ASSESSING THE IMPACTS OF SEA LEVEL RISE ON SAND EXPLOITATION IN THE CAN GIO COASTAL AREA (VIETNAM)

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Abstract

In recent years, due to the demand for economic development in Ho Chi Minh as well as the Key Economic Zone of Southern Vietnam, the requirement for construction materials has increased rapidly. There are about 10 sand mines which are reserved and licensed in the Can Gio coastal area. The exploitation of these mines is affecting this area. According to the climate change scenario for 2011 prepared by the Ministry of Natural Resources and Environment (Vietnam) and tidal observation, sea level is rising up in Can Gio area. Sea level rise will enhance the potential of coastal erosion, flooding, saline intrusion and increase fishing activities, as well as other artificial beach projects in the Can Gio area. To assess the impacts of sea level rise and sand exploitation activities in the Can Gio coastal area as well as artificial beaches, this research carries out. Numerical modelling was carried out to assess the effects of sand exploitation coupled with sea level rise on the Can Gio coastal area. The research showed that sand exploitation activities have led to erosion in the study area.

Keywords: Can Gio coastal area, Climate change, Coastal erosion, Numerical model, Sand exploitation, Sea level rise

Introduction

Coastal regions in southeastern Vietnam have been developing with a run and on a large scale in recent years. In order to supply building materials for construction demands, the exploitation of natural resources are being conducted rapidly to support the national economy development. Among them, the sand exploitation activities are promoted in everywhere.

With high urbanization rate, the Southern Key Economic Zone (including Ho Chi Minh City, Ba Ria – Vung Tau Province, Binh Duong Province, Dong Nai Province, Tay Ninh Province, and Long An Province - Southern Vietnam) needs a lot of building materials. Large volumes of sand have been exploited around the river mouth for the building materials and for the artificial beach project in the Can Gio coastal areas (Ho Chi Minh City). Deguchi and Sawaragi (1988) showed that structures influence deposition at the river mouth. Sand exploitation has affected to riverbank erosion as reported by Bui et al. (2008) and Dang et al. (2011). The characteristics of materials are important for evaluating coastal erosion (Bui et al, 2009).

According to the climate change scenarios in 2011 for Vietnam which was prepared by the Ministry of Natural Resources and Environment (Vietnam), the Ho Chi Minh City area will be flooded by about 13.3% of its total area if the sea level rises by 0.5 m. The Can Gio coastal area is located in the southeastern low land of Ho Chi Minh City. Therefore, sea level rise will increase the potential of coastal erosion, flood and saline intrusion and affect fishing activities, and other artificial beach projects in this area. The aim of this study is to assess the impacts of the sand exploitation coupled with climate change on the Can Gio coastal area, Ho Chi Minh City. This study area is shown in Figure 1.

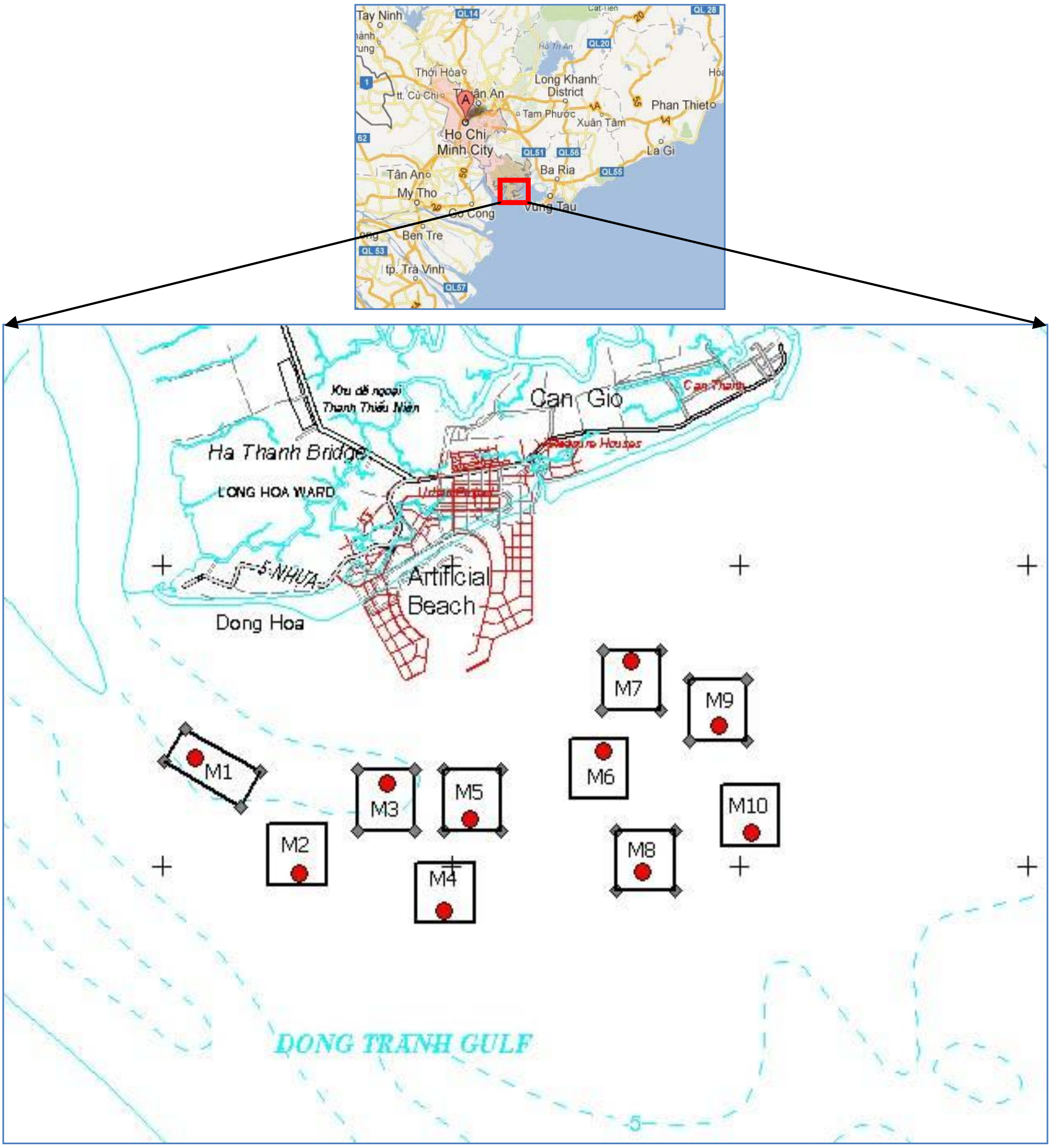


Figure 1. Sites of sand mines and sampling in Can Gio coastal area

The study area seems like an island and was bordered by river and sea. Can Gio coastal area faces to the East Sea with Dong Tranh Gulf in the right and Ganh Rai Gulf in the left. The entire of mining area is impacted by the semi-diurnal tidal regime. The study area is influenced by tidal currents from Long Tau river, Soai Rap river, Cai Map river, and Dinh river as well as wave – induced currents.

