NUMERICAL CALCULATION OF PHOSPHATE TRANSPORT IN BENOA BAY, BALI

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Abstract. A computational model to study the phosphate transport in the coastal environment was presented. It calculation involves the external sources of phosphate matter from the river discharge. The phosphate distribution within the bay forced by tidal current, was calculated by Princeton Ocean Model (POM) 2-dimension (barotropic mode). The tidal current obtained from simulation, shown a reasonably good agreement with in-situ tidal level data at Benoa tidal gauge station. The phosphate transport is generated by two-river discharge within the bay and three sources respected by wastewater treatment in Nusa Dua Bali, vessel parking area and waste garbage dump in Suwung, respectively. The results confirm that a good agreement with the experiment data carried out within the bay.

Keywords: *phosphate transport, Princeton Ocean Model (POM)*

1. Introduction

Benoa Bay is a semi-enclosed bay situated at the southern part of Bali Island (chicken foot area). It communicates with the Badung Strait that separated between Bali Island and Nusa Penida (Figure.1). Environmentally, the Benoa Bay is under the influence of human activities. Local activities such as marine transportation, fisheries port, tourism activity, and high land activity was suffering the water quality within the bay.

There are some good physical and computational models in the areas of oceanography and engineering to describe ocean dynamic (Backhaus and Hainbucher,1987; Nihoul and Djenidi, 1987; Abril and Garcia, 1994). These models can reproduce the variation in height of water and in the current system, induced by tides and wind, by solving the hydrodynamic equations with typical time steps of a few minute or some seconds (Backhaus and Hainbucher,1987; Nihoul and Djenidi, 1987; Abril and Garcia, 1994). Furthermore, they can be used to simulate the particulate matter tracks under specific conditions.

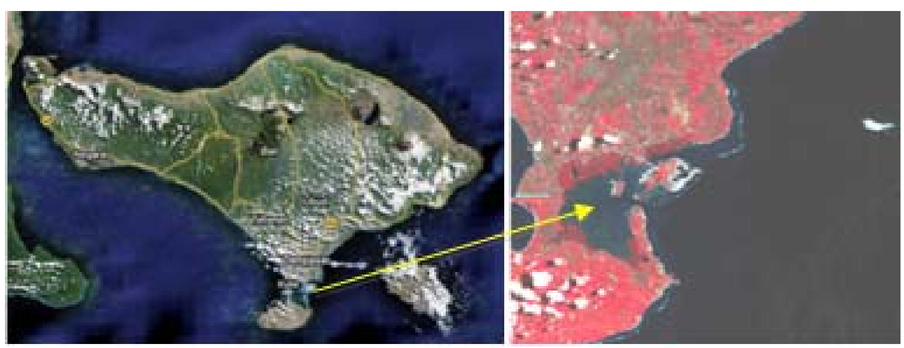

Figure.1 Benoa Bay, Bali.

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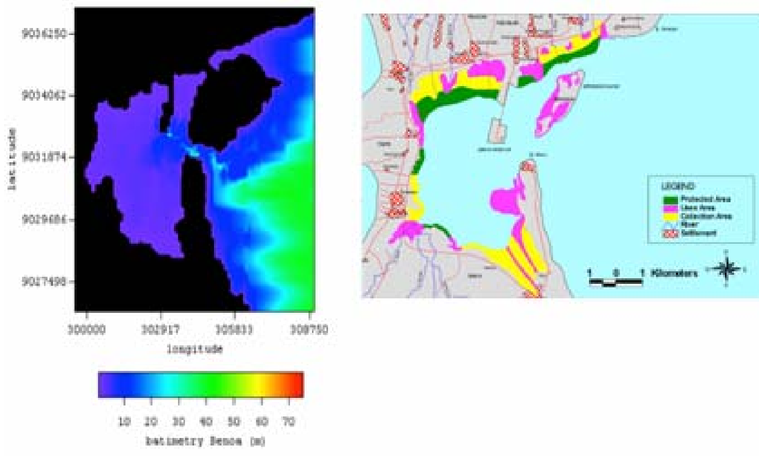


(a). (b).

Figure.2 a) bathymetry map, b) Benoa Bay situation.

