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Variation in morphology of the Red river and Duong river near Hanoi from 2000 to 2018

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Abstract:

In recent years, the construction of upstream reservoirs and the extraction and structural construction activities on the river banks and beds have caused downstream changes in river morphology and hydrological regime of the Red river system, which has especially accelerated from 2000 to 2018. These dramatic variations have significantly changed the morphological characteristics and relationship between the flow and morphology that are a fundamental parameter to evaluate the stability of the channels. In this study, the morphological characteristics and relationship between flow and morphology over some periods as well as under current conditions were analysed. This work provides basic river training parameters for studying river training planning of the Red river system in general and for the Red and Duong river sections in Hanoi in particular.

Keywords: **bankfull discharge, relationships, river morphological, river morphology, river training parameters.**

Classification number: **2.3**

Introduction

Since 1987, the Hoa Binh reservoir and also other cascade reservoirs on the Da and Lo rivers have affected the Red river downstream dramatically. Changes to the riverbeds, river morphology, hydrological, and hydraulic characteristics of the Red river system before and after the Hoa Binh reservoir have been shown in several studies. These studies confirm that the impact of the Hoa Binh reservoir on downstream changes is dominant and the impact of these reservoirs on the downstream decreases gradually by time.

However, from 2000 to 2018, the trend has reversed with sudden changes to the channel bed and hydrological regime. The riverbed has been continuously eroded leading to lower water levels, especially in the dry season. Therefore, the operation and safety of hydraulic works (sluices, pumping stations, revetment, etc.) as well as waterway activities, environment, and ecology downstream of the main rivers have been adversely affected [1].

The main causes of these changes to the riverbed and hydrology after 2000 has been analysed in recent studies [2]. In particular, the sediment imbalance across the river system is increasing due to sediment depletion coming from upstream. Besides, the total extracted sediment volume downstream is still increasing. The average annual sediment in the downstream is only about 20-30% of the total extracted sediment, however, the actual sediment volume cannot be extracted from the rivers [3].

Since 2000, changes to the river channel and hydrological regime downstream of the Red river have caused changes in the river's morphological relationships. However, these trends need to be clarified and evaluated along with the channel bed stability under the present conditions. This study will present and analyse new results of the changes in relationship between the flow and morphology for a representative area, which is the Red river and Duong river sections around the center of Hanoi.

The results shown in this paper only consider one of

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basic relationships between flow and morphology. This is the relationship between flow and river cross section that determines the stable width (B) and depth (h) of the cross section.

The calculation and evaluation of the changes in river morphological relationships are the foundation for proposing basic river training parameters to develop river training planning protocols in the Red river system, in general, and for the Red and Duong river sections in Hanoi, in particular. To ensure that it is suitable with actual changes of rivers itself as well as to adapt to the impacts caused by the process of extraction and development on the river.

In order to compare results, the study and evaluation for changes to the river's morphological relationships characteristics are limited to the period from 2000 to 2018, which are divided into 3 periods: from 2000 to 2005; from 2006 to 2010 and from 2011 to 2018 (Fig. 1).

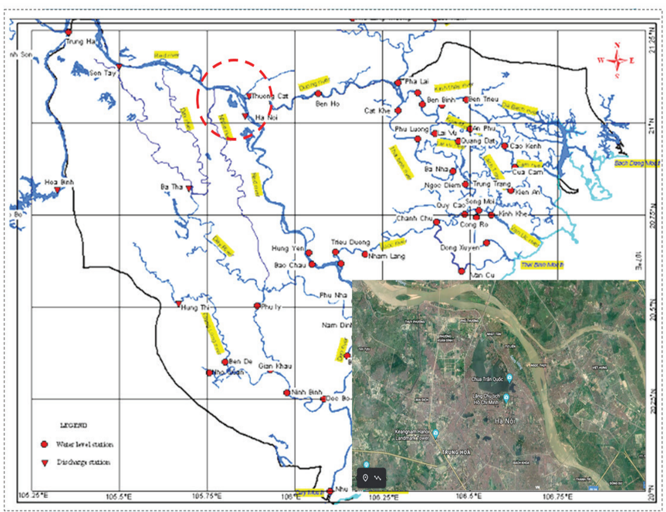


Fig. 1. Red river - Thai Binh river system and the Red and Duong river sections near Hanoi (source: Directorate of Water Resources, MARD).

