Numerical Simulation of Water Pollution in Shenzhen Bay

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Abstract The water pollution in Shenzhen Bay caused by sewage discharge is numerically simulated using ECOMSED, a two-dimensional hydrodynamics and water quality model. The results indicate that Shenzhen River and other land-based pollution sources lead to heavily water pollutions in Shenzhen Bay. The pollutant emissions in Shenzhen Bay and its influences were analyzed, taking the Chemical Oxygen Demand (COD) as a typical event. The water pollution exists in Shenzhen Bay during both wet season and dry season.

Introduction

Along with the rapid economic and social development of Shenzhen City, the growing amount of domestic sewage, industrial wastewater discharge and a large amount of hospital combined with weak environmental awareness, exacerbate the pollution of the Shenzhen River, the river water turning dark and stinking. At present, the Shenzhen river water quality is of class super V, while the Shenzhen Bay water quality is worse than Class III. The continuing deterioration of Shenzhen water environment, and water ecological environment have drawn high attention from the government and the community of Hong Kong and Shenzhen. There is no time to delay the treatment of Shenzhen River.

In this paper, ECOMSED model of the two-dimensional water quality flow is employed to numerically study the water quality variation of Shenzhen Bay. The ECOMSED model was built on the base of the POM model, which was widely popular in 1980s. After several decades of development and integration, ECOMSED is now applicable to rivers, bays, estuaries and coastal seas, lakes, reservoirs and other water environment, with high credibility. Numerical simulation makes it possible to visualize the transport of pollutants, and to provide a scientific basis for the analysis of the sewage situation under different scenarios.

Basic equations and computation domain description

Basic equations

Under the assumptions of hydrostatics and Boussinesq approximation, two-dimensional water quality equations in curvilinear coordinates are written as

$$\frac{\partial U}{\partial t} + \vec{V} \cdot \nabla U = -\frac{\partial h}{\partial x} + \frac{\partial}{\partial x}\left(A\frac{\partial U}{\partial x}\right) + \frac{\partial}{\partial y}\left(A\frac{\partial U}{\partial y}\right) \quad (1)$$

$$\frac{\partial V}{\partial t} + \vec{V} \cdot \nabla V = -\frac{\partial h}{\partial y} + \frac{\partial}{\partial x}\left(A\frac{\partial V}{\partial x}\right) + \frac{\partial}{\partial y}\left(A\frac{\partial V}{\partial y}\right) \quad (2)$$

$$\frac{\partial (C)}{\partial t} + \frac{\partial (UC)}{\partial x} + \frac{\partial (VC)}{\partial y} = \frac{\partial}{\partial x}\left(E\frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(E\frac{\partial C}{\partial y}\right) - KC + S \quad (3)$$

(U, V) are water velocities in the (x, y) direction respectively, η being water level, A being coefficient of horizontal kinematic viscosity, C being density of pollutant, E being turbulent diffusion coefficient, K being attenuation coefficient (or degradation coefficient), S being source and sink of pollutant.

According to the aim of this study, we applied ECOMSED model to Pearl River Estuary and Shenzhen Bay in order to numerically simulate the hydrodynamics characteristics. We developed the water quality model in this area, and analyzed the diffusion and distribution of pollutants, such as COD, inorganic phosphorus and ammonia nitrogen.

Description of area of interest and computation grid

Shenzhen Bay is located in the middle of the east of Lingdingyang Bay by Pearl River Estuary, as illustrated in Fig. 1, is a semi-closed bay narrow in the outside and wide in the inside. The tide in Shenzhen Bay is of irregular and semi-diurnal nature. Due to the reciprocating movement of tide of Lingdingyang Bay in a direction close to south and north, part of it laterally enters Shenzhen Bay. Then water depth decreases in the bay while restricted by the bay topography, and the tide appears to reciprocate along southwest-northeast.

To ensure the simulation accuracy of the influence of tidal current, our computation domain is the entire Lingdingyang Bay including Shenzhen Bay. We adopt body-fitted adaptive mesh generation, which is able to truly reflect the zigzag coast lines. We employ finer grid in the vicinity of Shenzhen Bay, with coarser grid in other area.

The grid number is of 144 × 132. The minimum mesh distribute in the vicinity of Shenzhen Bay with grid length of about 100 meters, while about maximum mesh with grid length of about 600 meters, as shown in Fig. 1. To study the impact of pollutant discharge in Shenzhen Bay, the Shenzhen River and Dasha River are added as sources of pollution. Fig. 1 also marks the location of the main sewage treatment plant neighboring Shenzhen Bay. The right bank of Lingdingyang Bay is the four outlets of Pearl River, from south to north namely, Humen, Jiaomen, Hongqimen, Hengmen. Simulation boundaries are set as following. The upper boundary is Dongsikou on the northeast side; the lower boundary is south to Jiuzhou to Dahao Island on the southside; the right boundary is Shenzhen Estuary on the east side.

