Evaluation estuarine and coastal bathymetry changes of Cua Viet using Digital Elevation Model

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Abstract: Cua Viet is the Thach Han river's mouth. It is quite big estuary that is located in the central coastal province of Quang Tri. In which, Cua Viet port plays an important role for water transport and commerce of the province. In recent years, accretion and erosion have occurred increasingly in term of scale and intensity. In addition, estuarine access channels suffer severely from sedimentation. Until now, there is no effective measure to train this estuary and Cua Viet morphological changes effect to navigation, flood control and other economic activities.

In the frame work of this paper, bathymetry changes of Cua Viet estuary, especially access channels to Cua Viet port are deeply evaluated by setting up digital elevation model (DEM) based on in situ measured data in recent times.

Key words: estuaries, bathymetry, bottom changes, DEM, Cua Viet

1. Problem definition

The sedimentation – erosion process of coastal zones and sedimentation at estuaries are considered as a substantial type of disaster in Vietnam, which occurred in all parts of the country, with complex variation, causing large damage to human lives and property, with long-term economic and environmental consequences. A large amount of expenditure is spent by the Government to recover, prevent and rescue as well as dredging maintenance and prevention of sedimentation and erosion in estuarine ports.

Cua Viet is an estuary of Thach Han river and is also a considerably large estuary within Quang Tri province, also the place where frequent natural disasters happen such as typhoons, floods, coastal erosion, estuarine sedimentation, etc. Specifically the sedimentation – erosion process are happening with increasing trend both in scale and magnitude. Sedimentation of the access channel within Cua Viet estuary happens quite seriously without any effective engineering measures yet. To help recover the consequence of sedimentation process in Cua Viet, we built a digital elevation model (DEM) to supply information on: annual sedimentation thickness at site, which causes difficulty for navigation, flood flushing and other economic activities in the region. The annual dredging such a large amount of sediment costs totals up to billions of VND.

The aim of this paper is to study and apply GIS in building a digital elevation model in order to evaluate the sedimentation – erosion process at the bed of access channel leading into Cua Viet port in seasonal or annual periods based on the field surveys in recent years.

2. Database and data source in use

In order to apply GIS for the study area, the authors mainly used the data and documents

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from four surveys implemented by the Institute of Geography in 2006 and 2007, including:

- *Bathymetry data*

+ Topographic map of the sea bed in scale 1:2000 for Cua Viet area, measured and drawn by the Institute of Geography in July 2006.

+ Topographic map of the sea bed in scale 1:2000 for Cua Viet area, measured and drawn by the Institute of Geography in December 2006.

+ Topographic map of the sea bed in scale 1:2000 for Cua Viet area, measured and drawn by the Institute of Geography in June 2007.

+ Topographic map of the sea bed in scale 1:2000 for Cua Viet area, measured and drawn by the Institute of Geography in December 2007.

Besides, we also refer to other documents such as: the topographic map constructed on the VN 2000 cartographic grid with scale 1:25000 at site, created by the Department of Cartography in 2003 and documents on depths of Cua Viet port measured by the Company for Navigation Assurance in Oct-2006, Dec-2006, May-2007, and Dec-2007.

- *Hydrodynamic data*

+ Results of survey by Institute of Geography, on the tidal current, alongshore current at Cua Viet in Jul-2006, Dec-2006, Jun-2007, and Dec-2007.

+ Result of discharge measurements through various profiles with current meters and integrated-discharge meters during the aforementioned time periods.

