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Hydrodynamic changes impacted by the waterway capital dredging in *Cikarang Bekasi Laut* channel, West Java, Indonesia

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Abstract

This paper presents one-dimensional numerical modeling using MIKE 11 to simulate the impact of capital dredging on the hydrodynamics of the *Cikarang Bekasi Laut* (CBL) channel flow. The CBL channel is located in Bekasi Regency, West Java Province, Indonesia. The river discharges upstream, and tidal fluctuations at the sea boundary were the governing parameters of the hydrodynamic model. Data such as river centerline, cross-sections, tidal elevation, and river discharges were compiled to construct the model. The instantaneous record of water level and river discharge data were used as model validation. The model results give decent validation when compared to water level and river discharge field data. Dredging on the canal is planned to be carried out across 19 km from the estuary to the upstream to allow large vessel navigation. The modeling results show that during the wet season, dredging affects the water level and river flow up to 25 km upstream, while during the dry season, dredging affects the hydrodynamics only up to 20 km upstream. It can be concluded that the canal dredging does not have a significant impact in terms of surface water elevation in the canal upstream. The critical finding is that the bed shear stress is significantly increased upstream of the dredging plan at kilometer 19, showing that there is potential riverbed erosion threat in the area. It is recommended to conduct a sedimentation study to predict the impact of sedimentation change from the dredging.

Key words: capital dredging, CBL, hydrodynamic, Indonesia, MIKE 11, waterway

INTRODUCTION

Port development contributes to the promotion of economic activities. The idea is that ports open spaces and opportunities in the market for both national and international firms, and the results are increased competition and lower prices (Rodrigue 2017).

Some rivers are utilized and engineered to be waterways in order to optimize the logistics of travel. Some of these are the Rhine and Danube Rivers in Europe, the Nile River in northeastern Africa, the Mississippi River in North America, and the Yangtze River in China, which can accommodate cruise and container ships. In Indonesia, there are waterways such as the Mahakam, Kapuas and Barito Rivers in Kalimantan, the Musi River in Sumatra, and the Digul River in Papua. However, most of them can only be navigated by small vessels for wooden logs, dry bulk commodities, and transport of daily needs.

Research on the inland waterway has increased in recent decades. Papers have mostly talked about a general overview, operational challenges, environmental threat, and cost analysis of the Rhine River (Jonkeren 2005) and waterways in Poland (Golebiowski 2016). Operational studies highlight aspects of trafficability and navigation safety of waterways (Harlacher 2016; Yang 2018; Segovia *et al.* 2019).

For environmental-related studies, the hot topics are the impact of dredging on living creatures (Clement 2017) and the influence of climate change (Jonkeren *et al.* 2011). In terms of cost, studies also address market conditions and specific vessels (Sihn *et al.* 2015; Wiegmans & Konings 2015).

This paper presents a study on inland waterway development in Indonesia, at the *Cikarang Bekasi Laut* (CBL) channel in Bekasi Regency, West Java Province. The CBL channel is currently used for flood mitigation and irrigation. The first 19 km of the CBL channel is planned to be an inland waterway. The port is to be placed in an area 17 km from the estuary. Capital dredging is required, in which the current bed elevations (in a range of 0.5 to 5 m below the lowest low water at spring tide) will be dredged to −4 m. This study aims to investigate the impact of dredging on the river hydrodynamics using numerical modeling. The potential impact on bed changes is also presented by looking at the bed shear stress parameter. The model tool is MIKE 11, which has been widely used to model river processes in one dimension.

