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*Research Article*

# Applying a two-dimensional open-source hydrodynamic model to evaluate the riverbed change in the upstream of the Cuu Long River, An Giang province

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**Abstract:** Riverbank erosion in the Mekong Delta, particularly along the Tien and Hau rivers and some primary and secondary tributaries, is undergoing highly complex and unpredictable changes, resulting in significant damage to the affected areas. The phenomenon of riverbank erosion here is caused by multiple factors, including intensified human activities such as sand mining, infrastructure development, and climate change. In recent years, the increasing activities of upstream Mekong River projects have led to a reduction in sediment deposition in the delta, which is considered one of the significant contributing factors to the increasing incidence of riverbank erosion. This paper will apply and build a two-dimensional open-source model (TELEMAC) to simulate in detail the sediment transport process during the 3-year period from 2017 to 2019 on the upstream section of the Tien and Hau rivers in An Giang province to evaluate and assess the sediment imbalance during this period and identify trends in riverbed erosion and deposition. As a result, in 3 years, the total silt deficit on the Tien River section is $-36.6\times10^6$ $m^3$, on the Hau River is $-2.7\times10^6$ $m^3$. At the same time, the erosion depth deepened by approximately 0.25-0.75 m (especially up to 1.0 m). This indicates an imbalance in sediment deposition and erosion, with a consistent trend of riverbed, banks, and shore erosion.

**Keywords:** Sediment transport; River bed evolution; TELEMAC 2D model.

## 1. Introduction

The Mekong Delta is the downstream of the Mekong river basin with an area of 40.9 thousand km². This place has a dense river network, and its tributaries are quite complex. In the upstream of the Mekong River (Tan Chau - Tien River) and (Chau Doc - Hau River), where the two rivers flow into the delta, their width is about 60 m to 300 m and gradually widens to about 2-3 km in downstream. An Giang province is one of the two upstream provinces of the Mekong Delta receiving water from the Tien and Hau rivers from Cambodia. This province has a dense system of rivers and canals: Tien River, Hau River, Vam Nao River, Binh Di River, Chau Doc River along with large canals such as Xang Tan An Canal, Ong Chuong Canal, Xep Nang Gu... are the streams main and important watercourses. These main rivers and canals are experiencing changes in their riverbeds, causing complex erosion and riverbank landslides, causing the loss of dozens of hectares of land each year, causing major consequences for life and property in the economic areas and residential areas along the river. In recent years, under the increasing adverse impacts of flow regimes as well as human activities, riverbank erosion has become more and more complicated and more frequent. This will be even more serious in the future because of climate change impacts from upstream development. The riverbank in An Giang province has quite strong and complex erosion. Among the 65 communes along the Tien and Hau rivers in An Giang province, there are currently 33 riverbank erosion areas (14 areas along the Tien river and 19 areas along the Hau river). Along both sides of the Tien and Hau rivers, there are districts where landslides occur frequently: An Phu, Phu Tan, Tan Chau, Cho Moi, Chau Phu, etc. Therefore, research, evaluation, and simulation of sand and mud developments and riverbank erosion here receive great attention and concern.

Research on the process of sedimentation and river bed erosion has been carried out and researched for a long time. Scientists around the world have focused research on directions such as: river morphology, river dynamics, modeling, in the laboratory combined with field measurements to determine the causes, mechanisms, and changes in the channel. Based on these, solutions were proposed to prevent and mitigate damages caused by bank erosion and channel sedimentation [1–7]. However, simulating bank erosion is still a challenging problem because the flow of water and sediment through channels changes continuously over time, and the diversity of bank materials in nature. This limits the accuracy of numerical models, which are often calibrated and applied to specifically simulate idealized natural river systems [8]. Furthermore, when integrated with the digital elevation model (DEM), the coarse or fine resolution of this model also greatly affects the accuracy of the model. In addition, the computation time and financial cost to perform the simulation are also very large, especially for large river basins with complex terrain. For example, for braided river sections, such as the Mekong River, the complexity of the problem is still a big challenge for scientists. It is difficult to select an appropriate approach for all cases [9].

Around the world, research has achieved progress in studying sediment transport and sand mining on rivers and has solved many complex practical problems such as: Calculate the sediment balance in the basin to determine sand reserves along the river and each mining location, using mathematical models and statistical methods; Solve economic problems combined with river dynamics problems, to determine the optimal exploitation plan that brings high economic efficiency with little impact on the environment and self-recovery after exploitation period; Combining social issues and harmonizing the rights of subjects in the community are also addressed [10–15], etc.

In Vietnam, riverbank erosion has recently been occurring nationwide, becoming increasingly complicated, directly affecting the lives and property of the people, the State, and prevention and control works. The study [16] has proposed a model to predict the process of erosion - sand and gravel deposition for coastal strips and estuaries at medium temporal scale (seasonal and annual), proposed scientific and technical solutions to prevent erosion and sedimentation and protect estuary coastal structures. The study [17] has identified the causes and mechanisms of evolution (accretion, erosion, displacement) of estuaries along the Central Coast, and proposed solutions to adapt and stabilize estuaries such as Tu Hien river estuary (Thua Thien - Hue), My A river estuary (Quang Ngai), Da Rang river estuary (Phu Yen) for socio-economic development and safety for fishermen and boats to avoid storms. The study [18] researched the rules of estuary evolution and evaluated the ability to escape floods under different evolution scenarios, taking into account sediment transport in the Vu Gia-Thu Bon river estuary. The study [19] has improved HOSODA's 3D model for calculating local erosion in the groin area, which was only applied to the case of bottom mud and unflooded sand, now taking into account the movement of suspended sand and submerged groynes. Applying physical models to experiment with continuous curves, formulas and charts were built to calculate the effectiveness of accretion techniques after circulation reversal works. The study [20] has identified the causes and mechanisms of formation, movement and sedimentation of the Lai Giang estuary, Binh Dinh province, and proposed solutions to correct and prevent estuary sedimentation and stabilize flood drainage. Another research on forecasting sedimentation and erosion of the Dong Nai - Saigon river channel under the influence of the flood protection system in downstream [21].