3. Methods for evaluating sea bed variation

Based on the field measurements and documents, we set up the DEM for the site of interest in each survey period. The DEM is a model for the elevation or depth of the earth surface, which varies continuously on any particular location. A location is represented by a cell (may have different areas), characterized with horizontal co-ordinates (x, y) and elevation (z). To evaluate sea bed variation, the DEM is constructed from contour lines and measured depth points through the TIN (Triangulated Irregular Network) method. The data structure of TIN comprises two main features: every point have 3 values: geographical coordinates (x, y) and elevation (z) so that the 3 line segments linking these points create a triangle; the single triangles compose to form an irregular triangular network. The elements of a TIN are: nodes, edges, boundary, and topology. To acquire highest accuracy in the research, we set up the DEM with a cell size of 2.0 m, corresponding to a contour map scale of 1:2000. The result of DEM construction for the study site is represented in the following figures:

From the DEM constructed for the various time periods, we apply GIS for calculation on the pixel of different DEMs to estimate the variation of sea bed elevation at site during a seasonal period and an annual period (see Figures 1 to 6), thus quantify the change in sea bed level, including: maximum sedimentation value, maximum erosion value, average sedimentation – erosion value and volume of sedimentation – erosion for an area.

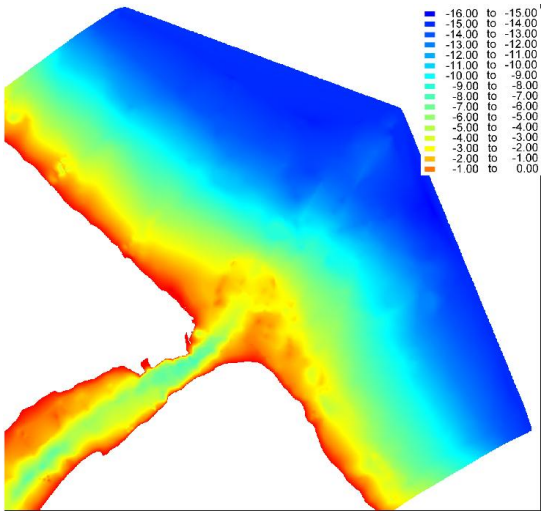

Figure 1. Digital elevation model for the Cua Viet estuary in Jul-2006

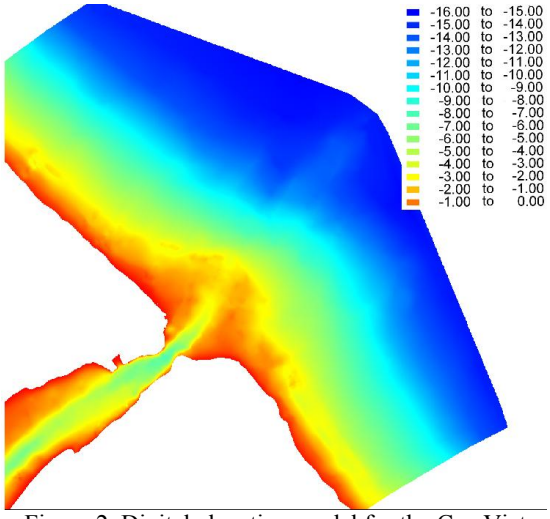

Figure 2. Digital elevation model for the Cua Viet estuary in Dec-2006

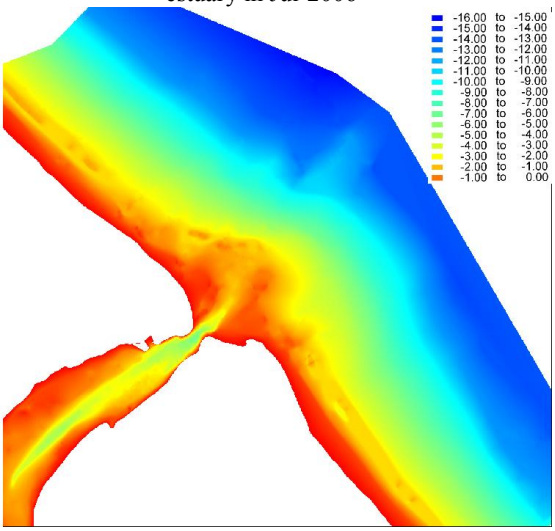

Figure 3. Digital elevation model for the Cua Viet estuary in Jun-2007

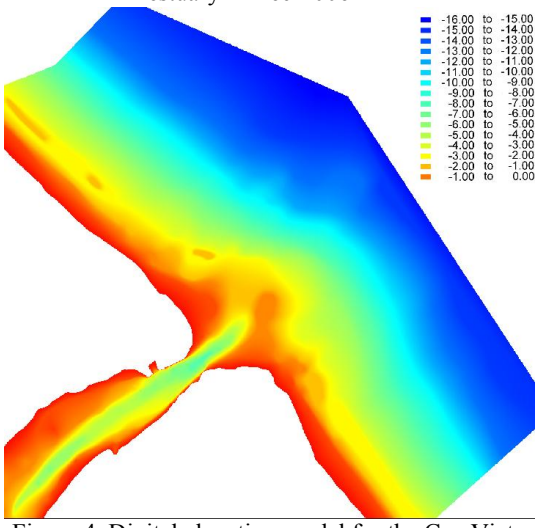

Figure 4. Digital elevation model for the Cua Viet estuary in Dec -2007

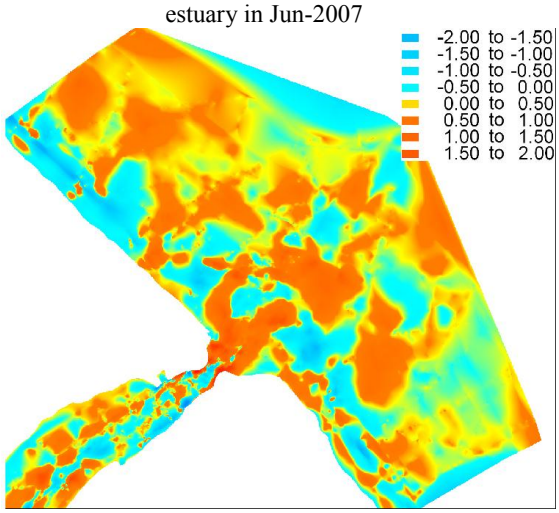

Figure 5. Sea bed variation in Cua Viet estuary between Jul-2006 and Jun-2007

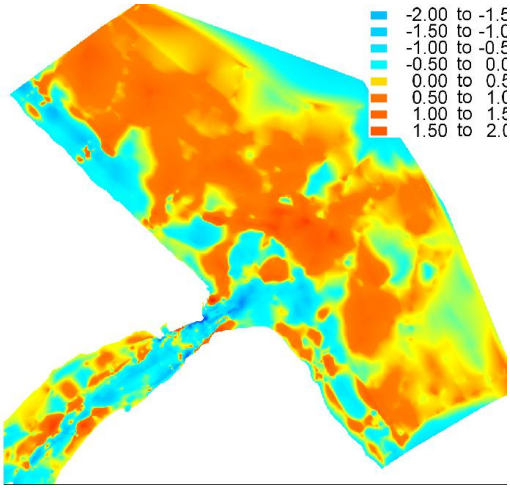

Figure 6. Sea bed variation in Cua Viet estuary between Dec-2006 and Jun-2007

4. Evaluation on variation of the accretion – erosion of Cua Viet coastal and estuarine zone

Based on the morphological features of the study site, also for convenience in comparison and evaluation of sedimentation-erosion processes of Cua Viet access channel, we divide the site into four different zones (Figure 7), in which:

