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Research Paper

Application of 2D modeling in simulation the erosion of dykes on Thach Han river basin in Vietnam

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ABSTRACT

Application of 2D modeling to carrying out research on the calculation of water flow rate and the amount of sediments transported has been proved effectively. In this paper, the hydraulic model MIKE 21 was applied to calculate and simulate the data of two big flood events in 1999 and 2005. The calibrated and validated results at Thach Han station and Dong Ha station were relatively similar in terms of phases and amplitude fluctuations of water level with the high value of Nash-Sutcliffe coefficient, and low value of RMSE-observations standard deviation ratio (RSR) and Percent bias (PBIAS). The hydraulic modeling and sediment transport were applied by using MIKE 21 gave an overall assessment on the erosion process on the Thach Han River Basin and river bottom before and after the construction of the dikes and embankments. The construction, accordingly, has proven its significant effects on alleviating the development of increasing erosion on parts of the river flowing through Trieu Do commune, Quang Tri province, Vietnam.

1. Introduction

Deposition has been identified as a natural feature, and it has occurred constantly on rivers around the word. Nevertheless, this tendency has been drawn much attention since it has adverse effects on land, resources and human's infrastructure, especially the damaging effect which is known as erosion. Erosion is a frequent interaction of water and soil leading to its consequence. The changes in a river or a canal maybe cause a change in dimension, shape, component of their bottom, levels of slope, surface. The critical issue, however, is to understand the mechanism of erosion, transportation and deposition of sediment. The hydraulics of flow in a river and its sediment transport characteristics are the two basic phenomena that determine its geometric and plan form shape. There are many variables that affect the hydraulics of flow and the nature of sediment transported in a natural stream. Flows in open channels are described by a set of partial differential equations for computer simulation of hydrodynamic and sediment processes (Chaudhry, 1993; Martin and McCutcheon, 1999). Analytical solutions for these equations are not available, except for simplified, one-dimensional cases. Therefore, these equations are solved using numerical methods. Mathematically represented simulations are an efficient way to estimate the time and space-dependent sediment processes (Van Rijn, 1989). There are numerous mathematical models available to simulate sediment transport and depositions in one-dimension (1D) (Doan et al., 2013), two-dimension (2D), and three-dimension (3D) (Martin and McCutcheon, 1999; Abbott,

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1992). Nowadays, different mathematical models with the support of computers allow people to describe events in the past as well as to forecast the future phenomena with unpredictable conditions. Many research programs have been devoted to the study of the sediment transported (Vanoni, 1984; Yallin, 1963, 1972; Yang, 1972, 1973). Yallin (1963, 1972) developed a bed load equation incorporating reasoning similar to Einstein (1950), Einstein and Chien (1955), however, with a number of refinements and additions. Yang (1972, 1973) approached the total transport from the energy expenditure point of view and related the transport rate to stream power. Hassanzadeh (2007) used the dimensional analysis and the Buckingham Π-theorem has presented a dimensionless semi-empirical equation on the bed load.

Central Vietnam has been adversely affected by storms, tropical cyclone and floods which caused damage to numerous dykes, embankments and salinity to farming crops where the water level was heightened due to storms. In the coastal areas of Quang Tri province, the storms No. 8, 9, and 10 occurred in 1999; No. 4 in 2000; No. 5, 6, 7, and No. 8 in 2005 destroyed many dykes and embankments. In particular, due to the deleterious effects of storms No. 6 and 7 combined with the tropical depression in cold front in October 6th, 2005, there was heavy rainfall in Quang Tri province, triggering the greatest flood in all rivers of the province, especially in Ben Hai River, O Hieu River, O Lau River, O Giang River and Thach Han River. This flood made severe damage to the property and people in Hai Lang commune. Every year, due to the detrimental effects of storm and flood, erosion has occurred along with rivers and coastal areas. This phenomenon occurs at many places on Thach Han River, flowing through Trieu Do commune. However, the construction of Giap Dong dyke still cannot prevent erosion from taking place (**Fig. 1**). In this study, the application of hydraulic MIKE 21 HD and MIKE 21 ST in the simulation and calculation has a significant role to evaluate the effect of dykes and embankments on the erosion on Thach Han River.

(a) (b)

Fig. 1. (a) Erosion on the river at Gia Do commune; (b) Erosion at the dyke system at Quy Ha commune.

