SHORELINE CHANGES AT SENDAI PORT DUE TO THE GREAT NORTH EAST JAPAN TSUNAMI OF 2011

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Abstract

The Great North East Japan Tsunami of 2011 had caused the drastic shoreline changes around Sendai Port, Japan. The shoreline gradually recovers and achieves a new balance. In this study, aerial photos were analyzed in order to investigate in details the shoreline changes after the tsunami and during the recovery process. It was found that a part of the shoreline was not affected directly by the tsunami, although the surrounding shoreline was severely eroded by the tsunami. During the recovery process, this part of the shoreline was continuously eroded, in order to supply sediment to the eroded shoreline nearby. It was also found that the nearby coastal protection helps to stabilize the shoreline condition, during the recovery process after the tsunami of 2011.

Key words: Shoreline changes, sediment transport, The Great East Japan Tsunami of 2011, aerial photos.

1. Introduction

The Great North East Japan Earthquake occurred on 11 March 2011 at 14:46 JST. The earthquake was recorded at a magnitude of 9.0. The epicenter was located approximately 70 kilometers, northeast of Japan. This mega earthquake caused a mega tsunami wave. The wave traveled and reached the north east coast of Japan. The tsunami caused severe damages along the affected shoreline.

Mori et al. (2012) reported around 40 meters of tsunami wave height in Iwate Prefecture, Japan. The massive wave reached the shoreline and caused destruction to the affected shoreline. Supasri et al. (2012) reported a large number of casualties and damages to coastal structures. Udo et al. (2012) reported land subsidence due to the earthquake. Adityawan et al. (2012a) analyzed the tsunami propagation characteristic on Sendai plane, based on video analyses. Tappin et al. (2012) reported based on their study in Sendai coast that coastal protection may not be highly effective in the case of massive tsunami as in the event of 2011. Adityawan and Tanaka (2013) detailed the morphology changes of the Samegawa River mouth, Fukushima, following the tsunami. They have shown that the river mouth was severely eroded due to the tsunami. Nevertheless, the river mouth morphological features contribute to the tsunami intrusion in rivers (Adityawan et al. 2012b). These studies have shown the great impact of the tsunami of 2011 to the affected shoreline along the north-east coast of Japan.

The shoreline in Sendai coast, prior to the tsunami had reached its balance, as reported by Pradjoko and Tanaka, 2010. They analyzed the long term shoreline changes and behaviors based on aerial photos. However, The Great North East Japan Earthquake and Tsunami of 2011 had caused the drastic changes to the affected shoreline, including Sendai coast. Severe shoreline retreat was observed in area with sandy beach such as in Sendai coast (Tanaka et al. 2012).

The shoreline retreat was soon followed with the recovery process to achieve a new balance of the shoreline. Tanaka et al. (2013) has reported the effect of the tsunami of 2011 and the recovery process that follows, at the area around Nanakita river mouth, Sendai, Japan. They reported that the sand formation in front of the Nanakita river mouth in this area was completely flushed and the Gamo Lagoon, located nearby was severely damaged. In addition, the recovery process of the sand formation was studied in

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details. It was shown that the recovery process causes the complete closure of the river mouth.

The recovery process around Nanakita river mouth has affected the nearby shoreline that was not originally affected by the tsunami. Therefore, further monitoring and analyses to the surroundings area is required. This study analyzed the shoreline changes around Nanakita river mouth, focusing in the Sendai Port area, Japan, due to The Great North East Japan Tsunami of 2011, based on aerial photos.

2. Study Area

The study area is located around Sendai Port, Sendai Coast, Miyagi Prefecture, Japan, as shown in Figure 1. The tidal range in this area is is about 1.5 m and semi-diurnal type. The prevailing wave direction is mostly coming from ESE ~ SE. It has been reported that long shore sediment transport moves from south to north (Tanaka and Takahashi, 1995). The shoreline in this area was already in dynamic equilibrium condition with no significant changes during the past few years (Pradjoko and Tanaka, 2010).

