The Study of Seawater Intrusion in Pearl River Estuary Area by a River Network-Estuary-Costal Ocean Coupled Numerical Simulation System

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ABSTRACT

In this paper, a river network-estuary-costal ocean coupled numerical simulation system is developed to study the increasing problem of seawater intrusion in the Pearl River delta and estuary area since it is greatly influenced by the coupled effects of river discharge and oceanic forcing conditions. A numerical model based on one-dimensional Saint-Venant equation is used to resolve the hydrodynamics of the whole river network which involves more than one hundred natural rivers and artificial channels to provide upward boundary conditions for the estuary-costal ocean model. In order to accurately satisfy the irregular coastlines and numerous islands as well as meet the need of grid flexibility and higher resolution, the three-dimensional unstructured-grid Finite-Volume Coastal Ocean Model (FVCOM) is applied to simulate the interacting processes of tidal forcing and river discharge. By establishing a communicational mechanism, these two models are integrated into a simulation system. Then, the simulation system is well calibrated and validated using field measurement and remote sensing data. The results show that the simulation system can correctly capture the dynamic processes of interactions between river discharge and oceanic and meteorological forcings. Based on the validated simulation system, several process-oriented numerical experiments are conducted to study the dynamic process and find out the relationship between these effecting factors such as river discharge, tidal forcing, wind, bathymetric etc. Simulation results indicate that fresh water drifting westward during ebb tide and seawater directly intruding during flood tide is the controlling dynamic process leading seawater intrusion. These important effects on the seawater intrusion from the dynamic interactions have never been investigated and have largely been neglected in the previous investigations of seawater intrusion in the Pearl River Delta and Estuarine area for its complexity of dynamics, which is characterized as “hundreds of interlaced rivers and eight connected outlets to South China Sea”.

KEY WORDS: Estuary; River network; Seawater Intrusion; Numerical Simulation; FVCOM; FVM; Unstructured-grid.

INTRODUCTION

Pearl River Watershed (PRW) is one of the most important water system as well as the most developed area in China. The Pearl River Delta (PRD) is located in the southern part of Guangdong Province, The Pearl River Estuary (PRE) encompasses most important cities such as Hongkong, Macau, Shenzhen, etc and the estuary bays southwardly faces the South China Sea (SCS). In addition, the PRD and PRE are emerged as one of the world’s most complicated hydrodynamic system for its coupled river network-estuary-costal ocean dynamic structure with numerous islands, interlaced rivers and irregular coastlines. At the upstream delta of PRE, more than one hundred of rivers and waterways interlaced each other and finally run into estuary bays and SCS through eight main outlets. For its complexity, a saying goes “hundreds of interlaced rivers and eight connected outlets to SCS”. At the PRE and offshore area, its geometry is characterized by a series of barrier shoals, numerous islands, irregular shorelines and variable water depths and its dynamics is significantly affected by river discharge, tidal force, wave and wind. In appropriate conditions, salty waters from the ocean abnormally advance into the upstream freshwater zone of the rivers and thus jeopardize the freshwater resources. Seawater Intrusion (SI) occurs. Clearly SI is greatly influenced by the coupled effects of river discharge and oceanic forcing conditions. It is largely neglected in the previous investigation of SI for the complexity of PRE and limitation of models. In order to correctly study the characteristics of SI in the PRE using the convenient and efficient numerical method, a river network-estuary-costal ocean coupled simulation system is necessary to be developed. It is tentatively developed in this paper. The simulation system comprises river network part and estuary-coastal part. In the long and narrow rivers, salty concentration distribution is always uniform in cross-sectional direction and linear one-dimensional in along-bank direction. Thus the correlative hydrodynamic factors are not the velocity distribution of rivers but the cross-sectional discharge and water level. In this paper, a one-dimension Saint-Venant equation based numerical model is developed to simulate the hydrodynamics of the whole river network. As to the estuary-coastal part, three kinds of numerical model are available: 1) the most popular Finite-Difference Method (FDM) models, like as the Princeton Ocean Model (POM) (Blumberg and Mellor, 1987), ECOM (Blumberg, 1996), the Regional Ocean Model (ROM) (Haidvogel et al., 2000) and the Environmental Fluid Dynamics Computer Code (EFDC). 2) The Finite-Element Method (FEM) models, like as the Dartmouth College Model (QUODDY) (Lynch and Naimie, 1993). 3) The Finite-Volume Method (FVM) models, like as the Finite-volume Coastal Ocean Model.