ASIA-PACIFIC NETWORK FOR GLOBAL CHANGE RESEARCH

Final Report

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Carbon fluxes and emission from the Red River (Vietnam and China): human activities and climate change

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Project Overview

Project Duration	:	August 2012 - November 2016
Funding Awarded	:	40,000$ for Year 2012/13; 32,000$ for Year 2014/15; 36,000$ for Year 2015/16
Key organisations involved	:	1. Institute of Natural Product Chemistry (INPC), Vietnam Academy of Science and Technology, VIETNAM 2. Institute of Environmental Technology (IET), Vietnam Academy of Science and Technology, VIETNAM. 3. Department of Meteorology, Hydrology and Climate Change (DMHCC), VIETNAM. 4. National University of Singapore (NUS), SINGAPORE. 5. University of Pierre and Marie Curie (UPMC), FRANCE. 6. Institute of Research for Development (IRD), FRANCE. 7. Yunnan University of Finance and Economics (YUFE), CHINA.

Project Summary (200 words)

The model Seneque/Riverstrahler was successfully applied to investigate the dynamics and seasonal distribution of carbon in the Red River (China and Vietnam). A good agreement between the modelling simulations and observations of the temporal variations and spatial distribution of organic carbon (OC) concentrations was observed. The results also indicated the important impact of high population in the watershed on OC inputs in surface runoff from the different land use classes and from urban point sources. A budget of the main OC fluxes in the river network, including diffuse inputs and point sources, algal primary production and heterotrophic respiration was established using the model results. It showed the predominantly heterotrophic character of the river system, and allows evaluating the flux of CO_2 across the river-atmosphere interface as 330 GgC yr^{-1}.

Long term observation and calculation showed that the total carbon fluxes of the Red River transferred to estuary significantly decreased from 2,816 ktonC yr^{-1} in 1960s to 1,372 ktonCyr^{-1} in 2010s in which, the proportion of OC fluxes also clearly decreased, from 40.9% in 1960s to 15.9% in 2010s mainly due to the important dam/reservoirs impacts despite the clear increase of deforestation and population in the whole Red River basin.

Keywords: Carbon fluxes, carbon emission, Red River, modeling, water quality observation

Project outputs and outcomes

List the project outputs and outcomes. Please refer to the **logical framework matrix** that that you developed in the proposal.

Outputs planned	Outcomes obtained
To provide a database for long-term period (1960 – present) of the Red River watershed.	A data base of meteorology, hydrology, reservoir impoundment, population, land use was obtained.
To estimate the influence of the point and non-point sources on the carbon transfer in the river system. Calculate the carbon fluxes of the Red River system to the sea, and carbon emission from the Red River to the atmosphere.	Carbon fluxes transferred to the estuary, carbon emission from the Red River to the atmosphere were determined by both measurement and modelling methods; Influence of the point and non-point sources on the carbon transfer and emission was estimated.
To provide an operational tool for the improvement of the regional scale management of water resources.	The Seneque/Riverstrahler model has been successfully applied for describing carbon transfer and emission in the drainage network of the Red River to the constraints resulting from human activity and natural conditions in its basin
Four peer reviewed papers, international workshop	+ 10 peer-reviewed papers published (of which 5 papers in SCI, SCIE journals) + 2 peer-reviewed papers in SCI/SCIE journals have been submitted/in revisions + 2 peer-reviewed papers in preparation (planned to be submitted in SCI/SCIE journals) + 3 papers in APN Science Bulletin + 7 papers in national journals + 6 full papers in different international workshop/conference proceedings
Organize 03 international workshops	Organized 3 international workshops
Website construction	A website has been uploaded for the project http://www.redriverprogram.com/
Training	+ Training course for modelling utilization and

	carbon emission calculation for Vietnamese, Chinese, and Singapore young scientists was organized in Nov. 2016 + Training young scientists: 2 PhD students, 2 Master students and 36 undergraduate students during the project time
Enhancing scientific Exchange	Project participants have attended to different international seminars, workshops on the topic of riverine hydrology, suspended solids, carbon transfer, water quality…or different international projects

Key facts/figures

Key figures and numbers from the research:

- Long-term variation on hydrology, population, land use, agricultural activities, urbanization was clearly observed for the whole Red River basin for the period 1960 – present.
- The model Seneque/Riverstrahler was successfully applied to investigate the dynamics and seasonal distribution of carbon in the Red River. The results showed that, in general, the model simulations of the temporal variations and spatial distribution of OC concentration followed the observed trends. They also showed the impact of the high population in the watershed on OC inputs in surface runoff from the different land use classes and from urban point sources. A budget of the main fluxes of OC in the whole river network, including diffuse inputs from soil leaching and runoff, point sources from urban centers, algal primary production and heterotrophic respiration was established using the model results. It showed the predominantly heterotrophic character of the river system, and allows evaluating the flux of CO_2 across the river-atmosphere interface as 330 GgC yr^{-1}. This value was in reasonable agreement with the few available direct measurements of CO_2 fluxes in the downstream part of the river network.
- Long term observation/calculation of carbon fluxes of the Red River transferred to the coastal zone showed that, the total carbon fluxes of the averaged 2,555 ± 639 ktonC yr^{-1}, equivalent to 16,3 ± 4,1 tonC km^{-2} yr^{-1} during the period 1960 – 2015 of which the DIC fluxes (64%) dominated total carbon fluxes. The total carbon fluxes of the Red River varied seasonally and spatially during this period. Overall, the total carbon fluxes of the Red River transferred to estuary significantly decreased from 2,816

ktonC yr^{-1} in 1960s to 1,372 ktonC yr^{-1} in 2010s in which, the proportion of organic carbon fluxes also clearly decreased, from 40.9% in 1960s to 15.9% in 2010s due to the important dam/reservoirs impacts despite the clear increase of deforestation and population in the whole river basin.

Potential for further work

The Red River is a large source of CO_2 to the atmosphere. It is therefore important to conduct in situ measurements over a long period of time to provide some ground-truthing data for these calculations.

The Trang An Scenic Landscape Complex (Ninh Binh province, Vietnam) approved by UNESCO is a good place to understand about nature, the environment and climate of the Red River Delta region. This is a target which might be interesting for new scientific project development for protection of environment and ecosystem in this system.

Publications

International peer-reviewed publications:

SCI/SCIE journals

Thi Phuong Quynh Le, Cyril Marchand, Phuong Kieu Doan, Cuong Tu Ho, Duy An Vu, Thi Bich Ngoc Nguyen, Thi Mai Huong Nguyen. 2016. Carbon dynamic and CO_2 emission from the lower Red River (Vietnam). (in preparation for a SCI journal)

Viet Nga Dao, Thi Phuong Quynh Le, Emma Rochelle-Newall, Cyril Marchand, Thi Mai Huong Nguyen and Thi Thuy Duong. 2016. Longterm variation of the carbon flux of the Red River (Vietnam): impacts of human activities and climate. *Applied Geochemistry*. (in preparation) (SCI, ISSN: 0883-2927).

Thi Mai Huong Nguyen, Gilles Billen, Josette Garnier, Thi Phuong Quynh Le, Quoc Long Pham, Sylvain Huon, Emma Rochelle-Newall. 2016. Organic carbon transfers in the subtropical Red River system (Vietnam): insights on CO_2 sources and sinks. *Biogeochemistry.* Submitted. (SCI, ISSN: 0168-2563, IF= 3.407).

Anh Duc Trinh, Thi Nguyet Minh Luu, Thi Phuong Quynh Le. 2016. Hydrological regime in the Red River Delta (Asia) as reflected by water stable isotopes. *Hydrological Processes*. In revision (SCI; ISSN: 1099 – 1085) IF= 2.768).

Thi Phuong Quynh Le, Viet Nga Dao, Emma Rochelle-Newall, Josette Garnier, XiXi Lu, Gilles Billen, Henri Etcheber, Thi Thuy Duong, Cuong Tu Ho, Thi Bich Ngoc Nguye, Bich Thuy Nguyen, Nhu Da Le and Pham Quoc Long. 2017 (accepted). Transfer of organic carbon in the Red River system (Vietnam). *Earth surface processes and landforms*. Accepted, SCI, ISSN: 1096-9837IF = 3.505).

Thi Mai Huong Nguyen, Gilles Billen, Josette Garnier, Emma Rochelle-Newall, Olivier Ribolzi, Thi Phuong Quynh Le. 2016. Modeling of Faecal Indicator Bacteria (FIB) in the Red River basin (Vietnam). *Environmental Monitoring and Assessment*. Vol 188(9), 1-15. DOI: 10.1007/s10661-016-5528-4. (SCIE, ISSN: 0167-6369, IF= 1.63).

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Thi Phuong Quynh Le, Gilles Billen, Josette Garnier and Van Minh Chau. 2015. Long-term biogeochemical functioning of the Red River (Vietnam): past and present situations. *Regional Environmental Change*. Vol 15(2): 329 – 339. DOI: 10.1007/s10113-014-0646-4. (SCIE, ISSN 1436-378X., IF = 2.66).

Other international journals

Le Thi Phuong Quynh, Phung Thi Xuan Binh, Duong Thi Thuy and Ho Tu Cuong. 2016. Relationship of dissolved inorganic carbon concentrations with some environmental variables in the Red River water in the period 2008 – 2015. *Journal of Vietnamese Environment.* (Journal of Dresden University, Germany). Vol. 8(2): 102-106. DOI:10.13141/jve.vol8.no2.pp102-106. ISSN 2193-6471.

Hoang TTH, Nguyen TK, Le TPQ, Dang DK, Duong TT. 2016. Assessment of the water quality downstream of Red River in 2015 (Vietnam). *Journal of Vietnamese Environment*. (Journal of Dresden University, Germany). 8(3), 167 – 172, DOI:10.13141/jve.vol8.no3.pp167-172. ISSN 2193-6471.

Duong Thi Thuy, Le Thi Phuong Quynh, Ho Tu Cuong, Vu Thi Nguyet, Hoang Thi Thu Hang, Dang Dinh Kim, Lu Xixi. 2014. Phytoplankton community structure and water quality of Red River (Vietnam). *Journal of Vietnamese Environment*. (Journal of Dresden University, Germany). Vol 6(1-3): 27-33. http://dx.doi.org/10.13141/JVE. ISSN 2193-6471.

Duong Thi Thuy, Vu Thi Nguyet, Le Thi Phuong Quynh, Ho Tu Cuong, Hoang Trung Kien, Nguyen, Trung Kien, Dang Dinh Kim. 2014. Seasonal variation of phytoplankton assemblage in Hoa Binh reservoir (North of Vietnam). *Journal of Vietnamese Environment.* (Journal of Dresden University, Germany). Vol 6(1-3): 22-26. http://dx.doi.org/10.13141/JVE. ISSN 2193-6471.

Le Thi Phuong Quynh, Ho Tu Cuong; Duong Thi Thuy, Nguyen Thi Bich Ngoc, Vu Duy An, Pham Quoc Long, Seidler Christina. 2014. Water quality of the Red River system in the period 2012 – 2013. *Journal of Vietnamese Environment*. (Journal of Dresden University, Germany). Vol 6(1-3): 191 -195. http://dx.doi.org/10.13141/JVE. ISSN 2193-6471.

APN Science Bulletin publications:

Thi Phuong Quynh Le, Xi Xi Lu, Josette Garnier, Gilles Billen, Thi Thuy Duong, Cuong Tu Ho, Thi Bich Nga Tran, Thi Mai Huong Nguyen, Thi Bich Ngoc Nguyen, Pham Quoc Long and Zhou Yue. 2015. Carbon Flux and Emissions from the Red River: Human Activities and Climate Change. *APN Science Bulletin* Issue 5, 38 – 39, ISSN 2185-761x.

Thi Phuong Quynh Le, Xi Xi Lu, Josette Garnier, Gilles Billen, Thi Thuy Duong, Cuong Tu Ho, Thi Bich Nga Tran, Thi Mai Huong Nguyen, Thi Bich Ngoc Nguyen and Zhou Yue. 2014. Carbon Flux and Emissions from the Red River: Human Activities and Climate Change. *APN Science Bulletin* Issue 4, 68 - 71 ISSN 2185-761x.

Thi Phuong Quynh Le, Xi Xi Lu, Josette Garnier, Gilles Billen, Thi Thuy Duong, Cuong Tu Ho, Thi Bich Nga Tran, Thi Mai Huong Nguyen, Thi Bich Ngoc Nguyen and Zhou Yue. 2013. Carbon Flux and Emissions from the Red River: Human Activities and Climate Change. *APN Science Bulletin* Issue 3, 92 - 95 ISSN 2185-761x

National papers published:

Nguyen Thị Mai Huong, Le Thi Phuong Quynh, Phung Thi Xuan Binh, Emma Rochell-Newall, Jean Louis Janeau, Josette Garnier, Gilles Billen. 2015. Relationship between bacteria and environmental factors in the Red River water of the section from Hanoi to Hung Yen. *Journal of Science and Technology*, Hanoi University of Industry. Vol 28-2015: 61- 65.

Nguyen Thi Bich Ngoc, Le Thi Phuong Quynh, Nguyen Bich Thuy, Nguyen Thi Mai Huong, Vu Duy An, Duong Thi Thuy and Ho Tu Cuong. 2014. Agricultural wastewater quality of a vegetable growing area Van Noi commune, Dong Anh district, Hanoi city. *Science and Technology Journal of Agriculture & Rural Development.* Ministry of Agriculture and Rural development, Vietnam. Vol 21: 65-71.

Vu Duy An, Le Thi Phuong Quynh, Nguyen Thi Bich Ngoc, Nguyen Bich Thuy, Pham Quoc Long, Christina Seilder and Phung Thi Xuan Binh. 2014. Wastewater quality of the agricultural region (vegetables - flowers - fruit trees) at Phu Dien and Tay Tuu wards (Hanoi). *Journal of Science and Technology Development*. Vol M2-2014 (17): 13 – 21.

Nguyen Thi Bich Ngoc, Nguyen Thi Mai Huong, Nguyen Bich Thuy, Vu Duy An, Duong Thi Thuy, Ho Tu Cuong and Le Thi Phuong Quynh. 2014. Preliminary monitoring results on contents of some heavy metals in the Red River system. *Vietnam Journal of Science and Technology.* Vol 53(1): 64 – 76.

Nguyen Thi Bich Ngoc, Nguyen Thi Mai Huong, Nguyen Bich Thuy, Vu Duy An, Duong Thi Thuy and Le Thi Phuong Quynh. 2014. Preliminary monitoring results on total coliforms and fecal coliforms in the Red River system, section from Yen Bai to Hanoi. *Vietnam Journal of Biology.* Vol 36(2): 240 – 246. DOI: 10.15625/0866-7160/v36n2.5122

Le Thi Phuong Quynh Nguyen Thi Mai Huong, Nguyen Thi Bich Ngoc, Duong Thi Thuy, Ho Tu Cuong. 2012. Preliminary results on the ratio of particulate organic carbon and chlorophyll a (POC/CHL-A) of the Red River system. *Vietnam Journal of Chemistry*. Vol. 50(4A): 387 – 390.

Le Thi Phuong Quynh Nguyen Thi Mai Huong, Nguyen Thi Bich Ngoc, Duong Thi Thuy, Ho Tu Cuong. 2012. Preliminary results of carbon contents in the water environment of the Red River system. *Vietnam Journal of Science and Technology*. Vol. 50(3B): 47 - 52.

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The completion of this project represents a milestone that could not have been accomplished without the help of a large diverse group of people. The present project thanks to numerous generous persons who help on local sampling campaign, sample in-situ treatment, data collecting... In addition, we highly appreciate the contribution, cooperation and helpful sharing knowledge from different scientists during the running of this project.

1- Introduction

Natural hydrological processes and biogeochemistry of many rivers in the world have suffered from the influences of climate and human activities in the drainage basins. Riverine carbon fluxes and outgassing are an important part of the carbon exchange among terrestrial, oceanic and atmospheric environment. Rivers and streams not only transfer various forms of carbon (dissolved and particulate) to oceans, but also evade a significant amount of carbon to the atmosphere (*Battin et al., 2009; Richey et al., 2002*).

In Asia where the river water discharge and sediment loads have been altered dramatically over the past decades as a result of reservoir impoundment, land use, population, and climate changes (*Walling & Fang, 2003; Walling, 2006; Lu et al., 2011*), there is limited understanding of spatial and temporal dynamics of carbon exchange between terrestrial, oceanic and atmospheric environment for the large Asian rivers. Solid sediment loads not only directly contribute to increase the organic carbon content, but also affect chemical weathering and hence carbon consumption and possible carbon emission. Therefore, studies of carbon emission from the large Asian rivers are crucial to quantify geochemical cycles accurately in the context of global change.

To obtain a good understanding of the global natural and human impact to global carbon cycle, it has to be examined at a regional scale, where the various climatic and socio-economical constraints can be taken into account. The Red River (basin area: 156,450 km^2) (figure 1) is a typical example of a South East Asia river which is strongly affected by climate and human activities. Previous studies focused on hydrology, suspended sediment load, flood control, deforestation, impact of dam impoundment, water quality… of the Red River (*Dang et al., 2010; Le et al., 2007* …) however, the knowledge of carbon transfer and exchange of the Red River is still limited.

The present project aims to quantify the spatial and temporal variability of carbon fluxes and emission (out gassing or evasion) from the Red River system and evaluate their response to sediment loads change and other environmental changes such as land use, intensive agricultural practice, reservoir construction and population increase. This work is structured around the SENEQUE/RIVERSTRAHLER model for relating the carbon transfer and out gassing at the scale of the whole drainage network to the constraints resulting from human activities and natural conditions in the watershed. In this work, the model is validated to describe the carbon transfer in the whole Red River system for the past and present situations, and then be used to explore various scenarios of changes in climate and human activities at the 2050s horizon.

The project has allowed the following achievements:

1. Completed database in the long term from 1960 to present (water and wastewater quality, meteorology, hydrology and human activities) which was used to calculate the carbon fluxes and emission, as well as used for the model validation in the past and at the present situations.

2. Calculated the carbon fluxes and emission from the Red River; to characterize and identify the variables (geology, rainfall, reservoirs, land use…) controlling carbon fluxes and emission from this river.

3. Has applied the SENEQUE/RIVERSTRAHLER model which allows relating the water quality, including carbon transfers in the drainage network to the constraints resulting from human activity and natural conditions in the Red River watershed. This allows us to predict the results of the overall water quality and carbon delivery of the river system for different possible future changes in 2050s.

2- Methodology

2.1. Water sampling campaigns and laboratory analysis

River water quality and carbon contents

Due to the lack of a complete water quality data base of the Red River basin, the monthly field campaigns were organized at ten gauging stations (Fig 1) Yen Bai, Vu Quang, Hoa Binh, Son Tay, Hanoi, Gian Khau, Nam Dinh, Truc Phuong, Ba Lat, Quyet Chien of the Red River system from August 2012 to December 2014.

Water quality checker, model WQC-22A (TOA, Japan), was used to measure physical-chemical variables such as temperature, pH, conductivity and dissolved oxygen (DO). Water samples were sequentially filtered through Whatman GF/F paper (0.7µm pore size) and stored at 4^0C for analyzing dissolved substances: nitrogen (nitrite, nitrate and ammonia); phosphorus (phosphate); silica (DSi); organic carbon (DOC) and heavy metals.

Nutrients (N, P, Si) and chlorophyll-a were spectrophotometrically measured by an UV-VIS V-630 (JASCO, Japan) by different methods described in *Le et al., (2005)*. DOC was determined using a TOC-V_E (Shimadzu, Japan). Dissolved heavy metals (DHM) such as Cu, Zn, Cr, Pb, Cd, Mn and Fe were spectrophotometrically determined by the Vietnamese standard methods: Cu: TCVN 4572 – 88; Zn: TCVN 4575 – 88; Cr: TCVN 6658 – 2000; Cd: TCVN 2664 – 78; Pb: TCVN 4573 – 88; Mn: TCVN 6002 – 1995 and Fe: TCVN 6177 - 1996. Particulate organic carbon (POC) was analyzed using a device LECO CS 125. Total coliform

TC and fecal coliform FC densities were numbered by the Vietnamese standards TCVN 6187-2: 1996. CH_4 and CO_2 concentrations were measured using a gas chromatograph (GC, Agilent) equipped with a flame ionization detector (FID) and with a thermal conductivity detector (TCD), respectively.

