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Hydrodynamics and Morphological Changes Numerical Model of the Jeneberang Estuary

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Abstract— ***Jeneberang Estuary, located south of Makassar, Indonesia, is one of the largest and most important river in Sulawesi. In this paper, a numerical model has recently been developed hydrodynamic and morphological evolution of the downstream rubber dam of the Jeneberang Estuary. The hydrodynamic model is derived from the hydro static assumption and Boussinesq approximation. A high-resolution computational grid was generated covering the Jeneberang estuary. The model was run with time driven by tidal forcing at the ocean boundary and river hydro graph at the upstream. The observed tidal data and hydrography were accessible for the set-up of the model. Hydrodynamic simulations have been performed and computed water levels were compared to observations of existing water level along the estuary from DISHIDRO data. For the period of a neap-spring-neap cycle, the model settings determined in the calibration process are verified satisfactions with respect to water level measurements. Good agreement was shown between model results and observed temporal and spatial variations in water elevation and currents, in the Jeneberang Estuary. The suspended sediments were generally transported from the Jeneberang River towards the Makassar Strait when overflow discharge through the Jeneberang Rubber Dam. Morphology change at the Jeneberang Estuary delta is affected by many factors, including tide, waves, river flows and sediment.***

Keywords—Numerical model, hydrodynamic, sediment transport, morphology, Jeneberang

I. INTRODUCTION

Estuaries are important to humankind as commerce, recreation, places of navigation and as well as habitats for biological life. Therefore, prediction and understanding of estuarine process behaviour is a crucial part of their management in a sustainable manner. The morphology of an estuary is formed through the interaction between flowing water, river form, sediment, plants, water flow, structures, and bank geography and provides a variety of habitats for different organisms. Pools, shallows, and loose stone stripes are all typical biological habitats in water. The most important unique of a river habitat is that it can be lost and reproduced again [1].

Understanding the physical processes that govern hydrodynamics, sediment transport, and morphology of estuary environments is necessary to both support management and improvement efforts. The complex interactions among biological activity, hydrodynamic, physical changes, and sediment transport to the surface and shoreline create a response cycle. [2] described the equilibrium concept for mud flats of intertidal through time and surmised that with changing external forces (engineering works, sea level rise), estuaries and mud flats are constantly adapting. Represent space was given to discussing morphodynamics and hydrodynamics in a argument of the state of research on estuarine processes in [3], marking the need to view all elements of the estuary evolutionary cycle evenly. More investigations that are recent present findings as a synthesis of the feedback cycle [4]. Estuary process can be analysed from many perspectives, including geomorphically or sedimentologically. [5] discussed estuary process for tide-dominated - and wave estuaries as a displace in sediment facies.

The primary hydrodynamic processes affecting estuarine morphology are river flows, tides and waves, which erode, transport and deposit sediments. Tidally generated currents within estuaries are driven by the tidal range on the open coast, the tidal volume of the estuary and interaction with the bed. They are also affected by density driven circulation and by the rotation of the earth, via the Corolis Effect. River flows have the greatest effect in the upper reaches of estuaries with tidal flows becoming dominant in the middle and outer regions. The outer estuary may also be significantly affected by wave-driven flows and sediment transport, leading to the development of features such as spits and barrier beaches [6]. Availability of sediment significantly influences the morphology.

High fluvial sediment loads tend to result in rapid sedimentation and the formation of deltas. The availability of marine sediment may influence the formation of spits, bars and barrier beaches as well as sand and mud flats in the middle and outer estuary. The morphology of estuaries is a result of interaction between sediment motion and water and bed topography. Predicting and understanding the morphodynamic process of estuaries is still limited, because of its difficulty and because it involves space scales and a wide range of time. The Jeneberang Estuary provides a case for studying estuarine dynamic and sediment transport. Sediments have been carried by Jeneberang River and trapped in the Jeneberang Estuary to form Barombong and Tanjung Bunga Deltas. The interaction between fresh water flow and tides and tidal current entering from the strait of Makassar acts a significant role in forming the deltas. Numerical simulation has been extensively applied in morphology studies in estuaries. With the utilisation of computer and numerical methods by means of hydrodynamic equations for solutions of unsteady flows, mathematical modelling has become an effective and economic way to obtain the required hydraulic parameters and to give a gain insight to morphological processes compared to the high cost of performing field observations. It gives a significant contribution to prediction and understanding of estuary evolution that allows creating a rational contingency planning.

