction. Tsunami hazard data include inundation, flow-depth, estimated time arrival time as accurate as possible.

The southern coast of Java is one of the areas that has the potential for a tsunami disaster due to tectonic activity in the south of Java, namely the existence of a subduction to the north of the Indo-Australian plate under the Eurasian plate with near normal direction to the trough [2]. Sudradjat in [3] included the southern part of Java into group of vulnerable tsunami disaster based on the cause of tectonic earthquakes. Based on the history, there was an earthquake that triggered tsunami on July 17, 2006 at precisely 15:19 WIB on the south coast of Pangandaran. The earthquake occurred at coordinates 9.33˚ LS and 107.26˚ BT at a depth of 10 km with a magnitude of 7.7 SR and the epicentre of the earthquake occurred in the Indian Ocean south of Ciamis Regency, and the location of the epicentre was 245 km south of Tasikmalaya [4].

Referring to the Indonesian Tsunami Catalog 416-2017 published by BNPB (National Agency of Disaster Mitigation) [5], the phenomenon of a potential tsunami that occurred earlier on January 4, 1840 was examined by [6] and [7] with magnitude 7.0 SR. The same study was carried out by observing the phenomenon of the tsunami that occurred on October 20, 1859 along with [8]. Furthermore, an earthquake occurred in the Cilacap, Central Java on September 7, 1904 which was studied together with [9]. The disasters continued on September 11, 1921 with magnitude 7.5 SR which hit Parangtritis and Cilacap according to [6], [10], and [11]. On June 19, 1930 an earthquake with a magnitude of 6.0 SR was observed in Teluk Betung and in the District of Besuki just a month after. In 1957 there was an earthquake in Banyumas accompanied by tidal flooding based on the reference of [6]. Entering the 21st century there has been an earthquake in Pangandaran, West Java in 2006 with a magnitude of 7.7 SR which caused a tsunami according to BMKG (Agency for Climatology and Geophysics) and BIG (Geospatial Information Agency) in the Tasikmalaya in 2009 with a magnitude of 7.6 SR which is potential to tsunami to be occurred. Some of tsunami sources around the Java Island are presented in Fig. 1.

![Figure 1. Tsunami sources around the Java Islands (red star with year of occurrence)](image-url)
2. Study Area

West Java (Jawa Barat) is a province of Indonesia on the western part of the island of Java. It is the most populous province of Indonesia with a projected population of 49,316,700 as of 2019 [12]. It occupies an area of 37,095 km2, which is divided into 26 cities or regencies. Five of those regencies (Sukabumi, Cianjur, Garut, Tasikmalaya and Pangandaran) are situated on the southern coast and will be used as the study area of this research (Fig 2).

![Figure 2. Study Area](image)

2.1 Hazard Characteristics

West Java Province is one of the area where the most of natural disasters occur. According to the DIBI (Data Informasi Bencana Indonesia or Indonesian Disasters Information Data) from BNPB [13], Fig.3 presents disasters data along with the number of deaths in related disaster within year 2004-2018.

![Figure 3. Number of disaster occurrences and its related deaths by type of disaster in the last 15 years (2004-2018)](image)

2.2 Mitigation Systems and Adaptive Capacity to Tsunami Hazard in the Study Area

According to Law No. 24 of 2007 concerning disaster management, mitigation is a series of efforts to reduce disaster risk, both through physical development and awareness and capacity building in the face of disaster threats. The concept of adaptation according to the United Nations Framework Convention
on Climate Change (UNFCC) is defined as something that involves the discovery and application of ways to adapt to environmental changes (climate change) [14].

Observed during the field survey, several districts already have various mitigation systems and adaptive capacities. In general, temporary evacuation sites (TES) are already established along the coastline and the evacuation routes are equipped with signs that indicate the direction to TES. According to the Disaster Mitigation Agency in Sukabumi, the sites are selected with the following criteria: (1) minimum distance of 500 m from coastline; (2) minimum elevation of 16 m from sea level. With those criteria, with its typical topography most of the TES are located quite far from the coastline (in the range 2-6 km), as a consequence the required time for the villagers to reach TES can be up to 30-90 minutes. One of the recommendation to solve this problem is to build a shelter for TES. However at this moment, the shelters are found only in Pangandaran, but none in the other regencies.

