THESIS INFORMATION

Title:	**RESEARCH ON THE CHANGE IN MORPHOLOGY OF THE SOAI RAP RIVERBED DUE TO DIRECT ACTIVITIES OF CHANGING RIVERBED AND SEA-LEVEL RISE**
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The changes in riverbed morphology at estuaries and coastal areas cause direct or indirect impacts on resources, water quality, environment, and ecosystems of wetlands and estuaries. Over the past three decades, the morphology of Soai Rap estuary has continuously changed. (In the first period (1982 - 2008), when the resource exploitation activities on the river were not much, the river bottom of the Soai Rap river occurred a tendency of accretion; In the period from 2009 to now, when the economy is developing rapidly, there is rapid and complicated erosion and tends to spread upstream (Figure 1).The construction of water exploitation works on the mainstream of Dong Nai river in the past has been related to the change in the source of sediment flowing to the downstream of the Dong Nai - Saigon river. Only considering the large constructions on the mainstream of Dong Nai river, there are about 14 large constructions (Figure 2). Operation of hydropower reservoirs upstream changes the flow and especially reduces the source of sediment from upstream. In the past, when there was not Tri An and Thac Mo reservoirs, the annual amount of sediment from upstream to downstream was about 3.5 million tons, now it is only about 2.5 million tons and after Ham Thuan, Phuoc Hoa reservoirs constructed, only about 1.5-2.0 million tons (reduced by 57%).