Therefore, in this paper, we address to model hydrodynamic and morphology in the Jeneberang Estuary by using a development fully integrated hydrodynamic and sediment transport model, ECOMSED. The scope of this study is to implement and improve the hydrodynamic and morphology numerical modeling system for an estuarine zone. The model used is fully integrated three dimensional (3D) hydrodynamic and sediment transport. A module of Estuarine Coastal and Ocean Modeling System with Sediment (ECOMSED), developed by [7], has been successfully applied to the estuarine and coastal waters. The development of ECOMSED was originated in the mid 1980's with the development of the Princeton Ocean Model [8]. Some recent applications of the module include Chesapeake Bay [9], Delaware Bay and Delaware River [10], the Gulf Stream Region [11. [12] well reproduced the tidal currents and tides with the use of a horizontally 3D hydrodynamic model which was applied to the Estuary of Mahakam, East Kalimantan, Indonesia.

II. STUDY AREA

Jeneberang Estuary is located in the southern of Makassar, Indonesia. The Jeneberang River flows from east to west across the province, is one of the largest and most important river in Sulawesi (Fig.1). Between these river mouths, the coastal of Jeneberang estuary had developed. The coastal area included Barombong Beach in the south to the Tanjung Bunga at north. The Estuary Jeneberang coast is very dynamic, natural, accumulation sediment from fluvial, coastal, marine processes and human activities. An active delta system which has been formed in humid tropical environments under condition of relatively tidal amplitude, low wave-energy, and fluvial input.

Originating from Mt. Bawakaraeng (2,833 m), it flows to the Makassar Strait. The river is 90 km long with a catchment area of 727 km2. There are two reservoirs, which have constructed in the catchment, the Bilibili reservoir located on the Jeneberang River, holds 375,000,000 m3 water flow and the Jenelata Reservoir located on the tributary Jenelata River. In the rainy season (October-April), floods are normally caused by rainstorms, and often short floods are seasoned. There is a productive land for paddy rice and the area under irrigation area is 17,400 ha. The Jeneberang river mouth had formed a delta, which divided the river into two river mouths, the north river mouth and the south river mouth (Fig. 2).

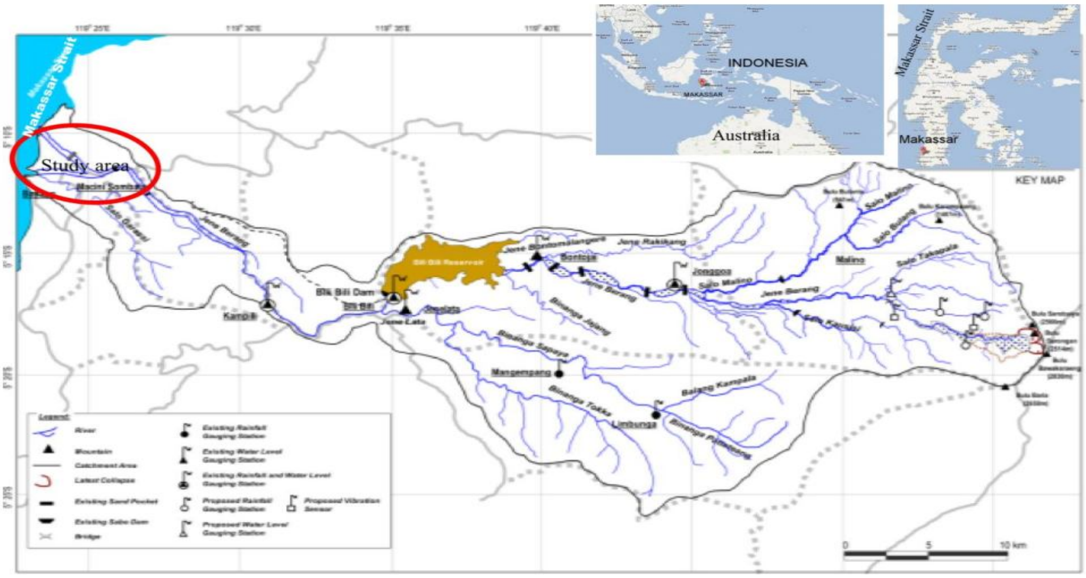

Fig. 1 Jeneberang River watershed

Fig. 2 Study area (Google earth image 2015)

Improvements Lower Jeneberang River work covered dredging, excavation, embankment and revetment constructions for a 9.6 km section between the mouth of the Jeneberang River and the Sungguminasa Bridge. The project was to conduct river improvements for the Jeneberang River, to provide flood protection of Makassar. [2]. Development activities that have been conducted in the Jeneberang to support the growth of Makassar include: River Improvement (1993), Long Storage / Closure North Estuary (1994), Jeneberang Rubber Dam (1999), and Bili-Bili Multi Purpose Dam (1999). Beside to reduce flood damage, The Bilibili Dam also stabilize supplies of raw water by installing a raw water transmission main to the Somba Opu water treatment plant, leading to the response to water demand from Makassar and the surrounding area [13]. Jeneberang Estuary is in the western part of the southern coast of the island of South Sulawesi, which consists of tidal areas, fluvial and river delta areas that are low slope (<2%) and is covered by alluvium and coastal sediments.