2. Materials and methods

2.1 Description of study site

Quang Tri is a province in Central Vietnam, encompassing four types of terrain: mountains, hills, plains and coastal areas. It has three main rivers including Ben Hai River, Thach Han River, O Lau River and many small rivers (**Fig. 2**). The acreage of natural land is 4.739,82 km^2 (in which 78% are mountainous areas, 14,5% are plains and 7,5% are sandy dunes and coastal areas). Quang Tri province possesses extreme weather conditions and unfavorable topography. Every year, it suffers a great deal of disasters such as storm, cyclone depression, flood, inundation, salinity, tide, flashing flood, drought, thunderstorm, erosions, erosion, wildfire, in which storm is a common disaster and cause serious damage. The most devastating effect is the damage caused by storm, flood and inundation on the major rivers in Quang Tri province. The dyke system protecting Trieu Do commune and Trieu Phong commune which are located at the bank of Thach Han River is 4,14 km. This dyke system belongs to the general construction plan of Trieu Phong commune, Quang Tri province. The dyke system from Xuan Thanh commune to Quy Ha dam located in the bottom of Thach Han River, near the water front (Cua Viet) was often affected by flooding and rising tide. However, due to the historical flood in 1999 and adverse damage of storm No. 8 in October, 2015, this dyke system was destroyed and many of its fragments were swept away. Therefore, the protection of the system for residents was removed.

2.2 Data collection

In order to establish, adjust and modify the hydraulic model for Thach Han River basin - Quang Tri province, input data were collected according to the following criteria:

Topography data: surface topography (topographic maps, DEM data), rivers' cross-section and river schemes (irrigation works, transportation systems, bridges and so on): (1) Topographic map of Quang Tri Province and Hue City with the scale of 1/50000 which was converted into digital format; (2) 25 topographic maps of Quang Tri Province with the scale of 1/25000; (3) National Atlas in 2000 (paper form). In addition, data of river schemes was collected as follows: (1) parameters of dykes and embankments of Quang Tri province; (2) basic technical parameters of the system of Southern Thach Han; (3) Disaster risk management plan of Quang Tri Province up to 2020 and Disaster risk management projects in Quang Tri.

Hydro-meteorological data: rainfall, evaporation, water level, discharge collected at meteorological and hydrological stations belong to the National Hydro-meteorological Service, Ministry of Natural Resources and Environment (**Table 1**).

Table 1. Lists of hydro-meteorological stations collection.

Name of stations	Name of rivers	Indicator	Years of collection	Notes
Cua Viet	Thach Han	H	1977-2009	The data were based on the measurement of tide
		Flood	1983, 1990, 1995, 1998, 1999,2004-2009	
Dong Ha	Cam Lo	H	1976-2009	The data were based on the measurement of tide
		Flood	1983, 1990, 1995, 1998, 1999, 2004-2009	
Thach Han	Thach Han	H	1977-2009	The data were based on the measurement of tide

2.3 Description model

In this study, the combination of hydraulic model of MIKE 21 (HD) and sediment transport model of MIKE 21 (ST) was used to carry out research on the development of erosion within the study (MIKE 21, 2012). MIKE 21 is commercial software in simulating the two-way flow, wave, sediment transportation, shape and environmental process. It is user friendly display, trustworthiness that have made the software an integral part in models applied to inland, coastal and offshore areas. The equation Saint-Venant was used for two-dimensional space consisting of one continuity equation and two momentum equations which are presented as the following:

$$\frac{\partial h}{\partial t}+\frac{\partial h\bar{u}}{\partial x}+\frac{\partial h\bar{v}}{\partial y}=hS \tag{1}$$

$$\begin{aligned}\frac{\partial h\bar{u}}{\partial t}+\frac{\partial h\bar{u}^2}{\partial x}+\frac{\partial h\overline{uv}}{\partial y}&=f\bar{v}h-gh\frac{\partial \eta}{\partial x}-\frac{h}{\rho_0}\frac{\partial p_a}{\partial x}-\frac{gh^2}{2\rho_0}\frac{\partial \rho}{\partial x}+\\ &\frac{\tau_{sx}}{\rho_0}-\frac{\tau_{bx}}{\rho_0}-\frac{1}{\rho_0}\left(\frac{\partial S_{xx}}{\partial x}+\frac{\partial S_{xy}}{\partial y}\right)+\frac{\partial}{\partial x}\left(hT_{xx}\right)+\frac{\partial}{\partial y}\left(hT_{xy}\right)+hu_sS\end{aligned} \tag{2}$$

$$\begin{aligned}\frac{\partial h\bar{v}}{\partial t}+\frac{\partial h\overline{uv}}{\partial x}+\frac{\partial h\bar{v}^2}{\partial y}&=-f\bar{u}h-gh\frac{\partial \eta}{\partial y}-\frac{h}{\rho_0}\frac{\partial p_a}{\partial y}-\frac{gh^2}{2\rho_0}\frac{\partial \rho}{\partial y}+\\ &\frac{\tau_{sy}}{\rho_0}-\frac{\tau_{by}}{\rho_0}-\frac{1}{\rho_0}\left(\frac{\partial S_{yx}}{\partial x}+\frac{\partial S_{yy}}{\partial y}\right)+\frac{\partial}{\partial x}\left(hT_{xy}\right)+\frac{\partial}{\partial y}\left(hT_{yy}\right)+hv_sS\end{aligned} \tag{3}$$

