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Current change caused by coastal reclamation and correlation between flows and pollutants in the Jakarta Bay

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Abstract

This work studied influence of coastal line change on the seawater flow patterns and relationship between concentration of pollutants and seawater flow structure utilizing an unstructured finite volume coastal processes and artificial human activities for the economic development as a port city during last 30 years. Dynamic change of coastal line by artificial activities and inflow of highly concentrated pollutants to the sea from land made difficulty in predicting water quality. In numerical model, 4 major rivers are included as main sources of pollution and driver discharge rate at the rainy season is considered since usually more pollutants are introduced into the sea than in the dry season. With the aim of showing flow tendency, circulations were simulated at high and low tides and residual flows were calculated in each 1971, 1996 and 2011. Frontal lines between dominant currents were visualized in each case as characteristics of current patterns in this area. Such fronts varied depending on tide in short term and the coastal line change in the term. Frontal lines were compared with contours of concentrations of DO, Pb, As and pH, which were collected in the previous researches. The distributions of each chemical component in the water column and bottom sediment coincide with the flow structures from the model. As a result, it could trace not only the origins but also the courses of movements of the factors.

Keywords: FVCOM, coastline, frontal line, concentration

1. INTRODUCTION

This study is aiming to know how the flow of the seawater changes by the coastline change related with pollutant distribution in Jakarta Bay using a coastal ocean model.

Coastline has some natural variabilities or can be changed artificially by structures such as groins, seawalls and breakwaters. As a natural sediment source, Mt. Salak in the upstream and upper Jakarta supplies sediment into Jakarta Bay through a river. While this mechanism extends coastline toward offshore, coastlines are eroded and retreated or proceed by sedimentation toward offshore by wave [1]. Figure 1 shows pre and post coastal shapes after an artificial change of coastline by the harbor construction and some reclamation.

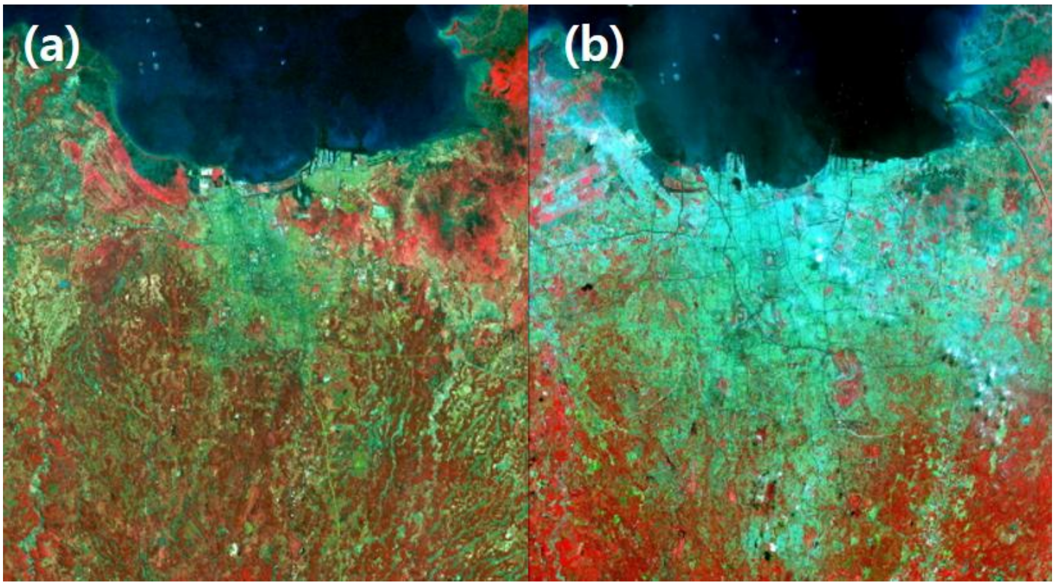

Figure 1. Satellite images of Jakarta Bay coastline [2]. (a) 1997, (b) 2004.

Along with the natural and artificial modifications of the coastal lines, the rapid economic growth deteriorated the environmental of Jakarta Bay due to use a port after 1970s [3]. Moreover, the wastes of the growing city have been released directly to the coast of Jakarta through rivers and canals, with illegal dumping (Figure 2). The environmental deterioration by heavy loads of waste and the current pattern change due to the coastal line variations must be serious but conflicting problems in Jakarta since the economic growth through developing coast along with reclamation should compete with the natural tourist attraction.