For the Mekong Delta, studies [22–25] have researched erosion and sedimentation forecasts and prevention solutions on the river system in the Mekong Delta: Determine the location, scale, and speed of riverbank erosion and identify key erosion areas for the entire Tien and Hau rivers using remote sensing and GIS methods. Quantify causes, erosion mechanisms and factors affecting erosion for the Mekong River in focus areas. Other studies [9, 26–30] have done in-depth research on the causes and mechanisms of landslides in typical study areas on the Tien and Hau rivers and oriented solutions to predict riverbank erosion in the Mekong Delta. The study [31] used Landsat satellite images on the Google Earth Engine platform to study bank erosion of all major rivers in the Mekong Delta for the period 1989 to 2014. The study [32] built a riverbank erosion prediction model based on high-performance computing technology using GPUs combined with implementation based on empirical models and applications for some river sections of the Mekong Delta. The study [33] applied TELEMAC-3D model to simulate flow and sediment transport at the confluence area of the Hau river and the Vam Nao river. The study [28] combined the TELEMAC-2D and MIKE 21 FM models to analyze the causes affecting the level of riverbank erosion. Remote sensing imaging technology was used to analyze and determine the extent of riverbank erosion in the Tien River [34]. Thus, in addition to traditional methods such as: using empirical formulas, physical models, and actual surveys, there are also methods using numerical models, GIS, remote sensing images, etc. Nowadays, there exist many methods that leverage machine learning and artificial intelligence to evaluate the riverbed erosion and aggradation.

Regarding the application of hydrodynamic and sand sediment simulation models in river basins, it shows: 1-2- or 3-D models have been established, calibrated and tested in previous studies as well as within the framework of projects at all levels to see the usefulness of these tools [9, 15–22, 26–27]. However, it is seen that the models differ in terms of usage conditions, input data requirements for the model, level of complexity, computation speed and accuracy. Certainly, no model can be called the best because each model has different advantages and disadvantages. The most important thing is to choose the right model. The main factors affecting model selection include: (i) input and output data of the model, (ii) applicability, (iii) user's purpose, (iv) computer hardware responsiveness, (v) software purchase costs, and (vi) updateability. If considering the six factors to choose the model above, TELEMAC is a very suitable model in this evaluation study, especially suitable for individuals or organizations that do not have the financial ability. The TELEMAC model system has been developed by the National Laboratory of Hydraulics and Environment under the national center for Hydraulic research of Electricity France (EDF) since 1987. This is one of the leading river morphology hydrodynamic models in the world that can respond to forecasting the morphological change process for estuaries and coastal areas. The TELEMAC model has been applied in many studies around the world [35–38]. However, the biggest disadvantage of TELEMAC is that it is difficult to use and requires users to have certain knowledge of hydrodynamics and programming skills. This study applies the TELEMAC model to simulate and analyse the level of riverbed erosion by identifying the lack of sediment and sand in the flow.

## 2. Materials and methodology

### *2.1. Methodology*

a) Hydrodynamic model (TELEMAC-2D): The TELEMAC-2D model solves the depth-averaged runoff equation based on the two-dimensional Saint-Venant equation [35].

The process of performing the simulation model is shown in Figure 1.

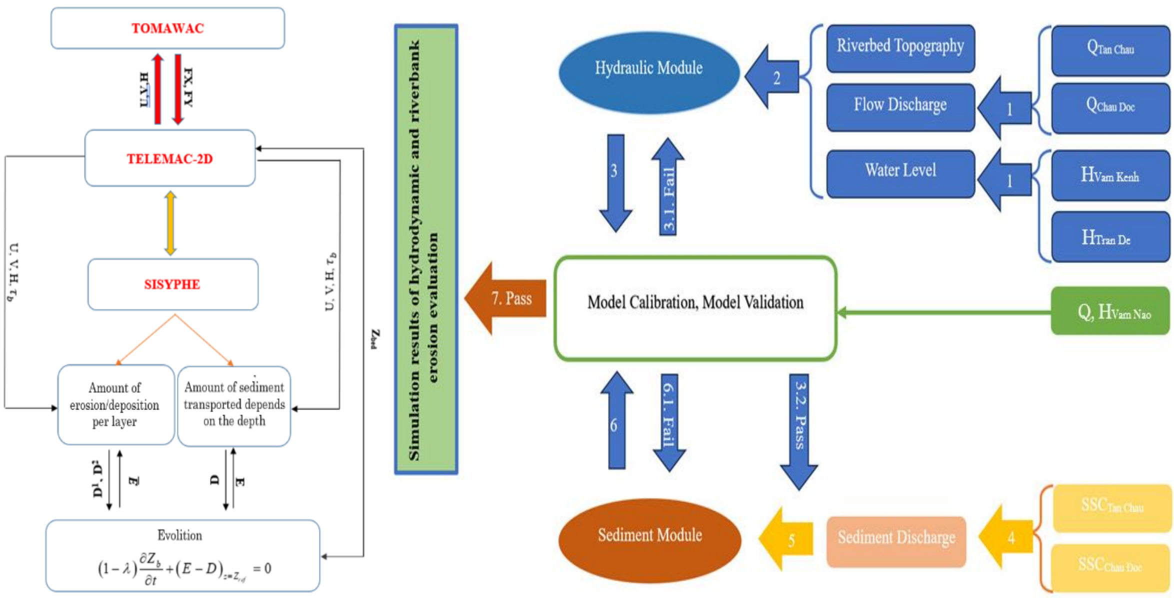


**Figure 1.** General flowchart of study using TELEMAC model.

Continuous equation:

$$\frac{\partial h}{\partial t}+u.\vec{\nabla}(h)+h\,\mathrm{div}(\vec{u})=S_h \qquad (1)$$