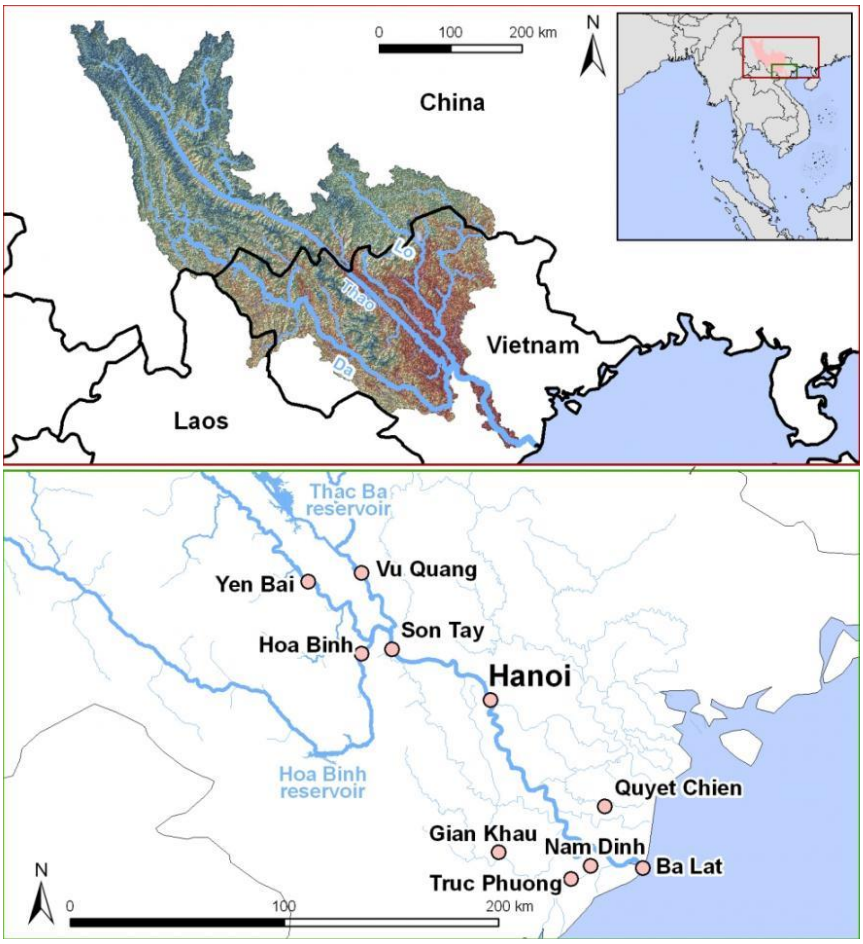

Figure 1. *Sampling sites for water quality of the Red River*

Figure 2. *In situ measurement and laboratory analysis*

Point and non-point sources

More than 100 agricultural and industrial wastewater samples in both dry and rainy season were taken (Figure 3) and analysed for the variables as presented above.

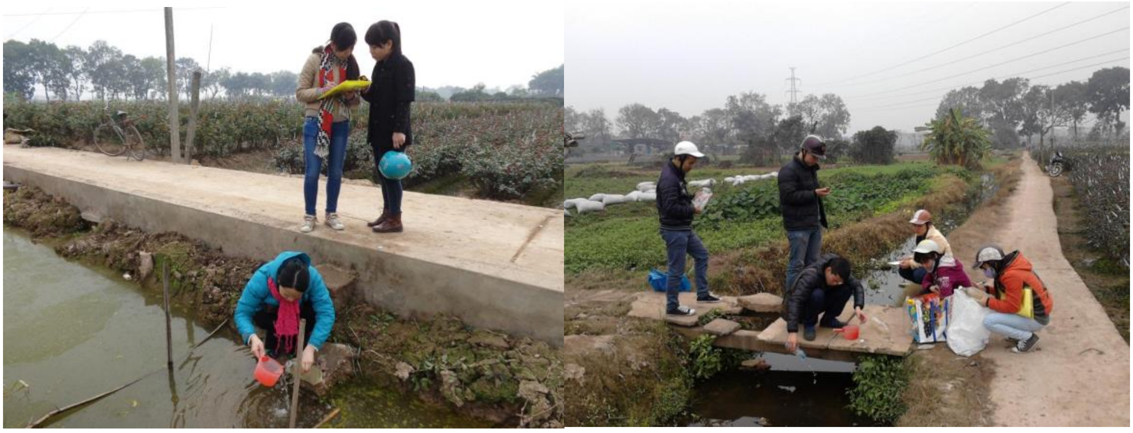

Figure 3. *Industrial and agricultural wastewater sampling.*

2.2. Measurement of carbon exchange/emission

CO_2 evasion rate at the air-water interface of the Red River was estimated by three different methods: i) calculation of CO_2 fluxes either using a floating chamber connected to an IRGA, ii) determining pCO_2 within the water column using an equilibrator; iii) calculation via CO_2 partial pressure pCO_2 basing on the total alkalinity and pH values measured with the CO_2-SYS software method (Figure 4).

Figure 4. *Measurement of carbon exchange at the water-air interface*

Determining pCO_2 within the water column using an equilibrator

Equilibrator (Figure 4) was used to determine the pCO_2 in water balanced with the air. The equilibrator was designed as described in *Frankignoulle et al., (2001)* as follows: a vertical plastic tube (height: 73 cm, diameter: 9cm) which is filled up with about 250 glass marbles (diameter = 1.5cm) in order to increase the surface exchange between water and air. The river water (water inlet) through a submerged pump at 20 cm below the river surface water comes into the equilibrator from the top of the tube. The water inlet can be regulated by a flow controller installed under the tygon tubing, which joins the water inlet with the pump. A closed air circuit ensures circulation through the equilibrator (from the bottom to the top), a water trap, a particle filter, a regulator and an IRGA (Licor 820, Licor, USA) (Figure 4), which was calibrated before each sampling campaign using a series of standards concentrations of 0, 551 and 2756 ppm CO_2 (Air Liquide). The Licor was connected to a computer interface, which allows recording the pCO_2 every second. Measurement was taken during 24h continuously.

The water-air CO_2 fluxes from the equilibrator measurement at each site were calculated by the formula proposed by *Raymond and Cole (2001)* as followings:

$$F_{Equi} = k_{600} * \alpha * (pCO_2\ \text{water} - pCO_2\ \text{air}) \quad (F1.2)$$

Where F is the CO_2 flux from water (µmol m^{-2} s^{-1}) and converted in mmol m^{-2} d^{-1};

k_{600}, is gas transfer velocity of CO_2 or piston velocity (cm h^{-1}), and is calculated according to a wind speed function (k vs. U_{10}). K600 is calculated using the equation from *Raymond and Cole (2001)*, which developed from a data set of different estuaries and rivers as follow:

$$k_{600} = 1.91 \times \exp(0.35 \times U_{10}) \times (Sc/600)^{-0.5}$$

Where U_{10} is the wind speed (m s^{-1}) at 10 m height above the surface water (was calculate from the wind speed (m s^{-1}) at 2 m height, (*"Appendix 8.6-Wind Speed Calculations" 2010*); and Sc is the Schmidt number, normalized to Schmidt number of 600 (*Cole and Caraco, 1998*).

α is the solubility coefficient of CO_2 for given temperature and salinity (*Weiss, 1974*) (mol L^{-1} atm^{-1}). In this case, $\alpha = 0.034$ mol L^{-1} atm^{-1}

pCO_2 water is CO_2 concentration in surface river water from Equilibrator measurement or from CO_2_SYS calculation.

pCO_2 air is considered as a constant of 400 ppm.

Since we measured wind speed on field at a height of 2 meters (Uz = 2) with a handle anemometer, the formula of *Amorocho and DeVries* (*1980*) was used to estimate the wind speed at 10m height (U10).

Calculated pCO_2 based on the total alkalinity and pH values measured with the CO_2-SYS software method.

- DIC content: As known, DIC content may be calculated from the sum of total dissolved inorganic carbon in water including HCO_3^-, CO_3^{2-}, H_2CO_3 and CO_2, or can be calculated from a combination of any two of the following measured parameters total alkalinity, pH, or partial pressure of CO_2 (pCO_2) (*Cai et al., 2008; Sun et al., 2010*). In this study, DIC contents were calculated from the sum of including HCO_3^-, CO_3^{2-}, H_2CO_3 and CO_2 contents, which were given by the calculation from the CO_2-SYS Software (version 2.0) basing on the total alkalinity contents and pH values measured in-situ.

- pCO_2 in water calculated: In order to compare with the results of pCO_2 in water measured by the equilibrator, pCO_2 in water at 5 sites was also simultaneously calculated on the CO_2-SYS EXCEL Macro Software basing on total alkalinity contents and pH values measured in-situ at 5 sites as described above.

2.3. Collection of available dataset from different sources

The long-term discrete existing data (since the 1960s) of the Red River, including water quality, land use, population, agricultural and industrial development, hydrological management, and hydrological - meteorological data have been collected from different sources, such as previous scientific research projects, data published in the national books, reports or data from different official agencies.

+ To collect and synthesize the long-term discrete existent data (since the 1960s) of the water quality, industrial and agricultural wastewater, meteorology, hydrology, population and land use of the whole Red River system in both China and Vietnam terrain;

+ To collect the data for prospective scenarios: climatic data (air temperature and rainfall); new reservoirs implementation, land use with intensive agricultural practices, industrial activities, population and urbanization increase of the basin in the 2050 horizon.

The data collection is used for:

- Modelling validation for describing the carbon transfer and carbon emission under the pressure of human activities and natural conditions in the whole Red River basin in the past, present and perspective scenarios

- Calculating carbon emission and flux from the Red River.

2.4. Modelling application

Principles of the Seneque/Riverstrahler model

The SENEQUE/Riverstrahler model *(Billen and Garnier, 1999; Billen et al., 1994; Garnier et al., 1999*) is a biogeochemical model (RIVE) of in-stream processes imbedded within a GIS interface (SENEQUE), providing a generic model of the biogeochemical functioning of whole river systems (from 10 to >100,000 km^2), designed to calculate the seasonal and spatial variations of water quality (*Ruelland et al., 2007; Thieu et al., 2009)*.

The SENEQUE/Riverstrahler model was developed for application in large drainage networks such as the Seine River, France (*Billen et al., 1994; Billen and Garnier, 1999*), Scheldt River, Belgium and the Netherlands (*Billen et al., 2009; Thieu et al., 2009*) and the Danube (*Garnier et al., 2002)*. It has also been adapted to the Red River in North Viet Nam (*Luu et al., 2010; Le et al., 2015*). The model uses drainage network morphology, meteorological conditions, and land-use, point and non-point sources, to calculate geographical and seasonal variations of the main water quality variables at a 10-day time step (Figure 5). Here the model was applied to the Red River to simulate the fluxes of organic carbon and to estimate the carbon metabolism of this large river system.

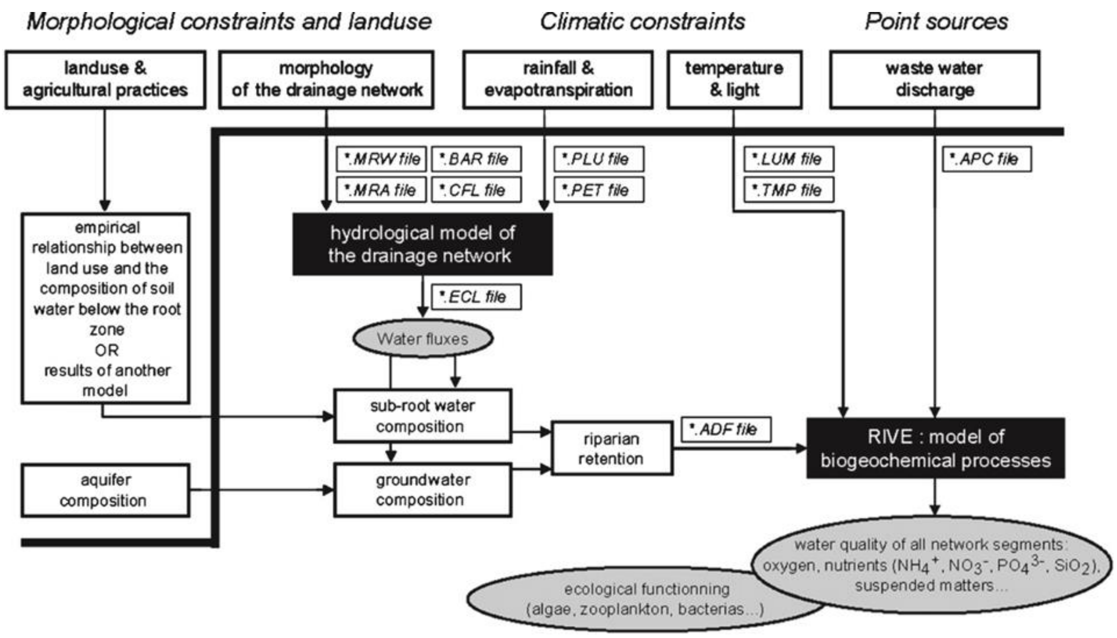

Figure 5. *Principles of the calculation of water quality by the Riverstrahler model (Ruelland et al., 2007)*

The SENEQUE interface

The GIS interface SENEQUE, allows the user to run the Riverstrahler model for a definite project. It first allows the explicit limitation the part of the basin concerned, and the degree of resolution required in its representation in terms of objects (branches and basins) combination. It then allows the testing of defined scenarios through the fixing of anthropogenic and hydrological constraints. The GIS files used are under Arc/Info or ArcView format however all other files are simple text files, conferring a large versatility in the dialog with other programs or applications. The results of the calculations are provided as seasonal variations of discharge or concentration of any variable at one station or as the longitudinal variations of discharge or concentration along a river branch at a specified time. A cartographic representation of the variable (with an adjustable colour code) over all basins and branches of the project at a given time period can also be produced. Furthermore, the possibility exists to automatically compare the calculation results with measured data when these are stored in the database and the results from several scenarios of the same project can also be compared simultaneously (Figure 6).

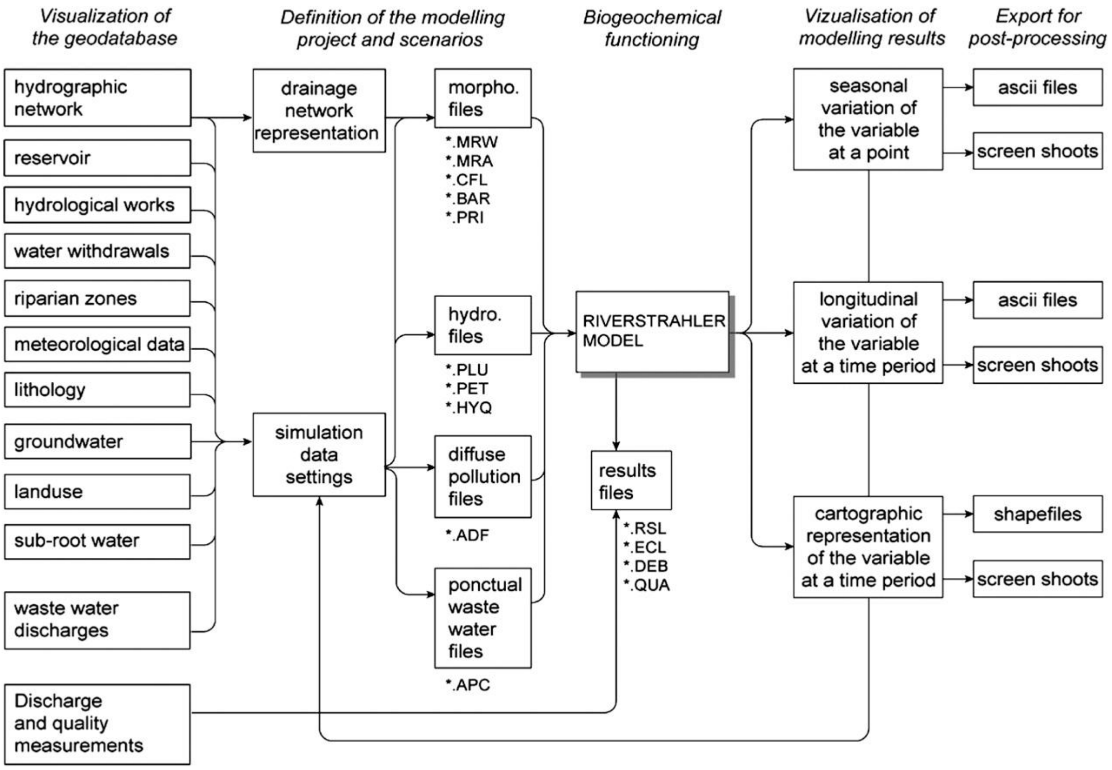

Figure 6. Schematic representation of the functionalities of the GIS interface of the SENEQUE software

The model includes a module describing the dynamics of OC as represented in Figure 7 (*Garnier et al., 2008*). In the model, organic matter has two fractions: particulate (HP) and dissolved (HD). Each of which is sub-divided into 3 classes of biodegradability that are indicated as HP1, HP2 (rapidly and slowly biodegradable, respectively) and HP3 (refractory) for particulate stocks, and as HD1, HD2, HD3 for the dissolved pool. The parameters used in the model were those determined experimentally and shown to be generic by *Garnier et al., (1992), Servais et al., (1999), Menon et al., (2003), Billen and Servais (1989), Billen (1991)*. Our measurements of organic matter biodegradability confirm the coherency of these values.

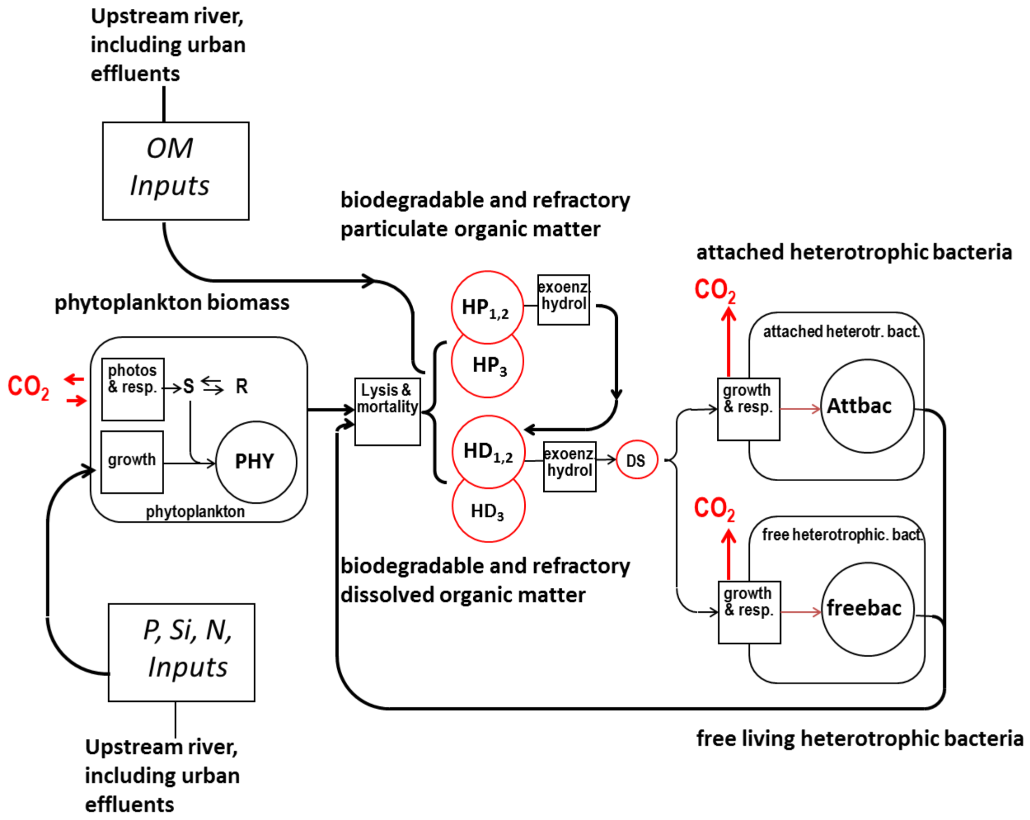

Figure 7. *Schematic description of the SENEQUE / RIVERSTRAHLER model (adapted from Garnier et al., 2008).*

The three major tributaries (the Da, the Thao and Lo Rivers) of the Red River are taken in account explicitly in the model. Each station is denoted as a function of the distance (pK in km) from an upstream station, namely Lao Cai, Son La, Tuyen Quang cities in the upstream section of the Thao, Da and Lo rivers, respectively. The main stations on the Thao River are Yen Bai, Ha Noi, Ba Lat at pK 402, 524, 652, respectively; in the Da River Hoa Binh is at pK 434; and in Lo River Vu Quang is at pK 135. The remaining part of the drainage network is considered as idealised Strahler basins according to the methodology of the Riverstrahler model (*Ruelland et al., 2007*).

