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NUMERICAL CALCULATION FOR THE RESIDUAL TIDAL CURRENT IN BENOA BAY-BALI ISLAND

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Abstract

Princeton Ocean Model (POM) was used to calculate the tidal current and M2-residual current in Benoa Bay using barotropic model (mode 2). The model was forced by tidal elevation, which was given along the open boundary condition using tide data prediction from Hydro-Oceanography Division-Indonesian Navy (DISHIDROS TNI-AL). The computed tidal current and residual current have been compared with both data in Benoa Bay, that are data of the open boundary of Benoa Bay and condition of Benoa Bay after developed a port and reclamation of Serangan Island. The maximum velocity of tidal current for open boundary conditions at flood tide is 0.71 m/sec, whereas at ebb tide is 0.65 m/sec and the maximum velocity after developed a port and reclamation of Serangan Island, at flood tide, is 0.69 m/sec. The simulation of residual current with particular emphasis on predominant constituent of M2 after developed a port and reclamation of Serangan Island shows a strong flow at the western part of Tanjung Benoa and Benoa Harbor and also at bay mouth between Serangan Island and Tanjung Benoa. Maximum velocity of M2-residual current is 0.0585 m/sec by the simulation and showed that the current which was produced forming two eddies in the bay of which one eddy is in the mouth of bay in southern part. The residual current for open boundary condition of bay shows four eddies circulation, one big eddies and the others small. The anticlockwise circulation occurs in the inner part of the bay.

Key words: model, simulation, tidal current, residual current

I. Introduction

Benoa Bay is located at the southern part of Bali Island (Figure 1), with the mangrove forest plants at the surrounding of its coast. Benoa Bay has a shallow water depth where generally the depth is 2-27 m. The coral covers almost the bottom water of the bay. This bay can be classified as semi-enclosed water where the lateral dimension is 10 km x 5 km. The bay is protected by Serangan Island and Peninsula in the mouth-bay.

The environmental features of the bay are under the influence of human activities in Benoa Bay. Local activities such as marine transportation port and fisheries port may also contribute to the spill from traffic vessel, organic pollution and eutrophication. In order to analyze the environmental impact in Benoa Bay, we have to know the water circulation of the bay. The circulation has an important role in material transport. Until now, we have not found a publication about the study on the water circulation in Benoa Bay yet. So, this research is a first attempt applied to Benoa Bay.

The aim of this research is to analyze the water circulation in Benoa Bay, especially for case of open boundary conditions around Serangan Island and another case generated by tidal elevation, residual flow using numerical experiments after developing Benoa port and

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reclamation of Serangan Island. The numerical model is applied by Princeton Ocean Model (POM) using external mode for two dimensional vertically integration approach. This approach is based on bathymetry profile, which has 2-25 m depth generally.

II. Numerical Model Descriptions

POM has two modes in numerical calculation related to split mode time step. This method was used in order to reduce the large amount of computational work in three-dimensional calculation. The two modes are: (1) External mode is used to compute two-dimensional problems (barotropic mode) by the vertically integrated equations, and (2) Internal mode is used to solve for three-dimensional problems (prognostic and diagnostic). A description of the model code was described in detail by Mellor (1998).

This research uses external mode to compute two-dimensional water circulation by the vertically integrated equations. The equations are presented as follows (Mellor, 1998):

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

$$\frac{\partial \overline{U}D}{\partial t} + \frac{\partial \overline{U}^2 D}{\partial x} + \frac{\partial \overline{UV}D}{\partial y} - \widetilde{F}_x - f\overline{V}D + gD\frac{\partial \eta}{\partial x} = -<wu(0)> + <wu(-1)>$$

$$\frac{\partial \overline{V}D}{\partial t} + \frac{\partial \overline{UV}D}{\partial x} + \frac{\partial \overline{V}^2 D}{\partial y} - \widetilde{F}_y + f\overline{U}D + gD\frac{\partial \eta}{\partial x} = -<wv(0)> + <wv(-1)>$$

(2)

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

$D = H + \eta$; U, 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 (Pond and Pickard, 1985) due to the small scale of Benoa Bay without effect on coriolis force.