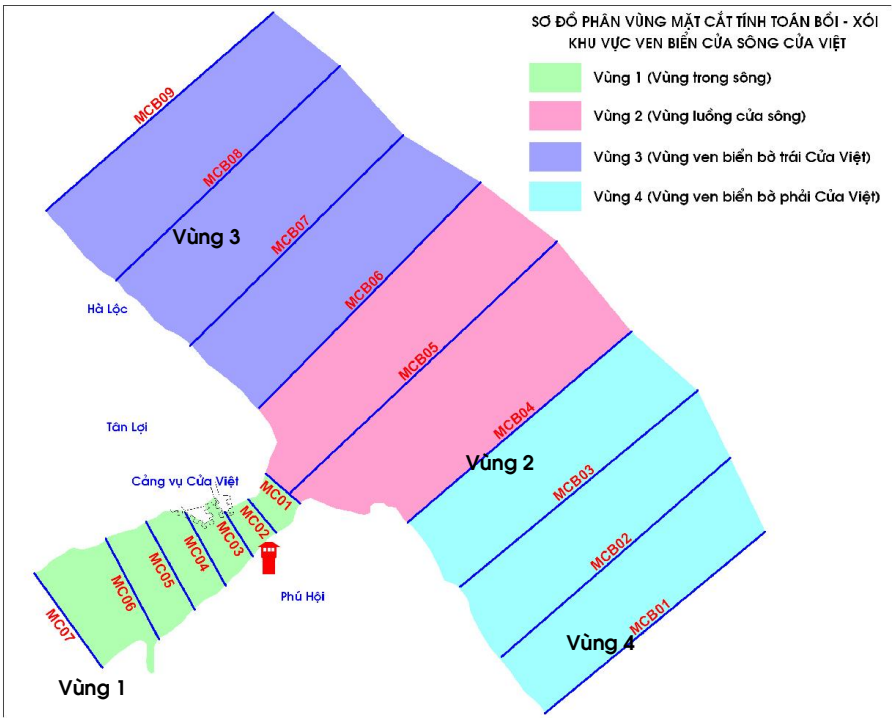

Figure 7: Schematic diagram on zoning for calculation of sedimentation – erosion in Cua Viet estuary

Zone 1 is defined from the inner Thach Han river reaching to the opening gap of Cua Viet (from cross-section MC01 to MC07).

Zone 2 is the access channel area from the opening gap of Cua Viet to the depth contour -15 m, bounding in a 1 km-width stripe, with a centerline as the axis of estuary (from profile MCB04 to MCB06).

Zone 3 is the coastal zone on the left of Cua Viet when looking seaward (i.e. Northern Cua Viet) from the shoreline to the depth contour -15 m, the width is 1.5 km (from cross-section MCB06 to MCB09).

Zone 4 is the coastal zone on the right of Cua Viet when looking seaward (i.e. Southern Cua Viet) from the shoreline to the depth contour -15 m, the width is 1.5 km (from cross-section MCB01 to MCB04).

Based on measured data at Cua Viet estuary, we evaluate the variation of sedimentation – erosion for all four aforementioned zones as follows.

4.1. Sedimentation – erosion process in Cua Viet access channel during dry season

The difference in bathymetry between Dec-2006 and Jun-2007 is the basis to evaluate the sedimentation – erosion of Cua Viet access channel in the dry season. The result shows that in dry seasons, the bed of channel is accreted quite rapidly, especially the middle part of channel. In details:

Zone 1: Bed elevation changes from -4.5 ÷ -9 m. Calculation results show that at the mouth of river the was raised, with a thickness of 0.7 ÷ 0.8 m, while the inner part of Cua Viet from the port entering Thach Han river, slight erosion occurs, with an average thickness of -0.2 ÷ -0.4 m. The total accretion volume in the entire zone is 40,479 m^3, which means an average rate of sedimentation around 6.747 m^3/month (Table 1).

Table 1: Total sedimentation – erosion volume of Zone 1 – Cua Viet access channel in dry season

No.	Profile	Distance	Max. sed. thickness	Max. erosion thickness	Average rate of sed. – erosion	Total net volume sed. – erosion
		(m)	$\Delta_{sed.max}$ (m)	$\Delta_{ero.max}$ (m)	(m)	$W_{sed.-ero}$ (m^3)
1	MC01					
2	MC02	160	1.530	-0.437	0.894	58381
3	MC03	160	1.631	-0.539	0.857	52173
4	MC04	220	0.944	-0.494	0.050	3225
5	MC05	220	0.403	-1.123	-0.239	-21622
6	MC06	240	0.560	-1.270	-0.381	-38725
7	MC07	280	0.491	-0.824	-0.076	-12953
	Total					40479

Note: (+) implies sedimentation; (-) implies erosion.

