

## An Analysis of Shoreline Changes Using Combined Multitemporal Remote Sensing and Digital Evaluation Model

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### Abstract

Cua Dai estuary belonged to Quang Nam province is considered to be one of the localities of Vietnam having a complex erosion and accretion process. In this area, sandbars are recently observed with lots of arguments about the causes and regimes of formation. This could very likely result of not reliable source of information on shoreline evolution and a lack of historical monitoring data. Accurately identification of shoreline positions over a given period of time is a key to quantitatively and accurately assessing the beach erosion and accretion. The study is therefore to propose an innovative method of accurately shoreline positions for an analysis of coastal erosion and accretion in the Cua Dai estuary. The proposed technology of multitemporal remote sensing and digital evaluation model with tidal correction are used to analyse the changes in shoreline and estimate the rate of erosion and accretion. An empirical formula is, especially, exposed to fully interpret the shoreline evolution for multiple scales based on a limitation of satellite images during 1965 to 2018. The results show that there is a significant difference of shoreline shift between corrections and non-corrections of tidal. Erosion process tends to be recorded in the Cua Dai cape located in the Cua Dai ward, especially in the An Luong cape located in the Duy Hai commune with the length of 1050 m. Furthermore, it is observed that there is much stronger erosion in the north side compared with south side of Cua Dai estuary.

*Keywords:* Cua Dai; Shoreline Evolution; Erosion; Tidal Correction; Tidal Level.

## 1. Introduction

Estuary and coastal zone located along the Quang Nam province of Vietnam frequently affected by the types of disaster such as tropical cyclones, floods, accretion/erosion processes and shifting water flow and level. Quang Nam province has a long coastline of about 125 km in which more than 85 km of coastline is formed by unconsolidated sediment materials [1]. Most recently, accretion/erosion processes are increasingly recorded in space and intensity. In the estuary of Cua Dai, specially, erosion process is strongly recorded in 2009, 2010, 2013, 2016 and 2017. According to the report of Quang Nam provincial people committees in 2018, the rate of erosion process is rapidly occurred and could be reached to several tens of meters per year with the length of several thousand meters [2]. More importantly, the situation of beach encroachment has become more serious, causing the disappearance of beaches and landslides, which tend to prolong in the North, threatening hotels and resorts. Many hotels are knocked down into the sea such as Fusion Alya or Vingroup resort. Consequently, the entry and exit activities of ships and boats, tourism and seafood exploitation services are directly affected. This has been drawing special attentions of national and international scientists. In the

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evolution of the Cua Dai estuary, Quang Nam province, it is observed that human activities (e.g., exploitation of sand) are main factors caused the strong erosion processes. To overcome this problem, Vietnam government and investors in nation and international are spent hundreds of billions of VND for Cua Dai beach [3]. These solutions, however, are only temporary. Still, for a long term plan, it is necessary to give scientific researches with solutions that are suitable with reality. To overcome these big issues, there is a need to accurately clarify the shoreline changes.

Several the latest studies in the role of meteorological forcings and hydrodynamic factors (i.e., wave, flood events) are introduced to further interpret the erosion and accretion causes and regimes over this area [4, 5]. It is demonstrated that the convergence of sediment from the river controlled by flood events and waves in wintertime and wind-generated waves from stronger-than-normal tropical cyclones are significantly contribute to the changes in shorelines and riverbank. Commonly, corrections of related-factors to the changes in shoreline have not yet considered in these studies that a couple numerical modeling and remote sensing technology is applied. Besides that, updated technologies of cluster analysis are efficiently demonstrated [6] and for the Suffolk coast, eastern UK as an example [7]. The robust quantification in shoreline behavior is, of course, greatly depended the available. In other words, with more data, understanding shoreline changes can be fully solved, but with data scarcity this is a big obstacle [8]. With the development of electronics, computing powerful and remote sensing, the earth monitoring and observatory system using remote sensing technology is widely applied to the field variety of environment, ecosystem, urban planning or agriculture over the past 30 years [9-11]. It is revealed to expose positive aspects and advantages of this technology; however, it is necessary to consider that lots of factors that may be lower their performance (e.g., natural dynamics or the angle of Sun). Consequently, uncertainty of the obtained results is very likely large, especially in application of remote sensing technology to studies in shoreline changes as an example.

In mapping the shoreline changes, to date, lots of algorithms for research and separation of waterlines using remote sensing imagery with the indices of Normalized difference water index (NDWI) [12], Modified Normalized Difference Water Index (MNDWI) [13], automated water extraction index (AWEI) [14] are widely introduced over the world. To develop the waterlines, several methods applied such as Thesholding [15, 16], Classification [17, 18], or Band ratio techniques [19, 20]. Another aspect, the influences of tidal level on shoreline changes are also considered in several publications [21-25]. These studies are, however, only applied to shoreline positions where are often affected by tide. In addition to this, uncertainty of the results is relatively large due to inflated estimations in comparison with the conditions in practice. For understanding and deciphering the coastal processes operating in the estuary, especially in the studies of erosion-accretion processes, accurate demarcation and monitoring of shoreline evolutions are very important. Therefore, the goal of this paper is to develop a simple method but high reliability with a reduced-uncertainty then to identify shoreline changes. A combined slope of beach topography and tidal level at the image acquisition time are applied to calculate the shoreline shift with and without tidal.

