Proceedings of the 10th International Conference on Asian and Pacific Coasts
(APAC 2019) Hanoi, Vietnam, September 25-28, 2019

MORPHOLOGICAL CHANGES IN THE RED RIVER DELTA, IMPACTS AND SOLUTIONS

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ABSTRACT: The Red River plays a particularly important role in the development of Vietnam. In the past 30 years, there have been serious changes in the morphology of the Red River. As a result, it has caused many negative impacts on production, the environment and life in the downstream areas of the river. This paper presents analyses on both subjective and objective causes that lead to these serious morphological changes. It helps to propose a comprehensive solution for establishment of a water regulating system on the Red River to ensure water security and environmental protection for the downstream areas of the river.

Keywords: Red River, morphological change, erosion, regulating headwork, water security

1. BACKGROUND

The Red River (Fig. 1) is categorized among the five major transboundary river systems in South-East Asia, flows from Yunnan province in Southwest China through northern Vietnam to the Gulf of Tonkin. The river basin covers an area of 169,020 km^2, in which 48% in China's territory, 51% in Vietnam's territory, and only 1% in Lao's territory. The portion in Vietnam is named Hong-Thai Binh River Watershed, in which the Red River Delta (RRD) includes mainly Hong River and Duong River, covering 11 provinces and cities (including Hanoi and Hai Phong) with total population of 25 million.

Since 1990s, in addition to the reservoirs that were already constructed (e.g., Thac Ba and Hoa Binh reservoirs), there are many reservoirs which were built in the upstream portions of the Red River. These include Son La reservoir (2012), Ban Chat reservoir (2013), Huoi Quang reservoir (2016), and Lai Chau reservoir (2016) on Da River; Tuyen Quang reservoir (2007), Bac Ha reservoir, Chiem Hoa reservoir, Nho Que reservoir on Lo-Gam River. It is also noted that about 50 reservoirs were built in portions belonging to China of the Da, Thao and Lo-Gam rivers (Dinh and Cuong, 2014). Given the influence of these artificial structures, both flow regime and sediment transport to the RRD have been significantly changed. Moreover, under the pressure of rapid development activities, excessive sand exploitation for construction materials has exacerbated the fluctuation of the flow regime and sediment transport in the RRD. In recent years, the discharge of the Red River downstream in the dry season has been seriously lowered; besides, according to actual monitoring data, the rate of water distribution from Hong River to Duong

Fig. 1 Map of Red River (upper) and Red River Delta and location of hydrological measurement points (lower)

River has increased dramatically compared to previous periods. This has greatly affected the use of water resources, serving life and production in the Red River downstream area.

This paper aims to provide preliminary analyses of the causes that lead to these serious morphological changes and the impacts of flow fluctuation on development activities in the RRD. These are a basis to initiate a comprehensive solution regarding the establishment of a flow regulation headwork system in the RRD to ensure water supply for the downstream areas.

2. METHODOLOGY AND DATA

According to the nature of the river, the stability of river bed depends on the interaction between the streamflow and river morphology, the expression of that interaction is the movement of sediment. However, in reality, morphological changes are very much dependent on human activities. Therefore, it is possible to represent the main factors that influence the evolution of the river morphology as a function of the nature of the river and human influences and expressed in Equation 1 below.

$$X = f(S, N) \qquad (1)$$

where: X is the morphological evolution of the river; S is hydraulic and sediment factors (e.g, flow, sediment, etc…); N is human impact factors.

In terms of hydraulic conditions, any change in sediment in the flow will affect future morphological evolution. To determine the total sediment transport in a river, bottom and suspended sediments must be measured or computed. Based on field observation data in the period (2009-2012), Dinh and Cuong (2014) have formulated an empirical formula to calculate the total sediment transport in the Hong River as seen in Equation 2.

$$s_t = 0{,}906\sqrt{g\Delta D_{50}{}^3}\,\frac{C^2}{g}\left(\frac{hi}{\Delta D_{50}}\right)^{1{,}22} \qquad (2)$$

where: s_t ($m^3/m/s$) is the total suspended sediment in a river width unit; Δ is relative density; C is Chezy coefficient; D_{50} is the diameter of the suspended material in the river bed, h is the average depth of the flow, i is the flow ingredient; g is the gravitational acceleration.

