Morphology recovery and prevailing sediment transport along sand spit at the Kitakami River mouth after the 2011 Tsunami

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Abstract

The Kitakami River mouth was one of many estuaries that experienced and got despoiled by the 2011 Tohoku Tsunami. The tsunami was highly energetic that the entire area of the river mouth was destructed severely and the remainder was a small area of sediment on the right bank. Afterwards, the phenomenon of intrusion pushed this deposited sediment towards upstream to a certain distance. Since that, the right sand spit has not been able to recover to its former shape due to special topography and the particular wave conditions near the river mouth. This study provides a thorough understanding of the morphology at the Kitakami River mouth by analysing aerial photographs obtained from many sources. Furthermore, unstable long shore sediment transport related to the seasonal variation is also discussed to interpret the change of the sand spit at the Kitakami River mouth.

Keywords: the Kitakami River mouth, the 2011 Tsunami, sand spit, recovery process, seasonal effect.

1. INTRODUCTION

The 2011 Tohoku Earthquake triggered a giant Tsunami waves with a record of 40m wave height in Iwate. With regard to the 2011 Tohoku Earthquake and Tsunami, many studies were conducted to immidiately assess the destruction caused by the tsunami onto the coastal areas and also give possible prediction of the recovery processes aftermath. Namely, Tanaka et al. (2012), Tappin et al. (2012), Supasri et al. (2012) and Udo et al. (2012). In detail, many remarkable changes in coastal and estuarine areas in Miyagi Prefecture such as beach erosion and breaching, sand barriers and sandspits' loss were reported in Tanaka et al. (2012).

The river mouths in Miyagi Prefecture suffered almost similar devastation that the sand spits located in each area were disappeared by the tsunami. Roh et al. (2016) and Hiep et al. (2019a) both discussed the disappearance for 7 years of the sandspit at the Naruse River mouth till the artificial construction to reform the sandspit in 2018. Recently, Hiep et al. (2019b) has brought a detailed understanding of the Natori River mouth recovery process with the assistance of human intervention to recreate the situation before Tsunami. In contrast, some areas have recovered fully due to the existence of sufficient sediment sources; for instance, in Abukuma River mouth as discussed thoroughly in Tanaka et al. (2017) and Hiep et al (2019c). The Kitakami River Mouth was also among the river mouths could not uphold the intensity of the tsunami that its sandspit was eroded into small area and the coast on its right side was destroyed entirely. The topography and wave conditions in the Kitakami River mouth are special resulting in the slow recovery process to the pre-tsunami morphology.

There are some former studies discussing about the morphology of the Kitakami River Mouth such as Tinh et al. (2011) discussing the morphology changes of the Yokosuka Coast and Purwanto et al. (2006) revealing the flow regime in the Nagatsura-Ura Lagoon nearby the Kitakami River mouth. The understanding of the mechanism at the Kitakami River, in this study, is examined more deliberately by considering the longshore sediment transport along the sand spit.

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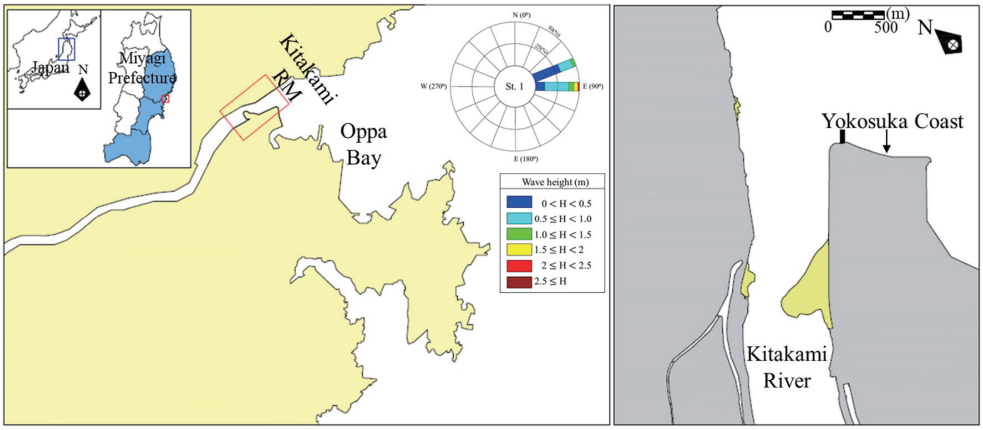