The model MIKE 21 (ST) provides the method to calculate the speed of sediment transport that is not coherent. MIKE 21 (ST) can measure the process of transporting sand solely based on data of water flow, or based on the combination of data of water flow and wave. MIKE 21 (ST) can simulate the speed of the process of transporting sand in a large-scale region, including natural environment such as tidal creek, estuary and coastal line, and man-made constructions like bridges, harbors so on. According to Engelund and Fredsoe (1976) theory, the total sediment volume transported q_t is equivalent the total volume of bed floor sediment transported q_b and volume of remained sediment transported q_s ($q_t = q_b + q_s$).

The total volume of sediment transported was measured as the following equation:

$$q_b = 5p\left(\sqrt{\theta'}-0.7\sqrt{\theta_c}\right)\sqrt{(s-1)gd^3} \qquad \text{If } \theta' > \theta_c \tag{4}$$

Einstein (1950), suspended sediment is calculated by the formula:

$$q_s = 11.6u'_*c_a a\left[I_1\ln\left(\frac{30.2h}{d_{65}}e\right)+I_2\right] \tag{5}$$

$$I_1 = 0.216\frac{A^{Z-1}}{(1-A)^Z}\int_A^1\left(\frac{1-X}{X}\right)^Z dX \tag{6}$$

$$I_2 = 0.216\frac{A^{Z-1}}{(1-A)^Z}\int_A^1\left(\frac{1-X}{X}\right)^Z \ln(X)dX \tag{7}$$

Engelund and Fredsoe (1976) has developed a semi-empirical correlation for the c_b at:

$a = 2d$; $c_b = \dfrac{0.65}{(1+1/\lambda)^3}$ with $\lambda = \sqrt{\dfrac{\theta'-\theta_c-\frac{\pi p\beta}{6}}{0.027s\theta'}}$ if $\theta' > \theta_c + \pi p\beta/6$.

The formulas of Engelund and Fredsoe were developed based on the data obtained from bed material experiments of grain size. Therefore, the bed material is used as an input for the deposition pattern in the appropriate range of particle size consistent with the formula. The physical should be processes are modeled by a "multi bed layer approach". An example with 3 bed-layers is shown in **Fig. 3**.

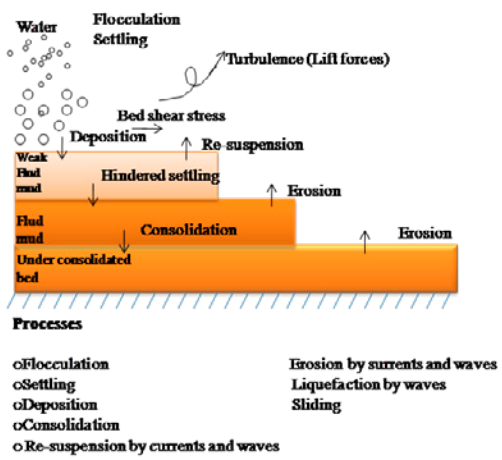

Fig. 2. Multi-layer model and physical processes

2.4 Establish computational mesh

In order to evaluate the effectiveness of dyke and embankment system on the erosion along Thach Han River (the section flowing through Trieu Do commune), the simulation was conducted as two scenarios:

Scenario 1: Simulation of the situation prior to the construction of dyke and the improvement of embankment system.

Scenario 2: Simulation of the situation after the construction of dyke and the improvement of embankment system.

To simulate the process of sediment transport in Trieu Do commune based on the two scenarios, MIKE 21 model was applied with the combination of hydraulic module and sediment transport module. The 2D visualization computation mesh constructed for the study area was presented in **Fig. 4**.

