Hydrological regime of a tidal system in the Red River Delta, northern Vietnam

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Abstract The Red River Delta (RRD) in northern Vietnam represents a complex hydrological network of tributaries and distributaries receiving large and seasonally fluctuating water flows from the upper Red River basin. The 14 300 km^2 of the Red River Delta are subject to tidal influence due to the very flat relief. This study deals with the Day-Nhue River system (DNR), which is one of the three main branches of the Red River Delta, with 20% of the total annual discharge of the Red River. This sub-basin is on the right side where the city of Hanoi is located and it provides water supply to the main part of the total population of the RRD. In consequence, the surface water and groundwater of the DNR are polluted by organic and inorganic contaminants. Very few studies have discussed the impact of the tidal movement in the wastewater mitigation. In this study, we investigated the tidal influence on the river discharge through several ADCP gauging measurements during repetitions of 24 h-long surveys. The integration of the measurements over the entire tidal cycle allowed the calculation of daily residual discharge. It was observed that the instantaneous discharges could vary from +150 m^3/s to –250 m^3/s. The consequence of this inversion of the river current means the same mass of water passed across the same river section three times. A second consequence is that the discharge values describe a daily cycle with one daily maximum, one daily minimum and a short period of stream current at value zero. These two facts could imply a significant impact on the sediment transport and water quality behaviour. It becomes impossible to calculate the river discharge by a classical calibration equation linking water level and discharge, since there is no univocal relationship.

Key words Red River Delta; tidal influence; daily residual discharge; inversed discharge

INTRODUCTION

In southeast Asia, the highest population densities are found in delta areas that are subjected to high freshwater flows from less populated inland rivers and to tidal influence from the sea (Luu *et al.*, 2010). For example, in Vietnam, the population is concentrated within two large deltas, the Red River Delta (RRD) in the north and the Mekong Delta in the south. The present study focuses on the RRD, which plays an important role in the agricultural, industrial and economic development of the country. This area provides a good example of a region that is experiencing rapid population growth, industrialisation and economic development, which is leading to an increase in water resource consumption and environmental degradation. This study deals with the Day-Nhue River system (DNR), which is one of the three main branches of the Red River Delta, with 20% of the total annual discharge of the Red River.

The goal of this study was taking account the impact of the tidal movement on wastewater mitigation and to prepare a complete database of water discharge at some key stations in the DNR by (i) direct measurement of instantaneous river discharge, (ii) calculation of daily residual discharge, and (iii) evaluation of the discharge and examination of the hydrology of the RRD.

MATERIALS AND METHODS

Description of the Red River Delta and its river network

The Red River Delta (RRD) (Fig. 1), which is located in the northern part of Vietnam, is a very complex hydrological network that has been heavily impacted by human activity. The area of the RRD is approx. 14 300 km^2, entirely lying below 3 m.a.s.l. and much of it is no more than 1 m.a.s.l.

The main branch of the Red River enters the delta at Son Tay, after which it diverges into two distributaries, the Day River on the right and the Duong River on the left side. In addition to these

three branches, the delta contains several other tributaries including the Duong, Thai Binh, Luoc, and Tra Ly rivers on the left side and the Day, Nhue, Chau Giang, Dao, and Ninh Co rivers on the right side. The Red River Delta also comprises a complex hydraulic system of channels that are used as irrigation and drainage arroyos (Dang & Fontenelle, 1997; Fontenelle, 2004; Ritzema *et al.*, 2008).

The right side of the delta is composed of the Day River watershed, which has a total area of approx. 8500 km^2 and a length of 240 km. The Day River is narrow and shallow in this area due to siltation. The Day River is currently virtually isolated from the Red River, and its water primarily originates from its five main tributaries, the Bui, Nhue, Chau, Boi and Dao rivers. The Bui and Boi rivers on the right bank of the Day River drain the upper western part in the mountainous region of Hoa Binh province, and join the Day River at Ba Tha and Gian Khau, respectively. The Nhue, Chau and Dao rivers on its left bank are fed by the Red River. The water flow of Nhue River originates from the Red River through the Lien Mac dam and then joins the Day River at Phu Ly; accordingly, its hydrological regime is controlled by a comprehensive irrigation system. The Nhue River also receives most of the untreated domestic and industrial wastewater from the Hanoi metropolitan area via the To Lich River. Further downstream, the Dao River accounts for a large portion of the water that is discharged into the sea at Nhu Tan by the Day River (Nguyen *et al*., 2005).