III. METHODOLOGY

A. HYDRODYNAMIC MODEL

The equations which form the basis of the circulation model describe the velocity and surface elevation fields. Two simplifying approximations are used [8]; first, it is assumed that the weight of the fluid identically balances the pressure (hydrostatic assumption), and second, density differences are neglected unless the differences are multiplied by gravity (Boussinesq approximation). The governing equations of the hydrodynamic component in the model are the continuity and momentum equations. The hydrodynamic part of the model uses the following basic equations. The basic equations for the three-dimensional mode are:

The continuity equations:

$$\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}+\frac{\partial W}{\partial z}=0$$

The momentum equations:

$$\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}-fV=-\frac{1}{\rho_0}\frac{\partial P}{\partial x}+\frac{\partial}{\partial z}\left(K_m\frac{\partial U}{\partial z}\right)+F_x$$

$$\frac{\partial V}{\partial t}+U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}+W\frac{\partial V}{\partial z}+fU=-\frac{1}{\rho_0}\frac{\partial P}{\partial y}+\frac{\partial}{\partial z}\left(K_M\frac{\partial V}{\partial z}\right)+F_y$$

$$\rho g=-\frac{\partial P}{\partial z}$$

where (U,V,W) are the eastward (z), northward (y), and upward (z) components of the current with the ρ_0 reference density, the in situ density, g the gravitational acceleration, P the pressure, K_M the vertical eddy diffusivity of turbulent momentum mixing. A dynamic boundary condition evaluated at the sea surface $z=\eta$ will indicate the relation between sea surface elevation h and vertical velocity at the sea surface W_η as,

$$\frac{\partial \eta}{\partial t}+\frac{\partial \eta}{\partial x}U_\eta+\frac{\partial \eta}{\partial y}V_\eta=W_\eta$$

B. SEDIMENT TRANSPORT MODEL

1) *The transport equation*

The transport of suspended sediment is described by the following advection-diffusion equation:

$$\frac{\partial C}{\partial t}+\frac{\partial UC}{\partial x}+\frac{\partial VC}{\partial y}+\frac{\partial (W-W_s)C}{\partial z}=\frac{\partial}{\partial x}\left(A_H\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(A_H\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_v\frac{\partial C}{\partial z}\right)$$

where *C* denotes suspended sediment concentration, W_s is settling velocity of the cohesive sediment (cm s_1) which will be shown later. *Bottom shear stress computation* The bed shear stress is computed as follows:

$$\tau = \rho u_+^2$$

where ρ denotes density of the suspending medium (2650 kg m_3), and u_+ a shear velocity. The shear velocity is defined by the Prandtl-von Karman logarithmic velocity profile:

$$u_* = \frac{\kappa u}{ln\left(\frac{z}{z_o}\right)}$$

where κ is von Karman constant (≈0.40), *u* resultant near bed velocity, *z* depth at the center of the bottom layer, and z_0 bottom friction specified as input to the model (0.001 m).

2) *The erosion model*

Erodibility of a cohesive bed is driven by current shear but also depends on bottom cohesive nature, which in turn depends, in poorly understood way, on clay mineralogy and on the geochemistry and microbiological processes occurring in the bottom. The amount of fine grained sediment eroded from a cohesive sediment bed is given by [14] as :

$$\varepsilon = \frac{a_o}{T_d^m}\left(\frac{\tau_b-\tau_c}{\tau_c}\right)^n$$

where ε denotes erosion potential (mg cm_2), a_0 a constant depending upon the bed properties (=2.1 mg cm^{-2}), T_d a time after deposition (days), τ_b bed shear stress (dynes cm^2), τ_c critical shear stress for erosion (=1.0 dynes cm^{-2}), *m* (=0.5) and *n* (=2.5) constants dependent upon the depositional environment.

3) *The deposition model*

The deposition rate for cohesive sediments is calculated according to the formulation of [15] as follows:

$$D_d = -W_sCP_d$$

where D_d denotes depositional flux (g cm^{-2} s^{-1}), and P_d probability of deposition described by

$$P_d = 1-\left(\frac{\tau_b}{\tau_d}\right) \quad for\ \tau_b \le \tau_d$$

$$P_d = 0 \qquad for\ \tau_b > \tau_d$$

where t_d is the critical shear stress for deposition (1.0 dynes cm2). Settling speeds of cohesive flocks have been measured over a large range of concentrations and shear stresses [16]. Experimental results show that the settling speed of cohesive flocks is dependent on the product of concentration and the water column shear stress at which the flocks are formed, resulting in the following relationship

$$W_s = \alpha(CG)^\beta$$

in which W_s, *C*, and *G* are expressed in m day_1, mg l_1, and dynes cm_2, respectively. For saltwater suspensions, analysis of [17] data revealed values of α and β of 2.42 and 0.22, respectively. The above equation implicitly incorporates the effect of internal shear stress (G) on aggregation and settling. The water column stress (*G*) is computed from the hydrodynamic output (i.e., current velocity and vertical eddy viscosity) as follows:

$$G = \rho A_V\left[\left(\frac{\partial u}{\partial z}\right)^2+\left(\frac{\partial v}{\partial z}\right)^2\right]^{1/2}$$