Methodology

For evaluating the erosion potential at the study area, measured and analyzed parameters were input to Mike 21 (DHI, 2007). Fundamental equations are based on the conservation of mass and momentum integrated over the vertical water column described the flow and water level variations:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = \frac{\partial d}{\partial t} \qquad (1)$$

$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial x}\left(\frac{p^2}{h}\right) + \frac{\partial}{\partial y}\left(\frac{qp}{h}\right) + gh\frac{\partial \zeta}{\partial x} + \frac{gp\sqrt{p^2+q^2}}{C^2.h^2} - \frac{1}{\rho_w}\left[\frac{\partial}{\partial x}(h\tau_{xx}) - \frac{\partial}{\partial y}(h\tau_{xy})\right] - \Omega_q - fVV_x + \frac{h}{\rho_w}\frac{\partial}{\partial x}\rho_a = 0 \qquad (2)$$

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial y}\left(\frac{q^2}{h}\right) + \frac{\partial}{\partial x}\left(\frac{qp}{h}\right) + gh\frac{\partial \zeta}{\partial y} + \frac{gq\sqrt{p^2+q^2}}{C^2.h^2} - \frac{1}{\rho_w}\left[\frac{\partial}{\partial y}(h\tau_{yy}) - \frac{\partial}{\partial x}(h\tau_{xy})\right] - \Omega_q - fVV_y + \frac{h}{\rho_w}\frac{\partial}{\partial y}\rho_a = 0 \qquad (3)$$

Where: ***h(x, y, t):*** water depth (= ζ -d, m); ***d(x, y, t):*** time varying water depth (m); ζ ***(x, y, t)***: surface elevation (m); ***p, q(x, y, t):*** flux densities in x- and y-directions (m3/s/m) = uh,vh) and (u,v) = depth averaged velocities in x- and y-directions; ***C(x, y)*:** Chezy resistance (m½/s); **g**: acceleration due to gravity (m/s2); ***f(V)***: wind friction factor; ***V, Vx, Vy(x, y, t)****:* wind speed and components in x- and y directions (m/s); Ω ***(x, y):*** Coriolis parameter, latitude dependent (s-1); ***p_a(x, y, t)***: atmospheric pressure (kg/m/s^2); ρ_w**:** density of water (kg/m^3); ***x, y:*** space coordinates (m); ***t:*** time (s); τ_{xx}, τ_{xy}, τ_{yy}: components of effective shear stress.

In combination of bed level data from sand mining projects (carried out in 2011) and Vietnamese Navy (published in 2010), topography data is input to model in *.xyz file. By Mesh Generator tool, study area is divided into 5510 elements which was applied flexible mesh (Figure 2).

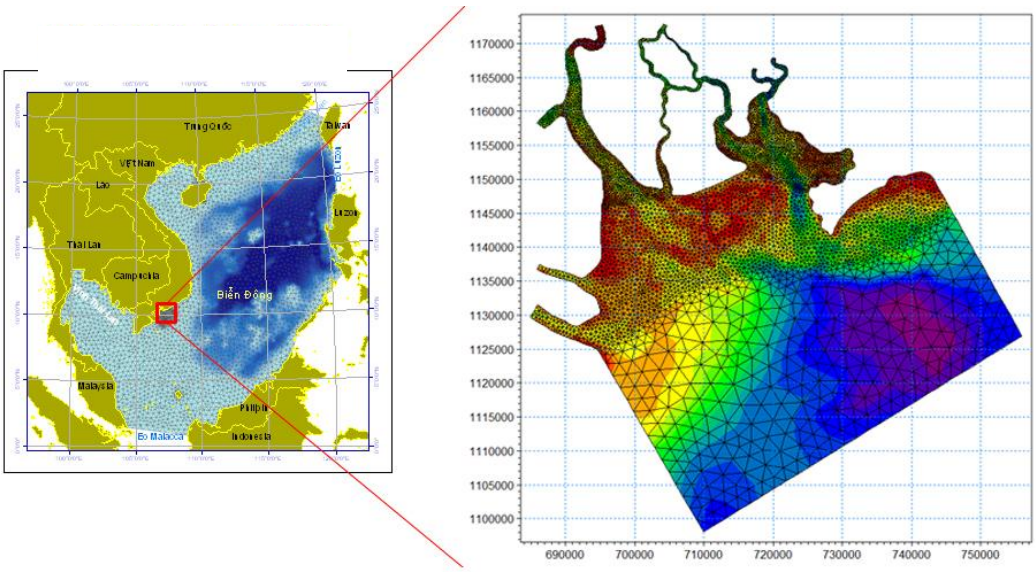


Figure 2. Modeled study area

Water level boundary is extracted from global data by MIKE 21 toolbox. Wave data is extracted from WaveWatch III model, which was published by National Center for Environmental Prediction (NCEP/NOAA). Besides, monitoring data from 2009 to 2011 at Vung Tau station (10^{o}20N; 107^{o}04E) is used to verify the simulation results.

In order to assess the impacts of sand exploitation coupled with sea level rise, the authors have set two scenarios for January and June in 2011 and a scenario on sea level rise condition (**Table 1**).

Table 1. Modeling Scenarios

No	Code	Description
1	0111_UST_A	Time: January (northeast monsoon season) Coastal structures: No Sand exploitation: No Sea level rise: No
	0611_UST_A	Time: June (southwest monsoon season) Coastal structures: No Sand exploitation: No Sea level rise: No
2	0111_UST_B	Time: January (North East monsoon season) Coastal structures: No Sand exploitation: Yes Sea level rise: No
	0611_UST_B	Time: June (South West monsoon season) Coastal structures: No Sand exploitation: Yes Sea level rise: No
3	SLR0.2_Jan	Time: January (northeast monsoon season) Coastal structures: Yes Sand exploitation: Yes Sea level rise: + 0.2 m
	SLR0.2_June	Time: June (southwest monsoon season) Coastal structures: Yes Sand exploitation: Yes Sea level rise: + 0.2 m

To determine the impacts of exploitation activities, some monitoring sites have been set up and verified with the simulated results. Sites of monitoring are shown in Figure 1.

Tidal Observation

Water levels collected and measured at the field trip by tidal gauge. Figure 3 shows the typical tidal conditions in the study area.