Zone 2, 3, and 4: This is the area of Cua Viet, extending towards the sea up to the -15 m contour line, with the alongshore extension of 4 km. Zone 3 has an eroding bed, with average rate of -0.15 ÷ 0.25 m/season and total erosion volume of -131267 m^3. Zone 2 is under intensive sedimentation, with average rate of 0.6 m/season and total accretion volume of 338227 m^3. Zone 4 also experience accretion in this season, with an average of 0.2 ÷ 0.3 m/season and total volume of 149851 m^3. Generally, these zones have the tendency of rapid sedimentation, with total sedimentation volume of 406811 m^3 (Table 2).

Table 2: Total sedimentation – erosion volume of Zone 2,3,4 – Cua Viet access channel in dry season

No.	Profile	Distance	Max. sed. thickness	Max. erosion thickness	Average rate of sed. – erosion	Total net volume sed. – erosion
		(m)	$\Delta_{sed.max}$ (m)	$\Delta ero_{.max}$ (m)	(m)	$W_{sed.ero}$ (m^3)
1	MCB09					
2	MCB08	500	0,397	-1,017	-0,145	-43506
3	MCB07	500	0,473	-1,302	-0,132	-50281
4	MCB06	500	0,361	-1,126	-0,275	-37480
5	MCB05	500	1,526	-0,706	0,268	103447
6	MCB04	500	1,772	-0,550	0,610	284780
7	MCB03	500	1,236	-0,427	0,193	77033
8	MCB02	500	1,134	-0,521	0,126	36833
9	MCB01	500	0,974	-0,252	0,265	35985
	Total					406811

It can be seen that in Zone 1 alternate sedimentation – erosion occurs; sedimentation area locates near the river mouth, where the river flow (with comparatively small velocity) meets the tidal flow and wave-induced flow, hence considerable sedimentation occurs.

On the coastal strip on two sides of the Cua Viet, during dry season, high wave comes from Northeast and North, bringing sediment from the Northern part depositing at Southern part of the river mouth, hence in Zone 3 erosion occurs. Besides, the influence of rising and falling tide combined with river flow results in a substantial deposition in the access channel of Cua Viet.

4.2. Sedimentation and erosion process in Cua Viet access channel in rainy season

Comparison between bathymetry of Cua Viet access channel between Jun-2007 to Dec-2007 is taken as the basis for evaluating the sedimentation – erosion process of the study site in rainy season. The variation in Cua Viet access channel is as follows:

Zone 1: Result of calculation on sedimentation – erosion shows that in rainy season this zone has high erosion rate, especially the river mouth where dredging takes place, with an average erosion rate of -0.8 ÷ 1.2 m. The area with slight sedimentation is from Cua Viet port going upstream along Thach Han river. The total erosion volume in this area is -167861 m^3 (Table 3).

Table 3: Total sedimentation – erosion volume of Zone 1 – Cua Viet access channel in rainy season

No.	Profile	Distance (m)	Max. sed. thickness	Max. erosion thickness	Average rate of sed. – erosion	Total net volume sed. – erosion
			$\Delta_{sed.max}$ (m)	$\Delta_{ero.max}$ (m)	(m)	$W_{sed.-ero}$ (m^3)
1	MC01					
2	MC02	160	0,196	-1,628	-1,021	-99586
3	MC03	160	0,014	-1,746	-1,163	-74068
4	MC04	220	0,239	-1,524	-0,813	-42141
5	MC05	220	0,220	0,813	0,284	16320
6	MC06	240	0,303	0,776	0,158	21298
7	MC07	280	0,168	0,425	0,069	10316
	Total					-167861

Zones 2, 3, and 4: In the rainy season, the left bank of Cua Viet access channel (Zone 3) experiences remarkable sedimentation, with average thickness from 0.4 ÷ 0.5 m and total sedimentation volume of 897492 m^3. In Zone 2, due to dredging in dry season, the access channel bed is eroded, with average erosion rate of -0.4 m and total erosion volume of -323614 m^3. Zone 4 has lower sedimentation – erosion rate, with total volume of -98820 m^3. Therefore the total sedimentation – erosion volume of Cua Viet estuary area (Zone 2, 3, and 4) in the rainy season is 475508 m^3 (Table 4).

