3D modelling analysis of sea-level rise impact in Semarang, Indonesia

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Abstract. Regarding the Intergovernmental Panel on Climate Change reports that sea-level may reach up to 74 cm in 2100. This prediction may be a crucial indicator for countries whereas located in low-lying areas. Due to the significant impact on economics and social, sea-level rise can be a severe problem in the future. Some of the big cities in Indonesia are in the coastal areas, such as Jakarta, Surabaya, and Semarang. They become the vulnerable city in Indonesia, which is affected by sea-level rise. The aim of the study is to model and analysis the impact of sea-level rise, particularly in Semarang city, Indonesia. In this study, sea-level rise can be estimated by satellite altimetry data for a long-term period. The impact of sea-level rise can be modeled and visualized using 3D modeling. The prediction over 50 years, the areas impacted by sea-level rise is about 807 km². They mostly cover in the northern of Semarang city.

1. Introduction
Several studies of global sea-level rise (Global Mean Sea-level (GMSL)) using altimetry satellite data show that the rate of sea-level rise reaches 3.4 mm / year since 1993 [1, 2]. From the results of data processing with altimetry satellites show that the spatial pattern of sea-level rise is not the same in every place or not homogeneous. Some regions, sea-level has increased faster than the speed of the global sea-level rises, such as the western and northern regions of the Pacific Ocean, the southern ocean of India and Greenland. Inverted conditions occur in the ocean area in the eastern Pacific Ocean in the same period [3].

The sea-level rise around the Indonesia seas has exceeded the average global sea-level rise, up to 5mm/ year due to some phenomena which influenced the areas such as ENSO [4, 5]. In addition to being an important indicator for countries that have coastal areas, sea-level rise is also a severe problem that has an impact on the occurrence of natural problems and has an impact on the economic life of the population around the coast.

Many the big cities in Indonesia are in the coastal area such as Jakarta, Surabaya Semarang, Cirebon which are facing of the Java Sea that the sea has an extreme prediction for sea-level rise [6]. Semarang City is the heart of the Central Java Province, where all government activities, trade, and population density are concentrated in the city of Semarang. However, the density of all socio-economic activities in the city of Semarang is precisely concentrated in the coastal area of Semarang. Of course, this further adds to the vulnerability of the Semarang City coast when measured from its sea-level rise. The coastal
vulnerability condition of Semarang City is exacerbated by the coastal geological structure of Semarang City, which is formed by alluvial type soil, thus triggering land subsidence.

This research was conducted to model the vulnerability of the coastal city of Semarang by considering the parameters of sea-level rise and land subsidence. From this modeling, we will get an overview of the areas affected by sea-level rise for the next 50 years.

2. Data and methods

2.1. Data

The data used in this study consisted of:

- Digital Elevation Model (DEM) Data
  DEM is digital data that describes the geometry of the shape of the earth's surface or its part consisting of a set of coordinate sampling points from the surface with an algorithm that defines the surface using a set of coordinates [7]. In this study, DEM data is used as a reference in determining the height of an area which in DEM data are represented point \( H \). The existing DEM data are then combined according to the research area and then cut according to the area of research administration.

- Land Subsidence Data
  The previous results of land subsidence measurements have been used for the parameter in this study, and then the data will be overlaid with DEM data to obtain the height value of the research area. The land subsidence data are critical, due to the geological structure of the coastal area of Semarang is alluvial land which has a high degree of vulnerability to experience land subsidence, particularly when compared with the condition of the buildings around the coastal area which are quite dense.

- Altimetry Satellite Data
  The altimetry data is extracted from the Radar Altimeter Database System (RADS) server from 1993 to 2016 in *.ncdf format. Converting the *.ncdf format to an ASCII file is DEM is digital data that describes the geometry of the shape of the earth's surface or its part consisting of a set of coordinate sampling points from the surface with an algorithm that defines the surface using a set of coordinates [7]. DEM is used as a reference in height determining of the DEM, which is represented by point \( H \). The existing DEM data are then combined according to the research area and then cut according to the area of research administration. From the processing of altimetry satellite data, the sea-level rise values are obtained, which will be overlayed with the results of the height of the study area using the ArcGIS application.