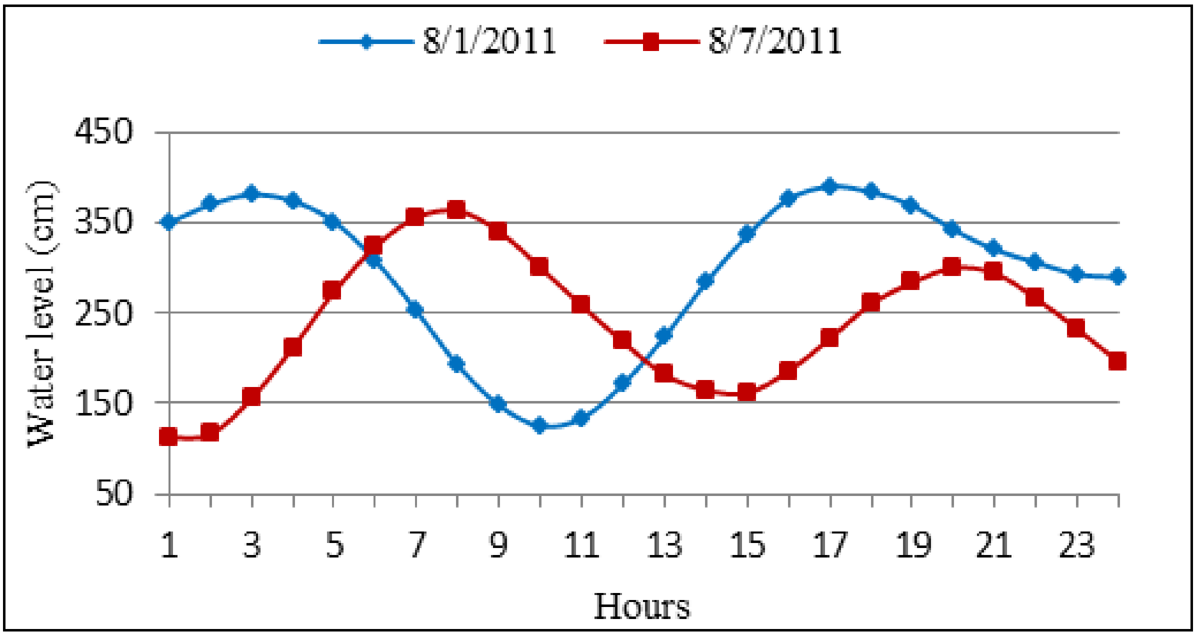
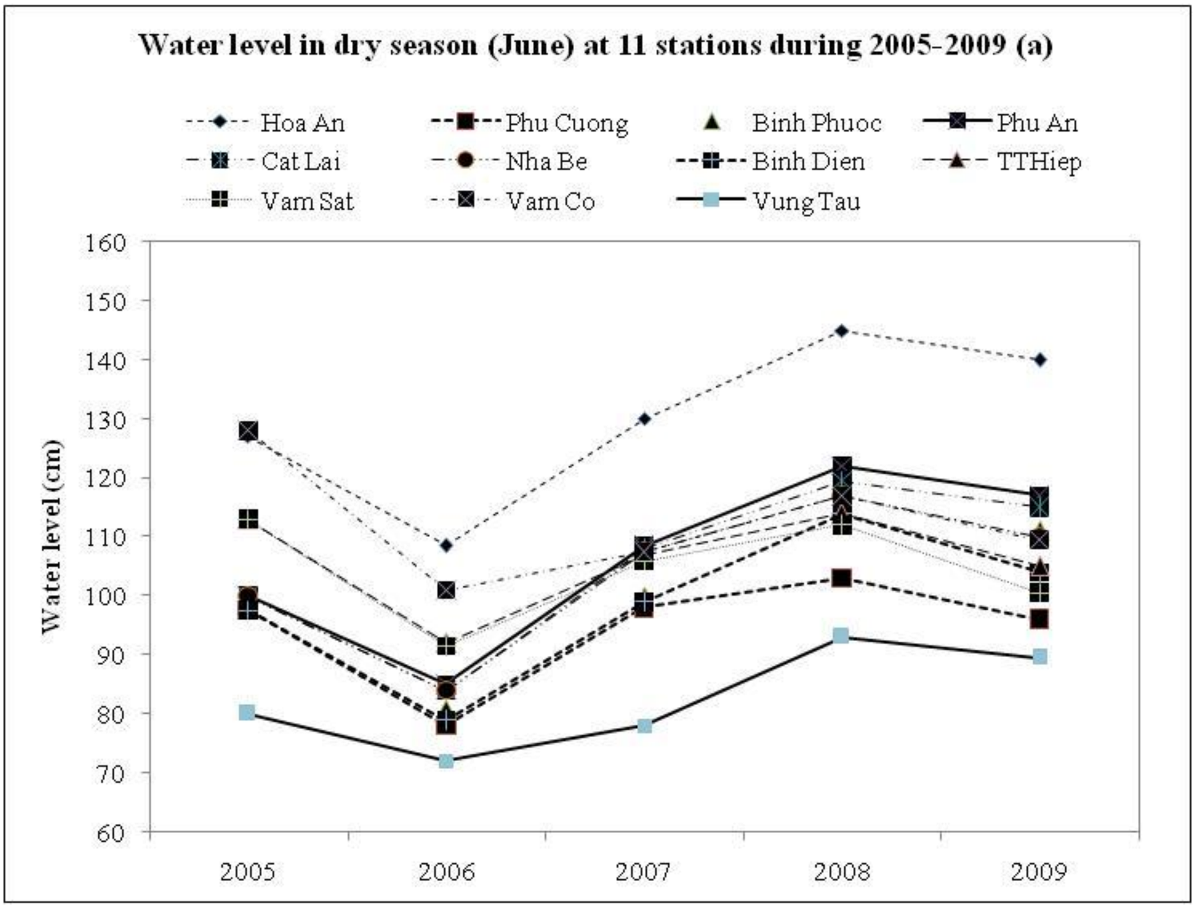


Figure 3. Typical tidal conditions in the study areas

The 1st and 15th in lunar day are the time for spring tide, while the lunar day 7th and 23rd are the time for neap tide. The average tidal amplitude reached 403 cm. Withdrawal to ebb tide is 6h and 45 minutes. The highest water level is +154 cm, the lowest water level is -335 cm and average water level is -26 cm.



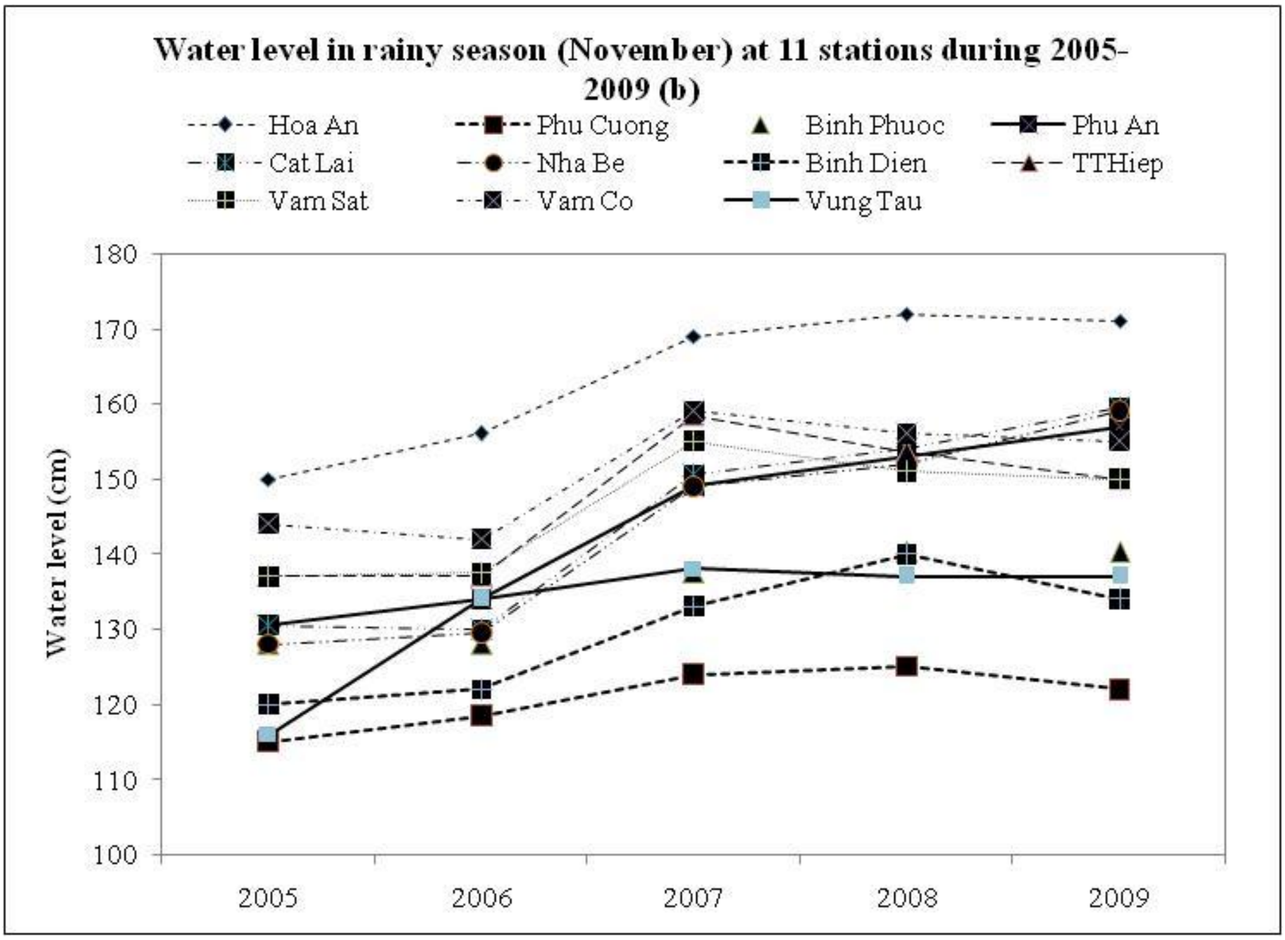


Figure 4. Water level in dry season (a) and rainy season (b) around the study area

Figure 4 shows the water level in dry season and rainy season in some areas around the study areas. In this figure, the water levels tend to increase from 2005 to 2009 in all observation stations. For dry season, at Hoa An station, water level increase about 20 cm averagely. For the rainy season, water level increase for all station clearly.

