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PREMINARY RESULTS OF RIVERSTRAHLER MODEL APPLICATION TO THE RED RIVER SYSTEM (VIETNAM)

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LE THI PHUONG QUYNH [1], GARNIER JOSETTE [2], GILES BILLEN[2], LAM NGOC THIEM[3], CHAU VAN MINH[1]

[1]*Institute of Natural Products Chemistry, Vietnam Academy of Natural Science and Technology*

[2]*UMR Sysiphe, Université P. et M. Curie, 4 Place Jussieu, 75005 Paris, France*

[3]*Faculty of Chemistry, Natural Science University, Hanoi National University, Vietnam*

ABSTRACT

The Riverstrahler model has been developed for representing the biogeochemical functioning of large drainage networks in Europe. It is originally here applied to a tropical river system, the Red river, a 156 448 km□ transboundary river system. For this purpose, a GIS data base is being assembled at the scale of the whole basin, with layers documenting geomorphology, lithology, meteorology, land-use and agriculture, population, domestic and industrial wastewater release, etc. The results of the model, although still preliminary, are in agreement with a set of validation discharge and water quality data newly acquired at the outlet of the 4 sub-basins (Da, Lo, Thao and in the main axe) during the year 2002. Some discrepancies are discussed and indicate the need for further research and monitoring.

INTRODUCTION

The RIVERSTRAHLER model [1], first developed for the Seine river system (France), then successfully applied to several other large European river basins such as the Mosel, Danube, Scheldt, addresses the issues of organic pollution and oxygen balance, eutrophication, nutrient contamination, transfer and retention at the scale of the whole drainage network. In particular, this model enables the diagnostic of the N: P: Si nutrient balance, which is the key for the control of fresh water and coastal marine eutrophication problems. The study intends to further enlarge the field of RIVERSTRAHLER model application to tropical systems, by applying the approach to the case of the Red river. A major objective is to establish the link between land use, human activities and water quality in the Red river basin. The implementation of such a water quality model at the regional scale offers an excellent framework for initiating and developing the dialogue, both between scientists of different disciplines and between scientists, decision-makers and the public.

SITE DESCRIPTION

The Red river (figure 1) is originating in the Yunnan province (China). It flows through different Vietnamese provinces before reaching the Tonkin Sea though 4 defluents Ba Lat, Day, Lach Gia and Tra Ly. The Red river [2] plays an important role in the economy, culture and politics in Vietnam. The basin area is of 156 448 km^2, of which 48.8 % are in China, about 50.3% in Vietnam and 0.9% in Laos. The total lengt of the Red river is approximately 1140 km

