Effect of human activities on coastal landform recovery after the tsunami at Padang Seurahet coastal zone, Meulaboh, Indonesia

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Abstract. Padang Seurahet coastal zone was eroded by tsunami of 26 December 2004. As well as the other coastal zone that eroded by the tsunami, at the coastal zone immediately occur recovery processes after the event. This study depicts how a recovery process of the coastal zone has been influenced by human activity. Images from Google Earth were used to analyze coastal landform condition visually before and after the tsunami. Results of this study show that the effect of the tsunami on the coastal zone and process of restoring the coastal zone in Padang Seurahet is affected by the existence of an old seawall remain along the coastline that was built to protect the coastal zone from wave erosion before the tsunami.

1. Introduction
The tsunami of 26 December 2004 devastated coastal areas of Sumatra Island from Meulaboh to Banda Aceh (Figure 1), and the coastline was significantly eroded [1, 2]. Instead of Sumatra, its destructive wave was also reached southern Thailand, southern India and Sri Lanka [1, 3]. This situation allows a lot of research to be carried out on the effect of the tsunami on geomorphological conditions and coastal recovery processes in coastal areas in many locations such as in Indonesia [1, 2, 4, 5], Thailand [6, 7], India [3, 8], and Andaman Islands [9].

A study on the recovery of various types of coast eroded by the tsunami on the west coast of Sumatra Island has been conducted [1, 2, 5]. In the studies, the coast with human activities have been studied is the coast with fish ponds. In Meulaboh, at the coastal area of Padang Seurahet (Figure 1), there is a sandy beach with a seawall along the coast and has not been included in the study. This study depicts how the recovery process of the coastal zone is affected by human activities in the form of seawall and jetty construction.

2. Research Method
Published multi years images dates from (2004) before and after the 26 December 2004 tsunami (2011, 2014, 2015, 2017, 2019) from Google Earth, were analyzed visually in this study to find out coastal landform and coastal processes data, and combined with field works data at Padang Seurahet from year of 2002. Systematic analysis of coastline recovery was done visually on images from Google Earth. In order to figure out how recovery processes has been taking place on the coastal zone, coastline shifting analyses were done along non-erosional segment, and coastal landform and coastal processes analysis were done in relative manner along erosional segment of the coastal zone. The visual analyzes were done on the images with no geometric correction.
3. Results and Discussions

3.1. Padang Seurahet coastal zone before the 2004 Tsunami

Padang Seurahet coastal zone is part of Meulaboh bay and it has curved plan shape and bounded by Meulaboh headland so that can be called as headland-bay beach or structurally controlled beach [12, 13]. The coastline directly faces Indian Ocean and is open from south to southeast. So, the coastline can be affected by waves and swells that coming directly from the ocean in form direct waves from south to southeast or diffraction waves after diffracted by Meulaboh peninsula. According to [14], based on plan shape coastline configuration and direction of Krueng Meureubo spit indicate that coastal sediment transport pattern direction from west to east as shown in Figure 2. Padang Seurahet coastal land as well as Meulaboh is a low flat plain. A stream (Krueng Cangkoi) bordered the coastal plain land ward. Based on its coastal condition, Padang Seurahet coastline can be divided into erosional and non-erosional segment (Figure 3). Seawall was built at erosional segment. In 2002, the seawall was damaged by erosion (Figure 4), and probably it was rebuilt again so we could see the seawall along the coast before the tsunami in 2004.

3.2. Effect of the 2004 Tsunami on Padang Seurahet Coastal Zone

When the tsunami of 26 December 2004 hit Meulaboh, the coastal zone of Padang Seurahet was also hit (Figure 5) and eroded (Figure 6). There is a difference in the impact of the tsunami on the coastal area of Padang Seurahet between the erosional sandy beach segment and the non-erosional sandy beach segment. In the erosional sandy beach segment, the erosion of the coastal plain due to the tsunami occurred locally along the coast due to the influence of the seawall previously constructed along the coast and some parts of it collapsed. The coastal plain erosion occurs in parts of the coast where there are no seawalls, and form short branching erosion channels (Figure 6) resemble the one that formed at west coast of Meulaboh [11]. On beaches with the seawall, coastline does not appear to have changed significantly.

Meanwhile, in the non-erosional sandy beach segment, the erosion of the coastal plains was occurred evenly along the coastline so that the whole coastline was shifted landward. Between the two coastal segments, a new outlet was formed. Based on its position which is located at the end of the seawall and at the bend of the river that leads to the sea so that this outlet acts as a collecting channel, it can be concluded that this new outlet is very likely to be formed by erosion that occurs during the tsunami flood the coastal land and also when the mass of sea water returns flow to the sea. According to [11], in natural condition, tsunami incisions channel has characteristic as funnel shape that wider seaward. This shape
character was not belonging to the new outlet of Padang Seurahet because of the existing of seawall at west side of the outlet (Figure 6).

**Figure 2.** Sediment transport along Padang Seurahet coastal waters. Arrows parallel to the coastline indicate net sediments transport (Image Source: Google Earth Images. Dated: July, 2 2019. Image Axis: 4°08’03.44”N/96°08’06.85”E).

**Figure 3.** Characteristic of Padang Seurahet coastline based on Google Earth Images (Dated: May, 18 2004. Image Axis: 4°08’24.18”N/96°08’12.13”E).

**Figure 4.** Erosional coastline at Padang Seurahet, Meulaboh in 2002 at foreground with vegetated of non-erosional background.