Current Observation

Current velocity was measured by current meter. Maximum current velocity measurement at Long Tau river is 1.5 m/s, at Soai Rap river is 1.3 m/s. Average of flow velocity on the field is 0.6 m/s.

Geological Properties of Sand Mines

Sand exploitation areas are located between Dong Tranh Gulf and Ganh Rai Gulf. The average water depth of the sand extraction areas is between 0.5 and 8 meters (Figure 1). The distance from sand mines to Can Gio beach is from 2 km to 5 km. The slope of the beach is about 0.2 degrees with the southern direction. The terrain accretion is type of estuary and coastal area.

In order to investigate the geotechnical properties of sand mines, 10 bore holes were drilled up to 8 m from the sea surface. The thick and samples were taken and analyzed (Figure1). Soil samples sent directly to the geological laboratory to analyze their properties. The results of geotechnical properties are shown in Table 2.

Table 2. Grain Size of Sand Material in the Sand Mines

Code	Grain Size (mm)						
	5-2	**2-1**	**1-0.5**	**0.5-0.25**	**0.25-0.1**	**0.1-0.05**	**<0.05**
M1			0.1	4.3	78.2	11.4	6
M2			0.1	0.2	85.6	9.4	4.7
M3			0.5	0.3	81.5	11.3	6.4
M4				0.3	79.1	5.4	15.2
M5			2.3	8.7	44.3	23.9	20.8
M6	0.6	2.1	3.7	6.9	62.7	15.6	8.4
M7	0.4	0.3	1.3	5.7	72.5	14.7	5.1
M8	0.1	0.1	0.3	1.2	80.4	13.4	4.5
M9	0.1	0.4	1.6	2.9	78.2	12.7	4.1
M10		0.2	0.3	0.5	50.3	28.1	20.6

It is can be seen that sand grain size is almost in the range of 0.05 to 0.5 mm. The mean grain size d50 equals to 0.3 mm. However, in the bottom surface, the marine sediment in some areas is finer with high silt and mud content (Modimo Mining, 2012). Therefore, with this sediment grain size, the mine company will not exploit.

Results and Discussion

Model Results

The paper will discuss on current, wave, and scenarios as below.

Current Field

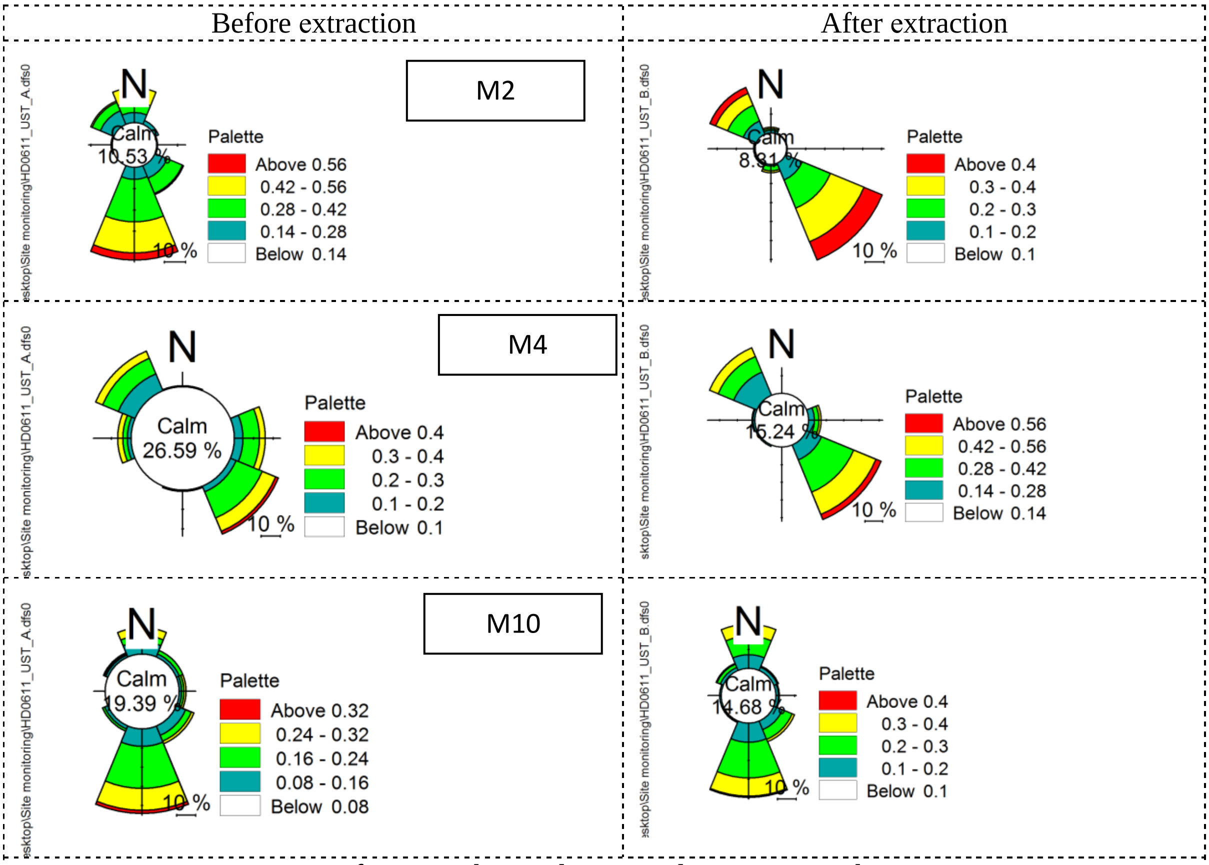


Figure 5: Comparison of current change due to sand extraction in the SW monsoon season

Wave-induced currents cause sediment transport along Can Gio beach. Figures 5 and 6 show the current velocities and directions in the south-west and north-east monsoon season around sand mines in two scenarios – before (figures at left side) and after sand extraction (bed level changed scenario) with figures at the right side. It shows that exploitation activities have affected on the hydrodynamics of the study area. Current speed at border of sand mining has increased, deviated to South East, V_{max} = 0.56 m/s. On the other hand, in the center of the entire of sand mining area, current speed is lower. Maximum current-induced speed distributes at the border of exploited areas, V_{max} is over 0.8m/s. In the entire of sand mining areas, current speed is lower and deviated.