Based on the theory of sediment transport, it is able to determine the morphological change in downstream areas. In terms of human impact, it is often more difficult to be quantified. Conventional methods used to understand morphological behavior are based on a combination of the actual measurement and survey data on human activities.

Therefore, this study merely uses surveyed data and information at three sites (Son Tay, Hanoi, and Thuong Cat as illustrated in Fig. 1) to perform of analyses of changes in flow, sediment transport, and river morphology in the RRD. The data and information on streamflow and sediment transport are gathered for three time windows (1960-1970; 1989-2006; and 2007-2014) that are in line with the operation of major reservoirs on the Hong River. River cross sections are periodically measured in 1991, 1996, 2000, 2005, 2008, and 2014.

3. DATA ANALYSIS AND DISCUSSION

Sediment depletion

Because most sediment is deposited in the upstream reservoirs, this leads to clear water erosion phenomena to the river bed in downstream sections. The average annual turbidity at Son Tay, Ha Noi and Thuong Cat hydrological stations is shown in Table 1 and at Hoa Binh in Figure 2 (Dinh, et al., 2012). In average, sediment transport in the period from 2007 to 2014 is about 1.9 million m^3/year on the Da River, 15.68 million m^3/year on the Thao River, and 6.48 million m^3/year Lo-Gam River. These statistics clearly show the significant decrease of sediment transport to the RRD, especially after the completion of reservoir construction in the upstream portions. For instance, Fig. 2 exhibits a substantial reduction of suspended sediment during high flow period when Hoa Binh reservoir was constructed.

Table 1 Average turbidity at Son Tay, Hanoi, and Thuong Cat measured in the three time windows

Period	Son Tay (g/m^3)	Hanoi (g/m^3)	Thuong Cat (g/m^3)
1960-1970	581.4	485	619.9
1989-2006	317.68	424.3	471.5
2007-2014	146.7	161.2	231.9

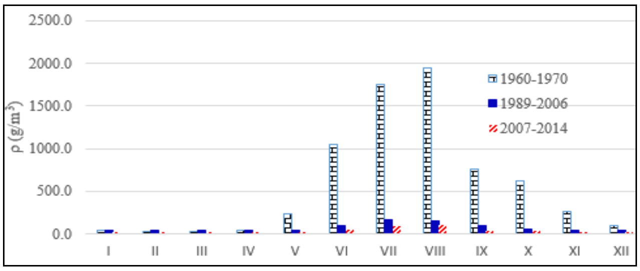

Fig.2 Monthly turbidity distribution at Hoa Binh station before and after the reservoir was constructed

Sand exploitation

Sand is important and indispensable material for construction. Sand exploitation takes place in most rivers and streams nationwide. According to the surveyed and analysed data from 2007 to 2014, the amount of sand exploitation was about 33 million m^3/year; meanwhile the amount of sand supplemented to the system was about 24 million m^3/year. In the upcoming year, the actual demand is estimated about 37.9 million m^3/year; in fact, sand exploitation is about 27.5 million m^3/year while the supplemented amount of sand is just 11 million m^3/year.

In principle of sustainable sand exploitation, the amount of sand taken away must be smaller than the amount of the supplemented sediment. Therefore, due to the excessive sand exploitation, the changes of the river bed of the Hong River and Duong River are complicated and extremely serious, causing river bank instability as well as on bank structures.

Thus, the erosion of river bed due to the nature of the rivers and the increase of sand exploitation may lead to the continuous trend of lowering the river water level in general.