The shoreline in this area can be classified into three zones (Figure 2), based on the effect of the tsunami of 2011. The first zone covers the Nanakita river mouth and the Gamo lagoon. Forest area in the north and the Nanakita river mouth in the south bound this zone. The sand formation in this zone was severely eroded by the tsunami. The lagoon was completely destroyed, flushed by the tsunami of 2011. The destruction was soon followed by a rapid recovery process. Tanaka et al. (2013) had studied in details regarding the morphology changes and the recovery process in this zone. They reported that the long shore sediment transport has contributed to the blockage of the Nanakita river mouth, which required artificial river mouth by dredging to re-open.

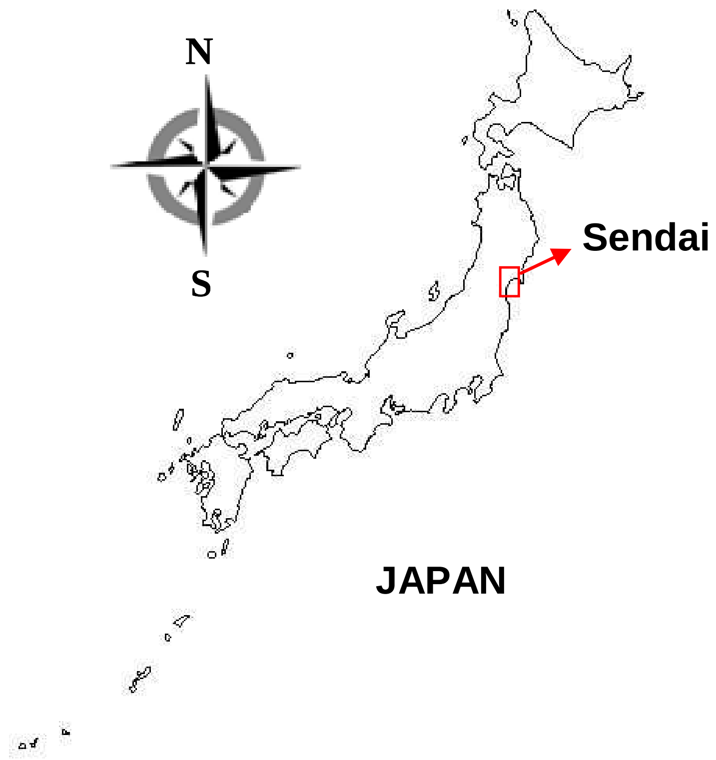

Figure 1. Study area.

