IMPACT ASSESSMENT OF UPSTREAM LARGE RESERVIORS ON SEDIMENT TRANSPORT IN THE DOWNSTREAM OF RED - THAI BINH RIVER SYSTEM OF HAI PHONG CITY

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Abstract: *The Red-Thai Binh River System in Vietnam is the second largest river system in Vietnam (after Mekong River system) and plays an important role in socio-economic development of the country. Four large reservoirs were constructed in the upstream for flood control, hydropowe and water supply (agriculture, domestic, navygation and fisheries...). Besides these benefits, the reservoirs also created negative impacts such as changing sediment stransport in the downstream which causes erosion, sedimentation, salinization, and natural imbalance. In this paper, the module of sediment transport of MIKE 11 ST model was applied to assess changes in annual sediment transport in 5 major estuaries in the downstream of Red-Thai Binh River system of Hai Phong city before and after the reservoirs construction. Results showed that the amount of sediment in the downstream is significantly decreased after mainstreams locked by the large dams. Before 1970 when no reservoirs bulit, the total amount of sediment is 45.5 million tons/year; after Thac Ba and Hoa Binh reservoirs are in operation (1989-2006) the sediment load was 29.4 million tonnes/year (remains 65%); from 2007 till now when four large reservoirs are in operation, it was only 15.1 million tons/year (remains 33%). This presents the deficit of sediement in the river system and leads to unstability of river banks and river bed in the study area. Therefore, this work could provide valuable information for better management and planning of this river basin.*

Keywords: Red River Basin, reservoirs, MIKE 11 model, sediment transport.

1. INTRODUCTION

Sediment load delivered to the sea from the river has decreased over the past few years by human activities, mainly as a consequence of reservoirs construction. Sediment transport from continental mass land to ocean is also fundamental aspects of the surface features and biogeochemistry of earth (Vörösmarty et al., 2003). It is important for the evolution of deltas at their mouths (Syvitski & Saito, 2007).

Due to increasing water demand, human always have tried to utilize water resources in sustainable ways by constructing canals and dams. During the 20th century, more than 45,000 large dams around the world have constructed for the management of water resources such as irrigation supplies, hydropower development, flood control and domestic use (World Commission on Dams - WCD, 2000) and at present their total number is around 50,000. Therefore, 10,800 cubic kilometer of water is artificially stored behind the reservoirs and this amount would be larger, if small reservoirs are included (Chao et al., 2008). Recently, one of the main problems aroused by reservoir construction is the decrease in sediment loads at global scale (Walling & Fang, 2003). It is estimated that 50% or more sediment is trapped by large reservoirs and local sediment trapping efficiency is 80% or more (Vörösmarty et al., 2003).

The Red-Thai Binh river system is the largest river in terms of area and water availability in Vietnam's territory. Three main tributaries of red river Thao, Da and Lo originate from the

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mountainous region of Yunnan province, which run through Vietnam and confluence in Vietnam Tri is collectively known as Red River System. This transboundary river is running through the Vietnam, China, Laos and merges into the East Sea (Tonkin Gulf). The total catchment area is about 169,000 km^2, of which 48% is in China, less than 1% in Laos and 51% in Vietnam (van den Bergh et al., 2007a). Thac Ba, Hoa Binh, Tuyen Quang and Son La reservoirs have constructed in the Red River basin for multiple purposes such as irrigation, water supplies, hydropower and flood control. Though dams provide a number of benefits, recently controversies are often raising about construction of dams as they are causing serious problems to our society and environment. One of the main problems aroused by reservoir construction is sediment trapping, which should be given primary concerns. A lack of sediment transport will impact on our environment and society also. Therefore, several studies have been done to understand the dynamics of reduced sediment fluxes as a result of dam construction on the Yellow River and Changjiang River (Ming et al., 2009; Wang et al., 2008).

