Modeling the seasonal nutrients dynamics and phytoplankton development in Saigon River Estuary, Vietnam

Modélisation de la dynamique saisonnière des nutriments et du développement du phytoplancton dans l'estuaire de la rivière Saigon (Vietnam)

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RÉSUMÉ

Cette étude examine les réponses saisonnières (nutriments et phytoplancton) d'un estuaire tropical (la rivière Saigon) aux charges de pollution provenant d'une mégapole (Ho Chi Minh City, Vietnam) à l'aide du Carbon Generic Estuarine Model (C-GEM). Le C-GEM est un modèle estuarien biogéochimique générique unidimensionnel qui tire parti de la relation entre la géométrie estuarienne et l'hydrodynamique pour minimiser les besoins en données. Le modèle simule bien la tendance d'évolution du carbone organique et du phytoplancton en 2017 - 2018. Les processus biogéochimiques et les effets hydrologiques simulés ont permis d'élucider les mécanismes de succession du phytoplancton. La disponibilité élevée en nutriments dans la section urbaine, et faible en amont et en aval explique les différences spatiales du phytoplancton. Les temps de résidence saisonniers variables expliquent les fortes ou faibles densités du phytoplancton pendant les saisons sèches et pluvieuses, respectivement. Pour la première fois dans un tel type d'environnement, notre étude démontre l'efficacité de C-GEM à démêler l'interaction complexe entre les réactions biogéochimiques et le transport dans un estuaire tropical avec un besoin assez réduit en données. Ceci est un atoût pour les pays en développement, où les programmes de surveillance intensive sont rares. Ces systèmes ont par ailleurs rarement fait l'objet d'investigations par la modélisation.

ABSTRACT

This study investigates the seasonal responses (nutrients and phytoplankton) of a tropical estuary (Saigon River) to pollution loads from a megacity (Ho Chi Minh City, Vietnam) by the Carbon Generic Estuarine Model (C-GEM). C-GEM is a generic one-dimensional, biogeochemical estuarine model which takes advantage of the relationship between estuarine geometry and hydrodynamics to minimize data requirements. The model well captured the evolution trend of organic carbon and phytoplankton in 2017 - 2018. The simulated biogeochemical processes and hydrological effects have elucidated the mechanism of phytoplankton succession. The spatial phytoplankton differences are explained by the high nutrient availability in the urban section and low in upstream and downstream. The distinct seasonal residence time explains the high and low phytoplankton densities in the dry and rainy seasons, respectively. For the first time in such a type of environment, our study demonstrates the effectiveness of C-GEM at unraveling the complex interplay between biogeochemical reactions and transport in a tropical estuary with a weak data requirement. This is significant for developing countries, where intensive monitoring programs are rare. Moreover, these systems have been rarely the object of modeling investigations.

KEYWORDS

Biogeochemical model, eutrophication, nutrient dynamics, primary production, residence time

1 INTRODUCTION

The rapid urbanization and ineffective water management practices are recognized as a risk of water pollution in rivers, estuaries and coastal areas. In contrast to coastal megacities in developed countries, population growth and domestic wastewater volume have increased rapidly in developing countries. Seasonal variations of water quality and eutrophication have been observed in urbanized tropical estuaries (Nguyen et al., 2019). Nutrient limitations, solar radiation, residence times of the water bodies are the drivers of seasonal variation of phytoplankton characterization in estuaries (Lancelot and Muylaert, 2011). This study investigates spatiotemporal patterns of nutrients, organic carbon and phytoplankton biomass (chlorophyll-a) in the urbanized tropical estuary (Saigon River Estuary) under the impact of Ho Chi Minh Megacity (Vietnam), by applying the C-GEM model.

2 MATERIALS AND METHODS

2.1 Study area

Saigon River Estuary is located in the south of Vietnam, with a catchment area of 4720 km^2. From Dau Tieng Reservoir to the estuary mouth, the Saigon River has a length of 200km (Figure 1). The average discharge is 50 $m^3\ s^{-1}$ (30 $m^3\ s^{-1}$ in dry season and 100 $m^3\ s^{-1}$ in rainy season). This estuary is influenced by the semi-diurnal asymmetric tidal regime of the East Sea of Vietnam.