Table 4. Total sedimentation – erosion volume of Zone 2,3,4 – Cua Viet access channel in rainy season

No.	Profile	Distance (m)	Max. sed. thickness	Max. erosion thickness	Average rate of sed. – erosion	Total net volume sed. – erosion
			$\Delta_{sed.max}$ (m)	$\Delta_{ero.max}$ (m)	(m)	$W_{sed.-ero}$ (m^3)
1	MCB09					
2	MCB08	500	1,314	-0,126	0,891	268183
3	MCB07	500	1,584	-0,207	0,923	350973
4	MCB06	500	1,411	-0,358	0,847	278786
5	MCB05	500	0,610	-1,787	-0,376	-145177
6	MCB04	500	0,542	-1,682	-0,382	-178437
7	MCB03	500	0,805	-0,627	0,048	19145
8	MCB02	500	0,417	-0,725	-0,192	-55866
9	MCB01	500	0,313	-0,916	-0,457	-62099
	Total					475508

Due to the dredging of access channel to Cua Viet port (in Zone 2 and the river mouth) done by the Transportation Joint Stock Company in early Aug-2007, the calculation of sedimentation volume in the access channel is very difficult, and only an approximate estimation can be made for the total volume of sedimentation – erosion.

At Zones 3 and 4, the sea bed variation on the left coastline part is apparent since in this season, the strong wind from Southeast and South causes current to bring sediment from the South to deposit at Cua Viet estuary.

4.3. Sedimentation and erosion process in Cua Viet access channel in a whole year

To evaluate the actual process of sedimentation – erosion in Cua Viet estuary in a time period of a whole year, we compare the change in bathymetry during the time period from beginning of Jul-2006 until end of Jun-2007. During this time the study site was under influence of two wind sources: Northeast monsoon and Southwest monsoon – these are the two wind sources which greatly affect the coastline morphology of Cua Viet estuary.

Zone 1: Calculation result shows that during a whole year, the Cua Viet estuary region (with bed elevation relatively low, from -2.5 ÷ -3.5 m) has large rate of sedimentation; the average sedimentation rate is 0.5 ÷ 0.6 m/year. Hence to allow entrance for heavy-load ships to Cua Viet port, intensive dredging must be done for this section. The erosive area resides inside of the river mouth (from Cua Viet port towards upstream), however with slight erosion, around 0.2 ÷ 0.3 m/year. Therefore in the whole year period, although dredging was done regularly, the total sedimentation within Zone 1 amounts up to 21455 m^3 (Table 5).

Table 5. Total sedimentation – erosion volume of Zone 2,3,4 – Cua Viet access channel in rainy season

No.	Profile	Distance (m)	Max. sed. thickness	Max. erosion thickness	Average rate of sed. – erosion	Total net volume sed. – erosion
			$\Delta_{sed.max}$ (m)	$\Delta_{ero.max}$ (m)	(m)	$W_{sed.-ero}$ (m^3)
1	MC01		1,514	-0,312	0,562	54806
2	MC02	160	1,264	-0,445	0,673	42867
3	MC03	160	0,748	-0,256	0,160	8295

No.	Profile	Distance (m)	Max. sed. thickness	Max. erosion thickness	Average rate of sed. – erosion	Total net volume sed. – erosion
			$\Delta_{sed.max}$ (m)	$\Delta_{ero.max}$ (m)	(m)	$W_{sed.-ero}$ (m^3)
4	MC04	220	0,378	-0,860	-0,176	-10124
5	MC05	220	0,194	-1,155	-0,289	-39022
6	MC06	240	0,202	-0,593	-0,115	-19356
7	MC07	280	0,175	-0,608	-0,081	-16011
	Total					21455

Zones 2, 3, and 4: Zone 2 (MCB04 ÷ MCB06) is the area with intensive sedimentation, with average deposition rate of 0.38 ÷ 0.42 m/year. The left part of channel (Zone 3) tends to be slightly eroded, with average erosion rate of 0.15 ÷ 0.2 m/year. The right part of channel (Zone 4) experienced sedimentation, with average deposition rate of 0.2 ÷ 0.3 m/year. Considering the entire area of Cua Viet estuary (within Zones 2, 3, and 4), in a year the total sedimentation volume is larger than erosion volume. The nett sedimentation volume is 383623 m^3, an average of 31969 m^3/month (table 6).

