【Research Note】

Numerical Study on Atmospheric, Hydrological and Coastal Circulation in Coastal City, Semarang Indonesia

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Abstract

This study is carried out seeing that it is important to understand the interacting components of the Earth system and global climate changes including seasonal changes and its variability in Indonesia. Unfortunately, until now there are only few researches into numerical study on atmospheric, hydrological and coastal circulation topics in coastal city in Indonesia, especially researches which consider the dynamic interactions among the major components of the Earth system, as atmosphere, watershed and the estuary.

The objective of this study is to evaluate and validate the applicability of non-hydrostatic meteorological model (MM5), watershed simulation model (HSPF), and three-dimensional hydrodynamic with sediment transport model for estuary and coastal ocean (ECOMSED) in Semarang, Indonesia as part of the Regional Environment Simulator (RES).

The simulated results showed that the modeling approach appeared to be a powerful tool to define relevancies between each component in the Earth system. For atmospheric simulation, although some biases were found by comparing the value of observed data and simulated results, trend of precipitation that occured at these meteorological stations shows a similar pattern. In hydrologic modeling, performance of simulation has reflected a good computation by numerical model and results met a good criteria with correlation coefficient (R) of 0.89, determination coefficient (R^2) of 0.79 and Nash-Sutcliffe Efficiency (NSE) criteria resulted in values of 0.68. The simulation which combines the hydrology model (HSPF) and the meteorological model (MM5) has shown better results than observation data. Model computation for coastal estuary modeling was also performed. The simulation provided a time series of sea water level, temperature, salinity, and distribution of sediment concentration in the Garang estuary, Semarang. The simulation result of sea surface elevation changes agree very well with the determination coefficient (R^2) of 0.83 if compared with Semarang station, and 0.85 compare with Tanjungmas Port station. The result also showed that circulation in estuary has been dominated by river discharge rather than sea tide. For further research, it is suggested to consider the

interaction of meteorology-hydrology-coastal/estuary components by using the coupler system in the Earth system modeling (RES).

1. Introduction

The phenomena of climate change is causing adverse impacts on human wellbeing and producing damage to the environment in many areas. IPCC (2007) argues that climate change is strongly affecting many aspects of the Earth system related to snow, ice and frozen ground (including permafrost); emerging evidence shows changes in the hydrological system, water resources, coastal zones and oceans. Climate change effects will likely increase water scarcity due to changes in the rainfall and hydrological pattern, increase the vulnerability of ecosystems due to temperature increase, frequent severe weather events and prolonged droughts and increase extreme precipitation and flooding, which will increase river water level, erosion rates and wash soil-based pollutants and toxins into waterways. Floods and inundations are considered as serious problems faced by coastal urban cities in the world.

Indonesia, as an archipelago country, has a cumulatived coastal perimeter for more than twofold circumference of earth and is one of the countries vulnerable to the effect of climate change. As a tropical country located at the equator, Indonesia archipelago is recognized to have an important part in global circulation and climate system. Moreover, it is located between two continents, Asia and Australia, and two oceans the Pacific and Indian ocean.

The dynamic interaction between atmospheric procesess and ocean in the Pacific ocean (ENSO) and the Indian ocean (DME) will influence surface temperature in Indonesian. Ashok et al. (2001) and Neale and Slingo (2003) stated that small changes in the sea surface temperature in maritime contingent such as Indonesia, can result significant changes in precipitation patterns across the Indo pacific region. During normal years, the variation of sea surface temperature (SST) and sea surface salinity (SSS) anomalies in the Java Sea are about $\pm$ 0.5^{o}C and $\pm$ 0.2 psu, respectively. SST decreases (SSS increase) during DME and El Nino events because of transport of watermass with cooler SST (higher SSS) from eastern Java Sea, while during the La Nina events, the SST increase (SSS decrease) because of the transport of watermass with warmer SST (lower SSS) from the eastern Java Sea (Putri, 2005). Land surface interaction with atmospheric circulation in Indonesia is also effected by the geographical position of Indonesia which is located between Asia and Australia continent. Wyrtki (1961), Petit (1996) and Sadhotomo (1996) had analysed seasonal variation of environment, climate and ocean dynamics in the Java Sea. Furthermore, regional dynamic changes of the climate system in Indonesia become important factors influencing the Earth global system.

No generally accepted definition of the “Earth System” exists (Haggag, 2009), and following notation was put forward by Schellnhuber (1998): the Earth system encompasses the natural environment, i.e the climate system or sometimes referred to as the ecosphere and the anthroposphere (Peixoto and Oort, 1992 in Haggag, 2009).

To learn on interaction between the Earth and its components, it is needed to have simulation models that are able to observe the Earth environment processes and feedbacks between the components which possibly influence the properties of the whole system (Haggag, 2009). Yamashita et al. (2007) had developed the Asian Environment Simulator (AES) that was improved to a Regional Environment Simulator (RES) by Haggag (2009) to simulate mesoscale water, material transport and energy circulation in continental and coastal area. The Regional Environment Simulator (RES) is a coupled system of computer simulation for meteorology, physical oceanography, land surface, vegetation, hydrology, coastal dynamics and urban environment which is mainly used for natural environmental assessment against human activities (Yamashita et al, 2007). Lee (2006) had developed the meteorological model to provide climatology data fields for the atmosphere-ocean model couple. Kuroki (2007) and Wahyu (2009) had applied AES/RES in their research related to meteorological and hydrological variability in subtropical and tropical basin considering climate variation.

Marfai (2003; 2008) had integrated GIS and hydrologic modeling in Semarang and some other researches related to coastal dynamics in the north coast of Java Island.

Since it is important to understand the interacting components of the Earth system and global climate changes including variability and seasonal changes in Indonesia, and the limited researches into this topic in coastal cities in Indonesia, especially researches which consider the dynamic interactions among the major components of the Earth system, as atmosphere, land surface/hydrology and the coastal/estuary, this study was carried out.

The aim of this study is to evaluate and validate the applicability of several models as part of the Regional Environment Simulator (RES) on Atmospheric, Hydrological and Coastal Circulation in Coastal City, Semarang Indonesia, such as non-hydrostatic meteorological model (MM5), watershed simulation model (HSPF), and three-dimensional hydrodynamic with sediment transport model for estuary and coastal ocean (ECOMSED).

By using RES as the Earth system modeling, future climate variability and change; including the possible effects of human activites on the global climate system, can be predicted. It is expected that this study becomes one of the effective environmental assessment tools for regional integrated sustainable development plans in Indonesia, especially in coastal cities.

2. Description of Study Area

Semarang is the capital city of Central Java Province and the fifth biggest city in Indonesia. Geographically, Semarang lies on the north coast at coordinates EL 109º 35'– 110º 50' and SL 6º 50' – 7º 10'. The topography of Semarang is divided into two parts representing the city contour, namely the low lying area in the north and highland in the south. The location of Semarang area is shown in Figure 1.

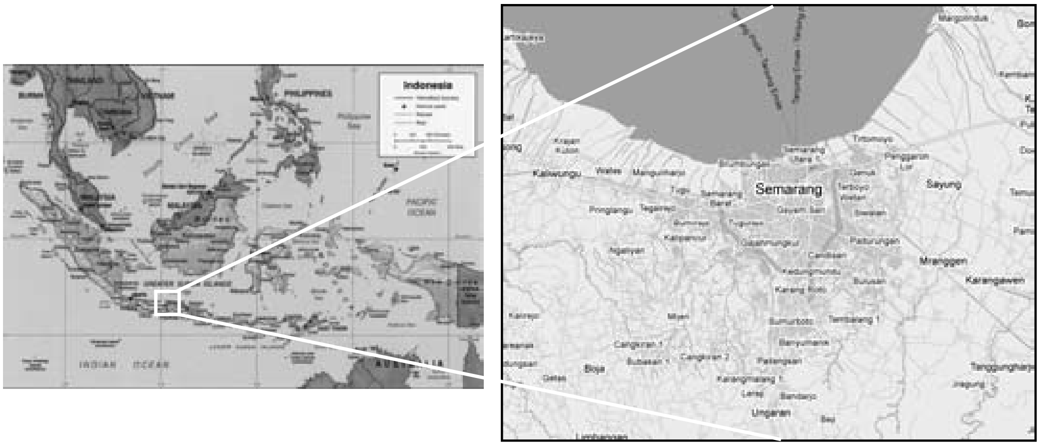
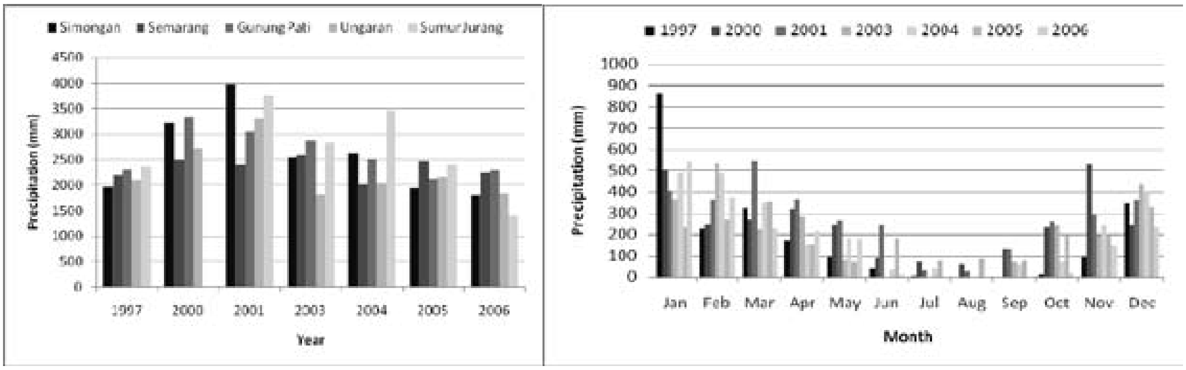


Figure 1: Map of Semarang

As a tropical city, Semarang is situated in a tropical humid climate characterized by two seasons, dry and wet season. The climate is influenced by monsoon high precipitation. Several meteorological stations record the precipitation data of Semarang area, such as the Simongan, Semarang, Gunungpati, Ungaran and Sumurjurang stations. Location of each meteorological station is depicted in Figure 3. Based on precipitation data from these stations in 1997-2006, except 1998,1999 and 2002, annual precipitation rate in Semarang was high, varying between 1,000 to 4,000 mm/year with an average of 2,655 mm/year for Simongan, 2,293 mm/year for Semarang, 2,554 mm/year for

Gunungpati, 2,623 mm/year for Ungaran and 2,701 mm/year for Sumurjurang station. The annual precipitation rate for each meteorological station in Semarang city is shown in Figure 2 (a).



