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NUMERICAL MODELING FOR THE SELECTION OF EFFLUENT OUTLET LOCATION

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ABSTRACT: This paper presents the hydro-environmental sustainability study of a planned mill in the Muan and Riko River area, Province of East Kalimantan, Indonesia. The study aims to choose the best location among the three options for the mill's water effluent outlet in Muan River. The surface-water modeling system is used to numerically model sedimentation patterns due to the placement location of the water intake and effluent outlet for the prospective mill. The model inputs are tidal propagation and river discharges from the tributaries. A field measurement is also carried out to provide solid data for the model construction and validation. The model shows a good agreement with the field data, with errors below 5%. It is found that the pattern of bed elevation change is closely affected by the location of the outlet, with a maximum yearly bed change of 1.4 m. The scenario where the effluent outlet is placed at the upstream of Muan River shows the lowest bed change along Muan River. However, dredging measures to maintain the river depth are required to make sure that the river remains accessible for water transportation.

Keywords: Numerical modeling, River processes, Bed elevation change, Effluent outlet, Muan River.

1. INTRODUCTION

Nowadays, there is increasing public attention to effluent and wastewater processing. The modern system first appeared around the middle of the 19th century when industrialization and urbanization first hit the world. Examples were the cholera outbreaks and Great Stink in London. [1]

Pertaining to studies of effluent spreading, some important parameters to consider are the pH, total suspended sediment, total dissolved sediment, color, chemical oxygen demand, and biochemical oxygen demand, as previously studied by Singh (2015) [2]. Singh compared the level of the mentioned parameters in the effluent water before and after treatment.

To better understand the spreading pattern of the effluent contents, hydrodynamic modeling is needed. Yang *et al.* (2015) demonstrated a three-dimensional hydrodynamic model using an Unstructured Finite Volume Coastal Ocean Model in Puget Sound Estuary, US [3]. The model is driven by tides, meteorological forcing, and river discharge. The result is presented in a spatial pattern and particle tracking.

On the other hand, Sana (2015) presented a thermal dispersion model in a tidal channel caused by industrial plant effluent using Delft3D [4]. The model showed that the temperature gradually decreased while flowing into the open sea. The bed shear stress obtained was insignificant to cause sediment movement.

In South Korea, a study on water quality for a harbor area was carried out by Cho (2014) [5]. The study took place in the proposed inland canal which was built to supply fresh water for Dongbin Harbor, South Korea. Using RMA2 and RMA4 of the surface-water modeling system, Cho found that the water quality in the harbor improved with the construction of the canal.

Ortiz *et al.* (2011) used Mike21 to model the submarine outfall in Santos [6]. The study investigated the significance of the outfall length and river discharges for the circulation pattern. The study also applied particle tracking.

Azarang *et al.* (2015) studied the river process in Karun River, the biggest river in Iran, by a numerical model using the HEC-RAS model [7]. The study presented the pattern of sedimentation and erosion in the river. Furthermore, the authors suggested several areas that required stabilization measures with banks and walls. In Yangtze River, China, Zhang *et al.* (2017) conducted a similar study, resulting in a prediction for the next 70 years [8].

In this work, the case study concerns a bleached chemical thermomechanical pulp mill which is planned to be built in the area of Muan River, Province of East Kalimantan. To support the future operation of the mill, such as its requirements for water and navigational water transportation, the hydrodynamic processes at the Muan River site are investigated.

This study objective is to determine the best location for the mill's water effluent outlet based on the resulting sedimentation using numerical modeling. A field measurement, numerical modeling, and cross-section sedimentation analysis are carried out as part of this study.

2. STUDY LOCATION

The mill is planned to be built in the area of Muan River, North Penajam Paser Regency, Province of East Kalimantan, Indonesia. Part of East Kalimantan Province is given in Fig. 1a. Riko River is the main river in Balikpapan Bay and Muan River is one of its tributaries, as shown in Fig. 1b. The site of the mill is also given in Fig. 1b, located near Muan River.

2.1 Water Intake and Effluent Outlet Scenarios

The main objective of this research is to recommend the most suitable location of the water effluent outlet based on the resulting yearly sedimentation. The location of the water intake is fixed, while the effluent outlet locations are planned in 3 scenarios. Considering the intake location, the outlet location should be plotted in 3 prospective locations as presented in Fig. 2. The location of the effluent outlet is determined by the distance to the effluent treatment facility (orange circle in Fig. 2) and also by the possibility of effluent distributions that would affect the quality of the water intake.

Referring to Fig. 2, there are three scenarios for the outlet location:

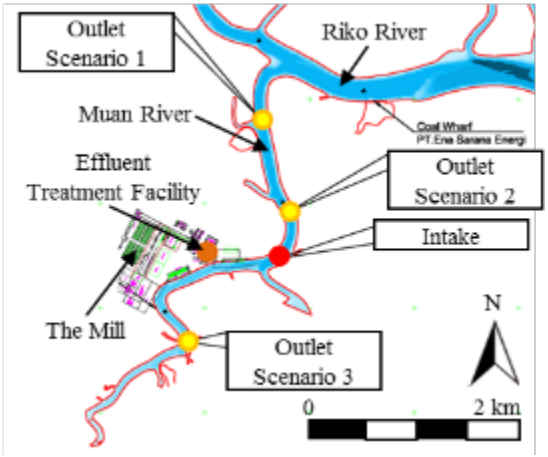


Fig. 2 Scenarios of water effluent location

- Scenario 1: The outlet is at the downstream of Muan River. The distance to the planned effluent treatment is approximately 2.2 km.
- Scenario 2: The outlet is near the intake location. The distance to the planned effluent treatment is approximately 1.2 km.
- Scenario 3: The outlet is at the Muan upstream. The distance to the planned effluent treatment is approximately 1.4 km.