METHODS

Study area

The study area is in the CBL channel located in Bekasi Regency, West Java Province, Indonesia. The first 19 km of the channel has been allocated for the inland waterway. The aim is to support traffic flow heading to Cikarang or other areas in Bekasi. At the same time, it is also projected that the waterway will reduce the severe congestion in Jakarta and the toll roads in the vicinity (KPPIP 2017). Figure 1(a) and 1(b) shows the CBL channel. Some aerial views of the channel are given in Figure 1(c)–1(e). The capital dredging is needed to allow larger vessels to navigate the channel. Currently, riverbed elevation in the CBL channel (from downstream to 19 km upstream) is around 0.5 to 5 m below the lowest low water level during spring tide, or lowest water spring (LWS). The future CBL waterway riverbed elevation is designed to be a uniform 4 m below the LWS, so capital dredging is required. The designated port is planned to be built at 17 km upstream from the estuary. All elevation terms, such as water level, are referred to LWS as the datum. The LWS is set to be zero.

Data compilation

Five types of field data are required to construct the hydrodynamic model: river centerline, cross-sections, tidal elevation, river discharge, and instantaneous record of water level and river discharge. A riverbed elevation survey was carried out to obtain the river centerline and cross-sections from the estuary at KM 0 to the upstream at KM 32.35, where KM stands for a kilometer and designates spot markings along the CBL channel, termed 'chainage.' The number following KM denotes the distance (in kilometers) from the estuary.

The tidal elevation field measurements were carried out using a tide gauge. The data were recorded hourly for 15 days. The location of the tidal observation is given in Figure 1(b), marked with a red circle. The observed tidal elevation is given in Figure 2. The type of tide is a mixed diurnal tide. The least-squares method was used for the tidal analysis and resulted in a tidal range of 1 meter. The extreme tidal elevations were used for the boundary conditions of the model to simulate extreme scenarios. The constant high tide (water level at 1 meter above the LWS) is used for the wet season, and the constant low tide (water level at the LWS) is used for the dry season. Each condition will indicate the maximum and minimum water level inside the CBL channel, respectively.

A total of 23 rivers flow into the CBL channel, most of them small tributaries. There are five large rivers: the Bekasi, Sadang, Jambe, Cikarang, and GT8 Rivers. The driving forces of the model are