Point and diffuse sources evaluation

For running the OC module in the Seneque/Riverstrahler model, inputs of OC from the watershed into the drainage network have to be provided. The model distinguishes between (i) point sources such as the discharge of domestic wastewater (either directly released or treated in wastewater treatment plants - WWTPs) (Table 1) *Le et al., (2005)* and *Servais et al., (2007b)* and (ii) diffuse sources of OC from forested, crop or grassland (considering paddy rice fields separately) and urban surfaces (Table 2) *(Baric and Sigvardsson, 2007; Chu et al., 2010; Stevenson et al., 2013*).

The point sources are taken into account in the model by considering all potential sources of wastewater in the watershed, based on the census of urban population and industrial activities (*Le et al., 2005*). The point sources of OC were determined using either the urban population (in the case of no wastewater treatment) or the capacity (in number of inhabitant equivalents) and the type of treatment for each WWTP in the Red River watershed. The capacity of each point source was then multiplied by the corresponding specific load of OC per inhabitant and per day according to the type of treatment applied, to obtain the flux of OC released to rivers (Table 2).

Table 1. *The flux of OM released to rivers according to the type of treatment taken into account (gC hab^{-1} day^{-1}). From (Servais et al., 1999; 2007b)*

Type of treatment	**OM, gC hab^{-1} day^{-1}**					
	HD1	**HD2**	**HD3**	**HP1**	**HP2**	**HP3**
Non-treated	2.4	2.4	1.75	9.6	9.6	4.8
Decantation	3.8	3.8	1.75	5.18	5.18	3.6
Biological	1.04	1.04	1.75	0.96	0.96	0.80

The diffuse sources of OC were calculated on the basis of land use in all elementary sub-basins of the watershed. The GIS land use coverage information was taken from the data of Le et al., (2005). Data from literature and from available monitoring programs on the concentration of OC in small rivers, streams and ditches draining homogeneous land cover types were used to characterize OC concentrations in surface runoff and in base flow as a function of land use.

Table 2. *The median organic carbon (OC) concentration assigned to each of the land use classes for surface runoff (SR) and base flow (BF) (mgC L^{-1}). Data from a compilation of values cited in Stevenson et al., (2013); Baric and Sigvardsson (2007); Pham et al., (2010).*

Type of land use	**OC, mgC L^{-1}**											
	HD1		HD2		HD3		HP1		HP2		HP3	
	SR	BF	SR	BF	SR	BF	SR	BF	SR	BF	SR	BF
Forest	0.02		0.05		0.6	0.5	0.01		0.05		0.9	
Degraded forest and bare land	0.02		0.05		0.6	0.5	0.01		0.05		0.9	
Agri. land excluding rice	0.05	0.01	0.4	0.05	3	1.5	0.01	0	0.2	0	0.9	0
Rice fields	0.1		0.4		4	1.5	0.05		0.1		1.3	
Urbanized area	0.5		4	0.5	10	2	0.1	0.01	0.5	0.1	4	1

Validation data

In order to validate the modelling results, data from the monthly monitoring surveys (January 2009 to December 2014) at the ten stations along the Red River were used.

3-Results & Discussion

3.1. Observation of river water quality and carbon contents

3.1.1. River water quality

Physico-chemical variables

The variability of the physico-chemical parameters observed in the ten stations for the wet and dry seasons. Temperature varied between 9.5 and 35°C and was significantly higher during the wet season ($p < 0.0001$). Temperature was generally highest at Ba Lat and lowest at Gian Khau.

The pH ranged from ranged 7.1 to 8.8, with the lowest values observed at the downstream Ba Lat station and the highest at upstream Hoa Binh station, however, no seasonal differences were observed. Salinity was almost 0 at all stations during the entire year; the only exception was during March at the most downstream station (Ba Lat, located at the river mouth and under tidal influence) where a salinity of 8.5‰ was observed. The highest conductivities were also observed at this station at this time (1410 µS cm^{-1}). At the other stations, conductivity varied between 136-423 µS.cm^{-1} and had no significant seasonal pattern.

Nutrients (N, P, Si) and TSS

Ammonium varied from 0.01 to 0.6 mgN L^{-1} and was significantly higher during the dry season (November – April) at low dilution and in the downstream stations (Gian Khau, Nam Dinh, Truc Phuong and Ba Lat) of the highly populated delta area. Similar to NH_4^+, the PO_4^{3-} tended to be higher during the dry season however the difference was not significant. TSS was significantly higher during the wet season, when particle load is higher. Overall, concentrations were generally lowest at the most downstream station Ba Lat in July and the highest at in the upstream Yen Bai station. As for TSS, TP was significantly higher during the wet season ($p<0.012$). Interestingly, high concentrations of TP were found at Yen Bai and Gian Khau during the dry season (January) when values of up to 1.39 and 1.59 mgPO_4^{3-} L^{-1} were observed.

Considering the proportion of nitrate, nitrite and ammonium in total inorganic nitrogen, it appeared that nitrate was, in proportion, the dominant form, around 83%. The proportion in nitrite remained very low (<2%).

DSi concentrations in rivers mainly originate from rock weathering, and therefore depend on the lithology. The lithological composition of the Red River watershed is dominated by sedimentary rocks, with about half of carbonated rocks. DSi concentration averaged 5.5 mgSi L^{-1} at four sites.

Total chlorophyll-a (Chl-a, µg L^{-1}) varied between 0.1 to 17.5 µgChl-a L^{-1}, with the highest values observed at the Hanoi station (17.5 µgChl-a L^{-1}) in the main downstream axe. The mean values of Chl-a concentration at Yen Bai and Hanoi (1.9±2.9 and 2.1±2.5; µgChl-a L^{-1}, respectively) were higher than at Hoa Binh and Vu Quang (1.1±0.8 and 1.3±0.9 µgChl-a L^{-1}, respectively ($p<0.05$). For the whole Red River system, the mean value of the Chl-a concentration was low, 1.8±2.2 µgChl-a L^{-1}, which may be influenced by high suspended solid and water flow.

Total Coliforms (TC)

The number of TC varied between <100 CFU.100mL^{-1} at Hoa Binh in January to over 39100 CFU 100mL^{-1} at Yen Bai in September. During the wet season, TC at Yen Bai, the most upstream station, was 9783±4431 (mean ± standard deviation) CFU 100mL^{-1} as compared to 4383±3797 CFU 100mL^{-1} for this station during the dry season. For the other upstream tributaries, relatively low mean TC numbers were observed during the wet season

(1850±715 and 800±789 CFU.100mL^{-1} for Hoa Binh and Vu Quang, respectively. The highest mean values were found in the downstream delta stations with 6066±4506, 5408±5379 and 6050±5469 CFU.100mL^{-1} for Nam Dinh, Truc Phuong and Ba Lat, respectively. The overall pattern was similar for the dry season, i.e. higher mean values at Yen Bai and in downstream delta stations such as the peri-urban Nam Dinh station where a seasonal average of 5016±5840 CFU.100mL^{-1} was found. When the data from all of the stations were combined TC exhibited a significant seasonal difference with lower numbers during the dry season as compared to the wet season

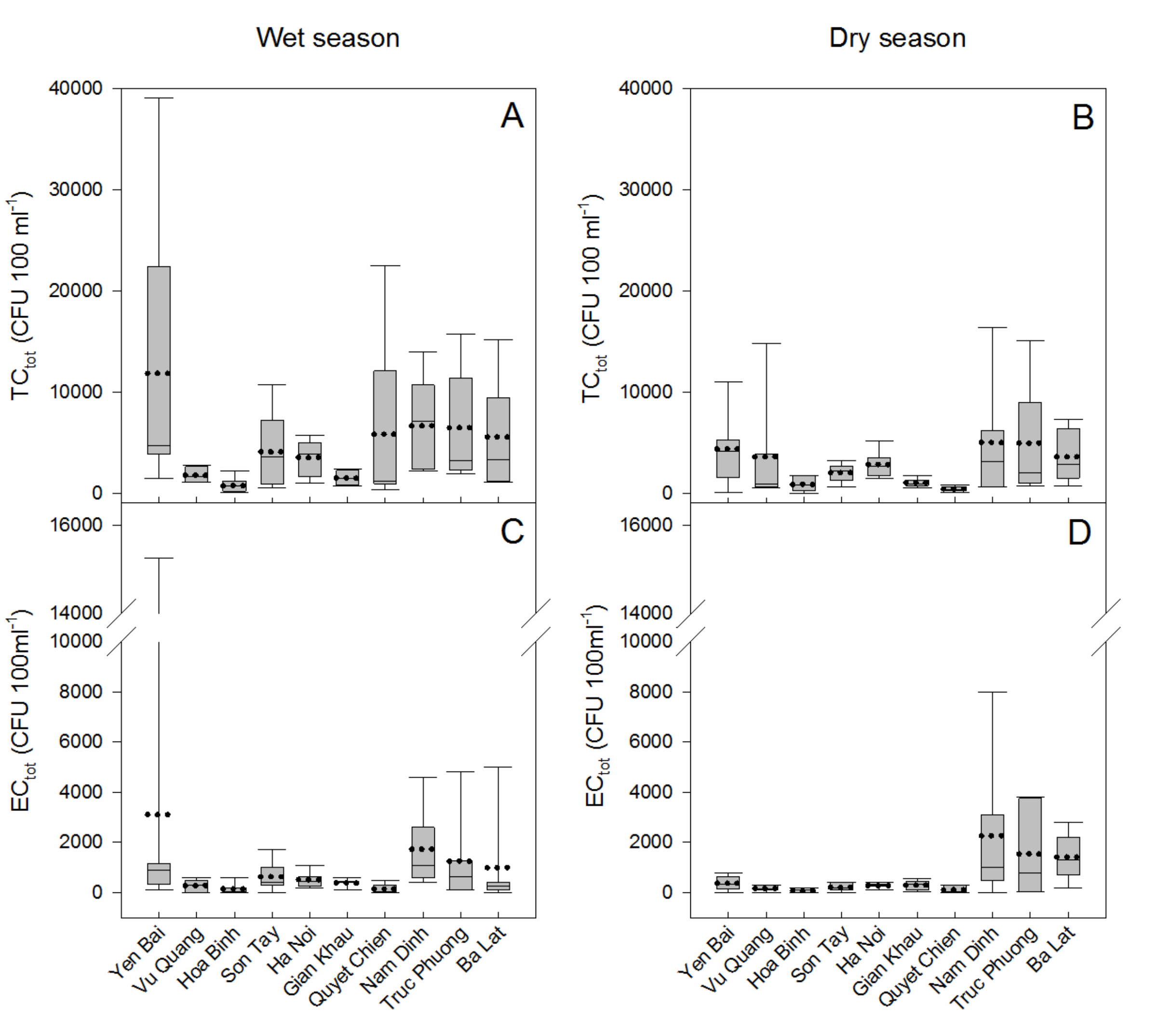

Figure 8. *Total coliforms (C) and Escherichia Coli (EC) densities at 10 gauging stations of the Red River system (Nguyen et al., 2016)*

In our work from the sub-tropical Red River system in Viet Nam, we found that FIB numbers exceed Vietnamese water quality guidelines of 20 and 150 CFU.100mL^{-1} for EC and TC, respectively, throughout the whole year at almost all of the 10 stations investigated.

Moreover, many values exceeded 500 colonies 100mL^{-1} above which the World Health Organization considers that there is a 10% risk of gastro-intestinal illness after one single exposure. Therefore, the use of water from sites with high FIB numbers such as those in the downstream sites pose a real risk to public health.

Dissolved heavy metals (DMH)

DHM concentrations in the Red River water at four gauging stations were monthly observed during the year 2012 (Figure 9). The results showed that the DHM concentrations varied in a high range (with the mean value): Cu: 10 – 80 (31) µg.L^{-1}; Zn: 2 – 88 (31) µg.L^{-1}; Cr: 0.2 – 5.1 (2.0) µg.L^{-1}; Pb: 2 - 107 (µg.L^{-1}**;** Cd: 2 – 12 (5.5) µg.L^{-1}; Fe: 160 – 2370 (950) µg.L^{-1}. No clear seasonal variation of DHM concentrations was observed, which may reflect the complex pollution sources of heavy metals in the river basin.

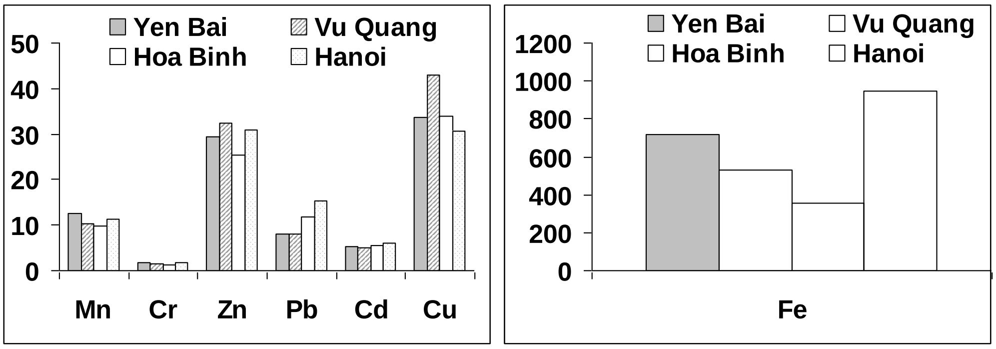

Figure 9. *Average values (µg.L^{-1}) of DHM contents at four main gauging stations of the Red River system (Nguyen et al., 2015)*

These average concentrations of DHM of the Red River water were higher than the average values of the World Rivers, proposed by *Viersa et al., (2009)*: Cu: 1.48µg L^{-1}; Zn: 0.60µg L^{-1}; Cr: 0.70µg L^{-1}; Pb: 0.08µg L^{-1}; Cd: 0.08µg L^{-1}; Mn: 34µg L^{-1}; Fe: 66µg L^{-1} except the value of Mn; and these values were much lower than those in rivers impacted by urban or industrial zones.

Almost values of DHM contents were lower than the ones of the QCVN 08:2008/BTNMT. However, at several time during the observation period, the contents of some DHM such as Fe, Cd and Pb exceeded the Vietnamese standard limits and values proposed by *WHO (2011)* (Cr $\leq$ 50µg L^{-1}; Cd $\leq$ 5µg L^{-1}; Mn $\leq$ 50µg L^{-1}; Pb $\leq$ 25µg L^{-1}). The high DHM in the Red

River water can influence indirectly and/or directly to the human health due to the river water use as drinking water, irrigation and aquaculture.

3.1.2. Carbon content

3.1.2.1. Carbon content

Organic carbon

Monthly DOC and POC concentrations at the outlets of the Thao, Da, Lo and in the main branch of the Red River showed that no clear spatial or seasonal variation was observed for DOC concentrations whereas POC varied significantly both spatially and between the dry and rainy seasons (Figure 10).

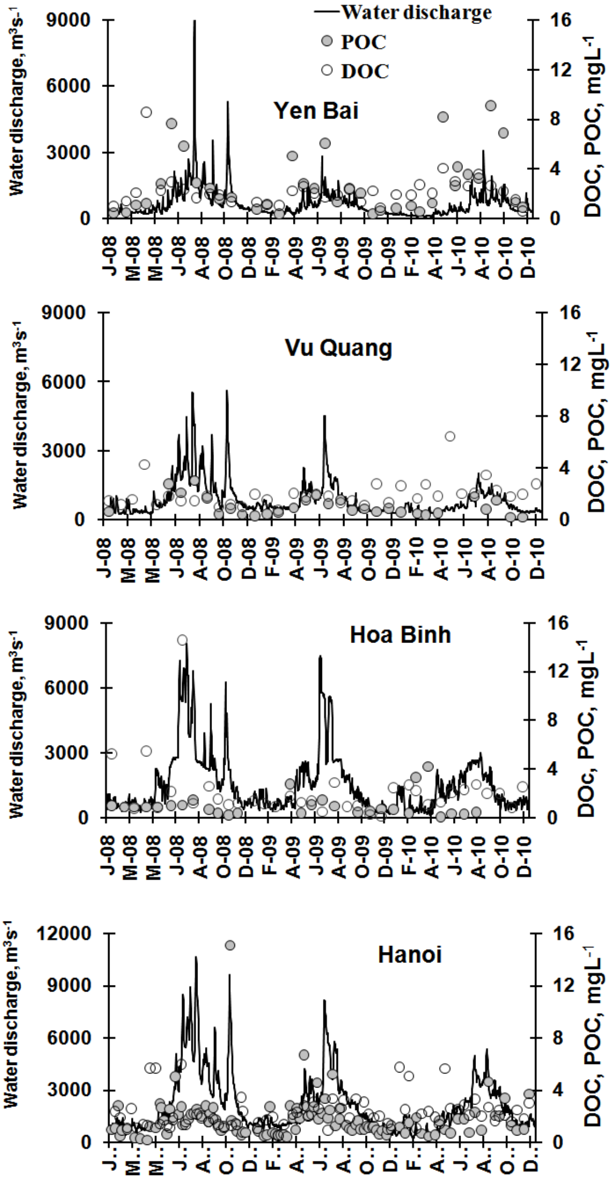

Figure 10. *Seasonal variation of water discharge and DOC and POC concentration at the four gauging stations: Yen Bai (Thao river), Vu Quang (Lo River), Hoa Binh (Da River) and Hanoi (downstream main axe of the Red River). Note difference in scale on the left-handy-axis for the lower panel (Hanoi). (Le et al., 2017, accepted)*

The DOC concentrations in the Red River (0.1 – 8.5 mgC L^{-1}) are within the range cited by *Tao (1998)* who proposed that DOC concentrations in most non-contaminated rivers are relatively stable varying from 1 to 10 mgC L^{-1}. It is also close to those of some Asian rivers such as the Pearl (1.9 – 3.5 mgCL^{-1}), the Ayeyarwady-Thanlwin (1.2 – 2.9 mgCL^{-1}) and the Yangtze Rivers (1.6 – 3.3 mgCL^{-1}) (Table 4). However, the concentrations were lower than those of the Yichun (2.9 – 16.7 mgCL^{-1}) and the Ashop Rivers (13.6 – 27.5 mgCL^{-1}). The mean value DOC concentration (2.1 mgCL^{-1}) of the whole Red River was also lower than the global mean value of 8.0 mgCL^{-1} found by *Meybeck (1988).*

POC concentrations in the Red River (0.1 – 9.0 mgCL^{-1}, mean 1.5 mgCL^{-1}) were also in the range of some other large rivers. Indeed, the values were similar to those of the Luodingjiang (0.1 – 6.3 mgCL^{-1}), Yangtze, Pearl River (1 – 3.8 mgCL^{-1}) and Ayeyarwady - Thanlwin Rivers (1.9 – 7.6 mgCL^{-1}). They were, however, lower than the global mean value of 5 mgC.L^{-1} provided by *Meybeck (1982).* The Red River values were also much lower than in the Yellow River (116 mgCL^{-1}) (*Hu et al., 2015*), where 90% of the TOC loading is transported as POC despite the existence of numerous reservoir impoundments (*Ran et al., 2013*).