Where K_M = vertical eddy viscosity, and ρ = density of the suspending medium.

The complex interactions occurring at the vicinity of the sediment-water interface cause only a certain fraction of settling sediments to actually become incorporated into the bed. [16] developed an empirically based formulation that realistically represents the effects of variable flock size on probability of deposition.

IV. DESIGN MODEL

The computational domain and bathymetry of the Jeneberang Estuary is shown in Figure 3, which located in the area of 119°22'9.19”-119°24'28.76" E 5°10'24.81" - 5°12'28.46" S. The region of the Jeneberang Estuary was simulated in the model using horizontally finite difference mesh of 45 x 40 grid squares, equally spaced at 100 m interval, and vertical grid of 10 σ-levels.

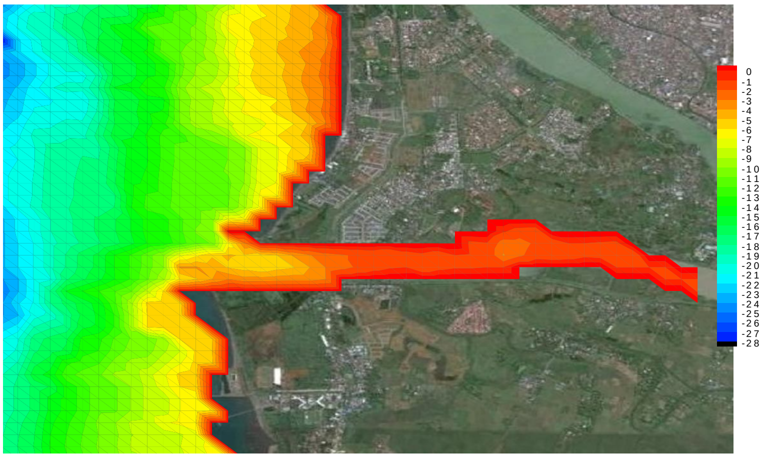

Fig. 3 Computational domain and bathymetry.

The model domain is bounded by three open boundaries: one in the west, one in the north and one in the south of the domain. The main force of the model is the tidal elevation, which is worn on the open sea boundary by eight constituent tides (M2, S2, N2, K2, K1, O1, P1 and Q1) from the calculation of tide data published by the Indonesian Hydrooceanographic Service (DISHIDROS). The tidal constituents given model are shown in Table 1.

TABLE 1- THE AMPLITUDES AND PHASE (REFERENCED AT GMT 08.00) OF THE HARMONIC CONSTITUENTS ALONG THE OPEN BOUNDARY

	S2	M2	N2	K1	P1	O1
A (m)	0.13072	0.10184	0.0412	0.28832	0.09972	0.23296
g^o	145.0251	113.693	53.99814	81.27207	51.94985	266.5232

The river discharge at the upstream boundary was given at the Jeneberang Rubber Dam. The river discharge data obtained from the authorities of Balai Sungai Jeneberang – Pompengan, Ministry Public Work, Republic of Indonesia are shown in Fig. 4. Temperature, salinity, and suspended sediment concentration at the upstream boundary under river discharge were 29^{o}C, 0.1 psu, and 170 mg/l, respectively.

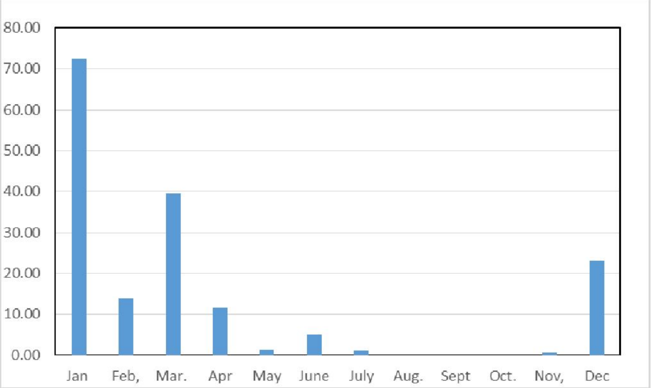

Fig. 4 The monthly river discharge average (m^3/s) data of the Jeneberang Rubber Dam

The sediment concentration was given and the average sediment discharge is 98 mg/lt. The initial conditions of temperature and salinity are necessary for the start of the simulation. The initial suspended sediment concentration was set to be 5 mg/l.