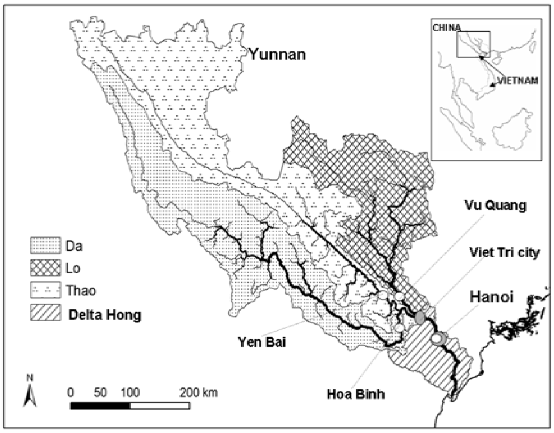

Figure: The Red River basin and its main 3 sub-basins

THE RIVERSTRAHLER MODELLING APPROACH

The basic idea of the RIVERSTRAHLER Model [3] is that, throughout the whole river continuum from headwater to downstream sectors, the same ecological processes potentially determine the functioning of aquatic ecosystem, while the hydro-meteorological and morphological constraints, as well as the point- and non-point sources of nutrient and organic matter, and modulate their expression. The RIVERSTRAHLER model thus results from the coupling of a unique model of the ecological processes (the RIVE Model) with a hydrological model (HYDROSTRAHLER) describing the water fluxes in the drainage network. For the purpose of the present application of the model to the Red river, 3 main sub-basins, the Thao, Da and Lo river basins, largely differing in their morphology and land use characteristics, are distinguished (figure 1). Each of them is represented in an idealised way by a regular scheme of confluence of rivers of increasing stream orders with mean characteristics. The drainage network of these 3 basins are then connected to the main branch of the Red river, from the Da-Thao-Lo confluence down to Hanoi city, the morphology of which is described with a finer, kilometric, resolution. The HYDROSTRAHLER Model[3] calculates the discharge in the whole drainage network from precipitation and potential evapotranspiration data with a classical rain-discharge conceptual model, taking into account the role of soil and aquifer reservoir, and involving 4 calibrated parameters (soil saturation, infiltration rate, internal flow rate, aquifer flow rate). Based on these water fluxes, the RIVE model calculates the variations of 22 variables characterizing the water quality and ecological functioning.

VALIDATION DATA

1. Sampling campaigns and analyses

In order to assemble a coherent data base for the validation of the model, a sampling program has been set up throughout the year 2002: monthly campaigns at the Tung Thon district (Ha Tay province) and two sampling campaigns carried out in April (low discharge) and August (high discharge), at the outlet of the 3 sub-basins (Lo, Da and Thao) and at the Hanoi site (figure 1). The main water quality variables taken into account in the model were analysed: suspended matter (SM), nutrients (nitrogen, phosphorus, and silica), total organic carbon, and algal biomass as chlorophyll a concentrations. Analytical methods are described in *Quynh et al.* (2005). All samples were analysed for intercalibration both in the Sisyphe laboratory (CNRS, Paris) and in the

Institute of Natural Products Chemistry (INPC, Hanoi).

Hydrological data

The discharge in the main branch is maximal in July, during the rainy season, and averages 2870 $m^3.s^{-1}$ for the year 2000. Occasionally, discharge values as high as 20000 to 30000 $m^3.s^{-1}$ can be observed in the flood season. The maximum value at Son Tay station (37800 $m^3.s^{-1}$) for the last 100 years was observed in 1971.

ELABORATION OF A DATABASE FOR DEFINING THE CONSTRAINTS TO THE RED RIVER SYSTEM

For the requirement of the modelling approach, the data characterizing the various constraints to the hydrological and biogeochemical functioning of the Red River system have been assembled into a database under the GIS software Arc-Info.

Geomorphological constraints

The hydrographic network of the Red River constitutes the first layer of the GIS database. The information was formatted according to the requirements of the RIVERSTRAHLER model, distinguishing 3 sub-basins and one major branch (figure 1). The drainage network representation was validated by the topography and the ordination of the different arcs was carried out. The elementary watersheds were delimited by tools developed in the framework of the PIREN-Seine programme. The parameters describing the geometry of the tributaries (watershed area, length, slope, width) were then automatically calculated.

Meteorological constraints

The climate in the Red river basin is of tropical and sub-tropical type. The rainfall and temperature data (monthly data in the years 1999 and 2000) have been obtained from 13 meteorological stations. The rainy season cumulates 85 to 95% of total rainfall in the year. Monthly rainfall data for the 3 sub-basins are showed in figure 2. The mean temperature varied between 10 and 27°C and is homogeneously distributed throughout the seasonal cycle for the 3 sub-basins [4].

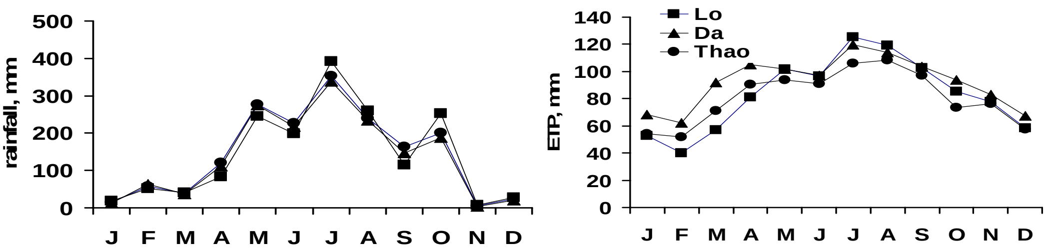

Figure 2: Seasonal variations of rainfall and evapotranspiration (ETP) in the 3 sub-basins of the Red River (monthly averaged values in 2000)

The evapotranspiration data (figure 2) have been calculated in the same way, by using Turc's formula [5], based on monthly temperature and sunshine duration data.

