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Sea Level Rise Impact on Eastern Coast of North Sumatra, Indonesia

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Abstract-Indonesia is an archipelagic country consisting of nearly 17,000 islands with a total coastline length exceeding of 90,000 km had a significant negative impact on coastal activities and ecosystem such as in the eastern coast of North Sumatra (ECNS). To study the impact of sea level rise impact in the ECNS were used the satellite altimetry data during 23 years (1993-2016), tide gauge and Digital Elevation Model (DEM) data. Regional mean sea level trend in ECNS during the period 1993-2016 estimated from satellite altimetry was 5.0 mm/year. The potential lost of coastal area in the ECNS due to 1 m and 2 m inundation could range from 11.9 km^2 to 63.8 km^2 respectively. Heavy flooding has been seen hit coastal areas including fishing port, settlement, railway, agricultural and tourist area.
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***Keywords*:** altimetry, coastal, inundation, north Sumatra, tide.

1. Introduction

Sea level rise is now becoming a strategic issue in global. According to the Intergovernmental Panel on Climate Change (IPCC) 2001 [1] it is very likely that warming will contribute significantly to future sea level rise. However, sea-level rise is not globally uniform [2]. Indonesia is an archipelagic country consisting of nearly 17,000 islands with a total coast line length exceeding of 81,000 km. Indonesian waters have large variations of tidal regime, and sea level rise (SLR). Increasing of SLR is one of the impacts of global warming and will cause inundation of many small islands and coast in Indonesia. The impact of sea level rise from global warming could be catastrophic for Indonesia such as in eastern coastal zone of North Sumatera.

Thousand of people in Eastern Coastal Zone, North Sumatera are living below normal high tides leading to vulnerable to flooding by extreme sea level. This level of rise would inundate some beaches and overflow many barrier islands that serve as natural protection against storm surge from tropical and non-tropical cyclones. It would also raise the risk of tidal flooding, and in areas that are expected to see an increase in rainfall, flash flooding and river flooding would compound the flood risk associated with coastal waters. As seawater reaches farther inland, it can cause destructive erosion, flooding of wetlands, lost habitat for fish, birds, and plants. Adaptation to sea level rise impacts requires understanding of where impacts are to be expected and what their magnitude may be.

Sea level in South East Asia Sea include Indonesia has increased by 3–10 mm per year [3] This may contribute to a loss of arable land through inundation and increased soil salinity, affecting crop growth and yield. Food crops grown in low-lying areas adjacent to the coast are specifically vulnerable to inundation. Many fish aquaculture and rice fields in Indonesia are located in coastal zones, it is estimated that by 2050 the area of paddy rice fields could be reduced by 182,556 ha in Java and Bali, 78,701 ha in Sulawesi, 25,372 ha in Kalimantan, 3,170 ha in Sumatra, and 2,123 ha in Lombok [4]. In South Kalimantan, tidal swamp-lands have been reclaimed for various agricultural activities and are now especially prone to risk due to sea-level rise [5]

Therefore, monitoring of sea level rise and analysis their impact on coastal area is very important in eastern coast of North Sumatera. Based on the results of this study can be done adaptation strategies to reduce the sea level rise impacts in Eastern Coast of North Sumatera. Improving estimates in future sea-level change is identified as an important research, which could help to inform adaptation and response options for human society. The objective of this study was to determine the trend of mean sea level anomaly in ECNS waters during the 23 years period of satellite altimetry observation.

2. Methods

2.1 Data Sources

The study was conducted in ECNS (03°39’00”S - 98º38’00”E to 03°53’00”S - 98º58’00” BT). This study used multi-source data, such as altimetry satellite, SRTM, tide gauge and water level data. Regional mean sea-level trends was analysed from satellite altimetry data during the period 1993-2016 (http://sealevel.colorado.edu/). Digital elevation model (DEM) data were used to predict the area that will be inundated by the sea level rise. We used the NASA Shuttle Radar Topography Mission (SRTM) 30 m (https://earthexplorer.usgs.gov/). Several steps in the processing of DEM data have done such as reading data, cropping data, extraction of data, the integration.

2.1. Data Analysis

Tide gauge hourly data during the period 6 September 2016 to 6 October 2016 were analysed to calculate mean sea level (MSL), Lowest Water Level (LWL), Mean Low Water Spring (MWLS), Mean High Water Neap (MHWN), Mean High Water Neap (MHWN), and Mean High Water Spring (MHWS). Tidal type was calculated using Formzahl Number as shown in Eqs. (1) below,

$$\mathrm{F} = (\mathrm{O1} + \mathrm{K1})/(\mathrm{M2} + \mathrm{S2}) \tag{1}$$

Where, M2 is Principal lunar, K1 is Luni-solar diurnal, S2 Principal solar, O1 is Principal lunar diurnal.

The coastal areas potentially affected by a 1 and 2 m sea-level rise scenario were calculated using Geographic Information System (GIS) software.