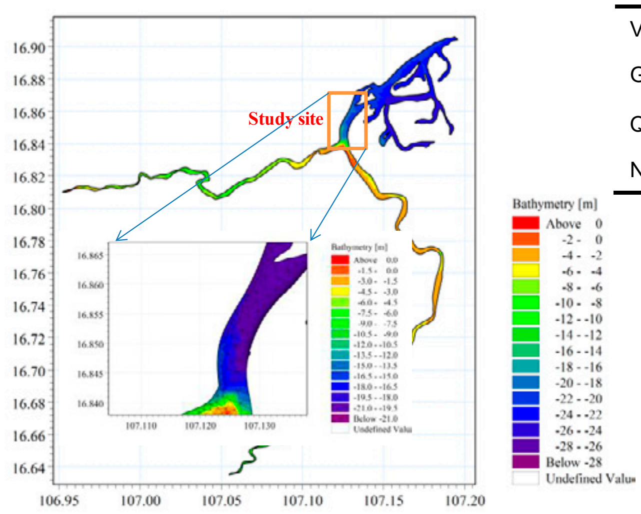

Fig. 3. 2D visualization in study area

3. Results and discussion

3.1 Calibration and validation

Validation and calibration of 2D model were calculated and simulated based on two enormous storms. The storm No. 01 from 1.00am on 5th October, 2005 to 11.00pm on 13th October, 2005 was used to calibrate the model, and the storm No. 02 from 1.00am on 01st November, 1999 to 11.00pm on 11th November, 1999 was used to validation the model. The input data were the volume of rainfall collected at Thach Han station (1999, 2005), Dong Ha station (2005), and Cua Viet station (2005), and the tide data collected at Cua Viet station and the tide water level collected at the estuaries. The modification data were the observed water level at Thach Han station (1999, 2005) and Dong Ha station (1999, 2005).

The process of calibration model was applied to the historical flooding on 05-12 October, 2005. On the Ben Hai River basin, the maximum hourly precipitation registered 96mm, at Dong Ha station with 408mm of the amount of rainfall within 12 hours. The comparative result between simulated and measured water level at Thach Han station (Nash = 0.97) and Dong Ha station (Nash = 0.94) with optimal results of Nash (Nash-Sutcliffe, 1970) (**Figs. 5, 6, Table 2**). Based on the results of calibration model parameters was used to validate the model of the flood event in 1999.

Table 2. Evaluation criteria for indicator quality (Moriasii et al., 2007)

Evaluation	RSR	Nash	PBIAS (%)
Very good	0 ≤ RSR ≤ 0.5	0.75 < Nash ≤ 1	PBIAS < ± 10
Good	0.5 ≤ RSR ≤ 0.6	0.65 < Nash ≤ 0.75	±10 ≤ PBIAS < ±15
Qualified	0.6 ≤ RSR ≤ 0.7	0.5 < Nash ≤ 0.65	±15 ≤ PBIAS < ±25
Not qualified	RSR > 0.7	Nash ≤ 0.5	PBIAS ≥ ±25

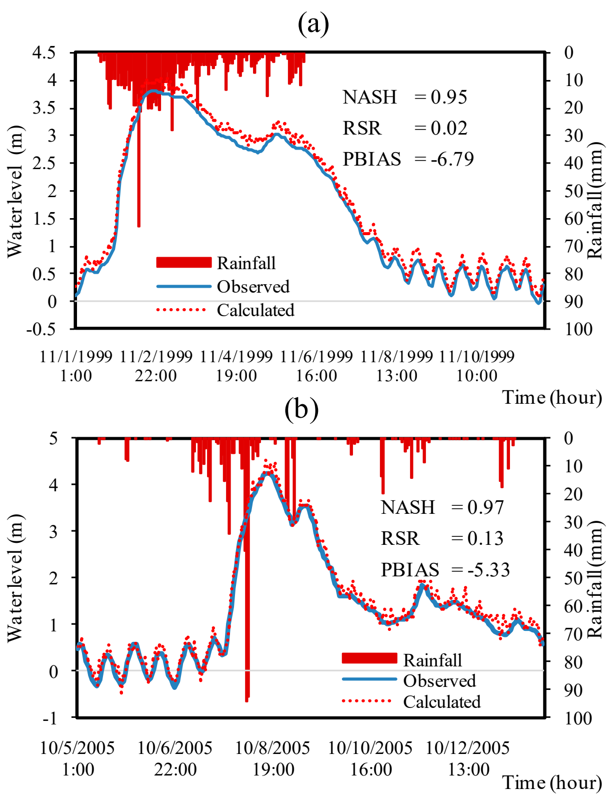

Fig. 4. The calibration and validation of simulated and measured water level at Dong Ha station in 1999 and 2005