Hence, the main aim of this study is to estimate the sediment transport rate before and after construction of Hoa Binh (1989), Tuyen Quang (2007), Thac Ba (1972) and Son La (2012) reservoirs. This paper represents the changing sediments in the down stream of Red - Thai Binh river system in Hai Phong city by impact of upstream reservoirs.

2. STUDY AREA AND DATA COLLECTION

The study area is located in North and North-East of Vietnam, namely Red-Thai Binh River basin. Figure 1 shows the Red River basin which originates from mountainous region in Yunnan province of China and then flows through Vietnam and Laos. The river basin borders Truong Giang and Chau Giang river of China in the north; Mekong River in the West; Ma River in the South; and the Tonkin Gulf in the East. More than 47% of the topography of the Red River basin is mountainous type, i.e. elevation is at above 1000 m.The higher elevation is mostly found in the western part in Da and Thao sub basin. Most flat plain are found in the valleys of big river. “Red River basin lies between latitude 20°00’ and 25°30’N and longitudes 100°00’ and 107°10’ E”. The total catchment area is about 169,000 km^2, of 48% is in China, less than 1% in Laos and 51% in Vietnam (Dang, 2010, p. 43). “The three major tributaries in the upstream of the Red River include the Da, Thao and Lo Rivers. The Da River joins the Thao River at Trung Ha town where the mainstream to downstream is called the Red River. Afterwards, the Lo River joins the Red Riverat Viet Tri city that is called 60 km north of Hanoi Capital.

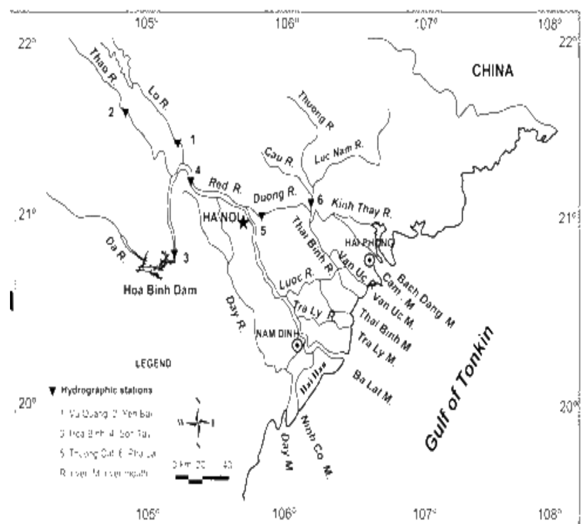

Figure 1. Red river system and river mouth

(Source: Vinh et al., 2014)

The Da River is the largest catchment of the Red River and joins it at Trung Ha – the confluence of Da, Thao and Red Rivers.The Thao River is the second largest catchment in Vietnam and is the mainstream part of the Red River before connecting to Da River at Trung Ha. The Lo River is the third largest catchment of the Red River and flows into the Red River at Viet Tri city” (Dang, 2010, p. 43). Red-Thai Binh River flows to the sea through nine estuaries: Da Bach, Cua Cam, Lach Tray, Van Uc, Thai Binh, Tra ly, Ba Lat, Ninh Co.