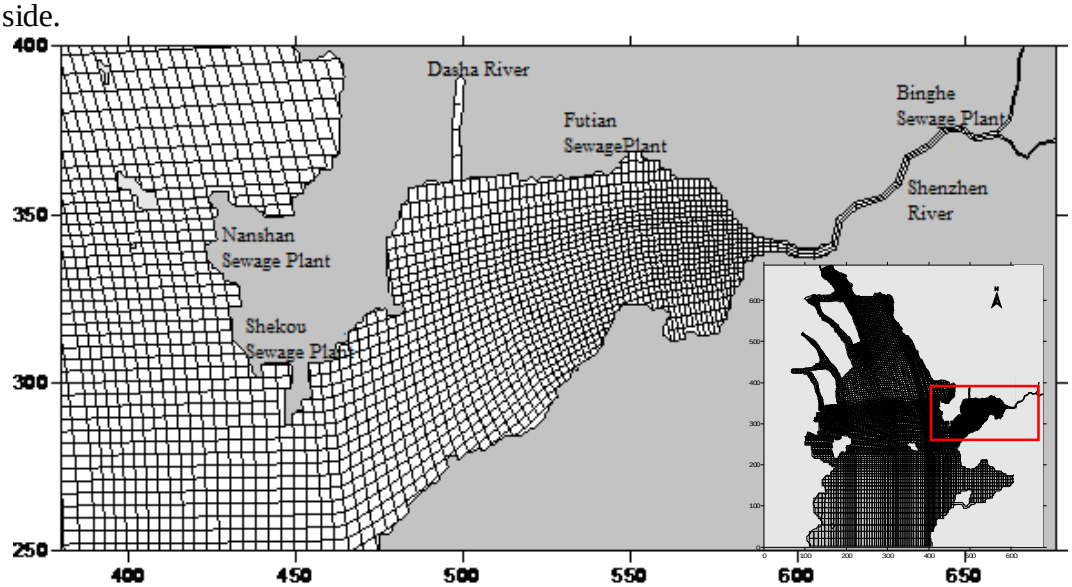


Fig. 1 Adaptive mesh and pollutant distribution of Lingdingyang Bay and Shenzhen Bay

Initial conditions and boundary conditions

The water level or runoffs of four outlets of Lingdingyang Bay and Shenzhen River are required for the two-dimensional hydrodynamic simulation as boundary conditions. Two sets of data is collected as boundary conditions, namely, (1) July 15th to 20th,1999 for wet season; (2) December 1st to 12th, 2003

for dry season, in which the upper boundary consists of Dahu water station and Hengmen water station in Hengmen, and lower boundary being extrapolated from the measured data in Guishan water station.

Shenzhen Bay water quality pollution simulation and result analysis

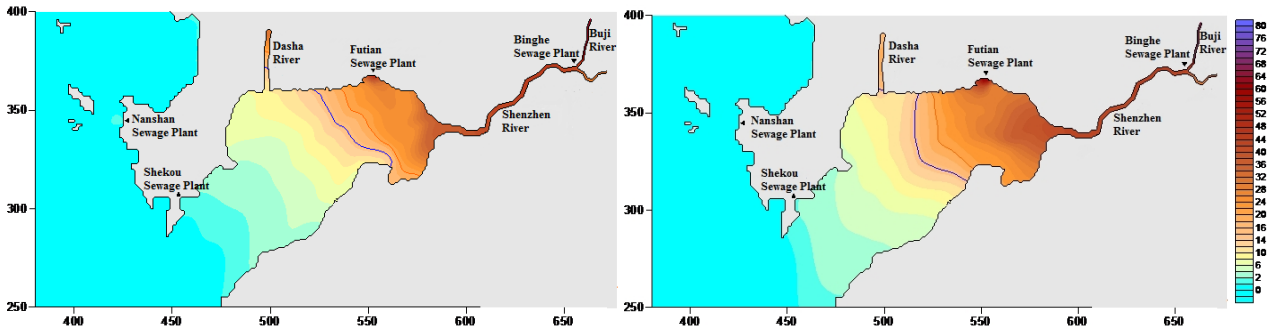
Given the sewage discharge propaganda of different seasons for every land-based pollutant around Shenzhen City and their water quality indexes, as illustrated in Table 1, we set the simulation boundary conditions for every land-based pollutant accordingly.

Table 1 Pollutant emissions statistics along Shenzhen Bay

Receiving Area	Sewage Plant Name	Sewage quantity $x10^4$（m^3/d）		Water Quality Index				
		Dry	Rainy	COD	BOD_5	SS	NH_3-N	TP
Lingdingyang	Nanshan Sewage Plant	100	112.9	60	20	20	8（15）	1.5
Shenzhen River	Luofang Sewage Plant	35	43.6	50			5	0.5
	Binghe Sewage Plant	40	95.35	10	8	10	4（8）	0.4
	Shawan Sewage Plant	6		40	8	10	4（8）	0.4
Shenzhen Bay	Futian Sewage Plant	40	129.7	40	8	10	4（8）	0.4
	Shekou Sewage Plant	8		60	20	20	8（15）	1.5
Dashe River	Xili Sewage Plant	8	13	40	8	10	4（8）	0.4
Buji river	Bujicaopu Sewage Plant	50	75	≤40	≤8	≤10	≤4	≤0.4
	Pudixia Sewage plant	6		40	8	10	4（8）	0.4

We simulate the pollutant diffusion in Lingdingyang Bay and Shenzhen Bay simultaneously, subjected to the boundary conditions of the wet season. Simulation ran 12 days and 288 hours. The results focus on full neap tide in wet season and full spring tide in dry season, we will discuss the Shenzhen Bay pollutant emissions and their influences.