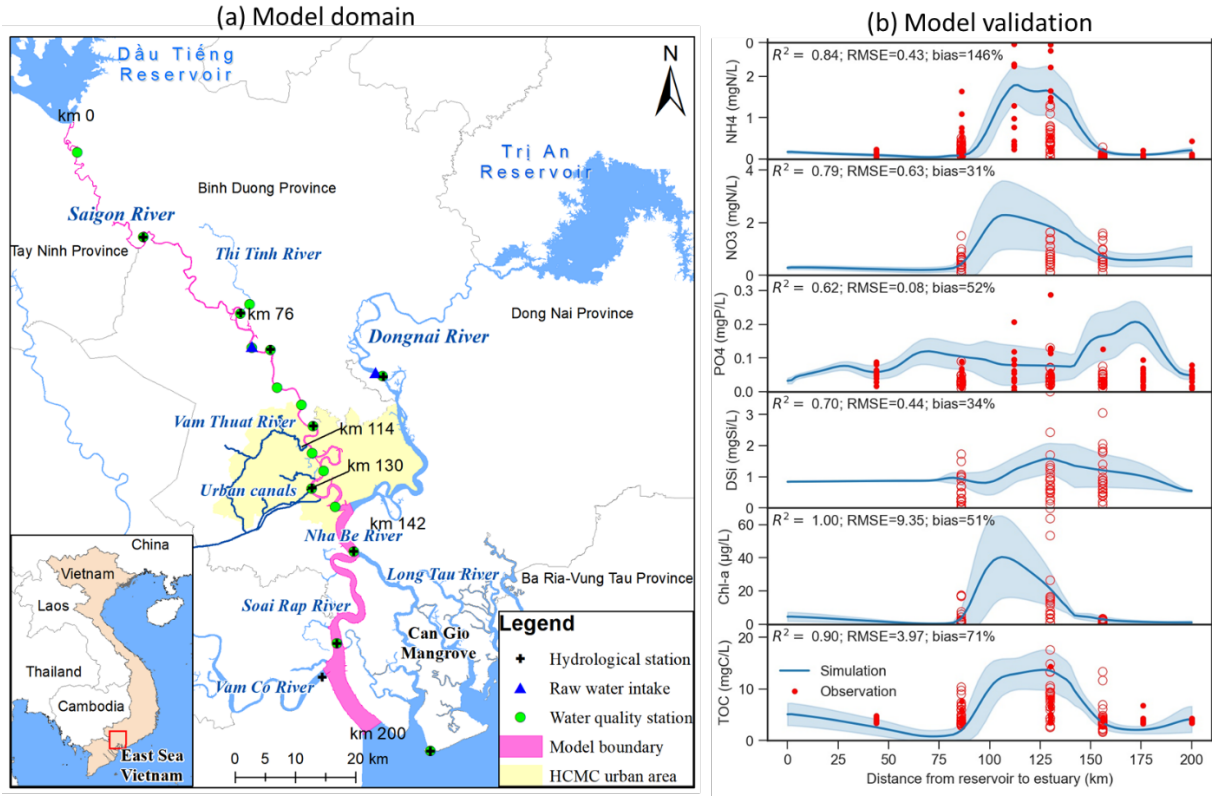

Figure 1. Map of study area (a) and C-GEM model validation (b) for Saigon River Estuary 2017-2018.

The Saigon River mainly lies within Ho Chi Minh City (HCMC), the largest economic center of Vietnam. About 80% of urban domestic wastewater from HCMC is discharged directly into the urban canals system of HCMC and then flow to the Saigon River. The phenomenon of mass fish deaths has appeared regularly in urban canals from 2014 – 2021. The high risk of eutrophication was also reported in the Saigon River (Nguyen et al., 2019).

2.2 Implementation of C-GEM model

The C-GEM is, beside generic, a one-dimensional, reaction-transport model that takes advantage of the relationship between estuarine geometry and hydrodynamics to minimize data requirements. This model has accurately described estuarine hydrodynamics and biogeochemical transformations in several temperate estuaries and recently in a tropical estuary.

The set-up procedure of C-GEM in the Saigon River Estuary is detailed by Nguyen et al. (2021). In general, in the hydrodynamics module, C-GEM requires the upstream discharge and the water level at estuarine mouth. For the biogeochemical module, water quality variables (ammonium-NH_4^+, nitrate-NO_3^-, phosphate-PO_4^{3-}, total organic carbon-TOC, Silica-DSi, dissolved oxygen-DO, phytoplankton and total suspended sediment-TSS) and weather conditions (wind speed, solar radiation) are required for boundary conditions. The input data for seasonal simulation is bi-weekly or monthly monitoring; only tidal elevation and solar radiation are hourly data.