The climate of the Red River delta is tropical monsoon type, characterized by the hot and humid climate. Precipitation varies greatly indifferent places, i.e., from mountainous region to delta areas. The mean annual rainfall varies from 1200 mm to 5000 mm in the whole river basin. The difference in rainfall intensity varies greatly in two seasons. Winter season: The amount of rainfall in dry season is much lower (November- April) than in wet season, i.e., only 20% of annual rainfall. Summer season: The amount of rainfall is higher in this season, it accounts for 80% of the annual rainfall (Dang, 2010). From 1997-2004, the upstream temperature of Red River basin in summer was 26-27°C and in winter 14-16°C. Temperature in the delta areas were slightly higher in summer, it varied from 17 to 30^{o}C. The annual average potential evapo-transpiration from 1997 to 2004 was rather homogenously distributed over the whole basin area, varied slightly from 880 to 1150 mm per year. Many reservoirs have been built in Vietnam, e.g. Day in 1937 (on the Day River), Thac Ba in 1970 (on the Chay River), HoaBinh in 1889 (on the Da River), Tuyen Quang in 2007 (on the Lo River) and Son La in 2012 (on the Da River). The HoaBinh dam is the second largest dam in Vietnam, which was built to control flood and produce power generation. It has effective storage capacity of 5.6 billionm^3, which provides 40% of Vietnam's electricity. Thac Ba reservoir was built to control flood and supply water for irrigation (storage capacity is 2.94 billion m^3. Effective storage capacity of Tuyen Quang is 1.3 billionm^3 of which 0.5 billionm^3 is used to protect the Tuyen Quan city from flood. Son La reservoir is biggest reservoirs in Vietnam, which was built to produce power generation; it has no storage for flood control (Dang, 2010).

Over 50 years (1960-1970) ofdaily water level and discharge data were used to build up the hydrodynamic model for this study. The required data to simulate the model are a river network map, cross-section of river branches and topographic map of the basin. A total of 1237 cross-sections in 42 river branches were collected in the Red – Thai Binh River mainstream. The data were gathered from the Center for River Hydraulic Engineering (National Key Laboratory of River and Coastal Engineering, Vietnam Academy for Water Resources).

3. METHODOLOGY

The impacts of reservoirs on discharge and sediment transport were assessed by using Mike 11 Model. The MIKE 11 is an implicit finite difference model for one dimensional unsteady flow computation and can be applied to looped networks and quasi-two dimensional flow simulation on floodplain (DHI, 2007a). Mike 11 model solves Saint Venant's equation for each channel segment, which is considered as basic finite difference elements. For this study, continuity and momentum equations were solved numerically using an implicit finite difference know as the six-point Abbott scheme. These equations are simultaneous, quasi-linear, first-order, partial differential equations of the hyperbolic type. The transformation of these equations into a set of finite difference equation is performed in a computational grid involving altering Q and H points. Q point are always placed midway between two adjacent H points, while the distances between the H points may vary.

In order to set up the model, the Red-ThaiBinh River System in the Vietnamese territory is schematized by 42 branches with 5346 chainages. Figure 2 shows the scheme of the main rivers, upstream reservoirs, and hydrological stations which were used in model's calibration and verification. Initial conditions of discharge and water level were set up with a global value and local values at 88 chainages. Bed resistance in river branches is very important for streamflow simulation in a river network. Manning's roughness coefficient or Manning's n was used to simulate bed resistance. The global value of Manning's n applied in the model was set at 0.022 s/m$^{1/3}$, while the local values of Manning's n were set 0.016 - 0.042 s/m$^{1/3}$ for different river branches in the Red-Thai Binh River System.

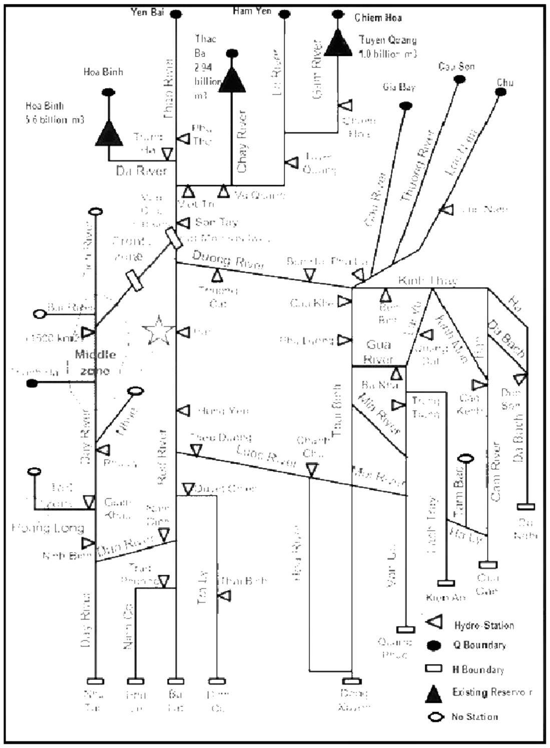

Figure 2. Schematic of the network and reservoirs considered in the Red-Thai Binh River System (Source: Dang, 2010).