In this work, POC and TSS concentrations were significantly correlated reflecting the close association between POC and suspended solids. POC concentrations changed synchronically with total suspended solids (TSS) concentration and the DOC:POC ratios showed significant relationships with TSS concentrations (Figure 11). That opens up the way for latter studies on the calculation of the TOC fluxes over longer timescales using daily TSS and river discharge values (see section below *Long term variation of carbon fluxes*).

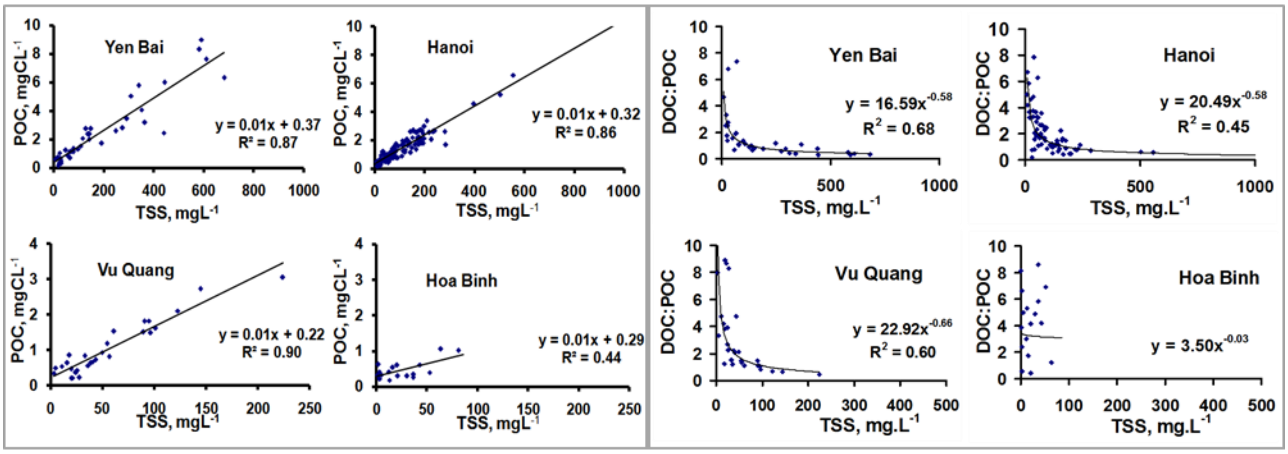

Figure 11. *Relationship between POC and TSS (in the left side) and relationship between DOC:POC ratio and TSS (in the right side) at 4 gauging stations in the Red River. Note difference in scale for the lower panels. (Le et al., 2017, accepted).*

The mean POC:Chl-a ratio (1585±870 mgC.mgChl-a^{-1}) for the whole Red River system was high due to light limitation of phytoplankton development in river water. The % POC in TSS, with a mean value of 1.4±0.6% is rather low, and the C:N ratios, with the mean value of 7.3±0.1 (from 2.4 to 11.2), all indicate that organic carbon in the Red River water is mainly derived from soil organic leaching and erosion in the basin.

Inorganic carbon

The dissolved inorganic carbon (DIC) contents of the Red River were higher in dry season (from November to next April) than in wet season (from May to October) (Figure 12).

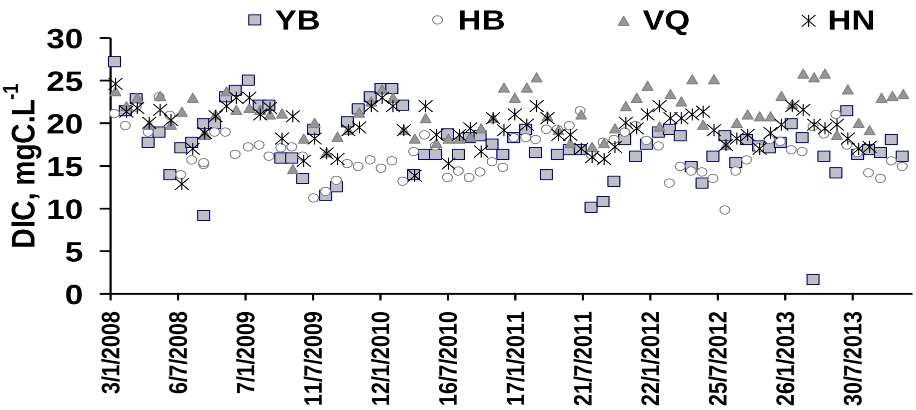

Figure 12. *Seasonal variation of DIC contents at 4 observation sites of the Red River during the period 2008 – 2013 (Le et al., 2015)*

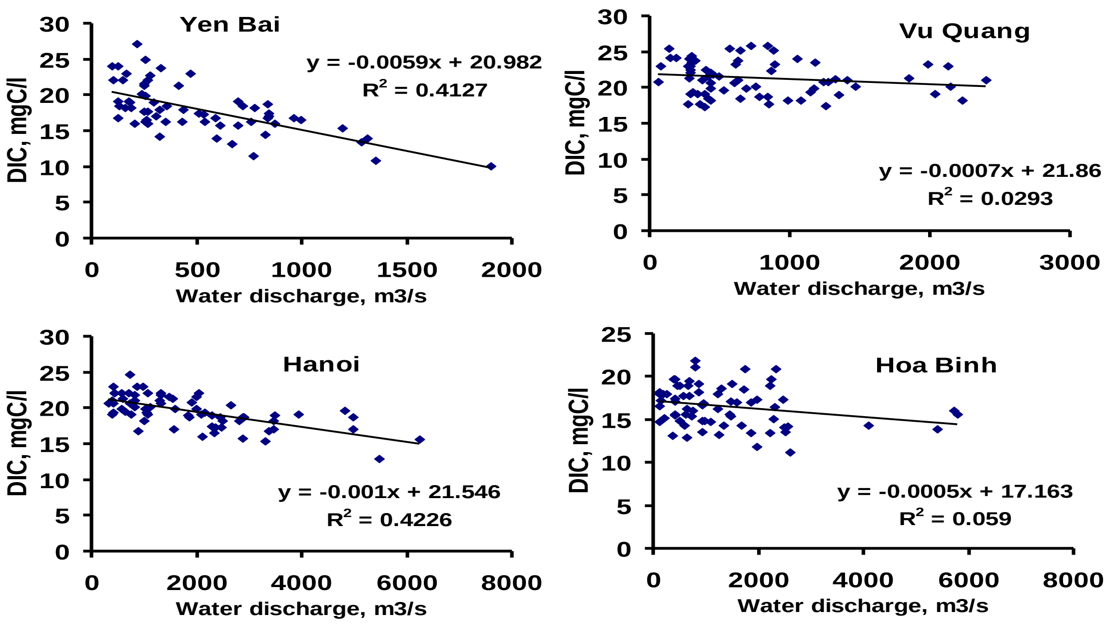

Figure 13. *Relationship between the DIC contents and river discharge at 4 observation sites of the Red River during the period 2008 – 2013 (Le et al., 2015)*

The DIC contents were negatively correlated with river water discharge in the main axe of the Red River, from Yen Bai to Hanoi (R^2 = 0.4). However, the correlation coefficients were lower for the two tributaries Da and Lo (Figure 13).

3.2. Carbon outgassing from the Red River system

As presented above, the in-situ measurements of CO_2 emissions towards the atmosphere were carried out by three methods: calculation of CO_2 fluxes either using a floating chamber connected to an IRGA, or determining pCO_2 within the water column using an equilibrator or calculation via CO_2 partial pressure pCO_2 basing on the total alkalinity and pH values measured with the CO_2-SYS software method. These two latter methods gave similar results whereas the first method is not applicable for a large river as the Red River.

The results of CO_2 outgassing of the Red River by the two latter methods were presented in Table 3. The riverine water pCO_2 was supersaturated with CO_2 with respect to the atmospheric equilibrium (400 µatm), averaging about 1590 µatm, thus resulting in a water–air CO_2 fluxes of 28.6±19.3 $mmol.m^{-2}.day^{-1}$ for the whole Red River system. This value was close to the ones of some Asian rivers such as the Lupar River (13±3.0 $mmol.m^{-2}.d^{-1}$) and the Saribas River (14.6±3.3 $mmol.m^{-2}.d^{-1}$) in Malaysia (*Wit et al., 2015*), the Pousat River (Tonle Sap River) in Cambodia (*Alin et al., 2011*), but obviously higher than results from other world rivers as some rivers in Indonesia (Musi, Batanghari, Indragiri, Siak Rivers: 5±1.1, 1.8±0.4, 9.7±2.2, 8.3±1.9 $mmol.m^{-2}.d^{-1}$, respectively) (*Wit et al., 2015*) or in upper Yukon River (6 $mmol.m^{-2}.d^{-1}$) (*Striegl et al., 2007*).

The results showed that CO_2 out gassing rate from the water surface Red river network was characterized by significant spatial variations, being the highest downstream Hoa Binh dam and in Hanoi, the main branch of the Red River. The highest value obtained at Hoa Binh may reflect the important impact of a series of large dams (Son La, Hoa Binh) in the Da river, and then leading to the higher value observed in the main downstream Red River branch at Hanoi after the confluence between Da, Lo, Thao rivers.

Differences in CO_2 out gassing were also observed between day and night. A difference between the dry season and rainy season for the five sites was also observed of the Red River system during sampling campaigns in 2014 (Figure 14).

In general, CO_2 fluxes of the Red River system in this study during daytime were a little higher than that during the night. This agreed with some reports for rivers in subtropical region (e.g. the Shark River in USA) which emphasised the influence of strong diurnal signal in wind speed leading to higher k values in day-time than the one in the night-time (*Ho et al*

2016). Another reason to explain this effect was temperature: CO_2 water solubility decreased with the increase in water temperature during the day (*Parkin & Kaspar 2003; Roulet et al 1997*), leading to higher CO_2 outgassing from river water interface. Otherwise, *Chanda et al. (2013)* also reported that the higher CO_2 flux from a tropical mixed mangrove (India) were observed when the lowest water vapour during the mid-nights occurred.

Table 3. *Wind speed, k_{600} parameterization, and calculated water-air CO_2 fluxes for day and night at five hydrological stations of the Red River in dry and wet seasons in 2014.*

	Wind speed $m.s^{-1}$	k_{600} $cm.h^{-1}$	**Water-air CO_2 flux** $mmol.m^{-2}.d^{-1}$	
			With pCO_2 results from equilibrator	**With pCO_2 results from CO_2-SYS**
Wet season				
Yen Bai				
Day	1.2±0.6	3.0±0.5	13.7±2.5	7.1±2.7
Night	0.0±0.6	1.9±0.6	9.2±2.6	3.9±1.1
Vu Quang				
Day	1.0±0.8	2.7±0.7	30.6±7.0	16.7±5.6
Night	0.0±0.6	1.9±0.5	18.7±4.0	10.8±2.9
Hoa Binh				
Day	1.7±1.1	3.5±1.2	53.9±36.3	54.9±23.4
Night	0.0 ± 0.6	1.9±0.7	53.7±20.1	21.8±8.7
Hanoi				
Day	1.5±0.7	3.2±0.8	25.4±6.6	13.8±4.9
Night	1.6±0.8	3.3±0.8	29.7±6.6	9.1±4.8
Ba Lat				
Day	0.1±0.5	2.0±0.4	18.6±2.2	13.9±5.6
Night	0.0±0.5	1.9±0.4	17.0±4.3	13.0±7.2
Dry season				
1-Yen Bai				
Day	1.7±0.8	3.5±0.9	16.9±3.6	8.1±7.3
Night	0.0±0.4	1.9±0.4	9.6±2.3	4.1±2.6
2-Vu Quang				
Day	1.2±0.8	3.0±0.8	17.6±6.1	9.0±3.9
Night	0.2±1.2	2.1±1.4	13.7±7.8	4.1±2.2
3- Hoa Binh				

Day	1.2±0.8	3.0±0.8	48.6±13.5	40.1±8.8
Night	0.5±0.5	2.2±0.5	32.2±7.4	29.9±4.7
4-Hanoi				
Day	2.3±0.6	4.2±1.0	26.1±6.6	11.8±7.3
Night	1.8±0.7	3.6±1.0	21.3±5.7	9.5±3.0
5-Ba Lat				
Day	3.1±1.5	5.6±3.7	14.5±13.8	14.9±10.0
Night	1.5±1.2	3.2±2.1	13.4±2.9	10.8±10.0

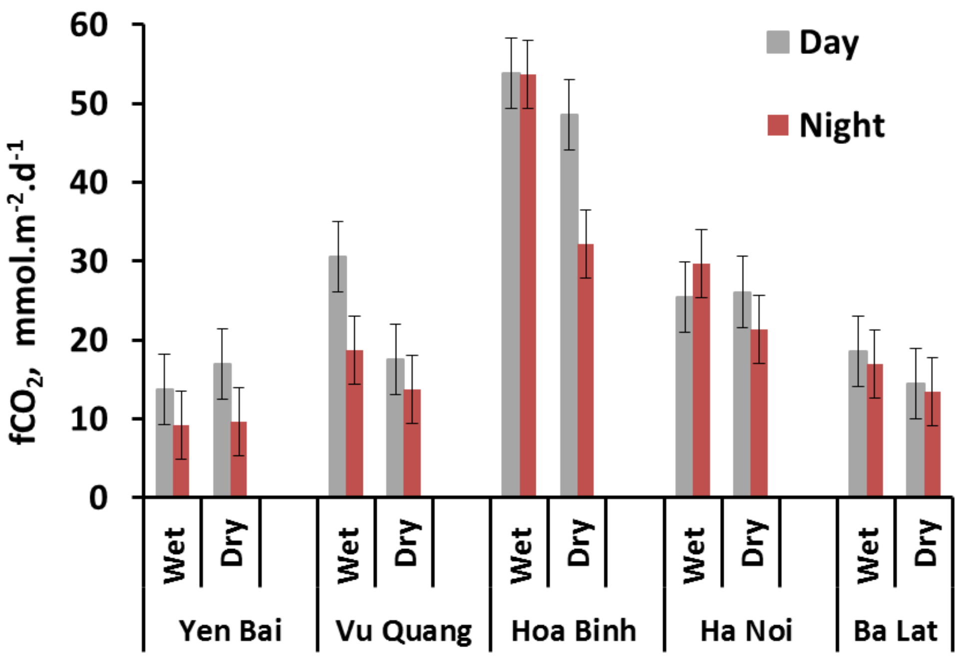

Figure 14. *Spatial and seasonal variation in day and night of CO_2 flux out-gassing in the Red River system.*

3.3. Long-term variation of natural conditions and human activities in the Red river basin (synthetizing dataset collected from different sources)

Climate and hydrology

The climate in the Red River basin, of sub-tropical East-Asian monsoon type, is controlled by the North-East monsoon in winter and South-West monsoon in summer. The rainy season cumulates 85–90% of the total annual rainfall in the Red River catchment. July and August are the two months with the highest incidence of typhoons in the Red River area.

The climate in the Red River basin is sub-tropical East Asia monsoonal type, where the South West monsoon from May to October brings warmer, wetter weather in rainy season and the North East monsoon from November to next April brings cooler, dryer weather in dry season. Annual rainfall strongly varies from 700 – 4,800 mm yr^{-1} across the basin with about 80% of rainfall occurring during the rainy season (May to October, *Nguyen et al 2007*). The rainy season cumulates 85–90% of the total annual rainfall in the Red River catchment. July and August are the two months with the highest incidence of typhoons in the Red River area.

The average daily temperature varied from low values of 14 – 16° C in winter to higher values of 26 – 27^{o}C in summer. Relative humidity was high throughout the year, averaging 82 – 84%.

The climate results in a hydrologic regime that is characterized by high runoff during the rainy season and low runoff during the dry season (*Le et al 2015b*).

The daily river discharges at the outlets of the three tributaries Thao (Yen Bai station), Da (Hoa Binh station) and Lo (Vu Quang station) and of the main axe of the Red River downstream at Hanoi stations were collected for the period 1960 - 2015 from the Ministry of Natural Resources and Environment of Vietnam *MONRE (2015)* (figure 1). The average river discharge of the Thao (at Yen Bai), Da (at Hoa Binh), Lo (at Vu Quang) and in the main axe at Hanoi stations were 721 ± 159 $m^3.s^{-1}$; 1,674 ± 284 $m^3.s^{-1}$; 1019 ± 227 $m^3.s^{-1}$ and 2,502 ± 477 $m^3.s^{-1}$ respectively for the study period.

The analysis of the daily and monthly river discharges at three main shows a significant relation to austral oscillations (ENSO). Over the considered period, the analysis of the cumulated sum of deviations from the mean (cusum) reveals inter-annual fluctuations with a frequency of 3–7 years, closely following the variations of the Southern Oscillation Index (Figure 15). Besides these variations, no evidence appears of any long-term trend of change in the hydrological regime, on either the annual water discharge or the water discharge in the dry or wet season.

