Simulation of Coastal Erosion Model to Support Disaster Mitigation in Coastal Sayung, Demak District

Ahsan Habib[1], Suripin[2], Denny Nugroho Sugianto[3]
[1]Diponegoro University, Master Programme of Civil Engineering, Department of Civil Engineering, Faculty of Engineering
[2]Diponegoro University, Department of Civil Engineering, Faculty of Engineering
[3]Diponegoro University, Department of Oceanography, Faculty of Fisheries and Marine Science
Jl. Prof. Soedharto, SH, Tembalang, Semarang, Jawa Tengah, Indonesia
a.habib.sda@gmail.com; suripin.ar@gmail.com; dennysugianto@yahoo.com

Abstract **-** Coastal Sayung, Demak has occurred agricultural land and mangroves conversion for opening the ponds. Land use change inflict 2 small villages sink, namely Tambaksari (1997) and Rejosari (2004). The small villages are damaged by coastal erosion. This coast is an area affected by tides. The study aims to evaluate the erosion in coastal Sayung, by simulation model with mathematic model. The simulation results are calibrated with March and June 2016 bathymetry data. Bathymetry data is obtained by echosounder to acquiring contour depth. Wind data was obtained from NOAA for 10 years. Sediment sampling results indicate the type of silt (72%), clay (24%), and fine sand (4%), with specific gravity 1.51 – 1.85 tons/m^3. The data used for hydrodynamics and erosion modeling with mathematic model. The simulation results indicate the greatest erosion value occurs in the transition season I, which is 94,000 m^3. Patterns of erosion strongly influenced by the current patterns of a particular season. When the West, current and erosion patterns move towards northeast, and otherwise with the East. The most eroded villages are Sriwulan and Bedono, then Timbulsloko, and the smallest is Surodadi. The results of this study can be used to support disaster mitigation in the coastal Sayung, Demak.

Keywords**:** *bathymetry, coastal Sayung, erosion, mathematic model, sediment*

1. Introduction

Coastal Sayung, Demak has occurred agricultural land and mangroves conversion for opening the ponds. Two villages were sinked by land use change, namely Tambaksari (1997) and Rejosari (2004) (Prasetyo, dkk., 2014, Putri, dkk., 2014). In 2002, the area affected by erosion has an area of 146 hectares, in 2005 increased to 750 hectares (Pranoto, dkk., 2016). Shoreline changes in 1999 – 2006 due to coastal erosion have an area of 771 hectares, whereas 178 hectare of accretion. Coastal erosion is caused by current and waves, while accretion is caused by 10 rivers that displace from upstream, sink at the shore (Parman, 2010, Astuti, dkk., 2016, Dewi, et. al., 2016). The Sayung River is a large river in the Sayung Coast that is used by people to wash, tourism, and small fishing voyages. Along the river crowded with houses (Putri, dkk., 2013).

In 1980, Timbulsloko occurred agricultural land and mangroves conversion for opening the ponds. Land use change inflict coastal sink is about 400 – 1300 metres (Astuti, dkk., 2016; Dewi, et. al., 2016). The shoreline retreating as far as 2.24 km in 2003, 2.58 km in 2009, and 2.24 km in 2013 (Pranoto, dkk., 2016). Bedono experiencing the same way, which is coastal erosion and tidal floods caused by residential, industrial, recreational and tourism development, and forests conversion into ponds (Erawati, dkk., 2013). Coastal erosion in the Sayung Coast requires a countermeasures to avoid getting worse. Simulation of coastal erosion model can be used to support disaster mitigation in coastal Sayung, Demak. The study aims to evaluate the erosion in coastal Sayung, by simulation with mathematic model.

