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Field Investigations on River Bed Changes and Salinity Intrusion along Tien and Hau Rivers in Vietnamese Mekong Delta Considering Upstream Dams' Impacts

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Synopsis

In the Vietnamese Mekong Delta (VMD), river beds have been degraded and salinity intrusion has been increased. Hydro-, sediment and salinity dynamics modelling of a complex river network in the VMD requires detailed bathymetric, turbidity, and salinity data. Therefore, we conducted two field surveys in the flood and dry seasons of 2017-2018 to measure river bed elevations, turbidity and salinity concentrations along Tien and Hau Rivers due to lacking of homogeneous data available in the delta. The results show that thse rivers can be divided into upper and lower reaches according to the variations of river bed elevation, turbidity, and velocity. These parameters are high in the upper reach, decreased seaward while low in the lower reach, increased seaward. The beds of Tien and Hau Rivers have been significantly degraded due to upstream dam developments with a rapid rate recently. Salinity intrusion varies seasonally. Horizontally, high salinity concentrations appear in the middle of the river. Vertically, salinity concentrations are almost the same near the banks but markedly increase downward in the middle of the river.

Keywords: River bed degradation, bank erosion, turbidity, VMD, salinity intrusion

1. Introduction

In the catchment scale, river channels play a role as a conveyor to transport sediment from the erosion sports (mainly bare soil on the slopes) to the deposition sites downstream (Kondolf, 1997). River deltas where the river slopes are small receive eroded sediment from the upstream through the interactive processes between the flows and sediment. Increasingly accumulative sediment has expanded river deltas, i.e. Nile River delta, Mississippi River delta, Mekong River delta, for centuries. The sediment supply (through erosion process upstream) therefore governs the river morphology and shoreline landscape (Anthony et al., 2015).

Sediment supply to river deltas worldwide have been dramatically reduced due to natural processes and human interventions. The latter seems to dominate the phenomena. Hydropower infrastructures, climate change, sand mining, land use change are attributed to sediment deficit in river deltas. For decades, hydropower dams have been raising scientific concerns on the sustainable development of river basins. Kondolf et al. (2014) argued that hydropower dams trap all bedload and huge amount of suspended load, releasing the sediment-starved (clear water) flow downstream. Closure of Aswan High Dam in Nile River has trapped almost all of sediment from reaching to the Nile River delta (Milliman and Syvitski, 1992). Similarly, as much as 80% of the sediment budget has been reduced by Sobradinho Dam in San Francisco (Walling, 2006). The completion of only Manwan dam in the mainstream of the Mekong River has trapped about 50% of the sediment budget of the river (Lu and Siew, 2006).

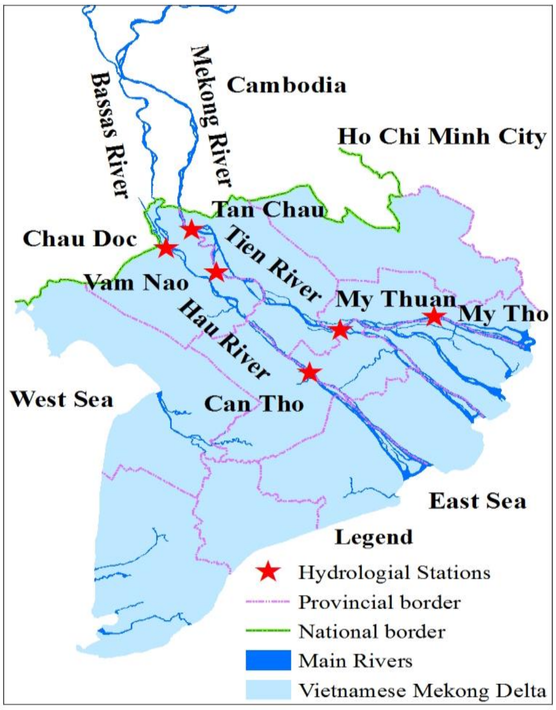

Fig. 1 Vietnamese Mekong delta: river network and hydrological stations

The sediment-starved flow below dams tends to erode river beds and banks to compensate for reduced sediment supply to balance with river sediment transport capacity. As a results, river beds tends to be deeper while river banks are supposed to be wider. River bed degradation may range from meters to dozens of meters for kilometers river long. For instance, Hoover Dam in Colorado River has caused a 7.1 m river bed degradation for 130 km downstream of the dam (Galay, 1983). In a lesser extent, the river bed has been lowered by 6.1 m for 52 km river long due to the completion of Davis dam in Colorado River (Galay, 1983). In addition, sediment grain size becomes finer due to dam constructions, which become vulnerable to be eroded due to strong flood flows. Sediment reduction can additionally cause coastline retreat, land subsidence which expose to flooding and sea level rise.