The knowledge of water movements in the coastal water is very important in order to describe the pollutant distribution. Water quality in general is a result of hydro physical and biogeochemical interactions. The water current and location of point sources give rise to horizontal differences, whereas many of the biogeochemical reaction depend on crucially upon the depth. In shallow water system the two dimensional (2D) vertically averaged model for water current, transport and water quality have proved successful in a great number of practical application (e.g. Shanahan and Harleman, 1982; Sarkula and Virtanen, 1983; in Virtanen et.al., 1986). Their applicability can largely be attributed to the effective vertical mixing during the open water period and to the proper computational approximation of the transport caused by the frequently varying wind. The objective of this paper is to simulated phosphate transport for the Benoa Bay using a coupled 2-dimensional physical and pollutant transport and use it to identify the environmental condition of Benoa Bay. The phosphate simulated here is ortho-phosphate furthermore called phospate in this paper.

2. Equations for the Model

The water current under the tidal level fluctuation is computed with 2D barotropic mode (external mode) of Princeton Ocean Model (POM). POM is a three-dimensional, primitive equation, time-dependent, σ coordinate, free surface, estuarine and coastal ocean circulation model (Blumberg A, 1987). There are three modes in POM in order to solve the hydrodynamic model, which are 2-dimensional depth averaged (mode 2), prognostic mode (mode 3) and diagnostic mode (mode 4). The equation which is used for this research are presented as follow (Mellor,1998):

$$\frac{\partial \eta}{\partial t} + \frac{\partial \overline{U} D}{\partial x} + \frac{\partial \overline{V} D}{\partial y} = 0 \quad (1)$$

$$\frac{\partial \overline{U} D}{\partial t} + \frac{\partial \overline{U}^2 D}{\partial x} + \frac{\partial \overline{U}\overline{V} D}{\partial y} - \tilde{F}_x - f\overline{V}D + gD\frac{\partial \eta}{\partial x} = -\langle wu(0)\rangle + \langle wu(-1)\rangle$$
$$\frac{\partial \overline{V} D}{\partial t} + \frac{\partial \overline{U}\overline{V} D}{\partial x} + \frac{\partial \overline{V}^2 D}{\partial y} - \tilde{F}_y + f\overline{U}D + gD\frac{\partial \eta}{\partial x} = -\langle wv(0)\rangle + \langle wv(-1)\rangle \quad (2)$$

Equations (1) and (2) are continuity equation and momentum equation, respectively, where:

D = $H + \eta$; $\overline{U}$, $\overline{V}$ are component of depth averaged velocity for x-axis and y-axis, respectively, where $\overline{U} = \frac{1}{D}\int_{-1}^{0} U\, d\sigma$ and $\overline{V} = \frac{1}{D}\int_{-1}^{0} V\, d\sigma$, t-time, H-water depth; η-elevation; g-gravitation acceleration; f-Coriolis effect. We have ignored the Coriolis effect based on the Rossby Deformation Radius due to the small scale of Benoa Bay without effect on coriolis force (Pond and Pickard, 1985).

Diffusivity terms are:

$$\tilde{F}_x = \frac{\partial}{\partial x}\left[H2\overline{A}_M \frac{\partial \overline{U}}{\partial x}\right] + \frac{\partial}{\partial y}\left[H\overline{A}_M\left(\frac{\partial \overline{U}}{\partial y} + \frac{\partial \overline{V}}{\partial x}\right)\right]$$
$$\tilde{F}_y = \frac{\partial}{\partial y}\left[H2\overline{A}_M \frac{\partial \overline{V}}{\partial y}\right] + \frac{\partial}{\partial x}\left[H\overline{A}_M\left(\frac{\partial \overline{U}}{\partial y} + \frac{\partial \overline{V}}{\partial x}\right)\right] \quad (3)$$

where: AM - horizontal diffusivity constant. The terms of <wu(0)> and <wu(-l)> are wind friction and bottom friction, respectively.