V. RESULTS AND DISCUSSIONS

A. MODEL VERIFICATION

For model verification, the simulated water surface elevation is compared to that of field data supply by DISHIDRO. The verification results of water elevation can be seen in Figure 5. From the figure, it is shown that the model predicts the free surface elevation quite well for the tidal phases and the amplitude. Current velocities are complement of the tidal elevation. The root mean squared (RMS) error between the model results and the observed ones is 0.13967 m.

Table 2 shows the current verification of simulation results with observation data conducted at the Jeneberang River, comparison of the predicted and measured velocity. Generally, one can see that the simulated velocity shows a good agreement with that of the measured one, mainly for the tidal current phases. However, the magnitude of predicted results is weaker, with a mean error of about 0.054229 m/s.

The difference between the predicted and measured results is probably caused by the estimation of the effect of the bottom friction, which does not reproduce adequately the nonlinear interaction of the extremely strong tidal currents with the bottom topography.

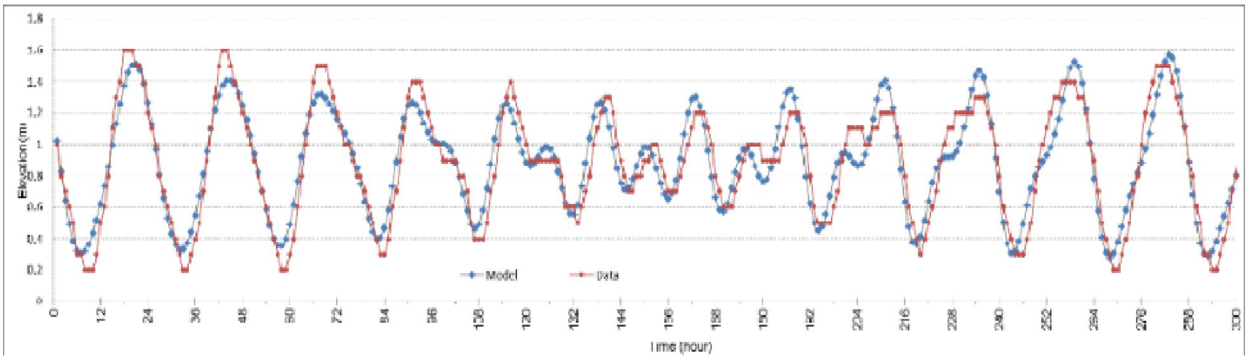

Fig. 5 Verification of elevation between the observation data

TABLE 2 - RMS ERROR VERIFICATION OF THE CURRENT VELOCITY

UTM Coordinate		Grid Model		Current Velocity (m/s)		RMS error	
X	Y	X	Y	V data	V model	(Vdata-Vmodel)	$(\text{Vdata-Vmodel})^2$
766239	9425536	35	20	0.369	0.413903	-0.045403	0.002061
766239	9425631	35	21	0.198	0.200161	-0.002161	0.000005
765681	9425527	34	20	0.422	0.398687	0.022813	0.000520
765668	9425431	34	21	0.100	0.120629	-0.020379	0.000415
765182	9425596	29	18	0.724	0.651880	0.071870	0.005165
765182	9425551	29	19	0.935	1.053236	-0.118236	0.013980
764642	9425446	24	18	0.883	0.849838	0.032912	0.001083
764637	9425381	24	19	0.531	0.547718	-0.017218	0.000296
$RMSErrors = \sqrt{\frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}{n}} =$							0.054229

B. HYDRODYNAMIC MODEL

Figure 6 shows the tide and river discharge-driven circulation for spring ebb and flood condition without the Jeneberang rubber dam overflow discharge, respectively. The figure clearly shows the existence of currents that flow back and forth representing tide and ebb conditions. At tide condition (Fig. 6a), they flow into the Jeneberang River. Otherwise, at low tide condition (Fig. 6b) the currents come from the Jeneberang River flow into the Makassar Strait through river and tidal channels that exist in the Estuary of Jeneberang Delta. Mass flow pattern of water in spring tide conditions against the tide dominated by the flow moving toward the north turn and then flows east toward the shoreline.