Objects, materials and methods

Objects

The relationship between cross section and corresponding water level and bankfull discharge or bed building discharge is the studied river morphological relationship.

The basic parameters of the river morphological relation are stable width (B) and depth (h) of a section.

Materials

Hydrological and hydraulic data: daily water level, discharge, turbidity at Hanoi hydrological stations (Red river) and Thuong Cat (Duong river) from 2000 to 2018.

Topographic data: annual river cross-sections above hydrological stations; river cross sections are measured discontinuously from 2000 to 2018 and topographic maps are measured in 1999, 2005, 2008, 2010, 2014, 2016, 2018 on the Red river section from Lien Mac to Thanh Tri and the Duong river from Duong gate to Duong bridge. These topographic data were collected from state-level science and technology projects under KC.08/10-15, KC.08/15-20 programs; waterway consultancy projects of the Ministry of Transport (MT); survey projects of the Red river channel by the General Department of Disaster Prevention, Ministry of Agriculture and Rural Development (MARD).

Survey data, geological surveys of river channel, sediment on the bed of the Red river section and the Duong estuary in 1999, 2009, 2013, and 2016 are provided by fundamental projects and research projects granted by the Vietnam Academy for Water Resources.

Hydraulic parameters (water level, discharge, hydraulic slope, etc.) of the Red river system in years 2000, 2005, 2010, 2013, 2014, 2016, 2017, and 2018 were calculated by using the MIKE11HD and MIKE21HD models provided by research projects at ministerial and Hanoi levels and at the State level of the Vietnam Academy for Water Resources Research.

Methods

River morphological relationships at cross sections:

In order to analyse and calculate parameters of the main river cross section, two relationships (methods) are commonly used in Vietnam as follows:

- The morphological method is based on the method of C.T. Altunin, which describes the relationship between the stable width and depth under the influence of bankfull discharge and the method of the Russian Hydrology Institute, which focuses on the relationship between the width and depth at a stable cross section. This relationship shows the stability of the river channel at the cross section for each period:

$$B = A\frac{Q_f^{0.5}}{J^{0.2}} \quad (1)$$

$$\frac{\sqrt{B}}{h} = \zeta = \text{const} \quad (2)$$

where: B and h are the average width and depth of the stable river bed, respectively; A is the lateral stability coefficient (also known as bank stability coefficient); Q_f is the bankfull discharge (discharge corresponding to a water level at bank elevation); J is the water surface slope corresponding to bankfull discharge.

- The method of Prof. Luong Phuong Hau [4] shows the relations of a stable width and depth of the riverbed over average water level periods (or main river channel) under the impact of bankfull discharge:

$$B = 2.60 \frac{W^{0.24} S^{0.24}}{g^{0.4} d_{90}^{0.32}} Q_f^{0.57} \quad (3)$$

$$h = 1.52 \frac{g^{0.05} d_{90}^{0.24}}{W^{0.43} S^{0.43}} Q_f^{0.32} \quad (4)$$

where: d_{90} is the calculated sediment diameter (mm); W is the calculated flow velocity (m/s); S is the average sediment load (kg/m^3); Q_f is the bankfull discharge (m^3/s).

