MORPHOLOGICAL PROCESSES OF THE HAMLUONG RIVER ESTUARY, MEKONG RIVER, VIETNAM

Le Trung Thanh[1]

Abstract: *The Mekong River is one of the longest rivers in Asia, stretching from the snowy mountains of Tibet to the East Vietnam Sea, and its run off is the ninth largest mean run off in the world. The Mekong River flows into the East Vienam Sea through eight estuaries; the formations of these estuaries are influenced by the combination of the river's fluctuating flows, tides, waves, winds, as well as sea currents. These factors also lead to intricate evolution of river shore. The purpose of this study is to identify the erosion and deposition processes of the Hamluong Estuary in the Mekong River. The complex morphology evolutions have been affecting the livelihoods of local residents and the development of this economically important area, Southern Vietnam. In this research, MIKE 21, a numerical model, is used to simulate the morphological change of this estuary. After calibration, this model is applied to analysis the erosion/ deposition pattern of the Hamluong River Estuary. The key factors impacting the morphological evolution are identified, and the tendencies of erosion and deposition in the Hamluong River Estuary are found.*

Keywords: Morphology evolution; Lower Mekong River; Hamluong Estuary; Mike 21 FM-MT.

INTRODUCTION

The Mekong River originates in the snowy mountains of the Tibetan plateau, crosses through China's Yunnan province, and then forms the border between Myanmar and Laos. It continues south, constituting most borders between Laos and Thailand. Part way through Cambodia, the Mekong River combines with the TonleSap River in Phnom Penh. From there, the Mekong River divides into two main branches, flows into Southern Vietnam, and empties into the East Vienam Sea through nine estuaries. Hence, the Mekong River's local Vietnamese name is "Cuu Long" or translated to English, "Dragon with Nine Heads". However, the Bassac Estuary, one in nine estuaries of the Mekong River, was closed in the 1970s due to long-term sedimentation. In Southern Vietnam, the two primary branches of the Mekong River are the Tien River and the Hau River. These two rivers, along with their dense networks, mainly create a big delta. In the upstream region, the Tien River's cross-section is larger than the Hau River's. Consequently, 80% of the Mekong River's runoff flows through the Tien River. Nevertheless when crossing the Vamnao Channel, the Tien River transfers a large volume of water to the Hau River, and both mean discharges become equal. In the downstream region, the Hau River flows straight to the East Vienam Sea through two estuaries, whereas the Tien River's flow is oscillatory and tortuous through Vietnam's geology. The Tien River finally empties into the East Vienam Sea through six estuaries. This noticeable difference has encouraged the Hau River to become the main navigation channel from the East Vienam Sea to Upper Mekong River. Besides, the Mekong River Delta region in Southern Vietnam is a low plain and slight slope from East to West or North to South, with sunken land from Vietnam's border to the middle of Southern Vietnam. This area is strongly influenced by flood.

The tropical monsoon climate dominates in Southern Vietnam. The wet season is about seven months from May to November, followed by the dry season from December to April. The wet season is responsible for approximately 90% of the annual total rainfall. In this season, the dominant wind is the southwest winds. In contrast, that is the northeast wind in the dry

[1] *Corresponding author. Thuyloi University - Second base, Hochiminh City, Vietnam.*

season. With wind speed of about 5m/s, the northeast wind is stronger than the southwest wind. Some high-speed winds, east-northeast winds, happen with a maximum speed of up to 15-20m/s. The Mekong River’s runoff also shows another seasonal particularity. Over 85% of the Mekong River’s total annual runoff occurs during the flood season. The maximum discharge of the Mekong River is over 60000m^3/s in the wet season, but the minimum discharge is only 2000m^3/s in the dry season.