Morphological changes

River beds in the downstream reaches of the Hong River and Duong River have been seriously eroded and their across-sections have been widened in many locations. According to topographic survey of river cross-sections over the years, the river beds are observed getting eroded severely. The river bed elevation of the Duong River has lowered from 4 to 6m, while the river bed elevation of the Hong River at Son Tay has lowered 5m (Fig. 3) (Hoa, et at., 2018). Along the river, the expansion of the cross-section has unpredictably changed depending on the location after the flood seasons.

On the Hong River, with respect to the change of the whole section during 2000-2014, the elevation of the river bed lowered from 1.25m to 2.0m. In Son Tay, the entire wet cross section was eroded (4m depth). In Hanoi, the river bed was almost the same, but the cross-section was expanded and wet area increased 1.6 times (Hoa, et at., 2018).

On the Duong River, in the same period of time, the river bed decreased from 3.27m to 4.87m in average [at the entrance, the river bed lowered by an average of 13m, the elevation was -5.0m in 2000, but it was -18.0m in 2014 (Hoa, et at., 2018)]. The lowering of the channel greatly affects the water level in the river, which is clearly seen in discharge versus water level relationship showed in Fig. 4 (Water Resources Master Plan Study for RRD, 2012).

The lowering of the river bed was due to two main reasons: the excessive sand exploitation and natural erosion phenomena. The excessive exploitation of sand causes the subsidence of the river beds, leading to lower water levels along the Hong River and Duong River. In addition, the excessive exploitation of sand on the Duong River also causes considerable change of the proportion of water distributed to the Duong River. According to recent research results conducted by Dinh, et al., (2012), the erosion caused by the excessive exploitation of sand was much higher than that of the natural erosion phenomena, as presented in Table 2.

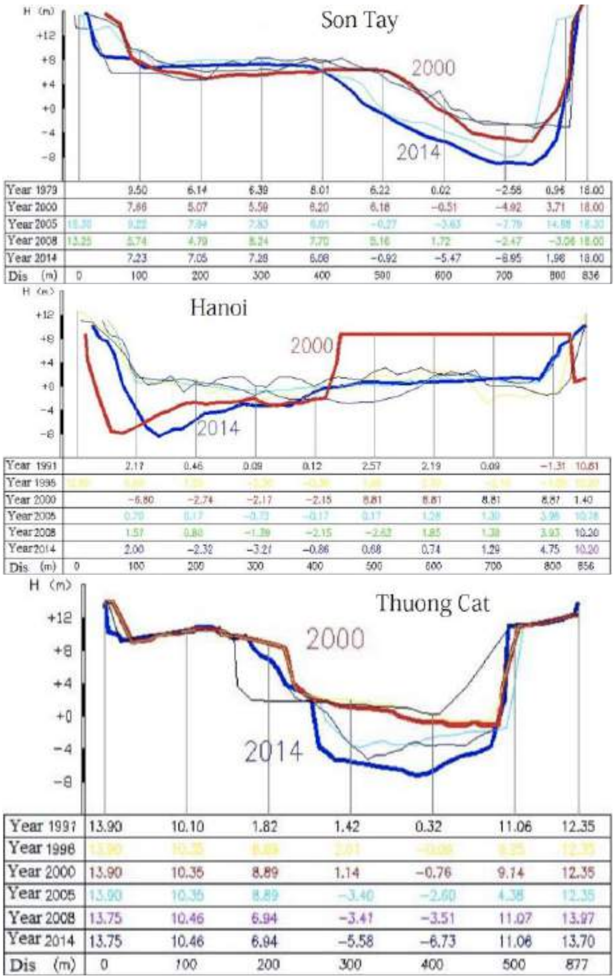

Fig. 3: Changes in river morphology over time and space: (top) at Son Tay (Da River), (middle) at Hanoi (Hong River mainstream), and (bottom) at Thuong Cat (Duong River)