Development of hydropower dams in the upstream of the Mekong River (56 dams have been completed while around hundred dams are under construction or planned stages) have caused changes in the seasonal flows of the Vietnamese Mekong Delta (VMD) (Binh et al., 2018). Moreover, river beds are deepening while river banks are widening. Recently, river bank collapses appear frequently. For instance, Vam Nao channel bank was collapsed around 130 m long in 2017. As our measured data, the river bed of Tien River from TanChau to VamNao stations (Fig. 1) has lowered, on average, by 1.5 m from 2014 to 2017. Due to river bed degradation, water levels in the rivers are lower causing disadvantage for irrigation and ground water recharge in the VMD. Water level reduction together with river deepening and widening has increased salinity intrusion in the VMD more frequently. For instance, drought event in 2015-2016 accompanied by disastrous salinity intrusion has caused detrimental damages to agriculture and livelihoods of millions of people in the VMD (Kantoush et al., 2017).

Although the rivers in the VMD are severely changed due to dam constructions upstream, little study has quantified the impacts. Most of previous studies quantifying the dam impacts based mainly on results of numerical simulations. However, the available topography and cross section data for the whole VMD are limited. Moreover, large scale hydrodynamics modelling of a complex river network and floodplains in the VMD requires detailed bathymetric, water level and discharge data. Therefore, we conducted two field surveys: (1) one in August 2017 to measure discharge, velocity, water levels, river bathymetry and sediment concentration along 570 km of Tien, Hau Rivers and VamNao channel, and (2) one in March 2018 to measure salinity concentration along 45 km along DinhAn and TranDe branches in Hau River. The objective of the field surveys is to comprehensively understand the fluvial-tidal interactive processes of the flow, sediment, and salinity dynamics in the VMD. Such measured data will be then used as boundary conditions for the two numerical models: (1) 2-dimensional hydro-sediment dynamics model to investigate morphological changes and (2) salinity dynamics model to investigate the mechanism of salinity intrusion in the VMD due to upstream dam development.

2. Regional setting

The Mekong River (MR) originates from the Tibetan Plateau and runs through 6 countries: China, Myanmar, Lao PDR, Thailand, Cambodia, and Vietnam. It is the 8th and 10th largest river in the world in terms of discharge and sediment load, respectively. The total catchment of the Mekong River Basin is shared by 24% from the Upper Mekong Basin, mainly from China, and by 76% from the Lower Mekong Basin such as Thailand, Lao PDR, Cambodia, and Vietnam. The Upper Mekong Basin contributes 18% of the mean annual flow to the MR while up to 75% of the low flow to Vientiane in Lao PDR and over 40% of the lowest flow at Kratie in Cambodia (Adamson et al., 2009). The hydrology in the Lower Mekong Basin is characterized by the wet season (May-October) and dry season (November-April of the following year). The wet season transports about 90% of the flow with an average discharge of 45,000 m^3/s while the dry season conveys about 15% of the flow with an average discharge of 15,000 m^3/s (Lu and Siew, 2006), controlled by the snowmelt in the Upper Mekong Basin.

From the last 200 km of the MR, the VMD has been formed through an abundant suspended sediment originated from the upstream since the last 6,000 years (Ta et al., 2002). The sediment budget of the VMD in the natural stage (pre-dam condition) is approximately 160 Mt/yr (Kondolf et al., 2014). The MR splits into two branches when entering the VMD, namely the Tien and Hau Rivers (Vietnamese names of Mekong and Bassac Rivers). Tien and Hau Rivers are about 250 and 220 km long, respectively (Kantoush et al., 2017). The former conveys about 80% of the flow to the VMD while the latter conveys the remaining 20% (Fig. 1). The VMD has a relatively dense river network, mainly constructed during the last century to increase the irrigation capacity for agriculture expansion, with a total length of 88,000 km (Hung et al., 2013). In the VMD, the flood season prolongs for about 6 months from June/July to November/December and the dry season lasts for another half of the year. Mean discharges of Tan Chau and Chau Doc stations are 9,940 and 2,490 m^3/s, respectively, which divide the hydrographs of the VMD into the rising stage (April-September) and the falling stage (October-March of the following year).

The VMD’s terrace is low (Binh et al., 2017). The mean elevation is 0.7-1.2m above mean sea level. The highest elevation is in the upper part of the delta where it can reach to 2.0-4.0 m. As moving downstream, the elevation is reducing, averaging of 1.0-1.5 m in the middle and dropping to 0.3-0.7 m at the areas around the estuary.