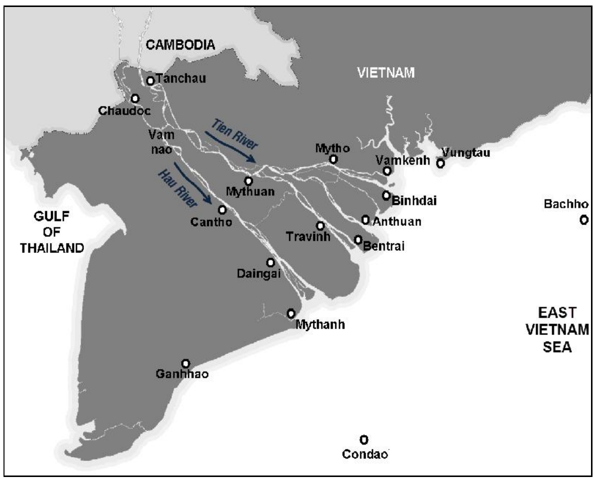

Figure 1. Mekong River’s estuaries, Southern Vietnam

In the middle of Southern Vietnam, the Tien River forms four distributaries: the Cochien River, the Hamluong River, the Mytho River, and the Balai River. Previous studies have shown that approximately 17% of Mekong River’s flow enters the East Vienam Sea through the Hamluong Estuary. One noticeable thing, most of the Mekong River’s distributaries have a pair of estuaries, such as: the Tieu Estuary and the Dai Estuary are from the Mytho River, the Cochien River separates the Cochien Estuary and the Cunghau Estuary, and the Hau River flows into the East Vienam Sea through the Dinhan Estuary and the Trande Estuary. But the Hamluong River forms only the Hamluong Estuary. Immediately prior to entering this estuary, the river straightens, and is accompanied by a narrow cross-section. This causes the current speeds to quickly increase, likewise increasing erosion and accretion in this region.

The tide is dominant at all of the Tien River’s estuaries, and there is a transition from fresh water to saline. At these places, the bed usually consists of very fine cohesive sediment, or mud. During the west season, silt is deposited. Some of this silt is resuspended in the channel during the dry season [1], [2]. Therefore, the suspended sediment concentration of the Tien River has some differences between two seasons. In the flood season, the mean suspended sediment concentration is approximately 0.15-0.25kg/m3, but this value dramatically decreases in the dry season to 0.07-0.1kg/m3. The suspended sediment concentration in the East Vienam Sea is much lower, at approximately 0.0001kg/m3. Previous studies have shown that the tide regime consists of semidiurnal macro-tides, tidal asymmetry, and waves driven by the monsoon [3], [4], [5]. The mean tidal range is 2.5m, and the mean wave height is 0.9m [6], [7].

There are two long shore currents corresponding with the two seasons in Southern Vietnam. The wet season is accompanied by a weak warm current from the Equator to the Arctic, while a cold current from the opposite direction predominates in the dry season. This cold current makes the sea level in the spring tidal is larger than that of neap tidal from 1 m to 3.5 m. It also leads salt water to intrude on 50 km upstream [8]. The predominant sediments in the Mekong River’s estuaries are clay and silt. Therefore, the shoreline is extremely sensitive to changes in the external conditions by deposition and/or erosion processes. These processes are coincident, and have occurred rapidly in recent years. Unexpected changes in morphology may affect the livelihood of local people and the development of this major economic interest area - Southern Vietnam. In the Mekong River’s estuaries, sedimentation is dependent on many factors, including river currents, suspended sediment from upstream, waves, wind, tide, sea currents, and human activities. Through complex interaction between these factors, the evolutions of the Mekong River’s estuaries are inestimable processes.

Due to the scarcity of measured data and poor application of the simulation model, the previous studies just sparsely pointed out the superficial characteristics of the sedimentary problems in the Mekong River Estuaries, including the Hamluong Estuary. Therefore, the tendencies of erosion and deposition in the Hamluong River Estuary have not been particularly clarified. In this research, MIKE 21, a numerical model, is used to simulate the morphological change of this estuary. After calibration, this model is applied to analysis the erosion/ deposition pattern of the Hamluong River Estuary, and the key factors impacting the sedimentation are identified. Consequently, the morphological processes of the Hamluong River Estuary are described in detail.

MODEL APPLICATION AND RESULT

Mike 21 Coupled Model FM description

MIKE 21 Coupled Model FM is a dynamic model system that can be applied to coastal and estuarine environments [9]. It includes the Mud Transport (Mike 21 MT), Sand Transport, the Particle Tracking models, the Hydrodynamic Module (Mike 21 HD), and the Spectral Wave Module (Mike 21 SW). Several of these models were used in order to research the morphological evolution of the Hamluong Estuary, such as, Mike 21 HD, Mike 21 SW, and Mike 21 MT.