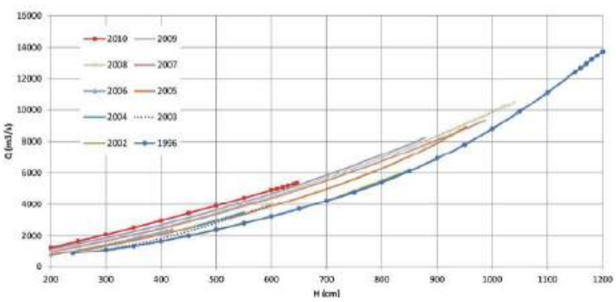

Fig. 4 Rating curve for different time periods at Thuong Cat station on the Duong River

Table 2 River bed subsidence in 1997 and 2012 measured at Son Tay, Hanoi, and Thuong Cat stations (Dinh, et al., 2012)

Stations	Riverbed elevation		The lowering of riverbed elevation	Due to erosion	Due to sand exploitation
	1997	2012			
Son Tay	0.38	-2.28	2.66	1.5	1.16
Hanoi	0.54	-1.13	1.67	0.5	1.17
Thuong Cat	1.12	-5.38	6.60	0.5	6.10

Changes in streamflow regime

According to water balance calculation, the total amount of water is enough for the needs of downstream areas of about 18 billion m^3, increase to 22 billion m^3 in 2050, accounting for 22% of the discharge from upstream sections (Hoa, et at., 2018). However, even in the case of satisfying the water demand, it will cause a lot of difficulties for the actual production because the water level tends to decrease strongly in the Hong River (Fig. 5). So lowering river bed phenomena in the Hong River may diminish the restoration of the river bed to the original form.

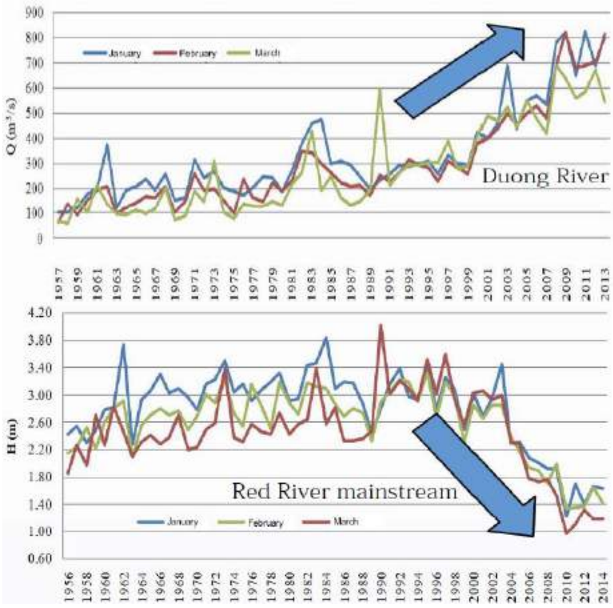

Fig. 5 Flow rate at Thuong Cat station and water level at Hanoi station on the Duong River and Hong River, respectively, in the dry seasons during 1956-2013

Impacts on irrigation schemes

In the whole basin, there are about 2,531 pumping stations supplying water for agricultural irrigation, in which 2,198 stations located in RRD irrigating for about 371,000 ha (accounting for 68%, the rest of more than 300 stations located in mountainous and midland areas, supplying water for about 60,000 ha which accounts for 14% compared with the total irrigation capacity of the basin). The lowering of the bed of the Hong River greatly affects the performance of all irrigation schemes. This is clearly shown in the chart between the elevation of normal water level and intensified water discharge according to production requirements.

The lowering of water level when reservoirs are normally discharged at Lien Mac sewer is 2.0 m; Xuan Quan drain is 0.9 m; Long Tuu sewer is 1.1 m compared with the design criteria (Fig. 6). In the case of the increased discharge from upstream reservoirs (Fig. 7), the increase in water level is only approximately the required design level, about 5 billion m3/year on average - causing huge losses in hydropower production (Hoa, et at., 2018).