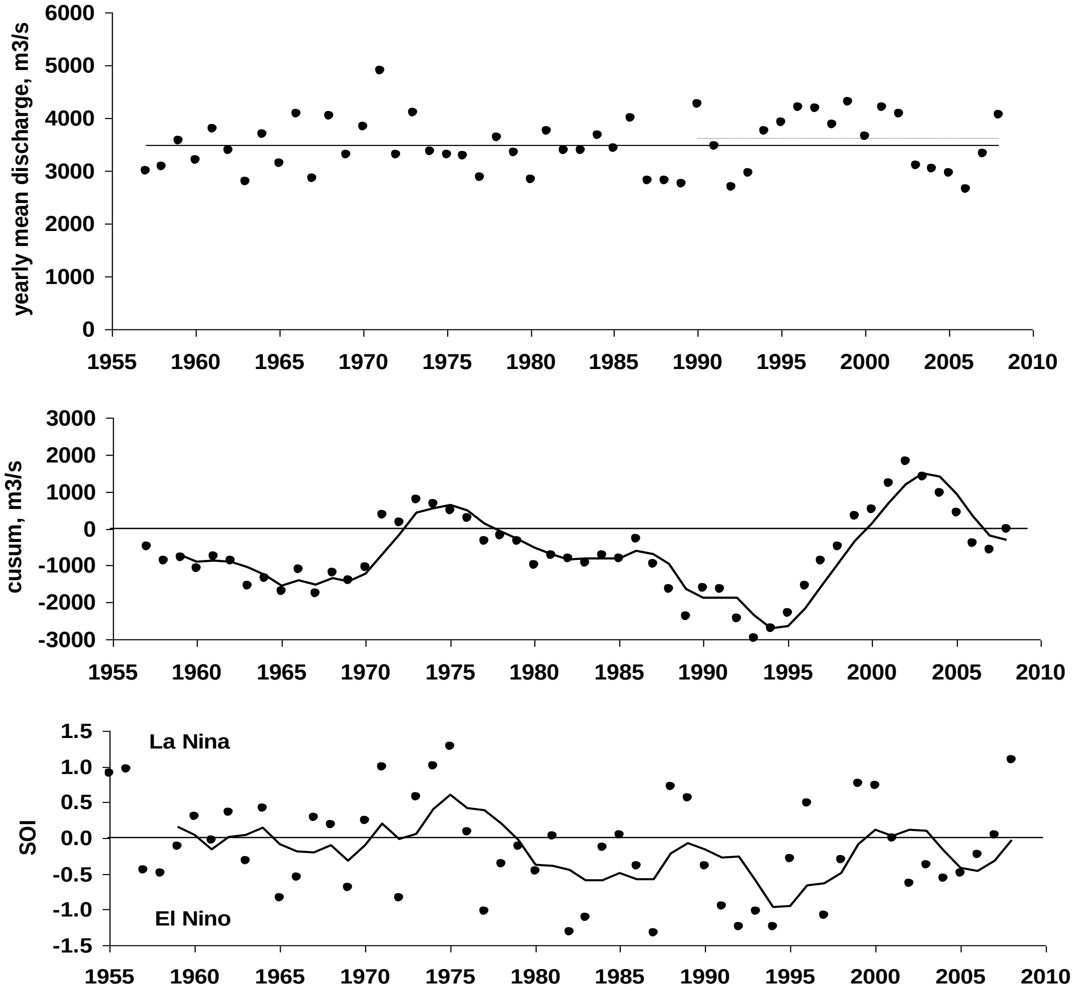

Figure 15. *Similarity of the trends of variations of discharge and Southern Oscillation Index.* ***a.*** *Long-term variations of the water discharge of the Red River at Hanoi (entrance of the delta area). The solid line indicates the long term average; the dotted line, the average calculated for the period 1989-2009.;* ***b****. Cumulated sum of discharge deviations from their long-term average value (i.e. cusum, Page 1954). The solid line represents the floating average of the cusum;* ***c.*** *The long-term variations of the mean annual value of the austral oscillation indices (SOI). The solid line represents the floating average over 5 years. (Le et al., 2015b).*

Reservoir impoundment

Reservoirs play an important role in the socio-economic development of both China and Vietnam. Reservoirs are used for flood control, irrigation, hydropower, water supply and flow management. In the Red River basin in both China and Vietnam territory, a series of reservoirs and dams have been constructed and operated. In the Chinese part, upstream of the Red River, there are a series of small and medium reservoirs/dams which have been impounded for hydropower since 2007: 29 dams constructed on the upstream Thao River (2 main intercepting dams, namely Namsha and Madushan (140km from the Vietnamese border to China) have a capacity of 130 and 300 MW, respectively (*IMRR, 2010*)); about 11 small hydrological dams on the upstream Da River; and at least 8 hydropower reservoirs on the upstream Lo River (*Ha and Vu, 2012*) (table 4). In the Vietnamese part, there are four large dams/reservoirs including: the Hoa Binh (in operation since 1989) and the Son La (in operation since 2010) reservoirs dammed on the main axe of the Da River; the Thac Ba (in operation since 1975) and the Tuyen Quang (in operation in 2010) reservoirs on the Lo River. Other reservoirs are presently under construction such as the Huoi Quang and Lai Chau reservoirs (in operation in 2017) on the Da River. Some characteristics of major dams – reservoirs in the lower Red River system were presented in table 4.

Table 4. *Major characteristics of the large reservoirs/dams in the upstream Red River basin and water discharge output from dams to downstream river.*

Name	Date of impoundment	River Basin area, km^2	Storage capacity, Mm^3	Reservoir surface area, km^2	Water level, (normal) M	Mean annual water discharge Qo, $m^3.s^{-1}$	Maximum water discharge, $m^3.s^{-1}$	Dam length, m	Mean depth, m
Thac Ba (Lo river)	1972	6,170	2.9	235	58	190.5	420	657	42
Hoa Binh (Da river)	1989	57,285	9.5	208	115	1781	2400	660	50
Son La (Da river)	2010	43,760	9.3	224	215	1530	3438	962	60
Tuyen Quang (Lo river)	2010	14,972	2.3	81.5	120	317.8	750	1105	70
Huoi Quang (Da river)	2017	2,824	16.3	8.7	370	1581	383.1	267	144-182
Lai Chau (Da river)	2017	26,000	0.7	39.6	295	851	1617.2	612	80.5

Population and urbanization

For observation of long-term demographic changes, the FAO data showed a clear increase of population in Vietnam in term of total population and urban population within the 1950 – 2050 period. According to FAO statistics (FAO, 2009), the total population in Vietnam increased from 27.4 million in 1950 to 83.6 million in 2005, and should reach 118 million in the 2050s (Figure 16).

Even if the urban population has increased rapidly, the rural population still accounts for the largest proportion in the country (about 80% in the 1990s), typical characteristics of the social organization in Vietnam. The analysis of the population data given by villages in the Vietnamese Red River basin showed that 80% of the population lived in agglomerations numbering between 1000 and 10,000 inhabitants (Figure 16).

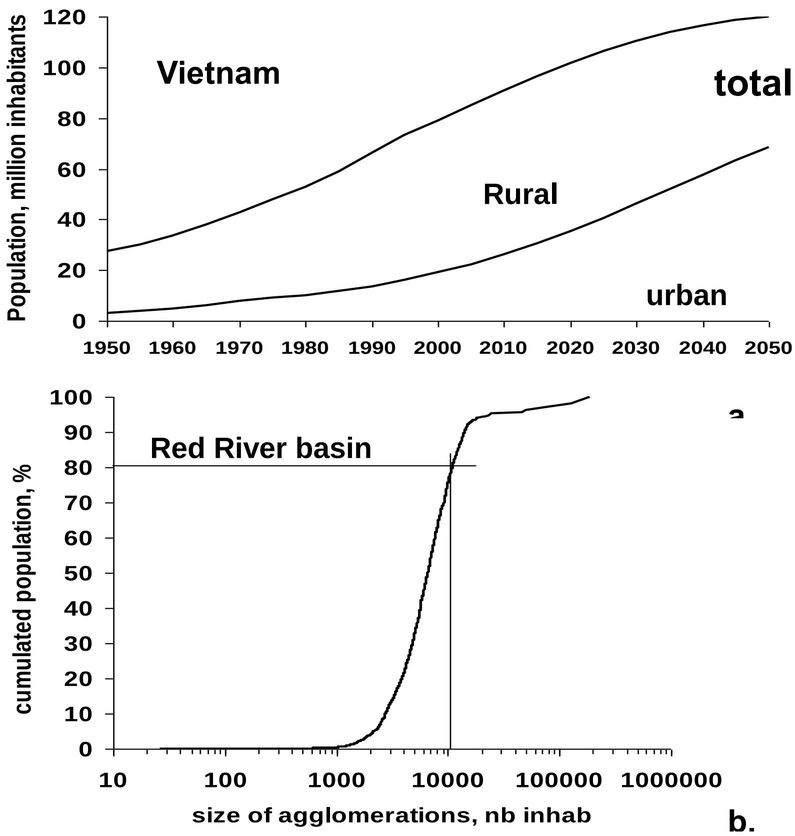

Figure 16. *Population in Vietnam and the Red River basin. a. Long-term changes in urban and rural population in Vietnam (FAOstat 2009). b. Distribution of the population of the Vietnamese part of the Red River basin according to the size of the agglomeration in 1999. The curves show the cumulated fraction of the total population with increasing agglomeration size. (Le et al., 2015b).*

Land use

The forest area in the Red River delta has been quite stable for several centuries but the deforestation in the plateau and mountainous regions dramatically accelerated during the war years (1970s) and the following period of rapid population growth and economic development (1990s) (Figure 17).

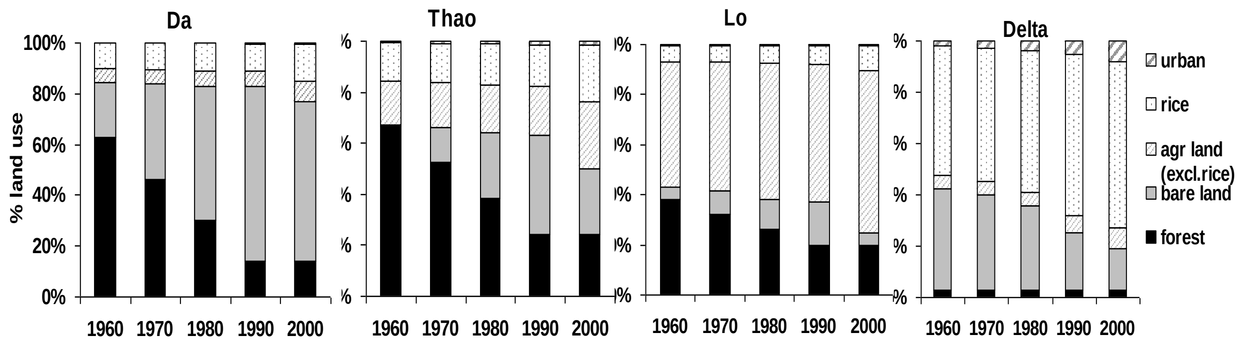

Figure 17. *Long-term variations of land use of the Red River sub-basins: Thao, Da and Lo and Delta. The bars are representing, for each decades, the estimated proportion of forest, bare land, agricultural land (excluding paddies), rice paddies and urban areas in the total land use (Le et al., 2015b).*

3.4. Modelling application

The SENEQUE/Riverstrahler model was applied to quantify riverine organic C dynamics in this large, subtropical river basin over the period 2009-2014 allowing giving insight on CO_2 respiration, and hence balancing between autotrophy and heterotrophy in the system.

The model was firstly run for five years (2009 – 2014) and compared with the observed temporal changes in bulk OC concentration and that of its biodegradable fraction for both POC (Figure 18) and DOC (Figure 19). In general, the model simulations of the temporal variations in OC concentrations followed the same pattern and reproduce the right level of values as that of the *in situ* data measurements, although the simulated concentrations was often lower for POC and higher for DOC, especially at the Vu Quang station.

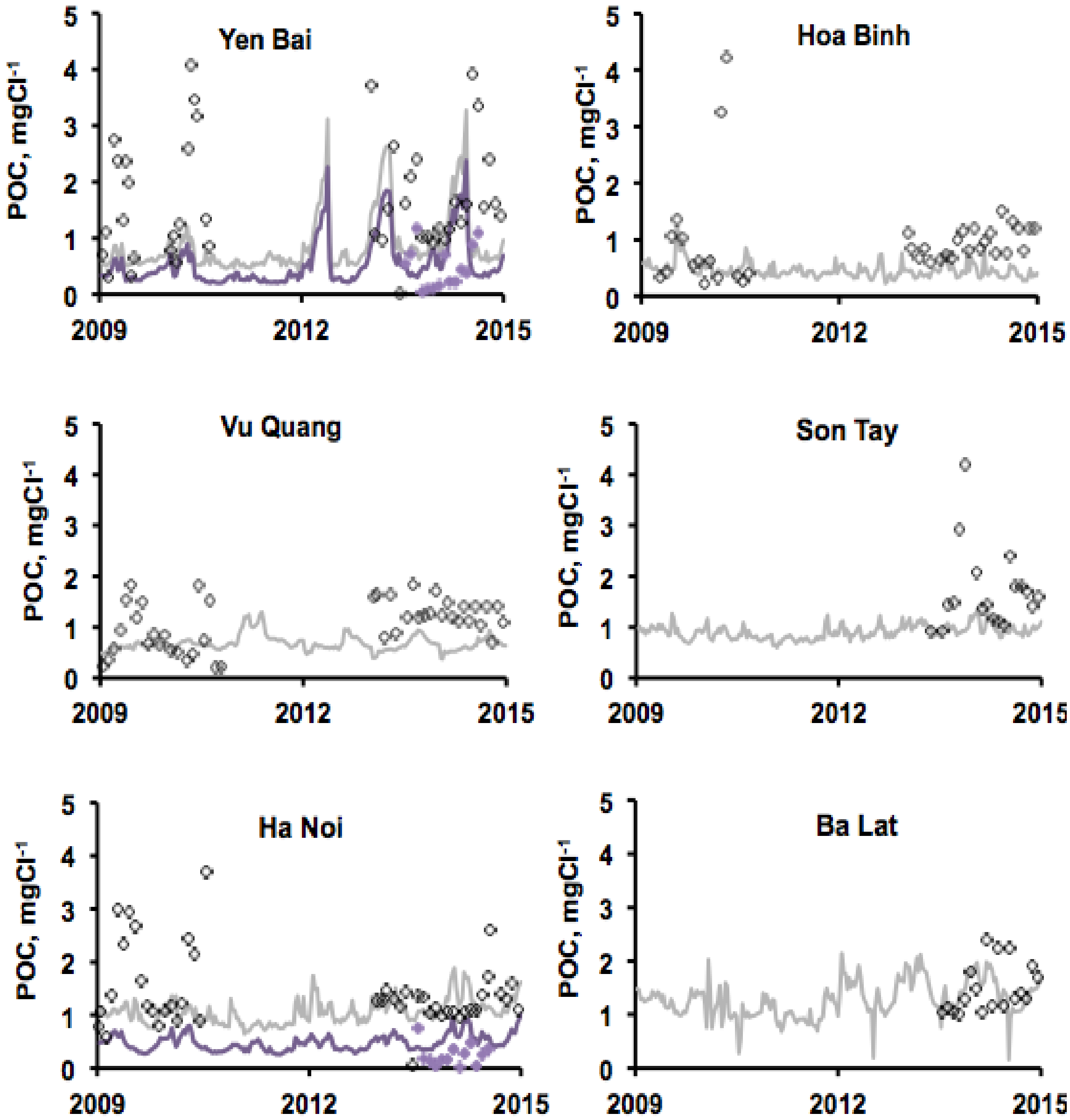

Figure 18. *Model simulated (gray line) seasonal variations of POC (mgCL^{-1}) and biodegradable POC (BPOC, mgCL^{-1}; black line) for six stations in the Red river system for the years 2009 - 2014. The points represent the measured values of POC and BPOC at the different stations. BPOC was only determined at Yen Bai and Hanoi. (Nguyen et al., 2016 submitted)*

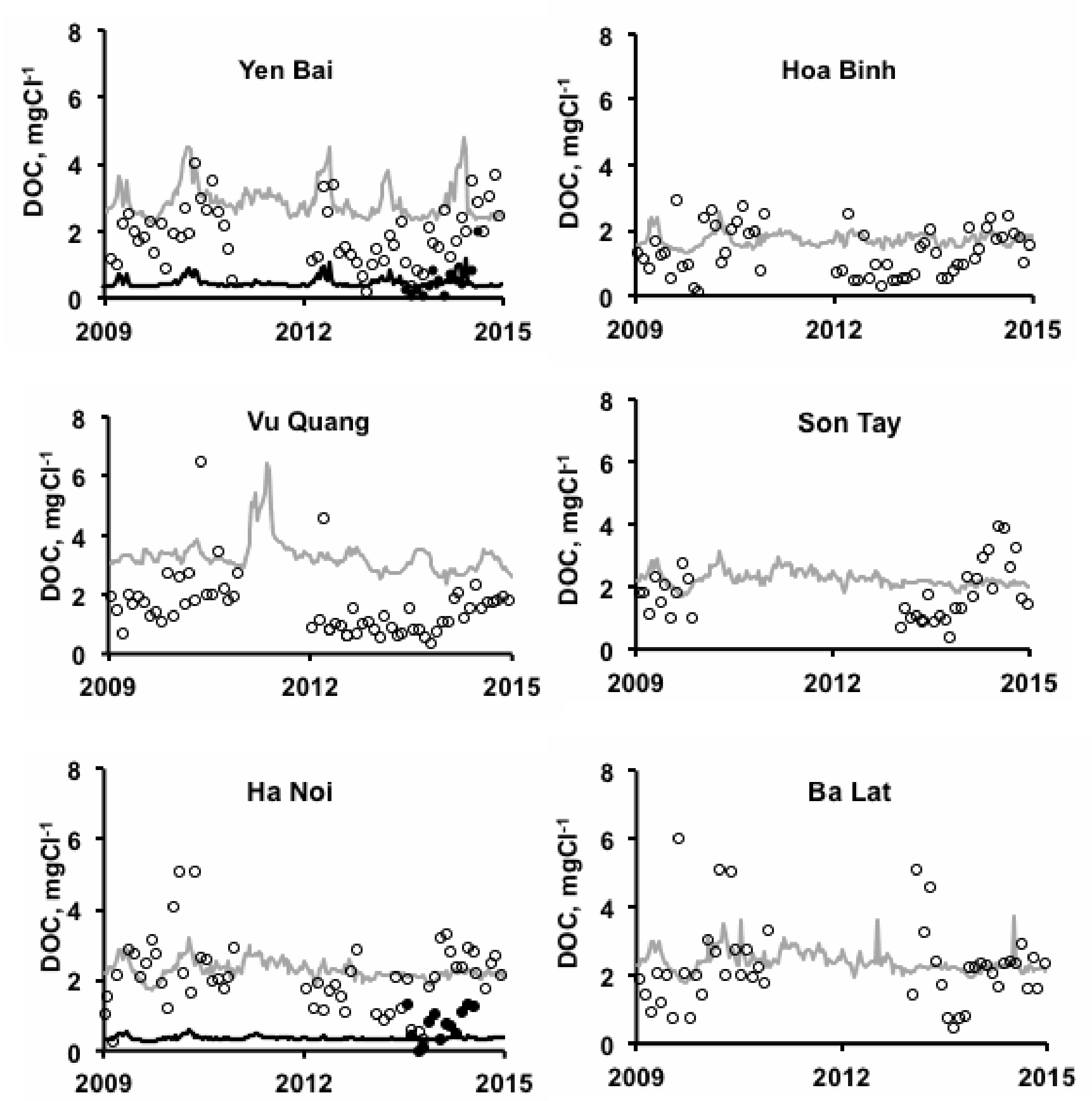

Figure 19. *Model simulated (gray line) seasonal variations of DOC (mgCL^{-1}) and biodegradable DOC (BDOC, mgCL^{-1}; black line) for six stations in the Red river system for the years 2009 - 2014. The points represent the measured values of DOC and BDOC at the different stations. BDOC was only determined at Yen Bai and Hanoi. (Nguyen et al., 2016 submitted)*