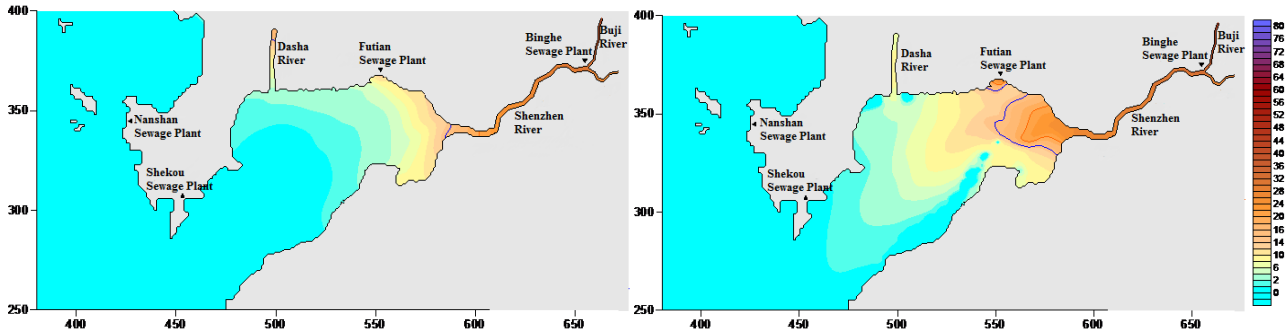
Taking the distribution of COD as a typical event, we discuss the distribution and influence of Shenzhen land-based pollutant produced by sewage discharge.



（a）flood slack （b）ebb slack

Fig. 2 Land-based COD distribution during wet season

Fig. 2 (a) and (b) show the COD distribution at flood slack and ebb slack respectively. During flood period, with upstream runoff increased, and tide effect weakened, pollution area is large. At flood slack, the backwater effects of tidal current make pollutant uneasy to spread. The influence area of pollutants is near the upstream of Shenzhen Bay. At ebb slack, pollutants diffuse with discharged water, exacerbating the pollution in the Shenzhen Bay. At this point, with the pollutants impacting on the entire area of the Shenzhen Bay, the effecting area of highly concentrated pollutants reaches the vicinity of the mid-girdle of Shenzhen Bay.



（a）flood slack （b）ebb slack

Fig. 3 Land-based COD distribution during dry season

Fig. 3 (a) and (b) show the COD distribution during dry season at flood slack and ebb slack respectively. During dry period, with upstream runoff decreased and tide effect strengthened, land-based pollutants from upstream of Shenzhen River are less likely to spread along the watercourse. Taking into account that sewage discharge decreases at this time, the pollution area is smaller than it is in the wet season. When flood slack, the backwater effects of tidal current make pollutant uneasy to spread. The influence area of the pollutants is near the upstream of Shenzhen Bay. When ebb slack, water pollutants discharged with the diffusion, enters the most area of the Shenzhen Bay, and highly concentrated pollutants aggregate at the top of Shenzhen Bay.

Thus, the Shenzhen Bay water pollution caused by the land-based sewage discharge is very serious. Especially during the flood season drop recreation time, the whole Shenzhen Bay contains pollutants. Highly concentrated pollutant is carried by the flow and spread to the girdle the Shenzhen Bay, affecting half of the Shenzhen Bay. The water pollution area in dry season is smaller, and the density is lower, comparing to them in the wet season.

Conclusions

The negative result caused by rapid development of economics and society of Shenzhen city, is the increasing pollution of the Shenzhen River, followed by the severe pollution of water environment in the entire region of Shenzhen Bay. In this paper, a 2D water quality ECOMSED model is employed to numerically study the water environment pollution caused by sewage discharge in the entire Pearl River Estuary Lingding Bay including Shenzhen Bay and its perimeters. The computation is carried for wet season and dry season separately. Taking Chemical Oxygen Demand (COD) as a typical event, we found that pollution exists in Shenzhen Bay during both wet season and dry season. In particular, pollutant in Shenzhen Bay lasts a whole wet season, and when tidewater goes down to rest, the entire Shenzhen Bay is polluted, and highly concentrated pollutant is distributed at mid-girdle of Shenzhen Bay. Simulation indicates that, Shenzhen River and other land-based pollutants are the causes of the severe water environment pollution of Shenzhen Bay.

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