BNPB and BMKG have built some Early Warning System (EWS) in the area to detect earthquakes and tsunamis, one of which is in the Districts of Tegalbuleud (Cianjur Regency), Ciracap, Ciemas, and Cisolok Districts (Sukabumi Regency) including some alert system (e.g. siren or alarm). Unfortunately, lack of maintenance leads to inoperative status of those system, particularly in the EWS alert system.

3 Data & Methods

3.1 Data types and sources

Detailed and accurate bathymetry and topographic data are required in tsunami modelling in order to produce good results. Bathymetry data are obtained from BATNAS (BAtimetri NASional) and topographic data obtained from DEMNAS (Digital Elevation Model NASional) that provided by BIG. Then, modelling domains are formed from these two data for tsunami modelling and earthquake parameter data and seismicity data are used as a tsunami wave generating factor. List of data used in the modelling are presented in Table 1.

| No. | Data Types        | Data Sources                          | Notes             |
|-----|-------------------|---------------------------------------|-------------------|
| 1   | Topographic Data  | DEMNAS (Digital Elevation Model NASional) – Badan Informasi Geospasial (BIG) | Resolution: 0.27 sec |
| 2   | Bathymetric Data  | BATNAS (BAtimetri NASional) – Badan Informasi Geospasial (BIG) | Resolution: 6 sec |
| 3   | Earthquake Parameter | PuSGeN (Pusat Studi Gempa Nasional) (2017) [15] |                  |
| 4   | Seismicity Data   | PuSGeN (Pusat Studi Gempa Nasional) (2017) [15] |                  |

3.2 Numerical simulations

3.2.1 Earthquake parameters

In this study, 5 scenarios that caused the tsunami were made, including: 1 historical scenario (Pangandaran 2006) and 4 probabilistic scenarios. COMCOT requires input parameters which are parameters of the earthquake that will generate a tsunami wave. These parameters are listed in Table 2.

In probabilistic scenarios, parameters such as length, width, and plate dislocation are obtained through the calculation process. Depth parameters, strike, dip are obtained from the USGS Slab model 1.0 [16], with the rake angle considered to be the opposite of the direction of movement of the plate in the interseismic phase. The epicentre centre parameters were obtained from the results of the study of the National Earthquake Study Centre (Pusat Studi Gempa Nasional) [15] by adjusting the segmentation carried out by PusGen.
Table 2. Parameters from elastic fault plane model

| Parameters                  | Symbol | Unit   |
|-----------------------------|--------|--------|
| Epicentre (Lat, Long)       | Lat;Long | Degree |
| Depth                       | d      | Meter  |
| Fault Length                | L      | Meter  |
| Fault Width                 | W      | Meter  |
| Dislocation (slip)          | MD     | Meter  |
| Strike                      |        | Degree |
| Dip                         |        | Degree |
| Rake (slip angle)           |        | Degree |

To get the value of length, width, and fault dislocation, the following equation is used [17]:

\[ \log L = -2.42 + (0.58 \times M_w) \]  \hspace{1cm} (1)
\[ \log W = -1.61 + (0.41 \times M_w) \]  \hspace{1cm} (2)
\[ \log MD = -1.38 + (1.02 \times \log L) \]  \hspace{1cm} (3)

\( L \) is fault length, \( W \) is fault width, and \( MD \) is fault dislocation. Seismic moment calculations can also be used to find the slip rate through equations [17] & [18]:

\[ Mo = \mu mS \]  \hspace{1cm} (4)
\[ Mw = \frac{2}{3} \log Mo - 6.07 \]  \hspace{1cm} (5)

where \( m \) is the slip rate, \( S \) is the area of the fault segment, \( \mu \) is normal rigidity \( (3 \times 10^{10}) \). After all parameters are obtained, fault parameter setup is done by entering the fault parameters according to Table 2 in the COMCOT v.1.7 modeling script.

3.2.2 Numerical Model Cornell Multi-Grid Coupled Tsunami (COMCOT)

Cornell Multi-Grid Coupled Tsunami v.1.7 is a software that is used to modelling tsunami waves using FORTRAN 90 programming language and uses the Shallow Water Equation (SWE) to calculate tsunami wave height during its propagation. In addition, COMCOT only simulates tsunami waves without the influence of wind and tidal waves. The COMCOT model will also produce inundation and run-up values from modelling [19].

