Geospatial modeling analysis of potential inundation impact of sea level rise: A case study of south coast Yogyakarta

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Abstract. Increasing human activity leads to increased concentrations of greenhouse gases in the atmosphere, especially carbon dioxide (CO2) and methane (CH4) that impact climate change and global warming. This condition encourages the occurrence of weather anomaly phenomena in the atmosphere such as rainfall fluctuations, dryness, an increase in air temperature and sea-level rise. Sea-level rise was a potency of seawater inundation that gave an impact on land degradation. The study aimed to determine sea-level rise used three variables of disaster with two cumulative scenarios. The toward step used the simulation using a raster calculator in ArcGIS 10.2 to analyze the impact of sea-level rise to inundation disaster. The results showed that the sea-level rise on the South Coast of Yogyakarta based on (1) Scenario 1A (existing) was 1.4457 m (the prediction year 2030) and 2.0827 m (the prediction year 2050). According to the scenario (2) 1B (extreme) is 1.6297 m (the prediction year 2030) and 2.2667 m (the prediction year 2050). The increase in the sea-level rise on the south coast of Yogyakarta provides a disaster effect of inundation in the area directly dealing the beach and near the river mouth for example in Bantul Regency and Kulon Progo Regency.

1. Introduction

The growing composition of greenhouse gases in the atmosphere caused by carbon emissions due to human activity has made a substantial impact on atmospheric warming. Rising temperatures in the atmosphere lead to the melting of polar regions and impacting the rising sea level in different parts of the world [1]. Rising sea level becomes the world's attention in the future because to be the most significant effect of climate change events. According to the estimated period of 100 years starting from 2000, the sea level will increase as high as 15-90 cm with the certainty of increased as high as 50 cm [2]. Areas that are geographically located on lowland, small islands, will be highly vulnerable to land degradation due to coastal inundation and erosion [3]. The south coastal area of Yogyakarta is geographically bordered by the waters of the Indian Ocean. This coastal region stretches in 3 districts, ranging from the region of Kulon progo Regency, Bantul Regency, and Gunungkidul regency. Impacts
of climate change degradation and hazards of coastal areas due to seawater rise [4]. Coastal areas are very vulnerable to environmental pressures, both from land and sea. An increase in carbon dioxide gas concentrations and surface temperature rise due to climate change cause coastal ecosystems to be threatened [5]. One of the coastal areas vulnerable to rising sea level is the south coast of Yogyakarta. Sea level rise is a rising phenomenon as a result of climate change which is an important issue today. The relative sea level changes (RSLC) associated with such subsidence will be in addition to future global warming effects [6].

Three components affect the incidence of sea advance in an area of the global sea-water rise, the regional meteo-oceanography factor and the movement of ground vertically [3]. The cause of the rising volume of the sea is increasing sea temperature and the melting of ice and glaciers is shown from the temperature from 1910 to 2000 with a trend reaching 0.8 °C/century, and a total increase of 0.4 °C ± 1.7 °C/century, if calculated from the year 1870 [7]. As for the component of the Meteo-oceanography factor is regionally a variation on the effect of rising temperatures, long-term changes in wind and atmospheric pressure, as well as changes in ocean circulation such as gulf currents. Increasing the temperature increases the density and causes a high increase in water, conversely if the salinity of water increases then the sea level rise becomes down [8]. Vertical land movement in the form of land loss becomes a serious problem even harms the community because when the land is falling and the surface is lower than sea level, then seawater will overflow to the mainland causing flooding. The decrease in the soil can be caused by human activities that excessive groundwater pumping can cause land subsidence degradation if not controlled [9].

Coastal areas are quite important areas in terms of social, economic and environmental, no exception to the province of Yogyakarta which is famous for its coastal tourism sector. The phenomenon of sea level rise can affect the stability of buildings, changes in landscapes, and can disrupt the stability of coastal ecosystems such as coral reefs, seagrass, and even socio-economic mangroves of coastal communities [10,11]. However, the level of damage inflicted on different regions may differ depending on the area or capacity of the coastal ecosystem. Therefore, it is necessary to research the potential of inundation due to sea level rise in the south coast of Yogyakarta and the impact of sea advance to the local scale of the south coastal region of Yogyakarta as a recommendation to the government in disaster mitigation efforts due to climate change.

2. Methods

2.1. Material and instrumentation
The materials used in this study consist of GPS tools, cameras, computer sets, GIS software, number data processing applications, tidal data processing applications while materials consist of elevation data (altitude), Sea Level Anomaly (SLA), high waves, tides, land use maps, coastlines and administrative boundaries. The instruments used are a computer, ArcGIS Software version 10.3, Software Ocean Data View (ODV) version 4.7.10, Software Global Mapper version 18, Microsoft Excel Software 2016, WEB-based tidal data processing application, GPS Garmin V, and camera. Digital Elevation Model (DEM) used in this study was the DEM SRTM with a resolution of 30m x 30m from the GeoTiff (.tif) https://earthexplorer.usgs.gov site. Other supporting data such as land use maps (paddy fields, settlements, roads/transportation, drainage), administrative boundaries and coastlines are obtained from BIG Indonesia's Geospatial portal website.