The non-cohesive sediment transport module (NST) can be run in two modes; explicit and morphological. There are five different models of non-cohesive sediment transport module for the calculation of sediment transport rate and alluvial roughness. The Engelund and Hansen model of non-cohesive module was selected for the case study site and the equation as below:

$$\Phi = 0.1\frac{\theta^{\frac{5}{2}}}{f} \quad (1)$$

Where, θ = dimensionless total bed shear stress; Φ = dimensionless sediment transport rate; f = friction factor which can be defined as:

$$f = 2\frac{u_f^2}{u^2}$$

Where, u_f and *u* are the friction and current velocities, respectively.

$$\Phi = \frac{q_t}{\sqrt{(s-1)gd^3}} \quad (2)$$

Where, q_t = total bed material transport per unit width; s = $\frac{\gamma_s}{\gamma}$ = relative density of sediment grains; d = mean fall diameter; g = acceleration of gravity; t = time.

4. RESULTS AND DISCUSSIONS

4.1. Calibration and validation

For this study, different grain sizes of particles were used for simulation of total sediment volumes in each grid point. During the calibration and validation procedure, sediment transport rate was adjusted by the factor 1. Due to lack of sediment data in the dry season in most stations in the river network, the calibration and validation for the model is only implented in rainy season, this is limitation of this study. However, in the dry season, sediment concentartions is small and accounted for 15-20% of hole year; the annual sediment amount mostly depended on sedimentation in rainy season. It is acceptable to simulate annual sediment using parameters calibarated in rainy season in case of lack sediment data in dry season.

The Nash Index efficiency was calculated to check the model performance with the observed data and simulated data. For calibration, modeled data were checked with observed data for Thuong Cat, Quyet Chien, and Cat Khe stations as shonw in Figures 3, 4, and 5. The Nash Index Efficiency at those stations were found 0.68, 0.65, and 0.65, respectively. After that, validation was done to check the reliability of the parameters those were found in the previous step. Ha Noi, Thuong Cat and Son Tay stations were used for validation as presented in Figures 6, 7, and 8. Nash Index efficiency for validation at those stations were 0.72, 0.69 and 0.64, respectively. Both calibration and validation results were found satisfactory, thus providing good agreement between measurements and simulations for sediment transport.

4.2. Impacts of reservoirs on sediment transport

This study has been conducted to assess the impacts of Thac Ba, Hoa Binh, Tuyen Quang, and Son La reservoirs on sediment transport rate. From the calculation of the sediment transport rate by the model, it is clear that sediment discharge rate has changed due to constructions of reservoirs as shonw in Table 1. From the result, it is seen that sediment delivery has also increased in the dry season (November to May) and decreased in the rainy season (June to October).

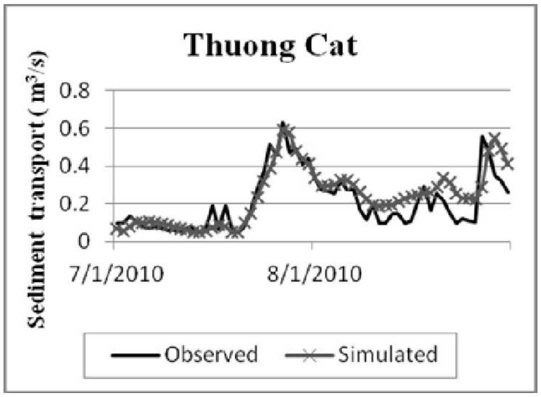

Figure 3. Calibration of sediment transport rate at Thuong Cat station, 2010.