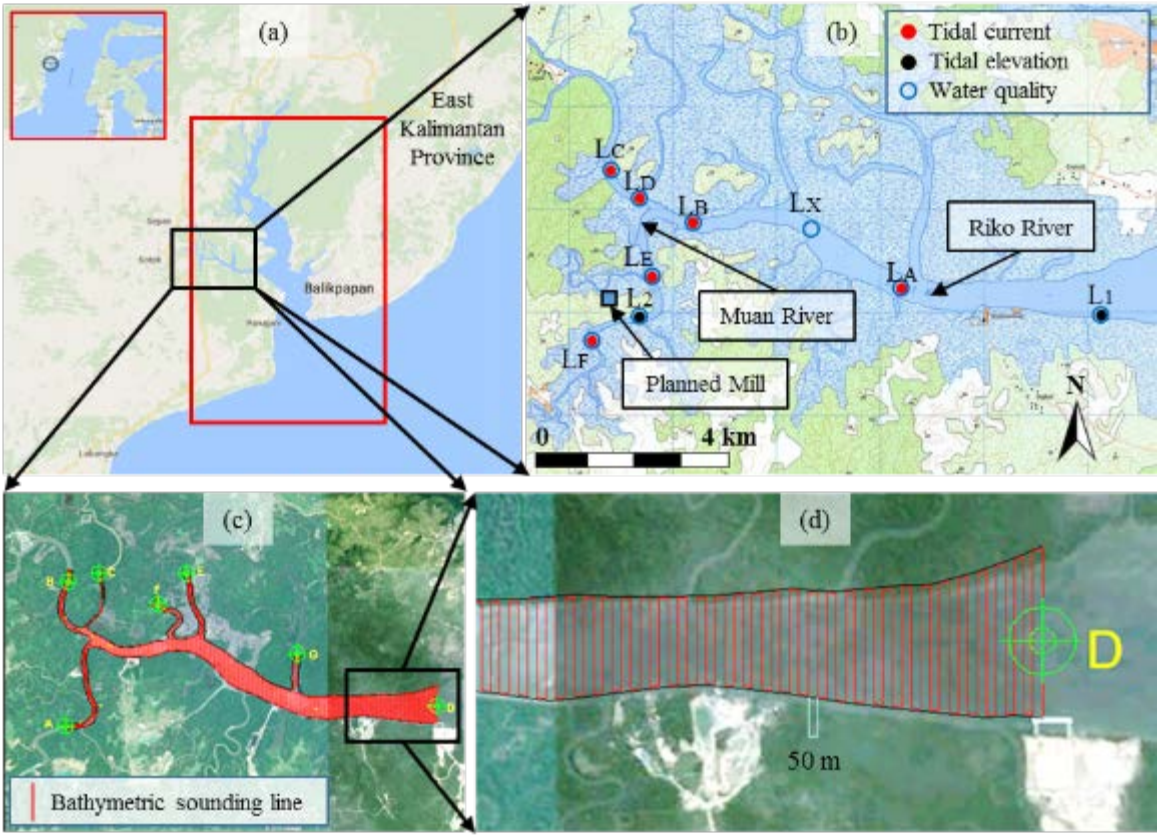


Fig.1 Locations of (a) Balikpapan Bay in Province of East Kalimantan, (b) Riko River, and (c, d) the area covered by the bathymetric survey

3. SECONDARY DATA AND FIELD DATA MEASUREMENT

The research includes field measurement to provide the data needed for the modeling and analysis stage, namely the bathymetry, tidal elevation, tidal current, and total suspended sediment.

3.1 Bathymetry

The area covered by the bathymetrical survey is given in Fig. 1c. The survey used a boat equipped with a Single Beam Echosounder (Odom Hydrotrack). The sounding gap is 50 m as shown in Fig. 1d. The resulting bathymetrical map is used to model the local domain. Meanwhile, for the global and regional models, the following secondary data were obtained from the Indonesian Navy Navigational Chart:

- Chart No. 127, Bathymetrical map of Central Portion Makassar Strait, Indonesia. Scale 1:500,000.
- Chart No. 125, Bathymetrical map of Manggar Cape to Klumpang Bay, Kalimantan East Coast, Makassar Strait, Indonesia. Scale 1:200,000.
- Chart No. 130, Bathymetrical map of Balikpapan to Muara Berau, Kalimantan East Coast, Makassar Strait, Indonesia. Scale 1:200,000.
- Chart No. 157, Bathymetrical map of Channel and Port of Balikpapan, Kalimantan East Coast, Makassar Coast, Indonesia. Scale 1:25,000.