COMCOT uses Linear Shallow Water Equation (LSWE) and Nonlinear Shallow Water Equation (NLSWE). In the tsunami event on the open seas, the tsunami amplitude is smaller than the depth so that it uses the LSWE equation as follows [19]:

\[ \frac{\partial \eta}{\partial t} + \frac{1}{R \cos \varphi} \left( \frac{\partial P}{\partial \theta} + \frac{\partial}{\partial \varphi} (\cos \varphi Q) \right) = -\frac{\partial h}{\partial t} \]  \hspace{1cm} (6)
\[ \frac{\partial P}{\partial t} + \frac{1}{R \cos \varphi} \frac{\partial}{\partial \theta} (P^2) + \frac{1}{R} \frac{\partial}{\partial \varphi} (H) + gH \frac{\partial \eta}{\partial \varphi} - fQ + F_x = 0 \]  \hspace{1cm} (7)
\[ \frac{\partial Q}{\partial t} + \frac{1}{R \cos \varphi} \frac{\partial}{\partial \theta} (PQ) + \frac{1}{R} \frac{\partial}{\partial \varphi} (Q^2) + gH \frac{\partial \eta}{\partial \varphi} + fP + F_y = 0 \]  \hspace{1cm} (8)

When the tsunami spreads in shallow waters, the NLSWE equation is used, this is because when a tsunami wave passes through an area that has shallow depth, the wavelength becomes shorter and the amplitude of the wave becomes larger. Following is the NLSWE equation used [19]:

\[ \frac{\partial \eta}{\partial t} + \frac{1}{R \cos \varphi} \left( \frac{\partial P}{\partial \theta} + \frac{\partial}{\partial \varphi} (\cos \varphi Q) \right) = -\frac{\partial h}{\partial t} \]  \hspace{1cm} (9)
\[ \frac{\partial P}{\partial t} + \frac{1}{R \cos \varphi} \frac{\partial}{\partial \theta} (P^2) + \frac{1}{R} \frac{\partial}{\partial \varphi} (HQ) + gH \frac{\partial \eta}{\partial \varphi} - fQ + F_x = 0 \]  \hspace{1cm} (10)
\[ \frac{\partial Q}{\partial t} + \frac{1}{R \cos \varphi} \frac{\partial}{\partial \theta} (PQ) + \frac{1}{R} \frac{\partial}{\partial \varphi} (Q^2) + gH \frac{\partial \eta}{\partial \varphi} + fP + F_y = 0 \]  \hspace{1cm} (11)

With:
\[ H = \eta + h \]  
(12)  
\[ f = \Omega \sin \phi \]  
(13)  
\[ F_x = \frac{gn^2}{H^{7/3}} P \sqrt{P^2 + Q^2} \]  
(14)  
\[ F_y = \frac{gn^2}{H^{7/3}} Q \sqrt{P^2 + Q^2} \]  
(15)  
\[ P = \int_{-h}^{\eta} udz = u (h + \eta) = uH \]  
(16)  
\[ Q = \int_{-h}^{\eta} vdz = v (h + \eta) = uH \]  
(17)  

where:

- \( g \) = gravitational acceleration (m/s\(^2\))
- \( P \) = volume fluxes in \(-x\) (West-East) (m/s\(^2\))
- \( Q \) = volume fluxes in \(-y\) (South-North) (m/s\(^2\))
- \( f \) = Coriolis force coefficient
- \( \varphi, \psi \) = latitude and longitude (\(^\circ\))
- \( R \) = radius of the Earth (m)
- \( h \) = water depth (m)
- \( \eta \) = water surface elevation (m)
- \( H \) = total water depth (m)
- \( \Omega \) = rotation rate of the Earth (7,2921 \times 10^{-5} \text{ rad/s})
- \( F_x, F_y \) = bottom friction in \(-x\) dan \(-y\)
- \( n \) = Manning’s roughness coefficient (s/m\(^{1/3}\))
- \( u \) = current velocity in \(-x\) (m/s)
- \( v \) = current velocity in \(-y\) (m/s)

3.2.3 Domains

The tsunami modelling domain is divided into 3 layers of Domain with Domain 1 is the Java Island Domain, Domain 2 is the West Java Domain, while Domain 3 is the domain of each Regency in the south of West Java including Sukabumi Regency, Cianjur Regency, Garut Regency, Tasikmalaya Regency and Pangandaran Regency. The design of the Domain 1, Domain 2, and Domain 3 models can be seen in Fig. 4-6.