3. Results and Discussions

3.1. Sea Level Rise Trend

Regional mean sea level trend during the period 1993-2016 estimated from satellite altimetry was 5.0 mm/year in ECNS (Fig. 1) provides a higher trend than global mean sea level trend was 3.4 mm/year [6]. The eastern coast of North Sumatera region exhibits sea level trends that vary drammatically over the period 1993-2016. Sea level trend values in the southeastern part of the Southeast Asian sea region include Indonesian waters have been particularly high in the past 2 decades [3]. Regional sea levels can be affected by changes in atmospheric or oceanic circulation [7]. The stronger equatorial westerlies occur mainly during the Asian summer monsoon, causing sea-level rise near Sumatra and in the Bay of Bengal [7]. Sea level is a controlled by the: volume of ocean water, volume of the ocean basins, and distribution of the water, and the *land surface*, which is affected by crustal deformation and sediment compaction [8]

The higher sea level trends in this area will affects the lives of millions of people more difficult who inhabit coastal regions. In addition to inundating low-lying coastal areas, rising sea level increases the vulnerability of coastal regions to flooding caused by storm surges, and extreme astronomic tides. As sea level rises, storms of a given magnitude reach higher elevations and produce more extensive areas of inundation.

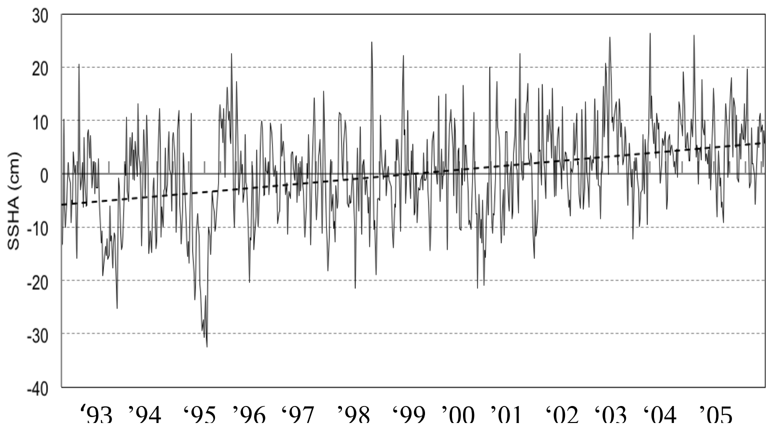

Fig. 1: Sea surface height anomali and trend in easternt coast of North Sumatra during the period 1993-2016

The tidal data (Fig. 3) shows that the MSL, LWL, MLWS, MLWN, MHWN and MHWS on the east coast of North Sumatra were 108.580 cm, 6.520, 35.631, 95.693, 121.467, and 181.529 cm respectively (Fig. 3). Meanwhile, base on the Formzahl Number (>3.0) the tides on the east coast of northern Sumatra was diurnal type.

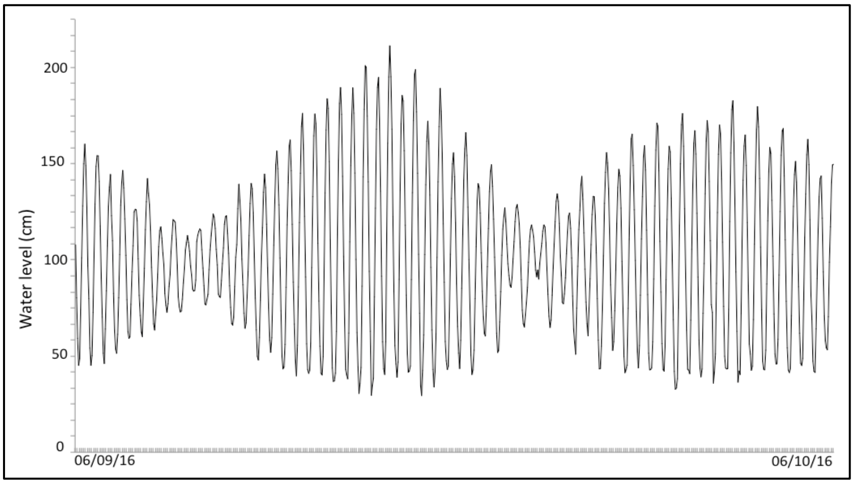

Fig. 2: Tidal level (hourly), 6 September - 6 October 2016 at Belawan city, ECNS.

Flooding has been seen in areas of eastern coast North Sumatra as a result of high tide during field survey on September 2016. In Belawan city saw heavy flooding hit coastal areas including fishing port, settlement, street and railway (Fig. 3). Tidal wave also hit such as agricultural areas and tourist place a long the coast. In these areas, the sea level rise will increased the effect of the seasonal high tides, causing the lowest lying areas to be immersed in water.