Figure 2. Condition of pollution of coast in Jakarta Bay. (a) Location of Maura Angke. (b) Coast of Maura Angke. (c), (d) The habitat of Mangrove in Maura Angke. The waste is dumped by ambient facilities such as harbor, factory. The poor lives over the waste of coast.

The researches for the environment of Jakarta Bay have been performed by the previous works. High variability of the metal accumulations has been reported by [4, 5, 6, 7]. [8] studied that mercury content were higher than standard maximum concentration with analysis of the freshwater and seawater sampling in the estuary and the river. The research of [9, 10] also showed metal pollutions of Java Sea through identifying the Mercury of sediment samples from the coast. [11] researched the seawater and found high metals and organic compounds by 59 sampling from the coastal sediment at the bay bottom. On the other hand, [12] argued the important of enforcement of regulations related with environment since the concentration of heavy metals such as Pb decreased after Indonesia government regulated.

The flow of Jakarta Bay is affected dominantly by wind and current. [13] shows that seasonal wind (monsoon) affects seawater flow significantly by simulating Java Sea including tide, wind driven circulation, wave, surface and bottom stress using WAM called a third-generation wave model. The flow tendency of Java Sea is changed according to wind direction because influence of seasonal wind is relatively stronger than tide. [14] explained that the wind is a dominant factor of not only seawater flow but also making vertically well-mixed condition by determining Ekman layer in Java Sea using Princeton Ocean Model (POM).

2. METHOD

2.1 Numerical Model

FVCOM (Finite-Volume Coastal Ocean Model) combines advantages of finite difference method and finite volume method [15]. Governing equations are below.

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}-fv=-\frac{1}{\rho_0}\frac{\partial P}{\partial x}+\frac{\partial}{\partial z}\left(K_m\frac{\partial u}{\partial z}\right)+F_u \quad (1)$$

$$\frac{\partial u}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}-fu=-\frac{1}{\rho_0}\frac{\partial P}{\partial y}+\frac{\partial}{\partial z}\left(K_m\frac{\partial v}{\partial z}\right)+F_v \quad (2)$$

$$\frac{\partial P}{\partial z}=-\rho g \quad (3)$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (4)$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\frac{\partial}{\partial z}\left(K_h\frac{\partial T}{\partial z}\right)+F_T \quad (5)$$

$$\frac{\partial S}{\partial t}+u\frac{\partial S}{\partial x}+v\frac{\partial S}{\partial y}+w\frac{\partial S}{\partial z}=\frac{\partial}{\partial z}\left(K_h\frac{\partial S}{\partial z}\right)+F_S \quad (6)$$

$$\rho=\rho(T,S) \quad (7)$$

x, y, z are elements of Cartesian coordinate and u, v, w are velocity of x, y, z directions. ρ, P, f, g, K_m, k_h, F_u, F_v, F_T, and F_S represent density, pressure, Coriolis parameter, gravity, vertical eddy viscosity, thermal vertical eddy diffusion coefficient, horizontal momentum, thermal diffusion, and salt diffusion term [15].

FVCOM is calculated by unstructured grid. Structured grid uses a rectangular shape for analysis of structures and solid matter. Unstructured grid to use a triangle shape can be used for analysis of rivers and oceans because unstructured grid is more flexible than structured grid to express topography. Sigma layer coordinate as vertical direction coordinate divides depth to the specified number of sigma layer by same interval. It has the advantage which handles easily bathymetry of complex change in the ocean.

2.2 Input Data

Coastlines in 1971, 2000 and 2011 are compared with each other to know how to change the flow by coastline change. Bathymetry, wind, tide and grid must be same because this case considers only coastline change. 1971, 2000 and 2011 coastlines are made from the map of [2, 11] and google earth. Coastline change like Figure 3 is applied. Depth data uses 184 points on Jakarta Bay in google earth and bathymetry is made like Figure 4 from these points. Grid and bathymetry are made by automatic grid generation and inverse distance weighted method in SMS (Surface water Modeling System). Open boundary stretches to seaward 40km, size of domains is about width 100km, height 70km. The number of elements is 6843, nodes is 3645, nodes of OBC 49 in 2011 case. Major 4 rivers (Figure 5) of Jakarta 13 rivers are applied directly as point sources in river discharge rate and wind is applied in rainy season (table 1). Rainy season has more serious problems than dry season since more pollutants can be introduced by more discharge than in dry season. This modeling uses only rainy season data because strong influence of rainy season on pollutant transport is significant in comparison with dry season. Tide data interpolates provided tide data from Korea Ocean Research & Development Institute (KORDI) by linear method. There are applied 6 constituents (K1, N2, M2, O1, P1, S2) as initial condition at the open boundary. Coriolis parameters have values between south latitude 5 and 7 degree. Beside, precipitation, evaporation, heat flux and irradiation flux are empty, total run time is 30 days.