In this study, we only calculate the parameters B and h according to the method of C.T. Altunin. The calculation according to Prof. Luong Phuong Hau's method requires one to determine the actual value of the parameters d_{90}, W, and S, which is not within the scope of this work because the above parameters fluctuate greatly due to impact of the upstream reservoir system as well as riverbed extraction in the downstream. Thus, it leads to sediment imbalance, deep bed erosion, lack of incoming discharge and a complicated hydraulic regime, especially at the confluence of the Red and Duong river.

Determining bankfull discharge method:

For both of the mentioned river morphological relations, the most important thing is to determine the bankfull discharge. Bankfull discharge is a quantity that indicates the combined impact of a river discharge on the bed building process over a long time.

According to the morphological relationship of stable river channel, when the bankfull discharge changes, the morphological factor of the river channel will be recreated to adapt to new conditions, in which the most important are the factors of river cross-section including stable width and depth.

There are several methods to determine bankfull discharge in Vietnam and we often use the V.M. Macckaveep method. This is a method mainly based on series of statistical hydrological data (discharge, Q, and sediment concentration, ρ) at main hydrological stations on rivers.

Currently, under the real conditions of the Red river system, the application of the V.M. Macckaveep method is unsuitable because the deep bed erosion keeps increasing, which causes severe changes in morphological and hydrological characteristics at the stations. Further, sediment concentration in the downstream has been continuously decreasing over recent years and is currently very low such that it does not correctly show the actual process of sediment transport and rebuilding in the river channel.

Therefore, the bankfull discharge, Q_f of the Red and Duong river sections surrounding Hanoi is calculated by the following methods: building the relationship between discharge and water level (Q-H relation) from the measured data at Hanoi and Thuong Cat stations over the research periods, determining the Q-H relation for each year and over each period, then analysing and determining discharges corresponding to the water level at the riverbank at the above two stations. It should be noted that the riverbank elevation is the elevation of the natural riverbank, which has not changed or been affected by development and extraction activities of the floodplain.

Results and discussion

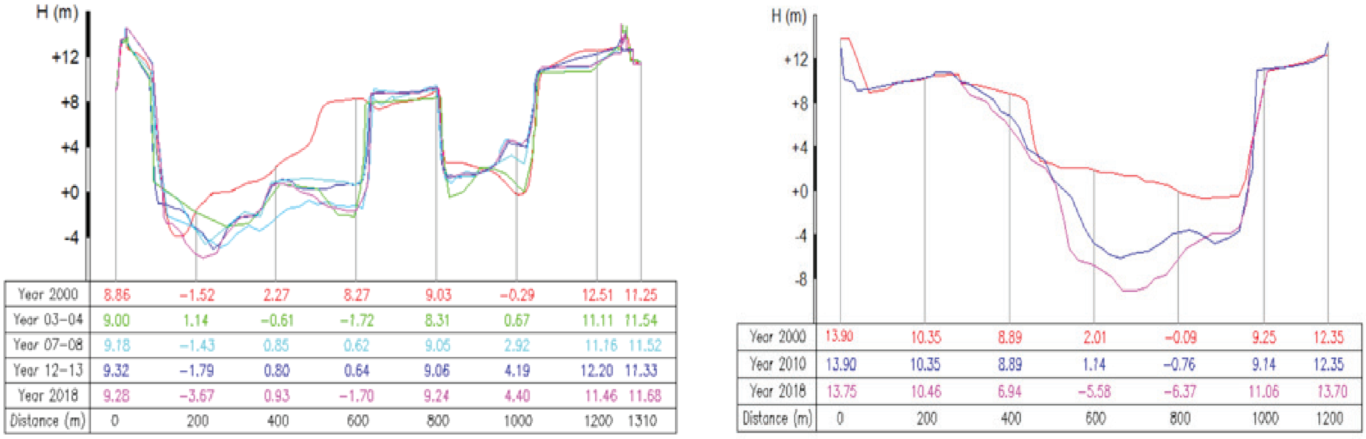
Results

Changes in river channel and hydrological regime of the Red and Duong river sections surrounding Hanoi from 2000 to 2018:

Analysed results of the changes to the Red and Duong River channel surrounding Hanoi in the period from 2000 until 2016 [1] confirm that the river channel tends to be continuously eroded. The results presented in Table 1 below have been updated until 2018 and the rivers are divided into sections appropriate for this study, in which the trend of deep erosion in the river channel has no sign of decline.