Diffusivity terms are:

$$\widetilde{F}_x = \frac{\partial}{\partial x}\left[H 2\overline{A}_M \frac{\partial \overline{U}}{\partial x}\right] + \frac{\partial}{\partial y}\left[H\overline{A}_M\left(\frac{\partial \overline{U}}{\partial y} + \frac{\partial \overline{V}}{\partial x}\right)\right]$$

$$\widetilde{F}_y = \frac{\partial}{\partial y}\left[H 2\overline{A}_M \frac{\partial \overline{V}}{\partial y}\right] + \frac{\partial}{\partial x}\left[H\overline{A}_M\left(\frac{\partial \overline{U}}{\partial y} + \frac{\partial \overline{V}}{\partial x}\right)\right]$$

(2)

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

In this paper, the tidal current and residual current is calculated by the tidal elevation and M2 component respectively. The tidal elevation is given by along open boundary using tidal prediction, which was based on tidal constituents from Hydro-Oceanography Division-Indonesian Navy (Figure 1). Calculation for tidal current was run for 20 days (480 hours). For the case of the residual current, the M2 component has been applied to calculation due to its highest amplitude among tidal constituents in Benoa tidal station (DISHIDROS TNI-AL, 2003) (Figure 2). The calculation for the residual current was run for 9 days, because after 9 days the calculation will be stable.

The horizontal grid is in the Cartesian coordinate system, contained 43 x 64 grid points. The grid resolution is 200 m x 200 m. The external time step is 5 seconds based on *Courant-Friedrichs-Levy* (CFL) stability. The bottom topography of Benoa Bay is shown in Figure 3, of which the bathymetric data was obtained from Hydro-Oceanography Division-Indonesian Navy (DISHIDROS TNI-AL), Bathymetric Map no. 290.