Figure 4. Java Island domain
Figure 5. West Java domain

Figure 6. Domain 3 of the tsunami modelling
3.2.4 Scenarios.
Tsunami modelling is carried out with a domain scenario as presented in the Table 3.

| Parameter                  | Domain          |
|----------------------------|-----------------|
| Simulation Time (second)   | Min. 7200       |
| Time Interval to Save Data (second) | 60             |
| Governing Equations       | Linear          |
| Parent Domain              | 0               |
| Numbers of Domain          | 1               |
| Grid Size (meter)          | 1800            |

The tsunami generating factor used in this study was from earthquakes that obtained from seismic studies in the southern subduction zone of West Java, as well as from historical tsunamis that have occurred before. The tsunami generating factor (earthquake scenario) scenario was carried out in this tsunami modelling is presented in Table 4.

| Scenarios | 1                  | 2               | 3                | 4                | 5                |
|-----------|-------------------|----------------|-----------------|-----------------|-----------------|
| Location  | Pangandaran 2006  | Seg. Selat Sunda, TE | Seg. Cilacap TE [15] | Seg. Selat Sunda [15] | Seg. Jabar-Jateng [15] |
| Mw        | 8.1               | 7.8            | 7.8             | 8.7             | 8.7             |
| Depth (km) | 10.575             | 10.575         | 34              | 20.188          |
| Length (km) | 200              | 215           | 340             | 460             |
| Width (km) | 70               | 70             | 180             | 160             |
| Max. Disp (m) | 9.269         | 9.979          | 15.926          | 21.678          |
| Strike (°) | 289             | 300            | 277.356         | 297             | 296.753         |
| Dip (°)    | 10              | 12             | 18              | 9.962           |
| Slip (m)   | 12              | 1.5            | 8               | 6.5             |
| Rake (°)   | 95              | 104            | 104             | 104             |
| Lat;Long(°) | -9.295; 107.347 | -8.46; 105.595 | -9.826; 109.255 | -7.239; 104.435 | -8.92; 107.88 |

4 Results and Discussions

4.1 Tsunami Hazard
The tsunami modelling came from 1 historical scenario and 4 probabilistic tsunami scenarios in the southern region of West Java Province. Fault parameter from the previous study is chosen as a reference data input to obtain tsunami inundation data based on the results of the latest study of the possibility of a tsunami generating earthquake in South West Java Province.

4.1.1 Inundation Maps
The following images in Fig. 7 show inundation maps of along the southern coast of West Java Province. Based on the map, the districts that have inundation height significantly are in the Cisolok District, Ujung Genteng Beach-Ciracap District, and the Tegalbuleud District (Sukabumi Regency), Cidaun District in Cianjur Regency, Cisewu and Cibalong District in Garut Regency, Karangnunggal District in Tasikmalaya Regency, and Pangandaran District in Pangandaran Regency. The mean of inundation height varies up to a dozen meters from five scenarios.
Figure 7. Inundation Maps of Southern Coast of West Java Province
4.1.2 Table of Tsunami Arrival Time, Inundation Range and Inundation Height

The following tables show the arrival time, inundation range and inundation height of the tsunami from each district in the southern coast of West Java. Arrival time refers to the time the tsunami reaches the area (in minutes) after the earthquake as seen from the first tsunami wave that reaches the coastal area based on modeling results. Inundation range is the range from coastline where the inundation caused by the tsunami may take. Inundation height is defined as the height of tsunami inundation above ground level. Tsunami arrival time, tsunami inundation range, and tsunami height can be seen in Table 5, Table 6, and Table 7 respectively.