3.2 Tidal Elevation

The tidal elevation field measurement equipment is a staff-gauge installed in a fixed position such as a pier pile as presented in Fig. 3b. The survey is conducted at two locations, indicated by the black dots in Fig. 1b; L1 and L2 are located in the middle of Muan River and at the inlet of Riko River, respectively. A similar tidal elevation measurement method was carried out by Ajiwibowo *et al.* (2017) in research on the ocean energy potential at Kelabat Bay [9], Kelian Cape [10], and Larantuka Strait [11].

3.3 Tidal Current Measurement

The tidal current is measured at 6 locations along Muan River and Riko River, shown as red dots in Fig. 1b. The survey equipment is a current meter as seen in Fig. 3c. Data readings are taken 3 to 5 times a day on 4 different days. The resulting velocity will be compared with the model data.

3.4 Total Suspended Sediment

The water samples are taken using a vertical sediment sampler (Fig. 4a). The locations are the same as for the tidal elevation and current survey, plus one additional point denoted as LX in Fig. 1b. In total, there are 9 points. The samples are stored in sampling bottles (see Fig. 4b), then tested in the laboratory, resulting in a TSS value at each point. The results are given in Fig. 4c.

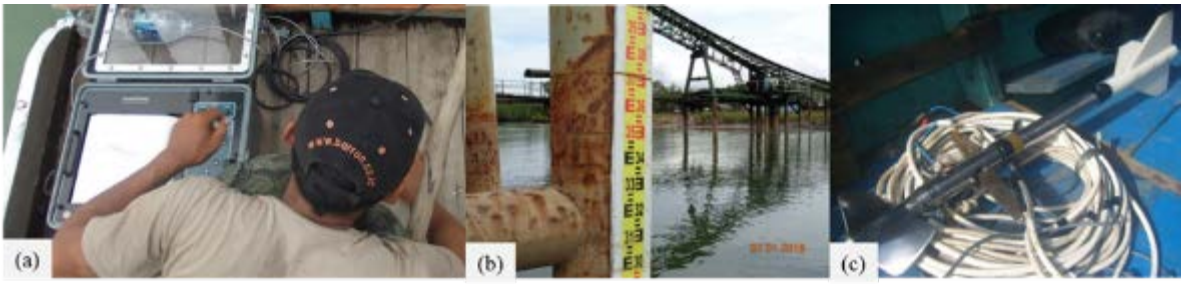


Fig. 3 Images of (a) the bathymetrical survey using Odom, (b) tidal elevation survey with tide gauge, and (c) tidal current survey with current meter

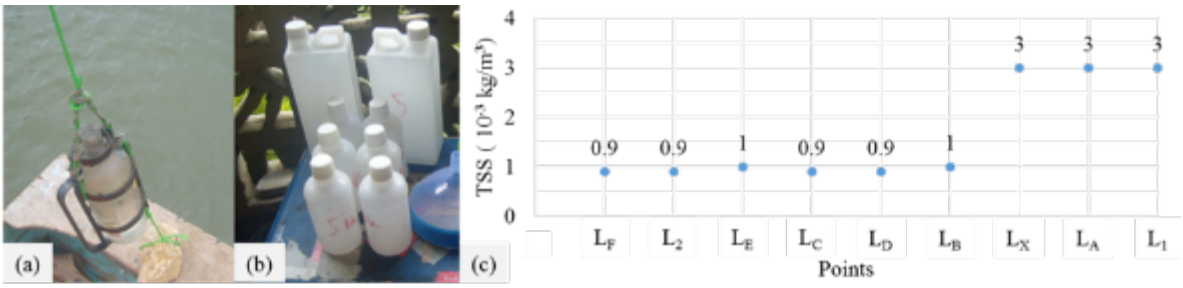


Fig. 4 (a) Nansen and (b) sampling bottles used in the water quality survey. The results are in the (c) graph.

4. NUMERICAL MODEL

The numerical model is required to present the hydrodynamic parameters pattern in the area of interest. In this study, the objects are the tidal and sediment transport. The models are developed with modules of finite element software, Surface-water Modeling System version 8.1 (SMS 8.1). SMS was developed by the Engineering Computer Graphics Laboratory of Brigham Young University in partnership with the US Army Corps of Engineers Waterways Experiment Station and the Federal Highway Administration. The modules used for the modeling are RMA2 and SED2D, to model sediment distribution using hydro-oceanography and TSS data. Ajiwibowo *et al.* (2017) have proven that RMA2 [12] and SED2D [13] are reliable, resulting in a good tidal and transport sediment simulation in their environment-related study at Jakarta Bay.