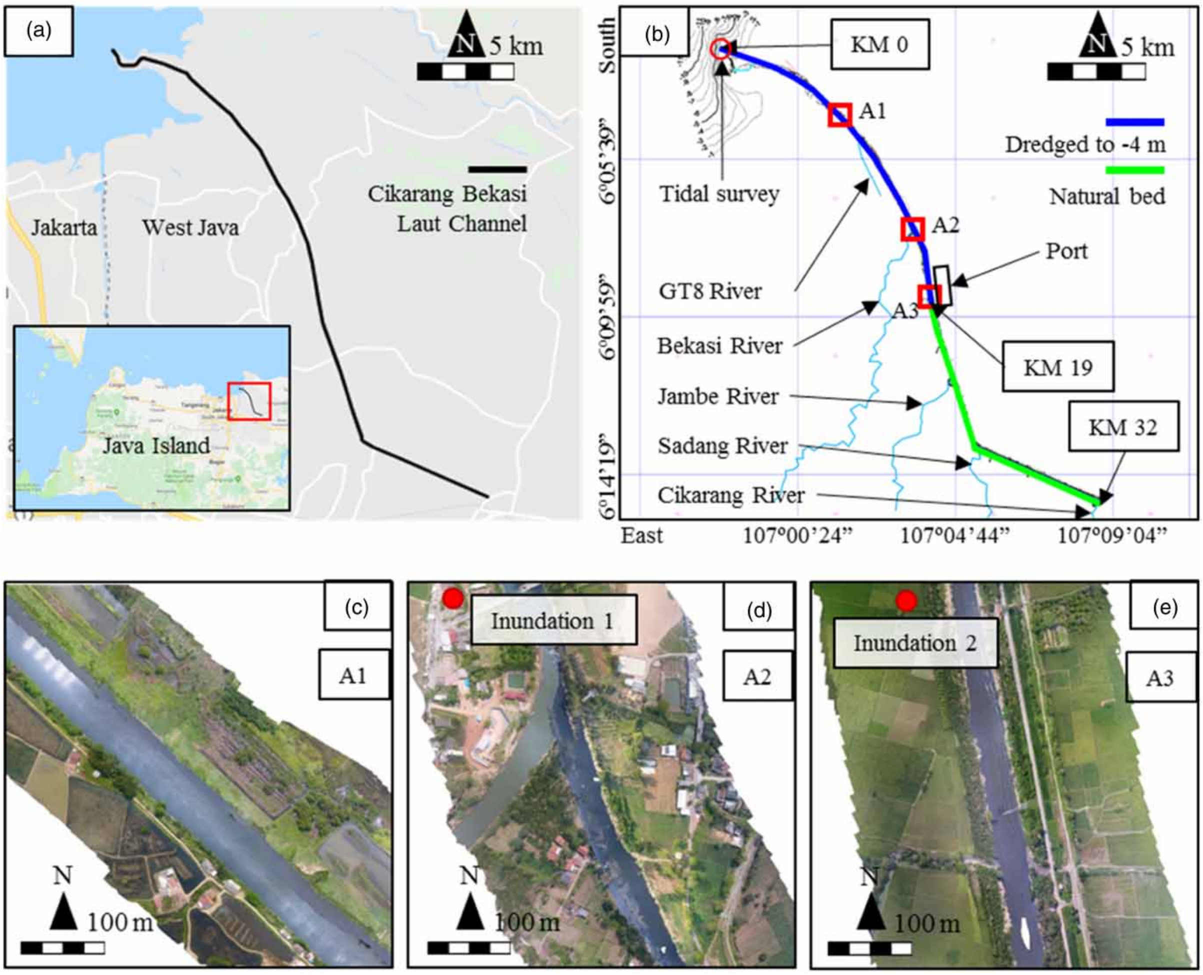

Figure 1 | (a) Networks of *Cikarang Bekasi Laut* (CBL) and five rivers; (b) sections of dredged and natural bed in the waterway scenario; and (c–e) aerial view of three spots along the CBL channel.

upstream river discharges and the downstream tidal elevations. For the river discharges data, a hydrological analysis is conducted. The analysis was introduced by Mock *et al.* (1973). The analysis is about evaluating the water balance, taking into consideration climatological parameters such as humidity, wind velocity, solar radiation, rainfall, and surrounding temperature (Mock *et al.* 1973). The monthly river discharges are the average discharge for each month of one year based on 10 years of climatological data. The resulting discharges for the five rivers are shown in Figure 3(a).

The last data compiled were instantaneous water elevation (WL), river discharge (Q), and flood inundation record. The WL and Q data were obtained by conducting a field survey at three locations along the CBL channel on 25 August 2018. The field survey was carried out using staff gauge, current meter, and total station. The results are shown in Table 1. Additionally, the flood inundation height data were collected by interviewing local people in two locations, denoted as Inundation 1 and Inundation 2 (red dots in Figure 1(d) and 1(e)). The survey documentation is given in Figure 3(b) and 3(c), which shows local people pointing to the inundation height of the previous flood.

Model description

Modeling tools for the hydrodynamic simulation included SMS (Ajiwibowo 2018; Ajiwibowo *et al.* 2019; Hariati *et al.* 2019), Delft-3D (Takagi *et al.* 2017), and MIKE (Ajiwibowo *et al.* 2017a, 2017b, 2017c). MIKE 11 was developed by the Danish Hydraulic Institute (DHI). The hydrodynamic

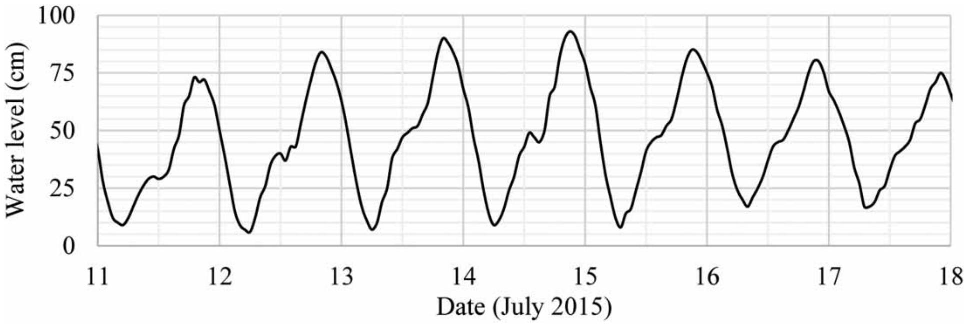

Figure 2 | Observed tidal elevation from 11–18 July 2015.

