Morphological change on Cua Dai Beach, Vietnam: Part II theoretical analysis

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Abstract

In the past decade, severe erosion has been occurred on Cua Dai Beach, Hoi An City, Quang Nam Province which is located in the central part of Vietnam. The highly possible mechanism of this erosion is the reduction of sediment supply from river. There are several factors causing that reduction such as the construction of irrigated and hydropower reservoirs, and sand mining along the river or at the river mouth area. The formation process of river delta from river sediment and the erosion regarding to the reduction of sediment supply are presented through the analytical solutions of one-line model. The reduction amount of sediment supply is discussed. The erosion propagating of sandy beach is reproduced. The prediction for future recovery when the amount of sediment recovered to the amount before the reduction is also conducted.

1. Introduction

Cua Dai Beach and the ancient town play very important roles in the economic development of Hoi An City and Quang Nam Province, Vietnam. However, severe erosion of Cua Dai Beach in recent years has caused significant changes of the morphology. That affects to the tourism and raises safety concern of local people. Viet et al. (2015) present the erosion happing on this beach in recent years. The highly possible mechanism of this erosion is regarding to the reduction of sediment supply from river. The reduction can be related to several reasons such as the construction of irrigated and hydropower reservoirs and sand mining along the river or at river mouth area.

The formation of river delta from river sediment has been investigated by many researchers. Komar (1973) studies the equilibrium form of a cuspate river delta through application of numerical computer simulation models. Ashton and Murray (2006) utilize one-line model and includes a simplified representation of barrier overwash to examine the high-wave-angle instability on the evolution of wave-dominated deltas. For the past decades, the erosion of river delta coast regarding to the reduction sediment supply has been also topics for many studies worldwide. Huang (2011), Miyahara et al. (2010) present the erosion of Tenryu River Delta Coast in Japan after the construction of reservoirs upstream. Andredaki et al. (2014) discuss on the erosion of shoreline adjacent to the Nestos River mouth, in Greece due to the reduction of river sediment after the construction of big reservoirs upstream in the 2000s.

In Vietnam, in the past decades, in order to respond to the high demand of power on the fast economic growing, there have been several hydropower dams constructed in the upstream of rivers. Vu Gia-Thu Bon River system is the fourth potential power river in Vietnam. Besides irrigated dams, there are several small and large hydropower dams have been constructed in the upstream of Thu Bon River (ICEM, 2008). Hence, it is necessary to study how the erosion is occurring due to the reduction of sediment and the possible recovery if the sediment supply

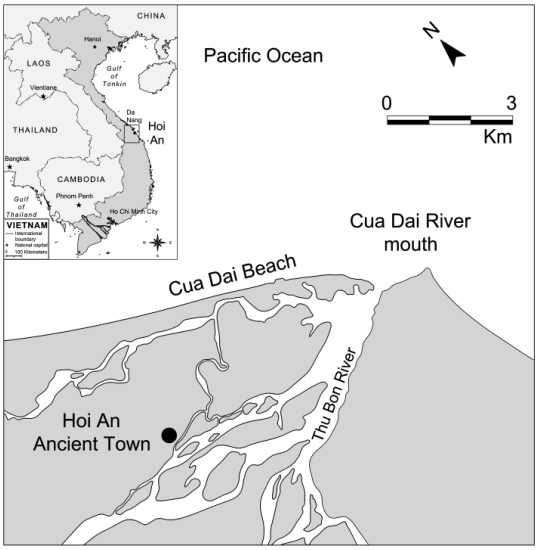

Fig. 1 Location map of study area

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recovered. This study attempts to present the theoretical analysis of the erosion occurred on Cua Dai Beach and the possible recovery through the analytical solutions of one-line model.

2. Study area and data collection

This study focuses on the beaches adjacent to Cua Dai River mouth, Hoi An City, Quang Nam Province, Vietnam (Fig. 1). Cua Dai is the name of river mouth where Thu Bon River pours into the Pacific Ocean. Thu Bon River has the length of 152km, the basin area of 4100km^2. Average annual discharge of Thu Bon River is about 327m^3/s. There is Vu Gia River basin which is next to the north side of Thu Bon River basin. There are two small rivers connecting and exchanging water between these two rivers. They are Quang Hue River and Vinh Dien River which are located about 30km and 20km upstream from the Cua Dai River mouth, respectively. Quang Hue River diverts apart of flow from Vu Gia River to Thu Bon River, and Vinh Dien River returns apart of flow back to Vu Gia River. Thus, Vu Gia River and Thu Bon River are commonly considered as a river system.