In order to calculate the phosphate transport, we coupled phosphate transport equation with POM where the transport advection-diffusion model was determined by adding of POM's subroutine. The equation of transport pollutant phosphate is advection-diffusion 2-dimensional equations. The mathematic equation formulated in the following equation (Rivera, Dian Noor H, 2001):

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = K_x\frac{\partial^2 C}{\partial x^2} + K_y\frac{\partial^2 C}{\partial y^2} + S + R \quad (4)$$

where:

C = Phosphate concentration (mg/l)

Kx,y = coefficient disperse x and y direction (m2/sec.)

u,v = velocity x and y direction (m/sec.)

S = sources term

R = kinetic process (reaction term).

The Kinetic process based on Thomann et. Al 1987 (Dian Noor H, 2001): as follow

$$\frac{\partial p_1}{\partial t} = K_{11}p_1 - K_{12}p_1 + Dpapp_3 \quad (5)$$

$$\frac{\partial p_2}{\partial t} = K_{12}p_1 - Gpapp \quad (6)$$

$$\frac{\partial p_3}{\partial t} = K_{33}p_3 + (Gp - Dp)P_3 \quad (7)$$

where:

P1 = dissolve organic phosphate (mg-p/l)

P2 = orto-phosphate concentration (mg-p/l)

P3 = phytoplankton concentration (mg-p/l)

Gp = phytoplankton growth (sec.)

Dp = phytoplankton death (sec.)

Ap = ratio between phosphate and phytoplankton concentration (mg-p/mg-p)

K12 = coefficient of change reaction P1 to P2 (/sec.)

K11 = lost coefficient P1 (net lost rate) (/sec.)

K33 = lost coefficient P3 (net lost rate) (sec.)

In order to calculate water circulation in Benoa Bay, the tidal level was used as open boundary condition obtained by ORI (Ocean Research Institute, The University of Tokyo) program; the calculation was run for 30 days (1 month). The horizontal grid is in the Cartesian coordinate system contained 75x106 grid point. The grid resolution is 125x125m. The external time step was 2 seconds, based on Courant-Friedrichs-Levy (CFL) stability. The bathymetry data was obtained from Benoa Administrative Harbor (PELINDO).

In lateral boundary condition, zero flow normal was applied to solid boundaries (the land), while along open boundary condition (the ocean) the radiation condition was applied for current and concentration of pollutant. Zero value has given at all grids as initial velocity condition and for the pollutant was given the average of observation data as initial value at all grid, such as organic phosphate 0.036 mg/l, ortho-phosphate 0.211 mg/l, and phytoplankton 0.7827 mg/l.

Tabel 1. Phosphate and Phytoplankton sources concentration.

Sources location	Organic phosphate (mg/l)	Ortho phosphate (mg/l)	Phytoplankton (mg/l)
Badung River	0.08	0.286	1.5654
Mati River	0.101	1.056	3.218
BTDC wastewater treatment	0.071	0.308	3.479
Suwung garbage dump	0.042	0.154	5.218
Vessel parking area	0.037	0.044	0.7827

