STUDY OF RAINFALL AND RIVER DEBIT INTERACTION USING RATIONAL METHOD TO DETERMINE INTRUSION OF SEA WATER IN THE JAKARTA BAY AREA

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Naskah diterima: 5 Mei 2010 - Revisi terakhir 28 Juli 2010

Abstract

The Ciliwung River that flow through Jakarta Province is one of important factor for the city. The deficiently water management in Jakarta caused water supply crisis within the area. The unsufficient water supply for Jakarta is causing groundwater pumping by the local people to comply their needs of water. Thus generated saline water intrusion from the Ciliwung’s downstream to the upstream through to the people’s settelement.

The objective of this research is to find how far the sea water intrusion at Jakarta Bay by analyzing the interaction between rainfall with the Ciliwung River’s debit. Jakarta’s land cover is dominated by watertight materials such as concrete and asphalt induced runoff greater than infiltration. The current land cover caused the groundwater contaminated by sea water intrusion. The hypothesis is based on the groundwater calculation for Ciliwung’s River Basin. It showed the average of baseflow for the the Ciliwung’s River Basin range between 550 – 680 mm per year. The baseflow range shows that water absorbed by the ground is lesser than the rainfall at Ciliwung’s River Basin that ranged between 2000 – 2500 mm per year.

Afterwards, using ten years of climate data and debit data from Katulampa Station (the Upstream of Sungai Ciliwung) and also using data from the Angke Estuary and the Ancol Estuary (Lower Ciliwung River) acquired the maximum sea water intrusion in Ciliwung River on May 6, 2005. The intrusion reaches is ranged between 14 – 20 kms measured from the downstream of Angke Estuary. While the intrusion at the Ancol Estuary ranged from 18 – 22 kms.

Keywords: sea water intrusion, groundwater, rainfall

1. Introduction

The crisis of water supply has been a threat for Indonesia, mainly in Java and Madura Island (Media Indonesia, 2005). It is estimated that by the year 2025 Indonesia will experience water supply crisis. Data from Indonesian State Ministry of Environment shows that the potential of water resources in Java Island is 4,700 m3/capita/year, but is decreasing to 1,200 m3/capita/year.
capita/year (Media Indonesia, 2005). This crisis is caused by the increase of water demand of 6.7% starting from year 2000 until year 2015. Another cause of this crisis is internal matters in water resources management in Indonesia. On the other hand, people are used to exploit the groundwater everywhere in Indonesia, and also the changing of landuse from water catchment area into buildings so the infiltration of precipitable water decreasing.

Water support for an area is ratio parameter between the demands and supply of water, or defined as capacity of an area to supplies its people in certain amount of water. The surface water supply is getting limited. This condition cause depletion of groundwater particularly in the big cities such as Jakarta and Bandung (Lubis, 2007). The depletion would be very danger because in the coastal cities like Jakarta it can cause sea water intrusion via underground, so it can pollute the groundwater supply.

The Indonesian Directorate of Geology and Environmental Order has made research regarding to this matter. The results are that within every 10 kms in Jakarta is experience sea water intrusion. The sea water intrusion from Jakarta Bay have reach Keboan Jeruk, West Jakarta, and The Golden Triangle in Setiabudi. This state is different from 20 years ago when the intrusion was only reach 2 kms from Jakarta’s coastal line (Sinar Harapan, 2005). Sea water intrusion is one of contamination forms to groundwater that will decreased the quality of drinking water, land depletion, and building damages (Kuishan).

Therefore, profound and comprehensive study of sea water intrusion regarding the contamination of groundwater in connection with the volume of clean water supply are required to find out the area that have been affected by sea water intrusion. This research will use the parameters of meteorology, oceanography, and stream debit such as rainfall, tides, salinity of sea water, and debit. The reason for Jakarta to be chosen as study area is because Jakarta have sufficient data to run the mathematical model.