(a) (b)

Figure 2: (a) Annual precipitation and
(b) Average monthly precipitation for each meteorological station in Semarang City

Figure 2 (b) shows the total monthly precipitation from 1997, 2000, 2001, 2003, 2005 and 2006 varying between 200 mm - 500 mm in the wet season and 0 mm – 50 mm in the dry season. This figure also shows the season pattern in Semarang that is the rainy season from November-March and the dry season from June to August.

Semarang, as one of the coastal cities in Indonesia, frequently suffers from flood which is typically caused by upper course overflow of one river (river flood), drainage overflow of lowland area due to high rainfall intensity (local flood), and tidal flood (or named 'rob' in Indonesia). Because the Garang River as the largest river taking an important role in the development plan of Semarang city, this study will focus on the catchment of the Garang watershed. The boundary area of the Garang watershed as shown in Figure 4 is made based on the landcover map from the Indonesia Ministry of Forestry and deliniated by using Arc View GIS version 9.2 and Watershed Modeling System (WMS) version 7.0. The Garang watershed width takes 211.3 km^2 of the catchment area or about 56,4% of Semarang area as shown in Table 1.

Table 1: Total width and percentage of landuse in the Garang watershed in 2006

Landuse utilized	Area (km^2)	Percentage (%)
Forest	25.64	12.13
Plantation	2.33	1.1
Residential	50.76	24.02
Dryland Farming	57.76	27.33
Mix Dryland Farming	66.82	31.62
Paddy Field	8.03	3.8
Total	211.3	100

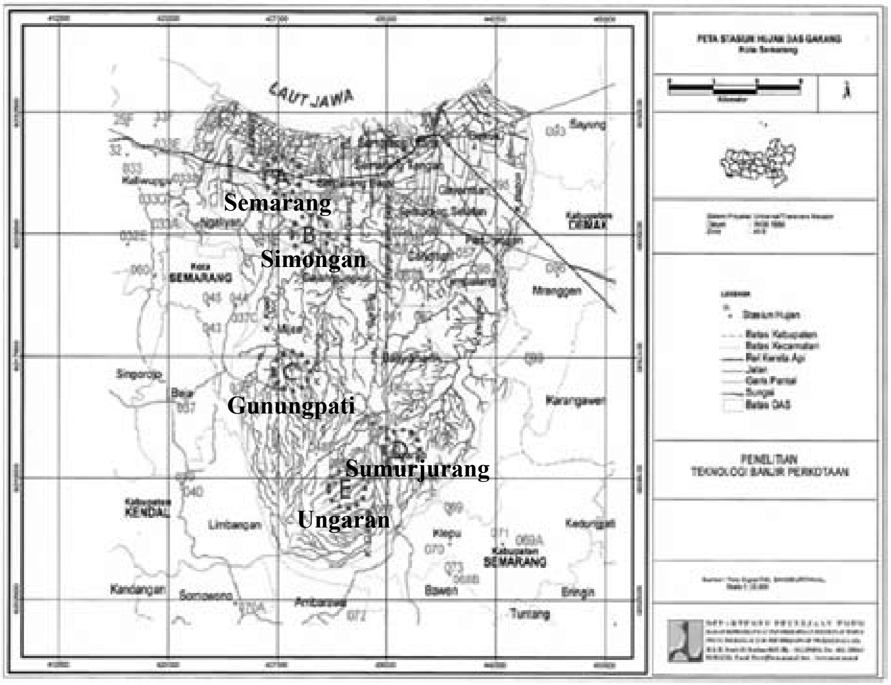


Figure 3: Location of meteorological stations in Semarang

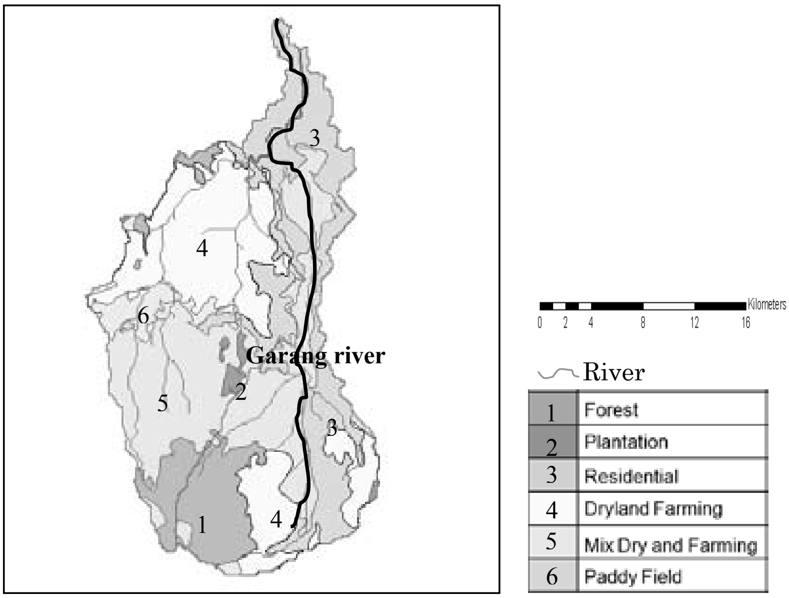


Figure 4: Spatial distribution of the Garang watershed landuse in 2006

3. Method

In this study, different models as part of the Earth system modeling, the Regional Environment Simulator (RES) were applied in order to achieve the objectives as given in the introduction. For atmospheric modeling, the Fifth Generation Mesoscale Meteorogical Model (MM5) was used while the Hydrological Simulation Program Fortran (HSPF) was applied for watershed simulation. For coast and estuary, hydrodynamic simulation used the ECOMSED (Estuary and Coastal Ocean Model with Sediment Transport).

3.1 Model description

MM5

MM5 is one of the meteorological/atmospheric models designed to simulate mesoscale and regional scale weather as closely as possible with actual atmospheric condition. MM5 was developed in 1970 by Pennsylvania State University and National Center for Atmospheric Research (PSU/NCAR) of U.S. This model is one of the most widely used three-dimensional prognostic meteorological models.

According to Grell et al. (1996), MM5 characteristics are functional in a regional/limited-area and non-hydrostatic model primarily designed to simulate or predict mesoscale/regional atmospheric circulation. The model is supported by several pre- and post-processing programs, which are referred to collectively as the MM5 modeling system and also uses a terrain following non dimensional pressure or sigma coordinates pressure. Schematic MM5 modeling is shown in Figure 5.

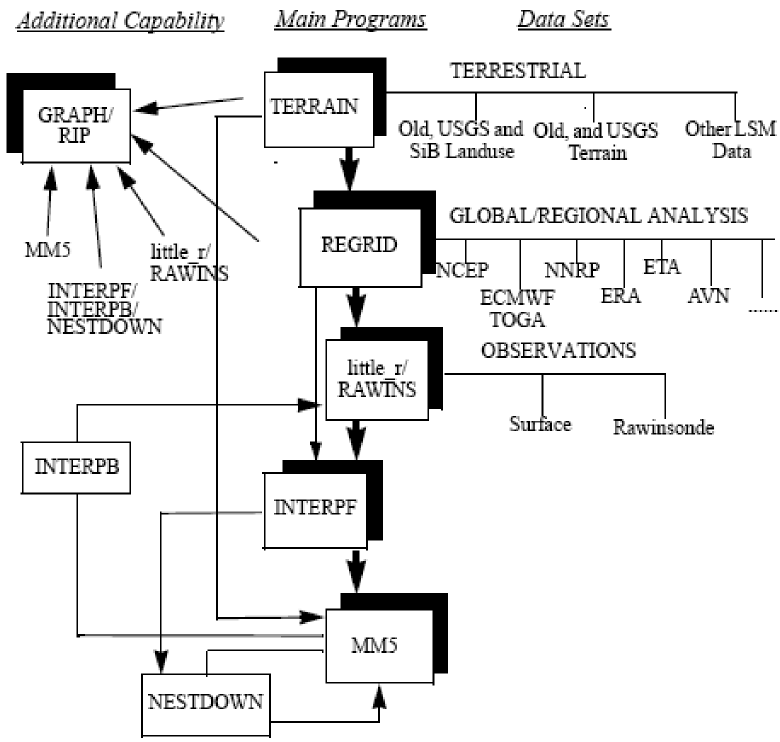


Figure 5: MM5 modeling system flowchart

The governing equation of MM5

According to Grell et al. (1996), vertical σ-coordinate is defined in terms of pressure as:

$$\sigma = \frac{p - p_t}{p_s - p_t} \qquad ...(1)$$

where p is reference state pressure, p_t a spesified constant top pressure, p_s the reference state surface pressure and the σ levels in non-hydrostatic system fixed in space are closely related to height rather than pressure and the pressure at a certain point, p, is calculated by $p = \sigma(p_s - p_t) + p_t + p'$ where p' is a computed value of pressure perturbation.

