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Using numerical modelling in the simulation of mass fish death phenomenon along the Central Coast of Vietnam

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ABSTRACT

A two-dimensional model was used to reconstruct scenarios related to the mass fish death phenomenon that occurred along the Central Coast of Vietnam. First, a Weather Research Forecasting model was used to simulate the wind field during April 2016, and was then used as an input to the two-dimensional (2D) model. Second, the calibration of the 2D model showed high conformity in both the phases and amplitude between the simulated and observed water levels. The simulation results of two scenarios, S1 and S2, were highly recommended for explaining the mass fish death phenomenon that occurred along the coast from Ha Tinh Province to Thua Thien-Hue Province. The calculated results of water quality data combined with the toxic concentration measured in fish will ultimately enable the simulation of the delimiting pollution zones and will facilitate response solutions when a similar phenomenon occurs in the future.

1. Introduction

Degradation of the environment due to discharge of wastewater from industrial sources is a real problem in many countries. The main source for this appears to be the chemical industry. Wastewaters from the industry may contain toxic pollutants. Some of them may contain a high concentration of nitrogen, which may exist in the form of ammonia, nitrate, and organic nitrogen (Priestly, 1991). The mass fish death phenomenon that occurred along the Central Coast of Vietnam in April 2016 was an environmental disaster in the country. According to the statistics provided by the Ministry of Natural Resources and Environment, there were over 80 tons of dead fish along a 200 km stretch of the coast from Ha Tinh Province to Thua Thien Hue Province from April 04–16, 2016. The disaster had both direct and indirect effects on society and the environment and its consequences may persist in the future. To reduce the long-term effects of the disaster, it is necessary to determine the causes of fish death and better understand the effects of pollutants, and address solutions for environmental and marine ecosystem restoration to prevent similar phenomenon in the future. During January to April 2016, there were over 30 cases of mass fish death phenomenon observed in the world. In general, it is very difficult to determine the cause of any environmental disaster, especially in developing countries where monitoring systems and environmental information are limited. In all cases, the government officials and local people should take a proactive approach in responding to such marine incidents.

Pollution of water resources due to wastewater discharge is one of the main environmental problems that the world faces today. Many human activities have affected the environment, and therefore, new methods need to be addapted for all human activities, and these activities should be well managed (Khodadadi et al., 2005). Water quality models can be useful tools for simulating and predicting transportation of pollution (Benkhaldoun et al., 2007; Hood et al., 2007; Semadeni-Davies et al., 2008; Zoppou, 2001; Bai et al., 2011; Huang et al., 2012; Wang et al., 2013). It has been well-established that surface water quality models play a vital role inestimating the single factors of water quality and representing multiple influences and aspects of water quality. Such models include steady-state models and hydrodynamic models, point source models and models that couple point and non-point sources, and one to three-dimensional models (Wang et al., 2011; Doan et al., 2013a; Doan et al., 2013b). Researchers can categorize these models on the basis of water body types, methods used to establish the models,water quality coefficients, model properties, water quality components, reaction kinetics, and spatial dimensions. However, there is no denying that limitations exist in all water quality models (Wang et al., 2013); therefore, new models or modifications of

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existing models continue to be developed. In recent years, the effect of wastewater discharge into surface waters have been evaluated using mathematical models of water quality (Yetik et al., 2014). Mathematical models can simulate the ecological systems and water qualities in response to changes in surface water resources, which enables the assessment of methods for reducing water pollution. Therefore, the following steps are involved in the development of most numerical models: (i) identification of the domain; (ii) development of the governing equations; (iii) formulation of the initial conditions for the problems; (iv) formulation of the boundary conditions; (v) selection of a method to solve the governing equations; (vi) preparation of a computer program; and finally, (vii) tests of the stability and convergence of the solution, model calibration and validation, and development of pollution scenarios.

2. Materials and methods

2.1. Description of study site

The Central Coast region of Vietnam is located between 14°32N and 18°06N, 105°37′E and 109°05′E. It includes four provinces (the Ha Tinh, Quang Binh, Quang Tri, and Thua Thien Hue Provinces) and one city (Da Nang) (Fig. 1). The distance from the coastline to the Viet-Lao border ranges from 46.5 km to 125 km. The Central Coast region has a very complex topography that includes narrow flat areas with some small, low hills in the east; a segment of the Truong Son high mountain ridge in the west; and many mountains passes crossing the area toward the east (Yokoi and Matsumoto, 2008). The topography is steep from west to east, which results in very short and steep rivers that drain into the ocean. This study focuses on twenty large rivers and 280 small rivers and tributaries. Five of the rivers have a length over 100 km, and the Thu Bon River is the longest river with a length of approximately 205 km. The slopes of the rivers are primarily 20–35 m/km, but in some places, the slopes approach 40–45 m/km. The Central Coast has a tropical monsoon climate. The combination of the climate and physiography, especially the Truong Son mountain range results in a northeast monsoon and the southwest monsoon in Vietnam and the Central region. There are two distinctive seasons in the region, a dry season (January to July) and a rainy season (August to December), with precipitation level higher in the mountainous areas than in flat areas (NCHMF, 2000–2015).

