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Modeling investigation of suspended sediment transport in a tidal estuary using a three-dimensional model

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ABSTRACT

This study presents an incorporation and application of a three-dimensional, unstructured-grid hydrodynamic model with a suspended sediment transport module in the Danshui-River estuarine system, Taiwan, and its adjacent coastal sea. The model is verified with data observed in 2010: water surface elevations, longitudinal velocities, salinities and suspended sediment concentration (SSC). The simulations agreed quantitatively with the observations. The validated model was applied to numerical experiments to investigate the formation of the estuarine turbidity maximum (ETM) and the influence of vertical mixing, different freshwater-discharge conditions and bathymetric change on suspended sediment dynamics in the main Danshui-River estuary. The model results reveal that the suspended sediment may be trapped in the deeper section of the river. Higher vertical diffusivity slightly increased SSC because of greater bottom stress during the ebb tide. Under extreme freshwater-discharge conditions, SSC increased considerably at both the surface and bottom layers of the water column, and ETM shifted its location upstream. When we change the bathymetry near the Guandu Bridge in our model, ETM extends its range a further 5.0 km from the river estuary because of higher velocity.

1. Introduction

Suspended sediment concentration (SSC) in tidal estuaries can affect the physical and chemical environment of the water column through resuspension and transportation. Suspended sediments can change light attenuation and affect the cycle of nutrients, organic micro pollutants and heavy metals. Therefore, knowledge on suspended sediment dynamics is essential for quantifying the fluxes of ecologically and chemically important substances and determining the fate of pollutants [1–4].

The estuarine bed is usually composed mainly of the cohesive sediment, which is only transported as a suspended load and undergoes periodic resuspension and deposition. In addition, while examining contaminant transport, the suspended load is usually of significant interest because contaminants are frequently attached to and transported by the suspended sediment. The upper portion of the river bed is only on the order of a few centimetres, and it is generally referred to as the active

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layer. The erosion or resuspension of the bottom sediment from the active layer is one of the major sources of the total suspended sediment in the water column [5]. To simulate the suspended sediment distribution in tidal estuaries, incorporating resuspension and deposition into the suspended sediment transport model is essential.

Because the measurement of suspended sediment dynamics in a laboratory or *in situ* is still difficult, suspended sediment transport models have been widely developed and applied to investigate the dynamic character of suspended sediment transport in tidal estuaries, bays and coastal waters. These include vertical two-dimensional models [6–9], horizontal two-dimensional models [10–16] and three-dimensional models [17–28].

Three-dimensional (3D) models are particularly appropriate in cases such as regions with complex bathymetries, the vertical gradients of salinity and SSC, and density currents. In this study, an existing 3D-unstructured-grid hydrodynamic model (semi-implicit Eulerian–Lagrangian finite element model, SELFE) incorporating a novel suspended sediment transport module was developed and applied to simulate hydrodynamics, salinity distributions and the suspended sediment dynamics of the Danshui-River estuarine system to the north of Taiwan. The model was calibrated and verified by observing water surface elevations, currents, salinities and suspended sediment distributions. The validated model was applied in model experiments aimed at understanding the formation of estuarine turbidity maximum (ETM) and the influences of vertical mixing, freshwater discharges and bathymetric changes on suspended sediment dynamics in the Danshui-River estuarine system.

2. Study site

The Danshui-River estuary (Fig. 1) is the largest estuarine system in Taiwan; its drainage basin covers 2728 km^2 and includes the capital Taipei. The tidal influence spans a total length of approximately 82 km, encompassing the entire length of the Danshui-River and the downstream reaches of its three major tributaries: the Dahan, Xindian and Keelung Rivers. The major portion of the estuary, downstream of the Guandu Bridge (Fig. 1), lies within the Taipei basin, whereas the meandering upstream is confined by high mountains on both sides. The depths and breadths are in the range of 3.95–11.07 m and 390–1452 m, respectively, in the main Danshui-River estuary. Because of the surrounding mountains and narrow river, wind-induced currents are less important in this estuary, except for typhoon-induced violent winds. The major forcing mechanisms of the barotropic flows are the astronomical tides at the river estuary and the river discharges at the upriver section. Tidal propagation is the dominant mechanism controlling the water surface elevation and the ebb–flood flows.

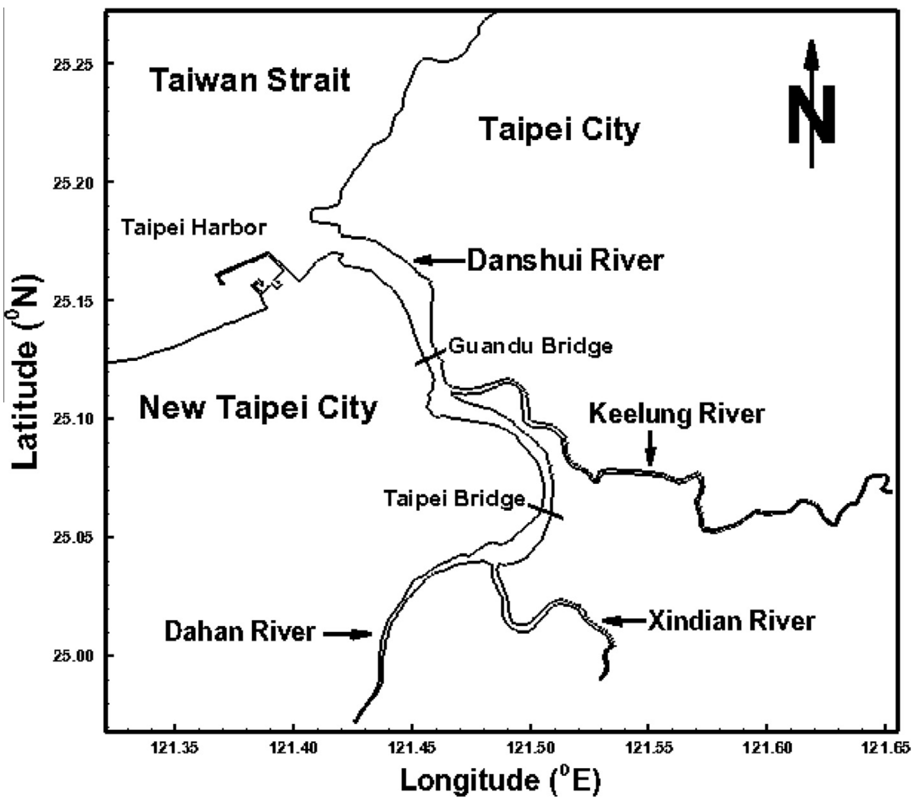

Fig. 1. The map of the Danshui-River estuarine system.