Table 1. Changes in river channel of Red river and Duong river sections surrounding Hanoi center from 2000 to 2018.

No	River/river section	Erosion level of river bed from 2000 to 2018 (m)	Note
1	***Red river***		
	From the confluence of Thao and Da rivers to the Luoc inlet	0.81÷4.22	Common deep erosion values (excluding local erosion points)
	River sections surrounding Hanoi: from Liem Mac to Thanh Tri	1.86÷3.25	
	At Hanoi hydrological station	3.08	
2	***Duong river***		
	Whole Duong river	3.30÷6.67	Common deep erosion values (excluding local erosion points)
	Upstream Duong river from Xuan Canh to Duong bridge	4.60÷6.67	
	At Thuong Cat hydrological station	5.32	



River cross section at Hanoi station

River cross section at Thuong Cat station

Fig. 2. Changes of river cross sections from 2000 to 2018 at Hanoi and Thuong Cat stations.

The deep erosion trend caused lower water levels, especially the water level during the dry season as well as hydrological and flow characteristics in most of the rivers (Fig. 2).

Changes to the hydrological regime on the Red and Duong rivers near Hanoi are considered through the increasing and decreasing trend of hydrological characteristics (discharge, water level) over the whole year, each season, and relation of discharge and water level (Q-H) over the period from 2000 to 2018. Based on the observed data, we made the following comments:

In the Red river section near Hanoi, the average annual discharge and discharges in the flood and dry season are reduced. Meanwhile, water level is significantly lower during the flood season, however, the annual water level reduces negligibly but the water level in the dry season increases.

In the section of the Duong river near Hanoi, the annual discharge and discharges in the flood and dry season tends to decrease more than that in the Red river sections. On the contrary, the average water level is unchanged during the flood season but increases significantly over the whole year and dry season.

The relations of Q-H at Hanoi hydrological stations (on the Red river) and Thuong Cat station (on the Duong river) show that the variation level over each period is very large and the common trend is that at the same discharge value the water level is continuously lowered (Figs. 3-5).