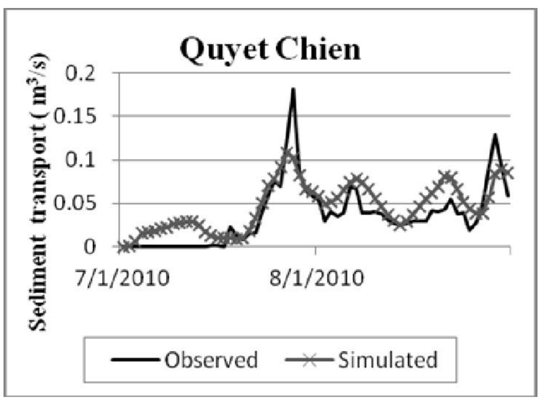

Figure 4. Calibration of sediment transport rate at Quyet Chien station, 2010.

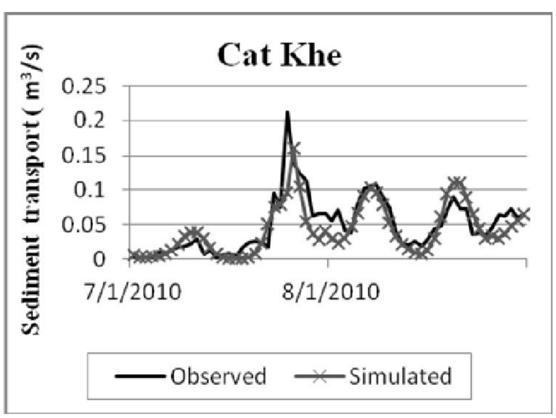

Figure 5. Calibration of sediment transport rate at Cat Khe station, 2010.

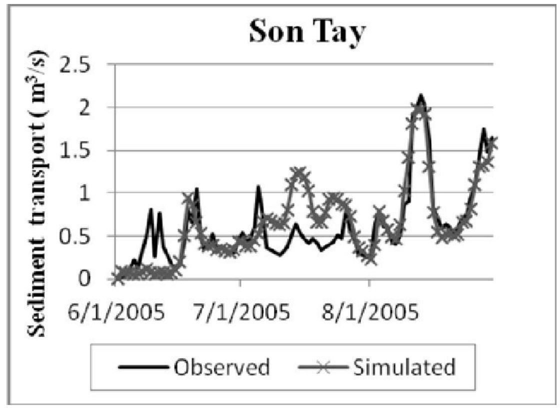

Figure 6. *Validation of sediment transport rate at Thuong Cat station, 2005.*

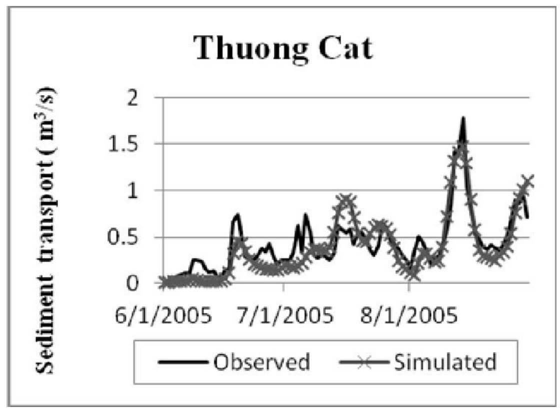

Figure 7. Validation of sediment transport rate at Son Tay station, 2005.

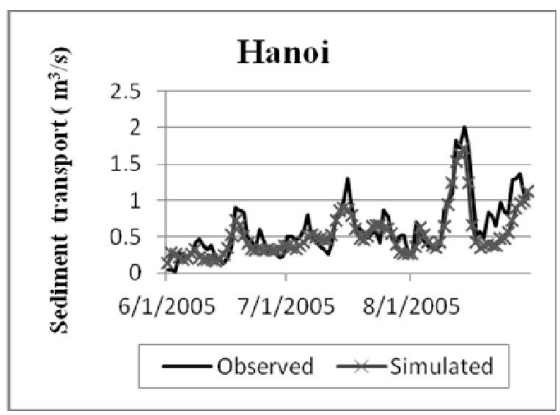

Figure 8. Validation of sediment transport rate at Hanoi station, 2005.