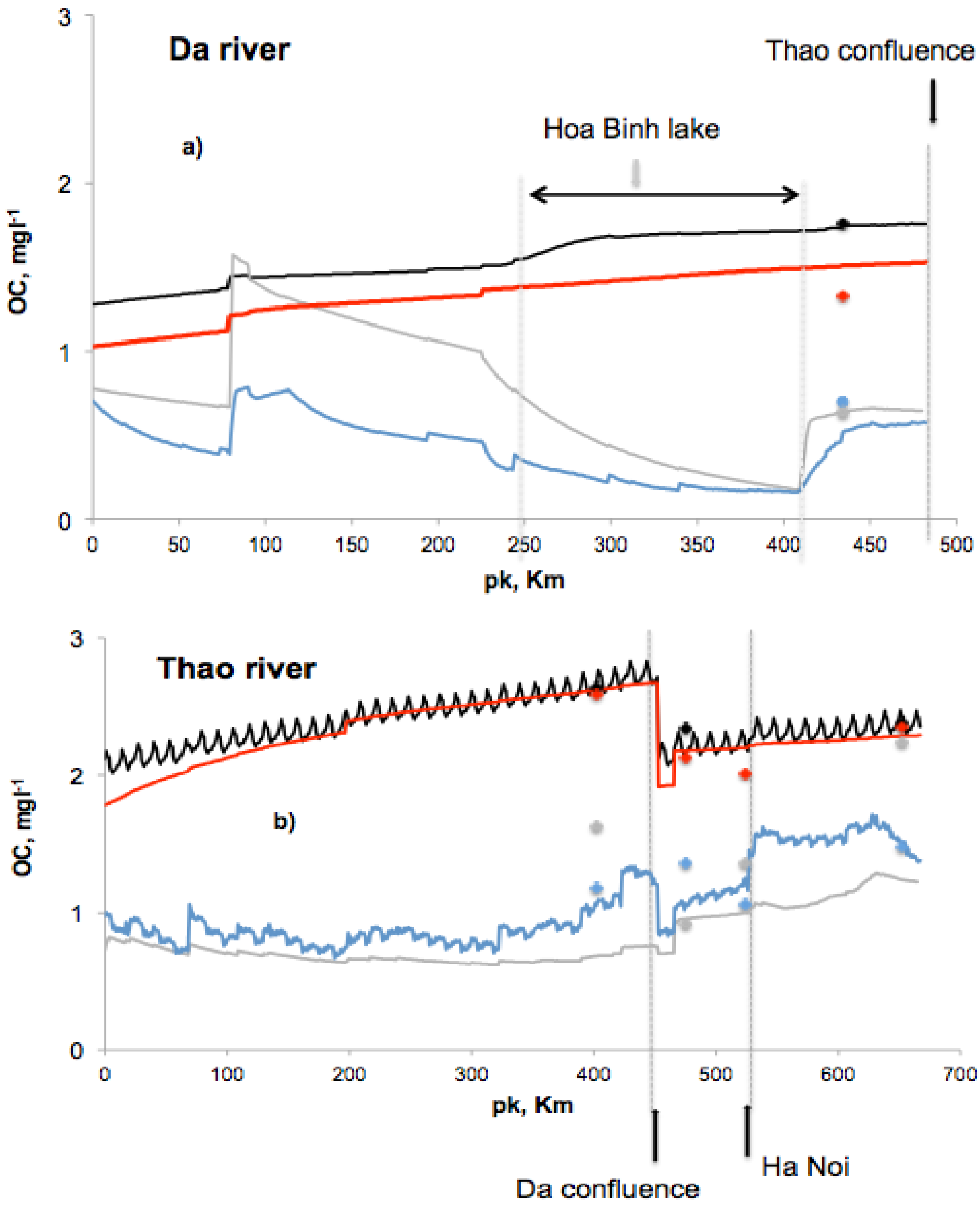

Figure 20. *Longitudinal variations of POC and DOC concentration in the Da (a) and Thao (b) Rivers as calculated by the SENEQUE / RIVERSTRAHLER model for the years 2009-2014. The simulated DOC and POC concentrations, represented as lines on the graphs, were averaged for low (December - March) and high (May - October) discharge periods. The observations, presented as dots on the graph, are the measured values of DOC and POC in the rivers. The x-axis is a kilometric unit (pk) along the upstream-downstream course of each tributary. The location of different features along the river courses is also noted. POC low and high water (blue and grey, respectively), DOC low and high water (black and red, respectively). (Nguyen et al., 2016 submitted)*

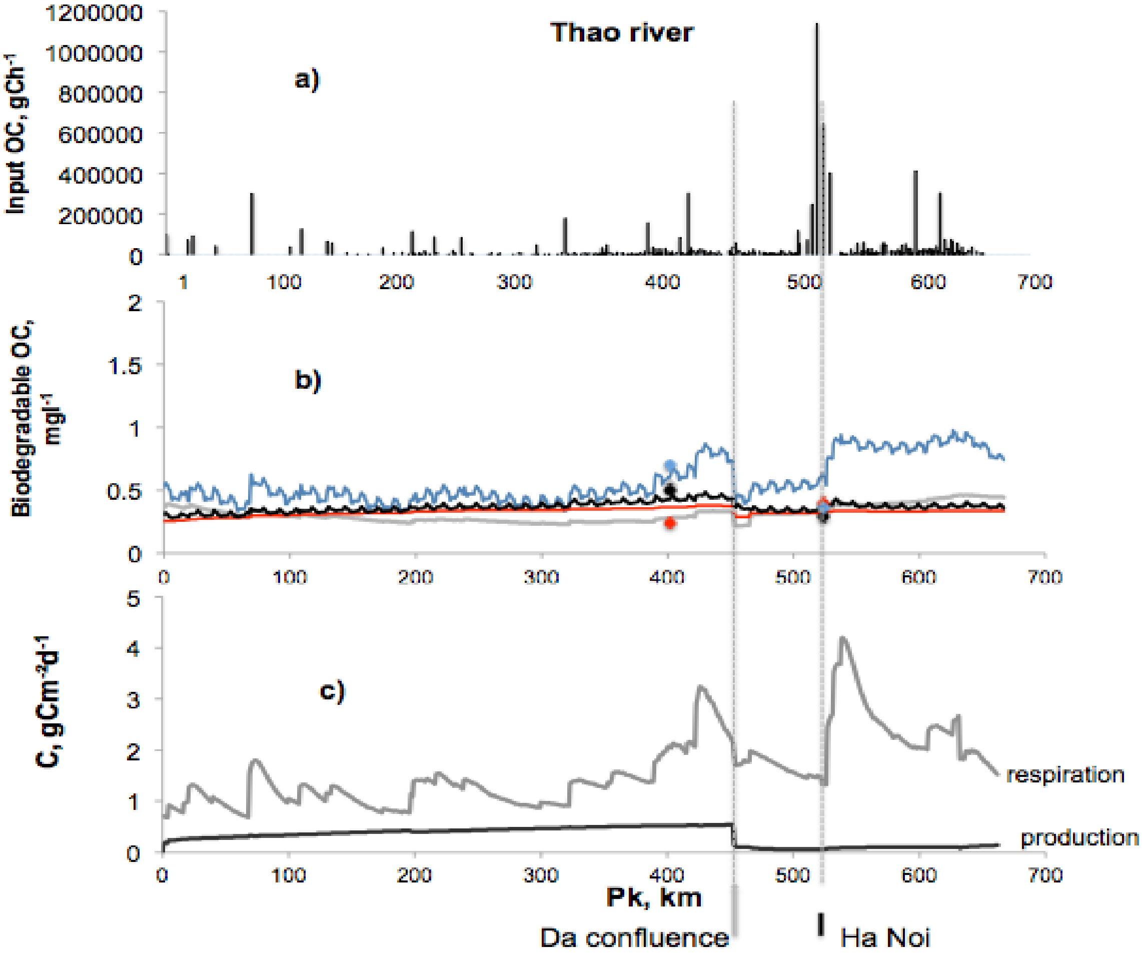

Figure 21. *Longitudinal variations of OC inputs (a), the median biodegradability (b); respiration and production (c) in the Thao River for high and low flow situations averages over the period 2009-2014. Lines presented the model simulation and the points are the measured values. The x-axis is a kilometric unit (pk) along the upstream-downstream course of each tributary. The location of different features along the river courses is also noted. POC low and high water are blue and grey, respectively, DOC low and high water are black and red, respectively. (Nguyen et al., 2016 submitted)*

The spatial distribution of OC in the river branches in terms of kilometric point (pk) at particular time of the seasonal cycle (Figure 20) was also well represented by the model. For both the Da and Thao Rivers, DOC concentrations were higher at low discharge than at high discharge (Figure 20). However, when POC concentrations were simulated, concentrations were highest during high discharge in the Da River, whereas in the Thao River, the opposite was found; e.g. POC concentrations were highest during low discharge (Figure 20). In the downstream sector of the Thao (or Hong) River, DOC and POC concentrations and C respiration rates increased in response to the elevated inputs of wastewater from this densely populated sector (Figure 21). In the Da River, a strong reduction of DOC and POC concentrations occurred in the region of the Hoa Binh lake (Figure 22) concomitant with increased C respiration rates.

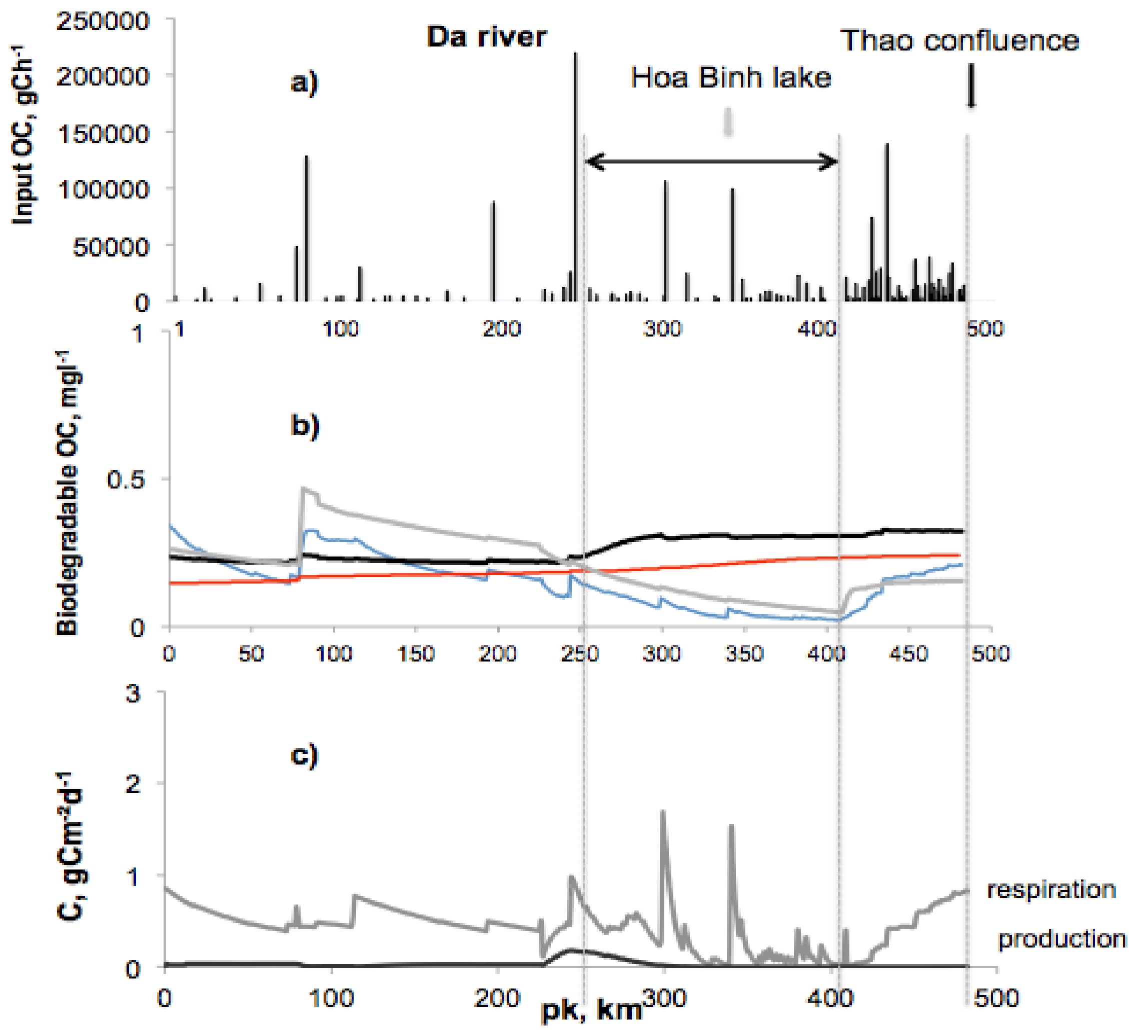

Figure 22. *Longitudinal variations of OC inputs (a), the median biodegradability (b); respiration and production (c) in the Da River for high and low flow situations averages over the period 2009-2014. Lines presented the model simulation and the points are the measured values. The x-axis is a kilometric unit (pk) along the upstream-downstream course of each tributary. The location of different features along the river courses is also noted. POC low and high water are blue and grey, respectively, DOC low and high water are black and red, respectively. (Nguyen et al., 2016, submitted)*

Carbon metabolism in the Red River

Rivers are not just conduits for the transfer of OC from terrestrial systems to the environment; they also can be a significant source of CO_2 to the atmosphere from outgassing across the water-air interface *(Cole et al., 2007; Farjalla et al., 2009; Richey et al., 2002*). Using the model, we determined the rates of P and R in the Red River over the 2009-2014 periods. Our calculated P rates are higher than those observed in some other tropical rivers. For example, *Davies et al (2008)* reported that in less contaminated river systems rates of 0.01 $gC.m^{-2}.d^{-1}$ to 0.20 $gC.m^{-2}.d^{-1}$ are common. However, in tropical and subtropical rivers with high nutrient inputs, primary production may exceed 3.84 $gC.m^{-2}.d^{-1}$. The values reported here are within the range reported by *Rochelle-Newall et al. (2011) f*or the Bach Dang estuary, one of the distributaries of the Red River. These low values of primary production are most probably due to the high turbidities in the Red River as it is known that turbidity, along with nutrient concentrations is a major factor controlling primary production rates in this and other aquatic systems *(Fisher et al., 1988; Rochelle-Newall et al., 2011*).

The model calculations of median respiration rates (R) 1.44±0.864 $gC.m^{-2}.d^{-1}$ are consistently higher than the rates of primary production. Moreover, the ratio of production to respiration (P:R) is low, varying from 0.00 to 0.28. This imbalance between P and R, also observed in other river systems and estuaries, and particularly in tropical ones *(Borges et al., 2015; Richey et al., 2002*), can be explained by the high respiration rates reflecting a high degree of allochthonous inputs, as it is the case for the Red River system *(Sarma et al., 2009*).

We compared our respiration rates with the results of direct CO_2 flux measurements that were made with equilibrator at several stations in the Red River during the wet and dry seasons in 2014. Values were in the range 0.05 to 3.15 $gC.m^{-2}.d^{-1}$. Considering a total area of 600 km^2 for the river-atmosphere interface of the whole drainage network (about 430 km^2 for the main branches and 170 km^2 for basins), this range corresponds to 11 - 690 $GgC.yr^{-1}$. Our model estimated respiration rate for the whole drainage network is thus in the middle of the range of the few available measurements of CO_2 efflux in our present project. This confirms the coherency of our model of OC of the whole Red River drainage network.

Overall, the Red River system appears to be a strongly heterotrophic system, receiving high amounts of allochthonous organic carbon from diffuse sources (soil leaching and erosion, with only limited biodegradability), and from wastewater inputs (with high biodegradability). In contrast, autochthonous primary production only contributes about 10% of the total OC inputs. About half the total inputs of OC to the system are respired and lost to the atmosphere, while the remaining part is exported to the estuarine and coastal zone. These results further underline the importance of tropical rivers and estuaries in the global carbon budget and highlight the need for more research on these systems that represent 66.2 % of the total global freshwater flow (*Huang et al., 2012*)

Table 5. *Model calculated C budget of the Red River system at Son Tay (in $GgC.yr^{-1}$) (Nguyen et al., 2016, submitted)*

$GgC.yr^{-1}$	2009	2010	2011	2012	2013	2014	*mean*
Respiration	238.5	230.3	208.5	255.7	263.3	270	*247.5*
Primary production	49.6	43.7	40.9	50.3	52.3	57.5	*49.1*
Diffuse sources	263	258	230	322	295	280	*275*
Point sources	233	233	233	233	233	233	*233*
River export (Son Tay)	293	282	258	359	336	327	*309*
Ave discharge ($m^3.s^{-1}$)	3112.6	2811.7	2514.4	3568.8	3453.6	3348.2	*3134.9*

Exploring scenarios

We used this model to predict future organic carbon concentrations in the Red River system for the 2050 scenario based on the present hydrological data of the 3-year period 2012-2014 and future demographics and land use in the Red River system for the 2050 horizon.

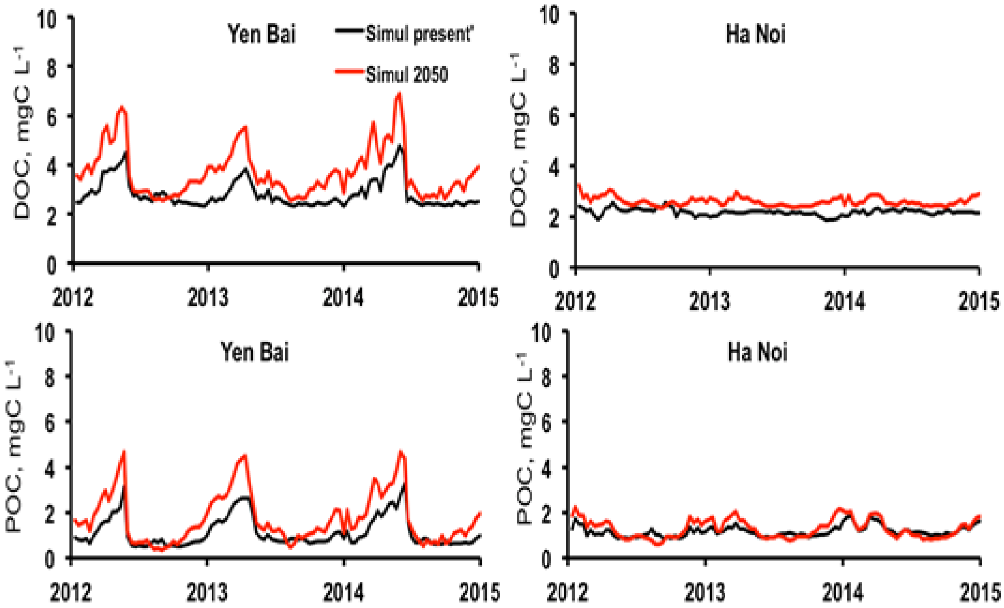

Figure 23: *Modelling results for DOC and POC concentrations at Yen Bai (upstream) and at Hanoi (downstream) of the main axe of the Red River for present situation (2012 -2015) and perspective scenario (2050)*

The scenario results showed that only a limited increase of OC concentrations compared with the present situation at two stations Yen Bai and Hanoi (Figure 23). This was particularly the case in Hanoi even though the population is expected to triple by 2050. This perhaps surprising result further underlines the difficulties that many developing countries are facing in terms of water quality. On one side, such a result can be considered as being relatively positive i.e. no decrease in water quality, at least in terms of OC loads despite large increases in population. On the other hand, it also means that water quality will not improve in the future unless efforts are made to control diffuse sources in the basin. However, the setting up and running of such a program requires extremely large investments, strong legislation and effective education programs.

As mentioned above, with the high inputs of allochthonous OC from both point and diffuse sources, the Red River system is a strongly heterotrophic system, which means that the Red River is strong source of CO_2 to the atmosphere. If the scenario for 2050 of OC is true that relatively little change in OC concentrations in the future despite large increases in the urban populations, it appears that this system will remain a strong source of CO_2 to the atmosphere in the future.

3.5. Long-term carbon fluxes loading from the Red River to the South Asian Sea

Based on i) the relationships between POC, DOC, and DIC, with respectively measured suspended sediment concentrations and river water discharge, and ii) the available detailed historical records of river discharge and suspended sediment concentrations, the long-term variations of the riverine organic and inorganic carbon concentrations and fluxes of the tributaries and the whole Red River system were examined for the period 1960 - 2015. Within the period 1960 – 2015, the calculated total carbon fluxes at the outlet of the whole Red River ranged from 993 – 3,903 kton yr^{-1}, with the mean value of 2,555±639 kton yr^{-1} (equivalent to 16,3 ± 4,1 ton km^{-2} yr^{-1}).

The overall mean DOC yield of the Red River system (1,801 kgC km^{-2} yr^{-1}) was closed with the global average (1,900 kgC km^{-2} yr^{-1}) (*Ludwig et al 1996*) and with other Asian rivers (e.g. the Luodingjiang River: 1,240 kgC km^{-2} yr^{-1} *Zhang et al 2009*). The overall mean POC yield of the Red River system (4,153 kgC km^{-2} yr^{-1}) was higher than the global mean (1,600 kgC km^{-2} yr^{-1}) (*Ludwig et al 1996*) and the ones of some Asian rivers (e.g. the Pearl River: 2,000 kgC km^{-2} yr^{-1} *Ni et al 2008*), the Yangtze River: 1,598 kgCkm^{-2}yr^{-1}, (*Wang et al 2012*). The overall mean DIC yield of the Red River (10,477 kgC.km^{-2}.yr^{-1}) was much higher than the mean value of the world rivers (2,829 kgC.km^{-2}.yr^{-1}) (*Huang et al. 2012*) but it was however, close to mean fluxes for tropical rivers of the Asia rivers (10,690 kgC km^{-2} yr^{-1}) (*Huang et al*

2012). The difference was explained that the specific DIC fluxes of these rivers were significantly correlated with the carbonate rock contents or other factors (surficial deposits, net precipitation vs. evaporation, and agriculture activities in their drainage basins).