Detected shoreline positions are extracted from satellite images which are collected from Google Earth. Detailed analysis and results have been presented in Part I of this study (Viet et al., 2015).

3. Results and discussion

(1) Annual sediment yield of Thu Bon River and reduction amount

Sediment supply from river basin to river mouth area is the sediment source for the advancement of river delta shoreline. In the case of Thu Bon River, the sediment yield per square kilometer basin area per year is about 146m^3/km^2/year (ICEM, 2008). This value is adopted from Vu Gia River which has similar geographical features with Thu Bon River. According to that data, the total sediment yield per year from the basin of Thu Bon River is obtained as about 600,000m^3/year. This value is assumed to be constant over the years before the reduction, and utilized for the computation in the next parts.

The reduction of sediment supply to river mouth area can be related to several factors such as the construction of reservoir in the upstream, or the sand mining along the river, or the dredging sediment deposition at river mouth area. These factors have been observed in the Thu Bon basin and at the Dai River mouth area. As several hydropower reservoirs have been constructed in the upstream. Hence, it could be the main factor to reduce the sediment supply to the downstream. However, in order to obtain the high accuracy about how much contribution from each factor, it needs to conduct more study and more data also need to acquire. In this study, only the reduction amount is concerned. The reduction of sediment can be varied from around 25% (Miyahara et al., 2010) to around 85% (Andredaki et al., 2014) of the total sediment yield. In this study, the reduction amount is considered about 60% (reduction rate, R=0.6). This value is roughly selected based on past experiences, further investigation need to be done in order to obtain more accurate value.

(2) Formation of the Thu Bon River Delta

Figure 2 shows the morphology of the Thu Bon River Delta. The delta is formed when sediment from Thu Bon River deposits at the river mouth area. That formation process has been being occurring continuously over several centuries. The deposition of the sediment makes the advancement river delta

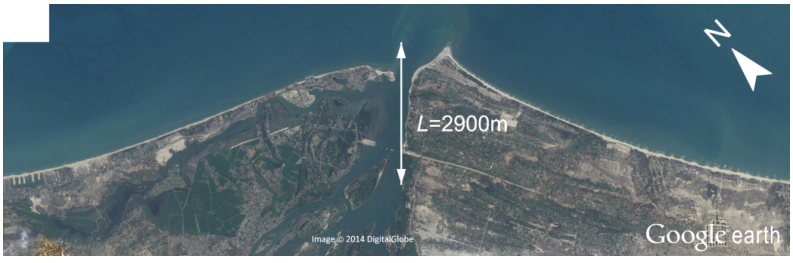

Fig. 2 Morphology of the Cua Dai River delta

shoreline. The length of the advancement over the past several centuries is roughly estimated as in Fig. 2 (L=2900m). During the formation process, sediment is transported from river mouth to both sides. In this case the longshore sediment transport is predominant. Hence, it can be described by one-line model. Governing equation of one-line model can be simplified as diffusion equation, Eq. (1), based on the following simplifications. The angle of wave breaking crests to local shoreline is supposed to be small, and breaking wave height is assumed to be constant along the coast.

$$\frac{\partial y}{\partial t}=\varepsilon\frac{\partial^2 y}{\partial x^2} \tag{1}$$

where x is the space coordinate along the axis normal to the trend of river; y is the shoreline position; t is the time; ε is the diffusion coefficient

Analytical solution of one-line model for the case of river delta formation is given by Larson et al. (1987) as Eq. (2). In this case, river mouth acts as a point source, and is assumed locating at x=0m.

$$y(x,t)=\frac{q_0}{D}\sqrt{\frac{t}{\pi\varepsilon}}e^{-x^2/(4\varepsilon t)}-\frac{q_0}{D}\frac{|x|}{2\varepsilon}\operatorname{erfc}\frac{|x|}{2\sqrt{\varepsilon t}} \tag{2}$$

where q_0 is the steady sediment discharge from river; D is the total of depth of closure and height of berm ($D=D_C+D_B$). In applying to the case of Thu Bon river, values of ε, q_0, D_C and D_B are to be assumed of 340m^2/day, 600,000m^3/year, 5m and 3m, respectively. Values of these parameters are adopted from other study area which has similar features. Thus, it is requested that the accurate values of these parameters of this study area for future study need to be estimated.