2.2. Data acquisition
The determination of the level of sea level increase is using three data of Sea Levels Anomaly (SLA), tidal and high tide. The SLA data (altimetry Merge Allsat satellite) with the 0.25 degrees data grid obtained from motu.aviso.altimetry.fr in the period from the year 2000-2015. Tidal data using BIG tidal data at Sadeng Station, Yogyakarta in December 2016 period. High Wave Data was obtained from the Cilacap Meteorological Station (BMKG) from 2012-2016. High wave data is a result of WindWave models with a period every 6 hours using WindWave 05 Application [12,13].
### Table 1. Research data variables.

| Data Variable          | Data Acquisition                                      | Analysis               |
|------------------------|-------------------------------------------------------|------------------------|
| Sea Level Anomaly (SLA)| Satellite Altimetry Merge AllSat (AVISO): motu.aviso.altimetry.fr | Linear regression      |
| Tidal                  | BIG Tidal observation Station in Sadeng, Yogyakarta   | Least Square Method    |
| High wave              | Meteorology BMKG station in Cilacap                   | Calculate and Max Averages |
| Digital Elevation Model (DEM) | DEM SRTM, https://earthexplorer.usgs.gov | Global Mapper and ArcGIS software |
|                        | BIG (tanahair.indonesia.go.id/home/)                  | ArcGIS                 |

#### 2.3. Data processing techniques

DEM data processing of the Global Mapper software using ArcGis 10.3 software is done interpolation with Inverse Distance Weighted (IDW) method with resolution spatial 10mx10m. While Sea Level Anomaly (SLA) data is processed with Ocean Data View (ODV) software while high wave data can be processed directly using Microsoft Excel. The study area is limited to coordinates -7.8 S to-8.4 S and 109.8 E to 110.10 E. Output ODV data formatted as text (.txt) is opened and performed data screening using Microsoft Excel software. The trend determination of SLA yearly, Hs, and Hs Max using Microsoft Excel software. The phenomenon of sea-front rise to SLA data can be determined by the trend analysis of sea-level rise using a linear regression approach. Tidal data from the observation station in Sadeng Yogyakarta analyzed with a least square method to be determined the value of tidal constants, tidal characteristics and tidal predictions for one year. The tidal characteristics are determined using the value of tidal constants as input values in the calculation of F or Formzahl values [14], with the following formula:

\[
F = \frac{(O_1 + K_1)}{(M_2 + S_2)}
\]

Based on the value of F it can be classified the tidal characteristic as the value of 0 < F < 0.25 double daily (semi-diurnal), the value of 0.25 < F < 1.5 double daily leaning mixture, the value of 1.5 < F < 3.0 a single daily leaning mixture, and a single daily > 3.0 (diurnal) [15]. The determination of the value of MHWL (Mean Higher Water Level) and HHWL (Higher High Water Level) uses the tidal components of the Least Square method analysis results. Sea level rise simulation using a cumulative scenario 1A (existing, SLA + MHWL + Hs combination) and scenario 1B (extreme, SLA + HHWL + Hs Max combination). Simulation using a raster calculator tool with ArcGis 10.3 software, reclassify and conversion into polygon form. The interpretation of affected areas classified into 2 categories is safe and impacted. The affected area is counted in hectares (ha).

#### 3. Result and discussion

The rate of sea level rise in an area can be known through the preparation of sea level rise. The formulation of sea level hikes can be using maritime data, namely Sea levels Anomaly (SLA), tides, and wave height. SLAS experience the dynamics annually. The dynamics of the SLA is influenced by the phenomenon of ENSO (El Nino and La Niña) and IOD (IOD + and IOD-). In figure 1, SLA in southern waters of Yogyakarta period from 2000 to 2015 experienced dynamic and tends to occur trend of SLA hike in southern waters of Yogyakarta experiencing dynamics with the lowest average value in the year 2006 by-0.03962 m. Value The highest average occurred in 2010 for 0.143123836 M. Results of a linear regression analysis of the SLA data on southern waters of Yogyakarta for 16 years (the year 2000-2015) showed an upward trend indicating an indication of the rise of Year of years. Results of linear regression analysis are known that in the years 2030 and 2050 coming from 2000, South waters of Yogyakarta
potentially occur in a successive sea-water rise of 0.2379 m and 0.4199 m. SLA data can be utilized to
know the phenomenon of sea level rise. The average variation of wave height (Hs) in the southern waters
of Yogyakarta in 2012-2016 is 0.512922 m – 0.739839 m. The average variation of the maximum wave
height (Hs Max) amounted to 0.826 m-1.216 m. The highest surge ever (Hs Abs) amounted to 0.93 M-
1.65 m. The average peak wave height (Hs) occurred in July, but the peak average height of the
maximum wave (Hs Max) and the highest wave ever occurred (Hs Abs) in January. for more detailed
seen in Figure 1.