Table 6. *Carbon fluxes of three main tributaries and the whole Red River system during the period 1960 – 2015 (Le et al., 2016b, in preparation)*

Stations	Carbon fluxes (kton.yr^{-1})	Period					
		1960-1969	1970-1979	1980-1989	1990 – 1999	2000 – 2009	2010 – 2015
Yen Bai (Thao river)	DOC	101 ± 30	104 ± 27	83 ± 26	111 ± 26	83 ± 32	34 ± 8
	POC	399 ± 195	392 ± 122	418 ± 285	683 ± 258	405 ± 267	67 ± 23
	DIC	500 ± 78	521 ± 117	319 ± 29	317 ± 33	442 ± 92	274 ± 35
Hoa Binh (Da River)	DOC	1229 ± 472	1103 ± 314	629 ± 384	202 ± 45	157 ± 71	58 ± 15
	POC	430 ± 169	384 ± 111	238 ± 135	66 ± 15	56 ± 20	23 ± 12
	DIC	849 ± 101	848 ± 83	770 ± 111	893 ± 133	1026 ± 187	675 ± 131
Vu Quang (Lo River)	DOC	70 ± 18	83 ± 22	81 ± 15	82 ± 12	60 ± 20	47 ± 20
	POC	128 ± 41	140 ± 63	134 ± 56	182 ± 45	112 ± 75	35 ± 20
	DIC	642 ± 93	699 ± 135	708 ± 103	712 ± 100	615 ± 162	675 ± 319
Hanoi (Hong River, main axe)	DOC	281 ± 56	305 ± 52	256 ± 58	251 ± 45	204 ± 57	97 ± 35
	POC	730 ± 238	782 ± 198	589 ± 210	532 ± 150	401 ± 231	77 ± 23
	DIC	1425 ± 141	1509 ± 131	1433 ± 204	1429 ± 169	1474 ± 237	1001 ± 176
Whole Red River	DOC	328 ± 66	356 ± 61	298 ± 67	294 ± 53	238 ± 67	114 ± 41
	POC	852 ± 278	913 ± 231	678 ± 245	621 ± 176	468 ± 270	90 ± 26
	DIC	1663 ± 165	1761 ± 153	1672 ± 238	1668 ± 197	1721 ± 277	1168 ± 205

The POC and DOC fluxes deliveries were highly seasonal, with about 95% and 82% of their respective loads transported during the high-flow seasons (May to October). More than 78% of the DIC fluxes were transported during the rainy season. Spatially, among the three main tributaries of the upstream Red River, the highest carbon loads were transported through the Da River (1,666±753 kton yr^{-1}) due to its higher river discharge. The Thao and Lo Rivers were equal in terms of total carbon transported (906±354 kton yr^{-1} and 870±211 kton yr^{-1}, respectively) during 1960 – 2015 period.

Overall, the total carbon fluxes of the Red River transferred to estuary significantly decreased from 2,816 ktonC.yr^{-1} in the period 1960s to 1,372 ktonC.yr^{-1} in the period 2010s (about 48% of reduction) (Table 6). That reflected the important impact of dams/reservoirs impoundment in the upstream tributaries despite the increase of deforestation and population in the whole river basin.

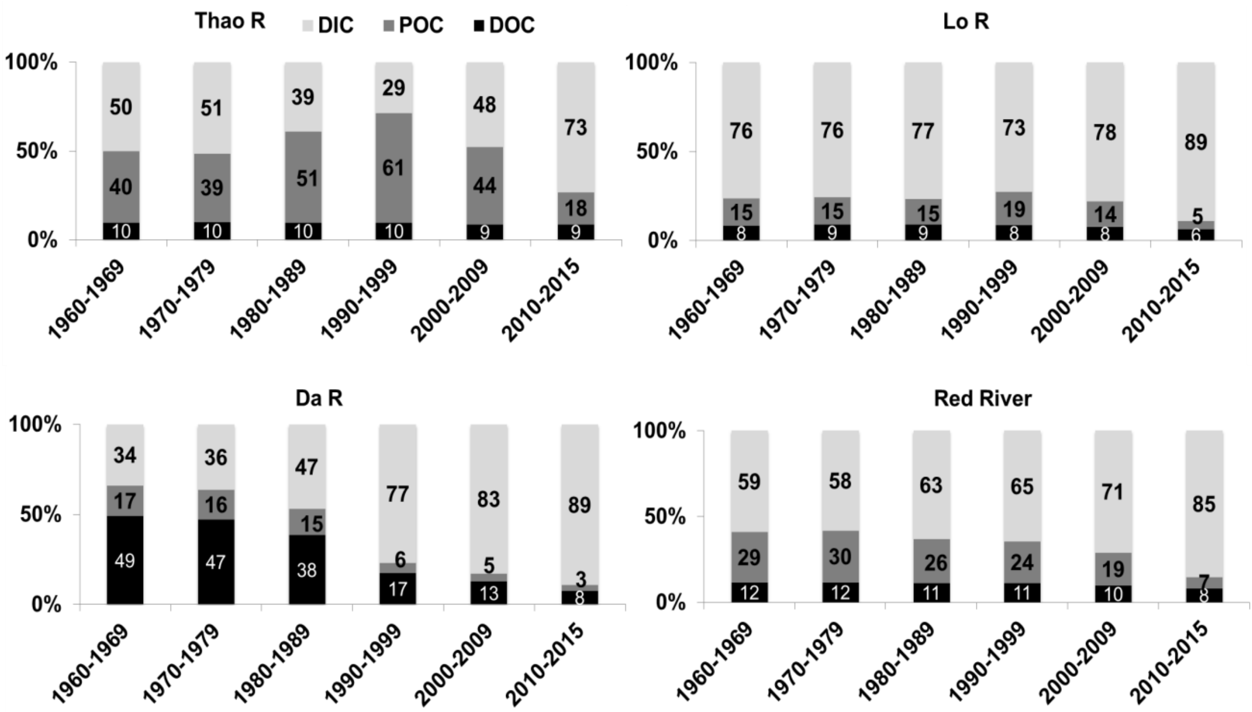

Figure 24. *Change in carbon proportions within 6 small periods (1960 – 1969, 1970 – 1979, 1980 – 1989, 1990 – 1999, 2000 – 2009, 2010 – 2015) at four gauging stations (Le et al., 2016b, in preparation)*

Over past 55 years, the proportion (%) of organic carbon (DOC + POC) fluxes of the three tributaries Thao, Da and Lo showed a significant decrease, from 40.9% in 1960s to 14.9% in 2010s for the whole Red River carbon fluxes due to a series of dams impounded in its main courses in both Chinese and Vietnamese parts. Actually, the major carbon species in the

Red River water was still DIC with its proportion up to 85 % in the period 2010 – 2015 (Figure 24).

For the future, after the year 2015, the new damming schemes such as the Lai Chau and the Huoi Quang will start operating. TSS, organic carbon fluxes and water discharges at the downstream Red River will probably be reduced even further. Moreover, the effects of climate change as well as changes in land use will all interact to further change the riverine carbon fluxes in this system and in other systems subject similar pressures.

4- Conclusions

The monthly observation of the DOC and POC concentrations at the outlets of the Thao, Da, Lo and in the main axe of the Red River showed that no clear spatial or seasonal variation was observed for DOC concentrations whereas POC varied significantly both spatially and between the dry and rainy seasons. POC changed synchronically with total suspended solids (TSS) concentration and with the river discharge, whereas no clear trend was observed for DOC concentration. The high mean value of the POC:Chl-a ratio (1585 ± 870 mgC $mgChl\text{-}a^{-1}$) and the moderate C:N ratio (7.3±0.1) in the water column system suggest that organic carbon in the Red River system is mainly derived from erosion and soil leaching in the basin.

The in-situ measurements of CO_2 emissions towards the atmosphere were carried out by three methods: calculation of CO_2 fluxes either using a floating chamber connected to an IRGA, or determining pCO_2 within the water column using an equilibrator or calculation via CO_2 partial pressure pCO_2 basing on the total alkalinity and pH values measured with the CO_2-SYS software method. These two latter methods gave similar results whereas the first method was not applicable for the large river as the Red River. CO_2 outgassing rate from the water surface Red river network was characterized by significant spatial variations, being the highest downstream Hoa Binh dam and in Hanoi. Differences in CO_2 outgassing were also observed between day and night, and between dry-rainy seasons for the five sites of the Red River system during two sampling campaigns in 2014.

Long-term variations on hydrology, population, urbanization, land use, and agricultural activities were clearly observed for the whole Red River basin for the period 1960 – present.

The model Seneque/Riverstrahler was successfully applied to investigate the dynamics and seasonal distribution of carbon in the Red River. The results showed that, in general, the model simulations of the temporal variations and spatial distribution of OC concentration followed the observed trends. They also showed the impact of the high population in the watershed on OC inputs in surface runoff from the different land use classes and from urban point sources. A budget of the main fluxes of OC in the whole river network, including diffuse inputs from soil leaching and runoff, point sources from urban centers, algal primary production and heterotrophic respiration was established using the model results. It showed the predominantly heterotrophic character of the river system, and allows evaluating the flux of CO_2 across the river-atmosphere interface as 330 GgC yr^{-1}. This value was in reasonable agreement with the available direct measurements of CO_2 fluxes in the downstream part of the river network.

Based on i) the relationships between POC, DOC, and DIC, with suspended sediment concentrations and with river water discharge respectively ii) the available detailed historical records of river discharge and suspended sediment concentrations, the long-term variations of the riverine organic and inorganic carbon concentrations and fluxes of the Red River system were examined for the period 1960 – 2015. The results showed that seasonally, almost all the Red River carbon (POC, DOC and DIC) flux deliveries were transported to the estuary during rainy seasons (May to October) (> 75%). Spatially, among the three main tributaries of the upstream Red River, the highest carbon loads were transported through the Da River (1,666±753 kton.yr^{-1}) due to its higher river discharge whereas the Thao and Lo Rivers were equal in terms of total carbon transported (906±354 kton.yr^{-1} and 870 ± 211 kton.yr^{-1}, respectively) during 1960 – 2015 period. Overall, the total carbon fluxes of the Red River transferred to estuary significantly decreased from 2,816 ktonC.yr^{-1} in the period 1960s to 1,372 ktonC.yr^{-1} in the period 2010s in which, the proportion of organic carbon fluxes also clearly decreased, from 40.9% in 1960s to 15.9% in 2010s due to the important dam/reservoirs impacts despite the clear increase of deforestation and population in the whole river basin. Actually, DIC fluxes notably dominated total carbon fluxes of all three tributaries Thao, Da and Lo and the main axe of the Red River system.

5- Future Directions

The Red River is a large source of CO_2 to the atmosphere. It is therefore important to conduct in situ measurements over a period of long-time to provide some ground-truthing data for these calculations.

The Trang An Scenic Landscape Complex (Ninh Binh province, Vietnam) approved by UNESCO is an interesting place to understand about nature, the environment and climate of the Red River Delta region. Moreover, this place is an attractive tourist point so the challenge is to protect water quality and environment. This is a target might be interesting for new scientific project development for protection of environment and ecosystem in this system.

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7-Appendix

7.1 Conferences/Symposia/Workshops

7.1.1 Workshops organized by the ARCP2014-03CMY-Quynh/ARCP2013-03CMY-Quynh/ARCP2012-06NMY-Quynh project

7.1.1.1. The first workshop in Hanoi (in December 2012)

The first international workshop was successfully held at INPC, in Hanoi, Vietnam from 17th – 19th December, 2012. More than 40 multi-discipline scientists, including project scientists from four main research teams, invited scientists and observers from different countries such as France, Germany, Singapore, China, Japan and Vietnam, have attended the workshop.

Figure 24. *The first International Workshop at INPC, VAST in December 2012, Hanoi, VIETNAM*

To achieve the scientific goals and produce the expected outcomes of the project, the workshop firstly informed the attendances about the objectives, main activities and expected outputs of the project. Then, 23 presentations of the invited scientists related to the project topics were introduced. Finally, the workshop discussed the future cooperation and activities planned in the scope of the project, focusing on three main issues:

- Data collection and exchange, water sampling, analysis, and future cooperation with other projects such as the Cau River (Canada-Vietnamese project), the Dong Cao catchment (French-Vietnamese project); the water quality of North coastal areas in Vietnam (National Vietnam Project); suspended solids and carbon transport of the Large Asian Rivers project (PI: Dr Lu XiXi, from Singapore).

- Training course for modeling utilization and carbon emission calculation for Vietnamese, Chinese, and Singapore young scientists.

- Website construction: to be connected with other website, e.g. the Piren-Seine for the Seneque/Riverstrahler utilization or new research results from the Piren-Seine program.

As part of the workshop, a one-day field trip in the Red River system (from Hanoi to Hung Yen province) was organized for people involved in carrying out the project. A water sampling campaign was undertaken along the main axe of the Red River, about 40 km downstream from Hanoi.

Figure 25. *One-day trip by boat in the Red River system (from Hanoi to Hung Yen province): field observation and water sampling campaigns.*

In order to strengthen the international scientific exchange and cooperation, some participants of the project (Dr Lu XX, Dr Le TPQ and Dr Duong TT) were participated in the International workshop titled "*Sediment Fluxes and Carbon Emission from Large Asian Rivers*" which was organized by Dr Lu XX at the National University of Singapore on 20th - 21st September 2012.

7.1.1.2. The second workshop in Hanoi (in December 2014)

The second workshop was successfully held at INPC, in Hanoi, Vietnam from 15th – 17th December, 2014. Ass the first workshop, more than 40 project scientists from four main research teams, invited scientists and observers from different countries such as France, Singapore, China, Japan and Vietnam, have attended the workshop. They all represented a large panel of disciplines, including chemistry, Biology, Biogeochemistry, agronomists, GIS-experts, etc…

The second workshop firstly focused on the main activities and some results obtained in the present project with various presentations from participant project and other invited scientists with their topics related to the project. And then, the workshop discussed the activities planned in the scope of the project and the future cooperation, focusing on three main issues: Data collection and exchange, water sampling, analysis, and future cooperation with other projects; planning for organization of training course workshop in 2016; Red River website construction will be opened as a forum for information exchange and researches relating to the Red River basin.

Figure 26. *The second International Workshop at INPC, VAST in December 2014, Hanoi, VIETNAM.*

One-day field trip in the Red River system (from Hanoi to Bac Ninh province) was organized for selected participants in which a water sampling campaign was undertaken along the main axe of the Red River, about 40 km upstream of Hanoi and in the Duong River, a distributary of the Red River in the Delta area (Figure 27).

Figure 27. *One-day trip by boat in the Red River system (from Hanoi city to Bac Ninh province, toward upstream of the Red River and in the Duong River): field observation and water sampling campaigns.*

7.1.1.3. The third workshop in Hanoi (in November 2016)

The third workshop is organized at Institute of Natural Products Chemistry (INPC), Vietnam Academy of Science and Technology (VAST), 1H building, 18 Hoang Quoc Viet, Cau Giay, Hanoi – VIETNAM on 14th– 17th November 2016.

More than 50 multi-discipline scientists, including project scientists from five main research teams, invited scientists and observers from different countries such as France, Singapore, China and Vietnam have attended the workshop.

During this workshop, a total of 19 presentations related to the ARCP project topics are performed by the invited scientists and present project participants. Notably, some main significant research results of the present project are introduced by different project participants. At the end of the workshop, participants discuss the activities planned in the scope of the present project (papers to submitted/in revision to peer-reviewed journals, final scientific report,...). The possibility for future cooperation on new project is also carried out.

Figure 28. *The third International Workshop at INPC, VAST in November 2016, Hanoi, VIETNAM.*

One-day field trip in the Red River delta is organized for people involved in carrying out the project and for some invited scientists. The Trang An Scenic Landscape Complex (Ninh Binh province, Vietnam) approved by the UNESCO is the good place to understand about nature, the environment and climate of the Red River Delta region. This is a target for new scientific project development for protection of environment and ecosystem.

 

Figure 29. *Part-day trip by boat in the Trang An Scenic Landscape Complex (Ninh Binh province, Vietnam).*

Thanks to the three international workshops funded by APN in the framework of the present research project, all project participants expressed their pleasure to meet and talk with other scientists in the related research topics in a constructive collaboration.

7.1.2 List of papers participated in international workshop/conference

Full papers in international workshop/conference proceedings

Thi Phuong Quynh Le, Viet Nga Dao, Thi Anh Mai, Thi Bich Ngoc Nguyen, Thi Thuy Duong, Cuong Tu Ho, Thi Xuan Binh Phung and Thi Bich Nga Tran. 2015. Transport of dissolved inorganic carbon in the Red River system (Vietnam). International Forum on Green Technology and Management (IFGTM), 28-30 July, Hue city, 2015. *Journal of Science and Technology* Vol 53(A): 151 -156.

Le Thi Phuong Quynh, Phung Thi Xuan Binh, Pham Quoc Long, Tran Thi Bich Nga, Garnier Josette, Billen Gilles. 2015. Impact of the Thac Ba reservoir on water quality of the downstream Lo-Gam_Chay river system over the period 1960 – 2009. *The International Science Conference on Green Growth and Energy for ASEAN*, Hanoi, 16 – 18 October 2015. pg 193 - 198, Publishing house for Science and Technology, ISBN 978-604-913-389-3.

Le Thi Phuong Quynh, Nguyen Thi Bich Ngoc, Nguyen Bich Thuy, Tran Thi Bich Nga, Garnier Josette, Duong Thi Thuy, Ho Tu Cuong and Phung Thi Xuan Binh. 2014. Observation of organic carbon contents in the Red river water (Vietnam). *2nd Vietnam National conference on Marine Biology and Sustainable development.* October 2014, Quang Ninh city, page 703 – 710. Publishing house of Natural Science and technology. DOI 10.15625/MBSD2.2014-0081.

Le Thi Phuong Quynh, Lu XiXi, Garnier Josette, Gilles Billen, Etcheber Henri, Duong Thi Thuy, Ho Tu Cuong, Nguyen Thi Bich Ngoc, Nguyen Bich Thuy and Pham Quoc Long. 2014. Seasonal variation of dissolved and particulate organic carbon in the Red River system (Vietnam). *The first International* *conference of the Vietnam – Bulgaria Scientific cooperation*. November 2014, Ha Long city. page 391-398. (ISBN 978-604-913-304-6). Published by the Vietnam Academy of Science and Technology.

Phung Thi Xuan Binh, Le Thi Phuong Quynh, Nguyen Thi Bich Ngoc, Vu Duy An. 2014. Assessment of suspended solids in the Hoa Binh and Son La reservoirs. *National Electric conference of Science and Technology*. 14th November 2014, Hanoi. page 200- 205. Published by the Vietnam Association of Electricity.

Le Thi Phuong Quynh, Garnier Josette, Billen Gilles, Tran Thi Bich Nga, Pham Quoc Long, Nguyen Thi Bich Ngoc and Phung Thi Xuan Binh. 2013. Impact of the Hoa Binh reservoir on water quality of the downstream Da river over the period 1960 – 2009. *The Third International Science Conference on Sustainable Energy Development, Hanoi-Ninh Binh*, 16 – 18 October 2013. page 219 -224, Publishing house for Science and Technology, ISBN 978-604-913-137-0.

Presentations in international conferences/workshops:

In 2016

Le Thi Phuong Quynh, Lu XiXi, Garnier Josette, Billen Gilles, Duong Thi Thuy, Ho Tu Cuong, Marchand Cyril, Pham Quoc Long, Nguyen Thi Mai Huong, Nguyen Thi Bich Ngoc, Nguyen Bich Thuy, Vu Duy An, Le Duc Nghia, Tran Bich Nga and Zhou Yue. 2016. Carbon fluxes and emission of the Red River system: impact of human activities and climate change. Some notes for the present research project. *International conference on «carbon emission and transfer from river system: impact of climate change and human activity* ». Hanoi, 14th -17th November 2016.