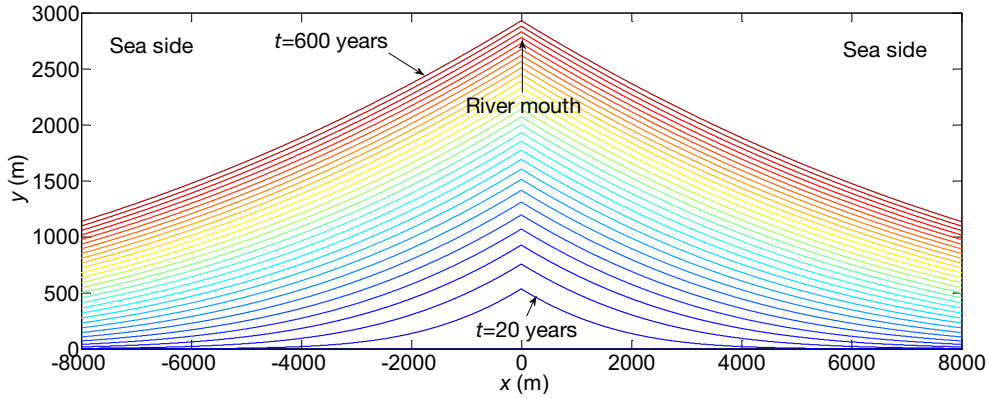

Fig. 3 Simulating the formation of the Thu Bon River Delta

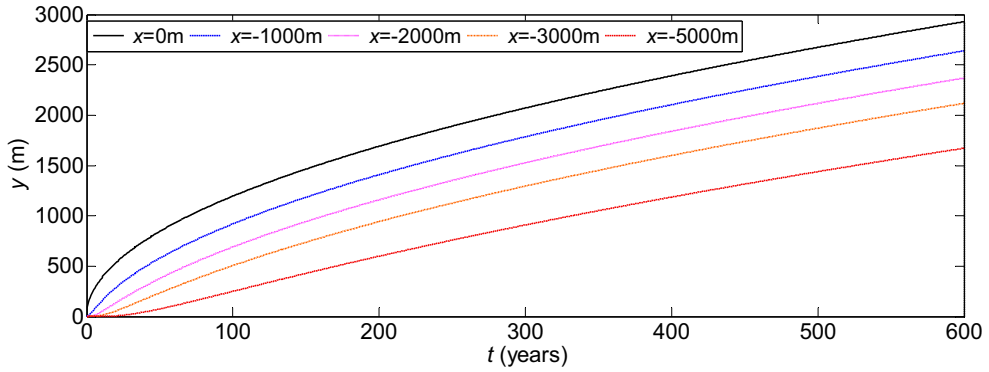

Fig. 4 Temporal variation of simulated shoreline positions in the formation of the Thu Bon River Delta

Figure 3 shows the simulated results of Thu Bon River Delta developing. The sediment from river mouth is transported to the beach on both sides; hence the shoreline is gradually advanced. Fig. 4 shows the temporal variation of shoreline positions at several transections on the left side. According to those results, the formation time of the Thu Bon River Delta is considered as about 600years.

(3) Shoreline retreat induced by the reduction of sediment supply from river

The reduction of sediment supply from river is considered as the factor causing the erosion of shoreline of river delta coast. From the results of latter part, the reduction is considered starting after the time t_1 = 600years of delta formation. Eq. (3) is the analytical solution of one-line model describing the evolution of shoreline when the reduction of sediment happening ($t > t_1$). It is the combination of Eq. (2), which describes the evolution of shoreline when $t \le t_1$, and the term representing for the reduction of sediment (the term in parenthesis in Eq. (3)). Since Eq. (1) is linear, thus the combination of Eq. (2) and the reduction term, Eq. (3), is also a solution.

$$y(x,t)=\frac{q_0}{D}\sqrt{\frac{t}{\pi\varepsilon}}e^{-x^2/(4\varepsilon t)}-\frac{q_0}{D}\frac{|x|}{2\varepsilon}\operatorname{erfc}\frac{|x|}{2\sqrt{\varepsilon t}}-\left(\frac{q_0R}{D}\sqrt{\frac{t-t_1}{\pi\varepsilon}}e^{-x^2/[4\varepsilon(t-t_1)]}-\frac{q_0R}{D}\frac{|x|}{2\varepsilon}\operatorname{erfc}\frac{|x|}{2\sqrt{\varepsilon(t-t_1)}}\right) \quad (3)$$

Viet et al. (2015) indicate that structures such as hotels and sheet pile seawall which were constructed