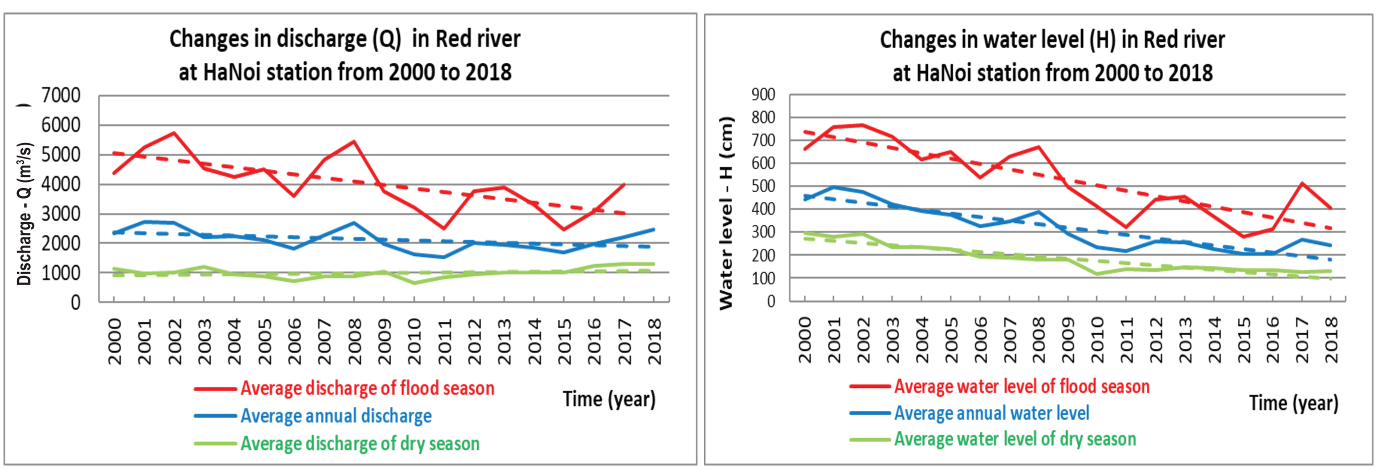


Fig. 3. Changes in hydrological characteristics in Red river at Hanoi station from 2000 to 2018.

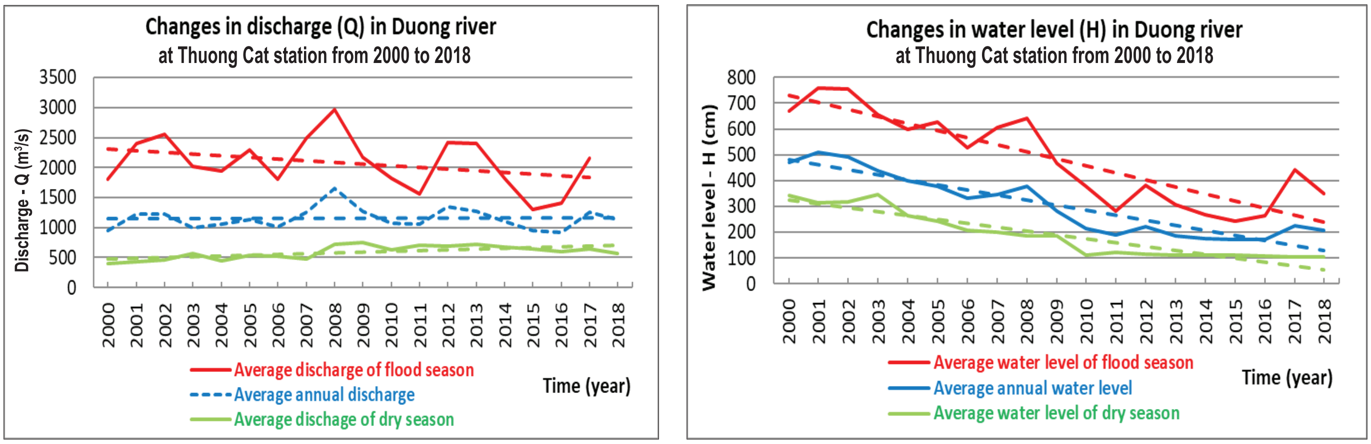


Fig. 4. Changes in hydrological characteristics in Duong river at Thuong Cat station from 2000 to 2018.