It can be seen that the magnitude of sedimentation – erosion within the study site in a year is as follows:

Zone 1 – the most intensive sedimentation area is the river mouth, where the river flow meets the tidal current and wave-induced current, therefore large sedimentation occurs here. However, this part has a low bed elevation (from -2.5 ÷ -3.5 m) also with high sedimentation rate (average 0.4 ÷ 0.5 m/year), thus the area is dredged yearly to assure frequent navigation and fast flood flushing.

Table 6. Total sedimentation – erosion volume of Zone 2,3,4 – Cua Viet access channel in a whole year

No.	Profile	Distance (m)	Max. sed. thickness	Max. erosion thickness	Average rate of sed. – erosion	Total net volume sed. – erosion
			$\Delta_{sed.max}$ (m)	$\Delta_{ero.max}$ (m)	(m)	$W_{sed.-ero}$ (m^3)
1	MCB09					
2	MCB08	500	0,552	-1,224	-0,298	-89.715
3	MCB07	500	0,931	-1,526	-0,337	-128.100
4	MCB06	500	0,846	-1,467	-0,172	-23.423
5	MCB05	500	1,464	-0,371	0,369	142.355
6	MCB04	500	1,607	-0,479	0,445	207.862
7	MCB03	500	1,313	-0,560	0,392	156.532
8	MCB02	500	1,293	-0,653	0,308	89.743
9	MCB01	500	1,282	-0,627	0,209	28.369
	Total					383.623

On the left of Cua Viet estuary (Zone 3), as late Northeast monsoon has just finished, slight erosion occurs while the right of Cua Viet estuary experienced slight sedimentation. However in general the total volume of sedimentation - erosion between two sides of the estuary is not large. Zone 2 experienced largest sedimentation due to supply from river flow and sea currents, which caused the sedimentation of the access channel to Cua Viet port.

5. Conclusion

Cua Viet is the estuary of Thach Han river; since the river is short and steep, with sediment component of the river mainly be sand, non-cohesive sand mixture under the impact of large river flow in rainy season, these material is conveyed and deposited at Cua Viet estuary. Besides, the coastal strip around Cua Viet mainly composed of small-sized to medium-sized well-graded sand grains, which are easy to move on the sea bed due to waves and wave-induced current, causing sedimentation in the access channel to the Cua Viet port. The research and application of Digital Elevation Model to evaluate the sedimentation – erosion process in seasonal and annual periods for the area is necessary.

The study site is considered in two periods: dry season and rainy season in a year, corresponding to the dominant periods of Northeast and Southwest monsoon. The hydrodynamics of Cua Viet estuary is also influenced by this factor. In the dry season, the sedimentation at access channel to Cua Viet port is much larger compared to rainy season. The main reason is the remarkable anthropogenic influence (dredging the channel). However in general, the total volume of sedimentation of Cua Viet access channel is very large in both seasons of a year.

The sedimentation process occurs intensively at the Cua Viet estuary, specifically right at the river mouth. In a year's time period, this area experience an accretion of 0.4 to 0.5 m (although being dredge frequently). On the other hand, this is the area with lowest bed level, thus causes difficulty for navigation for ships entering the port. It can be seen that the annual dredging work and lower the access channel bed to Cua Viet port is a costly short-term solution. On the long term, further research needs to be done in order to suggest efficient solutions which assure convenient navigation at the port, one of the economic development element of the Quang Tri province at present and in the future.

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