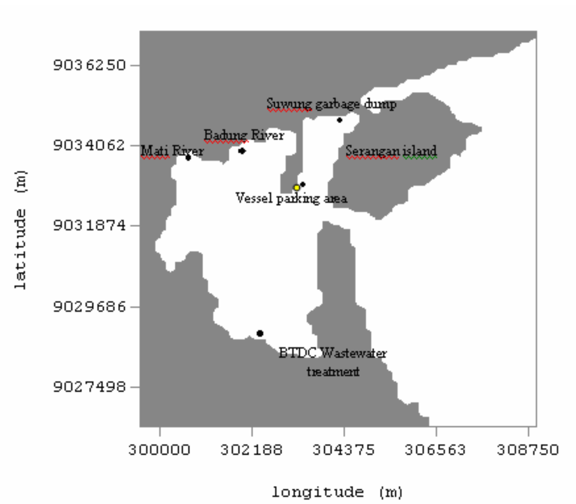


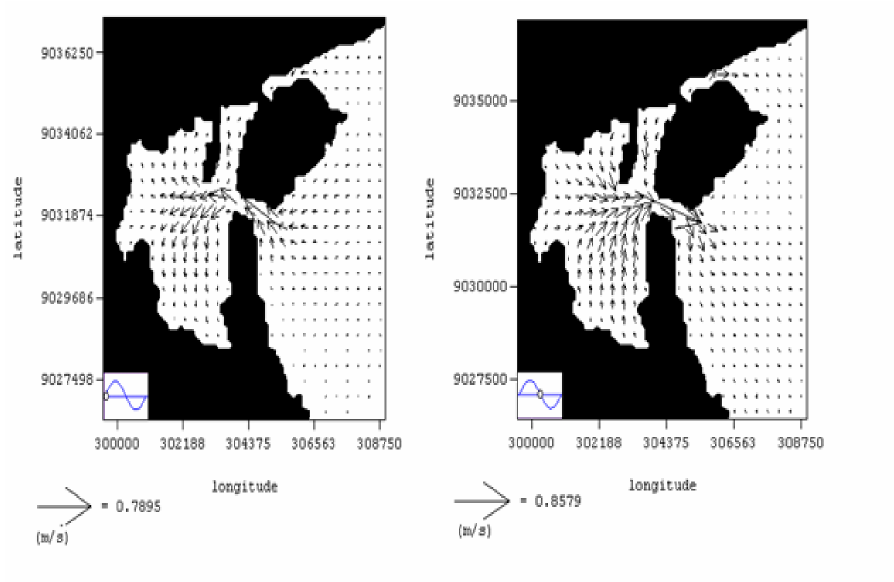
Figure 3. Location of phosphate and phytoplankton sources, indicate with black circle, yellow circle indicate the tidal gauge station.

There are 5 sources of organic phosphate, ortho-phosphate and phytoplankton concentration from rivers and harbor activity entering to Benoa Bay, such as; Badung River, Mati River, BTDC wastewater treatment, Suwung garbage dump and vessel parking area. These values were collected on February 28, 2008. Its loading concentration at each sources are presented in Table 1.

3. Result and Discussions

The simulated of tidal current are shown in Figure 4. The calculation results show that in the bay mouth region, during flood or ebb tide the strong current was occurred in the narrow strait between Serangan Island and Tanjung Benoa.

A strong westward tidal current during flood tide passed through the narrow strait and turn on to the south and northward within the bay. Flood tide current has a maximum velocity about 0.7895 m/s. During ebb tide, the opposite tidal current direction was developed with maximum ebb tidal current velocity about 0.8579 m/s. The comparison of observed data for tidal elevation with model calculation is shown in Figure 5.



(a). (b).

Figure 4. Tidal current pattern; a) during flood tide; b) during ebb tide.

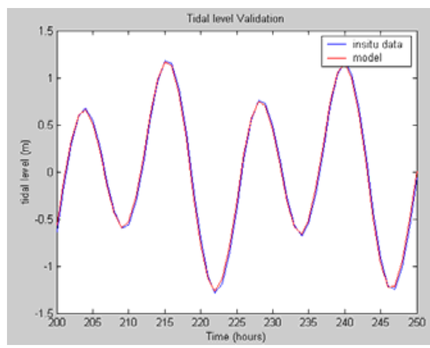


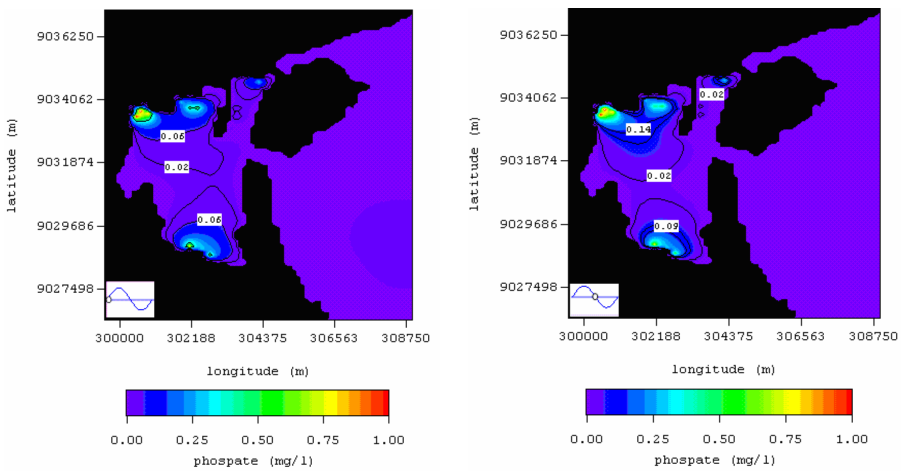
Figure 5. Tidal level verification.