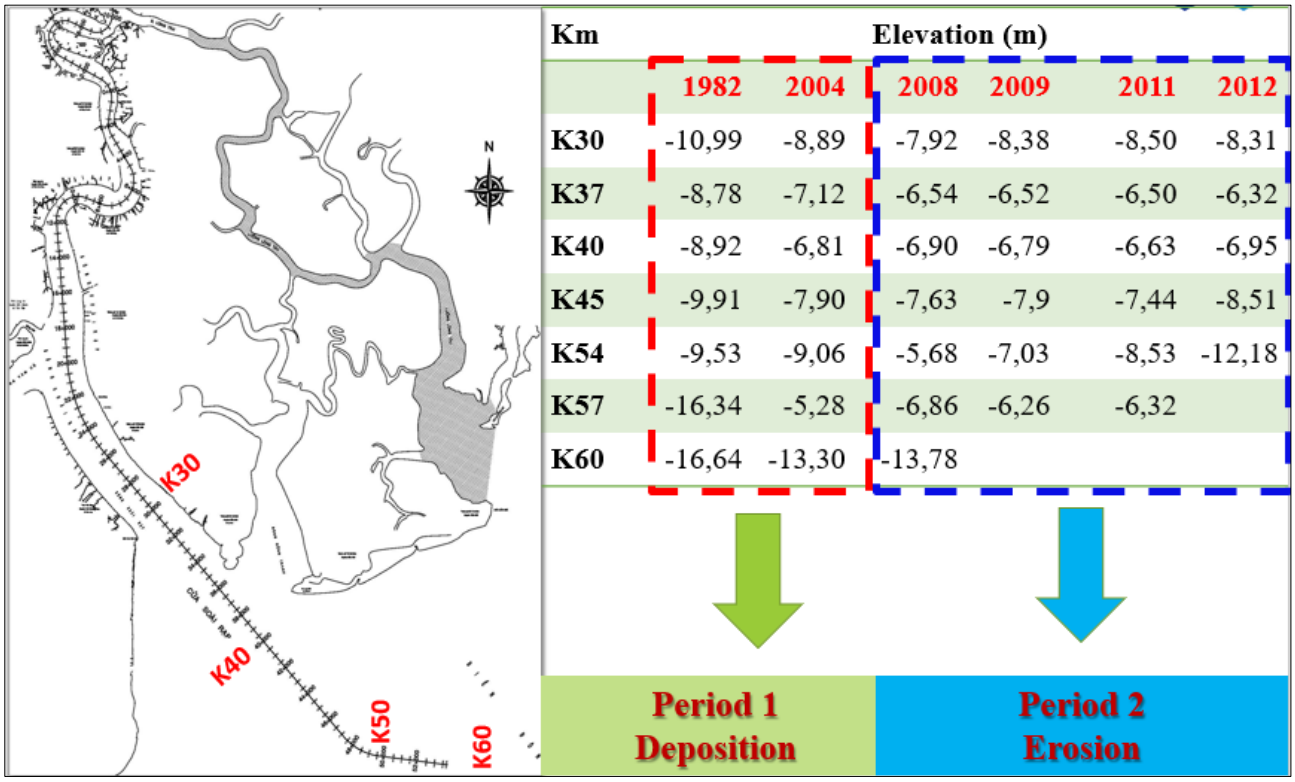

Figure 1: The process of changing the riverbed in Soai Rap river over the years

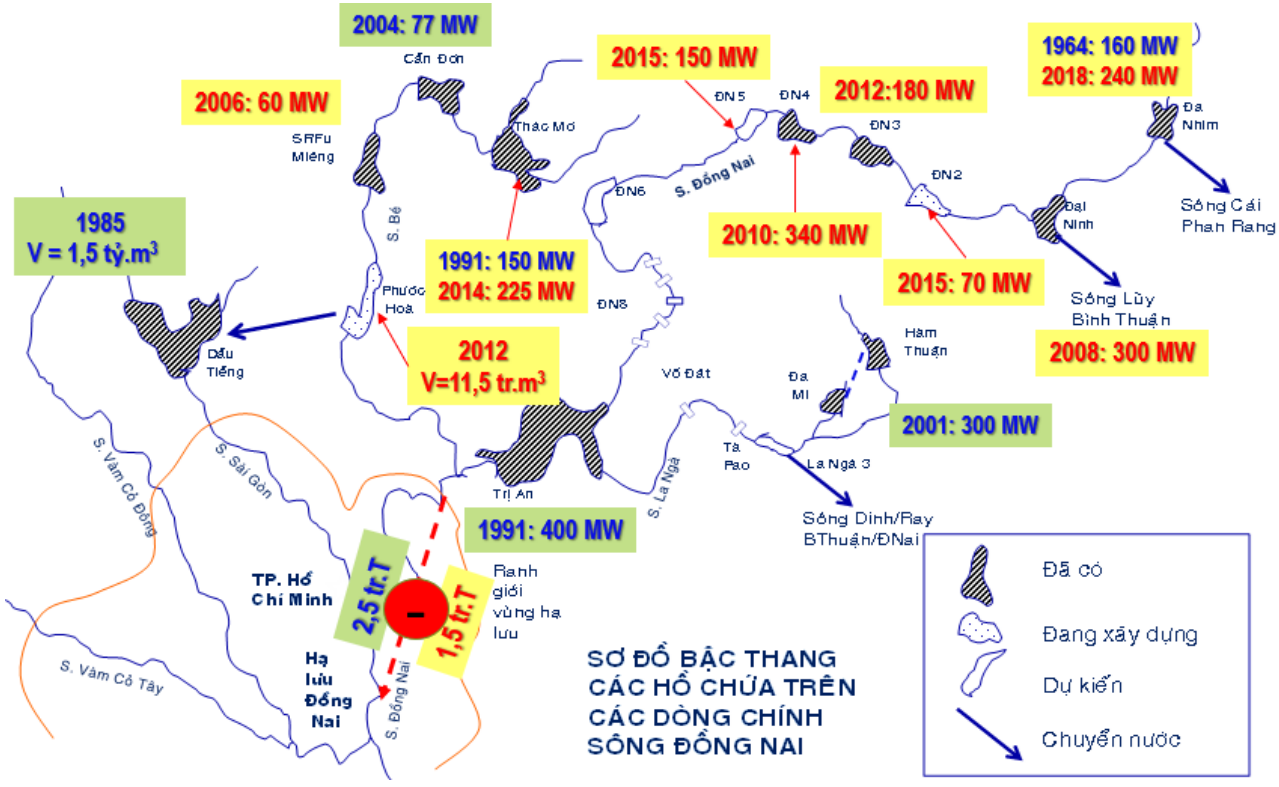

Figure 2: Hydroelectric constructions on the main stream of Dong Nai river

Those changes are the result of corresponding adjustments for changes in flow conditions and amount of sediment. Hypotheses such as: due to changes in hydrodynamic conditions related to climate change and human activities? Due to resource exploitation activities in the river causing imbalance of sediment and sand? Due to sea level rise change tidal regime and

exchange of sediment between ocean and river system, estuary/coastal area? Proving the above hypotheses is one of the important and necessary tasks, which is the basis for strategic planning for water resource management and exploitation of sand and gravel mineral resources in the river. Therefore, the objective of this study is to elucidate the sediment transport mechanism, the change in the conduction channel associated with changes in hydrodynamic conditions due to human activities and sea-level rise. Therefore, the PhD thesis title "**Research on changes in the morphology of the Soai Rap riverbed due to directly activities of changing of riverbed and sea level rise**" selected to defend doctoral thesis in Water Resources Engineering.