3.3. Recovery of Padang Seurahet Coastal Zone

Non-erosional Segment. On non-erosional segment, Padang Seurahet coastal zone recovery processes take place in natural way almost unaffected by any form of human activities. The recovery processes is characterized with coastline shifting seaward from erosional condition after tsunami until reaching relative stable condition. After about 15 years of the tsunami, inferred from Google Earth images, coastline position has been shifted seaward at least 50 m from coastline position after the tsunami, but has not reached the initial condition of the May 2004 coastline (Figure 7). Form of human activity that probably can be said influencing recovery processes is remain of the pre-tsunami seawall that in associate with new outlet (Figure 6).

Erosional Segment. Recovery processes on erosional segment of Padang Seurahet strongly affected by human activities in form of coastal structure development along the coast, namely seawall and jetty. The seawall has been built along the coastline of Padang Seurahet before the tsunami, so it can give influence in coastal zone recovery processes from the very beginning although some parts of the seawall
were failure (Figure 6). During the recovery processes, new seawall and jetty have been built in order to governing coastline development (Figure 8).

After 15 years of Padang Seurahet coastal zone recovery processes took place, the resulting landform is still different from its pre-tsunami condition as shown in Figure 8. Plan shape outline of the coastline has reached its original form, but surface morphology of the coastal plain is still different. There are two enclosed water bodies formed on coastal plain resulted of recovery processes. The seawall which has been built along the coastline cause the enclosed water bodies formed on the coastal land.

Figure 5. Meulaboh (28 December 2004) two days after the 26 December 2004 tsunami. Photo from [15].

Figure 6. Effects of the 26 December 2004 tsunami on Padang Seurahet coastal zone based on image from NASA Earth Observatory dated 7 January 2005. Sw: seawall, Er: eroded. Image from [16].

Figure 7. East Padang Seurahet coastal zone recovery processes that characterize by coastline shifting to reach initial condition as before the tsunami (Images Sources: Google Earth. Images Axis: 4°08’32.27”N/96°08’24.97”E).
The results of the analysis carried out on the development of the recovery process in the coastal area of Padang Seurahet provide an overview of the role of the seawall in the recovery process of the coastal area after the tsunami. A seawall is a coastal structure built to protect coastline from being eroded by waves [14, 17]. In the coastal area of Padang Seurahet, the tsunami hit the area and caused erosion of the coastal land in general, some part of the seawalls were able to survive and their position was more protruding towards the sea than the coastline in general. Thus, in the configuration of the coastline resulting from tsunami erosion, the seawall turns into a barrier that extends parallel to the coastline. The end of the seawall causes a wave diffraction phenomenon when the waves from the direction of the open sea are heading towards the shore. This phenomenon of wave diffraction is strongly suspected to be the cause of the closure of the new channel (see Figure 6) formed by the tsunami on the coastal lands of Padang Seurahet. This is because the new channel was located in the shadow zone of the end of the seawall and where there was sedimentation occurred like sedimentation that occurs in the shadow zone of an offshore barrier [12, 18].

At the Padang Seurahet beach after the tsunami, the beach with the remaining seawall is the part of the beach that is most resistant to wave activity, so that the remaining seawall becomes the control point for the recovery process, both for erosional and non-erosional beaches. The eastern coastline segment that before the tsunami was non-erosional, when the recovery process took place it became expansive, showing the coastline advancing towards the sea and minimizing the spacing between the seawall and the coastline at the control point area (Figure 7). The development pattern of the coastline and coastal
land in this segment illustrates the possibility that the coastal area is supplied with a large amount of sediment from near shore zone. There is the Krueng Meureubo which is a large source of sediment in the area, but the river mouth is located in the east of the Padang Seurahet coastal zone and is in the same direction as the net sediment transport direction or down drift position, Figure 1, so that the sediment load that comes out of the river mouth is scattered away from the waters of Padang Seurahet.

At present, at the end of the seawall which is the control point of the shoreline recovery, the shoreline recovery has not yet reached its original position as before the tsunami. Therefore, in this segment the coastline can be expected to still expand towards the sea. Monitoring coastline shifting during recovery processes after tsunami is important to understand recovery processes after severe erosion [7]. Therefore, further study is needed on the trend of the shoreline changes in the eastern segment of Padang Seurahet to determine whether the coastline has reached a stable condition which is an indication that the recovery process has been completed. On the coastal zone near Krueng Woyla, coastline stability was reach in 2011 although coastline position sill on average 45 m from its pre-tsunami position [4].

In the western segment of Padang Seurahet, in some parts of the coast where the seawall collapsed, the tsunami caused erosion (Figure 5). It can be ascertained that the seawall gap then develops into a gap where wave diffraction occurs during the recovery process so that a pocket beach is formed (Figure 6).

The coastal area of Padang Seurahet is open to incoming waves that coming from the south to the southeast, so that the pocket beach shows conditions of dynamic equilibrium [12, 18]. In subsequent developments, the seawall gaps were closed by constructing a long and intact seawall. This construction led to the confinement of the water mass that was previously part of the pocket beach, and resulted in a different landform from the initial pre-tsunami landform (Figure 8).

4. Conclusions
The coastal zone of Padang Seurahet is one of the places that were severely eroded by the tsunami that occurred on December 26, 2004. Before the tsunami, Padang Seurahet coast had two segments with different conditions, namely the erosional segment and the non-erosional segment. Landforms recovery processes in each of the both segment have taken place in two different patterns. In the non-erosional coastal segment, recovery processes has occurred naturally and results in coastal landform that is very similar to its pre-tsunami initial conditions but its coastline still does not return to its initial pre-tsunami position. The recovery process has marked by the advancement of the coastline seaward following the development pattern of the Headland-bay beach with the control point being the remaining seawall that can withstand the tsunami. It is needed to study the coastline stability in order to know if the recovery processes is complete. On the erosional segment, recovery has occurred with human intervention in the form of seawall and jetty construction, and the recovery process has finished and resulted in a different landform from the initial pre-tsunami landform.

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