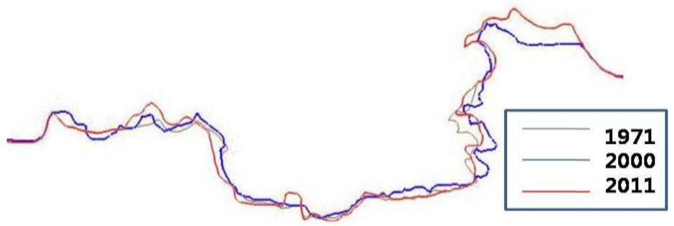

Figure 3. Coastline change of Jakarta. Gray, blue and red are each coast line in 1971, 2000 and 2011.

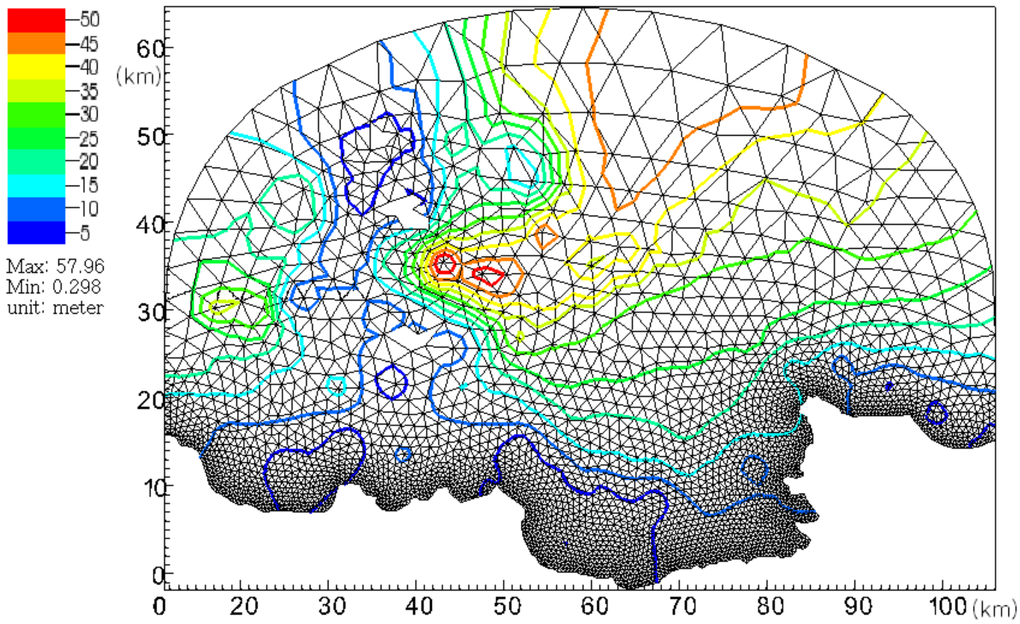

Figure 4. Domain in Jakarta Bay in 2011. This Figure shows shape of domain, mesh, bathymetry and coastline. Domain of 1971 and 2000 is similar except for coastline in Jakarta Bay.