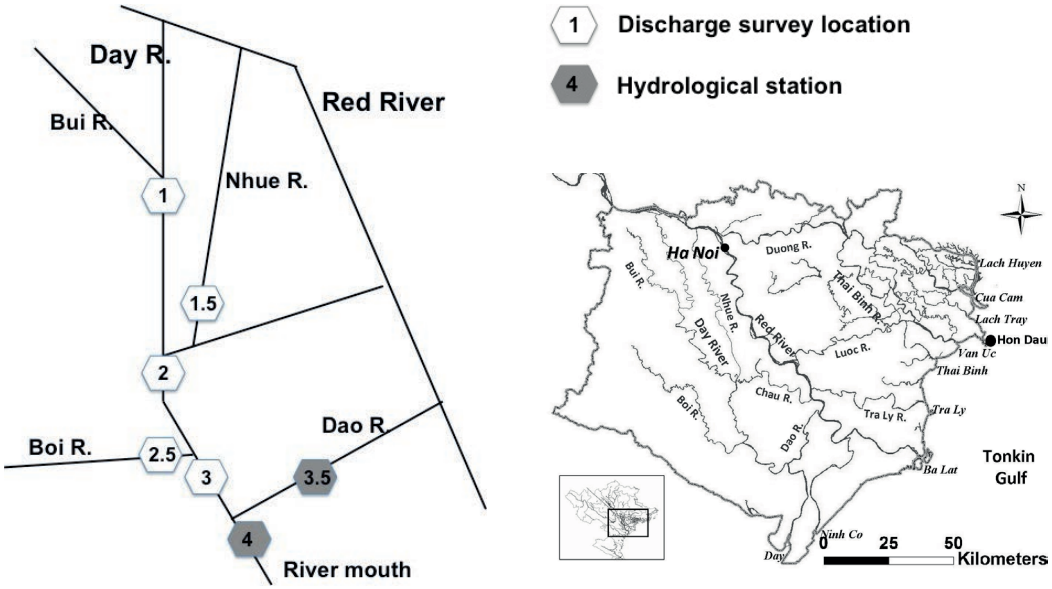

Fig. 1 Red River delta and its hydrographical network in the north of Vietnam.

Meteorological conditions

In the Red River Delta, the climate is dominated by monsoons: wet, hot and sub-tropical, which is typical for northern Vietnam.

The average annual rainfall for the entire delta is 1660 mm, 85% of which occurs from May to October (rainy season). July is the rainiest month and December and January are the driest (IMHE – MONRE, 2006).

When the temperature was evaluated, the coldest month was found to be January, when the temperature can fall to as low as 10°C; however, the seasonal mean is around 20°C. In summer (May to September), the mean temperature varies from 27 to 29°C. In addition, the daily average of 3.1 sunshine hours in July falls to only 1.3 h in March. The relative humidity is very high throughout the year, with an annual mean value of 84.5%.

Hydrology of the delta

There are two distinct seasons for the hydrology. Flood season occurs in June–October and accounts for 70–80% of the total annual flow (Nguyen *et al*., 2003). The hydrological regime of

the river system in the basin is controlled by a comprehensive irrigation system in the Red River. Water flow in the Nhue River changes accordingly to the operation of sluice gates. During the dry season, water supplied to the Day River comes mainly from Dao River, originated from the Red River, with an average of 200–300 m^3/s (MONRE, 2006; Tran *et al*., 2006).