Momentum equation (x direction):

$$\frac{\partial u}{\partial t}+\vec{u}.\vec{\nabla}(u)=-g\frac{\partial Z}{\partial x}+S_x+\frac{1}{h}\mathrm{div}(hv_t\vec{\nabla}u) \qquad (2)$$

Momentum equation (y direction):

$$\frac{\partial v}{\partial t}+\vec{u}.\vec{\nabla}(v)=-g\frac{\partial Z}{\partial y}+S_y+\frac{1}{h}\mathrm{div}(hv_t\vec{\nabla}v) \qquad (3)$$

where h is the depth (m); u,v are the velocity in x and y directions (m/s); g is the gravitational acceleration (m/s$^2$); $v_t, v_T$ are the momentum diffusion coefficient and substance diffusion coefficient, respectively; Z is the water level (m); $S_h$ is the specific discharge (m/s); $S_x$, $S_y$ are the external forces acting on a unit mass projected in the x and y horizontal directions (m/s$^2$).

b) Morphodynamic model SISYPHE and Mixed sediment

Sediment transport equation (x and y directions) for vertically averaged suspended sediment concentration C = C(x,y,t) is described as:

$$\frac{\partial hC_k}{\partial t}+\frac{\partial(hUC_k)}{\partial x}+\frac{\partial(hVC_k)}{\partial y}=\frac{\partial}{\partial x}\left(h\varepsilon_s\frac{\partial C_k}{\partial x}\right)+\frac{\partial}{\partial y}\left(h\varepsilon_s\frac{\partial C_k}{\partial y}\right)+E^k-D^k \qquad (4)$$

$$\left(E^k-D^k\right)_{Zref}=\omega_s\left(C^k_{eq}-C^k_{ref}\right) \qquad (5)$$

The k is constant (k = 1 - sand, k = 2 - mud grains).

where h = $Z_s$ - $Z_f$ ≈ $Z_s$ - $Z_{ref}$ is the depth, assuming the thickness of the bottom mud and sand layer is very thin; U is the average velocity in the x direction, V is average velocity in the y directions; E is an erosion unit; D: accretion unit; (E – D) is the amount of sediment stored; $C_{eq}$ is the concentration of sediment in near the bottom; $C_{ref}$ is the sediment concentration close to the bottom.

The vertical sediment concentration profile is described by Rouse's formula:

$$C(z)=C_{Z_{ref}}\left(\frac{z-h}{z}\times\frac{a}{a-h}\right)^R \text{ with } R=\frac{w_s}{\kappa u_*} \qquad (6)$$

where $C_{Z_{ref}}$= F×C

$$\begin{cases} F^{-1} = \dfrac{1}{(1-Z)} B^{R}\left(1 - B^{(1-R)}\right) \Leftrightarrow R \neq 1 \\ F^{-1} = -B \log B \Leftrightarrow R = 1 \end{cases} \quad \text{with } B = \frac{Z_{ref}}{h} \tag{7}$$

The change in the riverbed elevation is computed using Exner's equation as follows:

$$(1-\lambda)\frac{\partial z_b}{\partial t} + (E - D)_{z = Z_{ref}} = 0 \tag{8}$$

where $\lambda$ is the void coefficient, $z_b$ is the riverbed elevation.

## 2.2. Data

a) Input data

Upstream boundary: flow taken at Tan Chau and Chau Doc station, average daily flow data. Average daily sand and sediment concentration range (SSC) taken from Tan Chau and Chau Doc station period 2017-2019 (3 years).

Downstream boundary taken at water level stations at coastal estuaries at Vam Kenh, Ben Trai, Binh Dai, Tran De, average daily water level data period 2017-2019.

Testing boundary used to calibrate and verify hydraulics and silt content were taken at My Thuan and Can Tho hydrological stations.

b) Establishing domain

The computational domain is an unstructured grid with 124,644 elements and 8,126 nodes covering areas, river channels, and riverbanks. The maximum element length is 40.0 m and the minimum is 5.0 m (Figure 2).