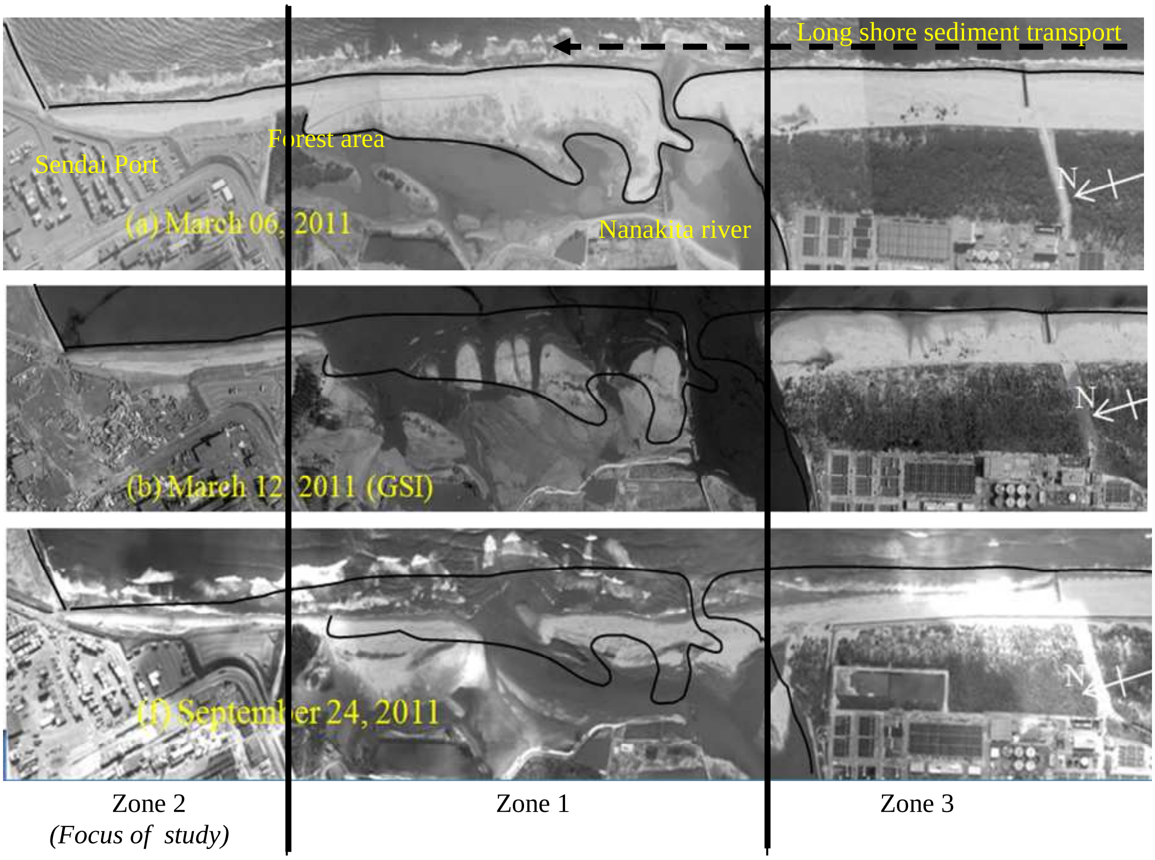

Figure 2.Focus of study

The second zone, the focus of this study, is the northern part of the shoreline. The breakwater of Sendai port in the north and the forest area in the south bound this zone. This area has higher elevation than the surroundings. There was no significant direct affect of the tsunami to the coastal morphology in this zone. Although the long shore sediment transport moves from south to north, this area was continuously eroded in order to reach a new balance condition of the shoreline.

The third zone is located on the right side of the Nanakita river mouth. As in zone 2, this area did not suffer significant effect from the tsunami. However, long shore sediment transport caused continuous erosion in this zone during the recovery process in zone 1. The process leads to the previously mentioned river mouth blockage.

Aerial photos and satellite images were collected for zone 2 during the period of March 2011 to February 2012. The acquired images are shown in Figure 3. Zone 1 and zone 2 are separated by a forest area as shown in Figure 3 (c). It can bee seen that the severe erosion due to the tsunami in zone 1 stopped approximately around the forest area.

3. Method

Aerial photos have been extensively utilized in shoreline change detection. Pradjoko and Tanaka (2010) had assessed shoreline changes in Sendai coast based on a series of consecutive aerial photos. It has been shown that the images are very useful for monitoring the coastal morphology changes.

(a) 2011-03-06

(b) 2011-03-14 (Google)

(c) 2011-04-06 (Google)

(d) 2011-09-07

(e) 2011-11-26

(f) 2012-02-22 (Google)

Figure 3. Aerial photos.