4.1 Governing Equations

RMA2 is a module of the Surface-water modeling system (SMS) V. 8.1 which uses the finite element method to provide a hydrodynamic numerical model. RMA2 was developed and is maintained by the Army Corps of Engineers Engineering Resource Development Center (ERDC). RMA2 is well known and widely utilized for many problems. RMA2 solves the depth-integrated equations of fluid mass as given in Eq. (2), while the momentum conservation in two horizontal directions is given in Eqs. (3) and (4) [14].

$$\frac{\partial h}{\partial t}+h\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right)+u\frac{\partial h}{\partial x}+v\frac{\partial h}{\partial y}=0 \quad (2)$$

$$h\frac{\partial u}{\partial t}+hu\frac{\partial u}{\partial x}+hv\frac{\partial u}{\partial y}-\frac{h}{\rho}\left[E_{xx}\frac{\partial^2 u}{\partial x^2}+E_{xy}\frac{\partial^2 u}{\partial y^2}\right]+gh\left[\frac{\partial a}{\partial x}+\frac{\partial h}{\partial x}\right]+\frac{gun^2}{\left(1.486h^{1/6}\right)^2}\left(u^2+v^2\right)^{1/2}-\zeta V_a{}^2\cos\psi-2hv\omega\sin\Phi=0 \quad (3)$$

$$h\frac{\partial v}{\partial t}+hu\frac{\partial v}{\partial x}+hv\frac{\partial v}{\partial y}-\frac{h}{\rho}\left[E_{yx}\frac{\partial^2 v}{\partial x^2}+E_{yy}\frac{\partial^2 v}{\partial y^2}\right]+gh\left[\frac{\partial a}{\partial y}+\frac{\partial h}{\partial y}\right]+\frac{gvn^2}{\left(1.486h^{1/6}\right)^2}\left(u^2+v^2\right)^{1/2}-\zeta V_a{}^2\sin\psi+2hu\omega\sin\Phi=0 \quad (4)$$

where h is the water depth, and x are y the Cartesian coordinates, t is time, u and v are the velocities in Cartesian coordinates, ρ is the fluid density, E is the eddy viscosity coefficient, g is the acceleration due to gravity, a is the elevation of the bottom, n is the Manning's roughness n-value, 1.486 provides the conversion from SI to non-SI units, ζ is the empirical wind shear coefficient, V_a is the wind speed, ψ is the wind direction, ω is the rate of angular rotation of the Earth, and Φ is the local latitude.

4.2 Model Setup

The area of interest is along the Riko and Muan River. The domain of modeling is extracted from the domain of Makassar Strait (global) to become the domain of Balikpapan Bay (regional) and the domain of Muan River (local).

The domains of the global, regional, and local model are presented in Figs. 5a to 5c. The global model was set up to produce the tidal elevation boundary conditions for the regional model. The input for the global model is the tidal forcing. The boundary condition was constructed using NaoTide of Poseidon [15].

The regional model of Balikpapan Bay is set up to produce the boundary conditions of the tidal elevation for the local model. Since Balikpapan Bay is one of the inlets of the rivers in Kalimantan Island, besides the tidal forcing, the river discharges are included in the simulation to generate a more comprehensive hydrodynamic model. The five rivers included are the Semoi, Tunan, Riko, Wain Besar, and Sumber Rivers (Fig. 5b). The notation and the discharge of the rivers are given in Table 1.

Table 1 River discharges in the regional model

Rivers	Notations	Discharges (m^3/s)
Semoi	Q1	160.18
Tunan	Q2	114.42
Riko	Q3	22.2
Wain Besar	Q4	24.41
Sumber	Q5	10.68

Similar to the regional model, the local model includes the tidal forcing and river discharges. The river discharges in the local model are given as varying monthly rather than a constant. For the 7 included tributaries, the notations and discharges are given in Fig. 6. The discharges of the water intake and the water effluent outlet are 0.2429 and 0.2235 m^3/s, respectively [16].