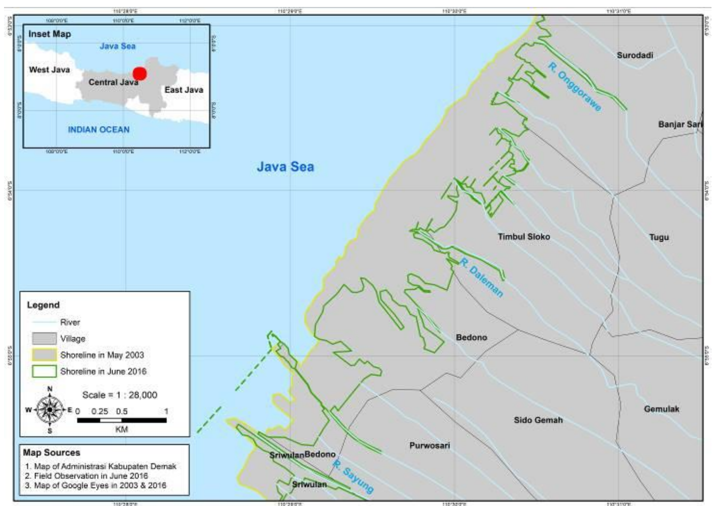


Fig. 1. Shoreline Sayung Coastal in 2003 – 2016

2. Methodology

This study was conducted in March and June 2016. Bathymetry data generated from the echosounder this month is used as a calibration model. ArcGIS 10.3 is used for further processing and analysis. Acoustic Doppler Current Profiler (ADCP) is used to measure waves and currents, tide gauges used to measure tides. Both are placed at coordinates 6^{o} 53' 24.12" S and 110° 27' 6.66" E at depth of 9.6 m.

Sediment grab is used to pick up bed sediment samples, while nansen bottles for water brightness. The number of sample stations is 12 points. Samples that have been taken are analyzed in Soil Mechanics Laboratory of Department of Civil Engineering Diponegoro University, Semarang. Rivers discharge data are estimated with NRECA method. Rainfall data used for 10 years (2005 - 2015) obtained from STA Karangroto, Banyumeneng, and Pucanggading, climatological data obtained from STA A. Yani, Semarang. WRPlot software is used to process wind data.

Two-dimensional hydrodynamics analysis using mathematic model, Flow Model FM, with Hydrodynamic and Mud Transport as module selection. The input data in this model are bathymetry, wind, river discharge, tidal, and sediment characteristics. Model simulation is for 4 seasons.

The mathematic model based on cohesive sediment transport module or mud transport (MT) deals with movement of mud in fluid and the interaction between mud and the bed. The transport of the mud generally described by the following equation:

$$\frac{\partial c^i}{\partial t}+\frac{\partial uc^i}{\partial x}+\frac{\partial vc^i}{\partial y}+\frac{\partial wc^i}{\partial z}+\frac{\partial w_s c^i}{\partial z}=\frac{\partial}{\partial x}\left(\frac{\upsilon_{Tx}}{\sigma_{Tx}^{i}}\frac{\partial c^i}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\upsilon_{Ty}}{\sigma_{Ty}^{i}}\frac{\partial c^i}{\partial y}\right)+\frac{\partial}{\partial z}\left(\frac{\upsilon_{Tz}}{\sigma_{Tz}^{i}}\frac{\partial c^i}{\partial z}\right)+S^i \quad (1)$$

Deposition:

$$S_D = w_s C_b P_d \quad (2)$$

$$P_d = 1-\frac{\tau_b}{\tau_{cd}} = \tau_b \le \tau_{cd} \quad (3)$$

Settling Velocity:

$$w_s = w_{s,r}\frac{(1-\Phi_*)(1-\Phi_p)}{1+2.5\Phi} \quad (4)$$

$$\Phi_p = \frac{c}{\rho_s} \quad (5)$$

Sediment Concentration Profile:

$$\beta = \frac{c_b}{\bar{c}} \quad (6)$$

$$\beta = 1+\frac{P_e}{1.25+4.75P_d^{2.5}} \quad (7)$$

$$P_e = \frac{w_s h}{\overline{\overline{D_z}}} = \frac{6w_s}{\kappa U_f} \quad (8)$$

Erosion:

$$S_E = E\left(\frac{\tau_b}{\tau_{ce}}-1\right)^n, \tau_b > \tau_{ce} \quad (9)$$

$$S_E = E\, exp\left[\alpha(\tau_b-\tau_{ce})^{1/2}\right], \tau_b > \tau_{ce} \quad (10)$$

Where,

t : time
x, y, z : cartesian co-ordinates
u, v, w : flow velocity components
Dv : vertical turbulent (eddy) diffusion coefficient
c^i : the i^{th} scalar component (defined as the mass concentration)
wsi : fall velocity
σTxi : turbulent Schimidt number
υTx : anisotropic eddy viscosity
Si : source term
S_D : deposition rate
P_d : probability of deposition