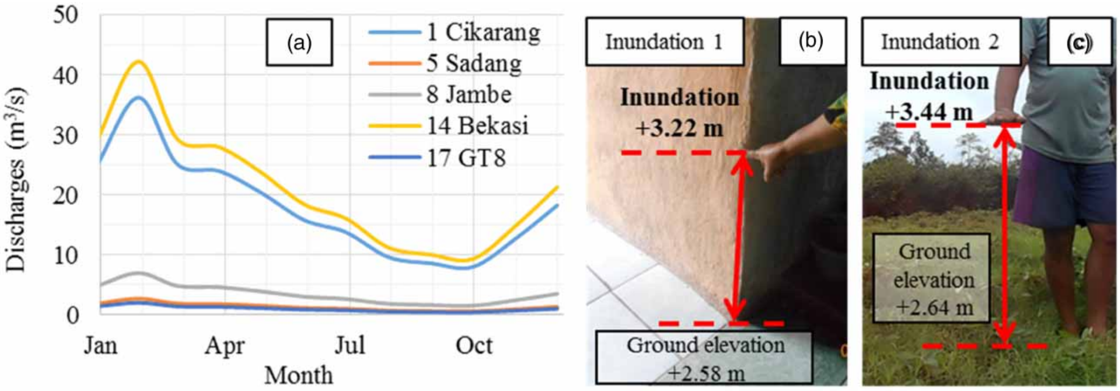

Figure 3 | (a) Discharges of five main tributary rivers and (b,c) documentation of flood inundation survey.

Table 1 | Results of water elevation (WL) and river discharge (Q) field measurements

Zone	Location	Time	Water level (m)[a]	Discharge (m^3/s)
A	KM 18.65	8.40	+1.11	6.77
		12.00	+1.12	6.8
		16.00	+1.19	7.02
B	KM 19.7	9.40	+1.21	3.2
		12.46	+1.33	4.21
		16.23	+1.35	3.63
C	KM 25.3	10.35	+3.06	3.45
		13.15	+3.03	3.6
		16.50	+3	2.73

[a] From low water spring (LWS).

(HD) module is mostly applied for flood forecasting, flood control, irrigation, and drainage operations, designing channel systems, and tidal and storm surge studies in rivers (DHI MIKE 11 2017a). The MIKE 11 HD module is a one-dimensional modeling tool that solves the conservation of continuity and momentum equations; that is, the St. Venant equations (DHI MIKE 11 2017a). The module uses an implicit finite difference scheme for the computation of unsteady flows in rivers and estuaries (DHI MIKE 11 2017b).

The required inputs of MIKE 11 are river network (.nwk), cross-sections (.xns), boundary conditions (.bnd), and hydrodynamic parameters (.hd). After completing the input, the simulation is executed in the simulation file (. sim11).

RESULTS AND DISCUSSION

Model calibration

A common practice in hydrodynamic modeling is validating the computed values with the field data. The first validation is a comparison between the computed WL and Q with the field data, as shown in Table 1. The governing parameter in this calibration is the bed roughness, defined as the M value. The value is set in the input file (.hd file). The WL will increase or decrease as the M value is modified.