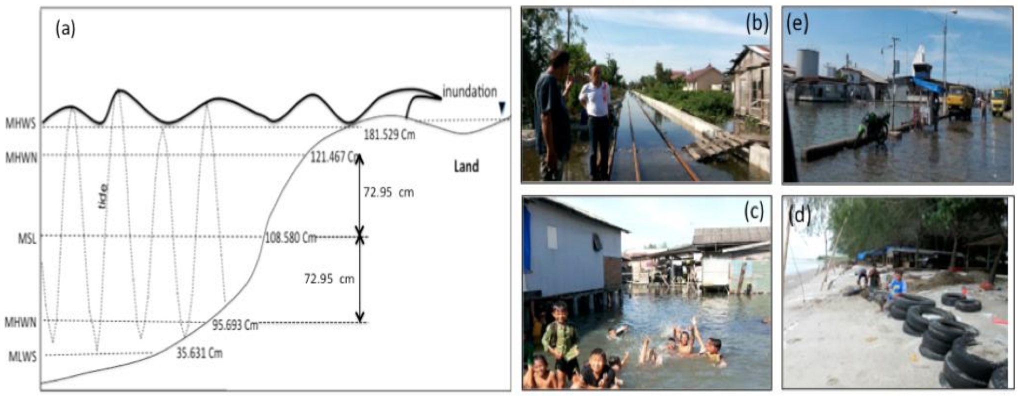

Fig. 3: (a) Illustration of inundation in the ECNS and flooding at (b) railway (c) settlement (d) tourist place, and (e) fishing port, 18-21 October 2017.

The coastal areas potentially affected by a 1 and 2 m sea-level rise scenario were calculated in a GIS. The potential lost of coastal area due to 1 m and 2 m inundation in the study area could range from 11.9 km^2 to 63.8 km^2 respectively (Fig. 4). Along of the ECNS a lot of people done economic activities such as agriculture, livestock, and tourism. Therefore, a projected global mean sea-level rise of 1 and 2 m potentially affects the food production in this area. During the high tide wave, all these activities disrupted due to inundation. Small buildings along the coast also hit by a tidal wave. These condition more difficult by the absence of mangrove forests for beach protections. Various efforts have been done by local public to reduce the threat of tidal wave such as planted mangrove, made traditional wall but haven't succeeded due to the tide wave energy very strong.

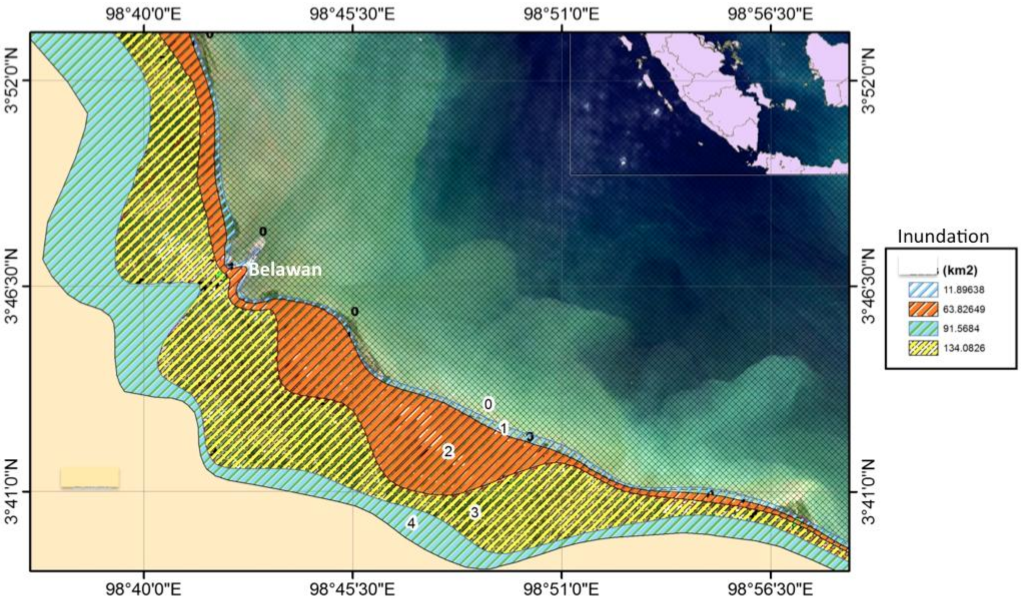

Fig. 4: Scenario of coastal inundation due to sea level rise in the ECNS.

Based on the data and the real conditions. Activities along the coast were dangerous then it must be programmed adaptation activities. Reforesting the bare lands along the coast by planting mangroves is the effective activity to reduce negative impact of sea level rise.

4. Conclusion

Regional mean sea level trend in the eastern Coast North Sumatra estimated from satellite altimetry was 5.0 mm/year. The potential lost coastal area due to 1 m and 2 m inundation could range from 11.9 km^2 to 63.8 km^2 respectively. Heavy flooding has been seen hit the coastal areas including fishing port, settlement, railway, agricultural and tourist area. Reforesting the bare lands along the coast by planting mangroves is the effective activity to reduce negative impact of sea level rise.

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