τ_b : bed shear stress
τ_{cd} : critical bed shear stress for deposition
τ_{ce} : critical bed shear stress for erosion
ρ_s : density of sediment grains
κ : Von Karman's universal constant (κ = 0.4)
Uf : friction velocity $\sqrt{\tau_b/\rho}$
E : erodibility of bed
n : power of erosion
α : coefficient ($m/\sqrt{N}$)

Verification of model through tidal field data and forcast of model, and calibration bathymetry in March and June 2016. Verification used Mean Relative Error (MRE) Method.

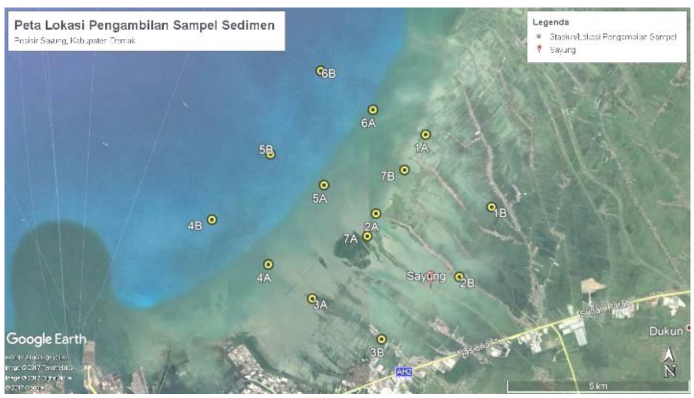
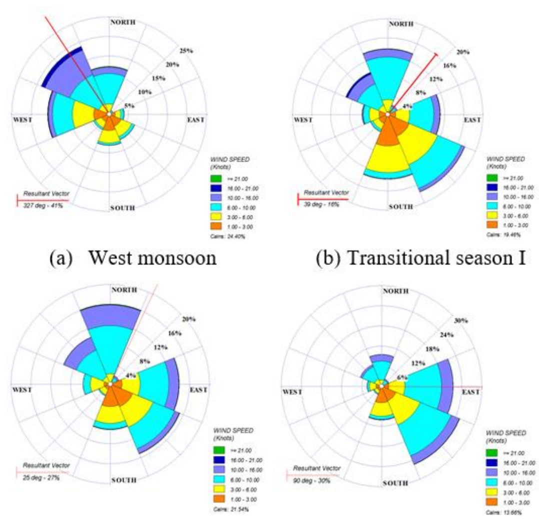


Fig. 2. Location of sampling in Coastal Sayung

3. Result and Discussion

3.1. Results Data Processing



(a) West monsoon (b) Transitional season I

(b) East monsoon (d) Transitional season II

Fig. 3. Wind rose diagram in 2005 – 2015

The results of data processing included in the model are bathymetry, shoreline map, river flow, wind, and sediment. Winds in the west monsoon have a dominant direction from the northwest with the resultant vector 327^o to the southeast. In the transition season I indicates that the dominant wind comes from the southeast with a resultant vector of 39^o (northeast). As for the east monsoon the dominant wind direction comes from the northeast direction with the resultant vector 25^o. In the transitional II the dominant wind direction originates from the northeast direction with a resultant vector of 90^o, this may be due to the topography of the Sayung which is not perpendicular to the northern coast, but slightly oblique.