The non-hydrostatic governing equations in Cartesian-sigma (x, y and σ) coordinate system in a rotating frame of reference can be written as follows:

Pressure

$$\frac{\partial p'}{\partial t} - \rho_0 g w + \gamma p \nabla \cdot \mathbf{V} = -\mathbf{V} \cdot \nabla p' + \frac{\gamma p}{T}\left(\frac{\dot{Q}}{c_p} + \frac{T_0}{\theta_0} D_\theta\right) \qquad ...(2)$$

Momentum (x-component)

$$\frac{\partial u}{\partial t} + \frac{m}{\rho}\left(\frac{\partial p'}{\partial x} - \frac{\sigma}{p^*}\frac{\partial p^*}{\partial x}\frac{\partial p'}{\partial \sigma}\right) = -\mathbf{V} \cdot \nabla u + v\left(f + u\frac{\partial m}{\partial y} - v\frac{\partial m}{\partial x}\right) - ew\cos\alpha - \frac{uw}{r_{earth}} + D_u \qquad ...(3)$$

Momentum (y-component)

$$\frac{\partial v}{\partial t} + \frac{m}{\rho}\left(\frac{\partial p'}{\partial y} - \frac{\sigma}{p^*}\frac{\partial p^*}{\partial y}\frac{\partial p'}{\partial \sigma}\right) = -\mathbf{V} \cdot \nabla v - u\left(f + u\frac{\partial m}{\partial y} - v\frac{\partial m}{\partial x}\right) + ew\sin\alpha - \frac{vw}{r_{earth}} + D_v \qquad ...(4)$$

Momentum (z-component)

$$\frac{\partial w}{\partial t} - \frac{\rho_0}{\rho}\frac{g}{p^*}\frac{\partial p'}{\partial \sigma} + \frac{g p'}{\gamma p} = -\mathbf{V} \cdot \nabla w + g\frac{p_0}{p}\frac{T'}{T_0} - \frac{g R_d}{c_p}\frac{p'}{p} + e(u\cos\alpha - v\sin\alpha) + \frac{u^2 + v^2}{r_{earth}} + D_w \qquad ...(5)$$

Thermodynamics

$$\frac{\partial T}{\partial t} = -\mathbf{V} \cdot \nabla T + \frac{1}{\rho c_p}\left(\frac{\partial p'}{\partial t} + \mathbf{V} \cdot \nabla p' - \rho_0 g w\right) + \frac{Q}{c_p} + \frac{T_0}{\theta_0} D_\theta \qquad ...(6)$$

where T, ρ, θ, Q and $D(\ )$ are the temperature, density, potential temperature, heating rate due to diabatic processes and subgrid-scale eddy viscous terms respectively. The constants g, f, Rd, cp and γ are the acceleration due to gravity, Coriolis parameter, the gas constant of dry air, the heat capacity of constant pressure of air and the ratio of heat capacity for air at constant pressure to that of constant volume. Here, the two new parameters, α, which is the angular difference between the y-axis of the grid and the true north and $e = 2\Omega\cos\varphi$ (note with the internal energy, e), are introduced to describe the full three-dimensional Coriolis effects where Ω and φ are the angular velocity of the Earth and the latitude.

Advection terms can be expressed as

$$\mathbf{V} \cdot \nabla A \equiv mu\frac{\partial A}{\partial x} + mv\frac{\partial A}{\partial y} + \dot{\sigma}\frac{\partial A}{\partial \sigma} \qquad ...(7)$$

where the vertical velocity, $\dot{\sigma}$, in σ coordinate is related to modeled values of velocity components by

$$\dot{\sigma} = -\frac{\rho_0 g}{p^*}w - \frac{m\sigma}{p^*}\frac{\partial p^*}{\partial x}u - \frac{m\sigma}{p^*}\frac{\partial p^*}{\partial y}v \qquad ...(8)$$

Divergence term can be expanded in the Cartesian-Sigma coordinate as

$$\nabla \cdot \mathbf{v} = m^2\frac{\partial}{\partial x}\left(\frac{u}{m}\right) - \frac{m\sigma}{p^*}\frac{\partial p^*}{\partial x}\frac{\partial u}{\partial \sigma} + m^2\frac{\partial}{\partial y}\left(\frac{v}{m}\right) - \frac{m\sigma}{p^*}\frac{\partial p^*}{\partial y}\frac{\partial v}{\partial \sigma} - \frac{\rho_0 g}{p^*}\frac{\partial w}{\partial \sigma} \qquad ...(9)$$

when p^* is constant, the second and fourth terms on right hand side will disappear. On surface (σ=0) and top (σ=1) levels, boundaries are considered as rigid conditions so that $\dot{\sigma} = 0$ is applied.

In order to improve the rainfall simulation results, Four Dimensional Data Assimilation (FDDA) was employed in the MM5 simulation. FDDA is a method and technique to assure a dynamical consistency that keep the model as closely to actual atmoshperic conditions and is making up for erors and gaps in the initial analysis and deficiencies in the physics model.

HSPF

Hydrological Simulation Program Fortran (HSPF) is a one-dimensional comprehensive watershed simulation model developed by the United States Environmental Protection Agency (US EPA). This model is derived from the Standford Watershed Model (SWM) and designed to simulate all water quantity and quality processes that occur in a watershed and in-stream including sediment transport and movement of contaminants. HSPF can reproduce spatial variability by dividing the basin in hydrological homogenous land segments and simulating runoff for each land segment, independently, using different meteorological input data and watershed parameters (Bicknell et al. 1996). HSPF includes parameterizations for the main hydrological process (e.g. precipitation, interception, evapotranspiration, surface runoff, ground water, interflow, etc).

There are three main stages that should be done in order to run this simulation model: pre- processing, processing and post processing.

1. In the pre-processing step, all data on topography, weather (precipitation, temperature, etc) and landuse in the watershed of study area are required. Landuse on this site is analysed by ArcGIS software version 9.2. ArcGIS is a tool to prepare the land use map and also to convert 90-meter resolution Digital Elevation Model (DEM) from Hydrosheds (Hydrological data and maps based on shuttle elevation derivatives at multiple scale). The landuse map covering the whole area of Semarang, specifically the Garang watershed, was obtained from Indonesia Ministry of Forestry in the year 2006.
2. The processing stage uses the WinHSPF model. Many hydrological parameters have to be considered in this stage. The model has three main modules: PERLND, IMPLND, and RCHRES which are representing pervious land segments, impervious land segments, and free-flow reaches/mixed reservoirs, respectively.
3. The post processing is the last process in hydrological modeling. Output result or simulation can be produced by using the hydrograph. In this study, the Scenario Generator (GenScn) was used. The GenScn provides the ability to change an input sequence interactively, to run the HSPF model, and to view results graphically. The results of different scenarios can be easily compared and analyzed because the model and analysis tools are linked in one package and use a common database.

ECOMSED

ECOMSED (Estuary and Coastal Ocean Model with Sediment Transport) is one of the comprehensive coastal-estuary models designed to simulate three-dimensional hydrodynamic in the marine and fresh water system. This model is developed from the Princeton Ocean Model (POM) since 1980. The complete ECOMSED model consists of several modules, these are hydrodynamic module, sediment transport module, wind induced wave module, heat flux module and particle tracking module (Blumberg and Mellor, 1987). The modules within the ECOMSED modeling framework are linked internally. These modules can be turned on and off by the users depending upon their needs. The ECOMSED modeling framework also allows for linking each module externally.

ECOMSED is potential to provide a time series of water circulation, temperature, salinity, number and diameter of particle, and deposition and re-suspension of cohesive and non-cohesive sediments as closely as possible with the observation data.

The governing equation of ECOMSED

According to Bryan (1969), the continuity equation is:

$$\nabla \vec{V} + \frac{\partial W}{\partial z} = 0 \qquad ...(10)$$

where ∇ is the horizontal velocity vector with components (U, V) and ∇ the horizontal gradient operator and z increasing vertically upwards.