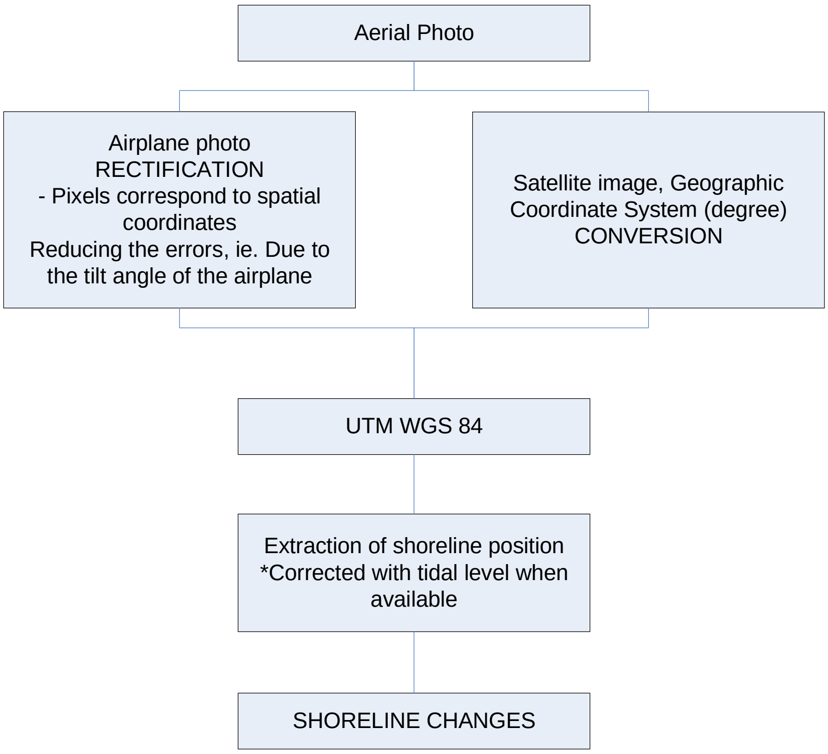

Figure 4. Shoreline analysis flow chart.

The collected data for the study area covers the condition before the tsunami, right after the tsunami, and during the course of recovery process until the beginning of 2012. The satellite images and the aerial photo are shown in Figure 3. Aerial photos for the study area were collected from Google Earth for the following dates, 14 March 2011 (DigiGlobe, resolution 0.6 m), 6 April 2012 (GeoEye, resolution 0.5 m), and 22 February 2012 (DigiGlobe, resolution 0.6 m). In addition, several aerial photos, captured from airplane, were acquired. These photos show the condition around the study area for the following dates, on 6 March 2011, 7 September 2011, and 26 November 2011.

The flow chart for this study is shown in Figure 4. The shoreline positions were extracted from the acquired images. The images were projected to the desired coordinate system prior to the extraction. In this study, all the images were converted to the Projected Coordinate System (UTM-WGS`84 Zone 54N). The extracted shoreline positions were corrected with the tidal level.

The images for the study area were acquired from two main sources. They are the Google Earth image, and aerial photos from airplane. The satellite images were acquired in Geographical Coordinate System (GCS-WGS`84) with longitude and latitude. Therefore, rectification process is not required. The satellite images can be directly converted to the desired coordinate system for analysis. However, the satellite images have no records of the exact capturing time. Thus, tidal correction was not applied for these images.

On the other hand, aerial photo contains no geo-reference information. Therefore, rectification to each image was conducted prior to the analysis. The images were rectified using reference points to the same coordinate system as the satellite images. More detail on rectification method can be found in previous study (Pradjoko and Tanaka, 2010). The aerial photos contain information on the exact time, when the photo was taken. Hence, the shoreline position from these images was corrected by the tidal level.

The projected images were digitized to obtain shoreline position and protection/structures. A local coordinate baseline was used to quantify the shoreline change. The shoreline change was investigated further by analyzing several cross sections along the coastline.

4. Results and Discussions

The extracted shoreline from each images are shown in Figure 5. The images in this figure have been projected to the Projected Coordinate System (UTM-WGS`84 Zone 54N). A baseline was proposed to quantify the shoreline changes. The baseline was taken at approximately 425 meters parallel to the shoreline position prior to the tsunami. A part of zone 2, nearby the forest area was included in the analysis for comparison with zone 1.

Zone 1 and zone 2 are shown to behave differently. Zone 1 suffered the direct effect from the tsunami of 2011, showing a massive erosion and shoreline retreat after the tsunami. Figure 5 shows that the severe erosion was limited to the south part of the forest area (zone 1). On the contrary, the tsunami of 2011 only affected zone 2 slightly. There was no significant shoreline change in the north part of the forest area to the breakwater (zone 1). The severe erosion in zone 1 was quickly followed by recovery process. However, there was no recovery process in zone 2. The area was continuously eroded following the tsunami of 2011 although the long shore sediment transport moves from south to north. The photographs showing the erosion in this area are given in Figure 6 (a) and (b) showing the condition in location 1 and 2 (Figure 5), respectively.