The VMD is interactively influenced by the inflow from the main stem MR and the tide from the East and West Sea of Vietnam. In flood season, the inflow is dominant, providing rich sediment resources to the delta. However, floods also cause inundation to a wide extent, usually about half of the delta. In the dry season, the flow from the upstream is limited. Therefore, the tide is dominant. The strongest tidal season can affect up to Vietnam-Cambodia border. Average tidal magnitude at river mouths of VMD is 2.2 m with a maximum of 3.2 m (Wolanski et al., 1996). Dry seasons accompanied by salinity intrusion cause huge damages to agriculture and aquaculture in affected regions (about half of the delta area). Recently, the VMD experienced a historical drought event accompanied by the highest salinity intrusion over the last 90 years (Kantoush et al., 2017). Water levels reduced by meters compared to other years (**Fig. 2**), leading to salinity intrusion length about 20-25 km more than average value (Kantoush et al., 2017) which has caused damages to 400,000 ha rice crop, 13,000 ha cash crops, 25,500 ha fruit gardens, and 14,400 ha aquaculture and caused shortage of freshwater for 208,394 households (CGIAR, 2016).

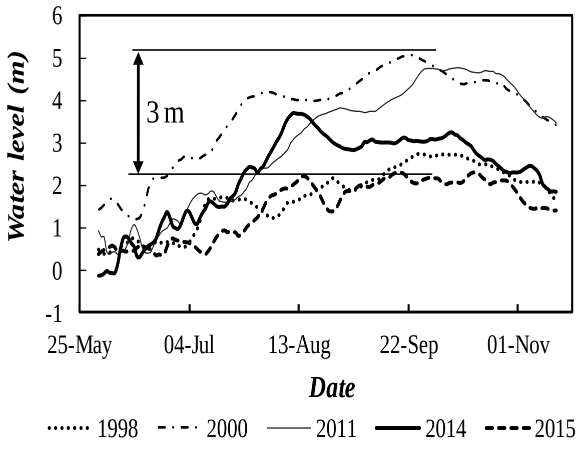

Fig. 2 Measured water level in flood season at Tan Chau

Agriculture, i.e. rice crops, is the main economic sector in the VMD. Two or three rice crops are cultivated annually. The VMD is therefore considered as the *rice bowl* of Vietnam (Ziv et al., 2012), supporting about its 17 million citizens. It provides 50% food and fruit for the whole country. It also contributes 90% of Vietnam's rice production and is the second largest rice exporter in the world (Anthony et al., 2015).

3. Field measurement instruments

We conducted a field survey in August 2017 along about 570 km in main rivers in the VMD, including Tien, Hau rivers and VamNao channels (Fig. 3) to measure the river bed elevations at selected cross sections, velocities, discharges, water levels, turbidity, and salinity. Various instruments were used such as Acoustic Doppler Current Profiler (ADCP), GPS, turbidity, and salinity meters. Each instrument used will be described in subsequent sub-sections. In total, 200 cross sections were measured with the distance between adjacent cross sections ranging from hundreds to thousands meters.

Fig. 3 Measurement path of the field survey

Fig. 4 Measurement instruments for the field survey

3.1 Acoustic Doppler Current Profiler

We used a boat to move along four river mouths of the VMD (CoChien, CungHau, DinhAn, and TranDe) to the upper parts at TanChau and Chau Doc stations (Fig. 3). A Teledyne RD Instruments Workhorse Rio Grande 600 kHz Acoustic Doppler Current Profiler was used to measure the river depths and 2-dimensional velocities. The ADCP was mounted at 0.3 m under the water surface on the boat side. A Trimble GPS with an antenna was combined with ADCP (Fig. 4). These devices connected to a field computer to control the speed and direction of the boat. We measured both along and across the rivers as the boat moving. The raw data were then processed using Teledyne RD Instruments WinRiver II software. The results were a set of river bed elevation, 2-D velocities, discharges at 200 cross sections along 570 km river long. Noticeably, the discharges were secondarily estimated through river cross section area and velocity.

Fig. 5 Infinity-ATU75W2-USB turbidity meter

3.2 Turbidity measurements

An Infinity-ATU75W2-USB turbidity meter (Fig. 5) was attached aside the ADCP (Fig. 4) to measure the turbidity along and across the Tien River from river mouths (CoChiena and DinhAn) to CaoLanh station which is about 130 km from the river mouth (Fig. 3). The turbidity meter recorded the turbidity once every 2 minutes. Ten readings were set up for every recording with an interval of 1 second. The results of the measurement are instantaneous turbidity along and across the Tien River. Besides that, time series of turbidity were also available at the several points where we were at rest and/or sleeping. This kind of data can capture a half of daily tidal circle.

Fig. 6 Route of salinity measurement along DinhAn and TranDe branches in Hau River: 64 points

Fig. 7 CastAway- CTD salinity meter

3.3 Salinity measurements

Four salinity instruments were used to measure salinity concentrations along 45 km along DinhAn and TranDe branches of Hau River (Fig. 6) during 4 days in the drought from March 2, 2018 to March 5, 2018. The selection of 45 km as a limit because the salinity concentration is negligible upstream of this point. These instruments are (1) Infinity- ACTW – USB-0628 (Fig. 5), (2) CastAway – CTD version 1.5 made by SonTek/YSI Inc (Fig. 7), (3) Pro30 and (4) ProDSS of YSI Professional Series instrument (Fig. 8).