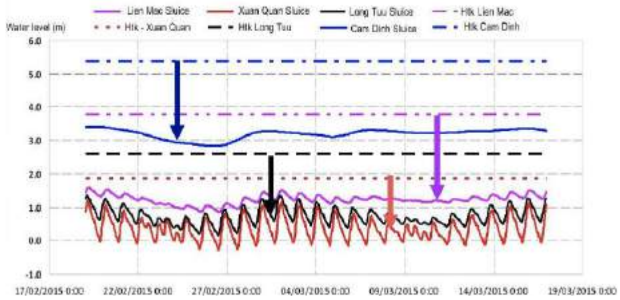

Fig. 6 Water levels at irrigation schemes during normal reservoir operation

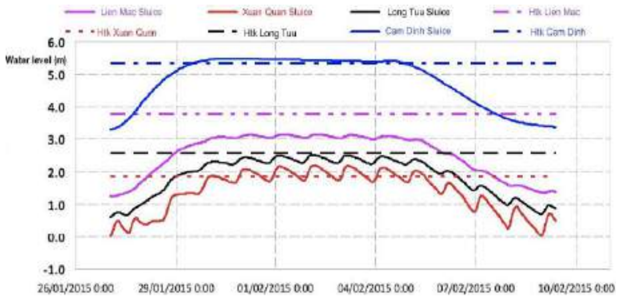

Fig. 7 Water levels at irrigation schemes during increased discharge from upstream reservoirs

Impacts on dyke protection and saline intrusion structures in coastal areas

The lowering of the rive bed will greatly affect the stability of embankments protecting river banks. During high tide periods, saline concentration of 1 ‰ also tends to spread further in land, about 30-35km from the river mouths. The greatest length of saline intrusion considering climate change can reach 35-45km and Ninh Co River is even entirely salted.

Impacts on waterway navigation and environment

In certain periods of the dry season, the lowering of water level disrupts the movement of water transport vehicles on the Hong River. In addition, low water level has greatly affected other aspects of socio-economic activities such as agriculture irrigation, domestic water supply, ecological and environmental maintenance.

Regularly failing to ensure the elevation of water intake to design irrigation systems as well as tributaries of the Hong River have made the circulation of water sources unsatisfactory, greatly affecting the water source environment.

4. INTERMEDIATE SOLUTIONS

In order to overcome the decline of water level in the RRD, recently, some immediate solutions have been implemented such as: (1) Increased discharge from reservoirs in order to raise the water level during irrigation schedule, (2) installment of mobile pumping stations to serve irrigation needs, (3) dredging the channel, lowering the bottom of the water intake structures along the Hong River. However, these solutions are basically meeting immediate needs in the scope of agriculture and irrigation.

The general trend for downstream areas of hydropower projects is an imbalance in the water supply and lower river beds that lead to lower water level in the river during the dry seasons. Therefore, in the long term, there should be a comprehensive solution for the water security problem of the Hong River. The solution should consider such aspects as strategy, multi-purpose, and sustainable development.

5. CONCLUSION AND REMARK

The problem of river morphological change and lowering the water level in the RRD, especially the section through Hanoi, associated with the sudden increase in water allocation the Hong River to the Duong River has seriously affected all aspects of life, induced long-term impacts on the effective, sustainable management, exploitation and use of water resources in the RRD in particular and the Northern Region in general. Therefore, it is necessary to have a comprehensive solution for the constructions of water regulation systems in order to cope with the situation of lowering the water level, ensuring water security for the Hong River downstream areas.

If such systems are built and operated effectively, they will help to tackle most problems to ensure water security for the RRD. For instance, the systems will raise the water level in case the water supply from the upstream can be reduced or unsatisfactory for water intake structures. The systems actively keep freshwater and prevent saltwater intrusion for irrigation and service activities, create water sources and favorable conditions for environmental improvement, ensure waterway transport capability in dry season. By creating a high and stable water level, the systems will create a landscape and promote tourism for the riversides along the capital city.

ACKNOWLEDGEMENTS

This study was financially supported by the National Independent Research Project (code DTDL.CN-58/15) for “Study on comprehensive solutions of weirs to cope with the situation of lowering the water level, ensuring water security for the Red River Delta". This research project is implemented at Vietnam Academy for Water Resources during 2015-2018.

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