Tidal regime

The tides along the shoreline of the Red River delta are diurnal with a neap tide–spring tide cycle of 14 days. The tidal wave propagates from south to north with mean velocities between 20 and 30 cm/s. The maximum ebb-tidal current is 60 cm/s and the maximum flood–tidal current is 50 cm/s (Thanh *et al.*, 1996, Pruszack *et al*., 2005). The mean tidal range is 2.6 m along the Red River delta coast. The maximum amplitude at spring tide is 4 m and the minimum amplitude at neap tide is 0.02–0.05 m (Fang *et al*., 1999). At the Ba Lat mouth, the average tidal amplitude in the 1972–1990 period was 1.92 m, with a maximum of 3.64 m on 23 December 1987 and 1 July 1988 (Susumu *et al*., 2003; Quartel *et al*., 2007).

According to Van Marren (2007), in the northeast margin of the Red River delta, the duration of the ebb tide is slightly longer than the flood tide duration. However, in the southwest margin of the Red River delta, the ebb tide duration exceeds the flood tide duration. Salinity intrusion is observed within the delta for up to 40 km landwards from the Cua Cam mouth, 38 km from the Lach Tray mouth, 28 km from the Thai Binh mouth and 20 km from the Ba Lat mouth (Pham, 2004). However, the tidal influence on water level and discharge extends much farther upstream. Indeed, we found that at Phu Ly, which is on the Day River 120 km from the coast line, there were daily water level variations as high as 1 m during the dry season and 0.6 m during flood season. In the summer monsoon season, tidal influences within the delta are restricted because of the overwhelming effect of the high freshwater discharge, but in the dry season, tidal effects are evident in all of the major distributaries almost as far inland as Ha Noi.

Determination of direct river discharge in the Day-Nhue system

Four hydrological campaigns were conducted in June, July and August of 2007 and in June of 2008 at Ba Tha (station 1), Nhue (station 1.5), Phu Ly (station 2), Gian Khau (station 2.5) and Ninh Binh (station 3) stations (Fig. 1). During each of these campaigns, the water flow over an entire cross-section of the river was monitored during a 24 h cycle using an ADCP current meter (Rio-Grand, USA), after which the data were integrated and used to calculate the instantaneous discharge. In addition, the water levels at these river stations and the sea water levels at Hon Dau station near the coastline were also monitored. When plotted against the corresponding daily mean water levels, these measurements were found to be in reasonable agreement with the discharge *vs* water level relationships derived from the MIKE11 results (Luu *et al*., 2010).

RESULTS AND DISCUSSION

Water level and tidal regime

On 4 June 2007, the tide range was high, 2.50 m in Hon Nieu station on the coastline. We decided to gauge on that particular day to get the highest variation of water level and discharge. The water level of the rivers follows the sea water level (Fig. 2). However, we see that the tide signal is distorted compared to the signal recorded on the coast in Hon Nieu station. This is due to the distortion of the propagation wave along the way to enter the Day Basin. Moreover the records of water level until Ba Tha station which is the farthest station from the sea (at 150 km from the coastline), revealed that there were substantial daily flow variations according to the tide, with flow inversions occurring until at least Ba Tha (Fig. 3). Then the integration of the measurements over the entire tidal cycle allowed the daily residual discharge to be calculated.

The hourly hydrological survey recorded during specific days in 2007 and 2008 underlined that the Day River water level is strongly affected by tidal movement. At 120 km distance inland (near Phu Ly town), the daily water level variation can be up to 1 m in dry season and 0.6 m during the