The infinity-ACTW and ProDSS salinity meters recorded data once every 1 minutes, while CastAway-CTD and Pro30 measured in cross sections having an interval of 2 km long. Only CastAway-CTD could measure vertical salinity profiles from the surface to the bottom and recorded data at every 0.3 m. Infinity and ProDSS meters were mounted at a fixed point of 1.35 m below the water surface while Pro30 was hung on at 1.25 m below the water surface (Fig. 9).

Fig. 8 ProDSS and Pro30 salinity meters

Fig. 9 Setup of salinity meters

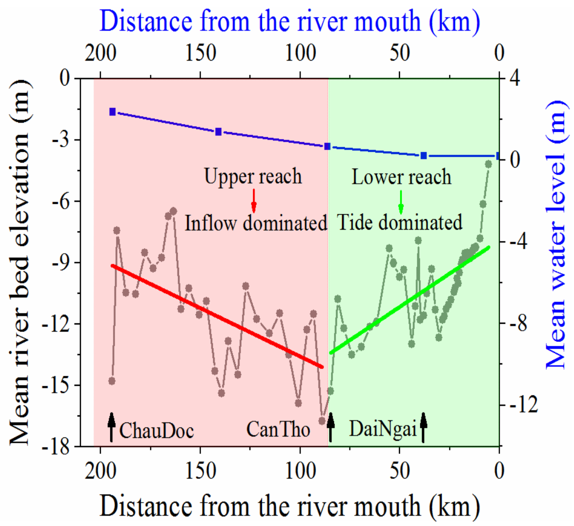

Fig. 10 Water level and river bed elevation along Hau River

4. Results and discussions

4.1 River bed elevation

The river bed elevation of Tien and Hau Rivers is very much variable, ranging from several meters near the river mouths to more than 30 meters in the upper parts (Fig. 10). The deepest point in Tien River is at a location about 2 km upstream of MyThuan station (46 m deep) while the deepest river bed in Hau River is just upstream of CanTho station (-31 m deep). The river beds are shallowest around the last 15 km near the river mouths (Fig. 10). This trend is similar with the results of field survey in 2015 conducted by Gugliotta et al. (2017) although the absolute river bed elevation is different. There are two clear reaches in terms of river bed elevation. The dividing points are at MyThuan station in Tien River and at CanTho station in Hau River. The upper reach is deep and decreasing seaward. It is dominated by the inflow from the main stem of the MR. On the other hand, the lower reach is shallower, increasing seaward. It is dominated by the tide. It is noticeable that after reaching the deepest elevation at around MyThuan and CanTho stations in Tien and Hau Rivers, respectively, the river bed immediately become shallower as the river moving downstream. In the upper reach, Tien River has a steeper slope than Hau River with a mean slope of 0.013% and 0.0088% respectively. Similarly, the lower reach of Tien River is also slightly steeper than that in Hau River with a mean slope of 0.019% for the former and 0.013% for the latter.

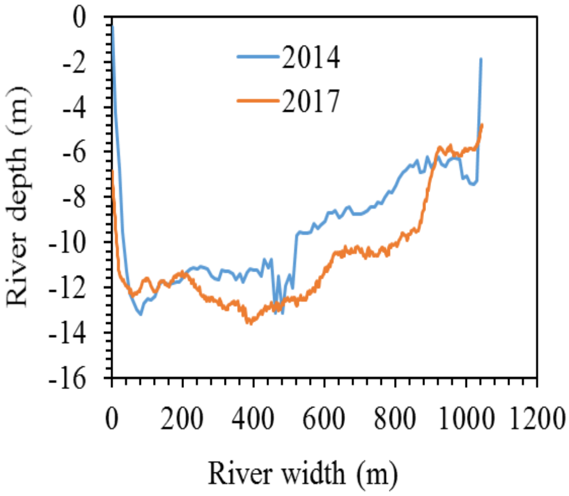

Fig. 11 Typical river bed degradation in Tien River

The river bed of Tien and Hau Rivers have been remarkably degraded. For instance, a comparison of river beds measured in 2014 and 2017 from TanChau to around VamNao station (Fig. 1) shows that the river bed, on average, has been reduced by 1.5 m. A typical of river bed degradation is shown in Fig. 11. This translates to a degradation rate of 0.5 m/yr. On the other hand, Brunier et al. (2014) reported a mean river bed degradation of 2.47 m from 1998 to 2008 in the similar area. That means the degradation rate is 0.25 m/yr. It is clear that the river bed degradation rate is much faster recently compared to the past (twofold faster). Such river bed degradation is attributed to a reduction in the sediment supply from the upstream of the MR which annually provides about 160 Mt/yr sediment load to the VMD (Kondolf et al., 2014). However, such huge sediment supply has been significantly reduced by hydropower dams in the upper Mekong basin, especially due to six mainstream dams in the Chinese territory. For example, only Manwan dam (the fourth largest among six mainstream dams) has caused a reduction of about 50% of the sediment budget of the MR (Lu and Siew, 2006). Our long-term sediment data reveal that the sediment budget of the VMD has been reduced by 83% in comparison between year 2015 (when all six mainstream dams are in operation) and pre-1992 (pre-dam period). It is worth noting that only four mainstream dams have been completed by 2008 while other two dams completed in 2011 which can explain why river bed degradation occurred very fast nowadays. The river bed degradation rate is expected to accelerate in the future.