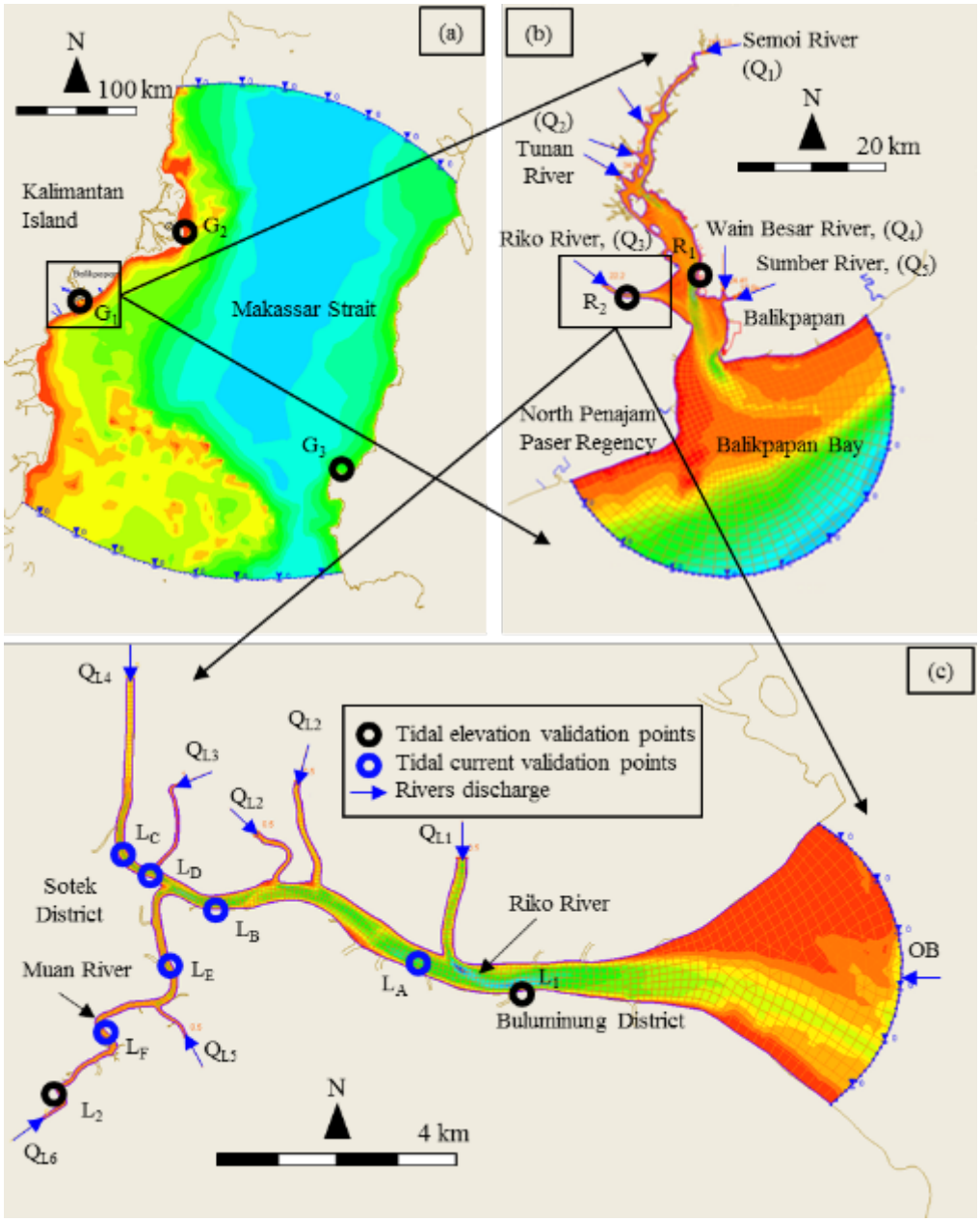


Fig. 5 Domain of the (a) global, (b) regional, and (c) local models

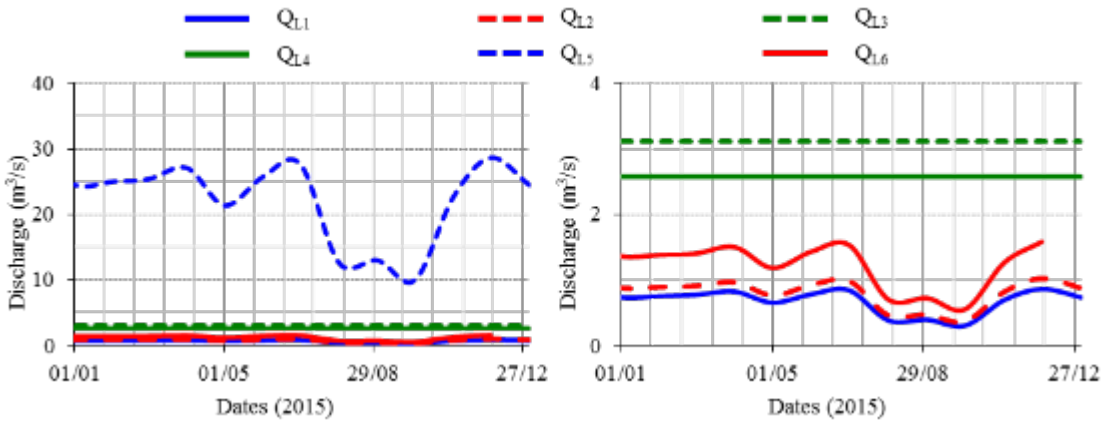


Fig. 6 (a) The discharge of tributaries in the local model, and also (b) particularly showing discharge which is lower than 4 m^3/s.

The results of the validation of the three models are given in section 4.3 below. As the validation shows a good agreement between the model and field data, the local model is developed into the scenario models. The scenario models include the three possible locations of the effluent outlet as given in Fig. 2 and the additional existing scenario. The existing scenario is the default setting of the local model without the water intake and effluent outlet.

Besides the tidal forcing and river discharges, the local model also includes the Total Suspended Sediment (TSS) parameters, which have various values. The TSS in the open boundaries and the rivers boundaries, given in Table 2, are based on TSS field data. The TSS of the water effluent is set to be 0.237 kg/m^3 [16].

Table 2 Value of TSS parameter at open boundaries and river boundaries

Boundaries	Notations	TSS (kg/m^3)
Water effluent	-	0.0237
Open boundaries	OB	0.003
River boundaries	Q_{L1}	0.003
	Q_{L2}	0.003
	Q_{L3}	0.001
	Q_{L4}	0.001
	Q_{L5}	0.001
	Q_{L6}	0.001

The three scenario model outputs are bed elevation changes due to possible water effluent locations along Riko and Muan River, which are presented in chapter 5.

4.3 Model Validation

The overall tidal elevation validation errors of the three models are given in Table 3. The error is calculated using Eq. (5), where e_{model} is the value obtained from the numerical model and e_{field} is the value obtained from field survey data [9–10]. The resulting errors show that the models have a good agreement with the field tidal data.

$$r = \frac{\left| e_{model} - e_{field} \right|}{e_{max}} \quad (5)$$

Beside the tidal elevation validation, tidal current validation was carried out for the local model. The model data was compared with the field current measurement data at 6 locations (denoted as LA to LF in Fig. 2b). The results are given in Fig. 7, which shows a good agreement between the model and field data. Hence, it is concluded that the models are reliable to simulate the tidal propagation in the domain of the models.