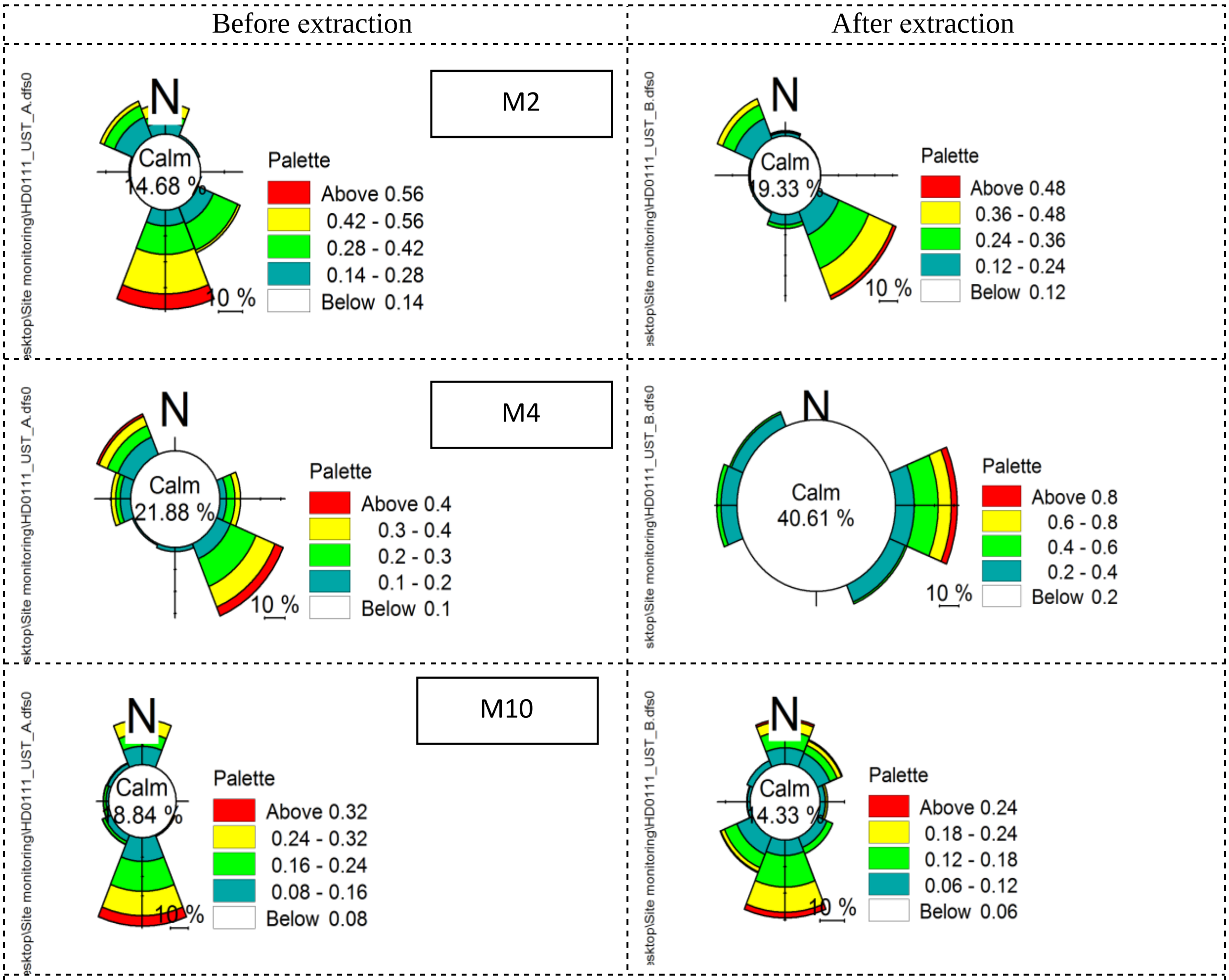


Figure 6: Comparison of current change due to sand extraction in the NE monsoon season

Wave Field

Figures 7 and 8 show the wave distribution in southwest and northeast monsoon season, respectively. In the southwest monsoon season, wave heights are higher than those in the northeast. Maximum wave height in the southwest monsoon measured is 1.25 m. Average wave height is about 0.6 m and wave period is 2.4 s. High waves often occur in the afternoon. Wave height around Can Gio beach is about 0.2 m.

In the northeast monsoon season, wind blows from mainland to the sea. Maximum offshore wave height measured is about 1.0 m. Average wave height appears is 0.3 m and wave period is 1.8 s. Wave height around Can Gio beach is around 0.15 m.

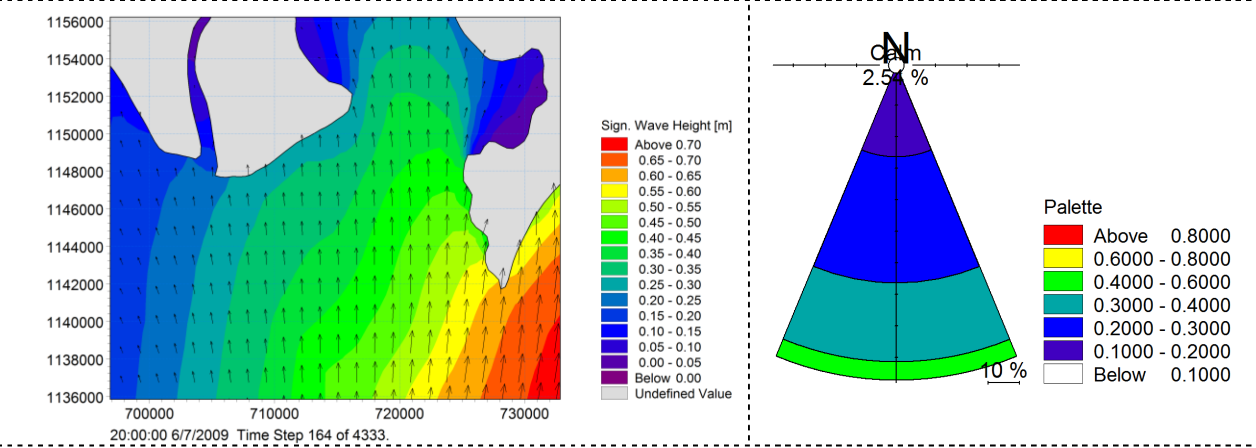


Figure 7: Wave distribution in the SW monsoon season

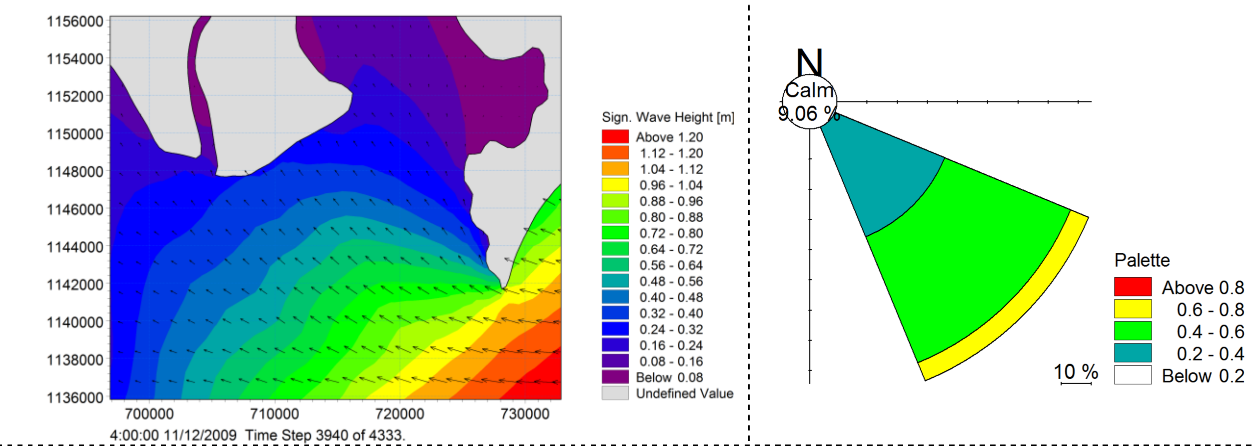


Figure 8: Wave distribution in the NE monsoon season

Impacts of Sand Exploitation Coupled with Climate Change

Figure 9 shows the scenarios of the sea level rise. The solid blue curves in the figure are the predicted maximum and minimum value of sea level rise by IPCC under A2 condition. The minimum prediction corresponds to the predicted result by JMA. Again, three values of 0.9m, 0.5m and 0.15m were set for long term, middle term and short term predictions. From this scenario and tidal observation (Figure 4) the scenario of 0.2 meter sea level rise has been chosen to simulate.