Fig. 12 Typical river bank erosion in Tien River

The flow released from dams is sediment-hungry (Kondolf, 1997) which tend to erode the river bed to compensate for what is trapped by the dams. Firstly, the sediment downstream close to the dams is eroded. Then it propagates downstream-ward. This process is so called “downstream progressing degradation” (Galay, 1983). Sediment reduction together with finer grain size due to dams will lead to a milder slope of the fluvial river downstream (Galay, 1983). River damming also alters the river from raided to meandering through river bank erosion. The degraded river bed make the river bank unstable to be collapsed or undermined (Kondolf, 1997). For example, the river width of Five Mile Creek in Wyoming has been widened by up to 300 m due to bank erosion (Galay, 1983). Bank erosion caused by river damming is also the case in the VMD. River bank along Tien, Hau, VamNao rivers and other many channels are experiencing erosion with a highly fast rate these days. Figure 12 shows a typical bank erosion taken in Tien River during our field survey in August 2017. Besides caused by local interventions, it is supposed due to mainly the consequence of sediment-starved water released from the upstream dams. It is well-known that the impacted processes of river damming on river bank erosion occurs for years or decades during dam operation. The time since the completion of the first dam till the last dam in the mainstream in the upper MR up to now is long enough for the VMD exposing to erosion. Consequently, livelihoods of local citizens are threatened.

4.2 Hydrodynamics

Longitudinally, the water levels of both Tien and Hau Rivers are reduced seaward (Fig. 13). The difference between two sides of the survey area is about 3 m in Tien River and 2 m in Hau River (Fig. 13). The water level variation in Hau River is smoother than that in Tien River because the river bed in Tien River is more changeable than that in Hau River, indicating that river bed of Tien River is more sensitive to changes (mainly reduced) of sediment supply from the upstream because about 85% of the sediment supply to the VMD from the upstream is transported through Tien River before VamNao channel. Moreover, the water level in Tien River is much steeper than that of Hau River. In Hau River, the water level is, on average, 1.36% steep, except for a gentle slope in the last 40 km near the river mouths of 0.025%. In Tien River, the water level is very steep from TanChau to MyThuan (2.4%) and a slightly milder from MyThuan to the river mouth (0.45%). Interestingly, the water level is exceptionally steep from VamNao to CaoLanh station with 4.45% slope.

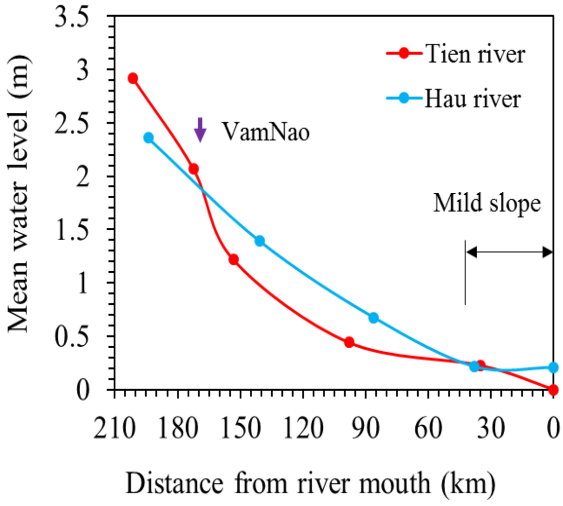

Fig. 13 Mean cross-sectional water levels in 8/2018 along Tien and Hau rivers

Along the first 35 km from TanChau and ChauDoc stations, Tien River has higher water levels than Hau River. For instance, mean water level at TanChau station in August 2017 is 2.92 m compared to that of 2.36 m at ChauDoc station in the same period. That together with an about fourfold larger in the discharge, a portion of the flow in Tien River is shared to Hau River through VamNao channel (Fig. 1) that maintains the flows of the two rivers downstream equally. However, downstream of VamNao channel, water levels in Tien River drop significantly and are lower than those in Hau River. This may be explained by combined effects of discharge and river bed elevation between the two rivers. Specifically, while the flow rates between Tien and Hau Rivers after VamNao channel is almost equal, the river bed of Tien River is deeper than Hau River. Moreover, downstream the bifurcation point near MyThuan station, Tien River splits into six branches (Tieu, Dai, BaLai, HamLuong, CoChien, and CungHau) compared to only two branches in Hau River (DinhAn and TranDe), therefore the discharge of each branch in Tien River is much smaller than that in Hau River. Allison et al. (2017) reported that DinhAn branch conveys the highest discharge among the eight branches.