## 2. Materials and Methods

### 2.1. Study Area

Cua Dai is the estuary of Thu Bon River, one of the rivers with the largest catchment area in Central Vietnam. Thu Bon River originates from the mountainside in the east of Truong Son range, with an average height of about 200 - 300m. Located in the upstream of Thu Bon mainstream, the elevation of Gle-Lang peak reaches up to 1855 m. Before flowing into the low-lying coastal plain, Thu Bon River has two main branches namely Thu Bon and Vu Gia connected by river Quang Hue in Dai Loc district, Quang Nam province. Then they flow into the sea with the branches of Ai Nghia river flowing into the Cua Han estuary and Thu Bon flowing into the Cua Dai Estuary. In this paper, the study area is to focus on Cua Dai estuary including a beach in the north of Cua Dai (about 3.5 km in length) and a part of south Cua Dai beach (about 3 km in length).

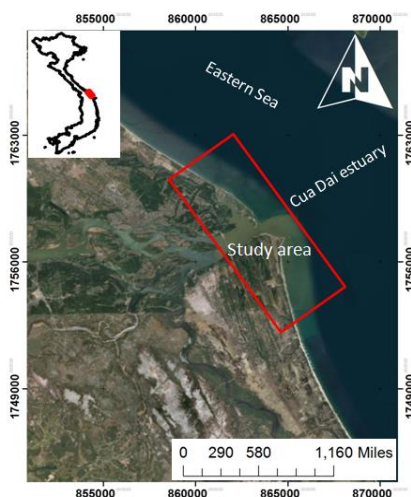


Figure 1. Sketch map showing the study area of Quang Nam province, Vietnam

## 2.2. Materials

The data of topography, satellite images and related-documents used in this study is taken from multiple sources:

- i. Topographic map under the projection of UTM labeled the code number of 6640-I issued by the U.S. Army Map Service AMS in 1965 on a 1:50.000 scale map, named DEM-1965.
- ii. Topographic map under the projection of UTM issued by Department of Survey, Mapping and Geographic Information Vietnam in 2010 on a 1:10.000 scale map for Cua Dai and its surround, named DEM-2010.
- iii. Topographic map under the projection of UTM surveyed and edited by the authors in the national project code of KC.09.03/16-20 in 2017 on a 1:10.000 scale map for Cua Dai and its surround, named DEM-2017. It is built based on two national elevation points under the code numbers of 80124 (X: 863303, Y: 1757227) and 801416 (X: 860072, Y: 1760673).
- iv. Landsat and Sentinel Images are downloaded from the website <http://glovis.usgs.gov/>. Landsat 2 has a spatial resolution of 60 meters. Finer than Landsat 2, Landsat 5 and Landsat 7 have a spatial resolution of 30 meters. Specially, Sentinel 2A has a resolution of only 10 meters. A series of snapshotted images by the satellites at different time points is to be downloaded but just a limitation of selected images on the basic of several criterions. They are images best reflected the shoreline shape with a little or without clouds.

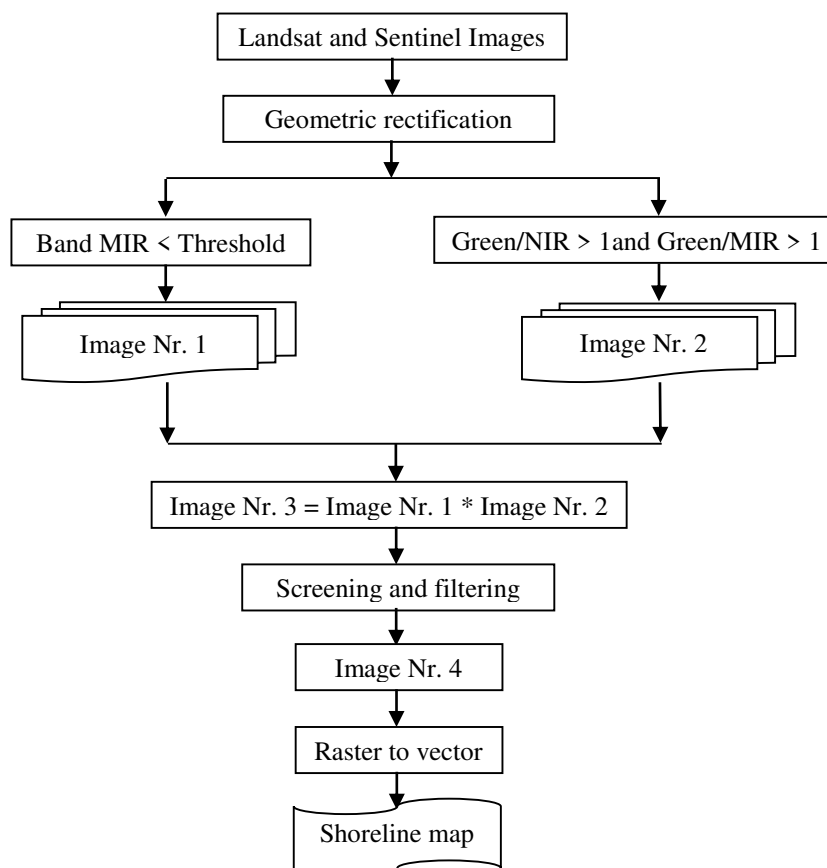
Parameters of Landsat, Sentinel Images and tidal levels at the snapshot are presented as shown in Table 1.