The Reynolds momentum equations are:

$$\frac{\partial U}{\partial t} + \vec{V}\cdot\nabla U + W\frac{\partial U}{\partial z} - fV = -\frac{1}{\rho_o}\frac{\partial P}{\partial x} + \frac{\partial}{\partial z}\left(K_M\frac{\partial U}{\partial z}\right) + F_x$$

$$\frac{\partial V}{\partial t} + \vec{V}\cdot\nabla V + W\frac{\partial V}{\partial z} - fU = -\frac{1}{\rho_o}\frac{\partial P}{\partial y} + \frac{\partial}{\partial z}\left(K_M\frac{\partial V}{\partial z}\right) + F_y$$

$$\rho g = -\frac{\partial P}{\partial z} \qquad ...(11)$$

with ρo the reference density, ρ in situ density, g gravitational acceleration, P the pressure, and K_M the vertical eddy diffusivity of turbulent momentum mixing. A latitudinal variation of the Coriolis parameter, f, is introduced by using the β plane approximation. The pressure at depth z can be obtained by integrating the vertical component of the equation of motion, from z to the free surface, η, and is:

$$P(x,y,z,t) = P_{atm} + g\rho_o\eta + g\int_z^0 \rho(x,y,z',t)dz' \qquad ...(12)$$

Henceforth, the atmospheric pressure P_{atm} is assumed to be constant. The conservation equations for temperature (θ):

$$\frac{\partial \theta}{\partial t} + \vec{V}\cdot\nabla\theta + W\frac{\partial \theta}{\partial z} = \frac{\partial}{\partial z}\left(K_H\frac{\partial \theta}{\partial z}\right) + F_\theta \qquad ...(13)$$

and for salinity (S):

$$\frac{\partial S}{\partial t} + \vec{V}\cdot\nabla S + W\frac{\partial S}{\partial z} = \frac{\partial}{\partial z}\left(K_H\frac{\partial S}{\partial z}\right) + F_S \qquad ...(14)$$

where θ is the potential temperature (or in situ temperature for shallow water applications) and S is the salinity. The vertical eddy diffusivity for turbulent mixing of heat and salt is denoted as K_H. Using the temperature and salinity, the density (ρ) is computed according to an equation of state of the form:

$$\rho = \rho(\theta, S) \quad ...(15)$$

3.2 Validation and evaluation

In this study, some calibration and validation was done on all simulation models in order to adjust the simulation results as closely as possible with the observation data. For atmospheric modeling, validation of the model was performed by comparing daily precipitation from meteorological stations in Semarang with MM5 results. Re-analysis data from the sattelite Tropical Rainfall Measuring Mission (TRMM) was also used as a comparison for daily rainfall distribution.

On the performing of the hydrological model, graphical and statistical methods were used to evaluate the model results. The hydrological model was calibrated by comparing the outflow of the Garang River from model results with daily measurement data. This simulation used three model evaluation statistics to evaluate the performance of HSPF model output, that is the coefficient of correlation (R), the coefficient of determination (R^2) which is defined as the squared value of the coefficient of correlation, and the Nash-Sutcliffe Efficiency (NSE), a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance.

Concerning validation of the coastal model, model results were validated by comparing calculated tidal levels with measurements of water level in the study area. A statistical analysis was perfomed as correlation (R) and determination of coefficient (R^2). A comparison of sediment concentration results was also verified by observed data. Due to limited observation data availability, some simulation outputs such as temperature and salinity distribution are validated by using re-analysis data.

The equation of evaluation criteria is shown below:

$$\mathrm{R} = \left(\frac{\sum_{i=1}^{n}\left(O_i - \bar{O}\right)\left(P_i - \bar{P}\right)}{\sqrt{\sum_{i=1}^{n}\left(O_i - \bar{O}\right)^2}\sqrt{\left(P_i - \bar{P}\right)^2}} \right) \qquad \mathrm{R}^2 = \left(\frac{\sum_{i=1}^{n}\left(O_i - \bar{O}\right)\left(P_i - \bar{P}\right)}{\sqrt{\sum_{i=1}^{n}\left(O_i - \bar{O}\right)^2}\sqrt{\left(P_i - \bar{P}\right)^2}} \right)^2 \quad ...(16)$$

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n}\left(O_i - P_i\right)^2}{\sum_{i=1}^{n}\left(O_i - \bar{O}\right)^2} \quad ...(17)$$

where O_i and P_i are the observed and simulated data, and O and P are the mean observed and simulated data during the evaluation period.

The range of R and R^2 between 0 and 1 will describe how much of the observed dispersion is explained by the prediction. A value of zero means no correlation at all, whereas a value of 1 means that the dispersion of the prediction is equal to that of the observation. NSE indicates how well the plot of observed versus simulated data fits the 1:1 line.

NSE ranges between –∞ and 1 with NSE = 1 being the optimal value. Value between 0 and 1 is generally viewed as acceptable level of performance (Moriasi et al., 2007 in Wahyu, 2009)

4. Results and Discussions

4.1 Atmospheric Modeling

In this study, atmospheric simulation in Semarang area with several physics configuration had been performed with other scheme option using non and with observation nudging technique (FDDA). However, only the optimum simulation results, which were acquired from the modeling process, are presented in this paper. Detailed physics parameters for optimum combination option in MM5 simulation are shown in Table 2.

Table 2: Configuration of MM5 simulation

MM5 Configuration	MM5	MM5+FDDA
Simulation time	January 1 – 30, 2005	
Dynamics	Non Hdydrostatic	
Input data	NCEP FNL (1^ox1^o resolution)	
Input Terrain data	USGS Global data	
Number of domains	2 domains	
Number of grids	Domain 1 : 35x41 Domain 2 : 49x52	
Horizontal resolution of domain	Domain 1 : 27 km Domain 2 : 9 km	
Atmospheric radiation scheme (FRAD)	Cloud radiation (Dudhia scheme)	
Planetary boundary layer parameterization (IBLTYP)	Medium Range Forecast (MRF) Scheme	
Land surface model (ISOIL)	NOAH	
Cumulus parameterization (ICUPA)	Grell	Kain-Fritz2
Explicit moisture scheme (IMPHYS)	Grauple (gsfc)	Schultz
Nudging	Non-FDDA	FDDA

MM5 simulation was conducted by two nested domains with grid resolutions 27 km and 9 km. Domain 1 consisted of 35x41 grids covering the whole of Java island with 945x1107 km width. While, domain 2 consisted of 49x52 grids covering the 441x468 km width area comprising Central Java province. Figure 6 shows the geographical locations of domain 1 and 2.

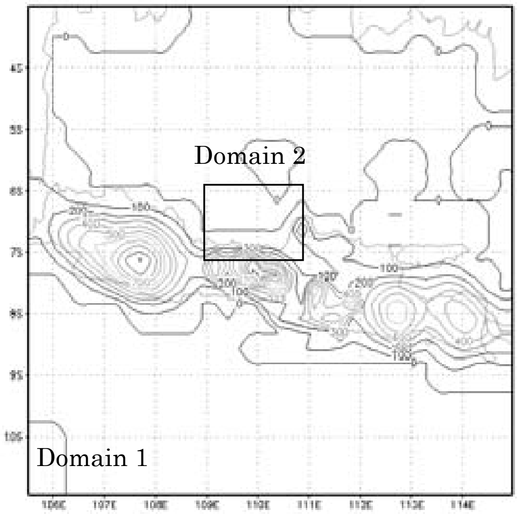


Figure 6: Geographical location of domain 1 and domain 2 in MM5 simulation

The distribution of daily precipitation from TRMM, MM5, and MM5 with FDDA data that occured in the simulation time periode during heavy precipitation event (January 5 – 7, 2005) and low precipitation event (January 23 – 25, 2005) are shown in Figure 7 and Figure 8. In heavy precipitation event, it is indicated that distribution of precipitation is presented quite different. Good relation between MM5 simulation and TRMM data was shown in low precipitation events. The precipitation pattern presents distribution levels which are relatively equal in both simulation results and TRMM.

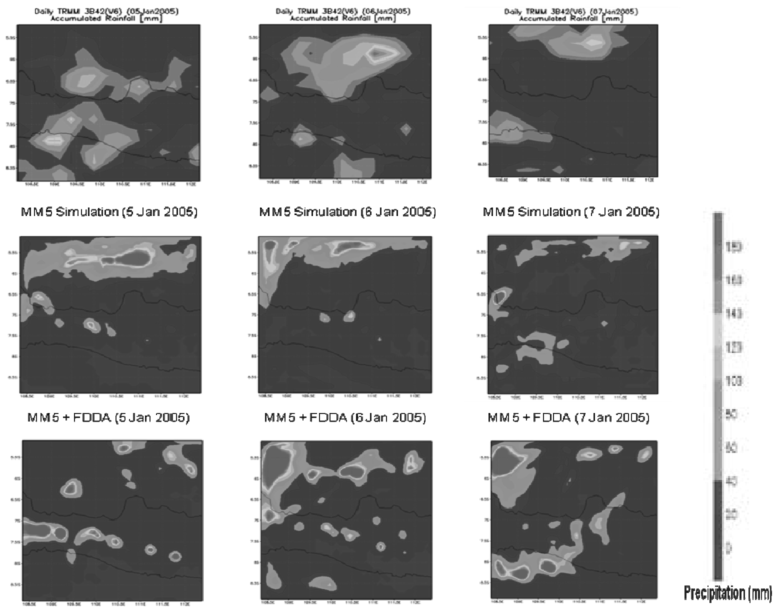


Figure 7: Daily precipitation distribution resulted by MM5 and TRMM during peak precipitation event (January 5-7, 2005)