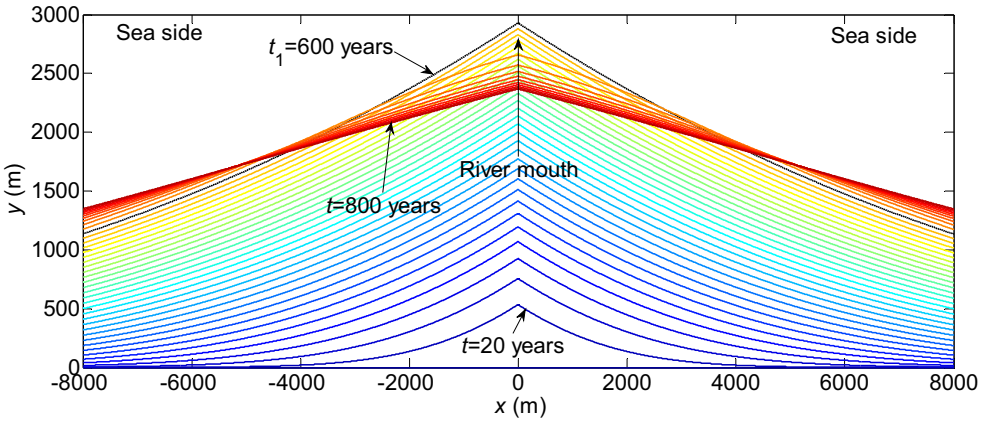

Fig. 5 Simulating the erosion of shoreline of Thu Bon River Delta induced by the reduction river sediment supply

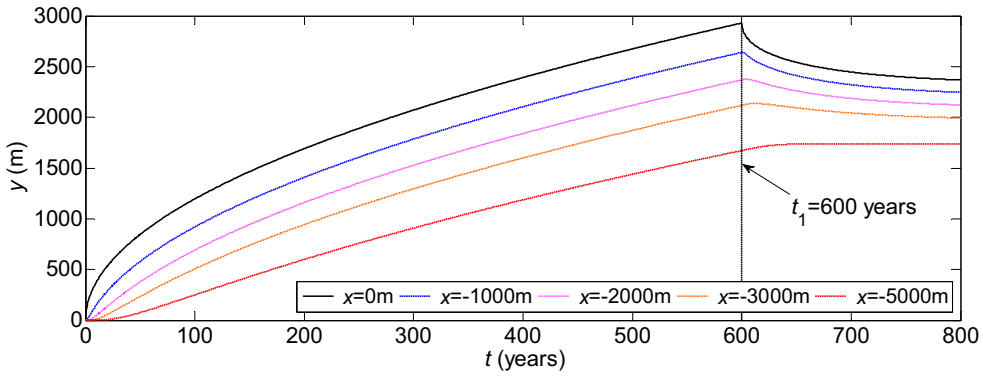

Fig. 6 Temporal variation of simulated shoreline positions of Thu Bon River Delta when occurring reduction of river sediment supply

along the beach, have influence on the surrounding morphology. Nevertheless, in this computation that influence is not taken into account.

Figures 5 and 6 show the evolution and the temporal variation at transections of river delta coast shoreline after a certain amount of sediment supply from river reduced, respectively. These results indicate that the erosion is most severe on the beach near the river mouth. It is reduced on the beach located farther from the river mouth. In addition, the deposing of sediment causing the advancement of shoreline can be observed on the beach far from the river mouth. The results discussed above are agreement with results of shoreline evolution from Viet et al. (2015).

(4) Shoreline advance when sediment supply from river recovery back to the condition before the reduction

Results in the previous parts indicate that the erosion of shoreline of Thu Bon River Delta Coast can be explained by the reduction of sediment supply from river. However, after some time when the solutions or policies have been applied and taken effect, the sediment supply from river can be recovered. Ideally case in this situation is the case which sediment supply recovers back to the condition before the reduction. It is assumed that the recovery back to the condition before the reduction takes place after 30 years of reduction (t_2=630years). The evolution of shoreline position of river delta coast when the sediment supply recovered ($t > t_3$) can be described by the analytical solution of one-line model as Eq. (4). It is noted that the evolution of shoreline positions when $t \le t_1$ and $t_1 \le t \le t_2$ are described by Eqs. (2) and (3), respectively.