**Table 1. Parameters of Landsat, Sentinel Images and tidal levels at the snapshot**

Satellite Image	Id	Date	Sensor	Snapshot	Tidal level (m)
Landsat 2	049-133	13/03/1975	MMS	09:26	1.16
Landsat 5	049 - 124	08/08/1990	TM	09:27	0.83
Landsat 7	049 - 124	07/05/2000	ETM	09:58	1.03
Landsat 5	049 - 124	14/07/2010	TM	09:56	0.79
Sentinel 2A	A006965	07/07/2018	2B	19:02	0.91

## 2.3. Methodology

Flowchart of the research methodology has been presented by the Figure 2.



**Figure 2. Flowchart of extracting shorelines from satellite images**

Since today, various methods for shoreline extraction are introduced (i.e., numerical modeling, remote sensing or field survey) [26]. The shoreline can even be extracted based on a single band image [19]. It should be noticed that none of these approaches could provide a clear information on the evolutions of shoreline. The reason for this is because a shoreline position on horizontal or vertical could vary anywhere, depending on the beach slope, tidal range and prevailing wave/weather conditions at the snapshot [27]. In other words, in the process of the identification of shoreline evolutions, possible errors could be originated from (i) shoreline extraction process, (ii) geometric correction of Landsat images or (iii) a variation in some factors affecting shoreline change. So, it is difficult to find a universal method of extracting shoreline for the coast. In the study, a proposed technology is to improve the accuracy shoreline extraction methodology. The method is divided into two steps. As first step briefly presented in Fig. 2, in order to detect shoreline, the method of Alesheikh (2007) [19] is used to extract the waterline from the original satellite images. It is primarily based on a combination of histogram thresholding and band ratio techniques. Band of green/Near-infrared (NIR) are used to define the threshold values which all water pixels separated from the land pixels in the former technology. Meanwhile, bands of green/NIR and green/mid-infrared (MIR) are considered in the later technology. Green/NIR is useful for separating land from vegetation, whereas green/MIR is useful for separating non-vegetation land. To get the final shoreline images, then, some isolated pixels without features are discarded by screening and filtering. The shoreline extraction is transformed to vector from raster format for analyzing the next step.

In the second step is to discard the tidal effects. This step is shortly called as tidal correction. As mentioned in the previous paragraph, one of factors affected the accurately identification of shoreline positions is tidal. So, in this step, tidal correction is considered and clarified. The effect of tidal level variations during highs and lows is corrected with the lowest level of tidal in the long-period tides. For the Cua Dai estuary, tidal levels range from 0.79 to 1.16 during 1975 to 2018. On the basic of tidal level at the snapshot for the Cua Dai estuary, the shorelines are interpolated based on the one-line shift method or shoreline change model [28]. The method assumes that the beach moves offshore or onshore with one bottom profiles as shown in Figure 3. A brief description of this method is presented with three beach profiles at three different times:  $t_i$  ( $i = 1,2,3$ ) (Figure 3a). At time  $t_i$ , the waterline is located at  $x_i$ , away from the origin of the transformed coordinates, and the corresponding water depth is  $h_i$  above or below MSL. When the sea surface is at MSL, the MSL-datum-based shoreline is located at  $z_i$  away from the origin. Fig. 3 illustrates an example of a beach profile moving from the right to the left. If the extracted waterlines from satellite images at time  $t_2$  and  $t_3$  are located at  $x_2$  and  $x_3$ , respectively,  $x_3 > x_2$ . Extracted waterlines ( $x_2$  and  $x_3$ ) without consideration of tidal effect imply that the beach moves from the left to the right. This inference conflicts with the assumption Figure 3. Shifting the extracted waterlines to the MSL-datum-based shoreline position is necessary to accurately estimate the beach movement. Tidal correction is then analyzed by comparing the position of the shoreline corrected by tides with the shoreline that is not corrected for tides. On the basic of triangle theory (Fig. 3b), shoreline shift is calculated as expressed by the Equation 1:

$$a = h \times \cot \alpha \tag{1}$$

Where  $a$  is value of shoreline shift at the highest tidal level;  $h$  is value of water depth between the highest to lowest tidal level at the snapshot and  $\alpha$  is slope angle of the beach measured in the field.

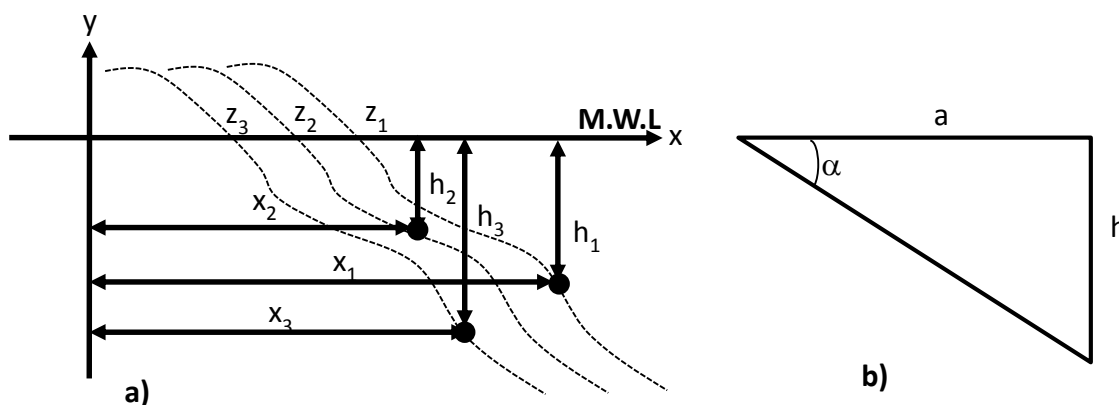


Figure 3. Beach slope for the correction of tidal level (adapted from [28])