**Table 5. Arrival time of tsunami disaster of southern coast of West Java Province**

| District          | Arrival Time (-minutes after earthquake) | Scenarios |
|-------------------|------------------------------------------|-----------|
|                   |                                          | 1 | 2 | 3 | 4 | 5 |
| Sukabumi Regency  |                                          |   |   |   |   |   |
| Cisolok           | 37                                       | 28 | - | 16 | 18 |
| Cikakak           | 36                                       | 27 | - | 16 | 18 |
| Palabuhanratu     | 35                                       | 27 | - | 16 | 18 |
| Simpenan          | 34                                       | 26 | - | 15 | 17 |
| Ciemas            | 33                                       | 26 | - | 14 | 16 |
| Ciracap           | 27                                       | 21 | 42 | 16 | 12 |
| Surade            | 27                                       | 24 | 41 | 19 | 12 |
| Cibitung          | 27                                       | 26 | 42 | 19 | 13 |
| Tegalbuleud       | 26                                       | 28 | 44 | 19 | 14 |
| Cianjur Regency   |                                          |   |   |   |   |   |
| Agravinta         | 25                                       | 28 | 38 | 20 | 11 |
| Sindangbarang     | 21                                       | 21 | 34 | 20 | 10 |
| Cidaun            | 23                                       | 25 | 33 | 20 | 12 |
| Garut Regency     |                                          |   |   |   |   |   |
| Caringin          | 23                                       | 24 | 32 | 20 | 11 |
| Bungbulang        | 23                                       | 25 | 32 | 22 | 11 |
| Mekarmukti        | 23                                       | 25 | 32 | 22 | 11 |
| Pakenjeng         | 23                                       | 25 | 32 | 22 | 11 |
| Cikelet           | 23                                       | 25 | 31 | 24 | 11 |
| Pameungpeuk       | 24                                       | 26 | 31 | 27 | 13 |
| Cibalong          | 23                                       | 28 | 30 | 27 | 13 |
| Tasikmalaya Regency |                                          |   |   |   |   |   |
| Cipatujah         | 27                                       | 33 | 33 | 30 | 17 |
| Karangnunggal     | 27                                       | 33 | 30 | 35 | 17 |
| Cikal longitud    | 27                                       | 38 | 33 | 37 | 18 |
| Pangandaran Regency |                                          |   |   |   |   |   |
| Cimerak           | 32                                       | 43 | 35 | 45 | 23 |
| Cijulang          | 42                                       | 48 | 39 | 54 | 28 |
| Parigi            | 45                                       | 53 | 46 | 57 | 34 |
| Sidamulih         | 45                                       | 54 | 46 | 57 | 34 |
| Pangandaran       | 45                                       | 55 | 47 | 57 | 34 |
| Kalipucang        | 47                                       | 57 | 47 | 58 | 37 |
| District          | Sukabumi Regency | Cianjur Regency | Garut Regency | Tasikmalaya Regency | Pangandaran Regency | Kalipucang |
|-------------------|------------------|-----------------|---------------|---------------------|---------------------|------------|
|                   | 1                | 2               | 3             | 4                   | 5                   |            |
|                   | Mean             | Max.            | Mean          | Mean                | Mean                | Mean       |
| Cisolok           | 289.6            | 563.84          | 197.37        | 509.15              | 754.44              |            |
|                   | 118.17           | 153.98          | 98.63         | 229.85              | 458.23              |            |
|                   | 203.6            | 341.09          | 187.87        | 760.16              | 840                 |            |
| Cikakak           | 130.56           | 186.9           | 95.78         | 355.4               | 462.32              |            |
|                   | 1061.5           | 1292            | 1330          | 2703                | 5298                |            |
| Palabuhanratu     | 420.6            | 690.56          | 409.7         | 823.88              | 755.96              |            |
|                   | 1015.5           | 2010            | 1104          | 2618                | 5864.8              |            |
| Simpenan          | 375.8            | 583.69          | 330.8         | 753.4               | 632.84              |            |
|                   | 431.18           | 2501            | 658.47        | 2292                | 2734.01             |            |
| Ciemas            | 155.46           | 289.1           | 136.32        | 215.6               | 475.66              |            |
|                   | 1022.1           | 3696            | 450.47        | 1664                | 2348.18             |            |
| Ciracap           | 355.81           | 548.78          | 155.42        | 612.3               | 697.87              |            |
|                   | 1010.6           | 1376            | 450.34        | 923.2               | 1791.2              |            |
| Surade            | 318.56           | 375.93          | 186.96        | 206.5               | 546.96              |            |
|                   | 554.06           | 1813.9          | 475.15        | 545.42              | 627.45              |            |
| Cibitung          | 330.86           | 362.85          | 179.6         | 235.11              | 563.45              |            |
|                   | 2202             | 2592            | 1749.1        | 2786.12             | 2847.67             |            |
| Tegalbuleud       | 409.12           | 970.95          | 650.6         | 660.07              | 1530.31             |            |
|                   |                  |                 |              |                     |                     |            |
