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Coastal Flooding Impacts Induced Sea Level Rise on Banda Aceh Coastal Morphology

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Abstract. The research focus is in assessing the impact of sea level rise induced by climate change towards coastal morphology. The process went through numerical modelling combining the flow and swan model generated by Delft3D to mimic morphology process within 100 years in Banda Aceh Coastal Defence. Banda Aceh coastal morphology keeps in recovery process as the coastal line keeps growing after the 2004 devastating morphology destruction until the late 2017. A sea level rise scenario was adopted from IPCC and TOPEX Poseidon with a 7 mm/year increase rate which was recorded between 1992 and 2015. Results recorded Banda Aceh had both sedimented and eroded area. Coastal protection gave the proper protection to Banda Aceh coastal defense while the three of Banda Aceh rivers (Krueng Neng river, Krueng Aceh river, and Floodway) gave sediment supply from the channel. Coastal line retreat between 15 to 100 m was also recorded on the side of Syiah Kuala- Alue Naga beach site, while others had enough sediment supply produced growing shoreline. The predicted regrow coastal area could be utilized as buffer zone as the government had difficulties in relocating the people from the coastal area.

Keywords: Sea level rise; Coastal defense; Morphology; Banda Aceh

1. Introduction

Banda Aceh is situated in a complex ocean system due to the conjunctures of three open seas, i.e., Indian Ocean, Andaman Sea, and Malacca Strait. As a coastal plain area, Banda Aceh is also facing another problem namely coastal flooding. Almost 14 years have passed after the 2004 Indian Ocean tsunami. Several parts of the coastal area have recovered from a severe erosion thanks to their natural ability. However, according to IPCC and recorded data of TOPEX Poseidon, there is a 7 mm/year of sea level rise (SLR) rate taking place between 1992 to 2015. This increase will enhance the vulnerability of the coastal area during future coastal evolution. The rise of climate change induced sea level rise will produced more frequent coastal floods [1]. Today's coastal development in many developing countries still does not properly include SLR impacts on their city development plan. As found in Jakarta, in 2050 several coastal areas will be flooded due to sea level rise and land subsidence [2]. Beside Jakarta, Banda Aceh also has been predicted that the impact of SLR will drawn 2.97% of the coastal area and disturb the city drainage systems in 2067 [3].



This research is aim at investigating the impacts of 100-year SLR on the coastal morphology of Banda Aceh. The impacted area was observed in terms of flooded area, coastal erosion, and sedimentation. We used Delft3D model that adopts Finite Difference Scheme Method with nonlinear shallow water equations. There are also the models which mimic the forecast of morphological change induced by sea level rise in western Mediterranean region, which also combine the mean condition along with extreme conditions [4]. The model domain was built based on topography data provided by BAPPEDA Banda Aceh in cooperation with JICA [5] and field measurement for bathymetry. Data was updated using the scenario of 100-year impacts of SLR with 0.7 m mean sea level increased. We compared both existing morphological change results and impact of the 100-year SLR scenario to investigate the consequences on Banda Aceh coastal morphology. The results are expected to be used as one of the considerations for the government decision-making in future coastal development plan in Banda Aceh. This study is aimed at estimating impacts of the sea level rise induced coastal flooding on coastal (Jetty) structures and coastal area. Numerical simulations of Delft3D were applied to investigate the influence of the gradual sea level rise in 100 years. The result will be presented in a quantity of flooded area that specified into several coastal areas around Banda Aceh.