In order to define  $\alpha$  and  $a$ , an assumption of beach slope made for tidal correction is continuously a linear trend during 1965 and 2010. The reason for this is that there is no measured data in this duration for the Cua Dai estuary. The flowchart as presented in Fig. 8 is implemented to reproduce the topography of Cua Dai for 1975, 1990 and 2000 based on the topographic data. In case 2018, the correction of shoreline using the lowest tidal level for Sentinel Image 2018 is calculated on the basic of topographic slope in 2017. The application of ArcGIS Tools is used to create slope maps and define the values of  $\cot \alpha$  and  $a$ .

In this study, to clarify the erosion and accretion processes for different periods in the Cua Dai estuary during 1965 to 2018 with a limitation of topographic data, the slope angle is calculated using the empirical Equation 2. From that, DEM-1975, 1990 and 2000 are created with the given assumptions to divide the period of 1965 to 2018 into five different periods.

$$\alpha_i = \sum_{start\_yr}^{end\_yr} \frac{(end\_yr-i)*\alpha_{start\_yr}+(i-start\_yr)*\alpha_{end\_yr}}{end\_yr-start\_yr} \tag{2}$$

Where  $\alpha$  slope for the Cua Dai estuary; start\_yr is the starting year of snapshotted image (1965); end\_yr is the ending year of snapshotted image (2010) and  $i$  = year of consideration (for this study,  $i$  = 1975, 1990 and 2000).

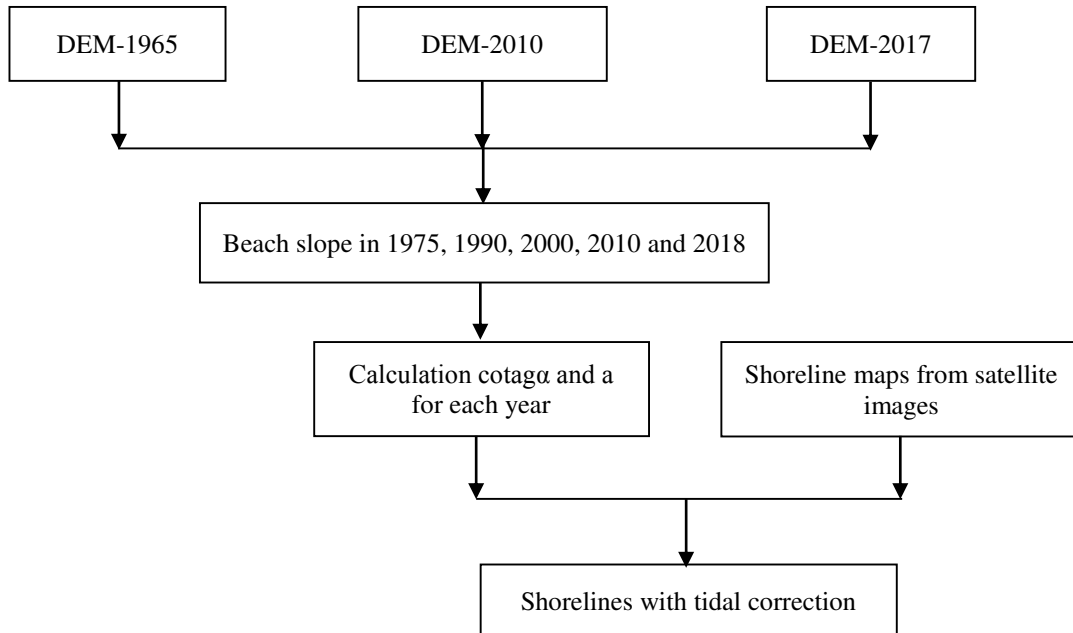


Figure 4. Flowchart of shorelines with tidal correction

### 3. Results and Discussions

#### 3.1. Analysis of Shoreline Maps

As the first step of the methodology, shoreline maps in 1965, 1975, 1990, 2000, 2010 and 2018 are directly created from the satellite images without tidal correction. A typical result for step by step in 2000 is shown in Fig. 5. A series of other shoreline maps is also presented in Figure 6.

As the second step of the methodology, beach slope angle is mapped based on the Equation 2 for the considered years (1965, 1975, 1990, 2000, 2010 and 2018) with tidal correction. The values of shoreline shift ( $a$ ) in the Equation 1 are relatively small ranging from 0.62 to 16.27. The reason for this is due to negligible values of beach slope and tidal level in the Cua Dai estuary. Even if small values of shoreline shift are, however, observed but this significantly makes a difference of shoreline shift between with and without tidal correction, especially in the south of Cua Dai estuary as shown in Figure 7c. During tidal correction, it should be noticed that shoreline maps from the satellite images are transformed to points with the distance of 10 m for each points. Then, values of latitude plus shoreline shift are implemented to transform the point to polyline format after getting the values of coordination and shoreline shift. From that, shorelines with tidal correction are produced as shown in Figure 8.