To achieve the above research objectives, the thesis uses a combination of the following methods: methods of synthesis and inheritance (collection, analysis, synthesis of documents, published studies); mathematical modeling method (using TELEMAC-2D – SISYPHE-TOMAWAC model to analyze hydrodynamic processes along with sediment transport, morphological change of riverbed/sea); statistical analysis method (to assess, identify trends of sediment changes in space and time, establish equations for distribution and exchange of sediment sources in different areas); harmonic analysis method (determine amplitude and phase of the main tidal subdivisions to clarify the change of tidal characteristics at Soai Rap estuary in the condition of sea-level rise); method using geographic information system GIS (used to analyze data, present analysis results of the evolution of dynamics and sediment transport in space-time). In which, the mathematical modeling method is the dominant method. For the open-source mathematical modeling method, we have established the relational expression $(ES_1, ES_2) = f(f_1, f_2, ES, n)$ addition to open source and impose a spatially variable sediment transport model with mixed mud/sand characteristics in the river and loose mud/sand in the sea. With this change, the mud/sand will have physical properties suitable for estuary areas where there is a transition from the river to the sea.

The results of the study can be summarized as follows:

The main objectives of this study are: (1) elucidating the conditions of the hydrodynamic regime and sediment transport mechanism, the law of balance of sediments between areas at Soai Rap estuary; (2) assess the impact of human activities on the morphological change of Soai Rap estuary; (3) evaluate the impact of sea-level rise on the hydrodynamic regime along with the morphological changes of riverbed. The main objectives and contents of the thesis

are summarized in the following four points:

1. A mathematical model of hydrodynamics and mixed sediment transport has been established with spatially variable characteristics of sediment.

The complexity in simulating hydrodynamics and sediment transport at Soai Rap estuary is shown in: (1) the interaction between seasonal river flow regimes and marine dynamics factors. Such as tidal currents, waves, and winds; (2) the spatial variation of sediment characteristics represents the mixed sediments in the river and the loose sediments in the sea; (3) the exchange of sediments between the upstream areas, the estuaries, and the East Sea.

- For the first and second requirements, the computational domain must be large enough to be able to simulate the dynamic interaction between rivers and seas; input conditions including upstream and marine boundary conditions, physical processes such as wind and waves need to be adequate; simulation time is long enough.

- For the third requirement, based on the openness of the Telemac model (open source), the study has added an algorithm to determine the thickness of ES_1 (sand) and ES_2 (mud) by prove the relationship $(ES_1, ES_2) = f(f_1, f_2, ES, n)$. In which: f_1 is the mass ratio of sand, f_2 is the mass ratio of mud, ES is the total thickness of a layer, n: grain porosity.

$$ES_2 = \frac{\rho . f_2 (1-n)}{C . f_1 + \rho . f_2 (1-n)} ES; ES_1 = \frac{C . f_1}{C . f_1 + \rho . f_2 (1-n)} ES .$$

2. To elucidate the impact of dynamic factors on the mechanism of sediment transport, the law of sediment balance between areas along with the riverbed morphology changes at the Soai Rap estuary.

The hydraulic regime here is a reversible interaction between seasonal flow and tidal flow related to the sediment transport mechanism which is summarized by the following main points:

- Sediment transport at Soai Rap estuary is affected by seasonal flows, the degree of influence of the seasonal nature in different areas is different. Upstream area (KV1) is strongly influenced by season, in dry season tends to accrete and in flood season tends to erode. The amount of sediment here is mainly from upstream basins that accumulate in the

dry season and move a lot downstream in the flood season. Soai Rap area (KV2) has balanced sedimentary dynamics, total amount of sediment accumulated is quite balanced between the dry season and the flood season. Ganh Rai Bay (KV3) is dominated by the East Sea tide, accumulated in the largest year, the source of sediment is mainly brought in by sea currents.

- The sediment transport at the Soai Rap estuary is influenced by the tides of the East Sea and interacts with seasonal flows, varying degrees of influence and interaction in the areas.).

- The transport of sediment at the Soai Rap estuary is influenced by the monsoon regime in the East Sea. During the southwest monsoon, the total amount of sediment accumulated at Ganh Rai Bay increased by 1.78 million million m^3 (corresponding to 10%) and reduced by 1.56 million m^3 (corresponding to 9.3%) during the Northeast monsoon.