This study has three zones of bed roughness (the Manning's coefficient), denoted by *M* value. They are zones A, B, and C, as shown in Figure 4 (noted as a, b, and c). Zone A is from the estuary (KM 0) to 19 km upstream (KM 19) and is called the downstream zone. Zone B is the transition zone, from KM 19 to KM 24.5. The stretch from KM 24.5 to KM 32.35 is called the upstream zone. The three zones, downstream, transition, and upstream, are defined based on their physical characteristics. The downstream zone is defined as a region highly influenced by the tide, lower than LWS. The upstream zone is defined as a region with less tidal influence, higher than the high tide, which is 1 meter above LWS. Transition is the region in between.

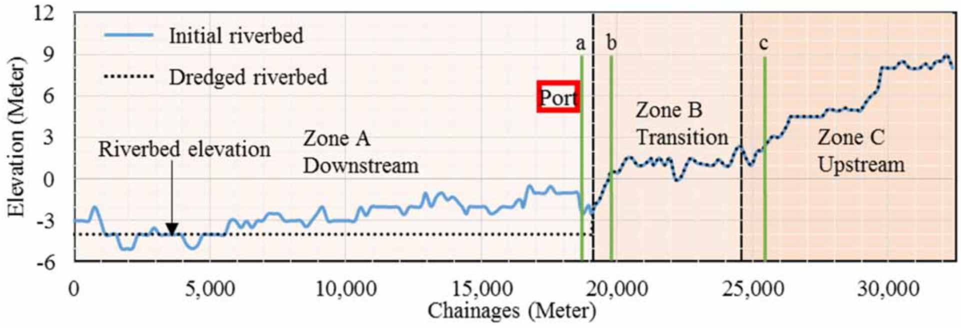

Figure 4 | Longitudinal section of CBL channel riverbed elevation. Three zones are defined as zones A, B, C separated by the vertical dashed black lines. The green vertical lines represent the calibration station for each zone.

The model is using the Manning's coefficient for bed roughness with a default *M* value (the unit is $m^{1/3}/s$) of 30 for zones A, B, and C. The Manning's value can also be defined as *n* value, which equals *1/M*. After four iterations, the best bed roughness configurations are 10, 15, and 50 for zones A, B, and C, respectively. The iteration summary is given in Table 2. The second validation is inundation. The floodwater level resulting from the model is compared with the field data at locations marked Inundation 1 and Inundation 2 (red dots in Figure 1(d) and 1(e)). The comparison produces an acceptable error between computed and field data, as presented in Table 3.

Table 2 | Errors in roughness calibration iteration

	Manning's value (*M*)			Errors (%)			
Iteration	**Zone A**	**Zone B**	**Zone C**	**Zone A**	**Zone B**	**Zone C**	**Average error (%)**
1	30	30	30	10.04	35.62	18.26	21.3
2	20	20	40	7.87	29.6	15.83	17.77
3	10	15	50	1.11	9.66	6.87	5.88
4	10	12	60	1.07	11	5.62	5.9

Table 3 | Results of flood inundation validation

Item	Field (meter)	Model (meter)	Difference (meter)
Water level during a flood at Inundation 1	+3.22	+3.21	0.01
Water level during a flood at Inundation 2	+3.44	+3.46	0.02

Model results

The capital dredging of the CBL channel to a bed elevation of 4 m below LWS resulted in changes in hydrodynamic parameters in part of the channel. In this study, three parameters are investigated: water level, current velocity, and bed shear stress.

Changes for each parameter are given as global and local descriptions. The global description covers all domains from KM 0 to KM 32.35, or the global range. The local description refers to sections between KM 15.55 and KM 20.55 (local range), where the port is planned to be built at KM 17. Figure 4 shows the longitudinal section of riverbed elevation. The capital dredging area ends adjacent to KM 19. The port is located on the east side of CBL, as seen in Figure 1(b).

Changes are observed during extreme conditions in the wet and dry seasons. Observations from 20 January to 20 February represents conditions with the highest river discharges during the wet season, and the lowest river discharges are between 20 September and 20 October during the dry season. Future adaptations for the port operation will consider these changes.