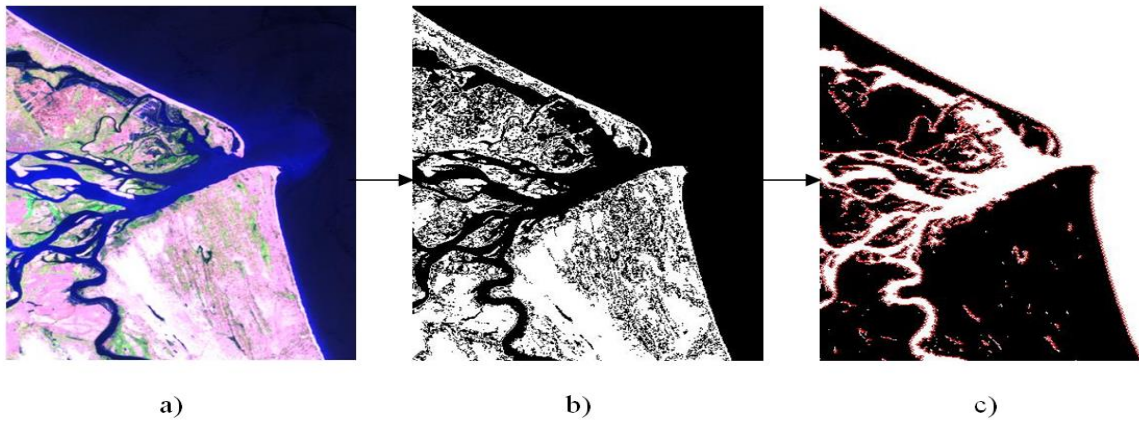


Figure 5. Landsat 7 ETM Satellite for the Cua Dai estuary, snapshotted on 07/05/2000 (a); processed shoreline (b); converted shoreline from raster to vector format (c)

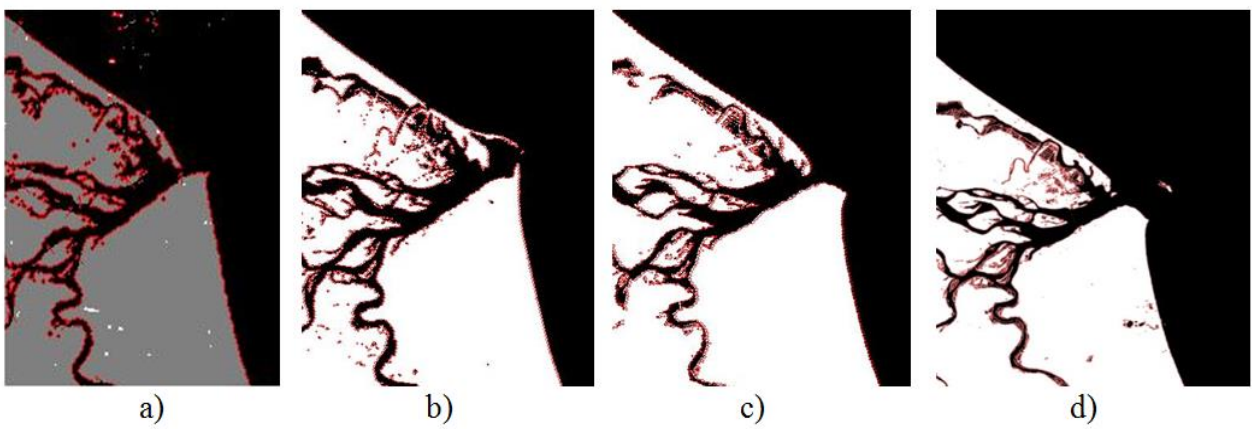


Figure 6. Shoreline maps under the vector format in 1975 (a), 1990 (b), 2010 (c) and 2018 (d)