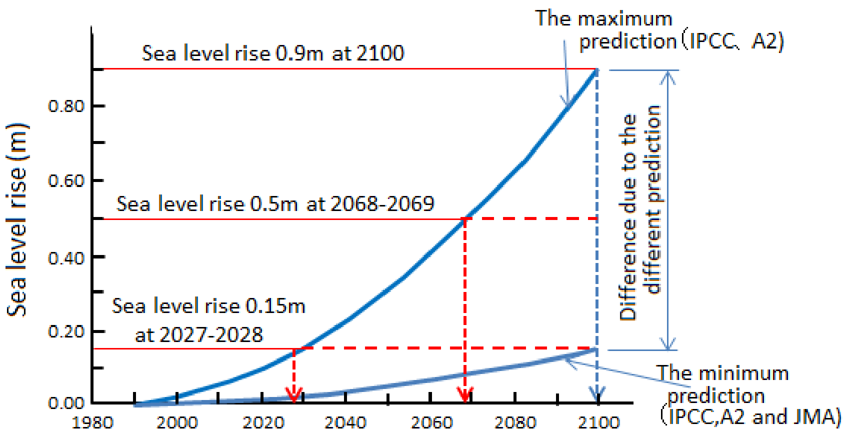


Figure 9. The scenarios of sea level rise (ministry of natural resource & environment, 2011)

Scenarios 1 - Bed Level Changes in the Southwest Monsoon Season

Figure 10 shows the change of bottom topography in the southwest monsoon season. Erosion occurs in Can Gio Cape area, 30-4 beach and M7 (Figure 11) sites caused by sand exploitation activities. After sand extraction, these areas have been eroded about 1-2 cm per 15 days. At M7 site, the initial erosion rate is about 4 cm per 15 days and increases 8 cm per 15 days after sand extraction. At site M4, bed level change has increased the erosion speed from 4 to 8 cm per 15 days.

In the otherwise, M4 (Figure 12) and M10 is deposited in this season. After the bed level has been changed, currents and waves move the sediment materials from the mainland to the sea and establish a new balance in exploitation areas. Deposition speed in these areas is about 1-3 cm per 15 days.

It is said that bed level changes due to sand exploitation, bottom sediment tends to move entirely in sand mining to establish a new balance at these sites. This causes erosion in the other sites (site M4, and M7).