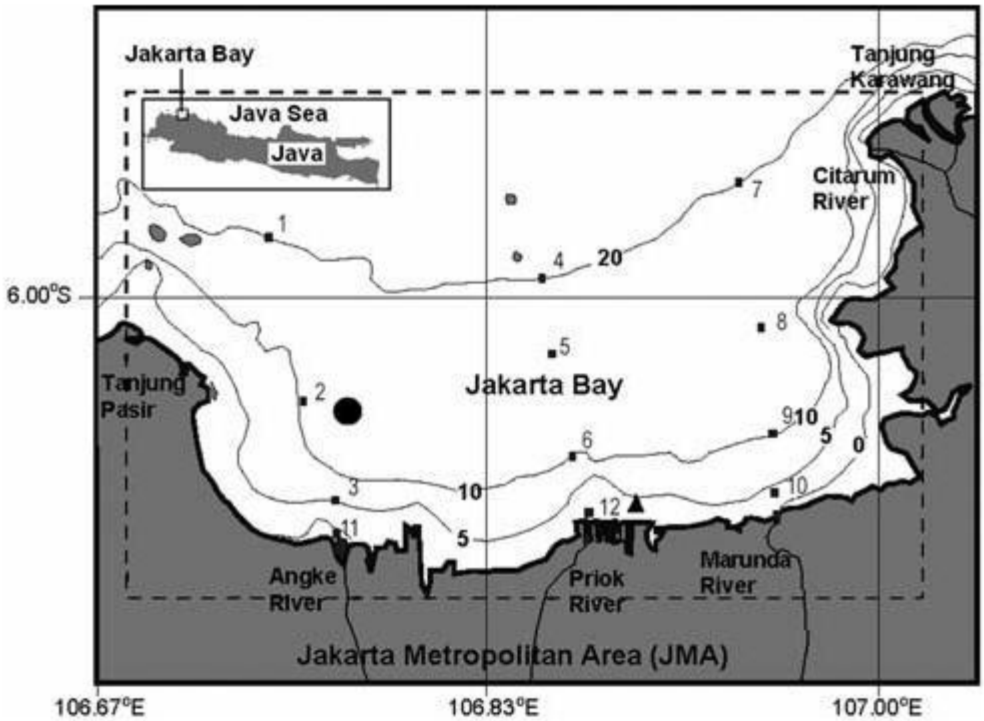

Figure 5. Location of major rivers [16].

Table 1. River discharge and wind in 2000 in Jakarta [16].

Discharge in rainy season (Dec)		Wind in rainy season (Dec, Jan, Feb)	
River name	Discharge	Property	Value
Angke	38 m^3/s	Prevailing wind	315 degree, SE
Priok	21.3 m^3/s		
Marunda	17.6 m^3/s	Mean wind velocity	1.1 m/s
Citarum	418.58 m^3/s		

3. RESULTS

3.1 Seawater Flow Patterns

Modeling results are verified by wave height during 6 days at one point observation. Figure 6 shows suitability between observation and results in 1971, 2000 and 2011. The results are classified with surface and bottom flow at residual flow, spring and neap tide in 1971, 2000 and 2011 cases. So, results about the flow pattern have 18 cases as 9 surface flow cases and 9 bottom flow cases.

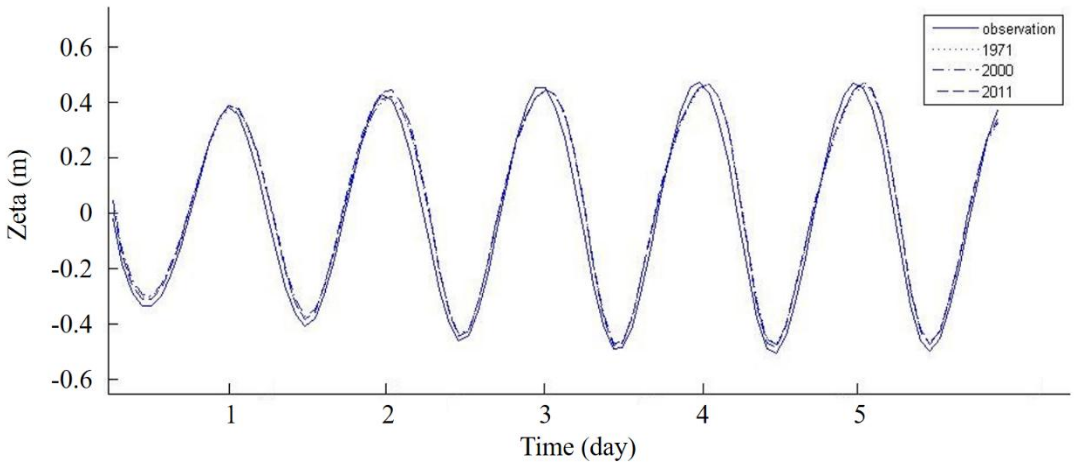

Figure 6. Comparison of observation and modelling result.