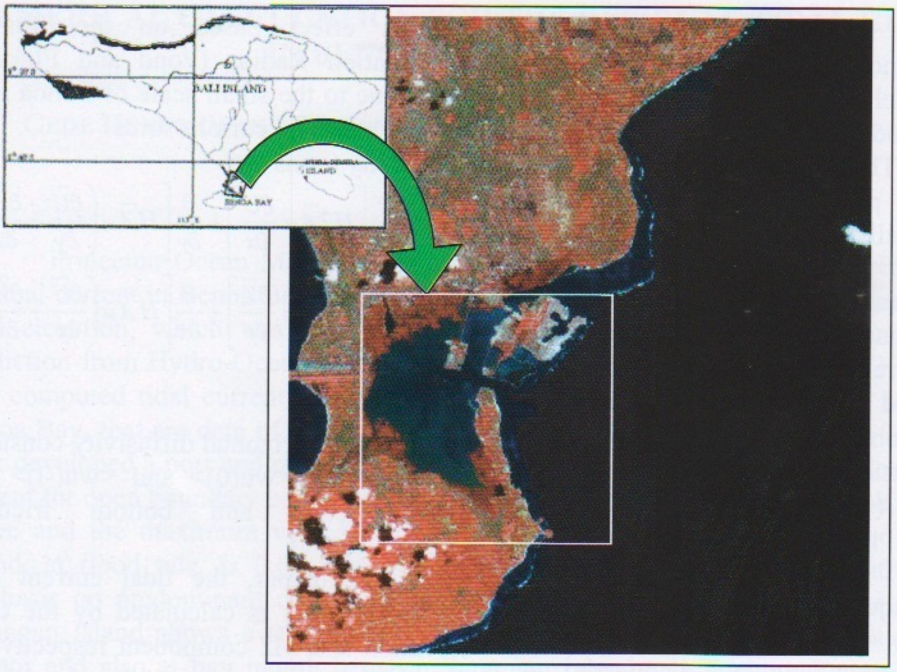

Figure 1. Model region (box line) in Benoa Bay

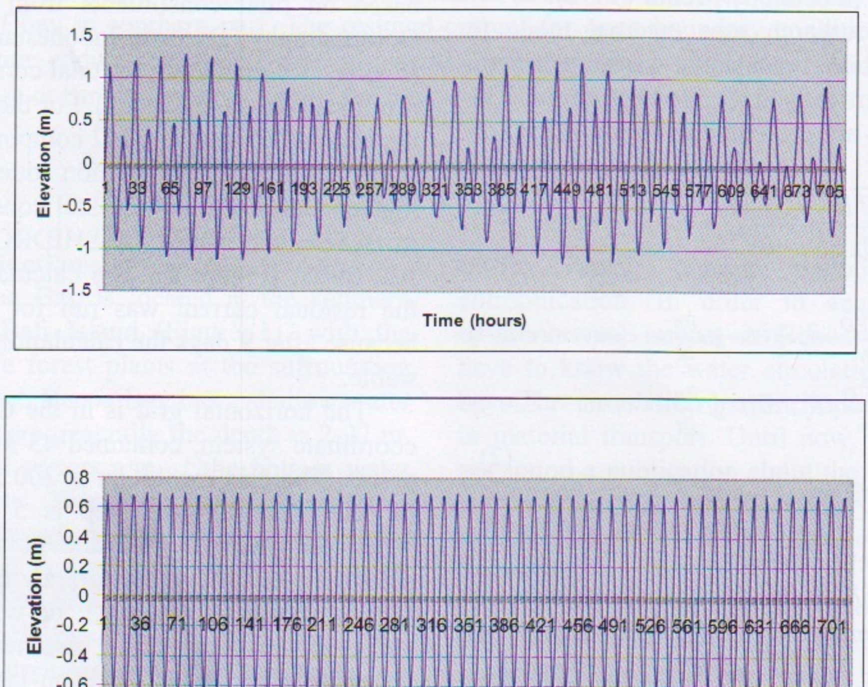

Figure 2. (a)Tidal elevation data prediction, (b) Tidal elevation of M2-component

In lateral boundary conditions, zero flow normal was applied to solid boundaries (the land), while along open boundary (the ocean), the radiation condition was applied for the calculating of currents. Tidal elevation was given along open boundary using tidal prediction, which was based on tidal constituents from Hydro-Oceanography Division-Indonesian Navy (DISHIDROS TNI-AL, 2003). Zero values have given at all grids as initial conditions.

III. Results Of Numerical Simulation

The calculated of tidal currents for open boundary condition of Benoa Bay and after developed a port and reclamation of Serangan Island are shown in Figures 4 and 5. Generally, the water column flows into the bay through flood tide current and outflows from the bay through ebb tide current.

The result of tidal current pattern in Benoa Bay after developed a port and reclamation of Serangan Island shows the current flow into the bay through southern part of the bay, but in northern part of bay the velocity is very low. The maximum velocity of tidal current reach 0.71 m/sec, it is occurred at narrow strait between Serangan Island and Tanjung Benoa. The weak of current occurs in western side of Benoa port, between Serangan Island and Benoa port, northern side of Serangan Island and southern side of bay, respectively. These occurred because the existence of Serangan Island and bridge which is connected Bali Island and Serangan Island can be blockaged the current which comes from open sea during flood tide and blockaged the current from inner part of bay to the open sea during ebb tide. This phenomenon will provide the water exchange, and later will be influenced the water quality in Benoa Bay.

Whereas the calculation of tidal current at the open boundary condition of north area of Bay, the current flow into the bay from northern part and southern part of bay mouth. The maximum velocities of tidal current reach 0.69 m/sec, it is lower than after Serangan island reclamation. At the open boundary condition it also shows that the current coming from the open sea and outflow from the bay can occur neatly. When the material flow into the bay from the river and human activity around the bay can be washed by the coast current, then the water quality in the bay can be better than condition of Benoa Bay after reclamation of Serangan Island.

The residual flow has been calculated by using tidal elevation of M2-component. The tide-induced residual current is defined as the flow which is caused non-linearity of tidal current in relation to horizontal boundary geometry and bottom topography. The M2-component was used by the reason of its highest amplitude among tidal constituents in Benoa tidal station (DISHIDROS TNI-AL, 2003). The calculated M2-residual current is shown in Figure 6. When in open boundary condition, the M2-residual current governs four eddies circulation; one big eddies and the other small. The anticlockwise circulation occurred in the inner part of the bay. The maximum velocity of M2-residual current can reach 0.075 m/sec, especially at surrounding of Tanjung Benoa.