![Figure 1. (a) Sea Level Anomaly and (b) High wave variation monthly southern waters of Yogyakarta.](image)

**Figure 1.** (a) Sea Level Anomaly and (b) High wave variation monthly southern waters of Yogyakarta.

| Table 2. Values of harmonic constants of the south waters of Yogyakarta. |
|-----------------------------|-----------------|-----------------|
| **Element of Hazard**        | **Hazard Code** | **Value (m)**   |
| Tide (MHWL)                   | 1a              | 0.835 m         |
| Tide (HHWL)                   | 1b              | 1.234 m         |
| Significant Wave (Hs)         | 2a              | 0.370 m         |
| Maximum Wave (Hs Max)         | 2b              | 0.608 m         |
| Sea Level Rise                | 3 (Year 2030)   | 0.2379 m        |
|                             | 3 (Year 2050)   | 0.4199 m        |

| Table 3. Cumulative scenarios of sea level rise and potential for affected land area. |
|------------------------------------------|-----------------|-----------------|
| **Scenario**                            | **Element**     | **Hazard Code** | **2030** | **2050** |
| Scenario-1A                              | Existing        | 1a+2a + (3)     | 1,4429 m | 1,6249 m |
| Scenario-1B                              | Extreme         | 1b+2b + (3)     | 2,0799 m | 2,2619 m |
| **2030**                                 | **2050**        |                 |          |
| Land affected                            | Scenario 1A     | Scenario 1B     | Scenario 1B | Scenario 1B |
| (Existing)                               | (Existing)      | (Existing)      | (Existing) | (Extreme) |
| Land area                                | 387, 403 ha     | 430, 384 ha     | 397, 797 ha | 444, 579 ha |
| Non-river land area                      | 229, 795 ha     | 264, 572 ha     | 238, 321 ha | 275, 279 ha |

The determination of the tidal area of Yogyakarta using BIG tidal observation data at Sadeng station in
December 2016. The value of tidal constants in table 3 that have the largest amplitude is M2 of 0.55163
and the smallest M4 of 0.00246. The calculation results of Formzahl value is 0.34. Formzahl value (F)
is located at 0.25 < F < 1.5 indicating the characteristics of the tidal waters south of Yogyakarta namely
the tidal mixture of double-leaning daily skewed (mixed tide, prevailing semidiurnal). Highest High-
Water Level (HHWL) value of 2.931 m, Mean High Water Level (MHWL) value of 2.532 m, and Mean
Sea Level (MSL) value of 1.697 m. The potential impact of damage due to future sea level rise is
conducted through the simulation of seawater rise. Simulations are based on 1A (existing) and 1B (extreme) scenarios that use 3 elements. The cumulative scenario of seawater advance increase uses 2 scenarios of scenario 1A and scenario 1B. Scenario 1A (Existing) of the south coast of Yogyakarta has the potential to experience a sea level rise of 1.4429 m in 2030 and 1.6249 m in 2050. Scenario 1B (Extreme), the south coast of Yogyakarta potentially experienced a sea level rise of 2.0799 m in the year 2030 and 2.2619 m in 2050. The year 2030 the south coast of Yogyakarta potentially loses a land area of 229,795 ha-264,572 ha. The year 2050 the south coast of Yogyakarta potentially loses a land area of 238,321 ha - 275,739 ha.

Figure 2. Potential inundation impact of sea level rise in south coast Yogyakarta year 2030.

Figure 3. Potential inundation impact of sea level rise in south coast Yogyakarta year 2050.

Based on figure 2 and 3, the results of geospatial modeling showed a potential inundation due to the increase of sea level including the coastal Bantul Regency and the coastal Kulon Progo Regency. Bantul Regency includes Srandakan district, Sanden district and Kretak district, while Kulon Progo Regency includes, Galur district, Panjatan district and Temon district. The most vulnerable areas are affected by the inundation of Galur district, Srandakan district, Sanden district and Kretak district. Galur and Srandakan districts are the most vulnerable areas of water. Sea level rise can result in the occurrence of the femdom resulting in the speed of flow of the river in the estuary slower and the sedimentation rate in the estuary will increase. The estuary will cause a significant effect that contributes to the frequency of flooding because of the river capacity that is not offset by the discharge of the river. This is what
causes an area surrounding the river flow, in addition to having a rampant topography, the slope of small land. The management of the coastal areas of Yogyakarta should not only with physical development such as revetments, groins, and seawalls. Community-based management, erosion management, tourism management around the coast, and coastal area arrangement are highly recommended to realize sustainable sea level rise improvement engineering involve the community as an important actor.

4. Conclusion
The water advance in the south coast of Yogyakarta is based on the scenario 1A (Existing) of 1.4457 m the year 2030 and 2.0827 m in 2050, while based on scenario 1B (Extreme) of 1.6297 m the year 2030 and 2.2667 cm in 2050. The area is potentially inundation in the area facing directly with the beach and near the flow of river estuary that is on the coast of Bantul Regency and Kulon Progo Regency.

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