5. RESULTS AND ANALYSIS

The resulting total yearly sedimentation of the scenario models is given in Fig. 8. Fig. 8a shows the initial condition. Figs. 8b to 8d present the yearly sedimentation for scenarios 1 to 3, respectively. The three scenarios present different patterns which are strongly affected by the location of the water effluent outlet. For clear comparison of the sedimentation, four cross-sections are investigated and presented in Fig. 9. Sections A to C are located along the upstream to the downstream of Muan River. Section D and half of section C cover part of the intersection of Muan and Riko River.

The resulting bed elevation after a year at the four sections is given in Fig. 10. To more clearly show the differences for each scenario, the yearly bed changes are also given in Fig. 11. In Figs. 10 and 11, there are four solid lines which represent the existing scenario (denoted by “Existing”), and scenarios 1 to 3 (S.1, S.2 and S.3 in Fig. 10). The other two vertical dotted lines are the locations of thr water intake and effluent outlet.

Table 3 The error in tidal elevation validations

Models	Stations	Notations	Sources	Duration (days)	Error (%)
Global	Balikpapan	G_1	Dishidros [17]	30	4.4
	Kutei Rivers	G_2	NaoTide	30	4.7
	Mamuju	G_3	NaoTide	30	3.1
Regional	Balikpapan	R_1	Dishidros [17]	20	4.6
	Riko River	R_2	Field Survey	15	4.5
Local	Riko River Downstream	L_1	Field Survey	15	4.3
	Riko River Upstream	L_2	Field Survey	15	7