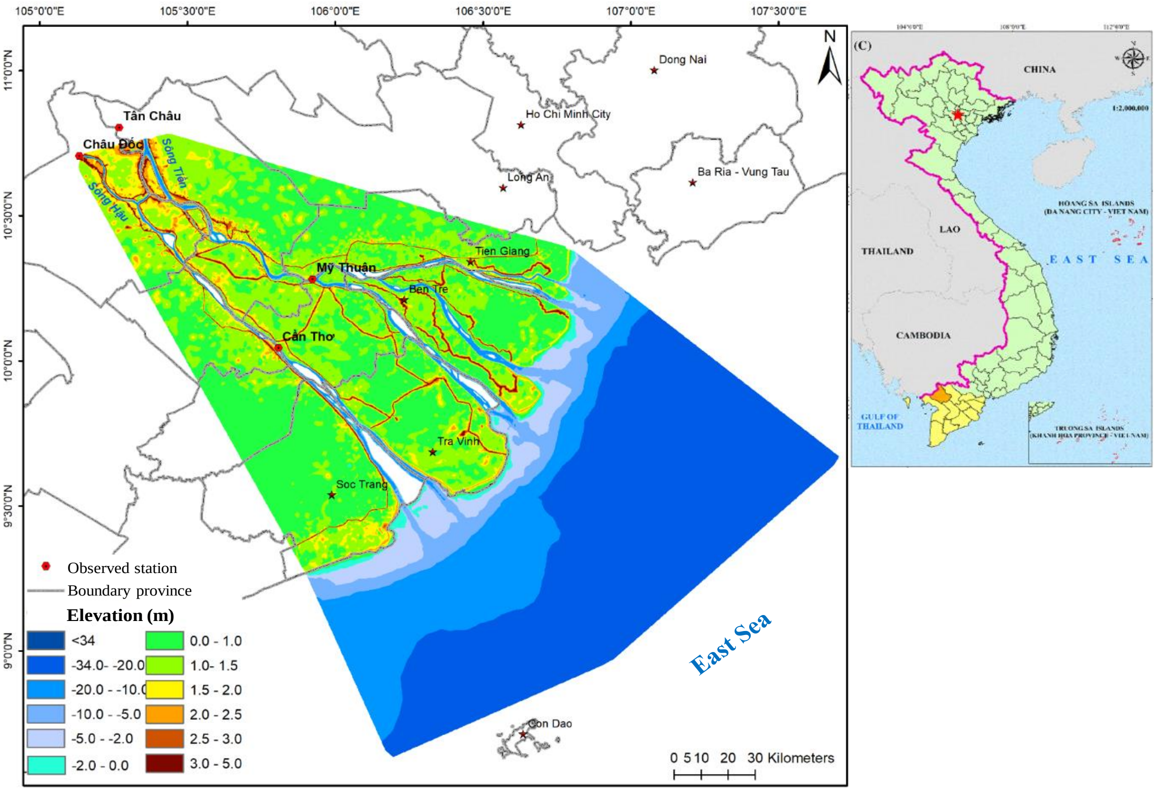


**Figure 2.** Topography of the computational domain [28].

The terrain data consists of elevation data with a resolution of 20 m × 20 m. Additional surveying and detailed calculations were conducted to refine the riverbed terrain data, achieving a resolution of 3-5 m. The data is inherited from [28]. The model setup is illustrated in the hydraulic schematic (Figure 3). The process, model validation is conducted after model calibration to check the reliability of the selected parameters with changed input factors.

Calculation time: Since there is no measured water level data that coincides with the time of survey, in this study, the period of water level calibration and validation will be chosen different from the time of calibration and validation of flow rate and direction.

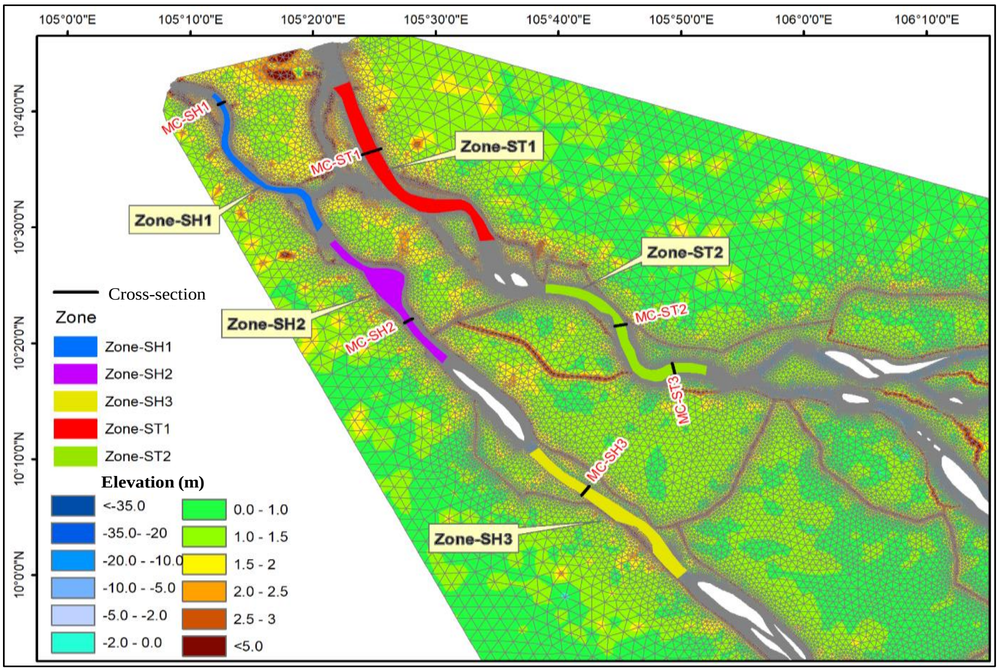


**Figure 3.** Research river section (ST1, SH1) and calculation grid.

c) Set of parameters

The model validation process is conducted after adjusting the model to recheck the reliability of selected parameters with changed input factors.

Hydrodynamic model: Manning's friction law is applied with friction coefficients from 0.015-0.032 varying in space.

Sediment transport model: The composition of sand and mud particles on the Tien and Hau rivers is very uneven and complex, ranging from gravel to silt and clay with diameters mainly of particles with diameter d = 0.008-8.0 mm. In this study, the bottom structure is established in the form of mixed sand mud consisting of two sand grain components (d = $0.30\times10^{-3}$m) and mud (d = $0.028\times10^{-3}$m). The sediment content in each layer is: $C_1$ = 160; $C_2$ = 260 (kg/m$^3$). Sedimentation critical stress $\tau_b$ = 1000 Pa; Erosion critical stress $\tau_{ce1}$ = 0.022 N/m$^2$, $\tau_{ce2}$ = 0.26 N/m$^2$, the settling velocity of sand and mud particles is $v_s$ = 0.15 mm/s (sand) and $v_s$ = 0.035 mm/s (mud) corresponding to sand and mud composition. The active layer is set to 0.05 m and the simulation time step is 120s.

