Analysis of prediction of sea level rise impact based on tidal gauge and altimetry satellite on land cover area of Saparua Island, Maluku, Indonesia

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Abstract. The sea level rise phenomenon can threaten the environmental, social, and economical aspect of the coastal area. Human activities and other living beings in small islands are very dependent on the resources that are available in the islands. Indonesia as the largest archipelagic state in the world that has 17,508 islands with 99.8% of them are small islands will be directly affected by the phenomenon, which is the submergence of the islands. This research aims to determine the sea level rise trend in Saparua Island using tidal data that are obtained from tide gauge and altimetry satellite. A 12-years tide gauge data and 17-years Sea Level Anomaly (SLA) value of altimetry satellite are used in the research. The monthly average in a 12-years range of tidal station data is calculated to obtain sea level rise trend, meanwhile SLA value from the altimetry satellite observation in the form of satellite footprint is interpolated to get the SLA value across the water area as the sea level rise parameter of altimetry satellite. Then, sea level rise trend will be used to predict the impact of the sea level rise based on topographical condition of Saparua Island. Using those methods, the sea level rise value will be obtained from tide gauge and altimetry satellite in a millimeter order.

1. Introduction

Indonesia is an archipelago that has 17,508 islands consisting of main and small islands [1]. According to the United Nations Statistics in 2007, Indonesia has about 2 times more water than land, with a total water area of 6,159,032 km² and a land area of 1,904,569 km². The numbers of island and the proportion of waters are 3 times more than the land portray that there are so many small islands in Indonesia. This statement is supported by Kodoatie (2012) [2] that of 17,508 islands in Indonesia, 99.8% (17,477) of them are small islands.

According to Government Regulation No 27 of 2007 concerning Management of Coastal Areas and Small Islands, small islands are defined as islands with area (and its ecosystem) less than or equal to 2,000 km² [3]. Phenomenon of sea level rise has been the main threat of coastal areas and small islands since 1980 [4]. From the observation of sea level from tide gauge and high-resolution remote sensing indicates that there has been an increase in sea level [5][6][7]. With the global average sea level increasing over the last 25 years hovering in the range of 3 mm per year, sea level rise is considered as a serious global threat [8]. The rate of sea level rise when compared to the previous quarter period is very significant, with the previous value in the range of 1.8 mm per year [9].

The main cause of sea level rise phenomenon is climate change, with melting glaciers as the main factor, followed by ocean warming [7]. With increasing sea level, some of the parts of islands with low elevation will sink. This phenomenon can cause disasters in coastal areas and small islands in terms of...
ecosystem, infrastructure, economy, and social. If this continue to happen, it is possible that in the future, sea level rise rate will increase in extreme values and have a more massive adverse effect than now.

2. Materials and Method

2.1. Study sites
The research was conducted on Saparua Island, Maluku (3°30' - 3°40'S, 128°32' - 128°40'E) which is located on the east side of Ambon Island as shown in figure 1. Saparua Island covers an area of 155.3 km² and had a population of 32,312 according to 2010 census. Saparua has an undulating land-scape rising up to 521 meter above sea level with mountain ranges in the western and eastern part.

![Figure 1. Study sites of Saparua Island](image)

2.2. Data
The data that is used in this research are tidal observation data obtained from tide gauge, sea level anomaly (SLA) data obtained from altimetry satellite observation, and Digital Elevation Model (DEMNAS) data. Table 1 described the data and source of the data that is used in this research.

Table 1. List of data with the source that is used in this research

| No. | Data                                                                 | Source                                |
|-----|----------------------------------------------------------------------|---------------------------------------|
| 1.  | Jason-1, Jason-2, Jason-3 Altimetry Satellite Observation from February 2002 to September 2019 Sea Level Observation in Ambon Tide Station (3.683°S; 128.183°E) from August 1992 to July 2004 and October 2008 to December 2018 | Radar Altimetry Database System (RADS) University of Hawaii Sea Level Center (UHSLC) |
| 2.  | Digital Elevation Model (DEM)                                         | DEMNAS                                |
2.3. Method

This research calculates the sea level rise trend from tidal observation of tide gauge and sea level anomaly observation of altimetry satellite. The result of sea level rise trend then will be used to estimate the vulnerability of Saparua Island based on DEM data.

Sea level observation data from the UHSLC site uses Ambon tide gauge data with coordinates 3.683S and 128.183E for 25 years 4 months and altimetry satellite data for 17 years, this tide observation data is used to find sea level rise trends or sea level rise phenomena. The trend of sea level rise from tidal gauge is carried out by plotting the sea level then looking for the linear equation of the sea level and looking for the annual increase in sea level from the line equation.

The altimetry satellite data is retrieved from Radar Altimetry Database System (RADS). RADS is a database system that provides ASCII formatted altimetry satellite data from various satellite altimetry missions as an archiving and processing system initiative by TU-Delft, NOAA and Altimetrics LLC. In RADS data processing, updated environmental and geophysical corrections are applied. Sea level data has been corrected for orbital altitude, altimeter range correction for instruments, sea state bias, ionospheric delay, dry and wet troposphere correction, tidal loading, polar tides, electromagnetic tides, and barometric inverse correction [10]. Table 2 is a summary of the corrections and models applied by RADS for this research.