Whereas after reclamation of Serangan Island and developed Benoa port, the M2-residual current governs three eddies circulation; two big eddies and the other small. The anticlockwise circulation occurred in western side of Tanjung Benoa and big one is clockwise circulation occurred in western side of Benoa Harbor. The clockwise circulation also occured at bay mouth. The maximum velocity of M2-residual current can reach 0.0585 m/sec. The tendency of these eddies circulation is caused by geometric profile, as found at Tanjung Benoa and Serangan Island.

For environmental management in coastal area in the Benoa Bay, the tidal residual current have an important role to make an arrangement, because the flow that occurs in the bay area used to be much affected by residual current for material distribution in the bay. At the open boundary condition of northern Benoa Bay the material distribution can be predicted to spread out in the bay mouth, but after reclamation and develop Benoa port, the material distribution will spread out in inner part of the bay. These are result of the pattern of residual current which has been formed in the bay. This condition of environment will affect on coastal pollutant accumulation in the bay.

If we look from satellite data (MODIS) for sea surface temperature (SST) (Figure 7), we can see the high temperature occurred in the eastern part of Benoa Bay, especially in the bay mouth. This can be influenced by the water circulation within the bay. But this data is not enough to be used for analysis the SST in more details, because the resolution of MODIS is 1 km, whereas the area of Benoa bay is not so large, it is around 10 x 5 km

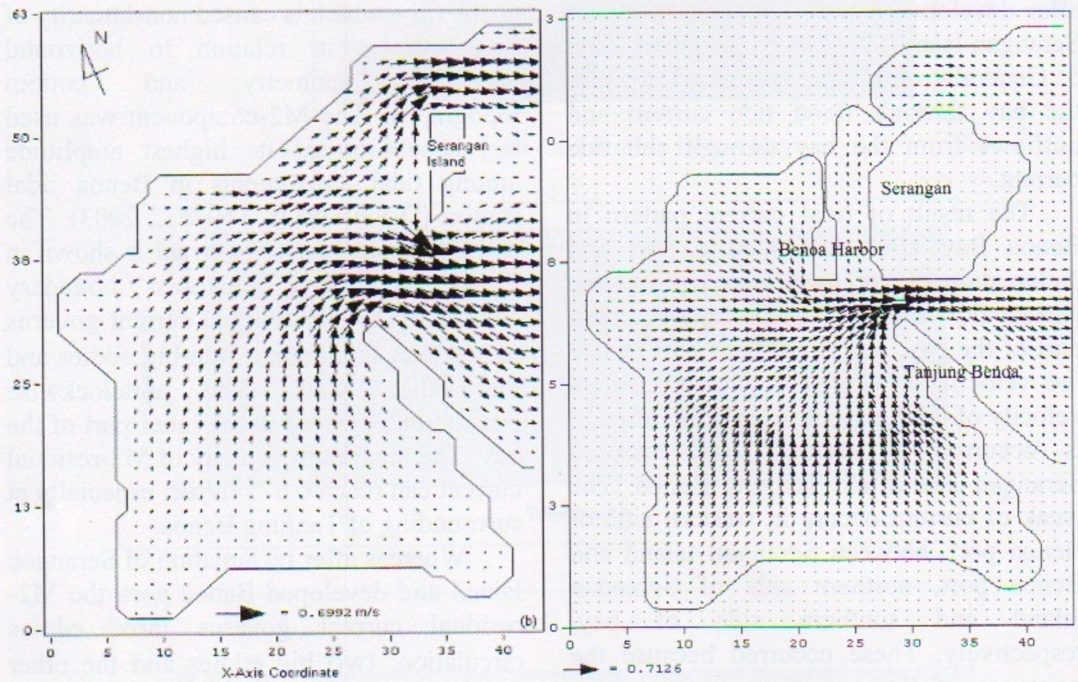

Figure 4. The calculated depth averaged tidal current during ebb tide at spring tide: (a) original condition (b) after reclamation of Serangan Island and develop Benoa port