2.1.1. Land subsidence.

The land subsidence data were conducted by [8], where data from the study found that from 2008-2011 there was an average decline of 6-7cm / year and could reach 14-19cm / year in specific locations that have a high level of vulnerability to land subsidence. The precise statistics are periodically determined using repeated GPS surveys at certain time intervals. By studying the characteristics and rate of change in the components of the survey from survey to survey, the land subsidence characteristics can be derived. For monitoring land subsidence, the ideal position is to be achieved at the mm level. In order to achieve this level of accuracy, the GPS static survey method based on dual-frequency carrier phase data processing should be implemented, with stringent measurement and data processing strategies.

2.1.2. Sea-level rise.

The altimetry satellite data were extracted from the Radar Altimeter Database System (RADS) server from 1993 to 2016 in the *.ncdf format. By applying the range and geophysical corrections, the SLA corrected was obtain. To get the time series SLA, inter-calibrated [9] among TOPEX/Poseidon, Jason-
1 and Jason-2 were performed. Finally, the linear trend was estimated using Seasonal Trend based on LOESS (STL) decomposition [10] and Original Least Square.

2.1.3. Overlaying data

- DEM and land subsidence
  The combining between DEM and Imagery around the selected area was performed. After the DEM data goes through the process of combining DEM images and cutting DEM imagery following the research area, then the DEM data are overlayed with data of subsidence. In this study, it was determined that the decrease in land face occurring in Semarang ranged from 14cm year\(^{-1}\) because the coastal area of Semarang itself has a geological structure of alluvial so that it has a high level of vulnerability to subsidence.

  Land subsidence data is created in ArcGis by using the *Fishnet* feature to create raster data that has a land subsidence value for each pixel. Then each pixel has a uniform value. The raster calculation process is performed to reduce the pixel value of the DEM data with ground-level data to obtain new pixel data that has been calculated against the DEM value and the value of the land subsidence.

  In this study, vulnerability modeling was carried out for the next 50 years, so that data on land subsidence was calculated for the next 50 years and obtained land surface forecasting values for the next 50 years.

- Overlaying sea-level rise and Digital Terrain Model (DTM)
  After forecasting ground level for the next 50 years, the data is overlayed with sea-level rise data. All processes are carried out using an ArcGIS device. So that it can be seen which areas are vulnerable to the danger of rising sea-levels.

3. Results and discussion

3.1. Sea-level rise

The sea-level rise was obtained from the processing of altimetry satellite data from the beginning of 1993 to the end of 2016 in the coastal region of Semarang is 5.1 mm per year. The rate of sea-level rise is higher than the global average increase. This is influenced by natural phenomena that exist around Indonesia. The dominant phenomenon, in this case, is the influence of El Nino and La Nina. In figure 1 shows a significant El Nino event occurred in 1997-1998, in the graph the condition of the seawater was in a down condition whereas La Nina conditions were seen in 2011, with the sea-level rising quite high.
3.2. Overlaying DEM and Land Subsidence in Semarang

The ground level forecasting results for the next 50 years are shown in Figure 2. The elevation data in the DEM data are reduced by land subsidence that occurs in the next 50 years, which is around 7m if each year ranges from 14cm per year.

3.3. The results of overlaying ground level forecasting data against sea-level rise that occur in the next 50 years.
The area affected by sea-level rise and land subsidence for the next 50 years is about 807km² that shown in Figure 3 below. Once calculated, the area affected by sea-level rise is ranged

The affected area has a relatively high population density because the density of the population of Semarang City itself is centered on the coast. The northern part of the city of Semarang itself consists of very young alluvium with high compressibility so that it is very vulnerable to land subsidence.

![Map of the area affected by sea-level rise in Semarang](image)

**Figure 3.** Map of the area that affected by sea-level rise in Semarang, affected areas are shown in magenta color on the northern part of Semarang.

4. **Conclusions**

In this study modeling of coastal vulnerability as a result of sea-level rise, in this case, the coastal area of Semarang City was performed. Based on coastline data in 2017, using the rate of sea-level rise 5.1 mm year⁻¹ on the coast of Semarang City, the affected area will be 807km² in 2067.

For the future work, a suggestion for the impact of sea-level rise in the coastal area of Semarang City, the Semarang city government needs to take action and anticipate in the form of spatial planning that takes into account the impact of sea-level rise.

5. **References**

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