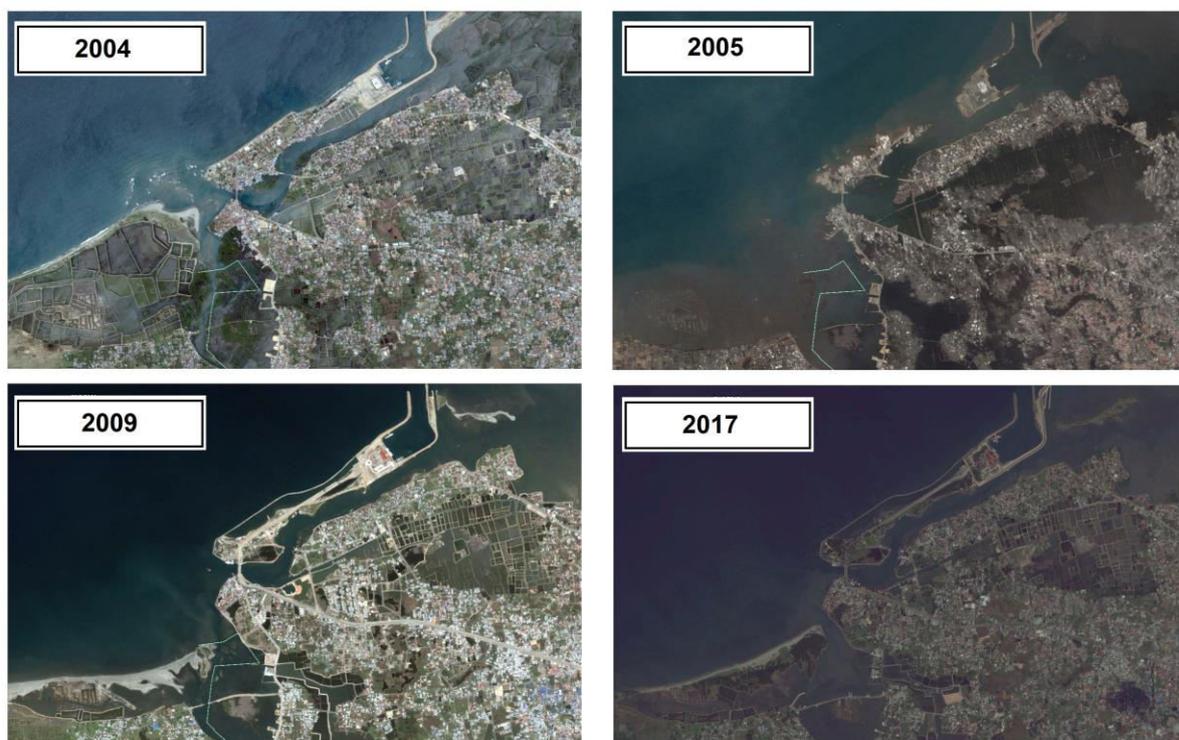


Figure 1. Coastal morphology condition after tsunami and it's recovery process (Google Earth images)

After the destruction of the 2004 Indian Ocean tsunami, the coastal area kept growing (figure 1). A wide area had been wiped away after tsunami and regrew a few meters back, this indicating that the sediment supplies were available around the area. Banda Aceh consists of three main river channels that end in the Banda Aceh Ocean. The three main rivers are Krueng Neng river, Krueng Aceh river, and Krueng Aceh Floodway and all of them provide supply towards Banda Aceh coastal defense. According to the growing process which has been occurring until 2017, the coastal areas were found to be healing with almost 70 m after a few years (google earth). In detail between 2005 to 2011 Ulee Lheue had 1.91 km² area formed naturally [6]. It If the growth of the coastal area was to happen in 100 more years, it would give a hope for coastal development, but if the erosion process was to dominate, then the problem wouldbe completely different.

2. Study Area

The study area for this research was Banda Aceh where many low-lying area present. The coastal area of Banda Aceh presents mostly a mild slope, and has only less than 2 m of elevation above the sea level. The conditions during high tide (highest water level) were relatively close to the coastal area that are inhabited. The highest tide that happened along with heavy rain could produce both coastal or river floods. Banda Aceh has three river streams which are known to produce sediment during heavy rain in upstream. The human activities around the coastal area were also found to be prone to floods as the distance was relatively close.