The simulation results of the numerical model depend greatly on the simulation parameters and these parameters are gradually accurate through the model calibration process. The basic parameters are summarized in Table 1.

**Table 1.** The parameters in the model TELEMAC-2D - Sisyphe.

| Parameter | Value | Unit |
|---|---|---|
| Model TELEMAC2-D (Hydrodynamic) | | |
| Law of friction | 4 (Manning's) | |
| Friction coefficient | 0.015-0.030 | m$^{1/3}$/s |
| Turbulence model | 2 (Elder) | |
| Kinematic viscosity coefficient | 10-Jun | m$^2$/s |
| Secondary currents | ☑ | |
| Tidal Flats | ☑ | |

| Parameter | Value | Unit |
|---|---|---|
| Model SISYPHE (Sediment transport) | | |
| Sediment characteristics | Mixed sediment | |
| Grain diameter | 0.33 (sand); 0.035 (mud) | mm |
| Grain porosity | 0.37 | |
| Bed layer | 2 | |
| Active layer | 0.05 | m |
| Sludge content per layer | 70; 80 (from top to bottom) | $kg/m^3$ |
| Erosion critical stress of mud | 0.021; 0.085 | $N/m^2$ |
| Critical shear velocity for mud deposition | 1000 | m/s |
| Partheniades constant | $1.5\times10^{-4}$ | $kg/m^2/s$ |
| Effect of slope | ☑ | |
| The sediment content is balanced close to the bottom | $C_{eq}=\frac{0.331(\theta'-\theta_c)^{1.75}}{1+0.72(\theta'-\theta_c)^{1.75}}$ | |
| Settling velocity | 0.15 (sand); 0.035 (mud) | mm/s |
| Influence of secondary flow | ☑ | |
| Crust friction | $k_s' = 3.6d_{50}$ | mm |
| Time step | 120 | s |

Simulation scenario: According to research, under the condition of a complete upstream hydroelectric system, the amount of sediment and sand reaching Tan Chau and Chau Doc will be reduced by about 80% compared to 2015 [27]. According to the latest report of the Mekong River Commission Secretariat (April 22, 2024, Phnom Penh, Cambodia), the average sand and sediment content (g/l) decreased by 8% in Tan Chau and 5% in Chau Doc [34]. However, these data only reflect the amount of sediment at Tan Chau and Chau Doc stations, it does not show the river morphology relationship, that is, how the sediment imbalance occurs. This study will simulate in detail the sediment transport process during the 3-year period from 2017 to 2019 on the mainstream of the Tien (ST1) and Hau (SH1) rivers in the upstream of An Giang province to evaluate the sediment imbalance and identify trends in riverbed accretion and erosion.

## 3. Results and Discussion

### *3.1. Results of model calibration and validation*

The results of water level calibration and validation are shown in Table 2, Figure 4. The criteria show that the results are good: MSE = 0.2-0.47; ME = 0.05-0.2; Nash = 0.72-0.89.

**Table 2.** Water level error and correlation values.

| Station | Min | | Max | | Average | | ME | MAE | MSE | R | NASH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | OBS | SIM | OBS | SIM | OBS | SIM | | | | | |
| Dry season 2018 | | | | | | | | | | | |
| Can Tho | -0.87 | -1.22 | 1.42 | 1.38 | 0.39 | 0.19 | 0.20 | 0.28 | 0.32 | 0.90 | 0.76 |
| My Thuan | -1.20 | -1.24 | 1.40 | 1.80 | 0.28 | 0.24 | 0.04 | 0.21 | 0.47 | 0.90 | 0.85 |
| Flood season 2018 | | | | | | | | | | | |
| Can Tho | -0.24 | -0.52 | 1.91 | 2.15 | 0.75 | 0.60 | 0.15 | 0.20 | 0.20 | 0.96 | 0.72 |
| My Thuan | -0.84 | -1.03 | 1.79 | 2.00 | 0.47 | 0.42 | 0.05 | 0.17 | 0.33 | 0.98 | 0.89 |

OBS: observation, SIM: Simulation, ME: average absolute error, MAE: average error, MSE: square error, R: Correlation coefficients.