Mike 21 Hydrodynamic module in Mike 21 is based on the numerical solution of the two dimensional incompressible Reynolds averaged Navier-Stokes equations with the assumptions of Boussinesq and of hydrostatic pressure. It comprises continuity, momentum, temperature, salinity, and density equations. The wind may be specified as a constant value for the entire area, or temporally and spatially varied values. The wind friction, Manning number and viscosity coefficient may be used as calibration parameters in the modeling [9]. MIKE 21 SW is particularly applicable for simultaneous wave prediction and analysis on regional scale and local scale. It is used in connection with the calculation of the mud transport, which for a large part is determined by wave conditions and associated wave-induced currents.

In the Tien River Estuaries, the mutual interaction between waves, wind, currents and tide is considerable. Thus, when Mike 21 HD and Mike 21 SW are simultaneously applied with variable water level in the tidal area, it is important that the correct water level is used in the wave simulation. This will ensure that the changes in wave conditions due to varying water depths resulting from the tides are properly modelled. The current field results of Mike 21 HD are not omitted for wave simulations. The current velocity results of Mike 21 HD have to be taken into consideration in calculating the propagation speed of the wave action. Furthermore, the effect of the current on the source functions is also taken into account. In this study the result of Mike 21 SW is the wave-induced current, which is generated by the gradients in radiation stresses. This wave-induced current is used as input in the classical hydrodynamic module [9].

The Mud Transport module describes the erosion, transport, and deposition of mud or sand/mud mixtures under the action of currents and waves. Waves and currents calculated by MIKE 21 SW and Mike 21 HD are included. In Mike 21 MT, the settling velocity of the fine sediment depends on the particle/floc size, temperature, concentration of suspended matter and content of organic material. With increasing concentration, collision between particles occurs more frequently and the cohesiveness of the particles results in formation of flocs. This leads to an increase in average particles/floc size with a growth of settling velocity, and consequently flocculation is formed. If sediment concentration increases further, the flocs maybe influence each other's settling velocity and the flocs can not fall freely. As a result, the hindered settling occurs, and the settling velocity is reduced. In addition, many other factors can increase or decrease the floc size. Salinity between 0 and 9 PSU can cause an increase in flocculation, but flocculation could not increase further when salinity exceeds 10PSU. However, the flocculation processes are reduced in fresh/brackish water, and a high level of turbulence can also decrease the floc size due to the destruction of flocs. The settling velocity could be reduced due to the smaller floc sizes. The relation for mass concentration $c \leq 10$ kg/m3 describes the flocculation of particles based on particle collisions [9].

Model Calibration

The long shore sediment transport between the Hamluong Estuary and the Tien River's other estuaries is a significant. Thus, appropriate selection of the modeling area included all of the Tien River Estuaries (Figure 2). The Mythuan gauge station was selected as the upstream boundary, while three downstream boundaries were at the Tien River's mouths. The bathymetry's data was provided by Second Base of Vietnam Water Resources University. In estuarine areas, the monsoon wind and waves are two important factors affecting the water level, current at the sea and transport of sediment [10].

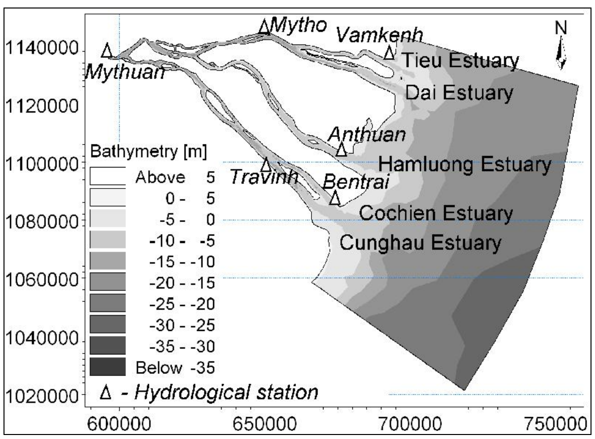

Figure 2. Simulation area of Tien River's estuaries

These factors were simulated in Mike 21 SW by collecting data from the coastal hydrology stations. The wind data of Vungtau station, close the north boundary (Figure 1), was opted. The offshore wave boundary condition was specified by the monthly wave height, wave period and main wave direction, were Bachho station's data (Table 1). For calibration, the Mike 21 SW result also was verified with survey wave data in 2003. The other momentous input data is salinity. In the sea water, salinity value is from 28‰-33‰, in this area. The minimum value is in August or September, and the maximum is April [7]. The saline intrusion in the dry season is significant due to tidal current; howbeit it is small in the wet season by the high fresh water flow [11].