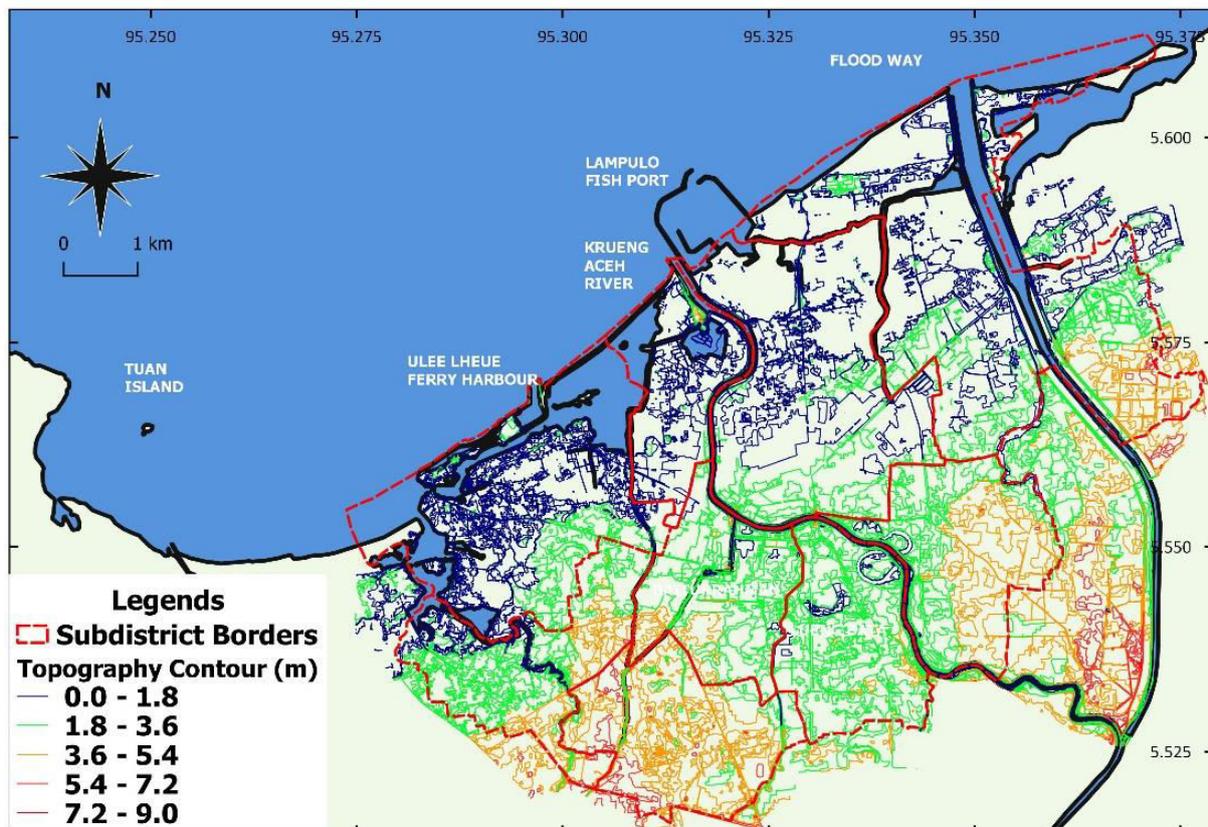


Figure 2. Banda Aceh region and topography condition



(a)

(b)

Figure 3. Ulee Lheue coastal area with houses nearby (a) and fisherman port (b).

Houses and public facilities also keep growing in the coastal area as it provide a cheaper costs compared to inland strategic locations. The coastal habited areas, such as Ulee Lheue are very close to water basins such as the lagoon which is directly connected to the ocean. The facilities were build on a relatively mild slope and low lying area which produce more vulnerability towards hydrometeorological hazards which combined with climate change (such as sea level rise).