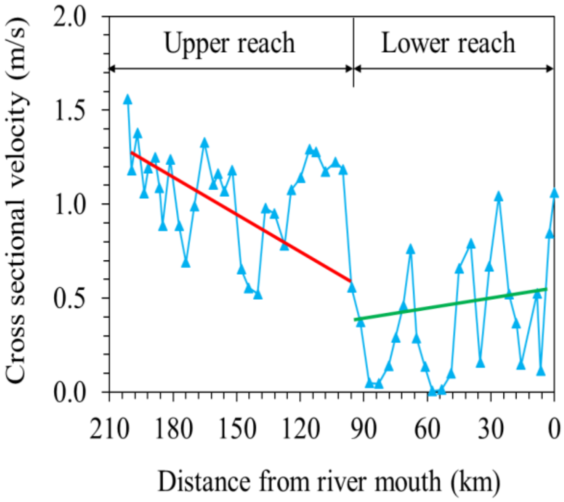

Fig. 14 Mean cross-sectional velocity along Tien River in 8/2017

The field survey has measured continuously for several days which captures the tidal cycles. Therefore, it is not concrete to compare the instantaneous cross-sectional discharges and velocities along Tien and Hau Rivers. However, despite of such discrepancy, there are different trends in the mean cross-sectional discharges and velocities in the upper and lower reaches (Fig. 14). Mean cross-sectional discharges and velocities in the upper reach is higher than those of the lower reach. For example, the mean cross-sectional velocity at TanChau station is 1.56 m/s while that at the river mouth of CoChien branch is only 1.05 m/s. Bot cross-sectional discharges and velocities in the upper reach are decreased seaward while those in the lower reach are increased seaward. These trend are similar with the river bed elevations as discussed above.

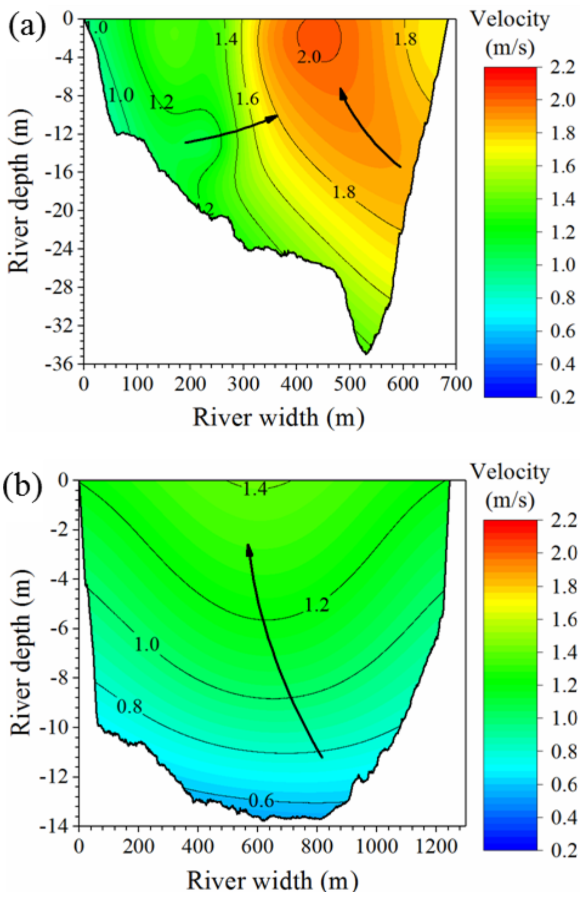

Fig. 15 Representative vertical velocity profiles of (a) upper reach and (b) lower reach in Tien River

Shapes of cross sections in the upper reach are also much different from those in the lower reach (Fig. 15). While the upper reach has asymmetric cross sections (Fig. 15a), the lower reach has symmetric cross sections (Fig. 15b). Accordingly, the vertical velocity profiles are also much different between two reaches. The velocity is very high, in general, in the upper reach. High velocity mainly concentrates in one side of a cross section and also stretches to the river bed (Fig. 15a). For instance, velocity near the river bed at TanChau station is up to 1.4 m/s which strongly links to the sediment transport capacity of the flow in this reach. On the other hand, the high velocity in the lower reach tends to concentrate in the middle of a cross section while the velocity values are small in general (Fig. 15b). Relatively, the ratios between lowest velocity (near the bed) and highest velocity (near the surface) are around 0.6 and 0.4 in the upper and lower reaches, respectively. Another important finding is that due to cross section asymmetry, the river banks in the upper reach are more susceptible to erosion than river banks in the lower reach. This explains the fact that severe erosions have been taken place in the upper reach only.