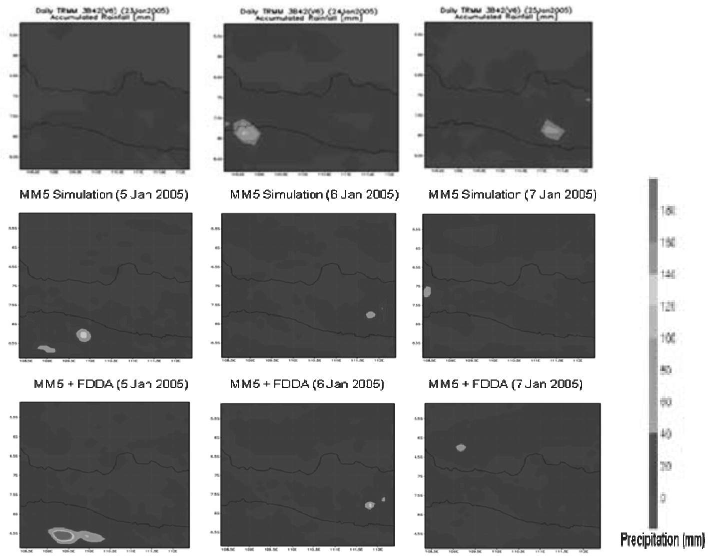
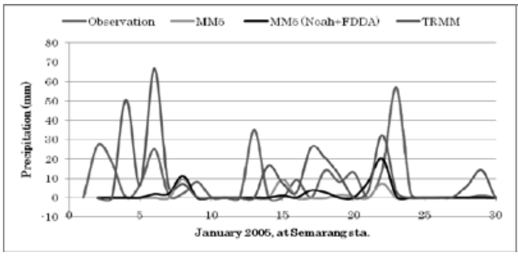
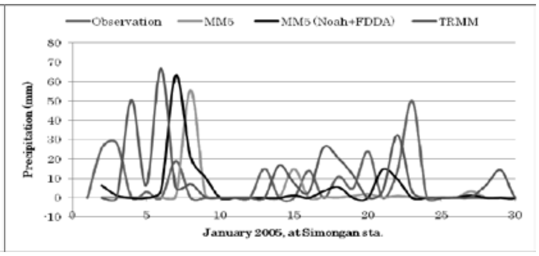


Figure 8: Daily precipitation distribution resulted by MM5 and TRMM during low precipitation event (23-25, January 2005)

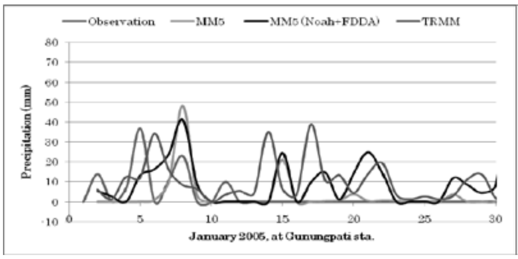
Figure 9 (a, b, c, d and e) shows precipitation distribution of MM5 simulation at each meteorological station in comparison with the field observation data and TRMM satellite.



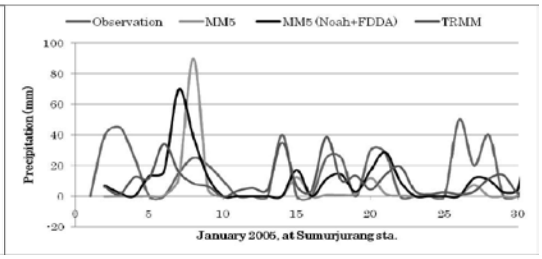
(a): Semarang station



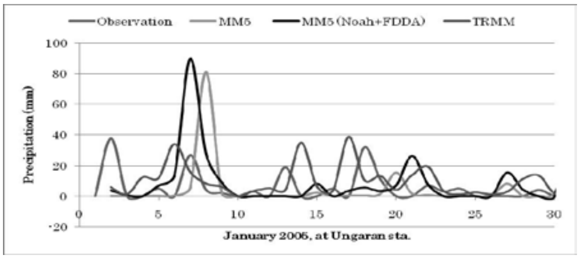
(b): Simongan station



(c): Gunungpati station



(d): Sumurjurang station



(e): Ungaran station

Figure 9: Comparison of daily precipitation at each station

These figures even showed some biases by comparing observed and re-analysis (TRMM) data, and simulated precipitation; generally, trend of precipitation that occur at these stations show a similar pattern. At Semarang and Simongan stations, simulated results are in a good relation with the observed data eventhough a large difference of total precipitation was shown on January 1 to 8, 2005. MM5 results at these two stations were underestimated, compared to observed and TRMM data. On the contrary, differences were also encountered at Gunungpati, Sumurjurang, and Ungaran stations especially on January 5 to 8, 2005. In these three stations, MM5 results was underestimated, compared to the observed and TRMM data.

Total cumulative of precipitation for each meteorological station in simulation period (30 days) shows an extreme deviation as depicted in Table 3.

Tabel 3: Deviation of MM5 simulation and observation data

	Total cumulative of precipitation (mm)				Deviation		
Stations	Observation (mm)	TRMM (mm)	MM5 (mm)	MM5 (FDDA)	TRMM (mm)	MM5 (mm)	MM5 (FDDA)
Semarang	241	282	31	53	-41	210	188
Simongan	209	282	82	148	-73	127	61
Gunungpati	102	301	105	322	-199	-3	-220
Ungaran	165	151	288	301	14	-123	-136
Sumurjurang	438	301	170	367	137	268	71

4.2 Hydrological modeling

In this study, hydrological simulation in the Garang watershed with several sensible parameters was performed in 2005. In order to verify HSPF results, simulated daily discharge was compared with the observed daily discharge of Garang-Panjangan station. Comparison of both datasets has given good results, as shown in Figure 10.

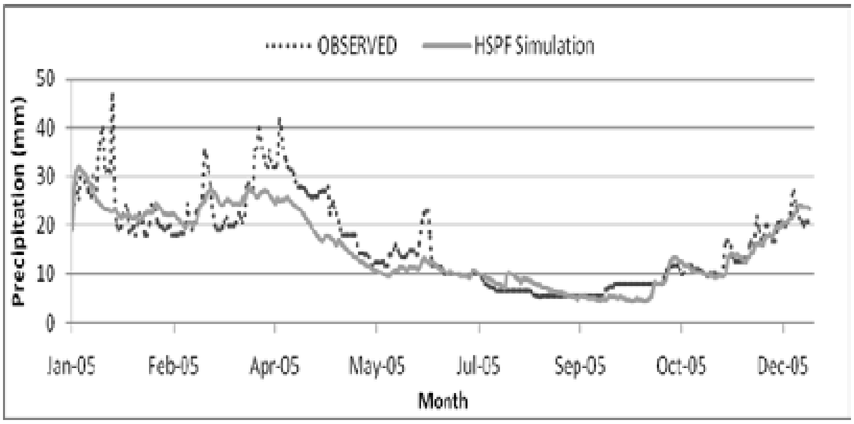


Figure 10: Comparison of daily discharge between simulated and observed data in the Garang-Panjangan station as a result of HSPF simulation

Statistic analysis resulted a coeffisient of correlation (R) of simulation model 0.89 and coefficient of determination (R^2) of 0.79. According to the United States Environmental Protection Agency (US EPA, 2007), for hydrological model, if R range between 0.85 – 0.90 and R^2 between 0.7 - 0.8, a good relation is being perfomed. The performance of this simulation reflects a good computation job by the numerical model and the results almost meets a good criteria. The Nash-Sutcliffe Efficiency (NSE) criteria show a value of 0.68. According to Moriasi et al. (2007), this simulation model can be judged as satisfactory because NSE value is higher than 0.5.

Figure 11 presents scatter plots of observed and simulated daily discharge of the Garang River at Garang-Panjangan station.

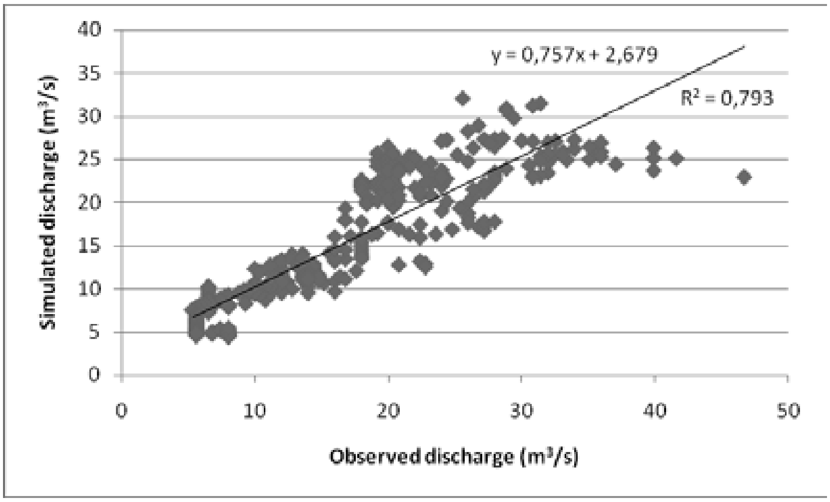


Figure 11: Scatter plots of observed and simulated daily discharge in the Garang River

Based on all calibration parameters that were verified as mentioned above, it can be concluded that this simulation model produces the reasonable result and good capability in order to represent hydrological condition and behavior in the Garang watershed.

4.3 Atmospheric and hydrological interaction

The simulation within the atmosphere-land surface interaction is one of the goals of this study. The meteorological data from MM5 simulation result will be used to set up the hydrological model (HSPF). Combining the input data from MM5 and the parameter settings of the calibration which was done by HSPF, it is possible to create a 100% simulated scenario. MM5 sends precipitation and temperature to the HSPF hydrological model in a one way interaction process. HSPF calculations is initiated, but without feed back to MM5.