3. Methods

Several methodologies were applied in performing this research. Data collection started with field measurements and was supported with available charts (secondary data) for topography and bathymetry data. Numerical simulation is one of the methods that we used to mimic the coastal morphological process which combine flow (tides) and swan (wave) simulation in Delft3D. The simulation domain generated by topography and bathymetry data which represented in 11 x 3 km simulation domain with hydrodynamic components that consist of tide and wave were also generated along with the discharge from the river streams. There are several steps which were performed during the research.

1. Domain data

Both bathymetry and topography data were collected and digitized from first source (measurement) and secondary data (available nautical chart). The domain was translated into 3 types of grid to speed up the simulation process. first grid contains of overall grid (40x40m) was used to generate the waves and forward it to a “detail grid” (20x20m) and a flow grid (10x10m) for tides and wave simulation for morphological processes.

2. SLR scenario

The SLR scenario was gained from IPCC (International Panel for Climate Change) from satellite observations of TOPEX/POSEIDON with 4 mm precision between 1992 and 2015 [7]. The hydrodynamic process which also combine with morphology mimics the Banda Aceh morphological change in 100 years projection with 7mm/year sea level rise rate.

3. Hydrodynamic and morphology parameter

Four harmonics components of tidal were used to simulate the tides. The wave generation were performed by wave generated data of Hs (wave height) and Ts (wave period) which was calculated from the wind data. In the process of producing the morphological process for a century (100 years) we used the morphological factor for time efficiency.

The result of coastal morphology change were analyzed further for coastal line change with spatial analysis and cross profile. Coastal morphological change map and cross profile of coastal change graphic were produced to inform the prediction of coastal condition within the next century.

4. Result and Discussion

During the simulation, sedimentations and erosions processes were projected to happen over the next 100 years. On the eastern part, the shoreline kept growing and created a new shoreline forward to the ocean based on the simulated projection. This happened due to the coastal protection (jetty) which trap the sediment from the eastern part. Mostly the sediments were deposited around the coastal protection which perpendicularly to the shoreline. Areas with this characteristics were found near Floodway estuarine, Lampulo fish port, and Krueng Aceh estuarine. In the long span coastal line such as Syiah Kuala – Alue Naga shoreline, the erosion was occurred instead of sedimentation. The erosion was measured ranging between 5 - 98 m.



Figure 4. Shoreline change prediction in 100 years after morphological process.

Three of the main river streams produce sediment supply through estuarine and disperse in the coastal area. Based on the simulation, the decreasing of the area that was eroded in the coastal area was mainly caused by the coastal protection which spans along the Banda Aceh coastal line. The depositions also appeared around the estuarine, producing shallow depth estuarine. The shallow estuarine made the fishermen boats unavailable to pass (figure 5. b).



Figure 5. Prediction of shoreline change in 2118 compared to 2018 in two sites in Banda Aceh (a. Syiah Kuala – Alue Naga, b. Alue Naga)

On the other site, the erosion occurred in the area of Syiah Kuala which located in Syiah Kuala–Alue Naga beach. The areas that were eroded nearly inhabited by people and also functioning as fish ponds. the erosion happened in the middle of two perpendicular coastal protection (Alue Naga jetty and Lampulo fish port breakwater). While the middle area was eroded, the areas on the eastern and western part were deposited with sediment that were transported by the erosion processes.