Water level

The maximum water level in the wet season and minimum water level in the dry season are shown in Figures 5 and 6, respectively. Figure 5 shows that during the wet season, the maximum water level drops about 1.75 m at the boundary of the dredged area. Figure 6 shows the maximum water level during the dry season. The water level drops to about 1 m. The summary of the modeled water elevation at the port site can be seen in Table 4. Water depth is measured as total depth from the water surface to the riverbed. The water depth in the port site (KM 17) is between 2.25 and 4.42 meters for initial conditions before dredging in dry and wet seasons. After dredging, the water depth increases to 4.46 and 5.96 m for dry and wet seasons, respectively.

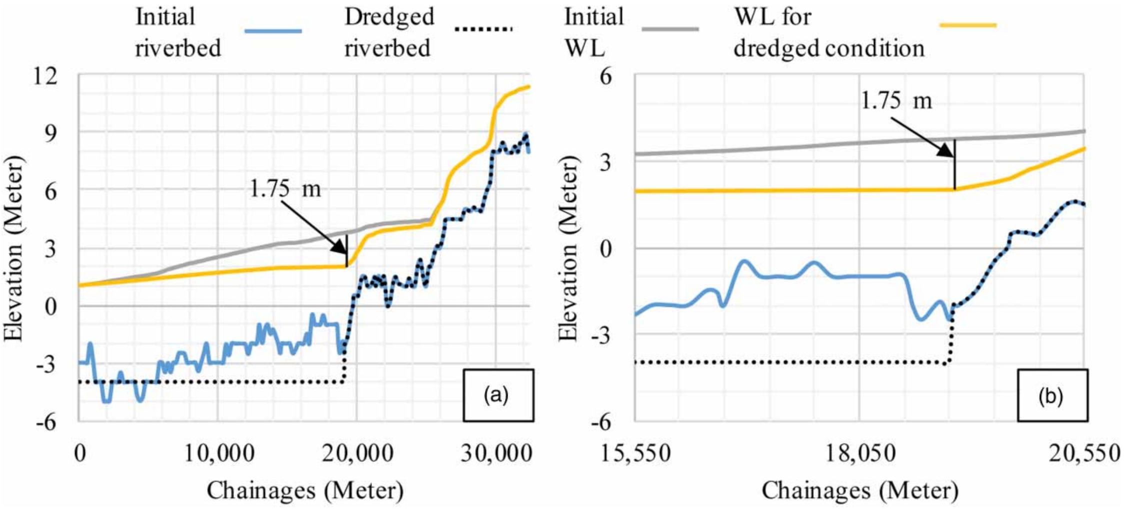

Figure 5 | Modeled maximum water level during the wet season for (a) global range and (b) local range.