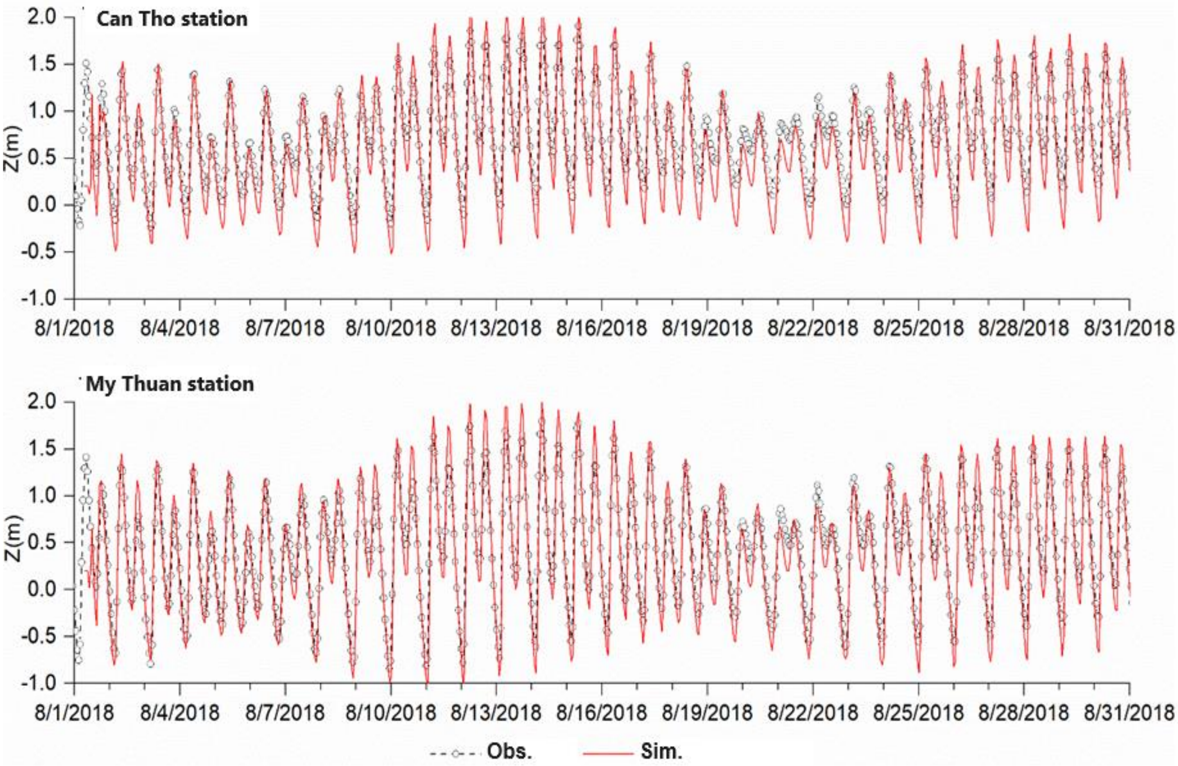


**Figure 4.** Illustration comparing water level process between simulation and actual measurements during the flood season (8/2018).

The results of discharge calibration and validation at Can Tho and My Thuan stations are shown in Table 3, Figure 5. The calibration results give quite good results: R = 0.90-0.95 and Nash = 6.8-0.84.

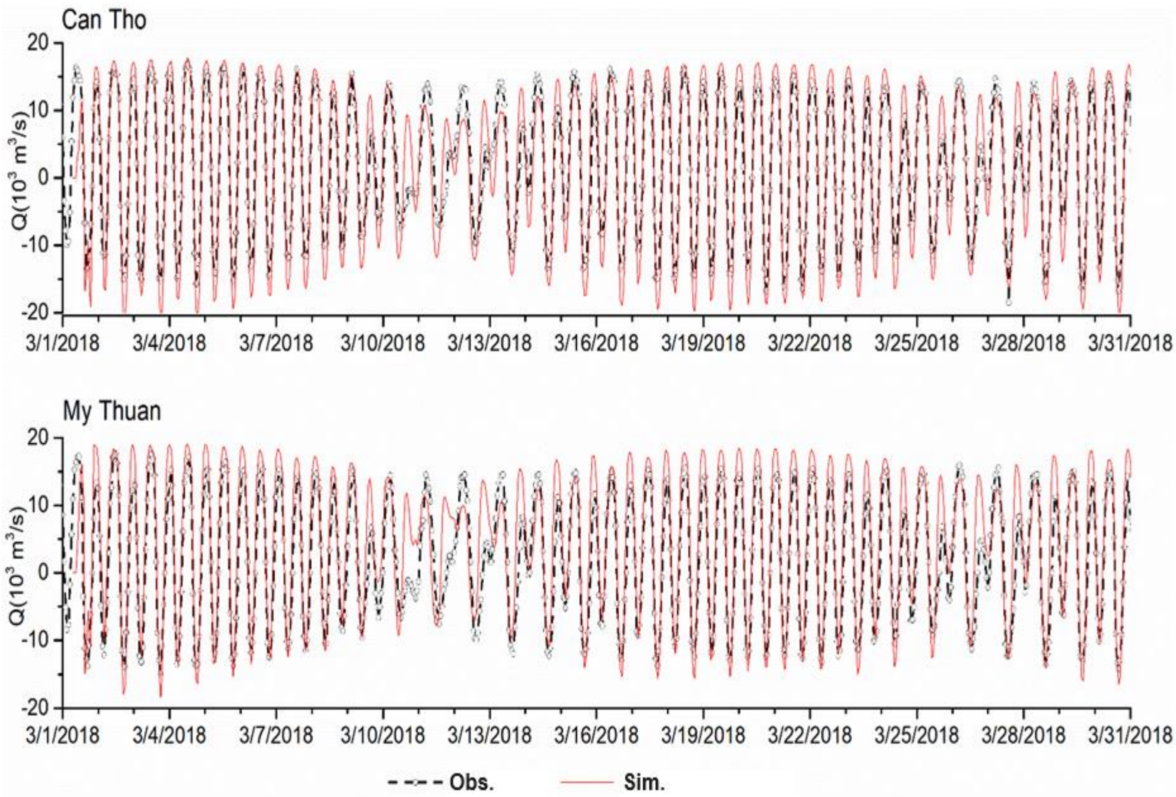


**Figure 5.** Illustration comparing discharge process between simulation and actual measurements during the flood season (8/2018).

**Table 3.** Discharge error and correlation values.

| Station | MIN | | MAX | | TB | | ME | MAE | R | NASH |
|---|---|---|---|---|---|---|---|---|---|---|
| | OBS | SIM | OBS | SIM | OBS | SIM | | | | |
| Dry season 2018 | | | | | | | | | | |
| Can Tho | -18.5 | -21.4 | 16.8 | 17.7 | 2.0 | 1.8 | 0.2 | 3.3 | 0.95 | 0.84 |
| My Thuan | -15.0 | -18.3 | 17.6 | 19.1 | 2.3 | 4.6 | 2.3 | 3.6 | 0.90 | 0.74 |
| Flood season 2018 | | | | | | | | | | |
| Can Tho | -2.9 | -13.2 | 23.5 | 22.4 | 15.3 | 12.8 | 2.4 | 2.7 | 0.91 | 0.68 |
| My Thuan | -3.8 | -1.3 | 25.6 | 27..0 | 17.5 | 17.7 | 0.1 | 2.1 | 0.90 | 0.70 |

Suspended sediment content (SSC): Calibration and validation results at Can Tho and My Thuan stations are shown in Table 4, Figure 6. Calibration and validation results show that the error between simulation and actual measurement is very low. Seasonal changes in sediment and sand content are regular and consistent with seasonal flow changes. Thus, the simulation results are very good, showing that the model is highly reliable.