Fig. 1 Current pattern without the Jeneberang rubber dam overflow discharge, (a) Spring tide flow condition, (b) Low tide flow condition

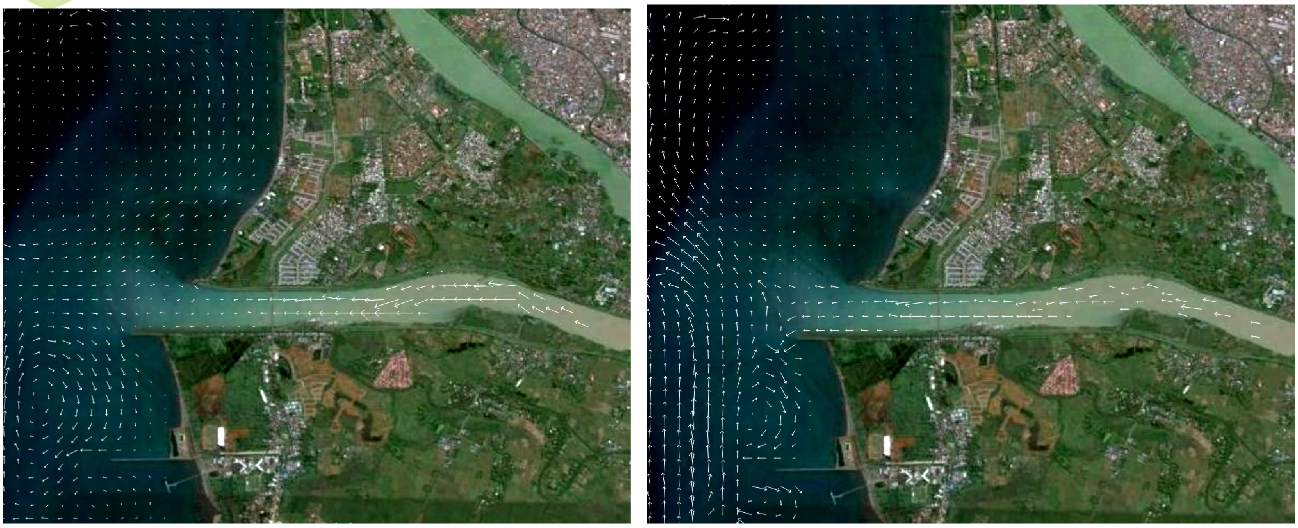

Fig. 6 Current pattern with the Jeneberang rubber dam overflow discharge (a) Spring tide flow condition, (b) Low tide flow condition

The model also shows the spring – low tide cycle when current come from rubber dam overflow discharge (Fig. 7). The pattern of the mass flow of water on to the spring tide conditions was dominated by the flow moving eastward then the flow was turned down to the south (Fig. 7a). On the offshore side in the open boundaries, the flow of water towards to the north. Encouragement tide happens withstand the speed of the river out towards to offshore. At the time of low tide, the current pattern move from the river into the sea (Fig. 7b). Tidal flow patterns of the low tide condition showed the flow is dominated by a movement the east to the west in the river channel (Fig. 7b). In addition, the flow around the river mouth is also appear to have currents moving to the north, with a pattern away from the shoreline. It is found that the currents come from the Jeneberang River into the Makassar Strait mainly through. The river discharges clearly influence the circulation

C. SEDIMENT TRANSPORT

The behaviour of suspended sediment varies depend on circulation pattern resulting from the relative importance of tidal current effect to river discharge. During the tide condition, the suspended sediment concentration stuck in the mouth of the river (Fig. 8). The concentration of sediment in the river flow is higher than on the sea side, it seems that around the mouth of the river, the distribution of sediments to the north and south is higher than concentration in the south side (Barombong Side).

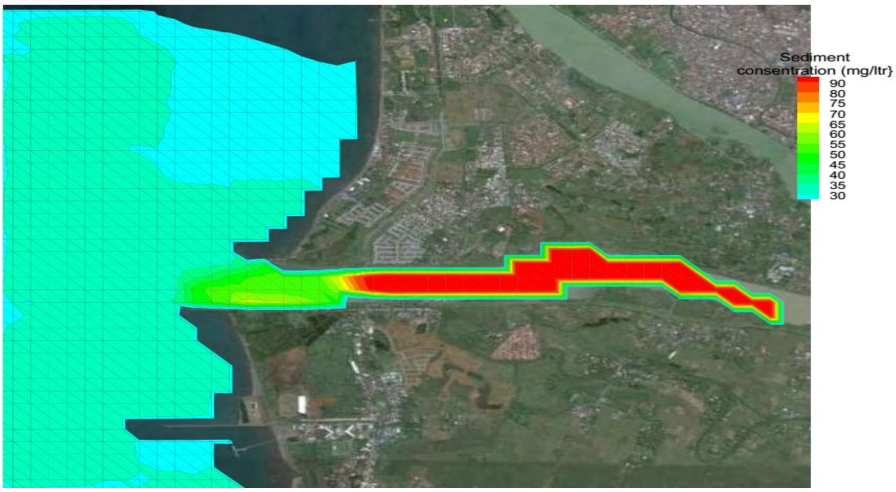

Fig. 7 Temporal variation of suspended sediment concentration, tidal current with rubber dam overflow discharge