- Finally, the sediment transport mechanism here is a combination of all dynamic factors including seasonal flows in the river, tidal currents, waves, and monsoons. The interaction between factors can be reversed in two-way reversible occurring at different areas, leading to a mechanism of balance and redistribution of sediments between areas. The equilibrium relationship between the areas can be represented by the correlation equation as follows: $\mathbf{Y = -4,452 \times X1 + 0,114 \times X2 + 6,958}$ (with X1 (10^6 m^3): total amount of sediment accumulated at KV1, X2 (10^6 m^3): total amount of sediment accumulated in the East Sea area, Y (10^6 m^3): total amount of sediment accumulated at KV3).

3. Assessing the impact of human activities and sea-level rise on the morphological change of Soai Rap riverbed

The human impact on estuary morphology change is summarized in the following key points:

- The dredging operation of Soai Rap channel causes changes in the hydraulic regime, the tidal amplitude at estuary can increase by 15cm during high tide. When considered on a large scale, dredging activities reduce the amount of sediment accumulated upstream (KV1) by 18% (scenario 1), 36% (scenario 2); Soai Rap area (KV2) had an increase of 6% (scenario 1), 13% (scenario 2); Ganh Rai Bay (KV3) decreased by 5% (scenario 1), decreased by 10% (scenario 2).

- Sand mining operations create deposits, where the sediment is trapped in the pits, causing a discontinuity of the sediment movement. This causes an imbalance and causes sand shortage in other areas. The final consequences is to cause redistribution of sediments in different areas. Simulation results show that, with a sand production of 26 million m^3 a year, the total amount of sand accumulated in all areas is deficient except KV3. The total amount of sand accumulated is -1.9 million m^3/year (KV1), -44,000 m^3/year (KV2), 28.7 million m^3/year (KV3).

The impact of sea-level rise for the SLR +0.5m and SLR +1.0m scenarios on the morphological change of Soai Rap estuary is summarized by the following main points:

- The increase of the SLR causes changes to the tidal regime in the downstream of Dongnai-Saigon. The amplitude of the main tidal waves increases with the sea level rise; the increase in water depth leads to an increase in tidal propagation speed and the wave phases tend to be faster in phase. Wave M2 has the largest increasing amplitude +2.49cm (SLR+0.5m), +4.43cm (SLR +1.0m) and phase faster than 7.5 minutes (SLR+0.5m), 14.1 minutes (SLR +1.0m) compared to the baseline scenario (SLR +0.0m).

- The sediment transport changed and the sedimentation/erosion behavior in the areas also changed due to the influence of SLR. Upstream area (KV1), the total amount of sediment accumulated in one year tends to decrease, specifically 2.6 million m^3 (SLR +0.0m), 2.0 million m^3 (SLR +0.5m) and 1.7 million m^3 (SLR +1.0m). For the KV2 area, the SLR reduces the amount of sediment deposited in the dry season but increases the amount of sediment deposited in the flood season, that increase makes up for the shortfall in the dry season, so in one-year the total amount of sediment does not much change in SLR conditions. For the KV3 and SLR area, it increases the amount of sediment accumulated during the year, specifically as follows: 32.0 million m^3 (SLR +0.0m), 34.8 million m^3 (SLR +0.5m) and 37.4 million m^3 (SLR +1.0m). Areas outside the East Sea have reduced the amount of sediment, the total amount of sand accumulated in the East Sea is 335.2 million m^3 (SLR +0.0m), 325.4 million m^3 (SLR +0.5m) and 313.4 million m^3 (SLR +1.0m).

Human activity and sea level rise cause different levels of impact on sediment shortages in different areas due to differences in sediment dynamics. Upstream (KV1) is the region with

the highest sensitivity to anthropogenic impacts, and under sea-level rise, the deficit is greatest and unlikely to recover. The middle area (KV2) is located in the middle, so it receives the sediment-flow from upstream and from the sea, so it has fairly balanced sedimentary dynamics, high stability, and the best resilience. KV3 is the area that is least affected by human impacts and in SLR conditions because it inherits a huge source of sediment from the East Sea.

The research results of the thesis provide information and scientific basis for the development of strategies to manage natural resources and environment; prevent, against, and minimize damage caused by water, prevent riverbank erosion; develop plans to exploit sand and gravel resources on the river for the downstream system of Dong Nai - Saigon river.

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	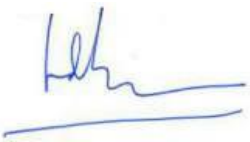	
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