Table 2. Summary of the corrections and models applied by RADS for this research [10].

| Correction/Model       | Description                                                |
|------------------------|-------------------------------------------------------------|
| Orbit / Gravity Field  | EIGEN GL04C                                                 |
| Dry Troposphere        | Atmospheric pressure grids; ECMWF (Model)                  |
| Wet Troposphere        | All Satellites                                              |
| Ionosphere             | NIC08                                                       |
| Inverse Barometer      | IB (Model, Local Pressure)                                  |
| Dynamic Atmosphere     | All satellites: MOG2D                                       |
| Solid Earth Tide       | Applied (Elastic response to tidal potential)               |
| Ocean Tide             | GOT4.8                                                      |
| Pole Tide              | Polar Wobble                                                |
| Sea State Bias         | CLS non parametric; ERS: BM3/BM4 parametric                |
| Reference              | DTU10                                                       |
| Engineering Flag       | Applied                                                      |

The data used is a time series of sea level anomaly (SLA) from several sample points around Saparua Island. SLA values that are within the boundaries of the study area as shown in figure 2, i.e. 124° -130° East Longitude and -4.5° - -1° North Latitude.
Figure 2. Distribution of altimetry satellite footprint around the study area

SLA trend is calculated to perceive the phenomenon of sea level rise from altimetry satellite. Altimetry satellites measure the distance from the satellite to the sea level by sending wave signals to the sea surface which are then reflected back to the signal receiver. The distance measurement is then converted to sea level relative to the reference datum [11]. The SLA value is obtained from the difference between mean sea level and instantaneous sea level [12]. The footprints are interpolated to obtain the spatial distribution pattern of sea level rise.

Tension Spline interpolation method is used to the SLA time series data. Spline estimates the value of each point using a mathematical function that minimizes curvature of the overall surface and produces a smooth surface through which the input points are passed. This method is best used for surfaces that vary gently, such as altitude, water level, or pollution concentration [13].

The results of the interpolation process from the altimetry data still contain fluctuating data caused by the spatial resolution altimetry satellite. The data distribution on the footprint is dense, but on the two opposite paths are quite far apart. One of the ways to remove noise in fluctuating data is by smoothing it [14]. The smoothing method used in this study is Gaussian Smoothing. The advantage of this method is that it can eliminate the high spatial frequency component more effectively [15].

The results of sea level rise trend from tidal observations at tide gauge and altimetry satellites are then used to estimate the vulnerability of Saparua Island based on its elevation using DEM data. Figure 3 is a visualization of the DEM on Saparua Island. Inundation models due to sea level rise are made using the assumption that the value of sea level rise is constant and the influence of other factors are ignored. The impact calculation is divided into three scenarios, namely the 20th year, the 50th year, and the 100th year to find out the stages of adaptation efforts with the closest term of up to 100 years, in accordance with IPCC projections [16].
3. Result and Discussion

3.1. Sea level trend from tide gauge

Data from UHSLC from August 1992 to December 2018 are plotted on one graph as can be seen in Figure 4.

Figure 3. DEM Map of Saparua Island

Figure 4. Sea level in Ambon tide station August 1992 to July 2004 and October 2008 to December 2018
Based on this data, it can be seen that the set sea level data data experienced shifting. This can be seen from the different MSL from the data set dated from August 1992 to July 2004 and October 2008 to December 2018. Therefore, it is necessary to correct the shifting in the tidal data. The results of the shifting correction can be seen in Figure 5.

![Figure 5. Corrected sea level and sea level trend in Ambon tide station](image)

Figure 5 shows the results of the tide chart plot at the Ambon tidal station. Based on the graph, the value of the linear equation is sought from the graph. The linear equation value shows the value of the sea level trend with the coefficient of the x value which is the slope of the sea level rise. Based on the value equation, the average sea level increase is 2.89 cm for 25.3 years or an increase of 1 mm per year. Data from Ambon station is carried out to estimate sea level rise in the Maluku region including around the Saparua Island area.

Data from tide gauge has advantages and disadvantages for measuring sea level trends. The advantage of the tide gauge is that it is able to record the tide phenomenon well and draw the real tide characteristics in the field, besides that the tide gauge also has an adjustable data recording time interval so that the quality of the tide data obtained is good. However, the tide gauge data has the disadvantage that it is necessary to ensure that the instrument of the tide gauge is functioning properly and is able to record data in full. This is illustrated by the sea level data at the Ambon tidal station where there are many gaps because the tide gauge does not record tide data properly. In addition, there is also a shifting of tide data from August 1992 to July 2004 and October 2008 to December 2018 which causes the tide data to be corrected and makes the processed tide data not the original tide data.