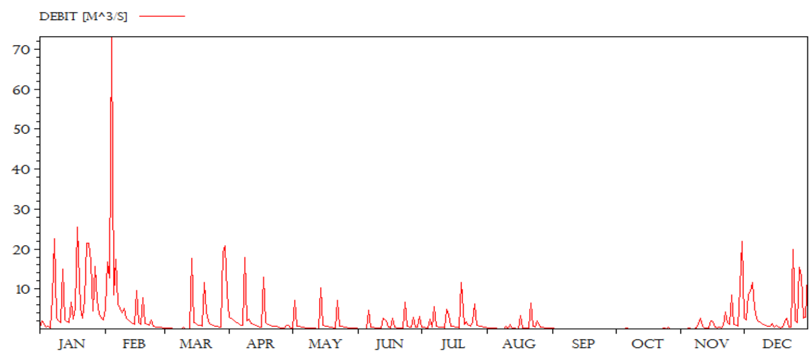


Fig. 4. Daily discharge from Daleman River in 2014

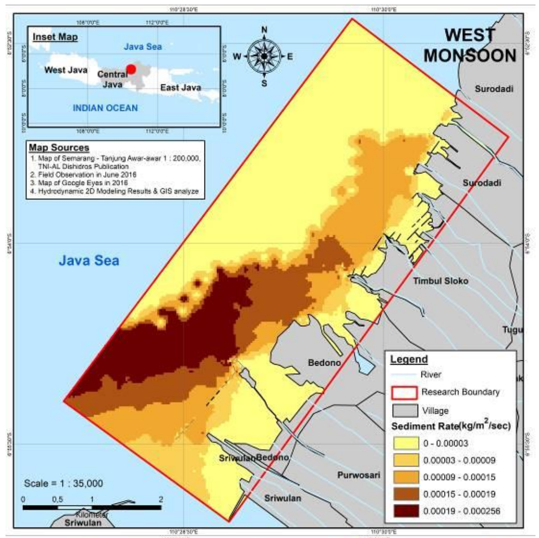
Laboratory results indicate the bed of the coastal Sayung is dominated by silt and clay. There is 1 location which is dominated by the grain size of fine sand that is at 3B. The location is in the Sayung River and probably the sand is carry from upstream.

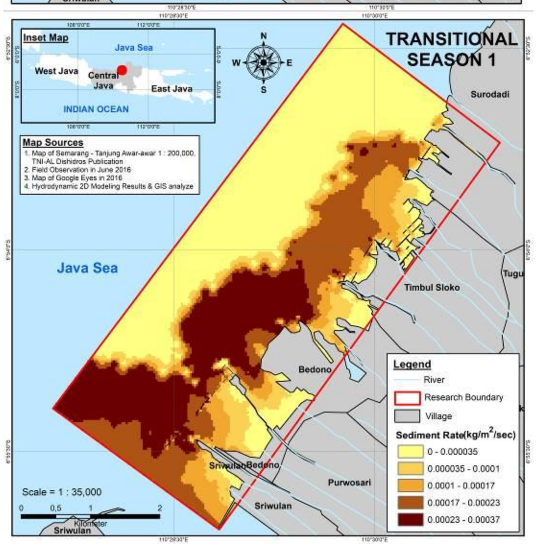
Table. 1. Classification of sediment in Coastal Sayung

No	Stasion	Location		Name of Sediment
		Latitude	Longitude	
1	1A	6° 53' 5.43"	110° 30' 30.83"	*Silty clay*
2	1B	6° 54' 9.56"	110° 31' 29.87"	*Silty clay*
3	2A	6° 54' 15.36"	110° 29' 46.43"	*Silty clay*
4	2B	6° 55' 11.47"	110° 31' 1.00"	*Silty clay*
5	3A	6° 55' 30.72"	110° 28' 49.55"	*Silty clay*
6	3B	6° 56' 6.68"	110° 29' 51.45"	*Silty sand*
7	4A	6° 55' 0.47"	110° 28' 10.26"	*Silty clay*
8	4B	6° 54' 20.75"	110° 27' 19.81"	*Silty clay*
9	5A	6° 53' 50.16"	110° 29' 0.06"	*Silty clay*
10	5B	6° 53' 22.75"	110° 28' 12.25"	*Silty clay*
11	6A	6° 52' 43.4"	110° 29' 43.75"	*Silty clay*
12	6B	6° 52' 8.94"	110° 28' 57.10"	*Silty clay*

3.2. Result of Coastal Erosion Model

Model simulations indicate there has been erosion along the Sayung Coast, Demak in each season. In the west season the erosion rate of 3 x 10^{-5} to 2.56 x 10^{-4} kg/m^2/sec moves northeast. This is due to dominant wave from the northwest (330^o) and perpendicular to the coastline of Sayung which has an odd slope, causing sediment moves in this directions.