Table 1. The offshore wave parameter, at bachho station

Month	Average heigth (H, m)	Average period (T, s)	Main wave direction
Jan	2.6	6.1	NE
Feb	1.9	5.7	NE
Mar	1.5	5.5	NE
Apr	1	5.1	NE
May	0.9	4.5	SW
Jun	1.4	5.1	SW
Jul	1.2	5.1	SW
Aug	1.5	5	WSW
Sep	1.8	4.8	WSW
Oct	1.5	5.9	NE
Nov	2.3	6	NE
Dec	3	6.4	NE

Through analyzing the result of previous studies and survey data, the constant value of upstream boundary salinity, in dry season and wet season, was 0.1‰ and approximate 0‰, whilst the monthly salinity data of Vungtau station was chosen as the downstream boundary condition.

The hydrodynamic model, wave model, and mud transport of the Tien River Estuary are firstly calibrated with observation data of water level, velocity, wave, and sediment concentration in September, 2009.

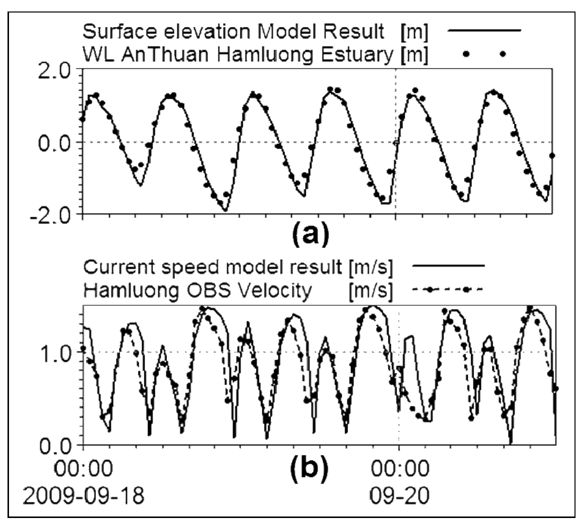

Figure 3. Computed water level and velocity result and observed (OBS) data.

The computed water level result is very little deviation (smaller 5%) from measured data at Anthuan (gauge station in the Hamluong River, see in Figure 2). Figure 3a shows that the two series of data (at Anthuan) have similar fluctuations with the amplitude of variation of the simulated results being unremarkable and traces smaller than that of measured water level. During that, the computed velocity result also received a good agreement with observed velocity data at the survey point, near Anthuan, and Figure 3b delineates the same order between computed results and observed data in current field.

The computed wave height result is also calibrated with measured data obtained from observation station, in the nearshore zone of the Hamluong Estuary. Figure 4 shows there is a discrepancy between the computed result and measured data. That discrepancy is due to the sparse wave data; the boundary wave conditions are based on the monthly averaged wave data. However, the fluctuations of measured data and computed results are reasonably similar. The calibration is acceptable given the available data, and indicates that the wave model can simulate wave effects in the study area. The performance of wave model may be improved with more observed data in further research.

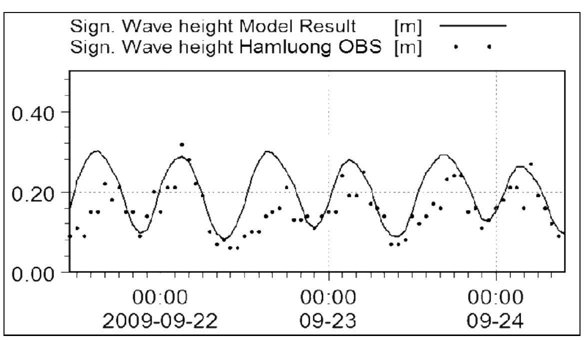

Figure 4. Computed wave height result and observed (OBS) data.