Fig. 16 Difference in water color between dry and flood seasons

4.3 Temporal and spatial variations of the turbidity in the VMD

The turbidity in the VMD is much changeable seasonally. The turbidity in flood season is about 8 times larger than that in the dry season. For instance, the dry season turbidity at TanChau station in 2013 is 17 mg/l while the turbidity in the flood season in the same year at this location is 141 mg/l. As a results, the water is much clearer in the dry season compared to the flood season (Fig. 16). This seasonal variations is controlled by the interactions between fluvial and tidal processes (Gugliotta et al., 2017). Depends on the season, the tidal flow is high or less turbid which controls the import or export of the sediment into the river or out to the sea. Gugliotta et al. (2017) found that the exporting flow is stronger than the importing flow, indicating that the flood flows carrying high sediment from the upstream are extremely important for maintaining the landscape of the VMD.

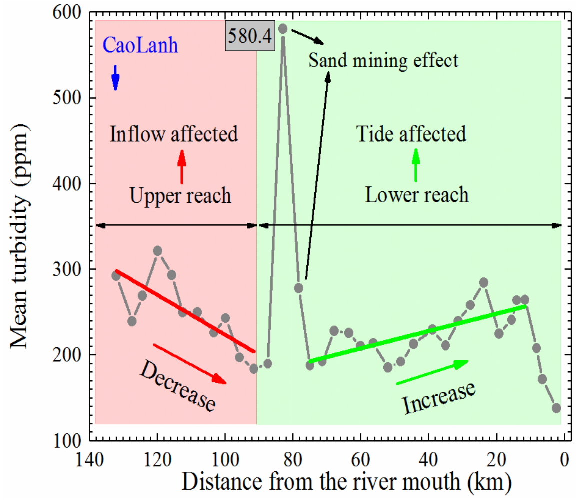

Fig. 17 Longitudinal variations of the turbidity in Tien River

Spatially, the turbidity can also be divided into the upper and lower reaches similar with the river bed elevation and velocity (Fig. 17). The upper reach has high turbidity and decreasing seaward while the lower reach is slightly lower and increasing seaward. However, the turbidity at around 20 km from the river mouth is very high which is almost in the same order with the turbidity in the upper reach. This may be the results of sediment resuspension caused by the tide and salinity or being imported from the coastal sediment wedge just beyond the river mouth (Wolanski, 2007). In fact, such sediment is circulating around the river mouths due to tidal circle for months except for the flood season. It is worth noting that August (time of field survey) is just the beginning of the flood season, therefore the tidal processes still relatively strong near the river mouths.

Around kilometers 90 and 70, the turbidity is exceptionally high (Fig. 17). This is because of sand mining activities in this area. It can be seen that sand mining locally increases the turbidity but not change the general trend.

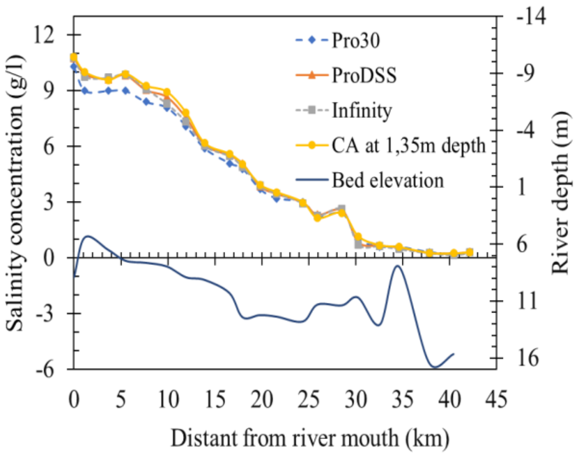

Fig. 18 Longitudinal variations of salinity concentrations in TranDe branch in high tide

4.4 Spatial variations of the salinity intrusion in the VMD

Referencing 0.5 g/l salinity concentration in Hau River, the salinity intrusion length in the low tide is 35 km which is about 18 km shorter than the salinity intrusion length in the high tide. The salinity concentrations measured by ProDSS and Infinity meters are relatively similar (Fig. 18) because they were mounted at the same water depth of 1.35 m below the water surface. On the other hand, the Pro30 was at 1.25 m under the water surface, therefore, the recorded salinity concentrations were small accordingly. Salinity at 1.25 m is much smaller than that at 1.35 m along areas near the river mouth where the vertical stratification of the salinity concentration is transparent (Fig. 18).