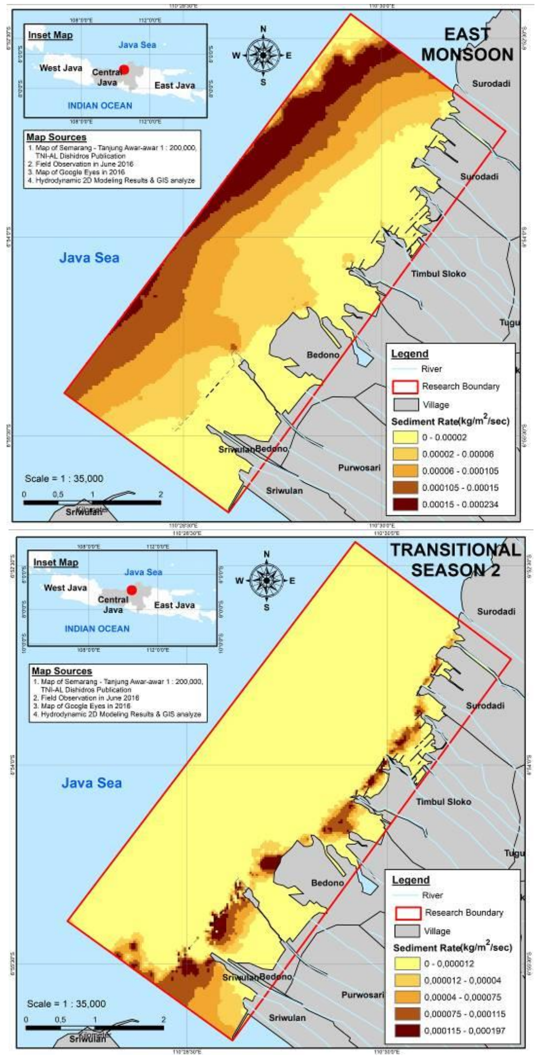


Fig. 5. The result of seasonal coastal erosion modeling in Sayung, Demak

Similarly, in the transition season I. The erosion rate is known to be 3.5×10^{-5} to 3.7×10^{-4} kg/m^2/sec. The rate of erosion moves northeast. This is due to the dominant wave from the north (360^o) and perpendicular to the coastline of Sayung, causing sediment moves in this directions.

Likewise in the east season. The erosion rate is known to be 2×10^{-5} to 2.34×10^{-4} kg/m^2/sec. The rate of erosion is moving northwest. This is due to the dominant wave of the southeast (100^o), encouraging and moving sediment in that direction.

In the transition season II the erosion rate of 1.2×10^{-5} to 1.97×10^{-4} kg/m^2/sec. The rate of erosion moves northwest. This is due to the dominant wave of the southeast (98^o), encouraging and moving sediment in that direction.

In addition there has been a wave deformation as the waves spread from deep water to shallow. The diffraction process takes place in slits of the breakwater and hybrid engineering (HE) causing a wave direction change (Harahab, 2016). It is seen that the erosion occurring in the breakwater gap has a directional deflection due to the diffraction process.

The process of refraction occurs when the waves spread in the deep waters to the shore, the wave vector will turn the direction and try to perpendicular to the shore. The direction changes is caused by depth change, then the wave speed will decrease. The waves have broken and formed a large angle (αb = 29.19^o, for the west season) to the coast and becoming to longshore currents that erode and transport the sediment. This is in accordance with the statement of Triatmodjo (2012), when a wave breaks into an angle to the shoreline ($\alpha b > 5^o$), a longshore current that can transport the sediment has been moved by the waves.

Table. 2. Sediment volume from simulation model results in the four season at coastal Sayung, Demak

No	Season	Volume of Sediment (m^3)		Notation
		Accretion	Erosion	
1.	West	7,700	58,600	Erosion
2.	Transitional I	7,100	101,100	Erosion
3.	East	4,300	46,700	Erosion
4.	Transitional II	4,800	8,800	Erosion

The sedimentation value in the west season is 7,700 m^3, and erosion is 58,600 m^3. In the transition season I sedimentation value is 7,100 m^3, erosion is 101,100 m^3. In the east season the value of sedimentation is 4,300 m^3, erosion is 46,700 m^3. In the transition season II sedimentation value is 4,800 m^3, erosion is 8,800 m^3. Based on the simulation results obtained erosion value greater than sedimentation. The mathematical model shows that the Sayung Coastal has erosion throughout the season because the volume of erosion is greater than the accretion. The most eroded villages occur in Sriwulan and Bedono, then Timbulsloko, and the smallest is Surodadi. Based on modeling results it can be predicted that erosion moves more dominantly from the southwest toward the northeast.