During the low tide condition, suspended sediment is transported from the Jeneberang River towards the offshore area in the Makassar Strait as shown in Fig. 9. The sediments distribution affected by river discharge, sediment concentration can be pushed farther out to offshore, and disperse to the sea towards the Makassar Strait. Distribution of sediment concentrations in the mouth of the estuary is higher, and decreases towards the north and the south, but the sediment concentrations is higher on the south side that lead to the beach Barombong to the jetty. The south Jetty Barombong sediment concentrations decrease affected by river discharge, sediment concentration can be pushed farther out to sea, and swept the sea towards the Makassar Strait.

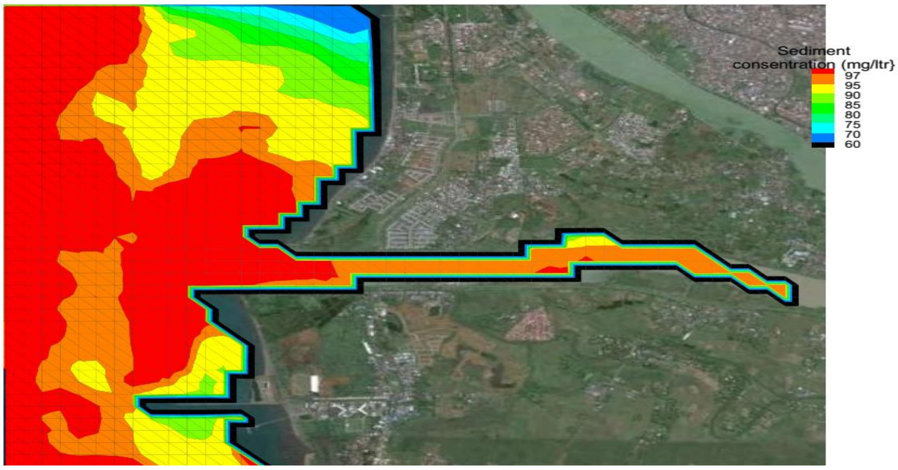

Fig. 8 Temporal variation of suspended sediment concentration, low tide current with rubber dam overflow discharge

Distribution of sediment concentrations in the mouth of the estuary is higher, and decreases towards the north and the south, but the sediment concentrations is higher on the south side that lead to the beach Barombong to the jetty, the south Jetty Barombong sediment concentrations decrease.

D. MORPHOLOGICAL CHANGES OF THE JENEBERANG ESTUARY

A process-based hydrodynamic and sediment transport model was used to investigate morphological change in estuary. Bathymetric changes pattern of the Jeneberang estuary was obtained from the simulation model using force generating tidal, river discharge and wave. Changes bathymetry of the estuary was known by the base thickness changes of bed topografi. The simulation results will determine the visible location with erosion / sedimentation area is eroded or deposition. Erosion area is indicated by the value changes with the minus sign, and vice versa. Changes in the thickness of the bottom waters were simulated so that Jeneberang River estuary known location sediments (silting) with changes in the thickness or otherwise erosion (Fig. 11).

Fig. 9 Map of long-section locations in model domain

From the fig. 11, it is clear that the mouth of river are more depositing than main river channel. Bed changes are more pronounced in the upstream closer to the sediment input to the system (Figure 10). Downstream shows less deposition meaning longer time is required for the sediment to travel up to the downstream and dispersions of sediment. Generally, only the upper reaches of the model with erosion occurring on the still dominant flow of river water. During the 30-day simulation, obtained the maximum thickness of 11.85 cm sedimentation around the mouth of the estuary.