Though sediment delivery has increased during the dry season, total sediment discharge rate in hole year has reduced to a great proportion because of reservoirs construction. For the periods 1989-2006 and 2007-2014, sediment load decreased by 35.45% and 67% respectively compared to the periods of before construction of reservoirs (1960-1970).

5. CONCLUSIONS

Human activities, mainly the constructions of reservoirs have influenced to transform the hydrological behavior of the Red-Thai Binh River system over the past few years. Understanding the impacts of reservoirs are very important, but during first decades those impacts were not clearly identified, recent studies have documented the negative effects of reservoirs. This study has implemented Mike 11 model ST to estimate the sediment transport rate of the Red River rate before (1960-1970) and after construction (1989-2014) of reservoirs.

Mike 11 ST model has been calibrated and validated using available observed sediment transport data at different stations in the Red-Thai Binh River System. Manning's roughness coefficient was the main parameter during the calibration procedure to achieve the satisfied result. Results showed that the model had an excellence performance. Red-Thai Binh River system is an example, where the constructions of large reservoirs have resulted in a decrease of sediment transport in the rivers and estuaries. Therefore, this work could provide valuable information for better management and planning of this river basin.

Table 1. Average annual sediment load (10^6 ton/year) in five estuaries in Hai Phong city before and after construction of reservoirs

River	The total amount of sediment load (10^6 ton/year)								
	No reservoirs (1960-1970)			Thac Ba and Hoa Binh (1989-2006)			Thac Ba, Hoa Binh, Tuyen Quang and Son La (2007-2014)		
	Rainy season	Dry season	Total	Rainy season	Dry season	Total	Rainy season	Dry season	Total
Da Bach	3.803	0.212	4.015	2.269	0.229	2.498	1.169	0.246	1.415
Cam	8.067	0.45	8.517	6.296	0.636	6.932	3.243	0.684	3.927
Lach Tray	1.994	0.111	2.105	1.313	0.133	1.445	0.676	0.143	0.819
Van Uc	24.322	1.548	25.870	15.324	1.691	17.015	6.99	1.482	8.472
Thai Binh	4.518	0.469	4.986	1.297	0.178	1.475	0.367	0.8	0.447
Total			45.493			29.365			15.079

REFERENCES

Chao, B. F., Wu, Y. H., & Li, Y. S. (2008). *Impact of artificial reservoir water impoundment on global sea level*. Science (New York, N.Y.), 320 (5873), 212–214. http://doi.org/10.1126/science.1154580

Dang, N. M. (2010). *Integrated flood risk assessment: concept, methedology and applicaton*. LAP LAMBERT Academic Publishing, Germany.

DHI. (2007a). *Mike 11-A Modeling System for Rivers and Channels*. Horholm, Denmark.

Ming, X., Quanxi, X., & Jing, Y. (2009). *Analysis of multi-factors affecting sediment load in the Three Gorges Reservoir*. Quaternary International, 208(1-2), 76–84. http://doi.org/10.1016/j.quaint.2009.01.010

Syvitski, J. P., & Saito, Y. (2007). *Morphodynamics of deltas under the influence of humans*. Global and Planetary Change, *57*(3-4), 261–282. http://doi.org/10.1016/j.gloplacha.2006.12.001

Vinh, D. V, Ouillon, S., Tran, D. T., & La, V. C. (2014). *Impact of the Hoa Binh Dam (Vietnam) on water and sediment budgets in the Red River basin and delta*. Hydrology and Earth System Sciences, 18(10), 333–370. http://doi.org/10.5194/hessd-11-333-2014

Vörösmarty, C. J., Meybeck, M., Fekete, B., Sharma, K., Green, P., & Syvitski, J. P. M. (2003). *Anthropogenic sediment retention: Major global impact from registered river impoundments*.