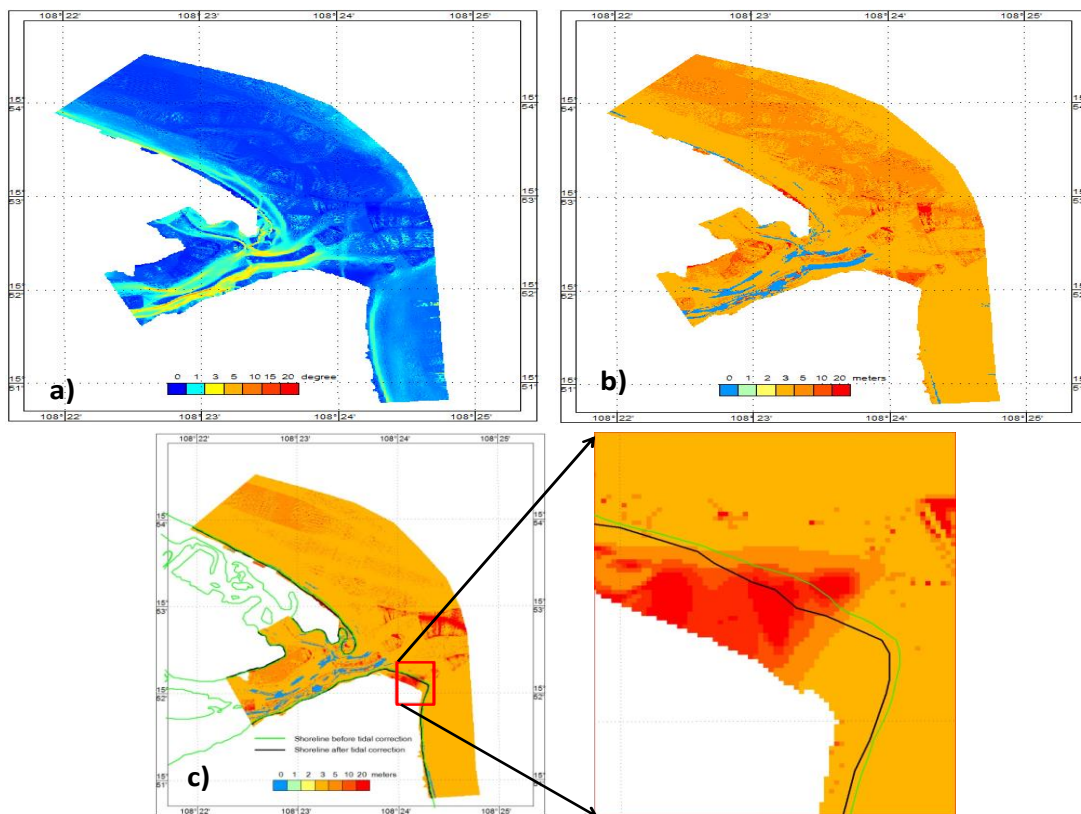


Figure 7. Tidal correction of shoreline steps with slope estimation (a), value of shoreline shift (b) and difference before and after tidal correction (c) in 2000.

### 3.2. Analysis of Erosion and Accretion Processes

Applying the proposed tidal correction, the shoreline changes are fully mapped with the processes of erosion and accretion for the Cua Dai estuary during 1965 - 2018 as shown in Table 2 and Figures 8 to 10.

Figure 9 clearly shows the overall rate of accretion and erosion in the north and south of Cua Dai estuary. In the year of 1965 to 1975 average accretion rate is + 18.71 m/yr and erosion rate - 10.19 m/yr acquired in the north of Cua Dai (Fig. 9a). A tendency of decreasing in accretion/erosion is observed during 1965-2018 for both northern and southern Cua Dai. It should be noticed that the accretion process is relatively stable in the south of Cua Dai ranging from +10.9 (1965-1975) and + 7.36 (2010-2018). In the decade of 1975 to 2000, the accretion process is rapidly reduced in the north of Cua Dai (Fig. 9a). Plus, fig 9a reveals a decreasing trend in accretion rate with a high certainty ( $R^2 = 0.7985$ ) in the north of Cua Dai estuary in the period of 1965 to 2018. Notably, fig 9b illustrates a sharp decrease in the erosion rate in the south of Cua Dai in the decade of 1965 to 1990. As shown in fig9b, specially, a stable trend in accretion rate observed in the south of Cua Dai estuary during 1965 - 2018 likely relates to an ensemble of waves in near shore, fresh flows from the river and tides where force of components is balanced in a given period.