Lu Xi Xi, Ran Lishan, Yang XK and Liu Shaoda. 2016. Carbon outgassing from large Asian rivers: an overview International conference on «carbon emission and transfer from river system: impact of climate change and human activity » *International conference on «carbon emission and transfer from river system: impact of climate change and human activity* . Hanoi, 14th -17th November 2016.

Billen Gilles, Garnier Josette and Théry Sylvain. 2016. The GRAFS / SENEQUE - RIVERSTRAHLER modelling suite: a tool for studying C, N & P transfers along the land sea continuum of large watersheds. *International conference on «carbon emission and transfer from river system: impact of climate change and human activity* ». INPC – APN. Hanoi, 14th -17th November 2016.

Nguyen Thi Mai Huong, Rochelle-Newall Emma, Le Thi Phuong Quynh, Garnier Josette and Billen Gilles. 2016. Organic carbon in the Red River, Vietnam: measurement and modelling*. International conference on «carbon emission and transfer from river system: impact of climate change and human activity* ». INPC – APN. Hanoi, 14th -17th November 2016.

Ho Tu Cuong, Le Thi Phuong Quynh, Marchand Cyril Vu Duy An, Nguyen Thi Bich Ngoc, Nguyen Bich Thuy, Dang Quang Le, Duong Thi Thuy and Nguyen Trung Kien. 2016. Relationship of bio-physico-chemical variables on the calculated flux of CO2 in different seasons at five sites along the Red River system. 2016. *International conference on «carbon emission and transfer from river system: impact of climate change and human activity* ». INPC – APN. Hanoi, 14th -17th November 2016.

Dao Viet Nga, Le Thi Phuong Quynh, Emma Rochelle- Newall, Le Nhu Da, Le Duc Nghia and Nguyen Thi Mai Huong. 2016. Longterm variation (1980 – 2014) of the riverine carbon flux of the Red River system (Vietnam). *International conference on «carbon emission and transfer from river system: impact of climate change and human activity*». INPC – APN. Hanoi, 14th -17th November 2016.

Tran Thi Bao Ngoc, Hoang Thi Thu Hang, Nguyen Trung Kien, Le Thi Phuong Quynh, Lu XiXi, Duong Thi Thuy. 2016. Seasonal variation of water quality and plankton community in the Red river system. 2016. *International conference on «carbon emission and transfer from river system: impact of climate change and human activity* ». INPC – APN. Hanoi, 14th -17th November 2016.

Le Thi Phuong Quynh. Phung Thi Xuan Binh, Le Duc Nghia and Duong Thi Thuy. 2016. Impact of the reservoir on the POC fluxes of the downstream Da River over the perios 1960 -2014. International longterm ecological research. *5th VNU-HCM International Conference for 5th Environment and Natural Resources (ICENR 2016) and 11th International Longterm Ecological Research -Asia-Pacific Regional Network Regional Conference* (2016 ILTER-EAP), 26-29 October 2016 Hochiminh city, Vietnam.

In 2015

Thi Phuong Quynh Le, Viet Nga Dao, Thi Anh Mai, Thi Bich Ngoc Nguyen, Thi Thuy Duong, Cuong Tu Ho, Thi Xuan Binh Phung and Thi Bich Nga Tran. 2015. Transport of dissolved inorganic carbon in the Red River system (Vietnam). *International Forum on Green Technology and Management (IFGTM)* , 28-30 July, Hue city, 2015. (poster).

Le Thi Phuong Quynh, Phung Thi Xuan Binh, Pham Quoc Long, Tran Thi Bich Nga, Garnier Josette, Billen Gilles. 2015. Impact of the Thac Ba reservoir on water quality of the downstream Lo-Gam_Chay river system over the period 1960 – 2009. *The International Science Conference on Green Growth and Energy for ASEAN*, Hanoi, 16 – 18 October 2015. (oral presentation).

In 2014

Le Thi Phuong Quynh, Garnier Josette, Billen Gilles, Ho Tu Cuong, Duong Thi Thuy, Tran Thi Bich Nga, Pham Quoc Long. 2014. Observation of carbon transfer in the Red river system (Vietnam and China). RPP SELTAR Workshop CHAMA. *Vegetated coastal habitats in the southeastern Asia: threats from global changes and management of human impacts, Hanoi*, Vietnam, 30-31st October 2014 (oral presentation).

Ho Tu Cuong, Le Thi Phuong Quynh, Duong Thi Thuy, Cyril Marchand, Nguyen Bich Ngoc, Vu Duy An, Nguyen Trung Kien. Measurement of CO2 flux at the air-water interface of the Red River system. *International workshop on "Source and transfer of organic matters and associated contaminations in River Basins*". 15-17th December 2014, INPC, VAST, Hanoi, Vietnam (oral presentation).

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7.2 Website construction and data uploaded

The need for the public forum to share the knowledge and scientific data concerning the Red River basin (Vietnam, Laos and China) urged us to set up the website ***www.redriverprogram.com***

This website is set-up with the support of the present ARCP project which is funded by the Asia Pacific Network for Global Change Research (APN). (http://www.apn-gcr.org/)

The website includes several windows concerning the present project such as the background, information, objectives, activities, images – photos, modelling tools, results, publications relating to the projects, data portal for registered users, contact and links for the partners who joined and funded the projects.

This website provides to the public some selected dataset (water quality, meteorology, human activities…) as well as the modelling tools and/or the results obtained during the researches. We try to update all possible information relating to the Red River basin in terms of research and management for the interested researchers, young scientists as well as students. It is also the playgrounds and sharing rooms for the researchers who want to publicize their scientific researches concerning the Red River basin.

With the website, researchers, concerned people and decision-makers can be brought together for the animation of interactive and visible tools on the whole Red River basin.

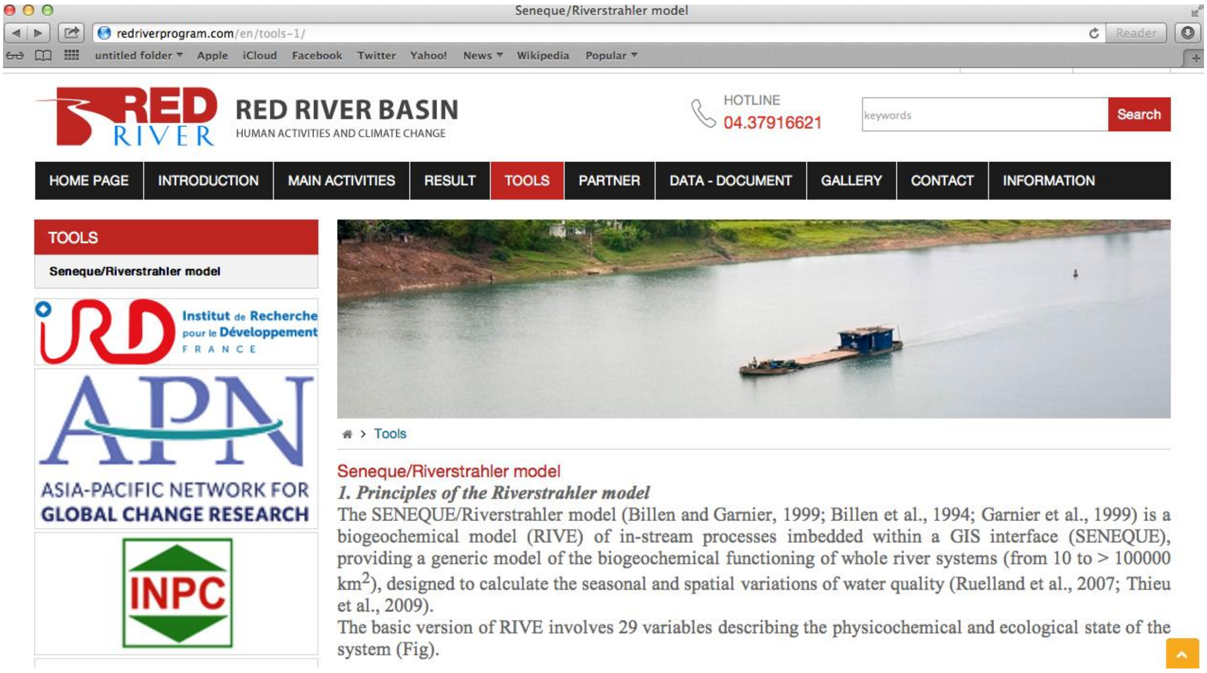

Figure 30. *A website for the Red River basin constructed in the framework of the present project*

List of Young Scientists

Training course

A training course was organized during two days 16th - 17th November 2016 for about 30 Vietnamese, Chinese, and Singapore young scientists and students.

The first day of the training course provides for participants focused on

+) a review about the recent understandings of carbon emission from the world rivers: source, sinks, factors impacted

+) how to calculate or to measure carbon emission from the river air-water interface?

The second day of the training course with the Seneque-Riverstrahler model aimed at synthetizing the work realized on the Red River upstream basin and the Day River on the right side of the delta. The several applications of the model concern the biogeochemical functioning of the drainage network in terms of sources and fate of (i) N, P, Si and their potential role for eutrophication and (ii) fecal contamination and organic carbon. The model was implemented in parallel to field and experimental studies for short period during the duration of 3 Ph-D thesis (2003-2004: Le TPQ, 2005; 2006-2008: Luu TNM. 2010; 2013-2014: Nguyen TMH, 2016). In addition, long term reconstruction, back the 1960's, has been realized with the model on the basis of existing data (*Le et al, 2015*) and scenarios for the future explored.

During this training the data gathered separately from these previous studies will be mobilized together.

Figure 31. *Some photos of two-days training course*

Below is the full list of participants of this training course.

Table 7. *List of young scientists participating training course in the present project in November 2016 at INPC, Hanoi.*

No	Full name	Working Agency (Fullname)	DOB	Email	Sex
1.	Dr Luu Thi Nguyet Minh	Institute of Chemistry, ICH, VAST, 18 Hoang Quoc Viet, Hanoi, Vietnam.	30/08/1983	Luu.minh@ich.vast.vn	F
2.	MSc Tran Thi Hong Hanh	Xuan Thuy National Park GiaoThien, Giao Thuy, Nam Dinh, Vietnam	11/02/1982	hanhvqgxt@gmail.com	F
3.	MSc Cao Van Luong	Institute of Marine Environment and Resources IMER, 246 Đa Nang, Ngo Quyen, Hai Phong, Vietnam	20/01/1984	caoluongimer@gmail.com; luongcv@imer.ac.vn	M
4.	PhD student, MSc Ha Thi Hien	Water Resources University, WRU175 Tay Son, Hanoi, Vietnam	06/11/1976	hienht@wru.vn	F
5.	MSc Khuong Van Hai	Institute of Meteorology, Hydrology and Climate Change 23/62 Nguyen Chi Thanh, Hanoi, Vietnam	11/10/1984	khuongvanhai@gmail.com khuonghai@imh.ac.vn	M
6.	MSc Nguyen Trung Kien	Institute of Environmental Technology, IET, VAST,18 Hoang Quoc Viet, Hanoi, Vietnam.	27/08/1984	nguyenkien.et@gmail.com	M
7.	MSc Pham Hong Ngoc	Institute of Oceanography - Nha Trang, 01 CauĐa, Nha Trang, KhanhHoa, Vietnam	09/12/1983	ruby912@gmail.com	F
8.	MSc Le Hung Phu	Institute of Oceanography - Nha Trang, 01 CauĐa, Nha Trang, KhanhHoa, Vietnam	21/09/1986	hungphu219@gmail.com	M
9.	Ms Pham Bich Ngoc	Institute of Natural Product Chemistry, ICH, VAST, 18 Hoang Quoc Viet, Hanoi, Vietnam.	04/08/1995	Phambichngoc_t58@hus.edu.vn	F
10.	MSc Tran Van Thuong	Ho Chi Minh City University of Pedagogy, 280 An DươngVương, District 5, HoCHiMinh city, Vietnam	10/06/1992	thuongtv@hcmup.edu.vn	M
11.	Ms Nguyen Thi Bao Ngoc	Vietnam National University of Agriculture, TrauQuy, Gia Lam, Hanoi, Vietnam	10/01/1993	Baongocnguyen1808@gmail.com	F
12.	PhD student Dang	Ho Chi Minh City	17/09/1971	Dvcuong971@gma	M

	Viet Cuong	University of Transport , 527/31 Ba Dinh, 8th District, HoChiMinh city, Vietnam		il.com	
13.	PhD student Pham Thi Diem Phuong	Ho Chi Minh city university of natural resources and environment, 236B Le Van Sy, 01 arrond, Tan Binh district, HoChiMinh city, Vietnam	19/10/1983	Phuongpham1910@gmail.com	F
14.	MSc Nguyen Anh Tuan	Climate Change Research Centre (CRCC), Institut of Meteorology, Hydrology and Climate Change, No. 23 lane 62, Nguyen Chi Thanh road, Dong Da district, Ha Noi, Viet Nam	05/07/1985	athnvn@gmail.com	F
15.	Tran Bich Thuy	Hanoi University of Science, 334 Nguyen Trai, Hanoi	02/12/1995	tranbichthuy_t58@hus.edu.vn	F
16.	Ms Nguyen Khanh Linh	Hanoi University of Science, 334 Nguyen Trai, Hanoi	21/10/1995	Linhnk2110@gmail.com	F
17.	Ms Nguyen Thi Kim Oanh	Hanoi University of Science, 334 Nguyen Trai, Hanoi	26/11/1994	Oanhcoi360@gmail.com	F
18.	PhD student Nguyen Thi Ngoc Tuyet	Université Grenoble Alpes, France,	14/12/1989	ngoctuyet1412@gmail.com	F
19.	Dr Tran Thi Tuyen	Vinh University No.182 Le Duan Str, Vinh City, Nghean Vietnam		ttt.dhv@gmail.com	F
20.	PhD student Shaoda LIU	National University of Singapore	10/05/1984	lsdeel@gmail.com	M
21.	Mr Sylvain THERY	UMR Sisyphe 7619, Pierre and Marie Curie University, Paris, FRANCE	16/07/1975	sylvain.thery@upmc.fr	M
22.	Dr Julien NEMERY	University Grenoble Alpes, FRANCE Ho Chi Minh City University of Technology, VIETNAM	11/03/1976	julien.nemery@grenoble-inp.fr	M
23.	Dr Kaidao FU	Asian International Rivers Center, Yunnan University, CHINA	30/11/1976	kdfu@ynu.edu.cn	M
24.	Dr Paul PASSY	National University of Singapore	17/07/1985	paul.passy@nus.edu.sg	M
25.	Dr NuFang FANG	State Key laboratory of Soil Erosion and Dry land Farming on Loess Plateau. Institute of soil and water conservation, CAS & MWR, CHINA	14/03/1985	fnf@ms.iswc.ac.cn	M
26.	Mr Tien Khang MAI	Industrial University of Hochiminh No3	29/04/1994	hoangbavuongone@gmail.com	M
27.	Dr Mai Huong NGUYEN	Institute of Natural Product Chemistry, Vietnam	09/09/1986	huongmtv@yahoo.com	F

28.	BSc Thi Bich Ngoc NGUYEN	Institute of Natural Product Chemistry, Vietnam	23/04/1987	nguyenbichngoc2304@gmail.com	F
29.	BSc Duc Nghia LE	Institute of Natural Product Chemistry, Vietnam	23/05/1993	lnghia2015@gmail.com	M
30.	Dr Nhu Da LE	Institute of Natural Product Chemistry,	29/07/1980	nhudal@yahoo.com	M

PhD students:

A sandwich thesis, under the training cooperation between the University of Pierre and Marie Curie (Paris, France) and the Vietnam Academy of Science and Technology (VAST, Vietnam) (2013 –2015) has been financially supported by the IRD French Institution. The thesis topic is the behavior of Coliforms in relationship with organic dissolved and particulate carbon fluxes, and aims to quantify the proportion of carbon issued from domestic waste water compared to the one issued from erosion and soils leaching in the Red River basin, including inorganic, organic and gazeous. PhD student NGUYEN Thi Mai Huong already successfully defended her thesis titled "***Faecal indicator bacteria and organic carbon in the Red River, Viet Nam: measurements and modeling***" on 18 March at University Paris VI, Paris, France.

Cooperating with a NAFOSTED project, another PhD student has been working on the impact of human activities on phytoplankton community of the Red River system at the IET, VAST, Vietnam.

Master students:

The ARCP present project scientifically supports for two Master students from University of Science and Technology (USTH, Hanoi) who work on the topic of measurement of carbon exchange at the water-air interface of the Red River and of the carbon transfer in the whole Red River system. Two Master students successfully defended their Master thesis desertions in September 2015 at USTH, Hanoi, Vietnam.

1. Ms DOAN Phuong Kieu "Measurement of carbon emission at the air-water interface of the Red River system".

2. Ms DO Viet Nga "Seasonality and long-term trends of carbon fluxes of the Red River system".

Undergraduate students:

From 2012, about 38 undergraduate students from different Universities such as the Hanoi University of Natural Resources And Environment (HUNRE), Hanoi Pedagogical University N^{0}2, Thanh Tay University, Hanoi University of Industry, University of Electricity … realize their bachelor desertions or university internship at INPC and IET with scientific topics related to this ARCP project.

List of student's works on scientific topics related to this ARCP project

No.	Full name	University	Email
1	VU Duy An	Hanoi University of Natural Resources and Environment	duyan.mt91@gmail.com
2	HOANG Thi Van		vanht18@gmail.com
3	VU Thi Ut		utthanh29191@gmail.com
4	DO Thi Hien		
5	VU Hong Diep		vuhongdiep.2210@gmail.com
6	NGUYEN Thi Nga		nguyennga92mt@gmail.com
7	NGUYEN Thi Huong Thao		buonoi_chaonhe_2005@yahoo.com
8	DUONG Thi Hong Nhung		gaupooh.gaupooh@yahoo.com
9	TONG Thi Thanh Loan		loanttt87@wru.vn
10	HOANG Minh Thuy	Hanoi Pedagogical University N^{0}2	thuythuy8990@yahoo.com.vn
11	DO Anh Diem	Hanoi University of Natural Resources and Environment	doanhdiem@gmail.com
12	VUONG Tuan		
13	MAI Thi Anh		maianh.spb@gmail.com
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18	NGUYEN Thi Hoai		nguyenhoai249@gmail.com
19	NGUYEN Thi Thanh		nguyenthanhthanh2411@gmail.com
20	DO Thi Yen		yenhoathanhque@gmail.com
21	BUI Thi Tuyen		tuyenkm3@gmail.com
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23	LE Hai Van		haivan26040509@gmail.com
24	NGUYEN Thi Hue		huenguyen0291@gmail.com
25	DO Thi Phuong		phuongdothi.92@gmail.com
26	DOAN Thi Am		hoangthilydan@gmail.com
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28	PHAM Thi Mai Phương		sakurapt@gmail.com

29	DO Thi Dao		cherry92kut3@gmail.com
30	NGUYEN Thi Nga	Thanh Tay University	Nguyenngabiotech93@gmail.com
31	TRAN Kieu Chinh	Electric Power University (EPU)	Trankieuchinh1394@gmail.com
32	VU Thi Hang		Vuhang94samson@gmail.com
33	NGO Thi Trang		Ngothitrang1510@gmail.com
34	NGUYEN Thi Minh Giang		Nguyengiangdanda@gmail.com
35	NGO Lan Huong		Ngolanhuong19194@gmail.com
36	DO Thi Minh Thuy		Dothuy623544@gmail.com
37	MAI Tien Khang	Industrial University of Hochiminh No3	hoangbavuongone@gmail.com
38	FUDAL Pierre	National Graduate School of Chemistry and Chemical Engineering of Montpellier, France	pierre.fudal@enscm.fr