Seawater flow at the surface is affected by construction of coastal structures and natural coastline change by erosion and sedimentation. Figure 7 shows velocity vectors as modeling results, figure 8 shows the changes of flow patterns briefly. Figure 7 and 8 show that surface flow of spring and neap tide and residual flow run to south-west direction by north-east wind because surface flow is widely affected by the direction and speed of wind. Moreover, effects of rivers is important. Discharge of Citarum river is larger than sum of Angke, Priok and Marunda river. Fresh water from Citarum river meets fresh water from other three rivers in center of Jakarta Bay, they make frontal line by each influence. Frontal line which two flows are converged varies to up and down by spring and neap tide in this study and by coastline change. In addition, if discharge rate is changed frontal line will be moved. When coastline is changed in 1971, 2000 and 2011, frontal line changes the shape according to each case. Frontal line doesn't move totally seaward, it just keeps balance by that a part of frontal line moves seaward and then other part of frontal line moves back. Frontal line interrupts mix of upper region and lower region can affect pollutant transportation from each river.

On the other hand, seawater flow at the bottom is too complex. The influence of wind and river discharge at the bottom is less than surface flow. The flow by coastline change is changed, but there cannot be found a distinct feature between each case. The reasons of the problem are bathymetry affection and that flow vectors follow a bumpy sigma layer. Elevation change of bottom layer by bathymetry is stronger than surface layer makes analysis of bottom flow complicated.

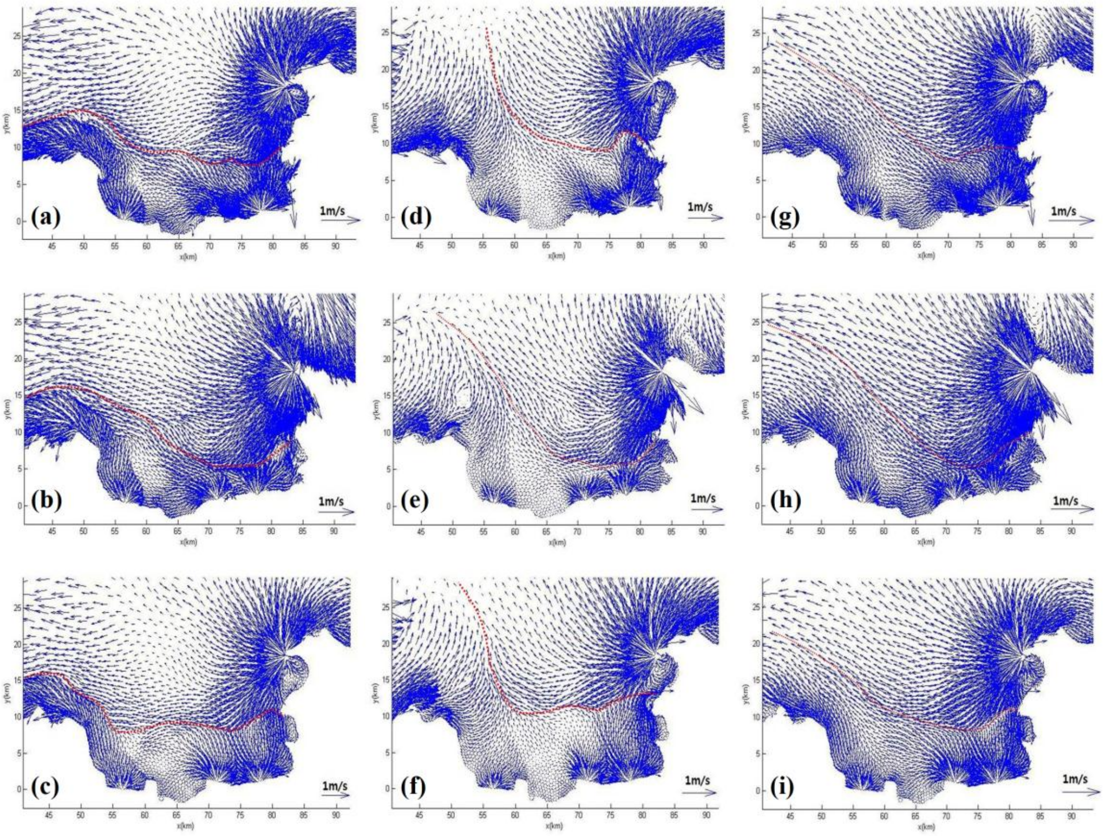

Figure 7. Velocity vectors in Jakarta Bay. (a) 1971, (b) 2000, (c) 2011 at high tide. (d) 1971, (e) 2000, (f) 2011 at low tide, (g) 1971, (h) 2000, (i) 2011 at residual flow.