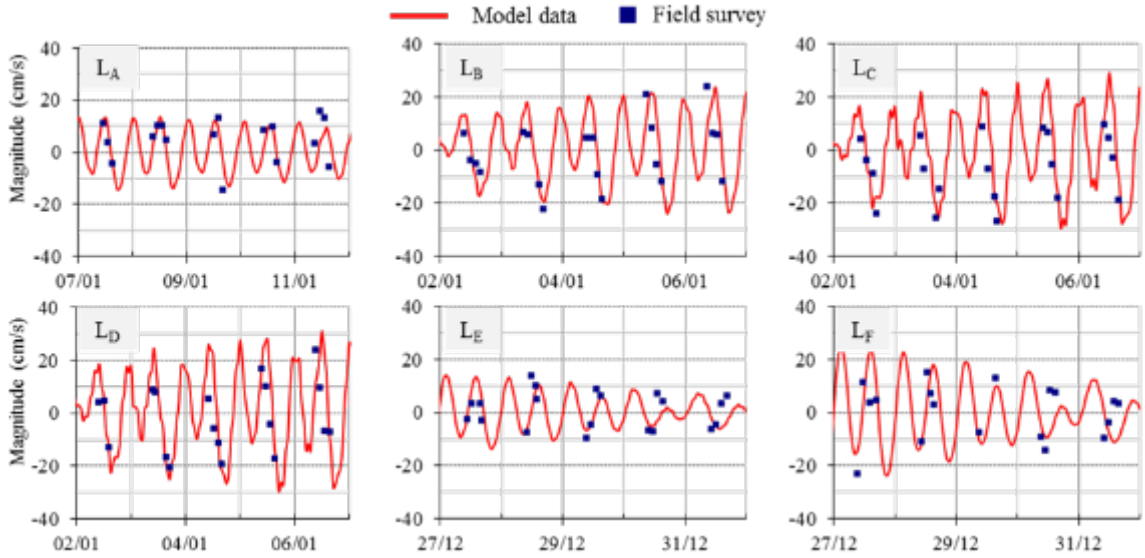


Fig. 7 The result of tidal current validation in local model

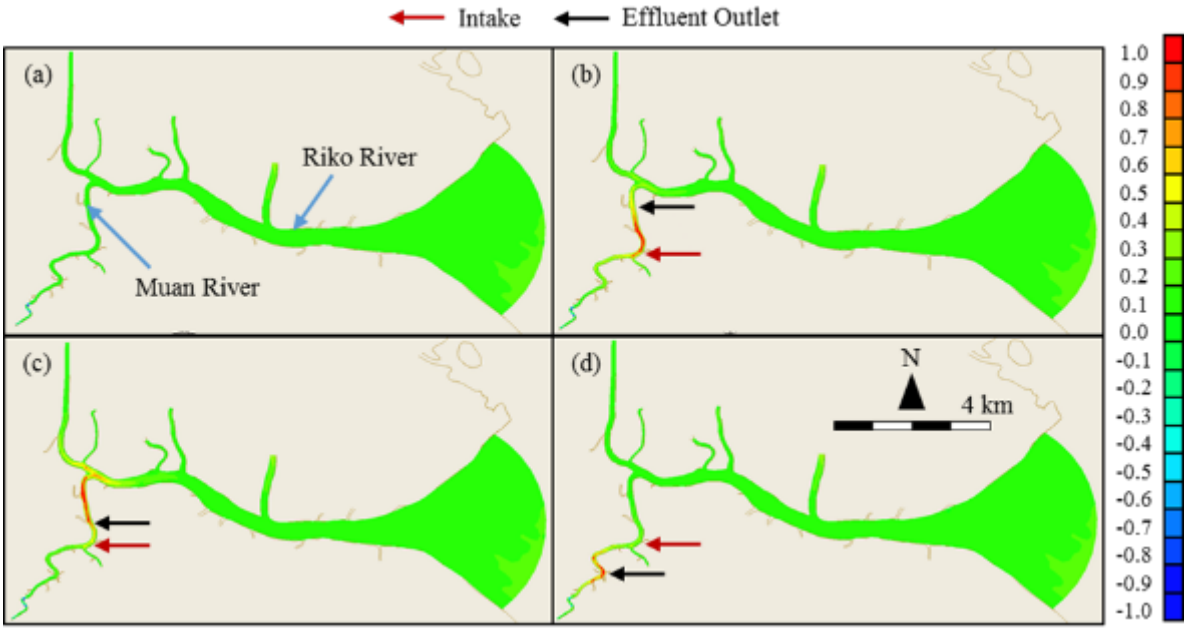


Fig. 8 The yearly sedimentation results in the local model for each scenario

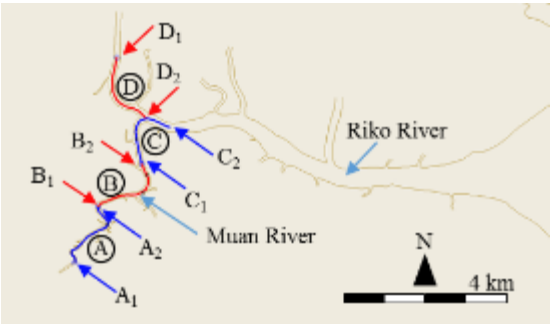


Fig. 9 Locations of the investigated cross-sections

Intuitively, points with the most change in bed elevation should be close to the location of the water effluent outlet and they are clearly shown in Fig. 11. From the figures, the maximum bed elevation changes for scenarios 1, 2, and 3 are 1.1, 1.4, and 1.1 m respectively. On the other hand, the existing scenario model shows no significant bed changes along the sections.

As presented in Fig. 11 and stated in the previous paragraph, each scenario results in a different pattern of sedimentation or bed elevation change. In this study, the scenario with the least bed change (nearest to 0) is taken to be the best scenario. Table 4 presents the cumulative bed elevation

Table 4 The cumulative and total bed change for each scenario

total bed changes. The total bed change is the sum of sedimentation along the 4 cross-sections.

From Table 4, scenario 3 gives the least total value. Although at section A, the bed change obtained for scenario 3 is the highest, scenario 3 still at section B, C, and D are significantly lower than in the other scenarios. Thus, scenario 3 is taken to be the best scenario for the location of the water effluent outlet.

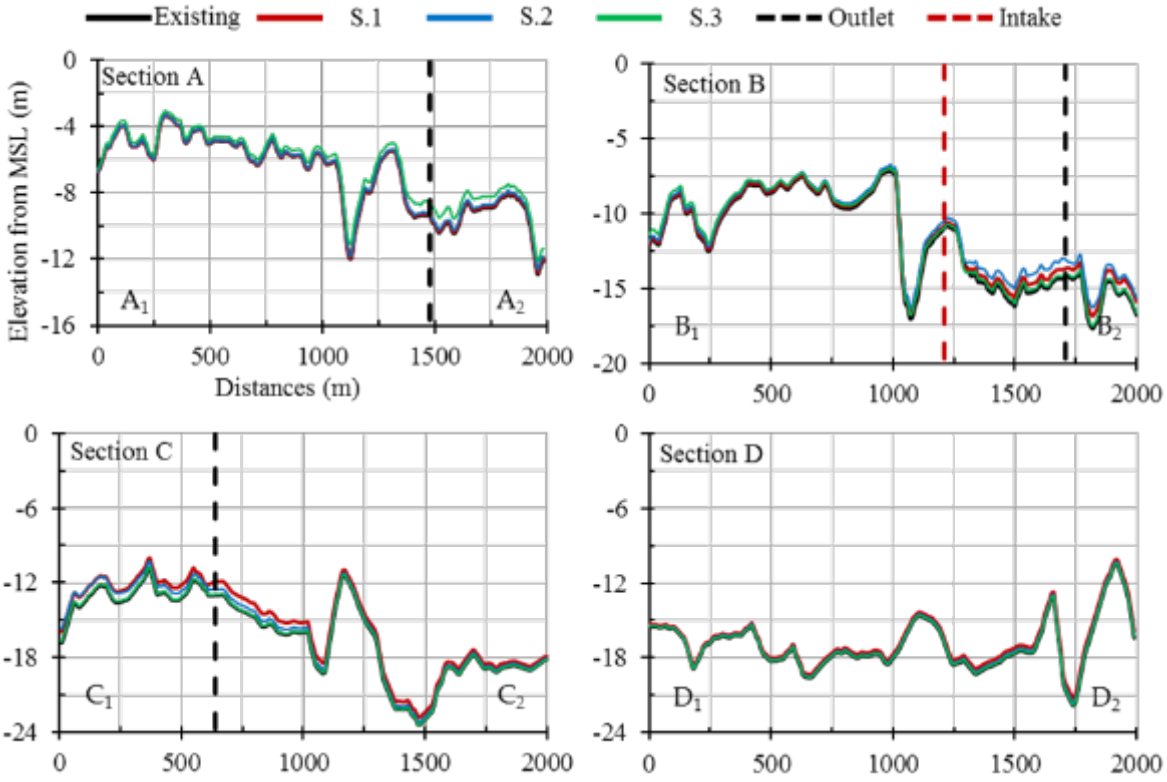


Fig. 10 Comparison of the resulting bed elevation at 4 sections after a year's simulation