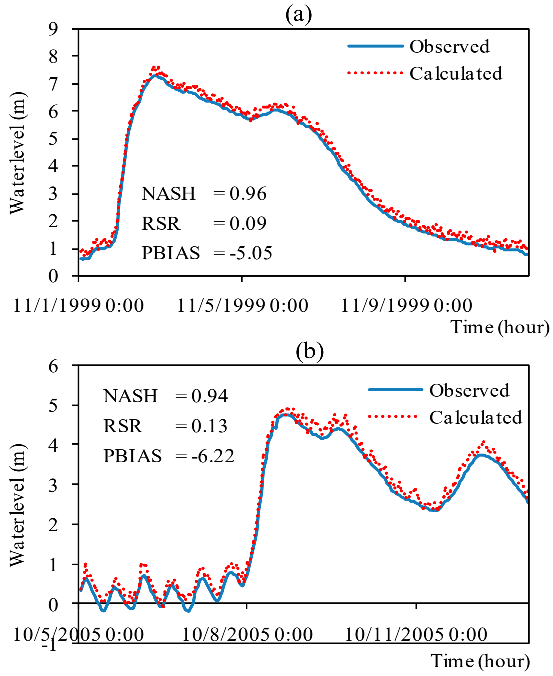

Fig. 5. The calibration and validation of calculated and measured water level at Thach Han station in historical flood events in 1999 and 2005.

The calibration model was applied to measure the historical flood event from 1-10 November, 1999 caused by torrential rain (the precipitation measured at stations fluctuated from 1300 mm to 1600 mm) and tides due low pressure of East Sea, triggering large-scale and perpetuated flooding (the water level at Thach Han River was 7.29m, more than the alarm level III by 1.79m). The calibration results of calculated and measured water level at two stations: Thach Han (Nash = 0.96) and Dong Ha (Nash = 0.95) demonstrated that the model was qualified to the measurement with optimal Nash results (**Figs. 5, 6, Table 2**).

The calibration and validation of calculated and observed water level in two huge storms in 2005 and 1999 (**Figs. 5, 6**). The calibration and validation of water level at Thach Han station and Dong Ha station proved the results of Nash oscillated from 0.94-0.97 (qualified). The RSR value varied from 0.02-0.13 < 0.5 (qualified) during both calibration and validation of the model. PBIAS value ranged from -6.22% to -5.33% after calibration, and from -6.79% to -5.05% after validation (**Figs. 5, 6**). The simulation value of average water flow was considered good (PBIAS < ±10) for both calibration and validation of the model (**Table 2**). Nash, RSR and PBIAS were all proven qualified for the whole measurement. The data after calibration and validation of the model may be used to simulate the construction.

3.2 Scenario developments

The data obtained by calibration and validation of the hydraulic model of two huge storms were reliable enough to simulate plans for flood prevention as well as other plans in the next stage. Hydraulic and sediment transportation models in two-dimensional MIKE 21 were applied to evaluate the effectiveness of the project on water flow. Non-parametric mesh terrain was used for both scenarios. After simulating the existing scenario, the scenario with the construction was calculated using the same input data and simulation of a 1.5 km of dyke system and updated data of a 2.7 km of embankment system. The model was simulated with the most unfavorable condition and marginal condition set by water level in flooding season.

Based on the data chain of water level and flood in many years, October was observed to have the highest water level and water flow, and the data in October 2007 was applied to simulate and calculate the effectiveness of construction on sandy regime on Thach Han River. The year 2007 was chosen as it had the biggest flood event on Thach Han River. Besides, the flooding flow acts a vital part when simulating the development of sandy regime.

The results in two scenarios are proven: (1) Flow velocity in the river section through Trieu Do commune was small (**Fig. 7**); (2) The changes in bed load illustrated serious erosion (**Fig. 8**); (3) Total sandy and sediment transported were a large (**Fig. 9**).

The results of **Fig. 8** and **Fig. 9** represented the scenario prior to the construction, due to the weakness of geological structure of the river and unregulated exploitation of sand that caused serious erosion in flooding season and considerable changes in the bed floor. The bed river was widened with low level of velocity and speed of water flow; erosion could lead to increased sediment in the river, resulting in a large amount of sediment transport; the erosion in the estuaries, affecting flood drainage. According to the simulation results, after the construction was built, the flow speed has been increased; the bottom transformation process has greatly reduced along with a small amount of sediment transport. It has showed that the construction established has improved the geological structure of the coastal areas, therefore, reducing riverbank erosion in the study area in case of heavy rainfall.