The meteorological data input for HSPF model is derived from the MM5 and MM5+FDDA results obtained from January 1 – 30, 2005. Comparison results of hydrological simulation for each source of data input can be seen in Figure 12.

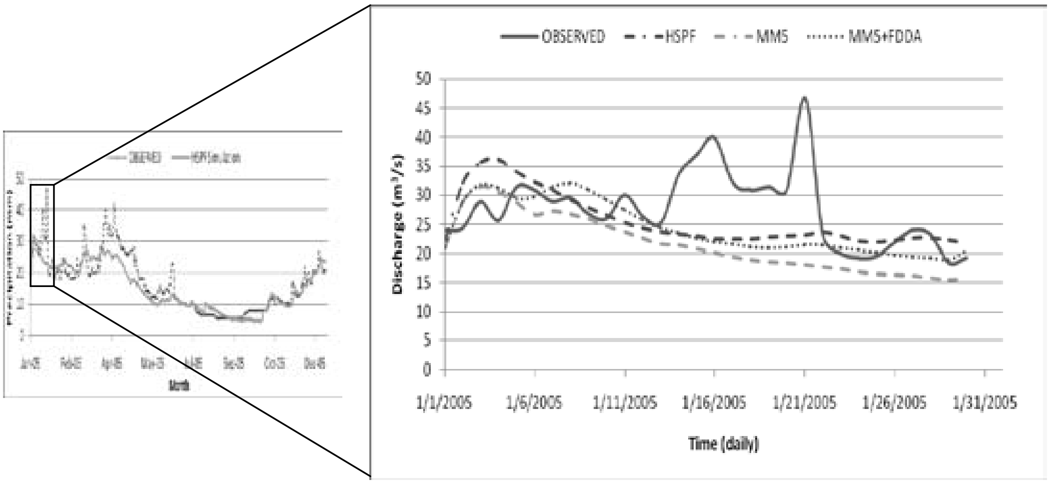


Figure 12: Comparison of observed and simulation daily discharge using different meteorological input data

Table 4: Comparison of HSPF simulation results using station based and MM5 input

Hydrology model	(R^2)
Station based (HSPF)	0.179
MM5 model	0.342
MM5+FDDA	0.292

According to Table 4, R^2 value of MM5 and MM5-FDDA shows a higher value than the station based model (HSPF). The R^2 value for MM5 and MM5-FDDA, as input data, are 0.342 and 0.292. The interesting point is that high improvement was produced by the MM5 model. R^2 increased 0.163 higher than MM5+FDDA (0.113) if compared with the original station based model input (HSPF).

Based on the statistical value, simulation result which combines the MM5 meteorological model as input data and HSPF hydrological simulation, provides better results.

4.4 Coastal/Estuary modeling

The coastal/estuary modeling in this study is attempted to be set up in the Garang estuary. This estuary is situated on the northward coast of Java island directly connected to the Java Sea. The model calibrated was used to conduct a simulation of combined freshwater and tidal flows to investigate flow velocities, salinity structure and distribution of sediment concentration as well as the estuary circulation in the Garang River system.

The computational domain of the Garang estuary as shown in Figure 13, is located at SL 6^0 55' 35'' - 6^0 57' 31'' and EL 110^0 23' 12'' - 110^0 24' 56''. The model computation for Garang estuary has horizontal finite difference meshes of 120 x 120 grids with 25 m interval for each grid (3 km x 3 km), vertically discritized with 10 σ-levels. The various parameters used in the numerical simulations are listed in Table 5 as follows:

Table 5: Parameters setting

D X	25 m, 120 grids
D Y	25 m, 120 grids
External interval time	1 s
Internal interval time (DTI)	2 s
NSTEPS	950400
Simulation time	November 24 - December 15, 2007 (22 days)
Initial Temperature	25 ^oC
Initial Salinity	32 psu
Freshwater salinity	0.02 psu
Initial concentration of TSS	1 mg/l
Elevation boundary condition	300 tidal constituent
River inflow	12.99 m^3/s As initial input, divided into 3 grid cells = 4.33 m^3/s
Cohesive sediment consentration	38.88 kg/m^3

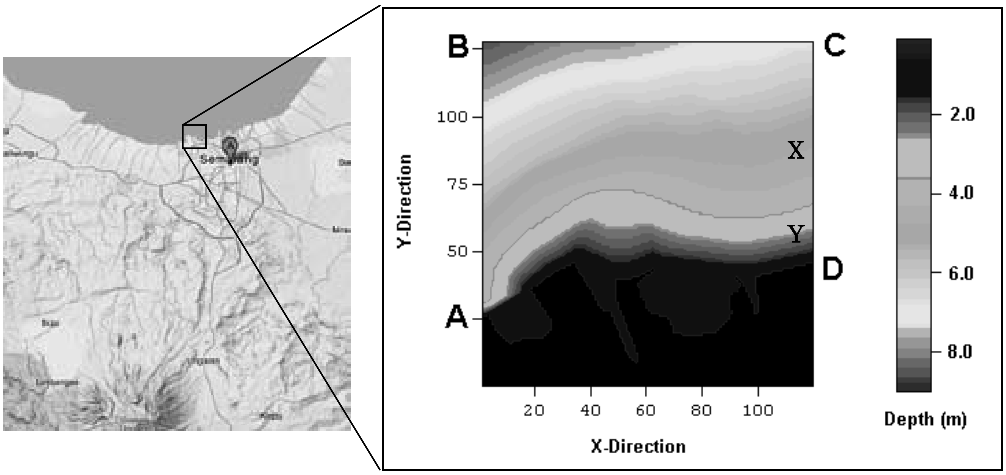


Figure 13: Horizontal grid of the Garang estuary in ECOMSED model

Results of the hydrodynamic model were validated by comparing calculated tidal levels with measurement in Semarang and Tanjungmas Port (marked with X and Y point in Figure 14) during the period of December 14-15, 2007. Figure 15 shows the comparison between simulation results and observation data for sea surface elevation.

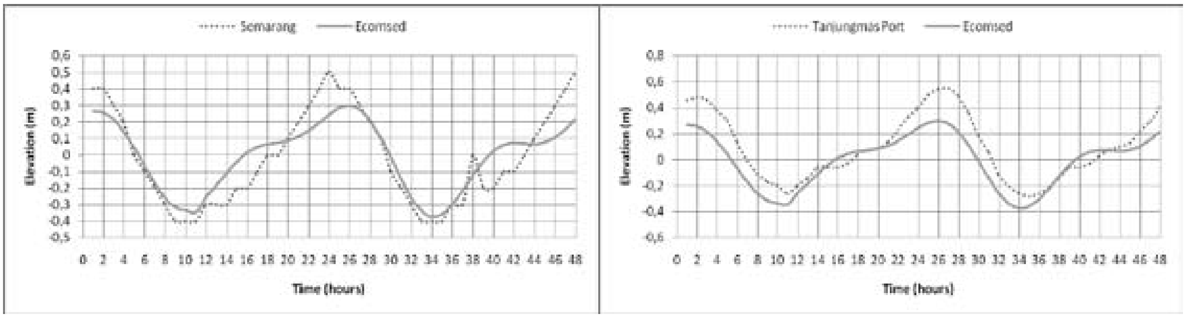


Figure 15: Comparison of Sea Surface Elevation (SSE) between observed data and simulated result at Semarang and Tanjungmas Port

According to Figure 16, coefficient of determination (R^2) of simulation models compared with Semarang station indicated 0.83 and 0.85 compared with Tanjungmas Port station. The simulation results of sea surface elevation changes shows very good agreement with observed data of 48 hours simulation It also shows that the model seems be able to reproduce tidal propagation well in tide and river flow conditions.

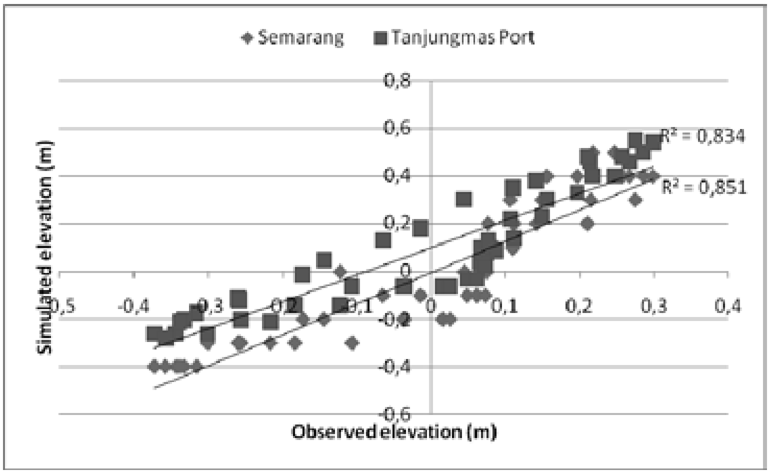


Figure 16: Scatter plots of surface elevation between observed data and simulated result

Figure 17 shows the simulation results of sediment concentration of the date that observed data are available. These results show that distribution of suspended sediment in Garang estuary. During the time period of simulation, it is indicated that sedimentation of simulated results located precisely at the end of the Garang estuary, produced approximately 32 mg/l – 40 mg/l of concentrates. If comparing these data with the observed data, it can be concluded that simulation results of November 24, 2007 (1st day) is in good performance (observed data = 38.8 mg/l), despite the fact that simulation result of December 8, 2007 (15th day), is showing a large difference with simulated results being much smaller than observed data (measured data was 242.67 mg/l).