**Table 4.** Suspended sand and sediment content error and correlation values.

| Station | Min | | Max | | Average | | ME | MAE | MSE |
|---|---|---|---|---|---|---|---|---|---|
| | OBS | SIM | OBS | SIM | OBS | SIM | | | |
| Dry season 2018 | | | | | | | | | |
| Can Tho | 0.015 | 0.018 | 0.038 | 0.025 | 0.026 | 0.022 | 0.004 | 0.005 | 0.00003 |
| My Thuan | 0.018 | 0.030 | 0.046 | 0.040 | 0.033 | 0.033 | 0.000 | 0.006 | 0.00004 |
| Flood season 2018 | | | | | | | | | |
| Can Tho | 0.062 | 0.094 | 0.122 | 0.182 | 0.093 | 0.131 | 0.038 | 0.042 | 0.000 |
| My Thuan | 0.093 | 0.175 | 0.320 | 0.279 | 0.218 | 0.217 | 0.001 | 0.039 | 0.002 |

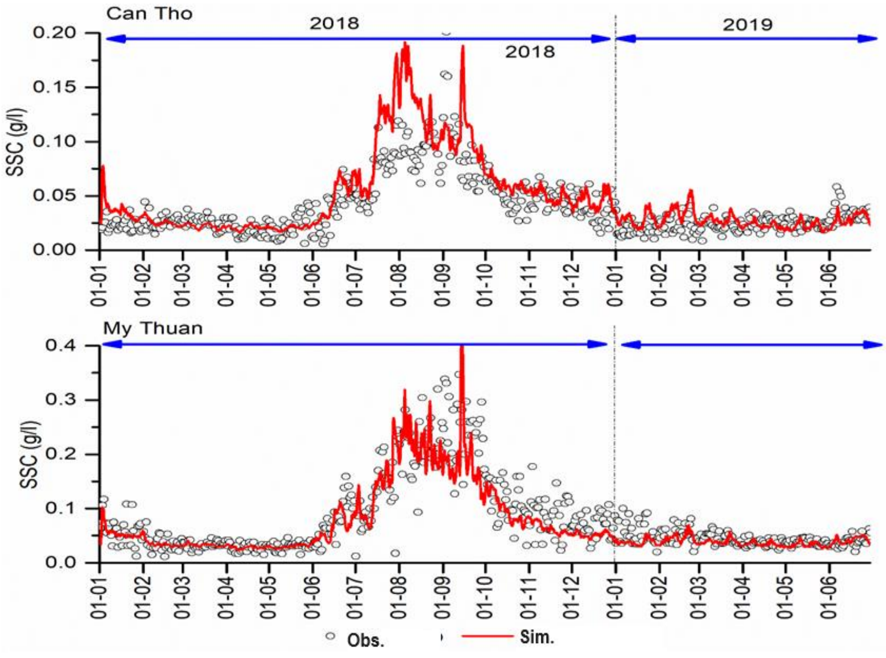


**Figure 6.** Illustration comparing SSC between simulation and actual measurements from 1/2018 - 6/2019.

The results of adjusting and testing the parameters of the open-source model TELEMAC 2D (Sisyphe - Mixed sediment) show the reliability of the parameters.

*3.2. Simulation results*

On the Tien River, at section ST1, the sediment flow passing through has a value of $Q_{tb}$ = 1,327 kg/s, $Q^+$ = 9,872 kg/s, $Q^-$ = -4,668 kg/s. At the Cross section SH1 On the Hau River, the transport volume of sediment and sand is much smaller than that on the Tien River. the sediment flow passing through has a value of $Q_{ave}$ = 232 kg/s, $Q^+$ = 5,605 kg/s, $Q^-$ = -408 kg/s.

On the Tien River at section (ST1), in the dry season, the maximum suspended sand transfer rate is from $6.4\times10^{-3}$ $m^2/s$, in flood season is $7.5\times10^{-3}$ $m^2/s$. Meanwhile, at section (SH1) on the Hau river, the sand transfer rate is smaller than that of the Tien river. In the dry season, the greatest value is $3.5\times10^{-3}$ $m^2/s$, in flood season is $7.0\times10^{-3}$ $m^2/s$.

After 3 years, the total deficit in sediment and sand compared to the beginning of the simulation period is $-36.6\times10^6$ $m^3$ at the section (ST1) and $-2.7\times10^6$ $m^3$ at the section (SH1).

Also from the simulation results, it shows that upstream of Tien River, the right bank tends to accumulate, the left bank tends to erode (there are many erosion locations from 0.25-0.5 m). For upstream of the Hau River, both banks tend to erosion and the level of erosion is also quite high, from 0.5-0.75 m, even up to 1.0 m in many places.

Thus, the upstream area is not able to balance sediment and always tends to lose sediment due to the process of transporting sediment from the upstream to the downstream area. Therefore, the upstream erosion trend is almost inevitable (Figures 7-8).