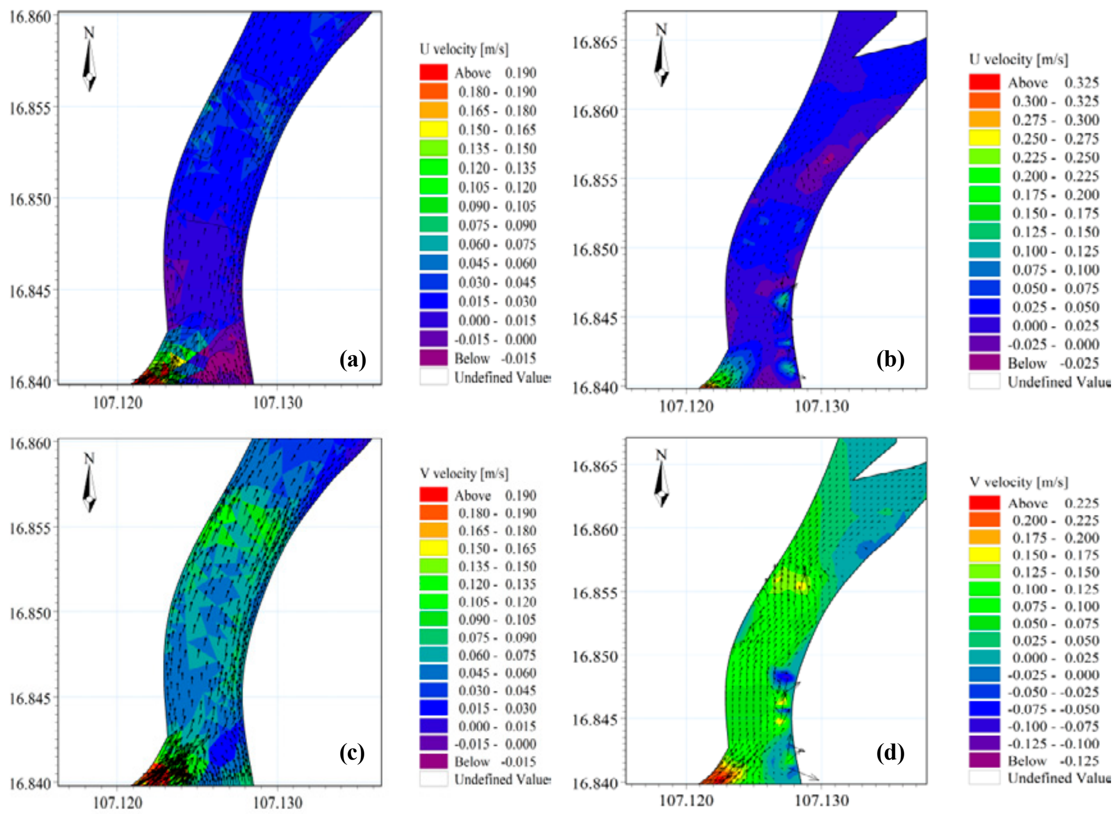

Fig. 6. Flow velocity components in the x- and y-direction: (a, c) current scenario; (b, d) construction scenario