2.2. Model description

The hydrodynamic module used in the two-dimensional (2D) model is a numerical modelling system that is generally used for the simulation of water levels and flows in estuaries, bays and coastal areas. It simulates unsteady 2D flows in single-layer (vertically homogeneous fluids) and has previously been applied in the development of a 2D model for the Central Coast of Vietnam. The 2D model simulates variations in water levels and flows in response to a variety of forcing functions that are resolved on a rectangular or triangular grid that covers the area of interest when provided with bathymetry, bed resistance, wind field, and hydrographic boundary conditions. The module solves the vertically integrated equations of continuity and conservation of momentum in two horizontal dimensions.

2.2.1. Hydrodynamic model

The governing equations of unsteady 2D flow are based on the nonlinear, vertically integrated 2D equations of conservation of mass andmomentum to delineate variations in the flow and waterlevel of all the grids (Martin and McCutcheon, 1998). The continuity equation representing the conservation of mass is given as follows:

$$\frac{\partial \varsigma}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = 0 \tag{1}$$

The momentum equation in the x-direction is

$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial x}\left(\frac{p^2}{h}\right) + \frac{\partial}{\partial y}\left(\frac{pq}{h}\right) + gh\frac{\partial \varsigma}{\partial x} + \frac{gp\sqrt{p^2+q^2}}{C^2.\, h^2} - \frac{1}{\rho_W}\left[\frac{\partial}{\partial x}(h\tau_{xx}) + \frac{\partial}{\partial y}(h\tau_{xy})\right] - \Omega_q - fVV_x + \frac{h}{\rho_W}\frac{\partial}{\partial x}(p_a) = 0 \tag{2}$$

The momentum equation in they-direction is:

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial y}\left(\frac{q^2}{h}\right) + \frac{\partial}{\partial x}\left(\frac{pq}{h}\right) + gh\frac{\partial \varsigma}{\partial y} + \frac{gp\sqrt{p^2+q^2}}{C^2.\, h^2} - \frac{1}{\rho_W}\left[\frac{\partial}{\partial y}(h\tau_{yy}) + \frac{\partial}{\partial x}(h\tau_{xy})\right] - \Omega_p - fVV_y + \frac{h}{\rho_W}\frac{\partial}{\partial xy}(p_a) = 0 \tag{3}$$

where p and q (m^3/s/m) are the fluxes in the x- and y-directions, respectively; t (s) is the time; x and y (m) are the Cartesian coordinates; h (m) is the water depth; d is the time-varying water depth (m); g (9.81 m/s^2) is the acceleration due to gravity; ζ (m) is the sea surface elevation; C is a Chezy resistance parameter ($m^{1/2}$/s); f(V) is the wind friction factor; V, V_x, and V_y are the wind speed and its components in the x- and y-directions (m/s), respectively; Ω is the Coriolis parameter, which is latitude dependent(s^{-1}); Pa is the atmospheric pressure (kg/m/s^2); ρ_w is the density of water (kg/m^3); and τ_{xx}, τ_{xy}, τ_{yy} are the components of effective shear stress.

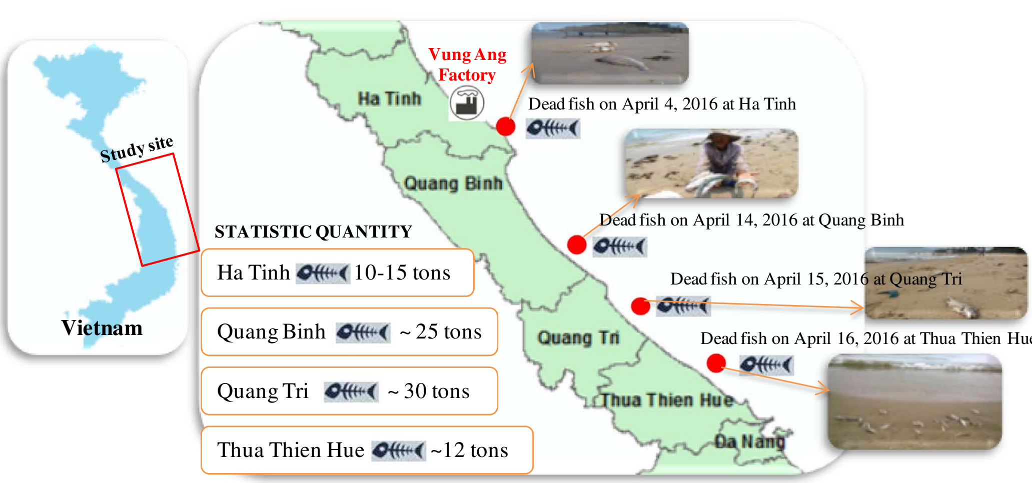

Fig. 1. Detection process of mass mortalities in the study site.