The model Mike 21 MT has been estimating the different site-specific parameters required. For the description of the vertical variation of the physical characteristics of the model bed, the number of bed layer was four unique layers, three soft mud layers and one hard mud layer.

Due to the lack of detailed studies and measurements, the parameters describing the settling velocity, erosion, and deposition processes were estimated by theory of Mike 21 MT model. By the mean suspended sediment concentration of the Tien River, the corresponding settling velocities were 0.0001m/s in the dry season and 0.0003m/s in the wet season. The critical shear stress for deposition varied from 0.08 to 0.12N/m2, befitted the different sediment characteristics in the research area [9], [12]. Basically, the critical shear stress for erosion is influenced by not only sediment characteristics but also parameters of bed layers [9], [13], [14].

The values applied varied from 0.15 to 0.35N/m^2 and 1.5N/m^2 for the bottom layer. The erosion coefficient (E) is a proportion factor governing the speed of erosion. It is set at 0.000005kg/m^2/s for all three soft mud layers, and 0.0001kg/m^2/s for hard mud bed. The α coefficient is also set the erosion rates will evolve exponentially. The α coefficient is recommended in the range 4-26m.N$^{-0.5}$, hence the calibrated value was 5m.N$^{-0.5}$, applied for all three soft mud layers.

The computed sediment result and observed data, near Anthuan gauge station, are shown in figure 5. The variations of the computed and observed series are similar and concurrent. The maximum measured data value is slightly larger than the corresponding model prediction, whereas the minimum observed data and computed result have almost the same value. Considering the uncertainty in measurement, the model is well calibrated.

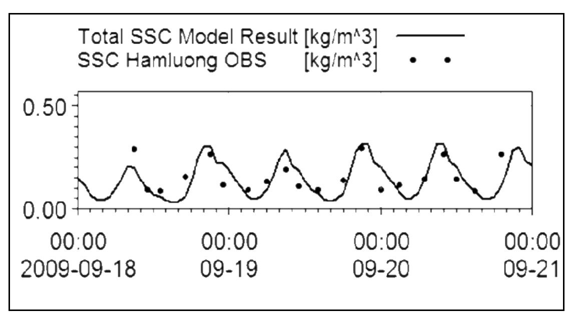

Figure 5. Computed suspended sediment concentration (SSC) result and observed (OBS) data.

The agreement between computed results and observation data in hydrodynamic (water level and velocity), wave, and mud transport inform September 2009, indicates that the hydrodynamic, wave, and mud transport models are well calibrated.

Result and Discussion

In order to investigate the morphological processes of the Hamluong Estuary, the input data are chosen as follows: the measured data at Mythuan, from 2001 to 2005, showed that the Tien River's flow acted peculiarly in 2001. In this year, the Tien River's mean wet season discharge was highest in this time period, while in the same year the dry season's mean discharge was the lowest. Therefore, hourly time series of water level, in two seasons from 1 Jan to 31 Dec 2001, were used as the boundaries conditions.

The computed results remark that, the analyzing current filed and sediment transport in the Hamluong Estuary should be divided in two parts. The first past is around the Dat Islet, where river current reigns. The second part is river mouth and seashore of the Hamluong Estuary, where river current interacts with sea current, waves, wind, and tides. Table 2 recaps the Mike 21 HD result in 2001, and it shows that the current velocity in the Hamluong River was larger than that in river mouth. In the wet season, the maximum value of velocity, in right side of the Dat Islet, peaked to 1.302 m/s, whereas that value was 0.791 m/s, in midstream of river mouth. This decline of velocity was due to the interaction of river currents and sea currents. The other prominence was that velocity of the dry season was about 10-15 % smaller than that of the wet season, around the Dat Islet. During that, velocity was little different between two seasons, in river mouth and seashore. The difference current speed between the left and the right riverbank of the Hamluong River's mouth was significant, in Table 2. If the mean current speed value was about 0.33 m/s in the left side of river mouth, that value was very small in the right side in both seasons so the right riverbank was expanded. In addition, the Hamluong Estuary's form is one of the influence factors on current filed in river mouth. Since the right river bank is more bulging into the sea than the left river bank, it creates a helical flow with small velocity in the left seashore. The mean current speed in the left seashore was approximate 0.07 m/s; and was very smaller than that mean value in the right seashore, was over 0.12 m/s, in the Hamluong estuary. It caused the accretion rapidly occurred in the left seashore. The Mike 21 SW results showed the inducement of wind field on the wave height was significant. In the northeast wind season, the waves associated with the winter monsoon current. Thence, the off shore wave height could reach over 2 m. The direction of the waves varied from west southwest in the southwest wind season, the values of wave height were smaller, and it decreased steeply from off shore zone to nearshore zone.