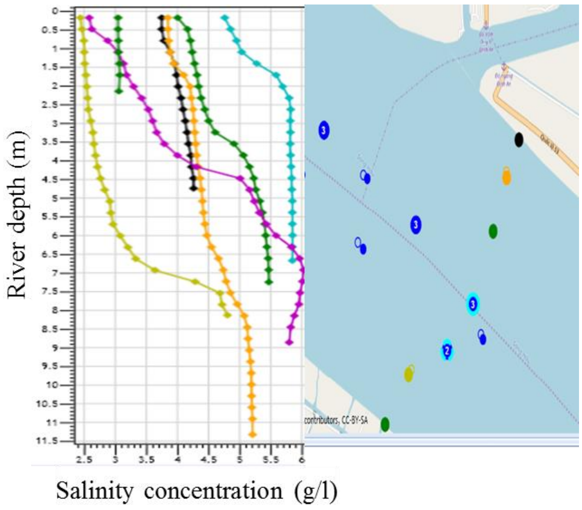

Fig. 19 Vertical and horizontal variations of salinity concentrations in a typical cross section in Hau River

Castaway-CTD (CA) provided vertical distribution of salinity concentrations (Fig. 19). Vertically, the lowest salinity concentrations are near the water surface, which are approximately equal to the values recorded by ProDSS and Infinity at 1.35 m under the water surface. That indicates that the salinity concentrations in a zone near water surface are less variable. However, such difference is more obvious along areas near the river mouths (Fig. 18) as mentioned above. The vertical profiles of salinity concentrations at locations in a cross section are very much different (Fig. 19). Near the river banks, the salinity concentration is almost unchanged vertically. However, in the middle of the river, salinity concentration significantly increases downward. For instance, at a cross section 10 km from the river mouth, the salinity concentrations near the river bed are about 4 g/l larger than those near the water surface. Transversely, the salinity concentrations in the middle of a cross section are much larger than those near the river banks, for instance, about 3 g/l at a cross section 10 km from the river mouth. The above observations indicate that to comprehensively understand the dynamics of the salinity intrusion in the VMD, one has to measure the salinity concentrations longitudinally, vertically, and transversely as conducted in this research. Vertical distribution of salinity concentrations provides a useful aspect for operations of the saltwater control sluice gates in the VMD.

5. Conclusions

Hydropower dam developments in the mainstream and tributaries of the MR have been significantly reduced the sediment supply to the VMD by as much as 83% in comparison between 2015 and pre-1992 (natural condition). The hungry water downstream of dams tends to erode river beds and banks to balance to the sediment transport capacity of the flow. This leads to a severe degradation of river beds and erosion of river banks in the VMD. Deepened and widened rivers in turn affect the interactive processes between the fluvial and tidal flows (which are very complicated in the VMD) and then will cause more severe salinity intrusion in the VMD. Large scale hydrodynamics modelling studies of a complex river network and floodplains in the VMD requires detailed bathymetric, water level and discharge data. However, the previously available bathymetry data in the VMD is limited and not homogeneous. Prior studies based on numerical simulation used combined bathymetry data that measured in different years at different regions. Therefore, we conducted two field surveys: (1) one in the beginning of the flood season in August 2017 to comprehensively measure the river bathymetry, water levels, discharges, velocities, and turbidity over 200 cross sections along 570 km of Tien, Hau Rivers and VamNao channel, covering four river mouths, and (2) one in the drought season in March 2018 to measure salinity dynamics in DinhAn and TranDe branches of Hau River. This field survey data serve firstly for physical understanding of the fluvial-tidal interactive processes of the flow, sediment, and salinity dynamics in the VMD. Such measured data will be ultimately used as boundary conditions for two numerical models: (1) the 2-dimensional hydro-sediment dynamics model to investigate morphological changes and (2) 3-dimensional salinity dynamics model to investigate the mechanism of the salinity intrusion in VMD due to upstream dam development. Below are main findings this research:

(1) In terms of river bed elevation, flow velocity, and turbidity, Tien and Hau Rivers are divided into the upper and lower reaches, partitioned at MyThuan and CanTho stations, respectively. The upper reach is inflow dominated while the tide is dominant in the lower reach. In the upper reach, the river bed elevation, flow velocity, and turbidity are high compared to those in the lower reach and decrease seaward which is opposite with the trend in the lower reach.

(2) Due to a significant reduction in the sediment supply from the upstream trapped by mainly six mainstream hydropower dams in the upper Mekong basin in China, the river beds in the VMD have been significantly degraded. Within three years from 2014 to 2017, the river bed of about 35 km river long from TanChau to VamNao stations has been degraded by 1.5 m with a degradation rate of 0.5 m/yr which is double the degradation rate of 0.25 m/yr from 1998 to 2008 found by Brunier et al. (2014). Severe river bank erosion is another consequence of dam development upstream.

(3) Salinity intrusion is much variable between low and high tide. The salinity intrusion length of the former is about 18 km shorter than that of the latter. Near the river banks, salinity concentrations are almost unchanged vertically. However, in the middle of a cross section, salinity concentrations significantly increase vertically. Longitudinally, salinity is regularly diminished upstream-ward due to the dilution of fresh water supplied from the upstream of the MR.

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