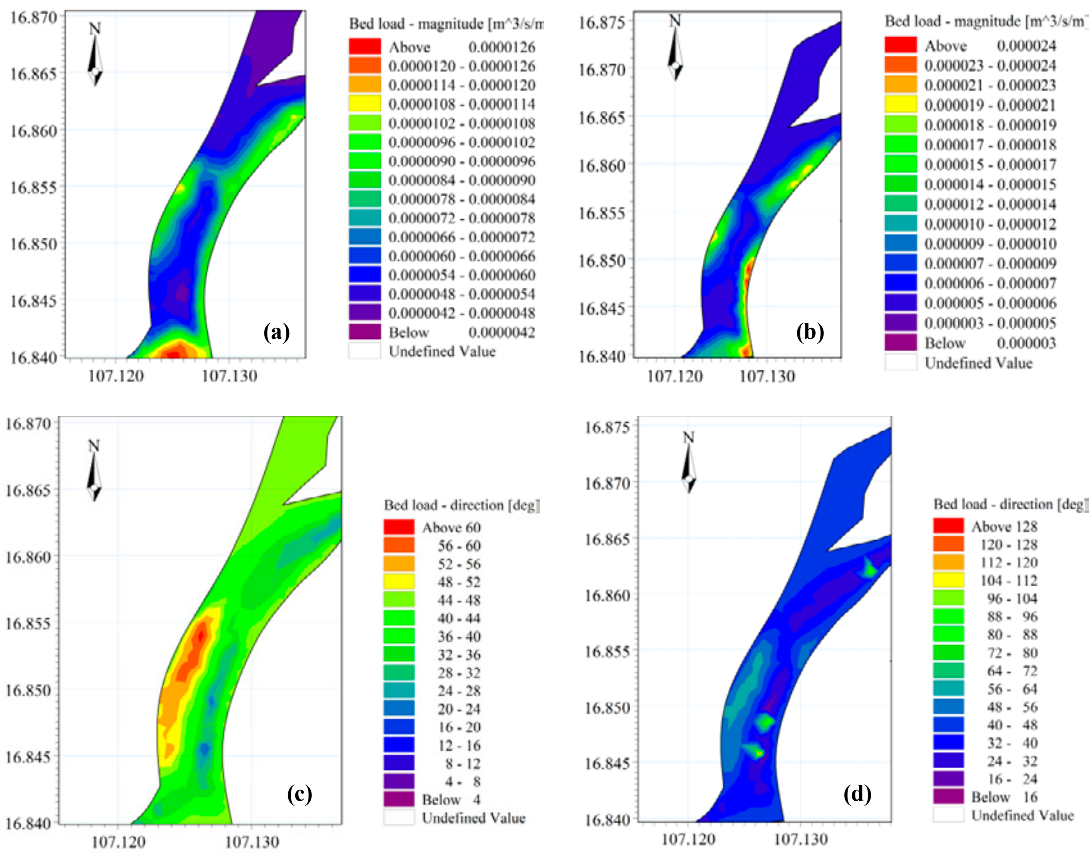

Fig. 7. The changes in bed load: (a, c) current scenario; (b, d) construction scenario

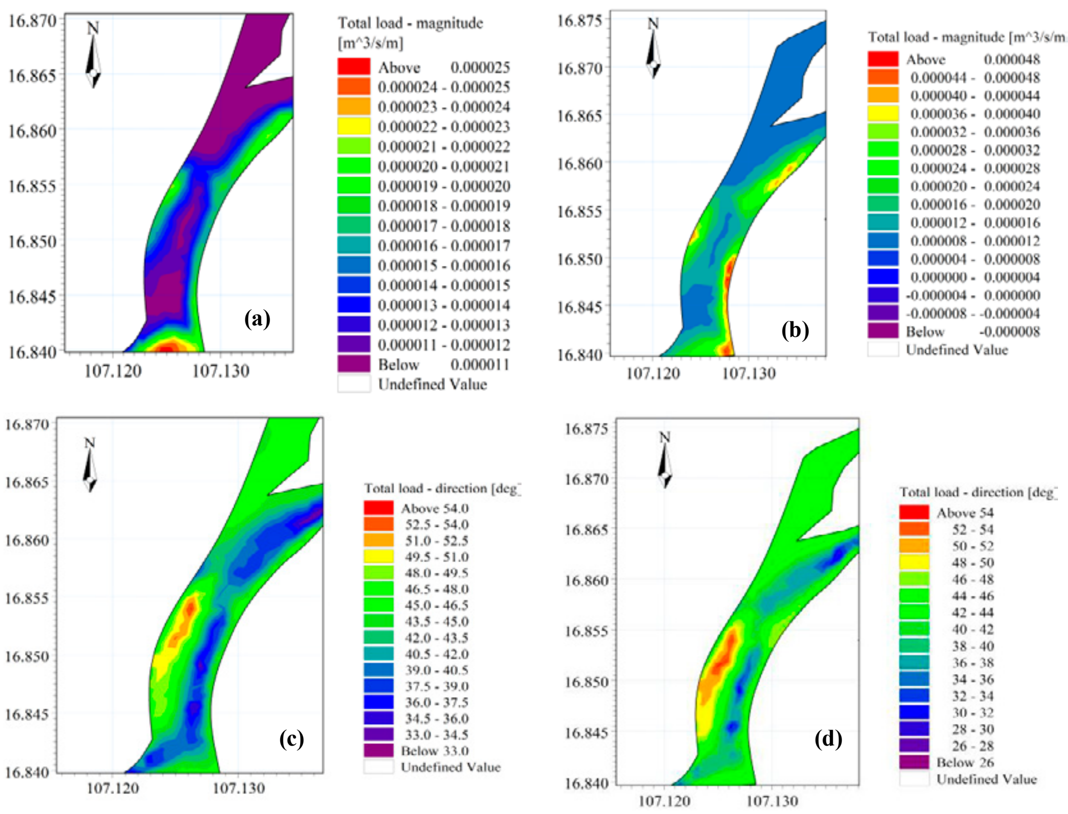

Fig. 8. Total sandy and sediment transport: (a, c) current scenario; (b, d) construction scenario

4. Conclusion

It is true that the construction plays a crucial role in the study site. As the results has showed that because of the construction, water flow speed has increased and changes in bed load has been slow down which resulted in the reinforcement of geographical infrastructure along the river, reducing the possibility of erosion in flooding season. The results using sediment transportation model of MIKE 21 presented an overall on the development of erosion along the bank and at the bed load in two scenarios: prior to the construction and after the construction. Based on the results, the construction has significant contribution to reducing the increasingly serious erosion on the part of the river flowing through Trieu Do commune. Consequently, the construction has been proven its usefulness and necessity. The results of the study showed that the application of the model in the other watersheds in Vietnam is guaranteed. It is likely to allow managers and planers to develop solutions to reduce the erosion along the bank and bed river in the similar basins.