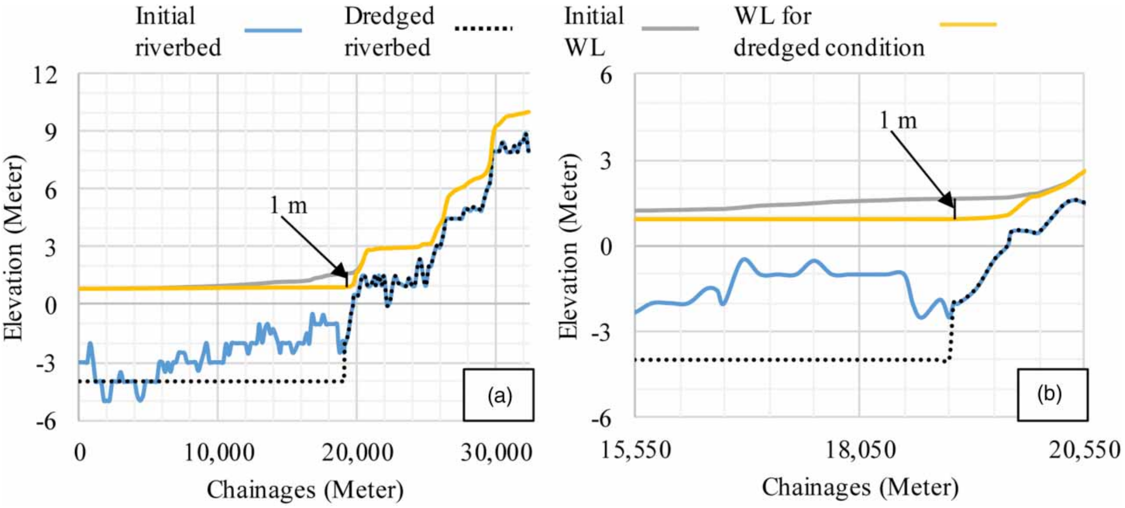

Figure 6 | Modeled minimum water level during the dry season for (a) global range and (b) local range.

Table 4 | Summary of modeled water elevation at the port site (KM 17)

No	Condition	Water level (m)[a]	Water depth (m)
1	Dry season, initial condition	+1.25	2.25
2	Wet season, initial condition	+3.42	4.42
3	Dry season, after dredging	+0.46	4.46
4	Wet season, after dredging	+1.96	5.96

[a] From low water spring (LWS).

Current velocity

Figure 7 shows the maximum current velocity at the CBL channel during wet and dry season conditions in both the initial and dredged scenarios. It is seen in all scenarios that current velocity at the upstream after KM 19 is higher and has many fluctuations caused by steep riverbed and tributary junctions. At the downstream, dredging increases the flow cross-section resulting in a lower velocity. Additionally, seawater enters the region and keeps the water depth large enough so that the Froude

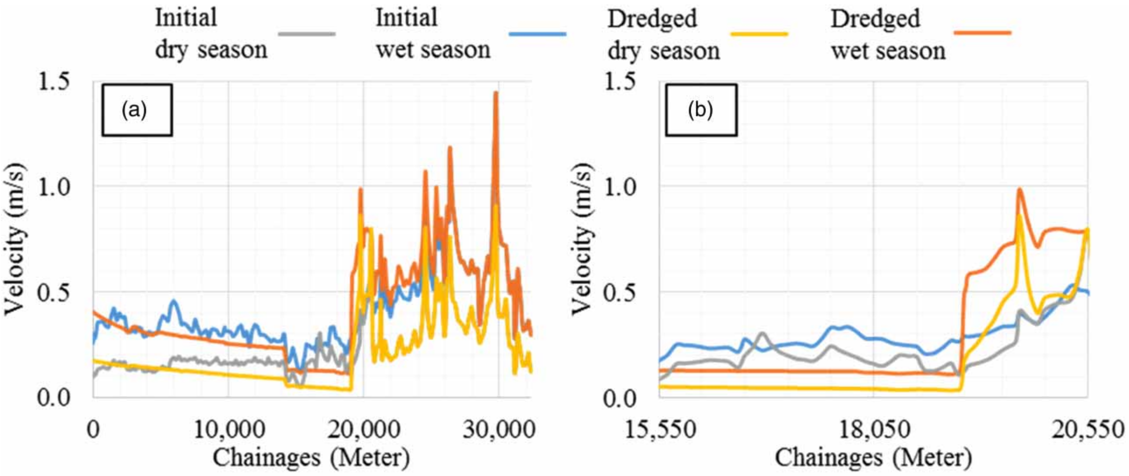

Figure 7 | Modeled maximum current velocity for wet and dry seasons for (a) global range and (b) local range.

number is small, resulting in subcritical flow. The changes in current velocity impacted by the dredging process can be seen in the area adjacent to the dredged boundary. The maximum changes are 0.59 and 0.45 m/s for the wet and dry seasons, respectively. The velocities fluctuate less in the downstream zone.

Bed shear stress

Bed shear stress (T) was also investigated to identify erosion that can occur after dredging takes place. Increased flow velocities after dredging indicate more erosions would occur in the channel.