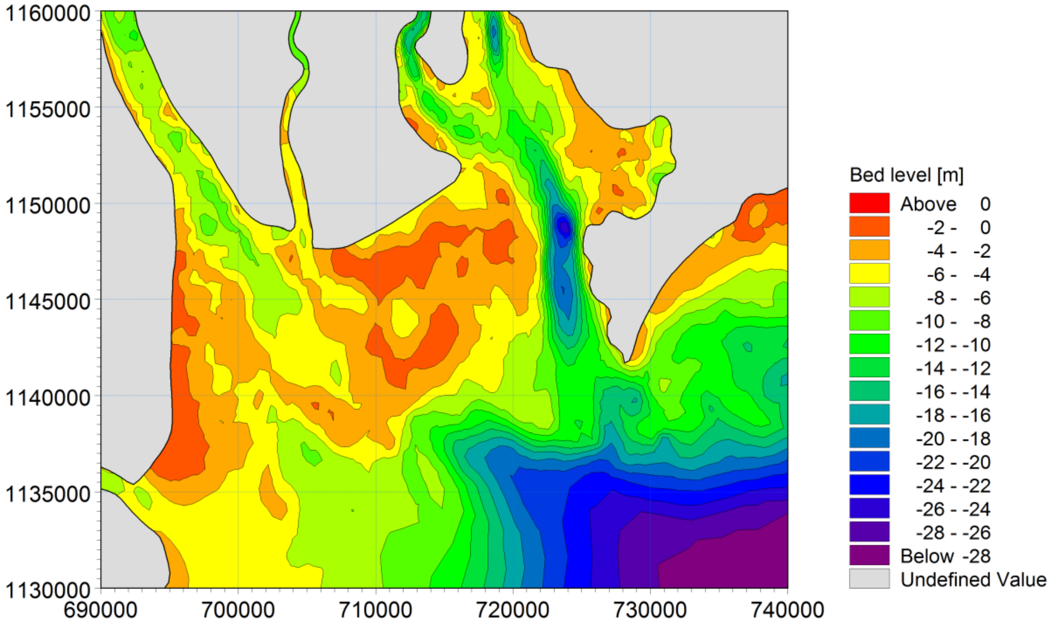


Figure 10. Bed level change in the summer impacted by SLR

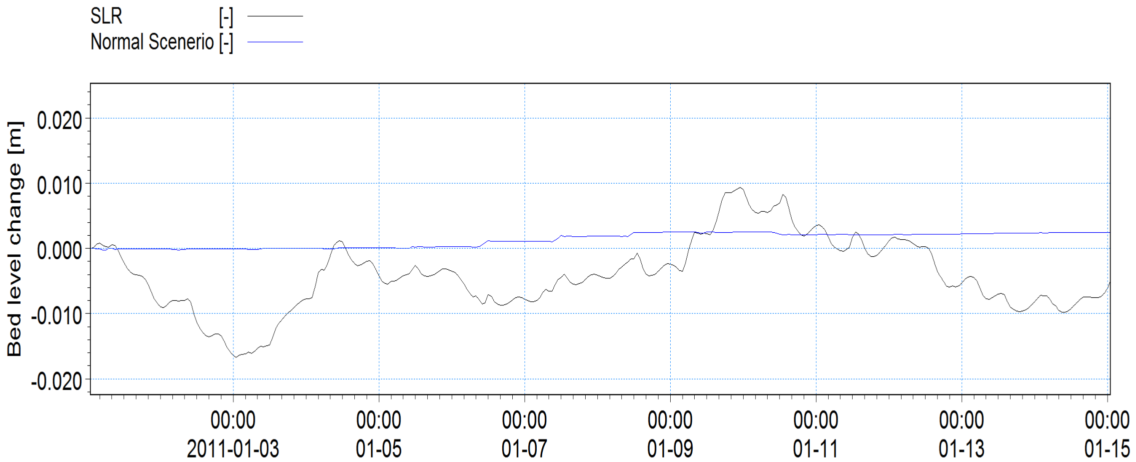


Figure 11. Bed level change in the M7 sand mine area

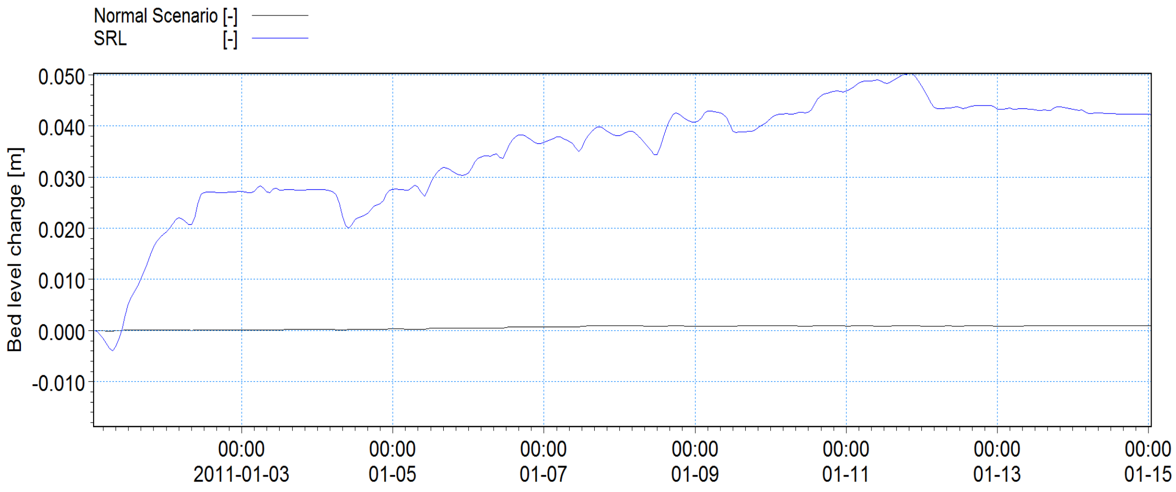


Figure 12. Bed level change in the M4 sand mine area

Scenario 2 - Bed Level Changes in the Northeast Monsoon Season

In study area, the northeast monsoon season coupled with high tide causes severe erosion in Can Gio coastal areas. In the offshore area, it also strongly affects on the hydrodynamic regime in this time. Results show that maximum current speed distributes at the border of exploitation areas, V_{max} is over 0.95 m/s. In the entire of sand mining areas, current speed is lower and deviated. Current distribution in the northeast monsoon season is shown in Table 3.

Bed level change in sand mining area has affected to the sediment transport, trends to set a new balance in this area. In this season, induced wave brings a large amount of sediment from offshore to onshore, generates the sand bar next to estuaries, and also caused erosion speed increases from 2 to 29 cm per 15 days. Determined results are shown in Table 4.

Table 3. Current Distribution in the Northeast Monsoon Season

Sites	Before		After	
	Speed (m/s)	Direction (degree)	Speed (m/s)	Direction (degree)
M1	0.5990218	206.7523	0.9518348	202.4366
M2	0.620171	219.0372	0.543887	201.5473
M4	0.4480402	173.2651	0.9212036	177.9088
M7	0.4005096	215.1679	0.384089	182.6333
M10	0.3739135	242.9521	0.279043	171.6217

Table 4. Bed Level Change in the Northeast Monsoon Season

Site	Before (m)	After (m)
M1	0.002925	0.247325
M2	0.001079	0.00226
M4	0.014835	0.017239
M7	0.022449	0.318996
M10	0.009661	0.004575

Figure 13 shows the erosion performances at the coastal zone in the northeast monsoon season. Coastal erosion occurs at the Can Gio and Dong Tranh points, and the 30 - 04 beach has been deposited. Maximum wave height is about 0.25 m. The Can Gio and Dong Tranh Capes are affected directly by waves and tidal currents.

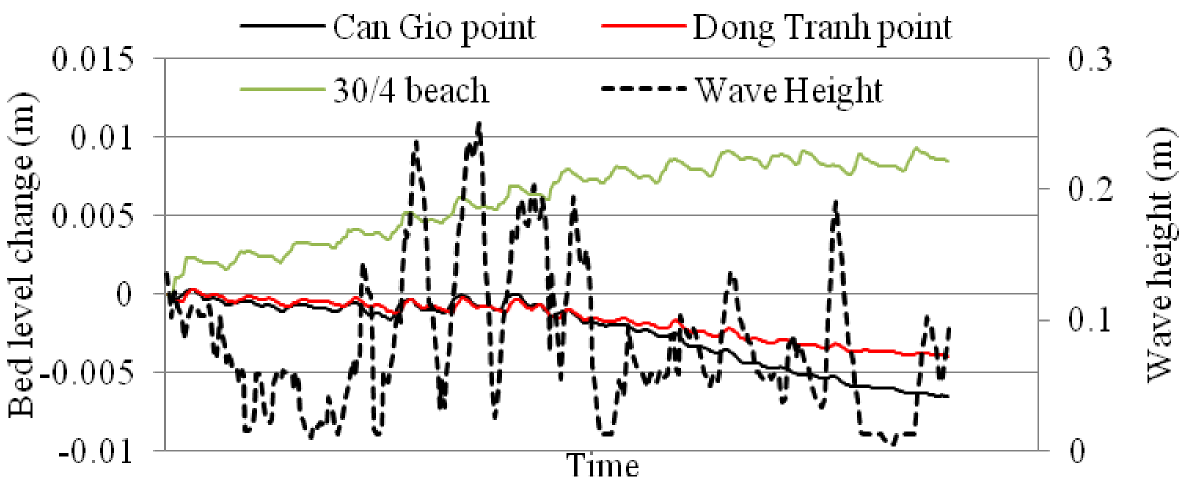


Figure 13. Bed level change in the northeast monsoon season

Scenario 3 - Coupled Impacts due to Sand Exploitation in Sea Level Rise Condition

Figures 14 and 15 show the relationship between water level and current speed in the northeast and southwest monsoon seasons. The water amplitude is in range of 2.5 in the northeast monsoon season and 3m in the southwest monsoon season. Maximum current speed is about 0.5 m/s.

Sea level rise make changes on the tidal dynamics and hydrodynamic regime as well as sediment transport in this area. Figure 16 shows that at M1 site (in the northeast monsoon season), deposition occurs in first 15 days. After this period, bed level tends to be eroded. However, in the southwest monsoon season, erosion rate gets about 2 cm per 15 days (Figure 17).