| Agravinta         | 2140.1           | 2802            | 1430          | 2655.82             | 3638.17             |            |
|                   | 486.2            | 712.03          | 582.57        | 521.51              | 1885.45             |            |
| Sindangbarang     | 631.96           | 880.3           | 841.23        | 757.7               | 2077.55             |            |
|                   | 289.34           | 259.1           | 258.92        | 330.03              | 875.65              |            |
| Cidaun            | 1511             | 521.84          | 388.38        | 776.67              | 3014.18             |            |
|                   | 345.23           | 148.4           | 145.12        | 150.31              | 1457.83             |            |
| Caringin          | 578.3            | 251.5           | 233.24        | 231.3               | 2369                |            |
|                   | 204.24           | 188.1           | 182.9         | 180.1               | 818.61              |            |
| Bungbulang        | 472.95           | 377.86          | 390.95        | 268.77              | 1472.2              |            |
|                   | 155.32           | 180.65          | 179.65        | 186.53              | 483.98              |            |
| Mekarmukti        | 872.87           | 663.78          | 521.21        | 603.8               | 1426.4              |            |
|                   | 217.86           | 192.86          | 193.56        | 206.56              | 587.65              |            |
| Pakenjeng         | 560.23           | 188.1           | 192.65        | 200.2               | 860.35              |            |
|                   | 182.89           | 80.3            | 80.92         | 82.44               | 522.96              |            |
| Cikelet           | 552.15           | 310.97          | 215.59        | 491.6               | 1221                |            |
|                   | 243.84           | 159.2           | 136.18        | 215.4               | 561.75              |            |
| Pameungpeuk       | 2086             | 1174            | 964.87        | 1405                | 3941                |            |
| Cibalong          | 873.53           | 474.69          | 347.9         | 586.2               | 1423                |            |
|                   | 888.27           | 464.62          | 304.77        | 600.87              | 1585                |            |
|                   | 355.02           | 182.3           | 155.32        | 243.81              | 670.47              |            |
| Lembang           | 284              | 165.05          | 230.04        | 189.72              | 2376                |            |
|                    | 164.74           | 106.72          | 114.76        | 126.07              | 492.94              |            |
| Cijulang          | 931.54           | 163.64          | 621.09        | 1012                | 2215                |            |
|                   | 134.54           | 95.86           | 142.84        | 145.96              | 264.45              |            |
| Parigi            | 312.68           | 117.06          | 335.3         | 457.47              | 2908                |            |
|                   | 100.39           | 88.27           | 142.32        | 184.78              | 940.14              |            |
| Sidamulih         | 902.19           | 519.67          | 732.92        | 600.4               | 3854.4              |            |
|                   | 125.68           | 60.96           | 146.68        | 172.62              | 2286.96             |            |
| Pangandaran        | 607.21           | 554.06          | 546.49        | 528.65              | 3735                |            |
|                   | 115.25           | 114.89          | 126.82        | 143.65              | 1856.83             |            |
| Kalipucang        | 1081             | 268.03          | 302.49        | 967.58              | 1890                |            |
|                   | 108.45           | 124.98          | 127.44        | 124.23              | 284.8               |            |
| District                  | Inundation Height (in meters) | 1   | 2   | 3   | 4   | 5   |
|--------------------------|--------------------------------|-----|-----|-----|-----|-----|
|                          | Scenarios                      | Mean| Max.| Mean| Max.| Mean| Max.|
| **Sukabumi Regency**     |                                |     |     |     |     |     |     |
| Cisolok                  |                                | 0.25| 0.41| 0.136| 0.25| 1.32| 1.75|
|                          |                                |     |     |     |     |     |     |
| Cikakak                  |                                | 0.32| 0.53| 0.125| 0.32| 2.56| 1.98|
|                          |                                |     |     |     |     |     |     |
| Palabuhanratu            |                                | 2.16| 0.53| 6.62 | 2.16| 8.62| 8.69|
|                          |                                |     |     |     |     |     |     |
| Simpenan                 |                                | 1.76| 0.53| 7.52 | 1.76| 7.52| 8.62|
|                          |                                |     |     |     |     |     |     |
| Siemias                  |                                | 2.86| 0.54| 11.23| 2.86| 11.23| 6.76|
|                          |                                |     |     |     |     |     |     |
| Ciracap                  |                                | 6.23| 0.62| 18.97| 6.23| 18.97| 10.69|
|                          |                                |     |     |     |     |     |     |
| Surade                   |                                | 7.59| 0.98| 16.84| 7.59| 16.84| 9.27 |
|                          |                                |     |     |     |     |     |     |
| Cibitug                  |                                | 3.75| 0.65| 9.13 | 3.75| 9.13 | 2.05|