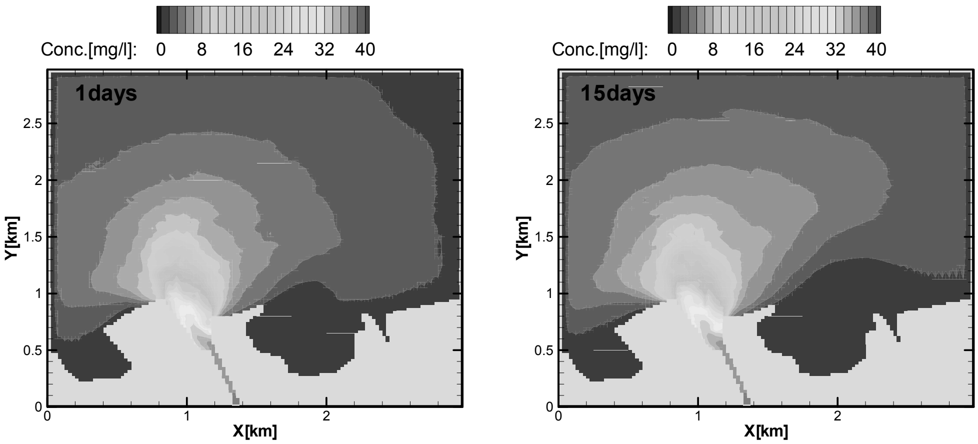


Figure 17: Computation of horizontal sediment concentration in ECOMSED model

Figure 18 shows the vertical profile of suspended sediment concentration in the longitudinal section that represents the position of the Garang estuary and Java Sea. These figures were plotted in order to visualize and interpret vertical transport. This figure, shows clearly the distribution of suspended sediment between fresh and salt water interface. It is also indicated that material of sediment with concentration higher than 30 mg/L ends up at a distance of 0.5 km from boundary border or precisely near the Garang estuary. The closer it empties into the sea, the smaller the sediment concentration showing a rate below 5 mg/L.

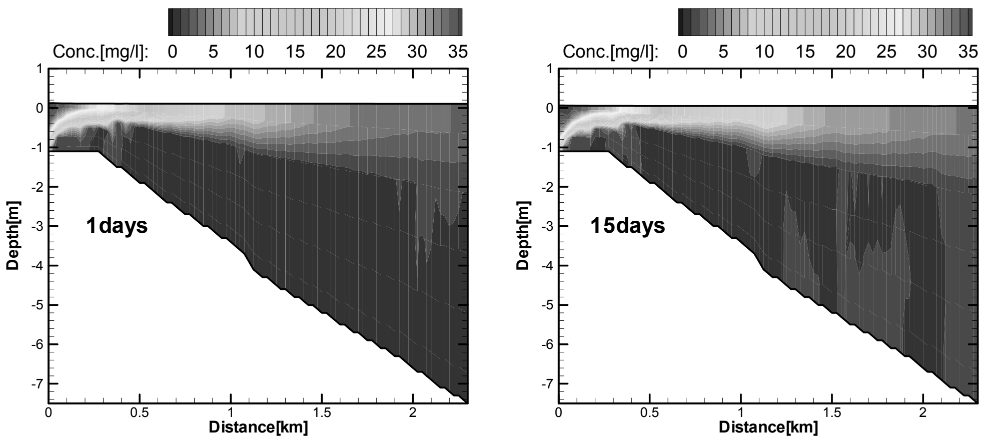


Figure 18: Vertical distribution of sediment concentration result in ECOMSED model

Sea surface temperature (SST) in and around the Garang estuary as one of some outputs of the ECOMSED modeling result, was compared with re-analysis data from the National Oceanic and Atmospheric Adminstration (NOAA), Earth System Research Laboratory. The SST re-analysis data is weekly based on 1^{o} grid. Figure 19, shows that the approximate temperature resulted from ECOMSED ranges between 24 ^{o}C – 25 ^{o}C, whereas output of NOAA re-analysis ranges higher, namely between 27.5 ^{o}C – 28.5 ^{o}C at all observed periods (Figure 20).

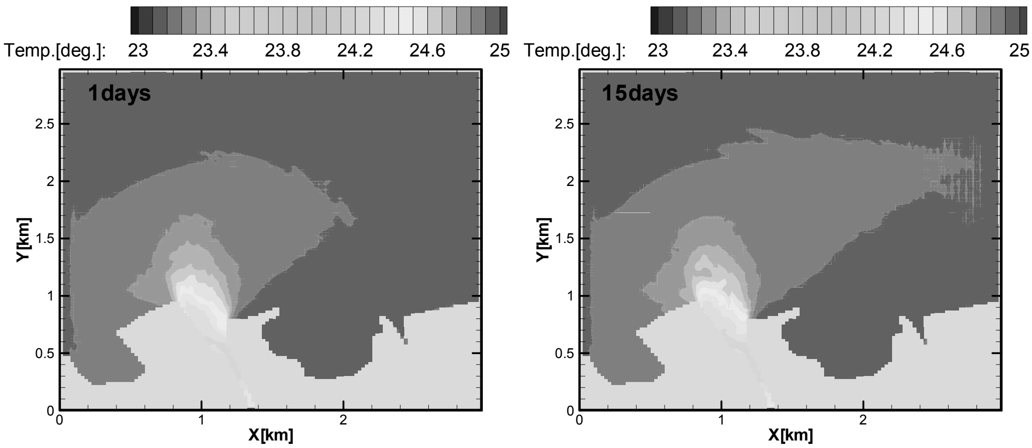
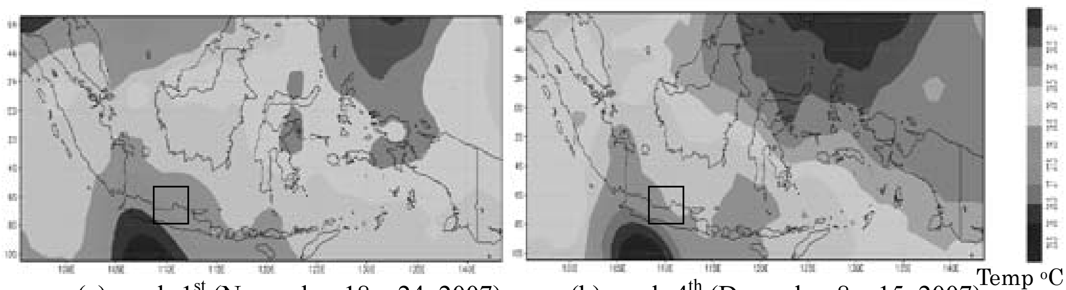


Figure 19: Computation of the horizontal distribution of temperature in ECOMSED model



(a) week-1st (November 18 – 24, 2007) (b) week-4th (December 8 – 15, 2007)

Figure 20: Weekly sea surface temperature (SST) in Indonesia based on NOAA re-analysis data

According to Wyrtki (1961), average temperature in the Java Sea ranges from 27 °C to 30 °C. This temperature is quite high for a typical tropical area range. There are some quite big differences between the ECOMSED simulation results and re-analysis data from NOAA and Wyrtki, which are estimated due to the small size of domain area of the model which covers only the width area of 3 x 3 km. If the domain area is enlarged, sea surface temperature may possibly be closer to or precisely equals NOAA or Wyrtki research results.

Figure 21 shows the simulation results of surface salinity in the time period of simulation. The salinity distributions present the consistent pattern over the whole estuary. These figures indicate some influences of river outflow near the estuary as indicated by the salinity rate in this area which ranges between 0 to 10 psu exactly at the confluence of fresh and salt water. The closer to sea, the higher salinity range from approximately 30 psu to 32 psu. According to Veen (1953), it is stated that the average surface salinity varies annually between 30.9 psu to 34.3 psu in the eastern part of the Java Sea and becoming smaller to westward with a range of 30,6 psu to 32.6 psu.

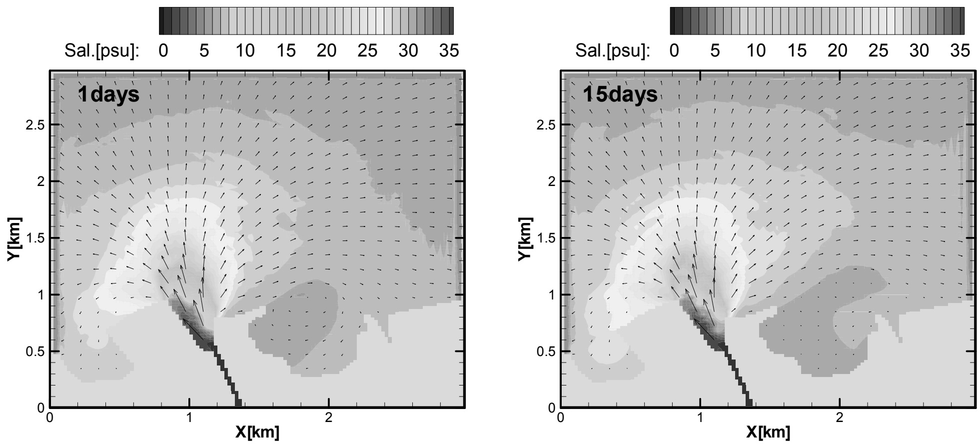


Figure 21: Computation of the horizontal distribution of salinity in ECOMSED model

Figure 22 shows the vertical profile of salinity. These figures were plotted in order to visualize and interpret vertical transport of salinity in the model area. From these figures, can be concluded that vertical salinity distribution change at the sea region is not extremely large with a range of 30 psu to 32 psu. This conclusion is also supported by the statement of Wyrtki (1961) who declared that generally vertical profiles of salinity in shallow sea region, such as in the Java Sea, show an almost homogeneous salinity from surface to bottom.