Table II. Typical result of Hydrodynamic model

Location	Current Speed in dry season (m/s)			Current Speed in wet season (m/s)		
	Min	*Max*	*Mean*	*Min*	*Max*	*Mean*
Dat Islet – Right branch	0.016	1.138	0.515	0.009	1.302	0.564
Dat Islet – Left branch	0.007	0.942	0.429	0.008	1.079	0.469
Bentrai Station	0.005	1.058	0.434	0.003	1.183	0.476
River Mouth – Right bank	0.000	0.313	0.041	0.000	0.261	0.040
River Mouth – Midstream	0.010	0.720	0.241	0.011	0.791	0.267
River Mouth – Left bank	0.019	0.769	0.328	0.017	0.846	0.338
Right Seashore	0.009	0.425	0.121	0.009	0.415	0.113
Left Seashore	0.004	0.424	0.070	0.005	0.329	0.069

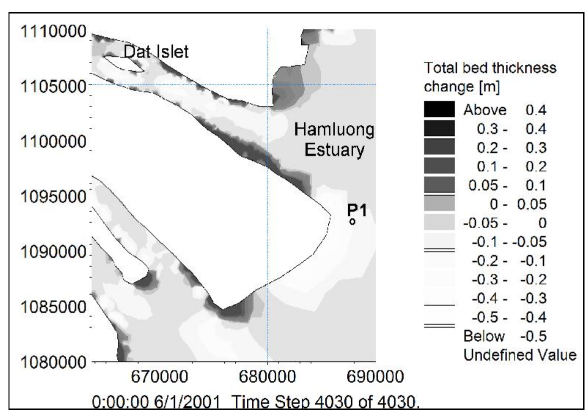

Figure 6. Model result map of total bed thickness change in in the dry season, 2001, Hamluong Estuaries.

The movement of suspended sediment was the same as current field from analyzing the Mike 21 MT results. In the wet season, when river current was stronger than sea current, the suspended sediment was moved to river mouth and deposited out of river mouth, where river current were degraded. In the dry season, sea current overthrew river current. Hence, the suspended sediment was not expanded. In the nearshore zone, under the impacts of monsoon wave-induced currents, sea currents, tide, and excess of river current, sediment transport also may be divided in to two components by direction: cross-shore and longshore [16], [17].

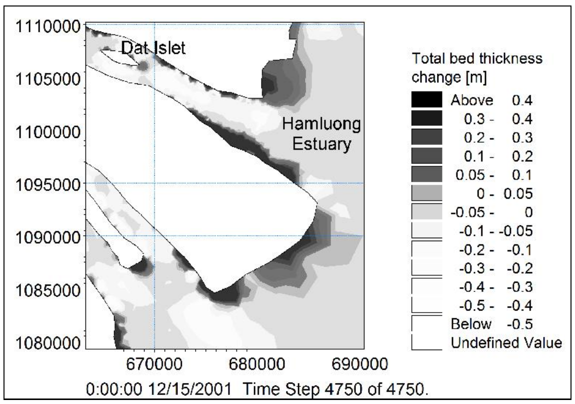

Figure 7. Model result map of total bed thickness change, in the wet season, 2001, Hamluong Estuaries.