Maximum bed shear stress (T) before dredging was between 0 and 13 Pascals. Increased current velocity actively caused the bed shear stress to increase, especially upstream adjacent to the dredged boundary, as seen in Figure 8. The bed shear stress after dredging changed from 5.17 to 38.22 Pascals, which indicates potential riverbed degradation. Table 5 shows the relationship between grain sizes and particle critical shear stresses. The higher the shear stress, the more potential for finer sediments to be washed away. At the initial stage, before dredging takes place, the bed materials that will potentially be washed away are of medium-fine size. Increased bed shear stress causes coarser bed materials to be washed away.

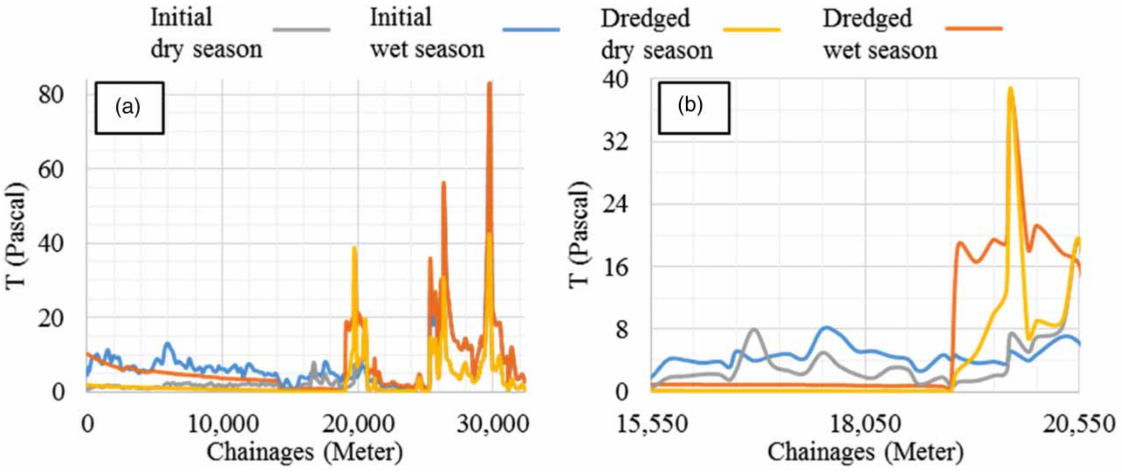

Figure 8 | Modeled maximum bed shear stress for wet and dry seasons for (a) global range and (b) local range.

Table 5 | Relationship of grain size and particle critical shear stress

Particle	Diameter (mm)	Critical bed shear stress (Pascal)
Cobble	64–256	53.8–223
Gravel		
Very coarse	32–64	25.9–53.8
Coarse	16–32	12.2–25.9
Medium	8–16	5.7–12.2
Fine	4–8	2.7–5.7
Very fine	2–4	1.3–2.7
Sand	0.125–2	0.145–1.3
Silt and very fine sand	0.0078–0.125	0.0378–0.145

CONCLUSION

Numerical one-dimensional modeling with MIKE 11 was carried out to simulate hydrodynamic changes impacted by capital dredging in the CBL channel. The model shows proper compliance with the field data. The investigated parameters are water level, current velocity, and bed shear stress during wet and dry season conditions. The capital dredging causes a drop of water level up to 1.75 meters, increased current velocity up to 0.59 m/s, and increased bed shear stress up to 33.05 Pascal. These impacts take place in the first 20 km and 25 km from the estuary during the wet and dry seasons, respectively. The findings show the need for sedimentation transport research in the channel. Further researches such as bed sampling and modeling some adaptation scenarios (i.e. infrastructure such as check dams) are important to identify and mitigate the potential changes in riverbeds due to the capital dredging. Also, the one-dimensional model has limitations, such as for reproducing flow on the flood plain area. Thus, the implementation of a two-dimensional model or coupling between the one and two-dimensional models is promising to represent the overflowing behaviour better.

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