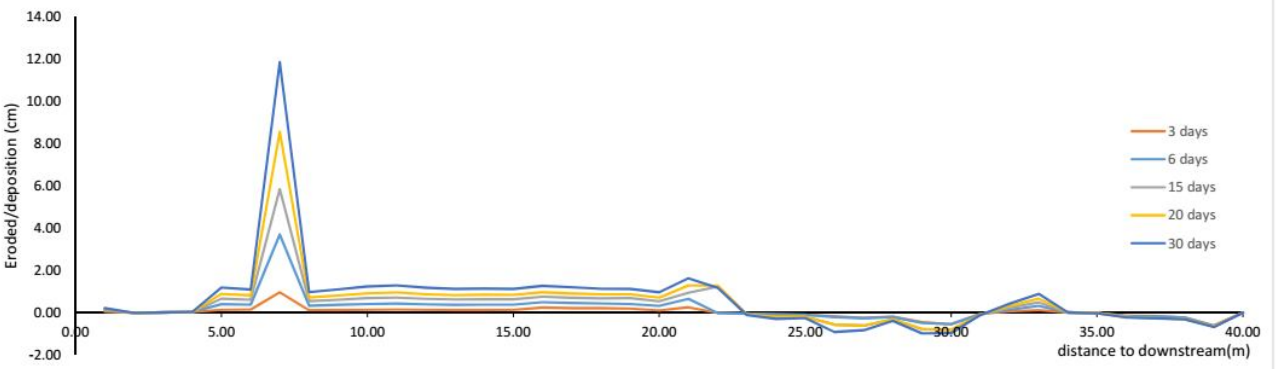

Fig. 10 Variation of bed erodibility

VI. CONCLUSIONS

ECOMSED models have described the hydrodynamics of the Jeneberang Estuary. Hydrodynamic simulations have been performed and computed water levels were compared to observations of existing water level along the estuary from DISHIDRO data. The hydrodynamic model realistically reproduces observed water levels with the tidal data. Based on the good model calibration to observed water level and velocity data, the overall water circulation in the model domain is well characterized. The spring-low tidal cycle is clearly visible and well represented by the model. The suspended sediments were mainly transported from the Jeneberang River towards the Makassar Strait when overflow discharge through the Jeneberang Rubber Dam, the simulation results of suspended sediment transport in the Jeneberang Estuary use 3D modified model of ECOMSED. Morphology change at the Jeneberang Estuary delta is affected by many different factors, including tide, waves, river flows and sediment

REFERENCES

[1] Lopa, R and Shimatani, Y, 2013. *Environmental Assessment Method For A Small-River Restoration Plan*, International Journal of Sustainable Development and Planning, Vol. 8, No. 4,p. 523–536
[2] Roberts, W., P. Le Hir, and R.J.S. Whitehouse. 2000. Investigation using simple mathematical models of the effect of tidal currents and waves on the profile shape of intertidal mudflats. Continental Shelf Research 20(10/11): 1079–1097.
[3] Uncles, R.J. 2002: Estuarine physical processes research: some recent studies and progress. Estuarine, Coastal and Shelf Science 55, 829–56.
[4] van der Wegen, M., B.E. Jaffe, and D. Roelvink. 2011. Process–based, morphodynamic hindcast of decadal deposition patterns in SanPablo Bay, California, 1856–1887. Journal of Geophysical Research 116: F02008. doi:10.1029/2009JF001614.
[5] Dalrymple, R.W., B.A. Zaitlin, and R. Boyd. 1992. Estuarine facies models: conceptual basis and stratagraphic implications. Journal of Sedimentary Petrology 62(6): 1130–1146
[6] Dyer, K.R., 1997. Estuaries, A Physical Introduction, 2nd ed. Chichester, Wiley. 195 pp.
[7] HydroQual, Inc., 2002. A primer for ECOMSED, Users Manual, Mahwah, N. J. 07430, USA.
[8] Blumberg, A. F. and Mellor, G. L., 1987. A description of a three-dimensional coastal ocean model. In: Coastal and Estuarine Sciences 4, Three-Dimensional Coastal Ocean Models, American Geophysical Union, Washington D.C, 1–20.
[9] Blumberg, A. F. and Goodrich, D. M., 1990. Modeling of wind- induced destratification in Chesapeake Bay. Estuaries, 13, 1236–1249.
[10] Galperin, B. and Mellor G. L., 1990. A time dependent, three-dimensional model of the Delaware Bay and River system, Estuarine, Coastal Shelf Sci., 31, 231–281.
[11] Ezer, T. and Mellor G. L., 1992. A numerical study of the variability and the separation of the Gulf Stream, induced by surface atmosphere forcing and lateral boundary flows. J. Phys. Oceanography, 22, 660–682.
[12] Mandang, I. and Yanagi, T., 2008. Tide and tidal current in the Mahakam Estuary, East Kalimantan, Indoensia, Coastal Marine Science, (in press).
[13] JICA, 2001. Evaluation of Lower Jeneberang River Urgent Flood Control Project.
[14] Gailani, J., Ziegler, C. K. and Lick, W., 1991. The transport of sediments in the fox river, J. Great Lakes Res., 17, 479-494
[15] Krone, R. B., 1962. Flume studies of the transport of sediment in estuarial shoaling processes, Final Report, Hydraulic Engineering Laboratory and Sanitary Engineering Research Laboratory, University of California, Berkeley, 110 p.
[16] Burban, P. Y., Y. Xu, Y., McNeil, J. and Lick, W., 1990. Settling speeds of flocs in fresh and sea waters, J. Geophys. Res.,95(C10), 18213–18220.