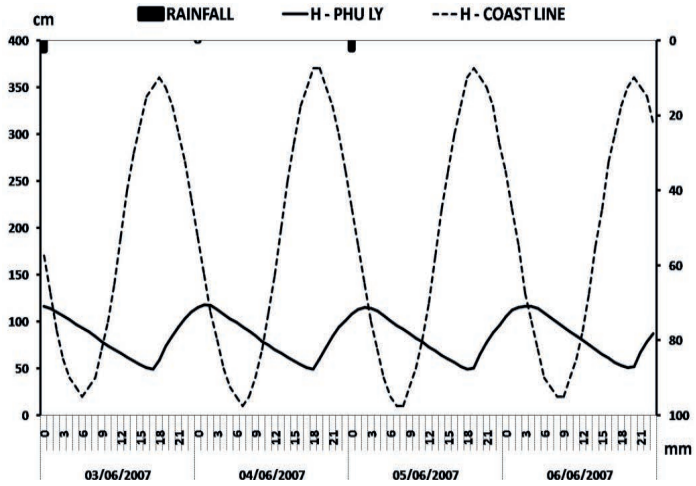

Fig. 2 Comparison of the tidal signal at Hon Nieu station on the coast line and the water level recorded at Phu Ly station on the Day River, from 3 June to 6 June 2007.

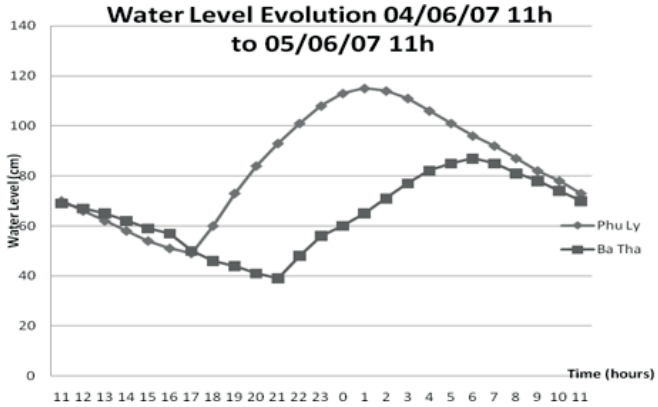

Fig. 3 Influence of the tide on the hourly water level in Ba Tha and Phu Ly stations on the Day River.

flood season. Based on our measurements of salinity, we determined that salinity intrusion length is weak for the Day River, since the maximum salinity intrusion length is less than 20 km.

Hydrology and tidal regime

The hydrological hourly monitoring proves that the water level within the Day River system varies according to the tide. Because the flood period is shorter than the ebb period, the tidal inflow velocities are higher than tidal outflow velocities, resulting in flood–tide asymmetry. However, this flood–tide asymmetry is compensated by the river outflow which is in the same direction as the ebb currents. On average, the propagation times from the coastline to Phu Ly (120 km from the sea) and to Ba Tha (150 km from the sea) are about 6 hours and 11 hours in dry season, 8 hours and 13 hours in flood season, respectively. At Phu Ly, which is the middle point of the Day River system, the water current becomes inverse each day. It is less important in the upstream part, but it was however measured until Ba Tha station on the upper river part. At Phu Ly, it was observed that the instantaneous discharges can vary from +150 m^3/s to –250 m^3/s. This meant the same mass of water pass the same river section three times.

A second consequence is the discharge values describe a daily cycle with one daily maximum, one daily minimum and often with a value zero. These two things could imply some significant impact on the sediment and water quality behaviour. Thus it is impossible to calculate the river discharge by a classical calibration equation linking water level (WL in cm) and discharge (Q in m^3/s), there is no univocal relationship. For example in Phu Ly about 60% of the flow goes downstream for 15 hours and 40% goes upstream for the rest of the day. The real effective flow is about 25% of the total water volume that goes through a cross-section during 24 h (Fig. 4).

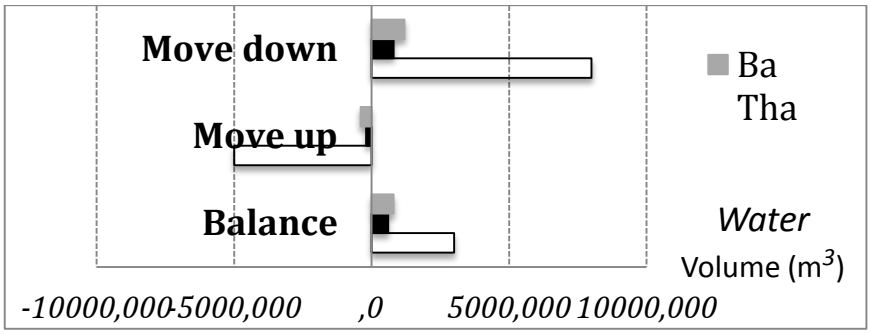

Fig. 4 Daily water volume in direction (positive when the discharge move downward, negative when the discharge move upward) in the Day-Nhue River System at three stations (Ba Tha, Nhue and Phu Ly).