|                          |                                |     |     |     |     |     |     |
| Tegalbuleud              |                                | 4.58| 0.72| 9.254| 4.58| 9.254| 9.38 |
|                          |                                |     |     |     |     |     |     |
| **Cianjur Regency**      |                                |     |     |     |     |     |     |
| Agrabinta                |                                | 4.97| 0.97| 6.76 | 4.97| 6.76 | 2.75 |
|                          |                                |     |     |     |     |     |     |
| Sindangbarang            |                                | 6.63| 1.43| 5.47 | 6.63| 5.47 | 2.83 |
|                          |                                |     |     |     |     |     |     |
| Cidaun                   |                                | 10.65| 1.43 | 8.7  | 10.65| 8.7  | 3.51|
|                          |                                |     |     |     |     |     |     |
| **Garut Regency**        |                                |     |     |     |     |     |     |
| Caringin                 |                                | 12.2| 2.11| 4.5  | 12.2| 4.5  | 3.21|
|                          |                                |     |     |     |     |     |     |
| Bungbulang               |                                | 10.28| 3.34 | 3.31 | 10.28| 3.31 | 2.18|
|                          |                                |     |     |     |     |     |     |
| Mekarmukti               |                                | 10.32| 3.78 | 4.36 | 10.32| 4.36 | 3.09|
|                          |                                |     |     |     |     |     |     |
| Pakenjeng                |                                | 7.85| 2.11| 2.53 | 7.85| 2.53 | 1.54|
|                          |                                |     |     |     |     |     |     |
| Cikelet                  |                                | 7.58| 2.11| 3.82 | 7.58| 3.82 | 3.26|
|                          |                                |     |     |     |     |     |     |
| Pameungpeuk              |                                | 12.96| 2.11 | 5.18 | 12.96| 5.18 | 3.05|
|                          |                                |     |     |     |     |     |     |
| Cibalong                 |                                | 13.86| 2.11 | 7.85 | 13.86| 7.85 | 4.97|
|                          |                                |     |     |     |     |     |     |
| **Tasikmalaya Regency**  |                                |     |     |     |     |     |     |
| Cipatujah                |                                | 13.6| 2.11| 4.19 | 13.6| 4.19 | 5.54|
|                          |                                |     |     |     |     |     |     |
| Karangnunggal            |                                | 5.87| 1.7 | 1.66 | 5.87| 1.66 | 2.71|
|                          |                                |     |     |     |     |     |     |
| Cikalong                 |                                | 1.7 | 2.11| 0.45 | 1.7 | 0.45 | 0.71|
|                          |                                |     |     |     |     |     |     |
| **Pangandaran Regency**  |                                |     |     |     |     |     |     |
| Cimerak                  |                                | 7.37| 1.78 | 1.78 | 7.37| 1.78 | 5.01|
|                          |                                |     |     |     |     |     |     |
| Cijulang                 |                                | 6.32| 2.11| 1.67 | 6.32| 1.67 | 8.59|
|                          |                                |     |     |     |     |     |     |
| Parigi                   |                                | 1.16| 0.72| 0.37 | 1.16| 0.37 | 1.09|
|                          |                                |     |     |     |     |     |     |
| Sidamulih                |                                | 5.47| 2.79| 1.61 | 5.47| 1.61 | 5.83|
|                          |                                |     |     |     |     |     |     |
| Pangandaran              |                                | 5.07| 2.79| 1.32 | 5.07| 1.32 | 5.36|
|                          |                                |     |     |     |     |     |     |
| Kalipucang               |                                | 7.64| 2.79| 1.8  | 7.64| 1.8  | 7.46|
|                          |                                |     |     |     |     |     |     |
The results of the tsunami arrival time show that each region has a tsunami arrival time that varies from 10 minutes to about 1 hour depending on the type of scenario applied. This is because in each scenario the tsunami modeling has different tsunami generating earthquake locations. For example in scenario 1, with the location of the earthquake in the south of Pangandaran Regency, the tsunami waves made it very quickly to the coast of Pangandaran and Tasikmalaya compared to other places farther away. Table 6 shows the mean and maximum inundation range in meters. The maximum inundation range in each regency is 5.86 km in Simpenan District (Sukabumi Regency – scenario 5), 3.63 km in Agrabinta District (Cianjur Regency – scenario 5), 3.94 km in Pameungpeuk District (Garut Regency – scenario 5), 3.37 km in Karangnunnggal District (Tasikmalaya Regency – scenario 5), and 2.28 km in Pangandaran District (Pangandaran Regency – scenario 5). The more details of inundation range of each scenarios in each district can be seen in Table 6. In Table 7 shows the mean and maximum inundation height in meters in each scenarios. The maximum inundation range in each regency is 19.34 m in Tegalbuleud District (Sukabumi Regency – scenario 5), 26.21 m in Cidaun District (Cianjur Regency – scenario 5), 26.24 m in Caringin District (Garut Regency- scenario 5), 26.73 m in Cikalong District (Tasikmalaya Regency – scenario 5), and 25.41 m in Kalipucang District (Pangandaran Regency – scenario 5). The more details of inundation height of each scenarios in each district can be seen in Table 7.