2. Objectives

The objectives of this research are:

- Calculate the concentration distribution of saline at surface water in the Jakarta Bay area using baroclinic numerical model of saline intrusion, with addition of river debit based on rational method.
- Analysis of water balance to analyze the precipitation fluctuation, in order to determine the intrusion dispersion and calculation.

3. Data

Data required for this research are: climatological data, tides data, salinity data, stream data. And additional data such as remote sensing and data from news. The boundary area of this research are:

A: 106° 48' BT dan 6° 01' LS
B: 106° 58' BT dan 6° 01' LS

Figure 1. Bathymetry of Jakarta Bay (Rima, 2004)
4. Methodology

Using mathematical model in numerical equation to determine the concentration of saline water with 3D hydrodynamic numerical model that developed by Alan Blumberg and George Mellor known as POM (the Princeton Ocean Model) and with 3D baroclinic model modification done by Ivonne M. Radjawane (ITB) and debit function modification. Data processing to develop input for the model is integratedly done with others secondary data which gained from field survey and remote sensing data processing.

Equations used to build saline intrusion process is hydrodynamics equations consist of continuity equation, conservative momentum equation, and saline transport equation. The adjustment equation used in this research are 1 dimensional equations. The method used are upstream explicit finite difference numerical method.

Water is incompressible substance, thus the continuity equation that apply to the fluids is (Pitara, 1987):

\[ Q = VA = \text{constant} \quad [1] \]

With:
\[ Q = \text{debit (m3/s)} \]
\[ V = \text{velocity (m/s)} \]
\[ A = \text{surface area (m2)} \]

For unsteady state with open surface, the continuity equation is more complicated. The equation has certain time and differences between input stream and output stream with the volume change.

\[ x = \text{distance (m)} \]
\[ A = \text{stream’s area (m2)} \]
\[ t = \text{time (s)} \]

The hydrodynamics equation are consist of conservative momentum equation and continuity equation (Nurhayadi, 1997 and Lukmanto, 2003), thus:

\[ [3] \]

With:
\[ Q = \text{stream debit (m3/s)} \]
\[ g = \text{earth gravity} = 9.8 \text{ m/s}^2 \]
\[ A = \text{stream’s area (m2)} \]
\[ h = \text{depth (m)} \]
\[ z = \text{surface elevation (m)} \]
\[ r = \text{friction coef.} \]
\[ b = \text{width (m)} \]

The numerical hydrodynamics model is known as POM (Princeton Ocean Model) created by Alan Blumberg and George Mellor. This model have been modified by Radjawane (2001) so this model can calculate the distribution of salinity. The inputs of this model are daily tides data, seasonal wind, and variation of salinity. The flowchart of POM can be seen below. The calculation begin with determining the preliminary data and continue with the baroclinic calculation.

The determination of the model’s boundary of water debit at the upstream (0-grid) and downstream (n-grid) are obtained from the field data. In the process of calculating the transport equation, salinity data at all grid both in the upstream and downstream is required. While the stream’s area and stream’s debit are obtain from the calculation of hydrodynamics. The coefficient of friction (r) determined by Chezzy coefficient factor (C) and hydrolics radius (R) given at equation below (Nurhayadi, 1997)

\[ [4] \]

And from Lubis (1996) and Nurhayadi (1997):
With:

\[ A = \text{transverse area} \]
\[ p = \text{wetted perimeter} \]

To simulate the saline water intrusion model so the range of saline intrusion could be measured, all the data mentioned earlier have to be obtain. Those data are correlated with hydrodynamics condition of the river.

The saline intrusion model is based on the model modification made by Yadi Nurhayadi (1997) and Suharjanto W. Pitara (1987) with a view modification so the result of the model could be closer to its natural condition. This simulation was made using PC (personal computer) with programming language of DELPHI 5. The output of this model are numeric, thus the output were plotted using Microsoft Excel.