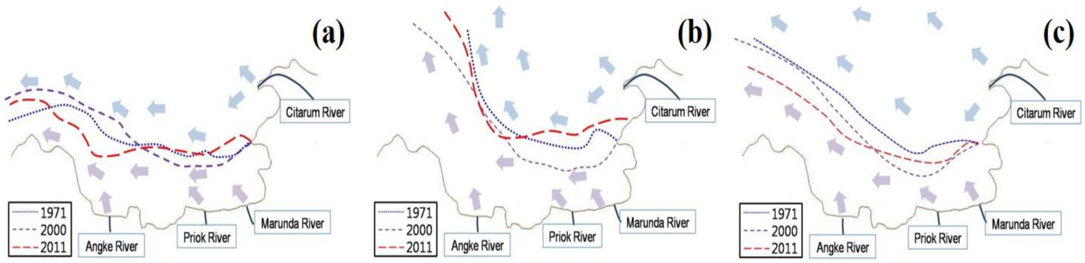

Figure 8. Comparison of the surface flows in 1971, 2000 and 2011 in Jakarta Bay. (a) High tide. (b) Low tide. (c) Residual flows. The dot lines in the center of figure are frontal lines changed according to 1971, 2000 and 2011.

3.2 Pollutant Distributions

Frontal lines at the surface of the flow structures from model coincide with concentration distributions of lead, arsenic, pH and DO from [11].

Since lead is easy to process as metal, it widely uses as stereotypes, sleeves, alloys, electric condensers, electric cables in industry, surfactants of paint, golf ball, axle greases, elements of fishing [17, 18]. Concentration of Pb on the frontal line is 3.5 μg/L (Figure 9 (a)), it will be asked to caution even if the concentration is low. It is expected that all rivers have the origins of Pb pollution.

pH is determined with 7 as the center. pH of seawater is 7.8-8.3, it is the first grade quality in Korea. In figure 9 (b), blue line area under frontal line is over pH 8.1, it is suitable grade. Red line area is under pH 7.3, it is low grade. The area of low pH grade is located in Citarum river mouth. It is expected that Citarum river basin has the origins of toxic pollution in contrast with Angke, Marunda and Priok river basin.

Arsenic is generated as oxide by melting copper, lead, zinc etc. Arsenic is used in medical treatment and agriculture as pesticides. Arsenic has strong toxicity after oxidation although it doesn't have toxicity in normal. The serious polluted areas by arsenic in the world are around sedimentary layers, abandoned mine and volcano. Polluted areas by arsenic can be around agriculture area or mine, special geological feature. In Figure 9 (c), concentration of blue line area over the frontal line is 67 μg/L, area under frontal line is lower concentration area. It is expected that Citarum river basin may have agriculture area and arsenic comes from Citarum river.

In figure 9 (d), DO over frontal line is constantly about 5.5 mg/L. But, DO under frontal line shows dynamic change from 3.1 mg/L front of Angke and Priok rivers to 8.5 mg/L in west of the Bay. DO 3.1 mg/L belongs to the third grade in Korea quality standard, it is explained that organic matters are transported to the region by Angke and Priok rivers. Beside, the region of DO 8.5 mg/L belongs to the first grade, it can be explained that organic matters are purified during going to the area despite of nearby location to flow direction. [14] explains active self-purification by active vertical mixing of Java Sea. But, purification region is not enough broad as natural process, it is limited region. It is expected that artificial facilities help purification in the region.

4. CONCLUSION

This study models coastline in 1971, 2000 and 2011 for characteristic flow of Jakarta Bay. Seawater flow by modeling results shows that SE wind, rivers dominantly affect flow of Jakarta Bay and coastline change affects location of frontal lines. Citarum river is largest, the influence of the river is larger than sum of other 3 rivers.