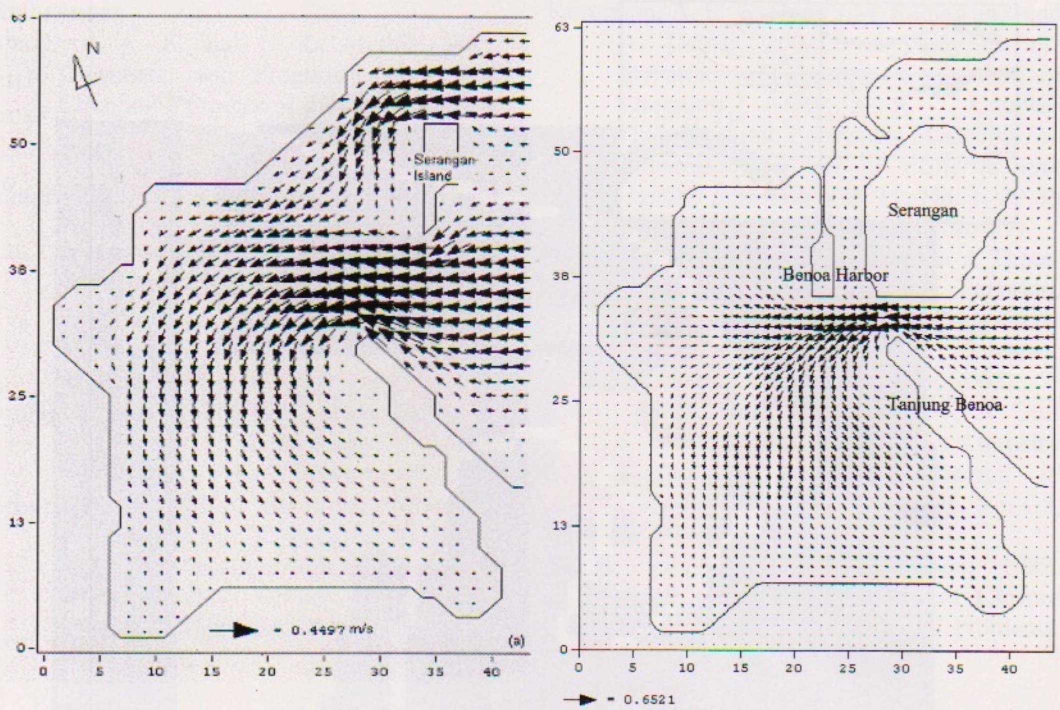

Figure 5. The calculated depth averaged tidal current during flood tide at spring tide: (a) original condition (b) after reclamation of Serangan Island and develop Benoa port

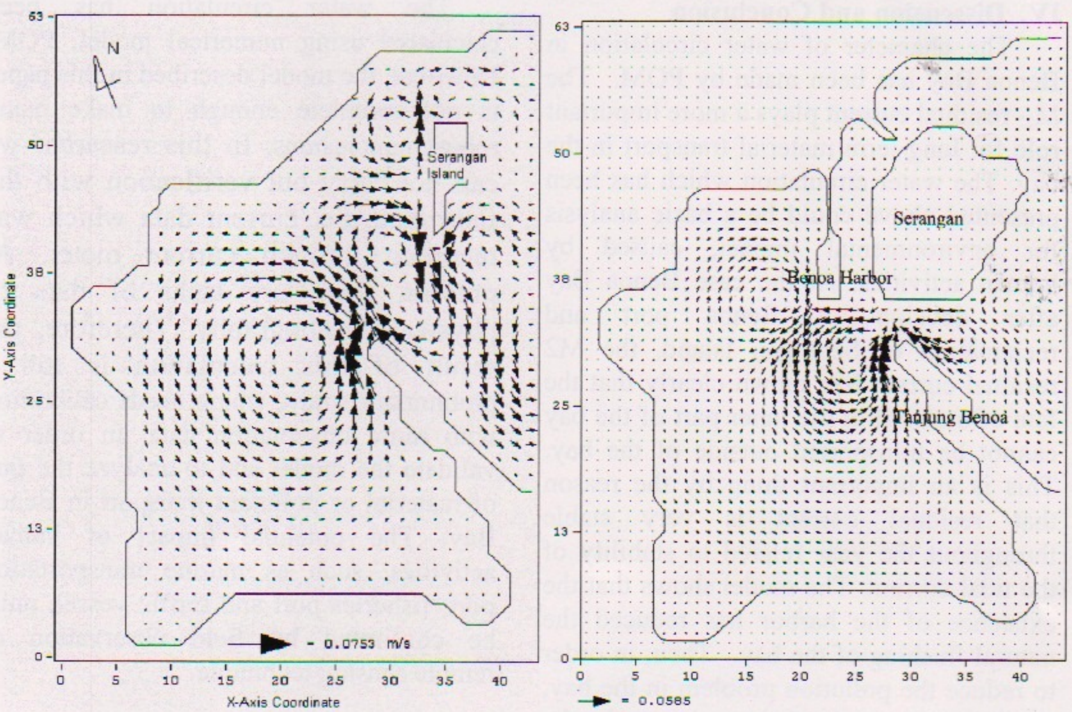

Figure 6. The calculated M2-residual current (depth averaged), (a) original condition (b) after reclamation of Serangan Island and develop Benoa port