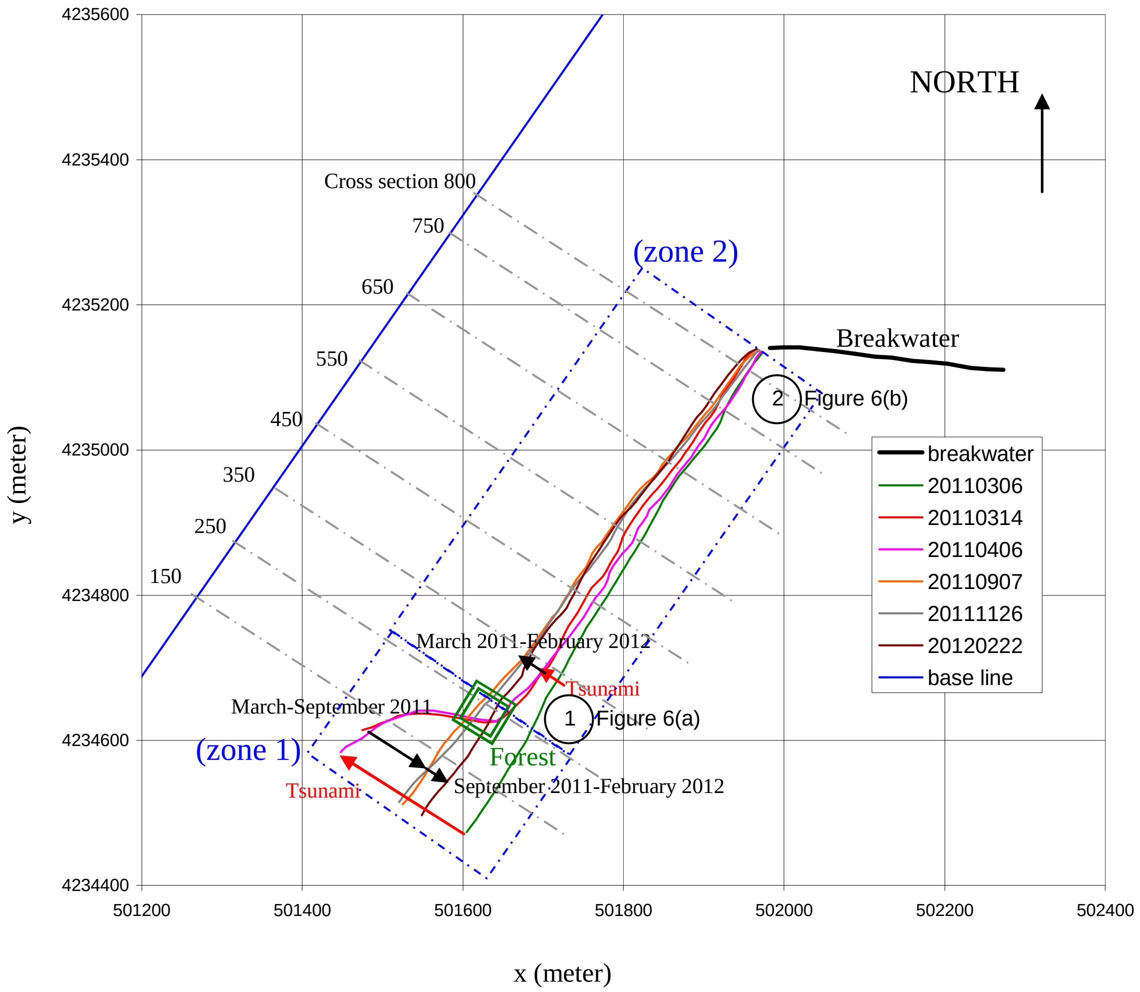

Figure 5. Extracted shoreline (UTM WGS `84, 54N).

a. Location 1

b. Location 2

Figure 6. Severe erosion in zone 1.