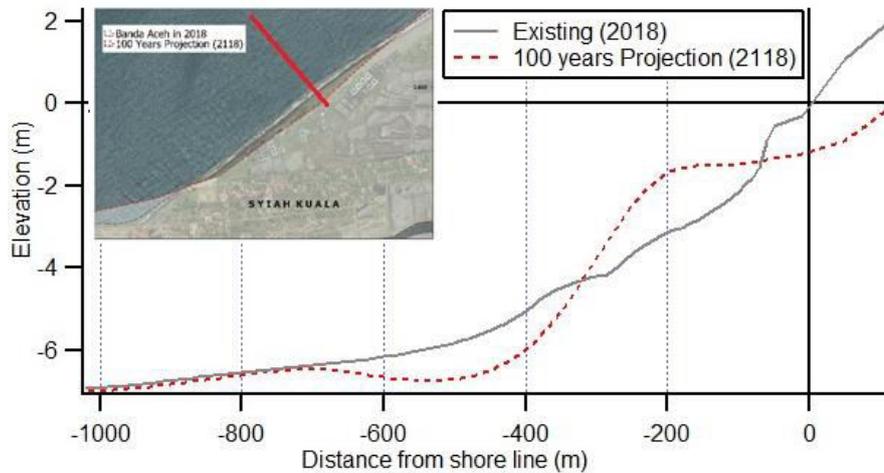


Figure 6. Cross profile Syiah Kuala – Alue Naga beach area.

The erosion went 98 m maximum inland while eroding more than 2 m thick of sandy layer leaving the former beach into water area (figure 6). The new shoreline had form relatively close to the houses even it still had the coastal protection. Erosion prone area were need attention from the government for future development plan since many property developers use the coastal area as a housing area for it's cheaper cost. A century long development in Banda Aceh can produce coastal based houses if there is no regulation regarding the condition between after the tsunami until 2018.

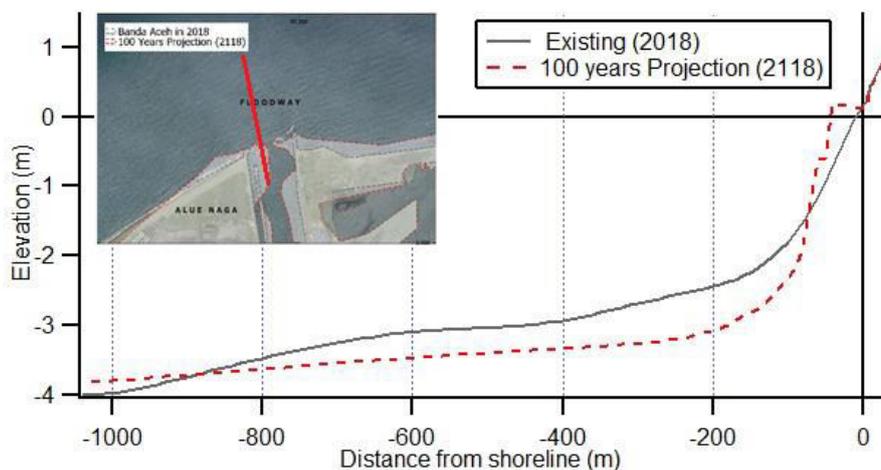


Figure 7. Cross profile Floodway estuarine.

The concerned also goes to the estuarine that functions as a fishermen transport channel, and at the same time plays a role as the floodway, delivering mass discharge when heavy rain happens. The sedimentation appeared to be more than 3 m thick, causing the estuarine to be shallow and defective for the fishermen transportation channel (figure 7). The sediment supply went from the river stream and was also transported from the mild slope bed. Both of the sediment supplies met in the estuarine and deposited there after having some turbulences process.

5. Conclusion

Sea level rise of 0.7 m, in theory, will cause the coastal line retreat automatically. However, in practice, the effect towards the hydrodynamic and morphology process gave more varied results. Most of Banda Aceh coastal area had been protected with coastal protection, i.e., riverment, breakwater and jetty. More than 3 m thick of sedimentation were produced in the estuarine after 100 years leaving the site very shallow until become not working. The Jetty facility in Alue Naga Estuarine (Floodway) become less functional after affected by the sedimentation. Hence, shoreline retreat also happened in a long span coastal line and mild slope area leaving a 98 m of coastal retreat as the work that need to be done by the government regarding the coastal line area were inhabited by the society. The rise of sea level produced both shoreline retreat and regrow; the coastal development should consider the sea level rise factor. Both erosion and sedimentation could happen, but which one is dominant depends on the sediment supply and the coastal morphology. The gulf bay coastal form will trap more sediment and the coastal with estuarine also has the sediment supply from the river streams.

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