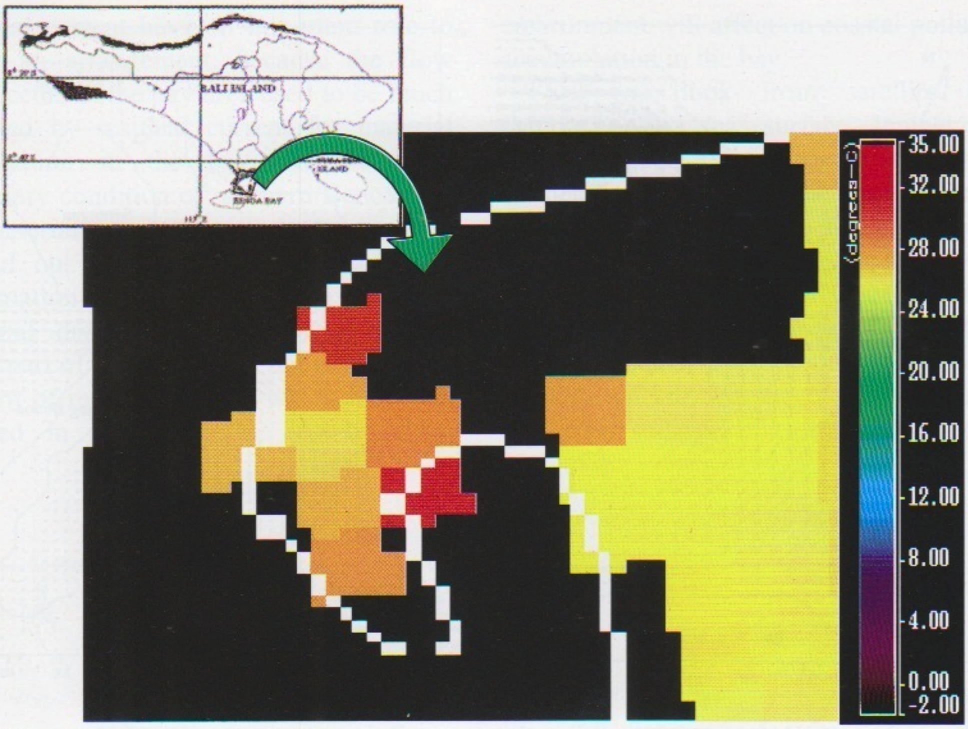

Figure 7. Sea surface temperature (SST) analysis from MODIS data

IV. Disscusion and Conclusion

The character of water circulation in Benoa Bay has been made by POM. The M_2- residual current plays a more important role for long-term material transport in the bay. The water circulation which has been presented above could be a basic analysis for environmental impact, caused by human activities. At the case Benoa Bay after develop of Benoa port and reclamation of Serangan Island, the M2 residual current has shown clearly that the fate of material in the inner part of the bay cannot be transported outside of the bay. This is an important thing by the reason that residual current is very stable throughout the year related to stability of the tidal current. The model shows that the existence of the harbor has reduced the natural flushing of the bay. Then, in order to reduce the pollution problem in the bay, the highly control of waste water in the rivers has to be made.

The water circulation has been calculated using numerical model, POM. However, the model described in this paper is not complete enough to make many robust conclusions. In this research, we can not carry out verification with the field data, i.e. current data which was recorded through current meter. At present, there are lacks of data of physical oceanography. Therefore, the result of this calculation is still a preliminary study, which needs calibration with more observation data, in order to validate the model and to analyze the fate of material or pollutant transport in Benoa Bay. The potential impact of human activities, such as marine transportation port, fisheries port and traffic vessel, must be confirmed by field observation or remote sensing technique.

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