The comparison of modeling results and test data of lead, arsenic, DO, pH from suspended particle matter can trace the origins of pollutants. Citarum river is polluted by arsenic and lead, moreover has toxic matter. Angke, Marunda, Priok are polluted by lead and organic matter. If the study about the ambient industry and Jakarta conducts, it will be expected a reliable research about transport, diffusion and sources of pollutants.

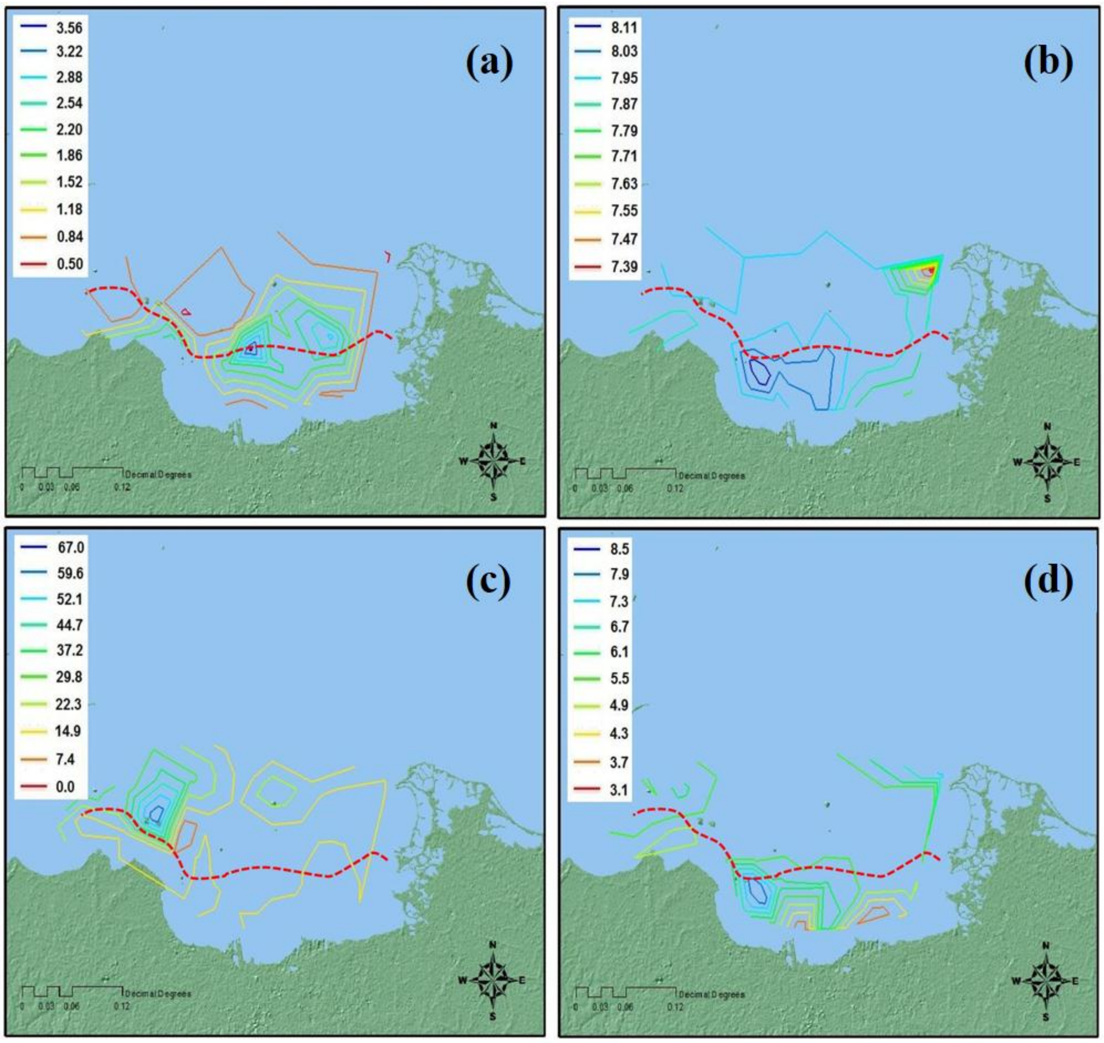

Figure 9. The relation of frontal lines and distribution of pollutants. (a) Pb (unit : μg/L). (b) pH. (c) As (unit : μg/L) (d) DO (unit : mg/L)

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