Figure 1: The Kitakami River mouth

2. STUDY AREA

The Kitakami River is ranked as the fourth largest river in Japan and the largest in the Tohoku region. The catchment area is approximately 10,150 km^2 flowing through the southern part of Iwate Prefecture and pouring into the Oppa Bay. The upstream river separates into 2 channels: The Old-Kitakami River and the currently so-called Kitakami-River (Fig. 1). Near the entrance area, a sandspit is located roughly 750m from the Yokosuka Coast at the right side.

The offshore wave condition in this area is driven by two main directions which are East and East South East. (Figure 1)

3. DATA COLLECTION

For the goal of understanding the morphology of river mouth, this study aimed to collect many aerial photos before and after the Tsunami taken by Tohoku Regional Bureau of Ministry of Land, Infrastructure, Transport and Tourism (MLIT) as well as satellite images from Google Earth and Sentinel II. All of the photos were geo-referenced and detected shoreline in order to monitor consistently the recovery process of the river mouth.

Moreover, transverse data of the several locations at the sandspit are also combined to emphasize the special conditions and the contribution of depth change around the sand spit on the development of the spit at the Kitakami River Mouth after the tsunami.

4. RESULTS AND DISCUSSION

4.1 Morphology change before and after Tsunami (2003-2012)

The Kitakami River mouth from 2003 to 2012 encountered an overwhelming change in size and configuration. Before the 2011 tsunami, the Yokosuka Coast and the sand spit were both wealthy with slight variations on the head of the sand spit due to the mutual interaction between long shore sediment transport derived by waves and the discharge from the river (Figure 2 (a~c)).

The Tsunami came and destroyed almost entire the Yokosuka Coast and the area behind was drowned in water (Figure 2 (d~e)). Afterwards, the width of the river mouth certainly became open since a remarkable area of sand spit was flushed away during the event. Then, waves propagate further and carry the sediment to upstream by a certain distance (Figure 2 (f)). This is called the intrusion process

4.2 Morphology change under slow recovery process (2013-2020)

Because of the intrusion phenomenon, the sand spit was located in a specific position in the river as seen in Figure 3 (a). The recovery of the sand spit throughout almost 6 years shows unsignficant change. The sand spit was not able to deposit in tranverse direction and only small amount of sediment accumulated on the side facing the sea area. (Figure 3 (b~f)).

However, it is also interesting that on the opposite left bank, sediment started depositing from 2017 which had been seen only in more downstream area.

Figure 2: Morphology change at the Kitakami River mouth before and after the 2011 Tsunami

4.3 Influences of river mouth's conditions on the morphology development

From the aerial photographs at the Kitakami River mouth, the sand spit has been solely accumulate onto the spit as new layers of sediment with a variant at the tip of sand spit. One of the reason for this phenomenon is due to the deep water depth around the sand spit. It is noticable from Figure 4 that the more offshore the measuring location was, the less sediment was deposited and only obsearvable at a small distance from the embankment (Figure 4 (a,b)). Figure 4 (c,d) also indicates from the tip of the shoreline to nearby tranverse region, the depth difference is up to 5 m. Hence, the accumulation can only be seen at the already seen area

Another main factor contributing the slow recovery process at the Kitakami is the direction of wave incident. Waves approach towards the river mouth in two specific directions which are East and East South East since the topography of rocky cliffs surrounding the entrance. Hiep et al. (2019d) discussed how the approaching waves refracted and resust in the breaking waves parrallel to the shoreline of the spit. This certain wave condition combining with deep water deep has been causing such a ineffective recovery at the Kitakami River mouth.