3.3. Model Verification

Verification using MRE method. Tidal and bathymetry data verification results appear to be almost as good. This can be proved by the MRE calculation results that have a small error rate. For tidal and bathymetry, each value is 38.90 % and 30.39 %.

4. Conclusion

The pattern of erosion is strongly influenced by the pattern of a particular seasonal current, as the western seasons flow patterns and erosions move towards the northeast, and in reverse with east seasons. Value of erosion for west season is 50,900 m^3, transition I is 94,000 m^3, the east is 42,400 m^3, and transition II is 4,000 m^3. So the erosion total is 191,300 m^3/year. The largest erosion value occurred in transition season I, while the smallest in the transition II. The most eroded villages occur in Sriwulan and Bedono, then Timbulsloko, and the smallest is Surodadi. Based on modeling results it can be predicted that erosion moves more dominantly from the southwest toward the northeast. The results of this study can be used to support disaster mitigation in the Sayung Coast, Demak District.

Acknowledgements

Author would like to thank to the Lembaga Penelitian dan Pengabdian Kepada Masyarakat (LPPM) Diponegoro University, Lingkup Loka Riset Sumberdaya dan Kerentanan Pesisir, Padang, BRSDMKP, Kementerian Kelautan dan Perikanan (KKP-Padang). Thanks also to all the respondents, the village chiefs, and all those who have helped so done research.

References

Astuti E.H., Ismanto A., Saputro S. (2016). Studi Pengaruh Gelombang Terhadap Trasport Sedimen di Perairan Timbulsloko Kabupaten Demak Jawa Tengah. “JURNAL OSEANOGRAFI 5” 1, 77-85. Semarang.

Dewi R.S., Bijker W., Stein A., Marfai M.A. (2016). Fuzzy Classification for Shoreline Change Monitoring in a Part of the Northern Coastal Area of Java, Indonesia. “Journal of Remote Sensing MDPI 8” 190, 1-25. Basel, Switzerland.

Erawati I., Mussadun. (2013). Partisipasi Masyarakat dalam Pengelolaan Sumber Daya Lingkungan Mangrove di Desa Bedono, Kecamatan Sayung. “Jurnal Ruang 1” 1, 31-40. Semarang.

Harahab M.I. (2016). Analisis Transformasi dan Spektrum Gelombang Berarah di Perairan Sayung, Demak, Jawa Tengah. “Skripsi Fakultas Perikanan dan Ilmu Kelautan Universitas Diponegoro”. Semarang.

Parman S. (2010). Deteksi Perubahan Garis Pantai Melalui Citra Penginderaan Jauh di Pantai Utara Semarang Demak. “Jurnal Geografi 7” 1, 30-38. Semarang.

Pranoto H.R., Atmodjo W., Sugianto D.N. (2016). Studi Sedimentasi pada Bangunan Groin di Perairan Timbulsloko, Kabupaten Demak. “JURNAL OSEANOGRAFI 5” 1, 86-95. Semarang.

Prasetyo E., Suwandono D. (2014). Konsep Desa Wisata Hutan Mangrove di Desa Bedono, Kecamatan Sayung, Kabupaten Demak. “Jurnal Ruang 2” 4, 361-370. Semarang.

Putri D.S., Purnomo P.W., Haeruddin. (2013). Tingkat Pencemaran Deterjen pada Sedimen Menggunakan Indikator Kimia-Biologi di Sungai Sayung. “Diponegoro Journal of Maquares, Management of Aquatic Resources 2” 4, 100-109. Semarang.

Putri M.P., Supriharyono, Muskananfola M.R. (2014). Karakteristik Hidro-Oseanografi dan Tingkat Partisipasi Masyarakat dalam Menanggulangi Kerusakan Pantai di Desa Bedono, Kecamatan Sayung, Kabupaten Demak. “Diponegoro Journal of Maquares, Management of Aquatic Resources 3” 4, 225-234. Semarang.

Triatmodjo B. (2012). Perencanaan Bangunan Pantai. “Beta Offset”. Yogyakarta.