Global and Planetary Change, 39(1-2), 169–190. http://doi.org/10.1016/S0921-8181(03)00023-7
Walling, D. E., & Fang, D. (2003). *Recent trends in the suspended sediment loads of the world's rivers*. Global and Planetary Change, 39(1-2), 111–126. http://doi.org/10.1016/S0921-8181(03)00020-1
Wang, H., Yang, Z., Wang, Y., Saito, Y., & Liu, J. P. (2008). *Reconstruction of sediment flux from the Changjiang (Yangtze River) to the sea since the 1860s*. Journal of Hydrology, 349(3-4), 318–332. Retrieved from http://www.academia.edu/5356196/Reconstruction_of_sediment_flux_from_the_Changjiang_Yangtze_River_to_the_sea_since_the_1860s
World Commission on Dams (WCD). (2000). *Dams and Development: A New Framework for Descision-Making*. London, United Kingdom: Earthscan Publications Ltd. http://doi.org/10.1097/GCO.0b013e3283432017

Tóm tắt:

ĐÁNH GIÁ TÁC ĐỘNG CỦA CÁC HỒ CHỨA LỚN THƯỢNG NGUỒN ĐẾN VẬN CHUYỂN BÙN CÁT Ở HẠ LƯU SÔNG HỒNG – THÁI BÌNH THUỘC THÀNH PHỐ HẢI PHÒNG

Hệ thống sông Hồng-Thái Bình lớn thứ 2 ở Việt Nam (sau hệ thống sông Cửa Long) và đóng vai trò hết sức quan trọng trong phát triển kinh tế - xã hội của đất nước. Trên hệ thống sông đã xây dựng các hồ chứa lớn ở thượng nguồn để phục vụ công tác điều tiết lũ, phát điện và cấp nước (nông nghiệp, sinh hoạt, giao thông thủy và thủy sản…). Bên cạnh những lợi ích đó, các hồ chứa có những tác động tiêu cực như làm thay đổi chế độ bùn cát ở hạ lưu hồ chứa gây sạt lở, bồi lấp bờ sông và đáy sông; ảnh hưởng đến xâm nhập mặn và môi trường sinh thái. Bài báo đã nghiên cứu ứng dụng mô đun vận chuyển bùn cát của mô hình MIKE 11 ST để đánh giá sự thay đổi hàm lượng bùn cát hàng năm tại 5 vùng cửa sông chính hạ lưu hệ thống sông Hồng-Thái Bình thuộc thành phố Hải Phòng trong các giai đoạn trước và sau khi các hồ chứa xây dựng và vận hành. Kết quả cho thấy lượng bùn cát ở hạ lưu giảm dần đáng kể theo các giai đoạn xây dựng hồ chứa. Trước năm 1970, khi chưa có hồ chứa nào xây dựng thì lượng bùn cát tổng cộng là 45,5 triệu tấn/năm; sau khi hồ Thác Bà và Hòa Bình đi vào hoạt động (1989-2006) còn 29,4 triệu tấn/năm (tương đương 65%); từ 2007 đến nay khi có đủ 4 hồ chứa lớn đi vào hoạt động thì chỉ còn 15,1 triệu tấn/năm (tương đương 33%). Điều này thể hiện sự thiếu hụt và mất cân bằng bùn cát ở hạ lưu và sẽ ảnh hưởng rất lớn đến sự ổn định bờ sông, bãi sông và đáy sông ở khu vực nghiên cứu. Đây là những thông tin bổ ích cho việc quy hoạch, quản lý bền vững hệ thống sông.

Từ khóa: Lưu vực sông Hồng, hồ chứa, Mô hình MIKE 11, vận chuyển bùn cát.

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