In the next section, the evaluation of sediment transport along the sand spit will emphasize the claim of the reduction of sediment along the sand spit and examine the effect seasonal varitons on the Kitakami River

4.4 Longshore sediment transport rate at the sand spit

Based on the notice of sediment movement which hardly deposit towards the left bank, it is ideal to define a fix location where the sediment is assumed to be interrupted or not able to transport further upstream in order to compute the longshore sediment transport along the spit. The coordinates and the direction of sediment transport towards the sand spit are defined as Figure 5 and it is noted that at the boundary the value of longshore sediment transport must be zero.

Figure 3: Slow recovery process at the Kitakami River mouth

The longshore sediment transport rate (Q) can be expressed as the equation below (Eq. 1)

$$Q(x) = -(D_B + D_C)\int_0^x \frac{\Delta y}{\Delta t} dx \qquad (1)$$

Where: D_C is depth of closure (m), D_B is berm height (m), $\frac{\Delta y}{\Delta t}$ is the shoreline change between consecutive times. From transverse section data, the total depth is assumed to be 6 m and the chosen shorelines were from 2013 when the new embankment was rebuilt.

The result of the computation is shown in Figure (6). According to the definition, the positive values refer to the erosion along the sand spit while the negative values represent the deposition of the spit. The distances that the sediment transported during each period did not resemble as a result of the observation of accretion along the embankment during some periods.

In order to investigate the change of the longshore sediment transport rate through time, tranverse sections at several locations along the sand spit are chosen (x = 100 m, 300 m and x_{max}) (Figure 7). The varitions of longshore sediment transport rate at these three locations reveals the influence of seasons on the evolution of the spit. Indeed, the positive values are seen during winter season in which wave height is not significant whereas during summer, deposition is certainly observed.

It is also interesting to compare the maximum longshore sediment transport at x_{max} with the volumetric deposition rate of sand spit. According to Hiep et al. (2019a), the rate of the area is 9.7×10^3 (m^2/y) and from the transverse section data, the thichness of the deposited layer on the sandspit is roughly 4 m. And the value of the volumetric deposition rate of sand spit is estimated as Eq. (2).

$$V_{Deposition\ rate} = 0.4 \times 10^5\ (m^3) \qquad (2)$$

As indicated in Figure 7(c), the spit deposition rate is almost similar to the value of longshore sediment transport rate when the seasonal effect is not overwhelming indicating the slow recovery of the sand spit under small sediment supply.