The verification was compared after 200 hours model calculation its concerning to model stability. The figure shown that the observed data has a good agreement with model calculation, but the model calculation little bit higher than in situ data with error value is 0.043 m.

In related to the phosphate transport, tidal generated current was applied to predict its distribution. For this purpose, one-month simulation of the coupled hydrodynamic-transport model has been applied in order to analyze the phosphate from the point sources. The model results of phosphate distribution are shown in Figure 6.

The phosphate distribution is transported well by the tidal current. During the flood tide, the phosphate tend to transported westward within the bay, and an opposite direction occurred during ebb tide. Nevertheless, the dispersion and diffusion also affected the phosphate distribution. It's can be shown that not all of phosphate flushing out to open ocean, but tightly tend to stayed nearest the sources and moved harmonically during ebb and flood tide. The phosphate distribution also affected by the reaction term that the movement of phosphate depends on chemical and biological reaction in the water, its mean that the ortho-phosphate, organic phosphate and phytoplankton in sources distributed chemically and biologically within the bay.

From the simulation the phosphate distribution surrounding the five sources, the phosphate concentration was over than 0.5 mg/l (based on Bali Governor regulation No.8, 2007), especially limitation concentration for fisheries cultivation and tourism activity. The comparison of observed data and model calculation are shown in Figure 7. Its verification shown that the model calculation has a good agreement with observed data.



(a). (b).

Figure 6. Phosphate distribution in Benoa bay: a) during flood tide; b) during ebb tide.

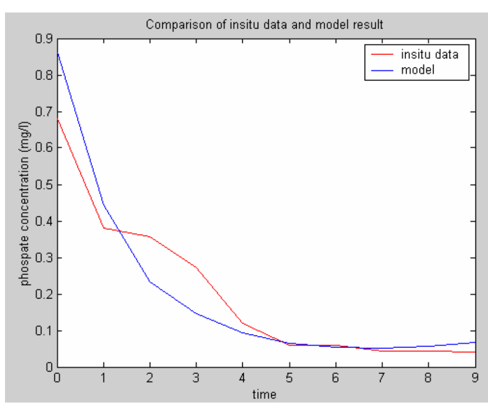


Figure 7. Validation of Phosphate concentration.

4. Conclusion

The tidal current during flood and ebb tide in Benoa Bay were simulated by 2-D barotropic mode using Princeton Ocean Model (POM), and the simulated result reproduce the main characters of current pattern within the bay. The coupled Hydrodynamic-transport modeling was also gives the phosphate transport distribution within the bay with five point sources of phosphate. Tidal current, chemicals, and biological processes were affected the distribution of phosphate within the bay. Phosphate concentration within the bay had also a higher value than the Bali Governor regulation for phosphate concentration.

5. References

Abril, J, M., and L. M, Garcia, 1994, Modelling the distribution of suspended matter and the sedimentation process in a marine environment, *Ecological Modelling,* 71:197-219.

Blumberg, A. F., and G.L,Mellor, 1987, A Description of A Three Dimensional Coastal Ocean Circulation Model. In: Three-Dimensional Coastal Ocean Models, *Coastal Estuarine Studies,*4:1-16.

Dian Noor H., 2001, Model Numerik Dua Dimensi Penyebaran Fosfat di Perairan Pantai Banjir Kanal Timur, Semarang. Bachelor final report at oceanography study program, Bandung Institute of Technology.

Mellor, G. L., 2004, Users Guide for A Three-Dimensional, Primitive Equation, Numerical Ocean Model. Program in Atmospheric and Ocean Sciences, Princeton University. Version: June 2004.

Pond and Pickard, 1985, Introductory dynamical oceanography. Pergamon Press. UK.

Virtanen, MA., L. J. Koponen, K. Dahlbo, and J. Sarkkula, 1986, Three-Dimensional Water-Quality-Transport Model Compared With Field Observations. *Ecological Modelling*, 31:185-199.