Land use and diffuse sources of nutrients from the watershed

Soil-water interactions within the watershed determine the magnitude of diffuse sources of nutrients, namely nitrogen, phosphorus and silica. The lithology alone determines the silica content of the surface and groundwater, while land cover and agricultural practices are important in determining nitrogen and, to a lesser extent, phosphorus concentrations.The principle used for calculating diffuse sources of nutrients by the Riverstrahler Model, is to assign a given background chemical composition respectively to the surface and the base flow components of river runoff according to the proportion of land use or lithologic type in the watershed (table 1).

Point sources of nutrients from the watershed

Contrarily to silica, which originates only from the weathering of rocks and therefore has only diffuse sources, significant amounts of nitrogen and phosphorus are added to the river system as point sources of wastewater. The population in the whole basin is estimated to 30.02 million inhabitants for the year 1997. These values have been geo-referenced in the Red river basin GIS. The population density within the different sub-basins is different, In order to determine the input by domestic effluents, we used a daily specific per capita load of 66 gSM, 60 $gBOD_5$, 10 gN and 1.7 gP [2]. In the upstream watersheds, only 25% of the population is distributed in urban areas [2]. We considered that only this fraction of the population effectively brings effluents to the river. Industrial input has not yet been inventoried.

SIMULATIONS BY THE MODEL

The simulations presented below result from running the model for hydrological conditions calculated as the mean of the years 1999 and 2000. At this stage, the model does not take into account the two major reservoirs on the Da and Lo rivers. The calculated water quality (N, P, Si, suspended matter and chlorophyll) will be compared with the observations gathered in 2002. For these reasons, the results must be considered preliminary and must rather be viewed as preliminary tests of the relevance of the approach.

Table 1: Nutrient concentrations characterizing sub-surface and groundwater runoff according to land use or lithology of the watershed in the model [6]

		Surface runoff		Groundwater runoff	
N		NO_3, $mgN.L^{-1}$	NH_4, $mgN.L^{-1}$	NO_3, $mgN.L^{-1}$	NH_4, $mgN.L^{-1}$
	Forest and meadows	0.4	0.03	0.4	0.03
	Cultivated area	5	0.3	2.5	0.15
	Rice cultures	0	0.7	0	0.3
SM* And P		SM, $mg/.L^{-1}$	TotP, $mgP.L^{-1}$	SM, $mg/.L^{-1}$	TotP, $mgP/.L^{-1}$
	Forest and meadows	300	0.05	50	0.02
	Cultivated area	5000	0.5	500	0.05
Si		SiO_2, $mgSi.\ L^{-1}$		SiO_2, $mgSi.\ L^{-1}$	
	All basin	7		7	

SM **: suspended matters.

Discharge and suspended matter: Simulation of discharge and suspended matter concentration are presented in figure 3, and compared with available observed data. The calculated discharge variations agree reasonably with the observations, except for the Da sub-basin, where they are underestimated. Considering that we do not take into account the hydrology of the Hoa Binh reservoir on the Da river, with an average surface area of 208 km² and a volume of 9.5 10^9 m^3, this is not really surprising. The Thac Ba reservoir on the Lo river system, with average surface area of 235 km² and a volume of 2.94 10^9 m^3 has also not be taken into account by the model, with however less effect on the quality of the simulation.

The same reasons explain the rather variable agreement between simulated and observed suspended matter. More knowledge on erosion in tropical regions is required to correctly incorporate suspended matter inputs from the watershed in the model.