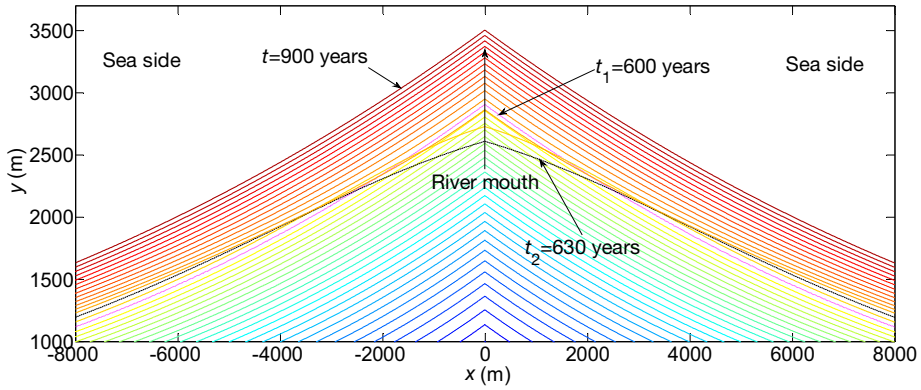

Fig. 7 Simulating the advance of shoreline of Thu Bon River Delta after river sediment supply recovering to the condition before the reduction

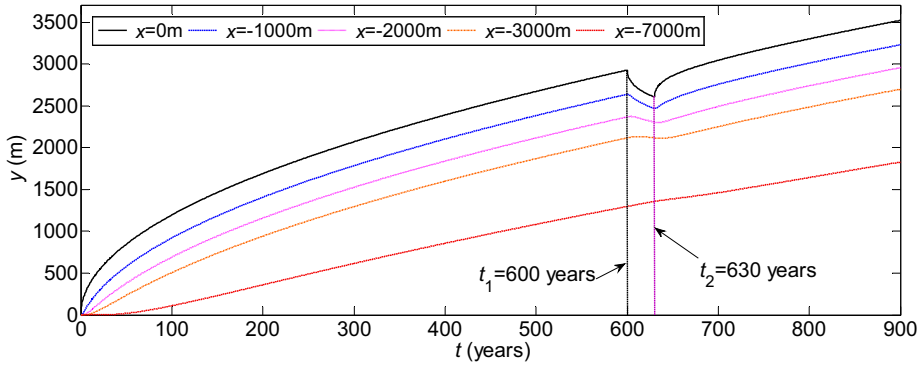

Fig. 8 Temporal variation of simulated shoreline positions of shoreline of Thu Bon River Delta after river sediment supply recovering to the condition before the reduction

$$y(x,t)=\frac{q_0}{D}\sqrt{\frac{t}{\pi\varepsilon}}e^{-x^2/(4\varepsilon t)}-\frac{q_0}{D}\frac{|x|}{2\varepsilon}\mathrm{erfc}\frac{|x|}{2\sqrt{\varepsilon t}}-\left(\frac{q_0R}{D}\sqrt{\frac{t-t_1}{\pi\varepsilon}}e^{-x^2/[4\varepsilon(t-t_1)]}-\frac{q_0R}{D}\frac{|x|}{2\varepsilon}\mathrm{erfc}\frac{|x|}{2\sqrt{\varepsilon(t-t_1)}}\right)$$

$$+\left(\frac{q_0R}{D}\sqrt{\frac{t-t_2}{\pi\varepsilon}}e^{-x^2/[4\varepsilon(t-t_2)]}-\frac{q_0R}{D}\frac{|x|}{2\varepsilon}\mathrm{erfc}\frac{|x|}{2\sqrt{\varepsilon(t-t_2)}}\right) \quad (4)$$

Figure 7 shows the simulated result of shoreline positions of Thu Bon River Delta Coast when sediment supply recovered to the condition before the reduction. According to those results, shoreline is advanced again after the retreat due to the reduction of sediment supply.

Figure 8 shows the temporal variation of shoreline position at several transections. Evolution of shoreline near river mouth shows clearly the retreat in the period of sediment reduction and the recovery after the amount sediment supply get back to the previous condition. Whereas, shoreline on the beach farther side of river mouth get weaker erosion effect during the reduction period, and also shows weaker recovery. In contrast, shoreline position, which is far enough from the river mouth, e.g., x=-7000m, is advance in the reduction and recovery periods. That advancement even is accelerated in the reduction period due to the deposition of sediment which is transported from erosion area at the river mouth.

4. Conclusions

This study has made discussion on theory of the erosion of shoreline around the Cua Dai River mouth, Hoi An City, Vietnam. The amount of sediment supply from Thu Bon River is discussed. The formation of Thu Bon River Delta is reproduced through the analytical solutions of one-line model. The erosion mechanism owing to the reduction of sediment supply from river is presented based on analytical solution of one-line model. Moreover, it also simulates the recovery of river delta coast after the recovery of sediment supply. In this study, there are some parameters and data such as diffusion coefficient, depth of closure, annual sediment yield, sediment reduction amount, etc. are assumed quantitatively, however the simulated results of shoreline evolution is agreement with the measured data of shoreline change. For future study, the investigation on these parameters and data for this study area need to be done in order to obtain more details on the mechanism of the erosion.

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