Lateral contribution

From the total water volume crossing the section (Fig. 4), it was estimated that the Nhue River contributed about 20% water for the Day River in the Phu Ly. We can estimate the part of the flow which comes from which river and can make the hypothesis of the conservation of flow (Table 2).

Upstream of Day River, water only comes from Bui River (we note that there is no connection between the Red River and Day River), contributing up to 85% water for the Day River in the flood season. However, in the dry season the Bui River supplies only 20% of water for the Day River as water is more abundant in the Nhue River. This is explained by the nature of these rivers; the Bui River is effectively a natural river while the Nhue River is more-or-less artificial, its water mass is controlled by some sluice gates along the river and its discharge does not change much through the year (60 m^3/s for yearly mean discharge, 50 m^3/s for dry season and 70 m^3/s for flood season).

In the middle reaches of the Day River, a small contribution comes from the Boi River to the Day River, being only 20% ($Q_2 + Q_{2.5} = Q_3$). Boi River flow ($Q_{2.5}$) decreased in the dry season and remains quasi unchanged in the flood season.

At the downstream reach of the Day River, more than 70% of the total yearly average flow at Nhu Tan (Q_4) next to the river mouth comes from the Dao River ($Q_{3.5}$), which is directly connected with the Red River (part $Q_3 + Q_{3.5} = Q_4$). It is seen that the Dao River contribution is lower in the flood season and higher in the dry season. The main characteristic of the Day River system is the contribution of tributaries to the Day River. Among its tributaries, those connected to the Red River (Nhue River, Chau River and Dao River) could supply up to 87% of water for the Day River, with only 13% originating within the catchment's area.

Table 2 The flow repartition among the different Rivers for the 3 points 2, 3 and 4 for yearly, flood and dry seasons.

		Year	Flood	Dry	units
		Q1 + Q1.5 = Q2			
Day (Ba Tha)	Q1	59	102	27	m^3/s
		43%	41%	49%	% of Q2
Nhue	Q1.5	79	150	28	m^3/s
		57%	59%	51%	% of Q2
		Q2 + Q2.5 = Q3			
Day (Phu Ly)	Q2	138	252	55	m^3/s
		79%	78%	82%	% of Q3
Boi (Gian Khau)	Q2.5	36	69	12	m^3/s
		21%	22%	18%	% of Q3
		Q3 + Q3.5 = Q4			
Day (Ninh Binh)	Q3	174	321	67	m^3/s
		26%	32%	16%	% of Q4
Dao (Nam Dinh)	Q3.5	493	676	361	m^3/s
		74%	68%	84%	% of Q4

CONCLUSIONS

The study shows it is important to carry out specific observational studies in assessing environmental conditions of lotic systems. In a tidal affected river system, 24 h monitoring of water discharge was essential to obtain a complete picture of its hydrology.

The main purpose of the hydrological survey was to determine how the discharge links to the water levels, but also to build a data set of discharge values which are not available in most of the rivers in the Red River delta. The integration of the measurements over the entire tidal cycle allowed the calculation of the daily residual discharge and the consequence on the real nutrients fluxes, which appeared to be underestimated by between 50% and 80% in the study based on the daily discharge. Besides the water level data, available for most of the rivers, however, only three gaugings in 2007 were completed and this cannot give an overall comprehension of the hydrological regime of a complex river system, such the Red River delta. Our investigations in 2007 have helped to understand how the Day River is affected by tide and its tributaries. While the Day River is now disconnected from the Red River, the role of tributaries is essential in regulating the river discharge.

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