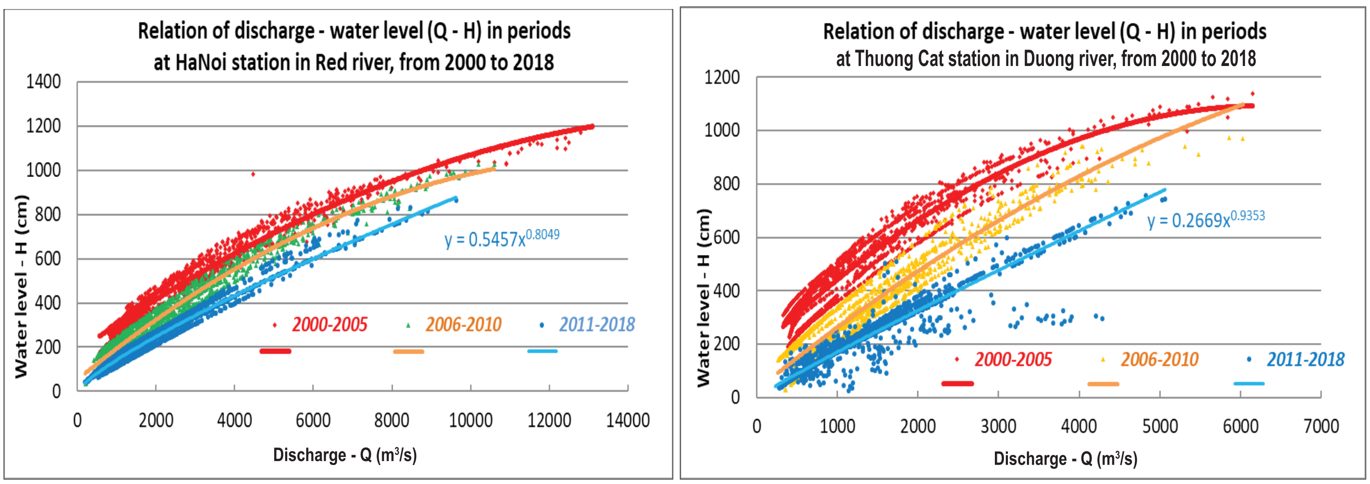


Fig. 5. Relation of discharge - water level (Q-H) in periods in Red river at Hanoi station, and in Duong river at Thuong Cat station from 2000 to 2018.

Determine bankfull discharge:

An analysis of the bankfull discharge (Q_f) in the Red river and Duong river sections near Hanoi over each period from 2000 to 2018 implemented based on the relation of Q-H and the floodplain elevation at Hanoi and Thuong Cat stations are shown in Table 2.

Table 2. Calculated bankfull discharge of Red river and Duong river at the cross sections of two stations.

Bankfull discharge	Period		
	2000-2005	*2006-2010*	*2011-2018*
Hanoi station (Red river)/floodplain elevation = 9.3/9.8m			
Q_f (m³/s)	8,280	9,100	10,240
Thuong Cat station (Duong river)/floodplain elevation = 9.0/9.2m			
Q_f (m³/s)	3,370	4,150	5,000

It is noted that the previously calculated bankfull discharge of the Red and Duong river sections near Hanoi based on the V.M. Macckaveep method is always less than results shown in Table 2.

The bankfull discharge in Table 2 is significantly greater than the calculated values based on other relations of river morphology in the past [4-6].

We believe that the changes to the incoming discharge and sediment transport from upstream tend to decline in recent years and our results of the bankfull discharge based on the relation of the measured discharge and water level Q-H is more appropriate.

Calculating average width (B) and depth (h) at river cross section according to C.T. Altunin method:

The stability coefficient of riverbank A according to the C.T. Altunin method that describes changes in riverbanks, river beds, and sediment transport in the river, is in the range of 0.9-1.7 for the Red and Duong river. Besides, based on previous studies from Professor Vu Tat Uyen and other researchers [5-7], the A coefficient varies from 0.9-1.1 and has slight changes during the periods. The bankfull discharge (Q_f) is illustrated in Table 3.

Table 3. Morphological and hydrological parameters of the Red and Duong rivers near Hanoi.

Morphological and hydrological parameters	Period		
	2000-2005	*2006-2010*	*2011-2018*
Red river from Lien Mac to the inlet of the Duong river			
Q_f (m^3/s)	11,930	13,160	14,800
J (10^{-4})	0.72	0.80	0.85
B (m)	818	810	792
h (m)	9.05	9.32	9.90
A	1.0	1.0	0.9
Red river from the inlet of the Duong river to Xuan Quan			
Q_f (m^3/s)	8,280	9,100	10,240
J (10^{-4})	0.70	0.75	0.81
B (m)	703	683	668
h (m)	8.27	8.61	9.42
A	1.0	0.95	0.9
Duong river from the inlet to Duong bridge			
Q_f (m^3/s)	3,370	4,150	5,000
J (10^{-4})	1.15	1.30	1.60
B (m)	366	357	360
h (m)	8.80	9.84	10.63
A	1.1	1.05	1.0

Note: the meaning of the parameters Q_f, J, B, h is the same as that in Eqs. (1) and (2).