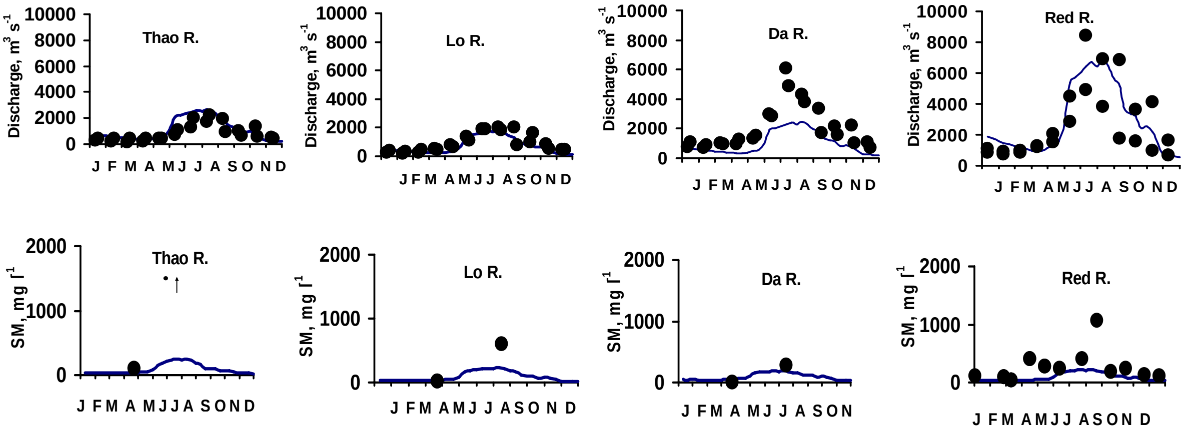

Figure 3. Simulations (☐) of the discharge and suspended matter in the 3 upstream sub-basins Da, Lo Thao and the main branch of the Red river. Comparison with the observations (•) (mean monthly discharge value in 1999 and 2000, and suspended matter value in 2002)

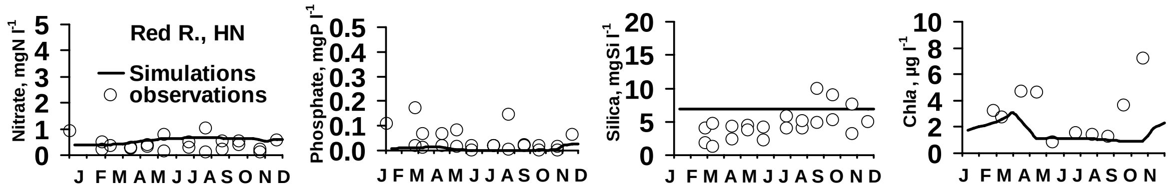

Figure 4: Simulations (☐) and observations gathered in 2002 (○) of nitrate, phosphate, silica and chla concentrations at the Hanoi station in the main branch of the Red river

Nutrient (N, P, Si) and chlorophyll a concentrations: Being aware that at this stage of the study, the hydrological year does not fit with the year of validation data, the result obtained regarding the nitrogen and phosphorus are quite encouraging (figure 4). Although the seasonal variations can not be followed due to the scarcity of the observations, the model gives the right level of the concentrations. The general level of observed silica concentration as well as of algal biomass is also correctly reproduced by the model (figure 4). Algal development, although rather limited in the Red river system, appears to be controlled by the hydrology, showing a peak in April-May, just before the beginning of the rainy season, then a second increase in October-November when the discharge decreases again.

CONCLUSIONS AND PERSPECTIVES

At this stage of the study, an ecological model of the Red river is operational, taking into account 3 sub-basins and one main branch, until Hanoi. It allows relating the water quality of the river system to land use and wastewater management in the whole watershed. The model however requires the improvement of the database regarding the constraints, particularly concerning point - and diffuse sources of nutrient. The incorporation of a module able to simulate the hydrological and biogeochemical functioning of the large reservoirs existing on the Da and Lo rivers will certainly improve considerably the quality of the simulations.

Once the constraints will be better documented, and the simulations validated, scenarios will be tested with the perspective of testing the effect of developing agricultural practices (increasing use of fertilizers□) or of different wastewater management policies (collection and/or treatment of domestic and industrial effluents). The model therefore potentially represents a powerful tool for environmental planning in North Vietnam.

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