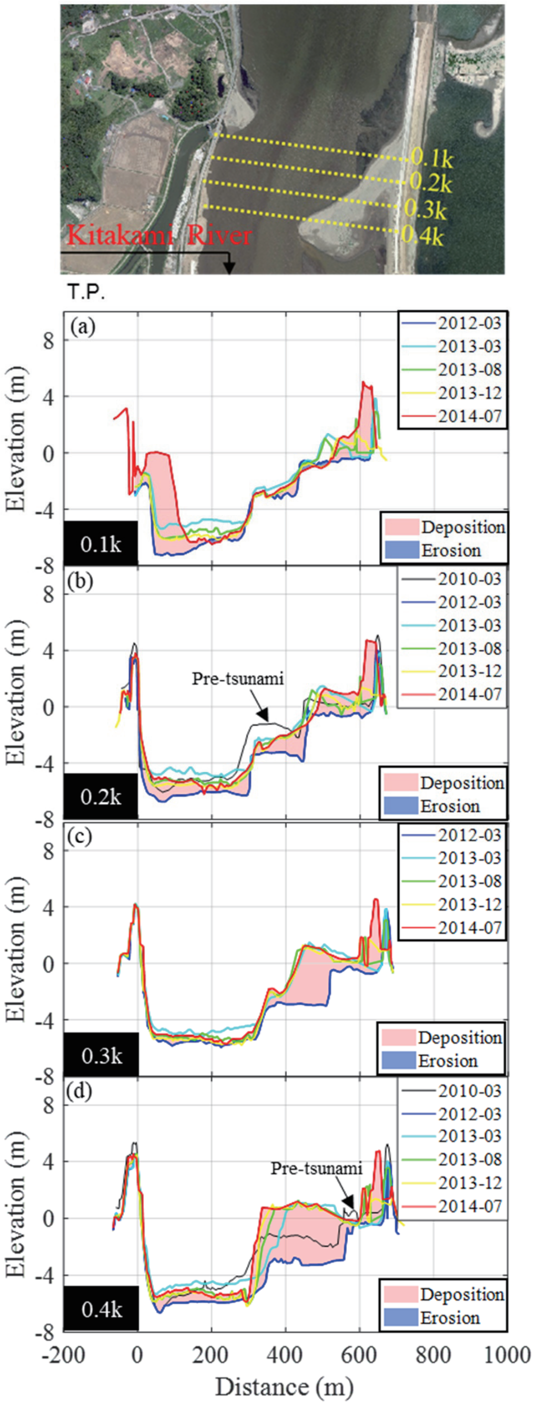

Figure 4: Transverse sections at the sand spit

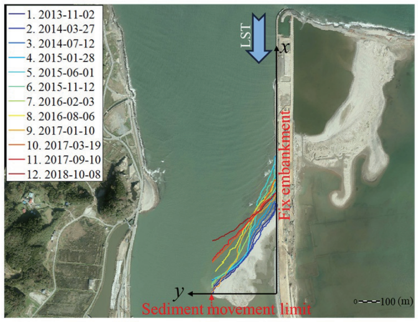

Figure 5: Coordinates for longshore sediment transport's computation

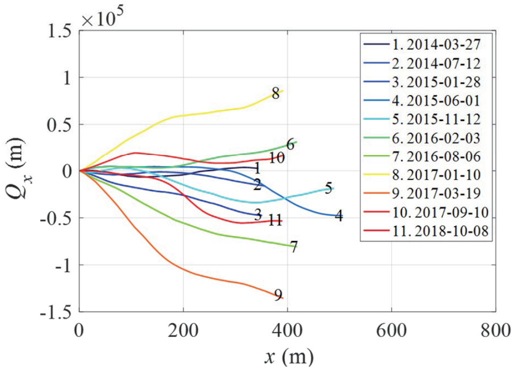

Figure 6: Longshore sediment transport along the sand spit

5. CONCLUSIONS

The Kitakami River mouth is a typical river mouth where the recovery process has been ineffective since the 2011 Tohoku Tsunami. Deep water depth around the sand spit and specific wave directions are the reasons for the slow restoration of morphology to its former situation. The longshore sediment transport in this river mouth is affected by the season effects which explained the different shapes of shoreline during some periods.

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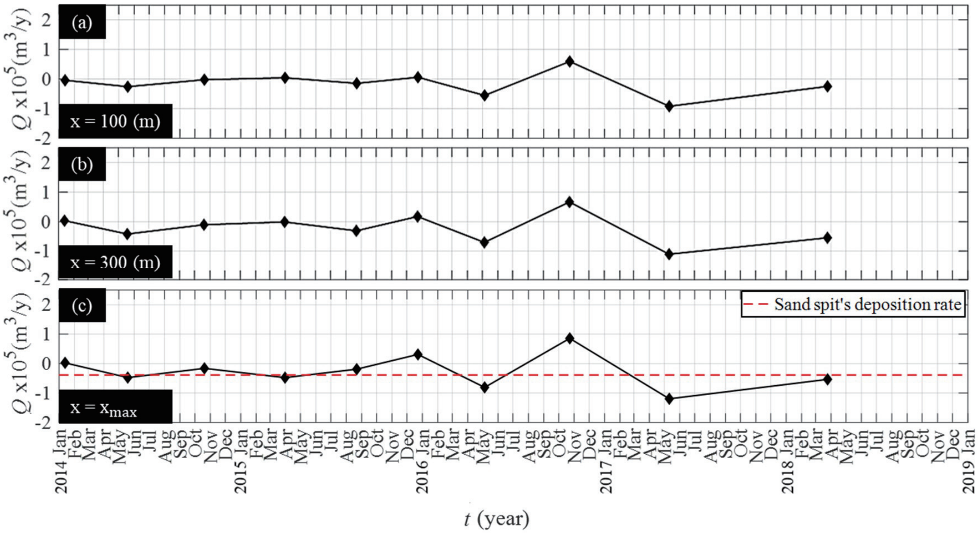

Figure 7: Time variation of longshore sediment transport rate along the sand spit

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