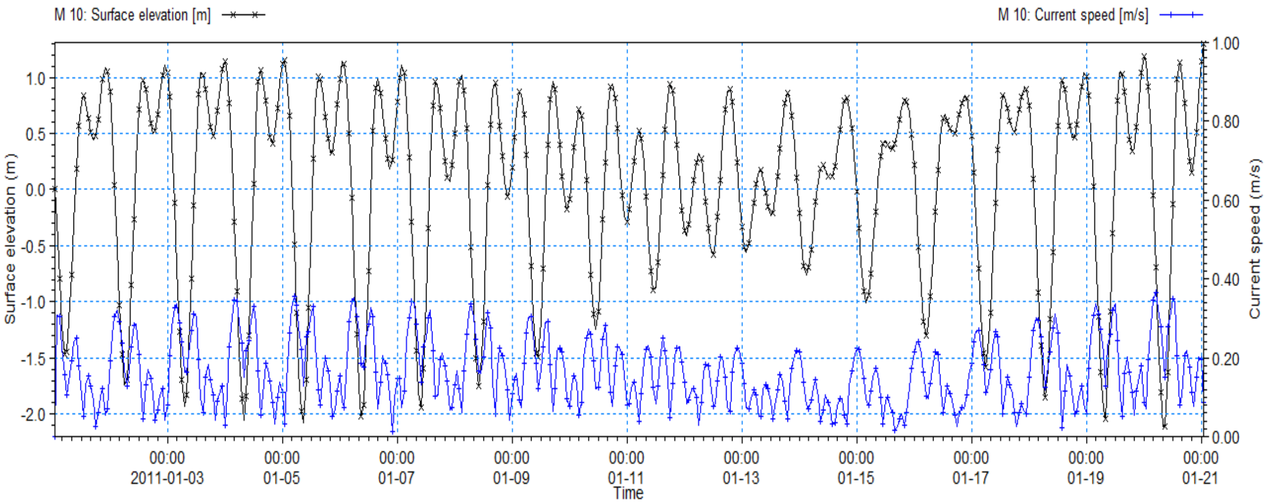


Figure 14. Water level and current speed in the northeast at SLR 20 cm

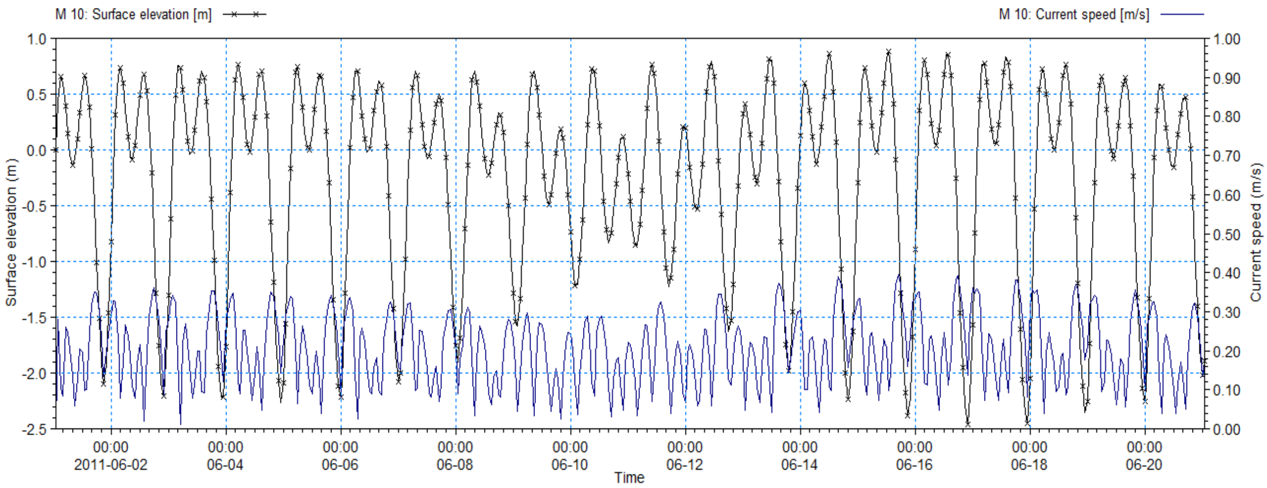


Figure 15. Water level and current speed in southwest at SLR = 20 cm

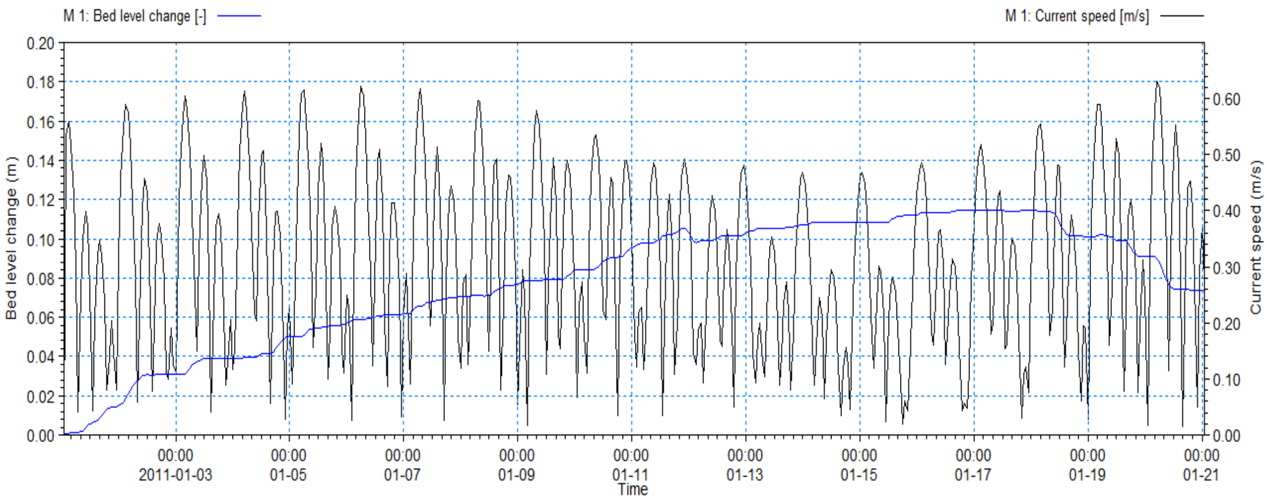


Figure 16. Erosion and deposition trend at M1 in the northeast at SLR=20 cm

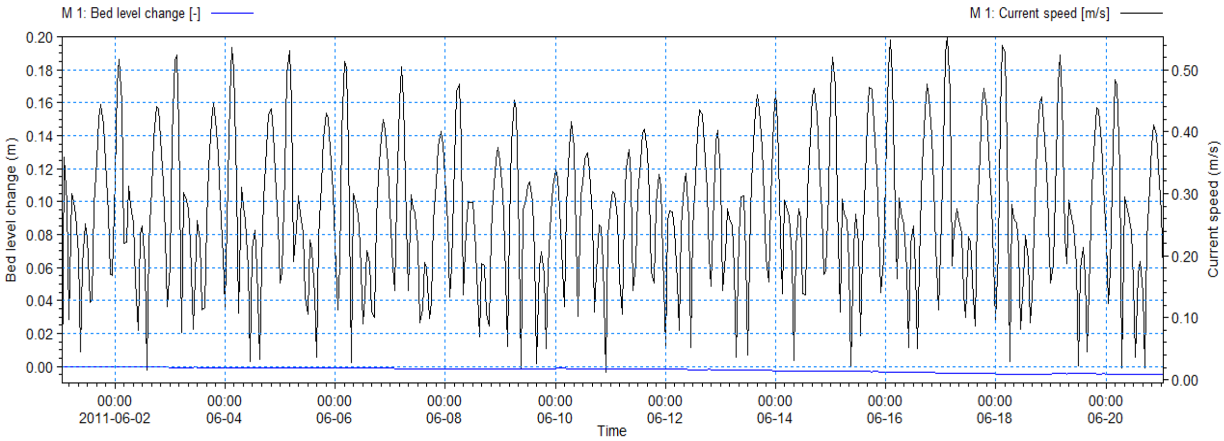


Figure 17. Erosion and deposition trend at M1 in southwest at SLR=20 cm.

Table 5 shows the calculation results of erosion and depositon processes at M1, M2, M4, M7, and M10 sites in the northeast and southwest monsoon seasons. From this table, it can be seen that the erosion and deposition processes take place from one site to the other site.

Table 5. Caculation Results of Erosion and Depostion Processes in SLR= 20 cm Condition

Location		Current Speed (m/s)		Current Direction Degree			Bed Level Change (m)		
		Min	Max	Min	Max	Mean	Min	Max	Mean
NE	M1	0	0.63	58	338	195	0	0.11	0.08
	M2	0	0.53	28	350	209	-0.019	0.05	0.038
	M4	0	0.7	21	337	194	-0.0022	0.03	0.01389
	M7	0	0.4	1	342	193	-0.0167	0.02	0.00028
	M10	0	0.36	5	357	208	0	0.01	0.00775
SW	M1	0	0.55	48	348	202	-0.005	0	-0.0022
	M2	0	0.6	12	348	210	-0.001	0.024	0.00601
	M4	0	0.62	66	349	200	-0.00207	0.002	-0.0007
	M7	0	0.34	3	354	177	-0.10506	0.0005	-0.0443
	M10	0	0.39	5	357	201	-0.0008	0	-0.0004

Conclusions

The currents and waves cause sediment transport around sand mines and Can Gio coastal area in different monsoon seasons. The erosion and deposition processes in the northeast monsoon season occur stronger than those in the southwest monsoon season. After sand exploitation, the erosion and deposition processes changes significantly. The erosion rate reaches 29 cm per 15 days in the northeast monsoon season and 8cm per 15 days in the southwest monsoon season.

Sea level rise has much stronger effects on Can Gio coastal area. The erosion and deposition processes have changed significantly as all sand mines finish extracting coupled with sea level rise.

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