3 RESULTS AND DISCUSSION

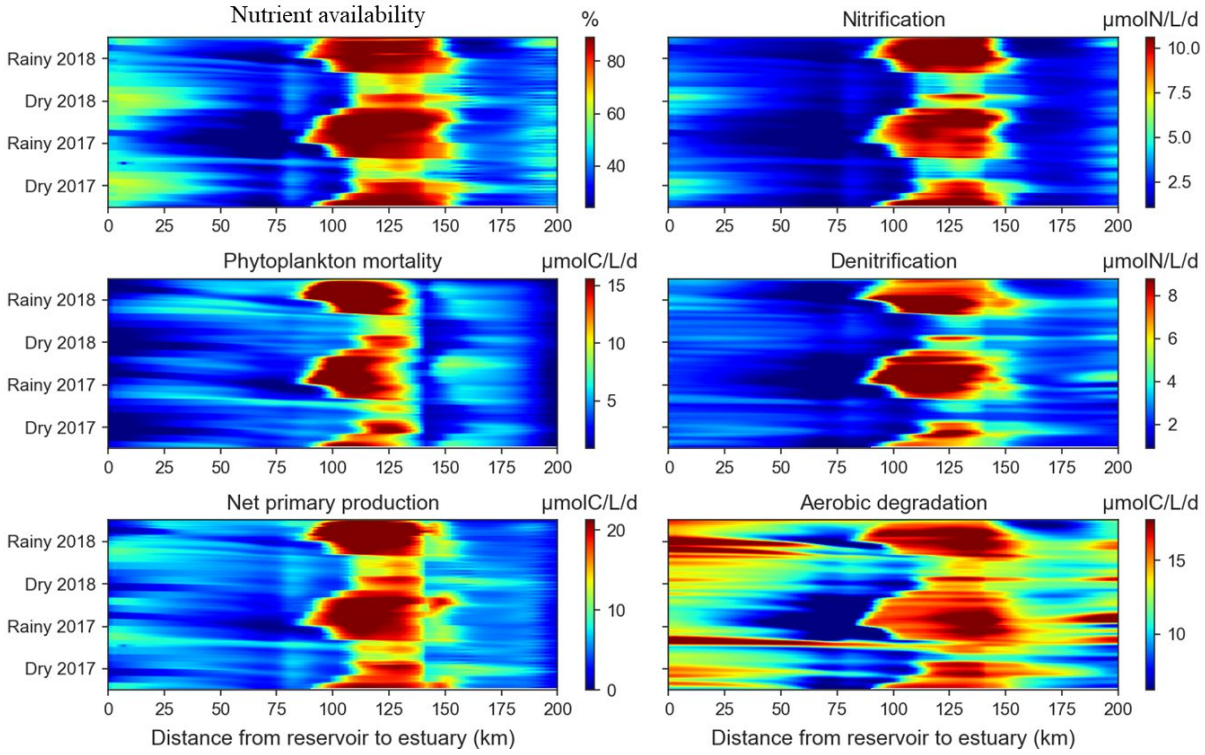

Figure 2. Spatiotemporal evolution of the nutrient availability and biogeochemical processes.

C-GEM performs well the spatial trend of water quality along Saigon River Estuary under the impact of urban wastewater of HCMC (Figure 1). The concentrations in NH_4^+, TOC, Chl-a, DO have significant differences between the three sections, upstream (km 0 – 86), urban (km 86 – 130) and downstream (km 130 – 200) of Saigon River estuary.

Figure 2 depicts the simulated evolution of biogeochemical processes involved in phytoplankton processes and nutrient cycling. A strong nitrification and organic carbon aerobic degradation have been shown in the urban section. These processes explain the decrease in DO concentration under the influence of high nutrient concentrations from urban canals. Besides, the nutrient availability in the urban section for the primary production process is nearly 100% in both dry and rainy seasons. The high nutrient availability explains the high phytoplankton in the urban section. However, phytoplankton biomass in the rainy season is 10-100 times lower than in the dry season, which can be explained by the long residence time of ~120 days in the dry season (vs.~ 20 days in the rainy season). Phytoplankton dynamics requires further studies as residence time is a driven factor of eutrophication.

In conclusion, C-GEM has allowed understanding the mechanisms leading to fluctuations in nutrients dynamics and phytoplankton. This model with a minimized data requirement is particularly useful for assessing the water quality management practices in urbanized estuaries of developing countries.

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