From all of these results it can be seen that the most severe tsunami scenario is scenario 5, which is the west java - central java segment scenario with magnitude 8.7 which causes a high tsunami inundation height and a far inundation range with a fairly short tsunami arrival time. In addition, the relatively flat topography of the coastal areas and the presence of river mouths made the tsunami disasters even worse.

Figure 8. River in Palabuhanratu District, Sukabumi Regency

Figure 8 is an example showing that the existence of the Cimandiri River in Palabuhanratu Subdistrict, Sukabumi Regency, which caused the tsunami waves to enter the river area and caused the riverbanks to be affected by the tsunami waves.

Figure 9. DEM on Cikalong District, Tasikmalaya Regency
Whereas in Figure 9 is DEMNAS data in the Cikalong Subdistrict, Tasikmalaya District which has a relatively high tsunami inundation height with fairly flat topographic characteristics and has several basins on the ground that cause tsunami traps resulting from the calculation of tsunami modeling.

4.2 Analysis to Socio-Economics Impact
In any district in the southern coast of West Java, the inundation area of tsunami will have an impact on the population living in the coastal area, and also on the social-economic aspects. In Sukabumi Regency, Cisolok District is an area that threatens 71.332 people in 6 villages including 8 schools, as well as economic activities dominated by tourism aspects (Cibangban and Karanghawu Beach) and fisheries (Cisolok and Cibangban Fishing Port). Besides that, Palabuhanratu District is area that potentially affected by tsunami with busy fishing activities and is equipped with 2 tourism sites, 2 fishing ports, 1 electricity steam power plants, and 2 markets that threatens 111.788 people of population. Whereas in Cianjur Regency, the impact of the tsunami included Cidaun District with a 66.729 people in 5 villages and Agrabinta District with 37.934 people in 3 villages. In Cidaun District there are 2 beaches and 13 schools while in Agrabinta District there are 3 beaches, 2 schools, 1 estuary and 1 fishing port that has an impact on economic losses.

In Pakenjeng District, Garut Regency there is Cimari Muara Fishing Port which is the centre of economic activity that has an impact on economic losses caused by the tsunami disaster and threatening 7.105 people. It is different from the Karangnunggal District, Tasikmalaya Regency which has 84.155 endangered people and 6 schools in the event of a tsunami. Pangandaran District, Pangandaran Regency consists of 6 villages with 53.057 endangered populations. there are also 32 schools, 2 beaches, 1 fishing port and the conservation areas that are at risk of being affected by the tsunami disaster.

Conclusions
In this study, tsunami hazards and its socio-economics impacts in five coastal regencies in West Java Province, Indonesia are examined. Highest possible tsunami hazard is found in Cikalon, Tasikmalaya Regency in scenario 5 which can reach up to 26,73 meters of inundation, while the maximum inundation range in can reach up to 5,8 km in Palabuhanratu, Sukabumi. Shortest arrival time may occurs in Sindangbarang, Sukabumi which only needs 10 minutes for tsunami waves to arrive after the earthquake.

Palabuhanratu, with busy fishing activities and is equipped with 2 tourism sites, 2 fishing ports, 1 power plants, and 2 public markets, and populated by 111.788 inhabitants, is area that potentially highest socio-economic impacted by tsunami.

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