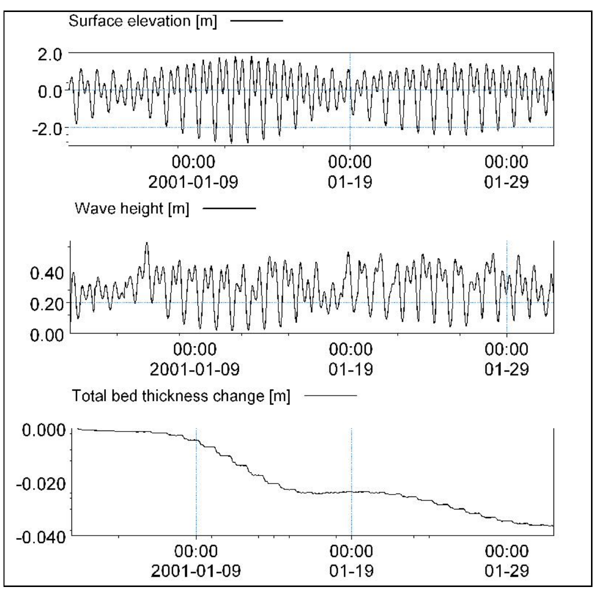

Figure 8. Surface elevation, Sign. Wave height and bed thichness change at point P1 - Figure 6

The cross-shore transport is mainly created by the wave orbital motion; the longshore transport is driven by the East Vienam Sea seasonal currents. In the dry season, the nearshore currents have same southward direction with cold sea currents. It causes the neashore current velocity of in the dry season larger than nearshore current velocity in wet season and it dominates. Besides that, saltwater intruded widely into mainland in the dry season, and made flocculation. The salinity distribution impacts on the sediment transport through baroclinic circulation convergence in estuaries. The deposition of sediment and suspended sediment concentration maxima are typically found near the limit of the salinity intrusion [1], [2]. The sea current and salinity lead out of river mouth to become deficient suspended sediment. Figure 6 reveals suspended sediment slightly deposited in river mouth and the erosion occurred in the right shoreline of the Hamluong Estuary. This erosion was due to impact of the strong cold sea current and monsoon waves. The computed results point out that the influence of sea current was exceeding harm in spring tide, if it coincided with high monsoon waves, the shoreline was easily broken. Figure 8 shows the surface elevation, significant wave height and bed thickness change in nearshore zone of the Hamluong Estuary (point P1 in Figure 6), in January, 2001. This month is one of the highest months in the wave height. In Figure 8, the bed level is remained constant in neap tide, but it is immediately decreased in spring tide, although the significant wave height is approximately unchanged. Figure 7 shows the accretion considerably happened in the flood season 2001. By the high river discharge, the sedimentation processes in the flood season were different from that in the dry season. In main land, since the Hamluong River cross section is small around the Dat Islet, the erosion rapidly took place. During that, for larger cross section, the current velocity was small in two riversides, in river mouth. Hence suspended sediment well deposited there. Furthermore, the left and right shorelines are strongly aggraded. However, due to continually changing the direction of currents, the riverbed was scoured and the bed level significantly decreased. The Hamluong River cross-section was narrower and deeper like horseshoe shape. The calculated result of accretion, in river mouth, could reach over +0.4m; the erosion's value in the right and left branch around the Dat Islet were about -0.4m and -0.3m.

The previous studies show the same morphological processes with the result of this study. The measurement morphological evolutions of the Tien River Estuaries during a 6-years period 1998–2003 by SIWRR, pointed out the riverbank's change of the Hamluong Estuary. The riverbanks of two the Hamluong River's branches, around the Dat Islet, were considerably eroded. The erosion of the right branch was about 4-5m/year, and that value of the left branch was 1-2m/year [8], [11]. While the accretion remarkably appeared in the river mouth, the right riverbank expanded about 1-2m/year. Under application of satellite remote sensing technology and GIS in three periods: 1989, 2001 and 2004, showed the same result, the erosion took place in around the Dat Islet and the Hamluong River's mouth was consolidated [15]. All these processes can be also noticed in the computed results (Figure 6 and Figure 7).

CONCLUSIONS

This research focuses on the application of a numerical model to the morphology evolution of the Hamluong Estuary. The effects of flows, wave, and tidal variation on sediment transport are studied and the influence of these factors on erosion and accretion are evaluated. The result of this research identified the key factors of the Hamluong Estuary's morphology evolution. The interaction between monsoon wave-induced currents, sea currents, tide, and excess of river current mainly determine changing of shoreline. Whereas the influence of river currents, sediment discharges, semidiurnal macro-tides, tidal asymmetry, saline intrusion, and geological structure on river's topography are high.