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References

Abbott, M.B., 1992. Computational Hydraulics. Ashgate Publishing Company, Brookfield, Vermont 05036, USA.

Chaudhry, M.H., 1993. Open Channel Flow. Prentice Hall, New Jersey: pp 483.

Chanson, H., 2004. Hydraulics of open channel flow. Elservier, Butterworth-Heinemann, 650. https://doi.org/10.1016/B978-0-7506-5978-9.X5000-4

Doan, Q.T., Chen, Y.C., Quach, T.T., Mishra, P.K., 2013. Numerical Modeling in Shore Line Evolution Prediction: Case Study of Tat Dike, Vietnam. International Journal of Earth Sciences and Engineering, **06**, 05(01): 1251-1259.

Einstein, H.A. and Banks, R.B., 1950. Fluid resistance of composite roughness. Trans. Am. Geophys. Union, **31**: 603-610.

Einstein, H.A., and Chien, N., 1955. Effects of Heavy Sediment Concentration near the Bed on Velocity and Sediment Distribution, M.R.D. sediment series No. 8, University of California, Institute of Engineering Research and United States Army

Engineering Division, Missouri River, Corps of Engineers, Omaha, Neb.
Engelund, F., Fredsoe, J., 1976. A sediment transport model for straight alluvial channels. Nordic Hydrol, **7**: 294-298.
Hassanzadeh, Y., 2007. Evaluation of Sediment Load in a Natural River" Journal of Water International, **32** (1): 145-154.
Nash, J.E. and Sutcliffe, J.V., 1970. River flow forecasting through conceptual models part I - A discussion of principles. J. Hydro. **10** (3): 282-290. https://doi.org/10.1016/0022-1694(70)90255-6.
MIKE 21, 2012. Hydrodynamic module, Sand Transport module, Scientific ducumentation. http://manuals.mikepoweredbydhi.help/2017/MIKE_21.htm
Martin, J.L. and McCutcheon, S.C., 1999. Hydrodynamics and Transport for Water Quality Modeling. Lewis Publications, Boca Raton, Florida.
Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D., Veith, T.L., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, Transactions of the ASABE, **50** (3): 885-900.
Vanoni, V.A., 1984. Fifty Years of Sedimentation, Journal of Hydraulic Engineering, **110**(8): ASCE.
Van Rijn, L.C., 1989. The State of the Art in Sediment Transport Modeling, in Sediment Transport Modeling, edited by Sam S.Y. Wang, 1989. American Society of Civil Engineers, New York.
Yalin, M.S., 1963. An Expression for Bed Load Transportation, ASCE 89, HY3.
Yalin, M.S., 1972. Mechanics of Sediment Transport, Pergamon Press.
Yang, C.T., 1972. Unit Stream Power and Sediment Transport, Proc. ASCE, 98, HY10: 1805-1826.
Yang, C.T., 1973. Incipient Motion and Sediment Transport, Proc. ASCE, 99, HY10: 1679-1704.

Symbols and abbreviations

t	The time (s)
x,y	The Cartesian coordinates (m)
η	The surface elevation (m)
d	Average water level (m)
h	The total water depth (m)
$\bar{u}, \bar{v}$	Depth-average velocity components in the x- and y-direction (m/s)
$f = 2\Omega \sin\varphi$	The force Coriolis
g	The gravity (m/s^2)
ρ	The water density (g/m^3)
$S_{xx}, S_{xy}, S_{yx}, S_{yy}$	The components of radiation stress tensor
P_a	The atmospheric pressure (mb)
ν_t	The vertical turbulent (or eddy) viscosity
S	The magnitude of the discharge due to point sources (m^3/s)
u_s, v_s	The velocity by which the water is discharged into the ambient water (m/s)
T_{xx}, T_{yy}, T_{xy}	Three stress components
p	The probability that all the particles of a layer are moving
q_b	Rate of bed load trasport in volume of material per unit time and unit width of the channel
θ'	Shields parameter/non-dimensional shear stress
θ_c	non-dimensional critical shear stress
s	Relative density of sediment
g	Acceleration of gravity
d	Fall diameter of sediment particle
β	The coefficient of friction
c_b	The bed concentration
u'_*	The current-related bed-shear velocity due to the grains (m/s)
c_a	The reference concentration (volume)
$a = 2d$	The reference level (m)
I_1, I_2	Einstein integral
h	The water depth (m)
d	The particle diameter (m)
$A=a/h$	Diemensionless reference level
$X=z/h$	Imensionless vertical coordinate
$Z=w_s/(ku^*)$	Suspension number
E	Correction factor