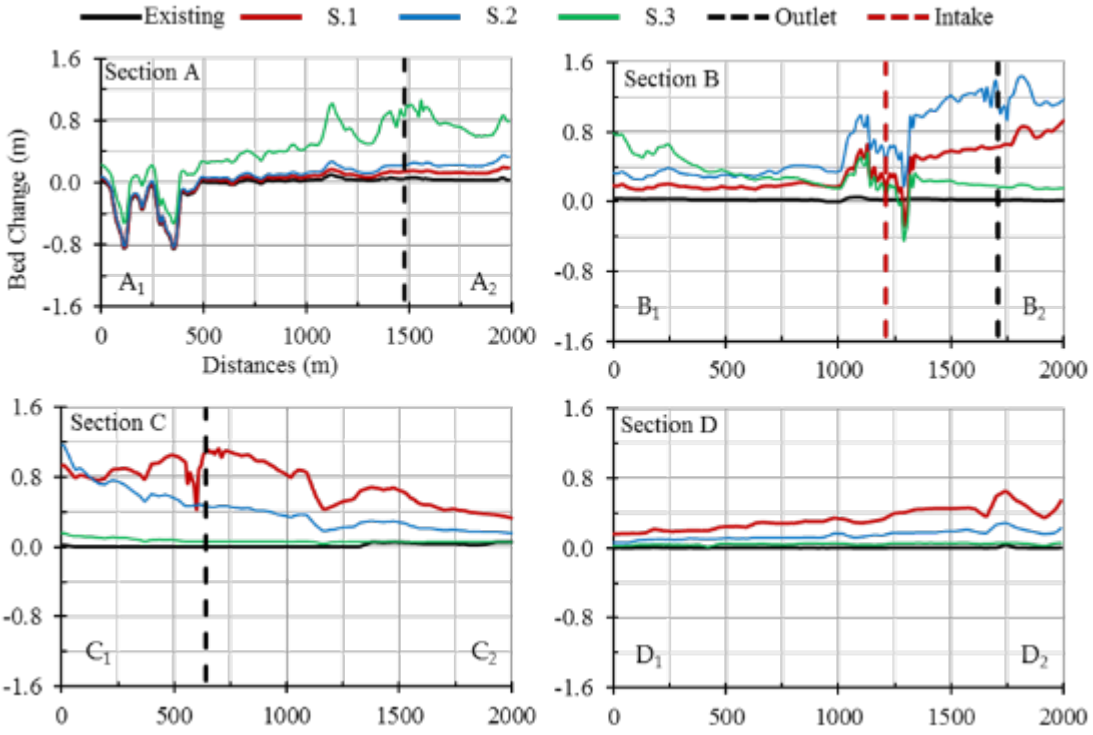


Fig. 11 Comparison of the resulting bed elevation change at 4 sections after a year's simulation

6. CONCLUSION

	Cumulative bed change at each sections (m) Section length = 2,000 m				Total bed change (m)
	A	B	C	D	
Existing Scenario (Existing)	-10.29	5.26	3.08	0.76	-1.19
Scenario 1 (S.1.)	0.59	71.14	146.72	66.46	284.91
Scenario 2 (S.2.)	11.84	132.61	82.85	29.25	256.54
Scenario 3 (S.3.)	88.80	58.81	13.72	9.00	170.32

Field measurement and numerical modeling have been carried out to develop a sedimentation analysis and the results are used to deduce the best location of the water effluent outlet.

The field measurement and the numerical modeling are in good agreement, with an average error less than 5% for the tidal elevation. The model tidal current also presents a good validity with the measured velocity data.

The model includes the astronomical forcing, river discharge, and total suspended sediment with various outlet locations. The results are a yearly spatial sedimentation at Riko and Muan River and a bed elevation change at 4 investigated sections at Muan River.

The resulting sedimentation patterns are strongly affected by the location of the water effluent outlet. Finally, scenario 3 is taken as the best scenario, having a lower total bed change than scenarios 1 and 2. In scenario 3, the total bed change along sections A to D (along a 8,000 m line) is 170.32 m, with the highest change around 1.1 m at Section A, near the outlet location.

Overall, all the scenarios produce a significant bed elevation change while the existing scenario results in a nearly steady bed elevation. Further, to reduce the interference in the environmental equilibrium caused by the water intake and effluent outlet of the mill, routine dredging is required. Even more, the mills also need a water transportation infrastructure, so keeping the bed elevation steady is essential. An additional effluent processing plant inside the mill will also be built to discharge cleaner effluent to the environment.

7. ACKNOWLEDGMENTS

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