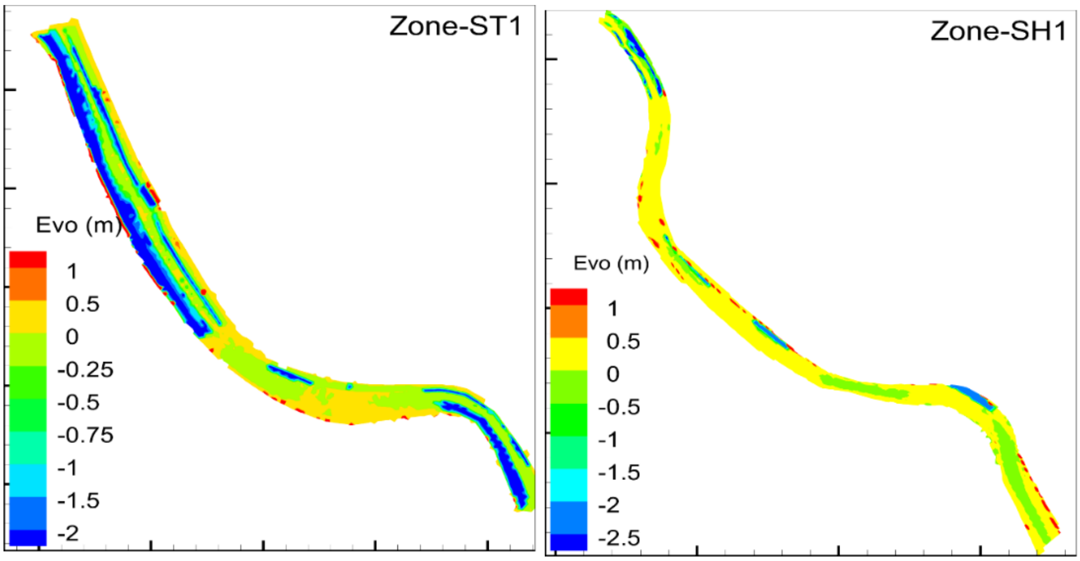


**Figure 7.** Illustration of bottom changes in the study areas.

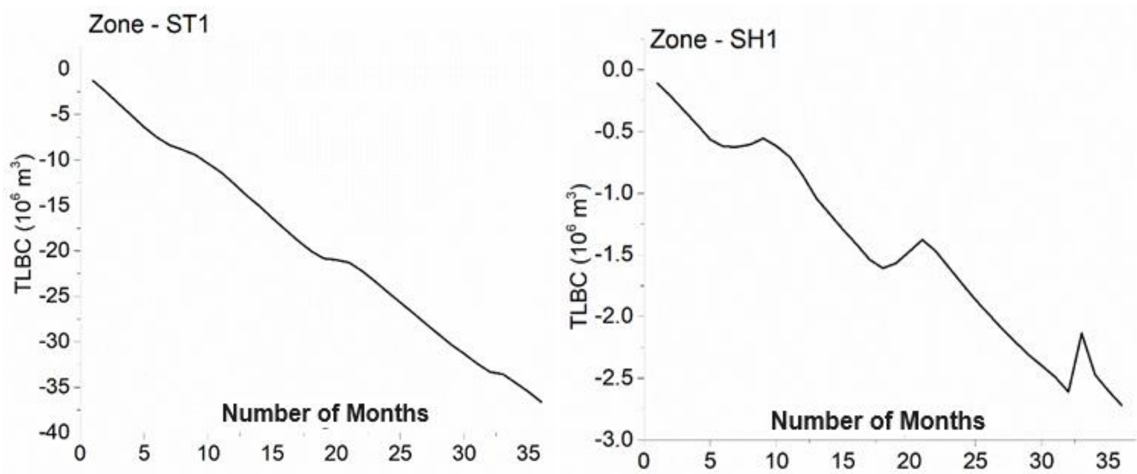


**Figure 8.** Illustrates the total of sediment accumulated at two study locations.

Due to the influence of seasonal regime, the sediment transport volume in the flood season is larger than in the dry season. During the dry season, sediment and sand are transported in both directions, but the amount of sediment and sand transported in the positive direction appears more often than in the opposite direction. During the flood season, sediment transport is mainly in the positive direction and this is even more evident when moving upstream.

## 4. Conclusion

In this study, the TELAMAC 2D model (Sisyphe - Mixed sediment) was applied and built for the main river system in the Mekong Delta with a set of parameters that were calibrated and validated to achieve a good level with Nash index > 0.68 (good), correlation coefficient R > 0.85 (very good) and errors are all within allowable limits. This shows the reliability of the model as well as the stability of the model parameters.

Simulation results of the sediment transport process and assessment of the sediment balance for the two upstream sections of the Tien and Hau rivers (An Giang province) have shown that after 3 years, the total amount of sediment lost over Tien River section is -36.6×10$^6$ m$^3$ at section (ST1) and -2.7×10$^6$ m$^3$ at section (SH1). The erosion depth deepened by approximate 0.25-0.75 m (especially up to 1.0 m). Thus, the upstream area has an imbalance in sediment and sand and always tends to erode the riverbed, banks and beaches. These values are not fundamentally different from previous studies such as [26, 27].

With this result, this research makes a small contribution to the development of the TELEMAC open-source model with the world scientific community. Furthermore, the simulation results have partly shown the trend of riverbed erosion and aggradation in the upstream section of the Cuu Long River, in An Giang province.

The application and use of the open-source model have great potential, but further research and applications are needed to demonstrate its usefulness. This study is only the first step, and more research is needed in other basins.

Calibration and validation results do not yet cover all hydrological and hydraulic conditions and different mining activities, so the stability and reliability of the parameter set is limited.

The calculation results of the value of sediment deficiency are only at a relative level. Simulations for longer sections and the impact of human activities on the river are needed to show more realistic results.

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