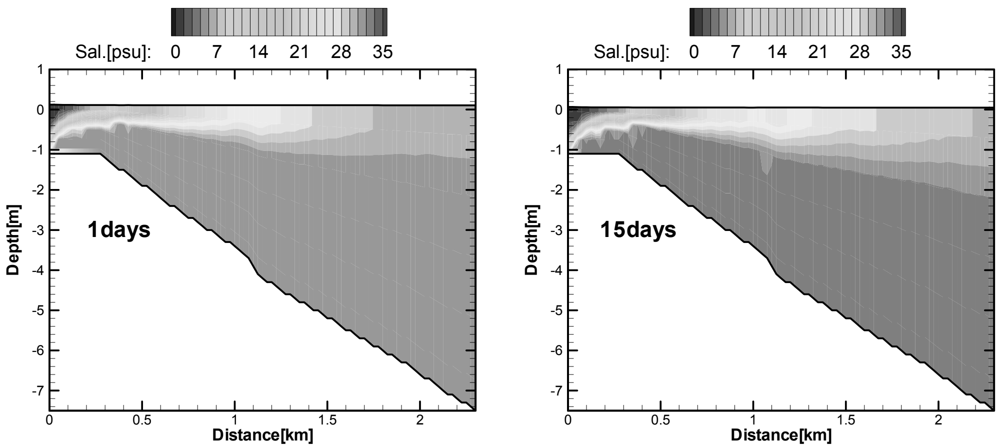


Figure 22: Computation of the vertical distribution of salinity in ECOMSED model

6. Conclusion

In this study, different models as part of the Regional Environment Simulator (RES) such as the Atmospheric model (MM5), Hydrological simulation programs (HSPF) and Estuary/Coastal model (ECOMSED) were applied. For atmospheric modeling, simulation of the MM5 model in Semarang was done in January 1 until January 30, 2005. Distribution of daily precipitation from TRMM, MM5, and MM5 with FDDA data have been compared. In general, even though biases were found when comparing observed data, re-analysis (TRMM) data and simulated precipitation, trend of precipitation that occured at the stations has shown a similar pattern. Moreover, the MM5 model is recommended as meteorological model to provide high resolution of gridded climatologic data as closely as possible with the observation data.

In hydrology modeling, HSPF model simulation in the Garang watershed with several sensible parameters was performed from January 1 to December 31, 2005. In order to verify the HSPF results, simulated daily discharge was compared with the observed daily discharge at Garang-Panjangan station. The comparison between both data gave a good results with correlation coefficient (R) of 0.89, determination coefficient (R^2) of 0.79 and Nash-Sutcliffe Efficiency (NSE) criteria of 0.68. In overall, performance of simulation in numerical model has reflected a good computation and the result has met a good criteria. It can be concluded that the simulation model produced a reasonable result and good capability to represent the hydrological condition and behavior in the Garang watershed.

The model computation for coastal estuary modeling was performed between November 24 and December 15, 2007. Whereas, model validation was carried out by comparing calculated tidal levels with measurement of Semarang and Tanjungmas Port and simulated results during the period of December 14 – 15, 2007. The comparison of simulated result of sea surface elevation changes for 48 hours simulation shows good agreement with the observed data with determination coefficient (R^2) of 0.83 if compared with the Semarang station, and 0.85 compared with the Tanjungmas Port station The results also provided a time series of temperature, salinity, and distribution of sediment concentration in the Garang estuary.

References

Ashok, K., Z. Guan, and T. Yamagata. (2001) *Impact of the Indian Ocean Dipole on the relationship between Indian Ocean monsoon rainfall and ENSO.* Geophysical Research Letter 28:4, p.499- 502.

Bicknel, B.R., J.C Imhoff, J.L. Kittle, T.H. Jobes, and A.S. Donigian Jr., (2001) *Hydrological Simulation Program Fortran: User's Manual for Version 12*: U.S. Environmental Protenction Agency, Athens, Ga., EPA/600/R-97/080.

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 and estuarine sciences,* Vol. 4, Editor N. Heap, American Geophysical Union, Washington, D.C., p.1-16.

BPS Jawa Tergah (2005), Central Java in Figures (Jawa Tengah dalam angka) 2005. Semarang. Statistics Indonesia (Badan Pusat Statistik).

Climate Change, The Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC) 2007. Switzerland. The IPCC Secretariat.

Grell, G., Dudhia, J. And Stauffer, D. R. (1994) *A description of the fifth generation Penn State/NCAR mesoscale model (MM5)*, NCAR/TN-398+STR, p.117.

Groot, R., Kwakman, P. and Velden, N. (2007) *Masterplan Semarang 2025*. TU Delft, the Netherland.

Haggag, M. (2009) *Regional Environment Simulator: Atmosphere Ocean Land Surface Hydrology Coupled Model*. Dr. dissertation, Graduate School for International Development and Cooperation, Hiroshima University, Japan.

Haggag, M. and Yamashita, T. (2009) *Environmental simulator and its application to the analysis of the tropical cyclone Gonu in 2007*, Journal of International Cooperation and Development, (in press) Vol. 15.

Haggag, M., Yamashita, T., Lee, H. S. and Kim, K. (2008) *A coupled atmosphere and multi layer land surface model for improving heavy rainfall simulation,* Hydrol. Earth System Science Discuss. Vol. 5, p.1067-1100.

HydroQual. (2002). *A primer of ECOMSED version 1.3: Users Manual*. HydroQual, Inc., Mahwah, New Jersey. USA.

Kuroki, A. J. P. (2007) *Hydrological analysis of water quality constituents transport and transform in Haji Dam watershed.* Dr. dissertation, Graduate School for International Development and Cooperation, Hiroshima

University, Japan.

Lee, H. S. (2008) *Guide for High Performance Linux Cluster (HPLC).* Graduate School for International Development and Cooperation, Hiroshima University.

Marfai, M. A. (2003). *GIS modelling of river and tidal flood hazards in a waterfront city: case study, Semarang City, Central Java, Indonesia.* M.Sc. thesis, International Institute for Geo-Information and Earth Observation, ITC, Enschede, The Netherlands.

Mellor, G. L. and Yamada, T. (1982) *Development of a turbulence closure model for geophysical fluid problems.* Rev. Geophys. Space Phys., 20, p. 851-875.

Nash, J. E. and J. V. Sutcliffe. (1970) *River flow forecasting through conceptual models: Part 1. A discussion of principles*. J. Hydrology 10 (3): p.282-290.

Petit, D., Cotel, P. and Nugroho, D. (1996) *The seasonal variation of salinity in The Java sea*. Procceding of Acoustics, p.29-41.

Research Centre for Water Resources, Ministry of Public Works. *Hydrology data.* Bandung. Indonesia

Sadhotomo, B. and Durand, J. R. (1996) *General features of Java sea ecology.* Procceding of Acoustics, p.43-54.

Santhi, C. J. G., Arnold, J. R., William, W., A Dugas., R. Srinivasan. and L. M. Hauck. (2001) *Validation of the SWAT model on a large river basin with point and nonpoint sources*, J. American Water Resources Assoc. 37 (5): p.1169-1188.

Semarang Drainage Masterplan Document. (2007) Semarang: Indonesia.

Shrestha, P.L., A.F. Blumberg, D.M. Di Toro and F. Hellweger. (2000) *A three-dimensional model for cohesive sediment transport in shallow bays,* Invited Paper, ASCE Joint Conference on Water Resources Engineering and Water Resources. Planning and Management, July 30-August 2, 2000, Minneapolis, MN.

The Agency for the Assessment and Application Technology (BPPT). (2006) Jakarta: Indonesia.

U.S. EPA. (2000) *BASINS Techinal Note 6: Estimating Hydrology and Hydraulic Parameters for HSPF*. United States Environmental Protection Agency. EPA-823-R00-012

Van Rijn, L. C. (1993) *Principles of sediment transport in rivers, estuaries and coastal seas,* Aqua Publications, Amsterdam, the Netherlands.

Veen, P .C. (1953) *Preliminary charts of the means salinity of the Indonesia archipelago and adjacent waters,* Org. Sci. Res. Indonesia, p.17-46.

Wahyu, A. (2009) *Annual and seasonal discharge responses to forest/land cover changes and climate variations in Kapuas river basin*. M.Sc. thesis, Graduate School for International Development and Cooperation, Hiroshima University, Japan.

Wyrtki, K. (1961) *Scientific results of marine investigations of the South China Sea and the Gulf of Thailand 1959-1961.* Naga Report, 2. University of California, Scripps Institute of Oceanography, La Jolla, California.

Yamashita, T., Kim, K. O., Lee, H. S. and Haggag, M. (2007) *Environment Simulator.* Annual Journal of Coastal Engineering, JSCE, 54, p.1301-1305.