3.2. Sea level trend from altimetry satellite

Figure 6 shows the result of the interpolation of SLA values from the altimetry satellite footprints. These results are then carried out by a smoothing process, the results are shown in figure 7.
Figure 6. Interpolation result of SLA values from the altimetry satellite footprints.

Figure 7. Smoothing result of SLA trend

From the prediction of sea level rise with SLA trend, sea level rise trend in Saparua Island is within range of 3.92 to 4.04 mm per year. The smallest SLA value, namely 3.92 mm per year, is located in the western part of the island, while the largest value, namely 4.04 mm per year, is located in the eastern part of the island. The sea level trend value increases from the West to the East of the island. In calculating the impact of sea level rise, the largest value is used as a worst-case scenario.

Sea level processing using altimetry satellites has each advantages and disadvantages. The advantages of using altimetry satellite data for the study of ocean water dynamics include being able to observe almost all of the world's marine areas quickly without being hindered by weather factors. Satellites method is also cheap and safe costs compared to conventional observations. However, the selection of sample points used in the calculation needs to pay attention to the distance between the points and the depth of the sea floor. The existence of land around the altimetry observation location
reduces the quality of geophysical corrections, orbit, and satellite instruments so that the quality of the data can be reduced.

3.3. Sea level rise impact
In conducting the analysis, land subsidence is not considered in Saparua Island. Inundation models due to sea level rise are made using the assumption that during this period the value of sea level rise is constant and the influence of other factors is ignored. The impact of sea level rise in this study is focused on the reduction in land area caused by inundation.

The scenarios that are made are divided into three, namely the scenario of 20 years, 50 years, and 100 years. From the results of sea level trend based on altimetry satellite and tide gauge, each scenario calculation is performed. Figures 8, 9, 10 show scenarios of sea level rise based on tide observations from tide gauge for scenarios of 20 years, 50 years, and 100 years respectively.

Figure 8. Scenario 20 years based on tide gauge observation

Figure 9. Scenario 50 years based on tide gauge observation

Figure 10. Scenario 100 years based on tide gauge observation

Figures 11, 12, 13 show scenarios of sea level rise based on SLA trend of altimetry satellite observation for scenarios of 20 years, 50 years, and 100 years respectively.
The impact of the sea level rise being studied in this research is inundation. The area of flooding area in each scenario is shown in the table 3.

**Table 3.** Estimation of sea level rise impact based on altimetry satellite and tide gauge observation.

| Scenario | Sea Level Rise (mm) | Flooding Area (ha) | (%) | Remaining Area (ha) | (%) |
|----------|---------------------|--------------------|-----|---------------------|-----|
| 20       | 80.8                | 74.09              | 0.47| 15458.67            | 99.53|
| 50       | 202.0               | 80.81              | 0.52| 15451.95            | 99.48|
| 100      | 404.0               | 93.85              | 0.61| 15438.91            | 99.39|

| Scenario | Sea Level Rise (mm) | Flooding Area (ha) | (%) | Remaining Area (ha) | (%) |
|----------|---------------------|--------------------|-----|---------------------|-----|
| 20       | 22.8                | 71.24              | 0.46| 15461.52            | 99.54|
| 50       | 57.0                | 72.97              | 0.47| 15459.79            | 99.53|
| 100      | 114.0               | 75.90              | 0.49| 15456.86            | 99.51|
Based on the calculation of altimetry satellite, the sea level trend is 4.04 mm per year. In 20-years scenario, sea level rise reaches 80.8 mm and the flooding area in Saparua Island reaches 74.09-hectare land which 0.47% of the land. In 50-years scenario, sea level rise reaches 202 mm and the flooding area in Saparua Island reaches 80.81-hectare land which 0.52% of the land. In 100-years scenario, sea level rise reaches 404 mm and the flooding area in Saparua Island reaches 93.85-hectare land which 0.61% of the land.

While based on the calculation of tidal observation data from tide gauge, the sea level trend is 1.14 mm per year. In 20-years scenario, sea level rise reaches 22.8 mm and the flooding area in Saparua Island reaches 71.24-hectare land which 0.46% of the land. In 50-years scenario, sea level rise reaches 57 mm and the flooding area in Saparua Island reaches 72.97-hectare land which 0.52% of the land. In 100-years scenario, sea level rise reaches 114 mm and the flooding area in Saparua Island reaches 75.90-hectare land which 0.49% of the land.

4. Conclusion
Sea level trend obtained from sea level data at Ambon tidal station shows that during 25.3 years there has been an increase in sea level of 2.89 cm or 1 mm per year. On the other hand, based on satellite altimetry observations, the sea level rise is 3.92 to 4.04 mm per year. In the long run, this will have an impact on the reduction of the Saparua Island area. Based on the calculation, Saparua Island will experience a reduction in land area of 75.9-hectare land for 100 years based on the sea level trend from the tide gauge and land area reduction of 93.85-hectare land for 100 years based on the sea level trend from the altimetry satellite.

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