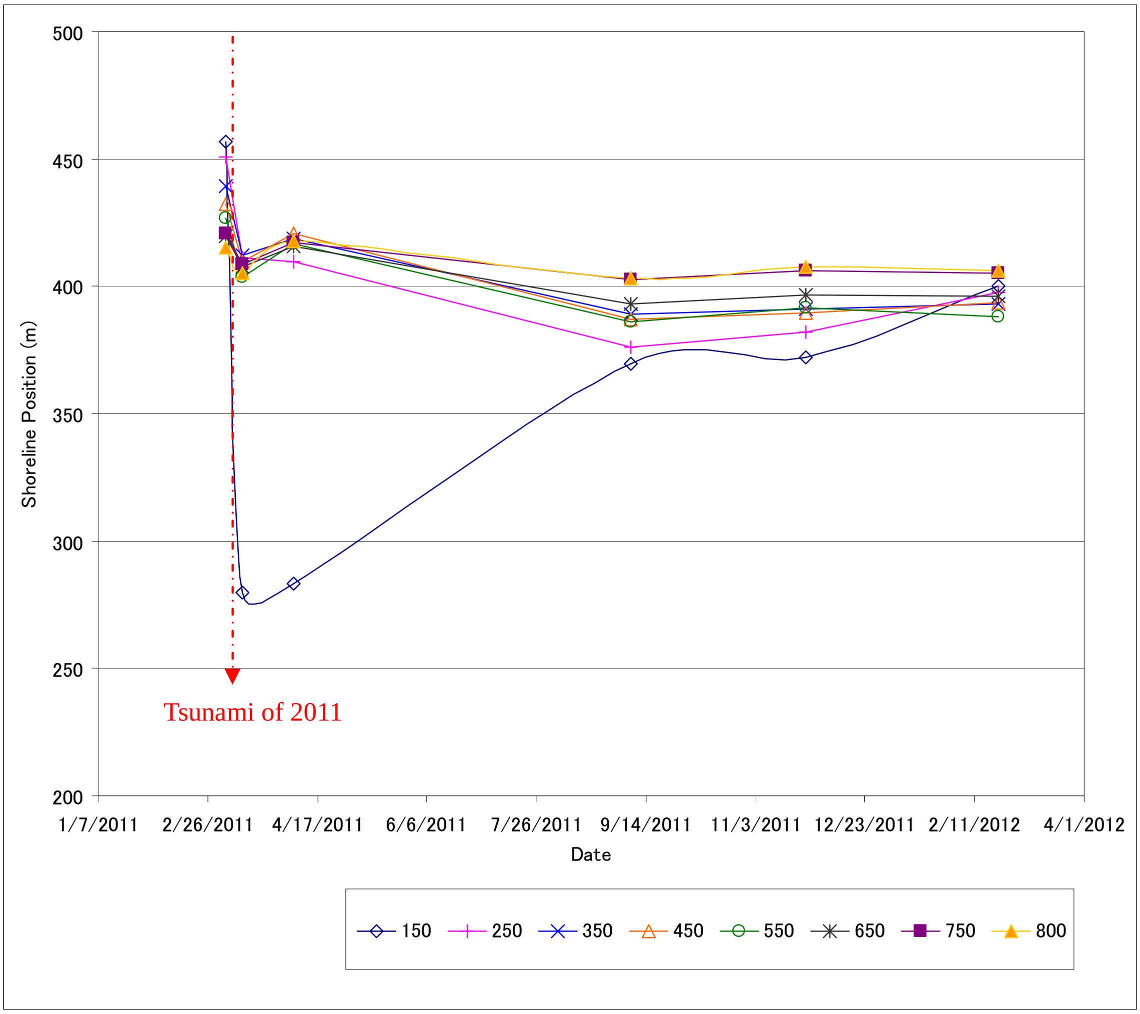

Figure 7. Shoreline changes.