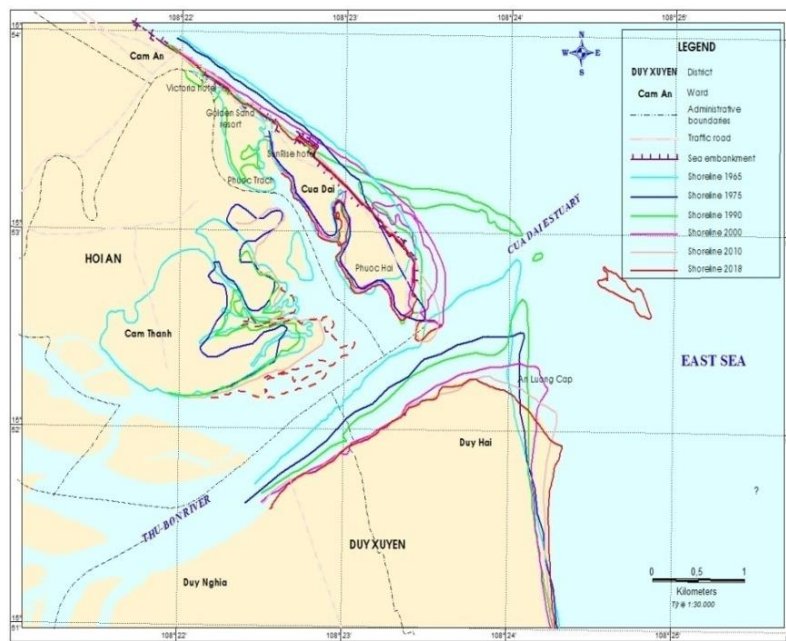


Figure 8. Shoreline maps during 1965 - 2018

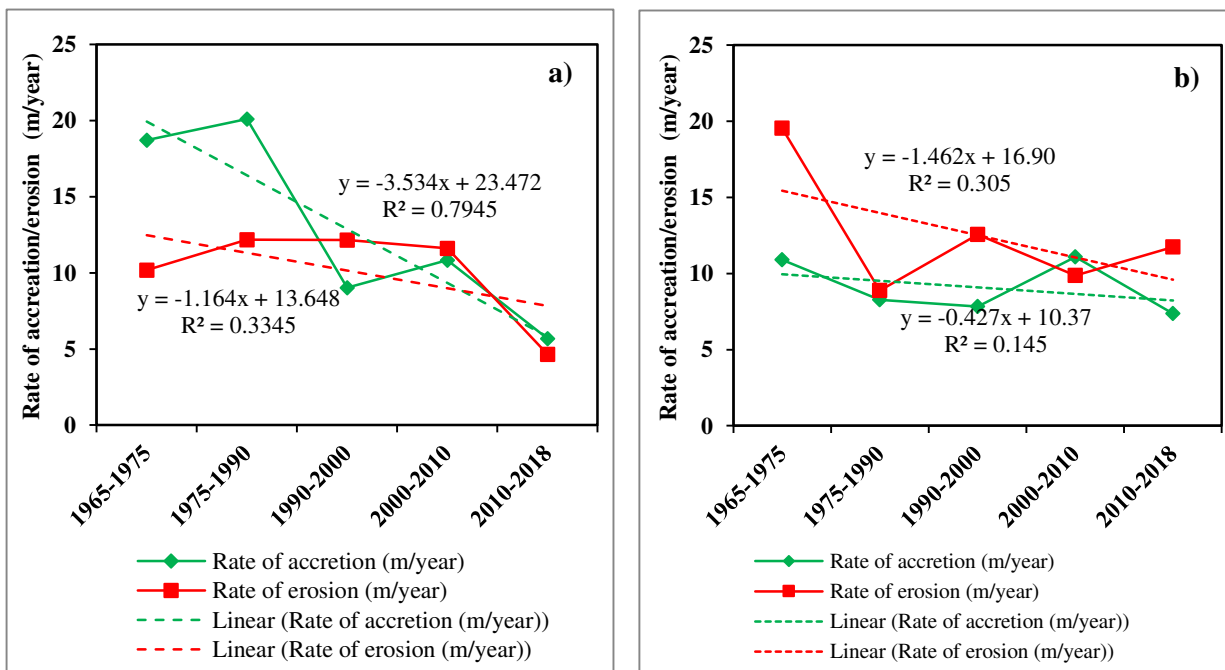
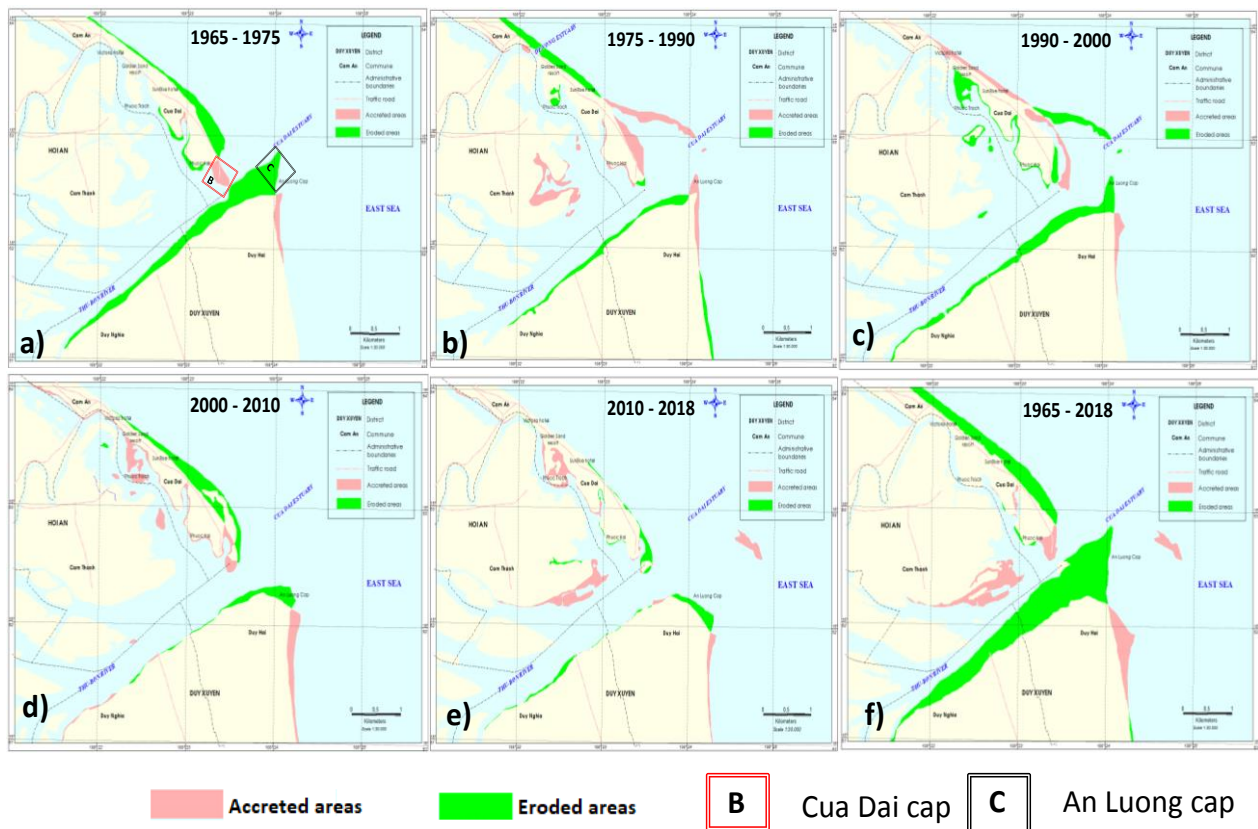


Figure 9. Rate of accretion and erosion in the north (a) and south (b) of Cua Dai estuary during 1965 - 2018