Based on the 2019 results of the report "Calculate hydraulic characteristics by using MIKE11HD model for Red and Thai Binh river systems" [8] under project number KC.08.10/16-20, the average water surface slope (J) of the Red and Duong river sections near Hanoi varies with time and tends to increase from 2000 to present. In general, the water surface slope in the Duong river is much larger than that of the Red river.

The average depth (h) is calculated based on average width (B) and representative cross-sectional area in the studied river section. The representative cross section in the Red river section downwards to the inlet of the Duong river is at the Hanoi hydrological station. For the Duong river, it is observed at the Thuong Cat hydrological station and for the Red river upwards it is observed in front of the Duong inlet at the Lien Mac sluice.

Determining changes of river morphological relationship in cross section ($\sqrt{B}/h$):

Table 4. Changes of river morphological relationship in cross section during periods.

Morphological and hydrological parameters	Periods		
	2000-2005	*2006-2010*	*2011-2018*
Red river from Lien Mac to the inlet of Duong river			
B (m)	818	810	792
h (m)	9.05	9.32	9.90
$\zeta=\sqrt{B}/h$	3.16	3.05	2.84
Red river from the inlet of the Duong river to Xuan Quan			
B (m)	703	683	668
h (m)	8.27	8.61	9.42
$\zeta=\sqrt{B}/h$	3.21	3.04	2.74
Duong river from the inlet to Duong bridge			
B (m)	366	357	360
h (m)	8.80	9.84	10.63
$\zeta=\sqrt{B}/h$	2.17	1.92	1.78

The results in Table 4 showed that the riverbed stability in the Red and Duong rivers in the study area tends to decrease.

Discussion

In recent years, the bankfull discharge is widely determined by using the V.M. Macckaveep method in most of the river training studies in Vietnam. It is a method mainly based on a dataset of hydrological characteristics (discharge, Q, and sediment concentration, ρ) at observed stations. Under the condition that the river system is greatly affected by human activities, including exploitation and use for socio-economic development goals, the discharge and sediment density values do not reflect their natural characteristics. Thus, the bankfull discharge value is no longer suitable in reality.

For this reason, the water level corresponding to the bankfull discharge calculated by the V.M. Macckaveep method is often much lower than the riverbank elevation. The main reason for this is the Red and Duong riverbeds have tended to be continuously eroded from 2000 to present.

In this study, the bankfull discharge is calculated by using the traditional Q-H relation method. This is more appropriate under current conditions of the studied river sections, however, it also requires further analysis and assessment in bankfull discharge for other rivers and river sections in the Red river system to show more convincing evidence for practical and theorical aspects.

Conclusions

Changes to the hydrological and morphological characteristics of the Red river from 2000 up to now show that the Red river has been in a new development process with different hydrological and morphological characteristics. Planning should be reviewed and studied, as well as parameters designed related to the current management as well as construction of hydraulic works and infrastructure in the Red river system.

Basic parameters such as B and h are also parameters for river training during the average water level season (main riverbed). When these factors change, there is a need to recalculate and redesign river training plans for the river channel during the average water level season and also for general river training plans during the flood and dry seasons to ensure environmental and ecological protection.

The river morphological relationship of cross sections ($\sqrt{B}$/h) tends to decrease, which shows the stability level on the cross section of the river bed of the Red and Duong rivers has also decreased.

This is an important issue to inform agencies at the Central and Hanoi levels. These issues are not only for river management, but also related to planning the river extraction and use of riverbeds and riverbanks for infrastructure and socio-economic development.

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The authors declare that there is no conflict of interest regarding the publication of this article.

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