A more detail analysis was conducted by measuring the shoreline position from the baseline, at several cross section. The result is shown in Figure 7. At the south of the forest (zone 1), severe shoreline retreat was found. The area suffered from severe erosion. The shoreline position right after the tsunami retreated by approximately 200 meters from the original position, as shown in cross section 150 in Figure 7. The severe erosion was also followed by rapid recovery process, during the period of March to September 2011. The shoreline advancement at this period was approximately 100 meter. The recovery process continued at a slower rate. The shoreline position advanced by another 25 meters in February 2012.

The north of the forest (zone 2) did not suffer from severe shoreline changes due to the tsunami of 2011. This area was significantly higher than zone 1, which may reduce the effect of the tsunami to the shoreline. The shoreline retreated in zone 2 due to the tsunami of 2011 varied from 10-25 meters, as shown in cross section 350 to 800 (Figure 7). The shoreline in zone 2 did not recover as in zone 1. Instead, the shoreline continued to retreat until February 2012. The total shoreline retreat varied from 25-70 meter.

In general, the erosion less affected the north part of zone 2, especially during the period of an unstable shoreline conditions, following the tsunami. The north part of zone 2 was bounded by coastal structure (breakwater). Therefore, the shoreline condition at the northern part is more stable than the southern part. The southern part of the zone 2 was bounded by forest area. The forest area does not maintain the stability of the shoreline as good as the breakwater. Cross section 250 (Figure 7) shows that the shoreline position around the forest area itself was not as stable as the shoreline around the breakwater.

The severe erosion due to the tsunami of 2011 and the recovery process in zone 1 requires sediment supply from its surroundings. It can be expected that the continuous erosion in zone 2 occurred in order to reach a new balance of the shoreline position. The hill in zone 1 was severely eroded during the recovery process, although there was no direct effect from the tsunami of 2011.

It is interesting to note that the overall recovery process of the shoreline has caused the sediment movement from the north to the south. This direction contradicts the normal direction of long shore sediment transport in this area, which is from the south to the north. It should be noted here that the sediment movement from the south to north may not reach the end of zone 2, due to the existence of the Nanakita river mouth. It has been reported in details that the normal long shore sediment movement from south to north, contributed to the closing of this river mouth, as the sediment tried to pass the river mouth. This suggests that the recovery process may require sediment supply from the north side, especially during the early stage of recovery process, when the river mouth was still wide open.

5. Conclusions

The shoreline changes around Sendai Port, following the Great North East Japan Tsunami of 2011, have been investigated from aerial photos as well as satellite images, covering the date before the tsunami, right after the tsunami, and during the recovery process. The focus of this study was to assess the coastal morphology changes in zone 1. The zone covers the area bounded at the north by the breakwater in front of the port, and bounded at the south by forest area.

It was found that zone 1 was not greatly affected by the tsunami of 2011, due to its naturally high elevation. The tsunami only caused 10-25 meters of shoreline retreat. This is far less than the shoreline retreat in zone 2, south of the forest area, which suffered shoreline retreat of approximately 200 meters due to the tsunami of 2011. However, the shoreline in zone 1 continued to retreat by another 15-45 meters after the tsunami of 2011 to February 2012. This process suggests that the sediment moved from zone 1 to zone 2 (north to south), in the opposite direction of the normal long shore sediment transport (south to north). The shoreline position in zone 1 continued to retreat following the tsunami in order to assist the recovery process in zone 2. The shoreline position in zone 1 has recovered by approximately 125 meters by February 2012.

The shoreline changes due to the erosion during the recovery process in zone 1 vary due to the existence of a coastal structure (breakwater) in the north. It was found that the shoreline around this breakwater is more stable than other areas. Nevertheless, the breakwater effect to maintain the shoreline stability was not significant during the tsunami of 2011.

This study has shown that the effect of the tsunami to coastal area is not limited to the direct-effect. The tsunami effect may cause additional after-effect. For example, a long-term shoreline changes, which requires further monitoring. Therefore, future coastal planning should cover the possibility of such after-effect from the tsunami. It has been shown that the existence of a coastal structure may help to reduce this after-effect. A more detail study of this phenomenon using modeling approach may provide more details information on the mechanism of the recovery process and interaction to the surroundings, following a massive tsunami incident.

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