The impact of rainfall to the intrusion is based on the amount of precipitation fall into the area of the river. The amount of precipitation fall will eventually effected the stream’s debit that included as one of inputs for the model. The calculation of precipitation effecting the river’s debit is based on the sensitivity analysis from monthly rainfall data and stream’s debit. The result of the sensitivity analysis is one of inputs needed by the model. Globally, most important variables to calculate the impact of precipitation to saline water intrusion through Jakarta Bay are: precipitation, temperature, wind velocity and direction.

5. Results

The data used for the model is started from May 6th 2005 (06.00) to May 7th 2005 (06.00). The boundary condition of downstream used for the model is the downstream of the Ciliwung...
River, Muara Ancol and Muara Angke. While the upstream boundary condition is the upstream of Ciliwung River, Katulampa. The intrusion model scenario used by changing parameters such as friction coefficient (r) and dispersion coefficient (E). The friction coefficient is obtained from the equation 4 that have been modified according the natural condition of Ciliwung River. The dispersion coefficient also have been set between 0 – 225 that correspondent with the condition of Ciliwung River.

Based on the graphic from output of the model, it can be seen if r increase the debit of the stream will be decrease. However, the simulation shows that the value of r and debit fluctuation are nearly linear. This condition might caused by variations of r are small so the variation of the debit would be small either. Stream’s debit variation at all grid is also effecting the elevation off all grid. If the value of r increase then elevation will be increase and vice versa. The condition develop because the bigger the friction results smaller debit nevertheless the streamflow velocity would also decrease so the elevation will increase.

From the plot of debit, the value of debit always positive at the middle of simulation at 18.00. It’s mean that the water is flowing from the upstream to the downstream, characterized by the decrease of debit value at the grid 24 and then increase at the downstream. Elevation plot shows that the value of elevation is support the debit value starting from 06.00 A.M to 11.00 A.M. The peak of elevation level is at 11.00 P.M. It’s mean that it’s uptide during that time.

As mentioned before that increased r will increase elevation and decrease the debit of the river. Different set up for dispersion coefficient (E) didn’t resulted in significant difference to hydrodynamics condition, but different value of E is affecting the distribution of saline water intrusion in the river.

When the streamflow reach the upstream, the saline intrusion will be more excessive. When the sea current is moving to the upstream it will help the process of sea water intrusion through the river. The output of the simulation shows that the maximum reach of the saline intrusion is in grid 41 or 14 kms from the downstream of Ciliwung River. However, different value of dispersion coefficient (255) result different maximum grid reached by saline intrusion to grid 38 or 20 kms from the downstream of Muara Angke. Saline water intrusion reached the maximum at dispersion coefficient of 0 at grid 36.

Figure 4. Salinity for each grid at Muara Angke’s downstream for different value of friction value (r)
or 18 kms from downstream of Muara Ancol. The amount of salinity is the same for all simulation, 0.001 o/oo.

Meteorological data from BMG (Indonesian Geophysics and Meteorology Agency) shows that average precipitation from year 1996 – 2000 is 2000 – 2500 mm. And for wet season (Jan, Feb, Nov, and Dec) the average precipitation is 350 – 380 mm. And maximum precipitation during the same year duration is 687 mm. With water balance method the result for debit over Jakarta from maximum precipitation is 15 billion litre/year. Only 27 % of precipitable water is directly infiltrate the ground, it’s make the storage volume is less than direct runoff, this condition will make the depletion of groundwater table. The depletion will make potential of saline water intrusion via ground and eventually will contaminate the groundwater.

6. Conclusions

1. The maximum range of saline water intrusion at Ciliwung River on 6 May 2005 is 14-20 kms from the downstream of Muara Angke and 18 – 22 kms from downstream of Muara Ancol for dispersion coefficient 0 – 255 with salinity of 0.001 o/oo.

2. The water gate of Manggarai near to Banjir Kanal is reducing/decreasing the river’s debit that will effected the saline water intrusion dispersion range.

3. The 1997 Water Balance analysis shows that extreme event is effecting the precipitation rate which will effected the river’s debit.

7. References


8. “Awas, Krisis Air Tanah di Jakarta”, Harian Sinar Harapan, 5 Mei 2005