The computed results show that the sedimentation processes is seasonal practicality. The river current in the flood season and the suspended sediment are main factors to govern the development of the narrow passage and sand bars at river mouth. In the wet season, by the high river flow suspended sediment is transported to the mouth of the Hamluong Estuary and deposited there. It aggrades the shoreline and forms barricades sand. However, the river current leads the riverbed to be eroded. In the dry season, a part of this sediment is roused up and southwardly moved by strong cold sea current. In the dry seasqon, the strong cold sea currents and northeast waves cause the shoreline sediment and recently deposited sediment to be unstable and raised into suspension. The suspended sediment is pulled into the sea, and moves southward. However, erosion is rapid in the Tieu and Dai Estuaries, whereas some deposition still occurs in the mouths of the Hamluong, in the dry season. The main reason for some deposition is the estuarial form. The Hamluong Estuary is indent and sheltered from the sea currents, hence the sediment is not impacted by the sea current to same degree as in the Tieu and Dai Estuaries. Moreover, due to the low river discharge in the dry season, saltwater intrudes widely into mainland. It raises flocculation and deposition of suspended sediment in the river, and reduces its propagation. In addition, tidal effect is an important aspect in creating the neap tidal trench and periodically altering the current's direction. It is a contributing factor to riverbed erosion.

As a result of this study, the erosion and deposition have been occurring strongly and complexly in the Hamluong Estuary. The cross section of the Hamluong River has been narrower by riverbed erosion, while the accretions of riverbanks and shorelines lead the Hamluong River to extend into the East Vienam Sea. By the high river discharge in the flood season, the suspended sediment is deposited in the Hamluong Estuary, it creates barriers sand in the north river mouth. In the Hamluong River, due to Dat islet is stretched, but the erosion on the both sides makes Dat islet be narrower. Since the south riverbank is bulging more than the north riverbank, the sediment easily settles in the low velocity region in the north river mouth, hence the north shoreline extends into the sea, while the south shoreline is eroded somewhat in the cap.

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Tóm tắt:

DIỄN BIẾN HÌNH THÁI CỬA SÔNG HÀM LUÔNG, THUỘC SÔNG MÊ KÔNG, VIỆT NAM

Sông Mê Kông là một trong những con sông dài nhất của châu Á, kéo dài từ dãy núi tuyết Tây Tạng (Trung Quốc) ra tới biển Đông (Việt Nam), bên cạnh đó lượng dòng chảy trung bình năm của sông Mê Kông cũng được xếp loại lớn vào hạng thứ chín trên thế giới. Sông Mê Kông đổ ra biển Đông qua tám cửa sông; Hình dạng của các cửa sông này chịu ảnh hưởng bởi sự kết hợp của các yếu tố dòng chảy sông từ thượng nguồn, thủy triều, sóng, gió và yếu tố dòng chảy hải dương. Các yếu tố này cũng là nguyên nhân dẫn đến sự biến đổi phức tạp của đường bờ. Mục tiêu của nghiên cứu này là chỉ ra quá trình bồi và xói tại cửa sông Hàm Luông thuộc hệ thống sông Mê Kông. Sự biến đổi phức tạp của hình thái cửa sông đang và sẽ tiếp tục ảnh hưởng đến cuộc sống của người dân địa phương cũng như sự phát triển của vùng kinh tế trọng điểm (đồng bằng sông Cửu Long). Trong nghiên cứu này, phương pháp mô hình toán (Mike 21) được sử dụng để mô phỏng sự biến đổi hình thái của cửa sông. Sau khi kiểm định, mô hình sẽ được áp dụng để phân tích đặc trưng bồi xói của cửa sông Hàm Luông. Các yếu tố chính ảnh hưởng đến sự biến đổi hình thái cửa sông sẽ được làm rõ, và xu thế bồi xói tại cửa sông Hàm Luông sẽ được chỉ ra.

Từ khóa: biến đổi hình thái cửa sông, hạ lưu sông Mê Kông, cửa sông Hàm Luông, Mike 21 FM-MT

Người phản biện: **PGS.TS. Nguyễn Cao Đơn**

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