Figure 10 shows the eroded and accreted areas in the Cua Dai estuary during 1965 – 2018 with six different periods of 1965-1975 (a), 1975-1990 (b), 1990-2000 (c), 2000-2010 (d), 2010-2018 (e) and 1965-2018 (f). Obviously, in the decade of 1965 - 1975 (Fig. 10a) for both northern and southern Cua Dai, the erosion processes are strongly occurred in the estuarine areas with a total length of eroded sections of 8755 m and an area of 136.73 ha. The total length of accreted section is 1763 m with an area of 22.3 ha. The strongest eroded section is observed in the north of Cua Dai estuary belonged to Cua Dai ward and riverbanks in the south of Cua Dai estuary belonged to Duy Hai commune. Contrary to this, the most accretion section is Cua Dai cap. Consequently, the seaport is narrowed and then shifted to the southward. A point needed to be considered is that the coastal area of Quang Nam province is directly affected by a total of 11 tropical cyclones including storms and depressions during this period [29]. Especially, in the Cua Dai estuary is strongly affected by Nr. 6 typhoon namely Louise in October, 1970 traveled from east to west direction with the strongest wind speed of 130 m/s. This causes of dramatically changes in the shape of shoreline and estuarine area. As shown in Fig. 10a-e, the accreted areas for both northern and southern Cua Dai are calculated in the different decades of 1975 - 1990 (3480 m in length, 52.12 ha in area), 1990 - 2000 (4520 m in length, 38.96 ha in area), 2000 - 2010 (3610 m in length, 39.64 m in area) and 2010 - 2018 (2492 m in length, 13.99 ha in area). In addition, the eroded areas are fully interpret for 1975 - 1990 (7139 m in length, 71.71 ha in area), 1990 - 2000 (7463 m in length, 92.65 ha in area), 2000 - 2010 (5778 m in length, 63.51 ha in area) and 2010 - 2018 (3277 m in length, 28.08 ha in area). During 1975-2018, generally, the complex changes are irregularly recorded both in intensity and space scale. The processes of erosion and accretion are intertwined between the coastline sections, but erosion is still dominant. The erosion is specially recorded in the An Luong cap.



**Figure 10. Eroded and accreted areas in the Cua Dai estuary during 1965 - 1975 (a), 1975 - 2000 (b), 1990 - 2000 (c), 2000 - 2010 (d), 2010-2018 (e) and 1965-2018 (f).**

It is especially noteworthy from the Fig. 10c-d that in the decades of 1990 to 2010, An Luong cape is shifted to the southward and extended to the sea. This very likely relates to (i) the historical flood recorded in Quang Nam province in November, 1999 and (ii) the concreted embankment in Duy Hai commune in 2006 and 2007 with the length of more than 1 km. Fig. 10f shows an overview map of accreted and eroded areas for a long period of 53 years (1965-2018) in the Cua Dai estuary. In a nutshell, the tendency of erosion and accretion could be divided as the typical accreted and eroded sections. (i) Sections along the coast of Quang Nam province tend to be accreted (i.e., Cua Dai cape in the Cua Dai ward, An Luong cape in the Duy Hai commune). They tend to shift in the northwest and southeast direction during 1965-2003 with average accretion rate of approximately 10 m/yr. In comparison with the position of the An Luong cape, the Cua Dai cape is westly pulled with a length of about 1050 m. Presently, the concreted southern Cua Dai sections are very likely cause of accreted areas in front of the Cua Dai estuary. (ii) Sections tend to be eroded: the north of Cua Dai estuary, coastline of Cam An and Cua Dai wards, Hoi An. The erosion recorded in the south of Cua Dai ward are



strongest. The shoreline tends to back to the mainland in the northeast and southwest direction. This is likely due to the oceanic dynamical processes (e.g., waves or currents). In the south of Cua Dai position belonged to the DuyNghia and DuyHai communes, the erosion process reduces after the year of 2010 due to the concreted riverbank, but the erosion observed in the sections belonged to the An Luong village, DuyHai commune.

**Table 2. Erosion and accretion processes in the Cua Dai estuary during 1965 - 2018**

Sections	Accretion			Erosion			Accretion - Erosion (ha)
	Length (m)	Area (ha)	Rate (m/yr)	Length (m)	Area (ha)	Rate (m/yr)	
Northern Cua Dai	492	12.21	4.6	3625	68.73	7.73	- 56.52
Southern Cua Dai	1558	30.86	3.73	5060	201.42	9.97	-170.56

#### 4. Conclusion

The study proposed an innovative method on the basic of a combination multitemporal remote sensing and digital evaluation model with a tidal correction. Tidal corrections are implemented for multiple years from 1965 to 2018 to detect the shoreline evolution. With a tidal correction, the accuracy of shoreline evolution is significantly improved. Only based on available three digital evaluation models of 1965, 2010 and 2017, the erosion and accretion processes are quantified for different periods of 53 years from 1965 to 2018 on the basic of proposed empirical formula. More importantly, a small difference between before and after tidal correction is fully observed.

The results illustrate complex erosion and accretion processes in the north and south of Cua Dai estuary. These processes are completely difference between two sides of the Cua Dai estuary. Strong erosion is observed in the north of Cua Dai estuary during 1965 to present, especially in 1965 to 1975 and 2000 to 2010. In the south of Cua Dai estuary, meanwhile, areas belonged to the ward of Duy Hai, Duy Xuyen are strongly eroded during 1965 to 2018, up to 1050 m in the south cape of Cua Dai estuary.

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#### 7. Conflicts of Interest

The authors declare no conflict of interest.

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